Unpublished manuscript
02/09/2000

GEOLOGY OF THE SAN BERNARDINO NATIONAL FOREST

The San Bernardino National Forest (SBNF) includes parts of, two major geologic-geomorphic provinces of western North America, the Transverse Ranges and Peninsular Ranges provinces. The San Gabriel and San Bernardino Mountains are part of the eastern Transverse Ranges and the San Jacinto and Santa Rosa Mountains, Thomas Mountain, and Coahuila Mountain are part of the northern Peninsular Ranges. The geology of the two provinces is vastly different one from the other.

The Transverse Ranges province boundary south of the San Gabriel Mountains is the Cucamonga fault zone, a major compressional fault zone at the base of the mountains. East of the San Gabriel Mountains the province boundary is right-laterally offset 15-20 km by the San Jacinto fault and is located in the structurally complex San Gorgonio Pass area.

Due to fundamental differences in all but the youngest geology, the pre-Quaternary geology of the San Bernardino National Forest is discussed in terms of three rock assemblages, the San Gabriel Mountains assemblage, the San Bernardino Mountains assemblage, and the Peninsular Ranges assemblage. Although within the same geologic-geomorphic province all but the youngest geology of the San Gabriel and San Bernardino Mountains is markedly different. Major lateral displacement on the San Andreas fault has juxtaposed the different rock assemblages of the two ranges. The San Bernardino Mountains rock assemblage underlies the area of the San Gabriel Mountains north of the San Andreas fault in addition to the physiographic San Bernardino Mountains. San Gabriel Mountains rock assemblage underlies the San Bernardino basin south of the San Bernardino Mountains and extends eastward through the northern part of San Gorgonio Pass. In contrast to the Transverse Ranges province, geologic-physiographic subdivisions of the Peninsular Ranges province are similar with only modest lateral fault disruption of the geology.

PREVIOUS WORK

A still very useful overview of southern California geology is "The Geology of Southern California" (R.H. Jahns, editor), published in 1954 by the California Division of Mines and Geology (current name ‘California Geological Survey). The section on the natural provinces of southern California provides a general overview of the two provinces in which the Forest is located. In the 1960's, the U.S. Geological Survey conducted reconnaissance geologic mapping at 1:62,500 scale for much of the region encompassed by the San Bernardino Forest (Dibblee, 1964a,b,c; 1967a,c; 1974). The U.S. Geological Survey also conducted mineral-resource investigations of wilderness areas and RARE-II planning areas in parts of the Forest (Morton and others, 198a,b; Evans, 1982; Cox and others, 1983a,b; Matti and others, 1983a,b; Powell and others, 1983; Morton and others, 1983) and for Bureau of Land Management planning areas adjoining the Forest (Matti and others, 1982a,b). A chemical study of Cretaceous plutonic rocks throughout the Forest was conducted by A.K. Baird and his coworkers (Baird and others, 1967, 1979; Baird and Miesch, 1984). Tectonic syntheses by Matti and others (1985; 1992) include most of the Forest. For the eastern San Gabriel Mountains, geologic syntheses are provided by Morton (1975), Ehlig (1981, 1982), and Dibblee (1982a); for the San Bernardino Mountains, by Dibblee (1982b), Sadler (1981), and Matti and others (1993); and for the Peninsular Ranges Province, by Todd and others (1988). Geologic-map compilations at 1:250,000 scale that span the San Bernardino National Forest include the San Bernardino 1¡x 2¡ Quadrangle (Rogers, 1967; Bortugno and Spittler, 1986) and the Santa Ana 1¡x 2¡ Quadrangle (Rogers, 1965).

SAN GABRIEL MOUNTAINS ROCK ASSEMBLAGE

GEOLOGY OF THE EASTERN SAN GABRIEL MOUNTAINS

The San Gabriel Mountains are a fault-bounded block that is lens-shaped in plan view. The San Bernardino National Forest is in the eastern part of the range with the highest part of the mountains that are the result from continuing rapid tectonic uplift (Morton and Matti, 1993). The range is bounded on the north by the San Andreas fault zone and on the south by thrust faults of the Cucamonga-Sierra Madre fault complex. The interior of the range is thoroughly and complexly fragmented by faults of many different ages and cut by deep, steep-sided canyons in pervasively fractured crystalline rocks. The sides of most canyons are blanketed by colluvial rock debris that is washed out to the range fronts where it is deposited on the valley floor as large alluvial fans.

Lower Plate Rocks

Cretaceous and older rocks of the eastern San Gabriel Mountains are divided into two groups by separated by the Vincent Thrust a regional old, low-angle thrust fault,. Above the thrust rocks are referred to as upper plate rocks and those below lower plate rocks. The Vincent Thrust, named for exposures in the Vincent Gap area west of the SBNF, apparently was first recognized by Levi Noble (unpublished mapping, 1928, though not published until 1954a), and later independently recognized by Ehlig in the early 1950's (1958) who first realized its regional importance. The thrust is well exposed in the lower part of Coldwater Canyon in the North Fork of Lytle Creek, and on the north side of Mount San Antonio. The Vincent thrust appears to be Late Cretaceous or early Tertiary in age (Conrad and Davis, 1977; Ehlig, 1981, 1982), and is a regionally-developed zone of crustal decoupling that probably underlies much of southern California (Haxel and Dillon, 1978; Ehlig, 1982). Oligocene granitic rock intrudes both the Vincent Thrust as well as the rocks of the upper and lower plates in the vicinity of Telegraph Peak.

Lower plate rock consist of a thick section of greenschist and lower amphibolite metamorphic grade schist termed the Pelona Schist named for exposures in the Sierra Pelona area west of the SBNFf. The protolith of the Pelona Schist was Mesozoic marine sedimentary and volcanic rocks. Most of the unit was derived from mudrocks with intercalated thick sections of basalt, thin sections of siliceous-carbonate sediments, local thin sections of barite-bearing chert and manganese-bearing siliceous sediments. Local pods of actinolite-talc rock were probably derived from serpentine. Fuchite, a chome-bearing muscovite commonly occurs in association with actinolite-talc rock. Small masses of rhodonite and minor occurrences of manganese epidote, piemontite are rare.

Pelona Schist occurs in two distinct blocks separated by the Punchbowl fault. North of the Punchbowl fault is gray, medium- to coarse-grained white-mica schist of lower amphibolite grade. Greenstone metabasalt layers, largely hornblende and garnet, are common, and metachert and metacarbonate-quartzite layers are rare. Commonly included in metachert are trains of complexly folded spessartite garnet. Locally metachert contains small amounts of barite and rarely blue amphibole. Most layers of metacarbonate-quartzite are slip-folded.

South of the Punchbowl fault the Pelona Schist is mostly a gray, well layered, greenschist-grade sequence of spotted albite-muscovite schist. The structurally upper part contains thick sections of greenstone (metabasalt). Most greenstone is an assemblage of albite-epidote-chlorite. Layering appears to be mainly transposed from sedimentary bedding by slip folding. Although much of the schist contains minor homoaxial slip folds some outcrops contain 3-to 4 none-homoaxial fold axes. Single and double sets of crenulations post dating slip folding are common. Biotite is rare in the Pelona Schist, but the biotite look-alike stilpnomelane is widespread.

North of the fault the Pelona Schist and structurally overlying crystalline rocks, both of which are intruded by a middle Tertiary granitic body; and (2) a southern group that, from north to south, includes metasedimentary rocks (marble, schist, quartzite), Cretaceous granitoid rocks, and high-grade granulitic metamorphic rocks that have been mylonitically deformed, retrogressively metamorphosed to greenschist and amphibolite facies, and intruded by charnockitic rocks. The northern and southern basement-rock groups are separated by the Icehouse Canyon fault, a late Cenozoic right-lateral strike-slip fault that apparently has re-occupied a major lithologic boundary created earlier during the late Mesozoic to early Cenozoic (May, 1986, 1988; May and Walker, 1989; Matti and Morton, 1993).

Rocks north of the Icehouse Canyon fault

Rocks north of the Icehouse Canyon fault consist of lower- and upper-plate blocks of the Vincent thrust, a major geologic structure in the San Gabriel Mountains.

Lower-plate rocks.--

Blue Ridge block:

Lytle Creek block: Southwest of the Punchbowl fault, Pelona Schist is fine-to medium-grained and is metamorphosed only to greenschist grade. Spotted albite-white mica schist predominates, but locally the schist contains tightly and complexly folded quartzite-carbonate layers. Quartzite commonly contains convoluted layers rich in manganese-aluminum garnet (spessartine) and barium sulphate (barite). Blocks of serpentine, actinolite and, in some places, small amounts of chromium mica (fuchsite) are scattered in both the amphibolite- and greenschist-grade schist. Beneath the Vincent thrust, structurally highest parts of the Pelona Schist are dominated by greenstone that consists of albite, epidote, chlorite, and amphibole.

Upper-plate rocks.— Unlike the overall homogeniety of the lower plate rocks, the upper plate includes a very wide variety of crystalline rocks ranging in age from Proterozoic to Cretaceous. Included within the upper plate are orthogneisses, paragneisses, mylonites, schist and related metamorphic rocks, and plutonic rocks. Many of the rocks have undergone repeated deformations. Above the Vincent Thrust is a varible thickness of mylonite thought to be the result of movement along the thrust. The variable thickness of the mylonite, ranging from a few tens of feet to 2,000 feet, post mylonization tectonic thinning. This thinning maybe the result of diaperic-like uplift of the Pelona Schist deforming rocks of the upper plate. Above the mylonite is a mixture of gneissic-textured pre-Mesozoic metasedimentary rocks and Mesozoic grantitoid rocks that include older units like the Triassic Lowe granodiorite (Barth and Ehlig, 1988) and younger tonalitic rocks of Cretaceous age.

Both the Pelona Schist and the overlying mylonitic and gneissic complex have been intruded by the Oligocene Telegraph Peak pluton and related dikes and sills (Hsu and others, 1963; Miller and Morton, 1977). The Telegraph Peak pluton consists of massive light colored hypidgranodiorite that has a typical granitoid texture except in the marginal parts of the pluton, where much of the rock has a hypabyssal texture indicative of shallow intrusive depths. The pluton is intruded by diabase dikes and one small body of olivine-bearing diabase-gabbro.

Rocks south of the Icehouse Canyon fault

Rocks south of the Icehouse Canyon fault include Mesozoic plutonic units and pre-plutonic metasedimentary units. The main group of metasedimentary rocks is assigned to the regionally extensive Placerita suite (Powell, 1993). It consists of amphibolite-grade metaquartzite, marble, biotite-sillimanite schist, and graphitic schist, all intruded by Cretaceous granitoid rocks of tonalitic composition. The Placerita suite forms large masses on Ontario Ridge in the vicinity of San Antonio Canyon, but is progressively fragmented and intruded by tonalitic rocks to the east in the vicinity of Lytle Creek, where it occurs as isolated pods and bodies. Many of the tonalitic rocks are gneissic and have a mylonitic fabric. The degree of mylonitic deformation increases southward toward the mountain front where, in places, tonalitic rocks have been uniformly converted to mylonite belts as much as 1000 ft thick. Dikes and small masses of relatively undeformed granitoid rock that are late Cretaceous in age (about 78 Ma according to May and Walker, 1989) intrude the deformed tonalitic rocks.

South of the Placerita metasedimentary suite and the intrusive tonalitic rocks is a heterogeneous metamorphic and plutonic assemblage (Hsu, 1955; Morton, 1975, 1976; May, 1986; Morton and Matti, 1987; May and Walker, 1989). Older metamorphic rocks consist of multiply deformed, compositionally layered, garnet-pyroxene-bearing quartzofeldspathic gneiss and minor marble and calc-silicate rock that originally were metamorphosed to high-grade granulite conditions, but subsequently were retrograded to amphibolite facies and then intruded by tonalitic granitoid rocks and pyroxene-bearing granitoid rock (charnockite). The resulting plutonic and metamorphic complex was mylonitized contemporaneous with plutonism. The age of the pre-granulite protolith is unknown, but usually has been interpreted either as (1) Precambrian, based largely on the granulite grade of metamorphism, or (2) Paleozoic, based on the occurrence of marble units that regionally are interpreted to be late Precambrian or Paleozoic in age. The granulite metamorphic event itself probably is mid Cretaceous based on a 108 Ma U/Pb radiometric-age determination from pegmatite contemporaneous with late-stage granulitic metamorphism (May and Walker, 1989, p 1260). Mylonitic tonalite associated with the granulitic rocks yields U-Pb ages of about 88 Ma (May and Walker, 1989).

Mylonitic rocks along and near the southeastern margin of the San Gabriel Mountains are deep parts of major tectonic zones of dislocation. The mylonitic fabric and minor structures within the mylonitic rocks are primarily oriented east; linear structures are subhorizontal or plunge at small angles. Vergence of minor folds suggests a movement direction of the San Gabriel Mountains westward relative to the valley to the south. For a recent structural analysis of basement rocks of the southeastern San Gabriel Mountains, see Morton and Matti (1987), May (1986, 1989), and May and Walker (1989).

Cenozoic deposits

Limited occurrences of Tertiary nonmarine sandstone and conglomerate occur within the Cucamonga fault zone just west of the mouth of Lytle Creek (Morton and Matti, 1987). Most of the unit consists of coarse-grained sandstone, conglomeratic sandstone, and conglomerate. Clasts in the conglomerate mainly are composed of gneiss and are not derived from any of the local basement rocks in the eastern San Gabriel Mountains. The sedimentary rocks are overturned and dip steeply north toward the mountain front; the structure appears to define the north limb of an overturned syncline.

Quaternary surficial deposits

Alluvial deposits

Several cycles of erosional denudation have sculpted the steep topographic relief of the southeastern San Gabriel Mountains, and have led to the formation of multiple generations of alluvial sediment that have filled canyon bottoms and adjacent valleys. The steep hillslopes locally are mantled with thin veneers of colluvium, some of which is active and some relict from older Pleistocene erosional episodes. Most canyon bottoms are flanked by several flights of alluvial-terrace risers, each marking a valley-filling aggradational episode followed by down-cutting of the main stream and its tributaries. Most of these stacked terrace gravels are Pleistocene in age, and their upper erosional surfaces are marked by pedogenic soils containing well-developed reddish B horizons. The youngests members of the terrace succession are Holocene, and these have soil profiles that generally lack B horizons. In all cases, the alluvial sediment consists of poorly sorted cobble-boulder gravel and gravelly sand. Where the canyons exit the mountains, repetitive aggradation and degradation have led to the formation of nested alluvial-fan deposits like those along the south front of the San Gabriel Mountains (Morton and Matti,1987).

Landslides

Landslides and landslide deposits are abundant in the eastern San Gabriel Mountains (Morton and Streitz, 1969). Steep hillslopes are subject to extensive rock falls, many produced by earthquakes. In the eastern San Gabriel Mountains, avalanche deposits appear to be localized in terrains of older plutonic rocks, gneiss, and mylonitic gneiss, excluding the Pelona Schist (Morton and others, 1989). Examples of large dissected Pleistocene avalanche deposits are in Cedar Canyon and Coldwater Canyon. The Manker Flat area in upper San Antonio Canyon is underlain by a landslide deposit that originated high on the south side of Mount San Antonio. Cow Canyon saddle, the divide between the San Gabriel River drainage and San Antonio Canyon, is underlain by the distal part of the Cow Canyon landslide. This slide originated high on the east side of San Antonio Canyon near the crest of Ontario Ridge. The pre-Cow Canyon landslide topography of San Antonio Canyon is ambiguous, but it is probable that San Antonio Canyon above the Cow Canyon landslide formerly was the head of Cow Canyon. Headward erosion of lower San Antonio Canyon following emplacement of the Cow Canyon slide segmented the landslide and captured a drainage that formerly flowed west down Cow Canyon (Morton and others, 1989). A much younger, largely undissected landslide, the Hogback landslide, blocked San Antonio Canyon below the Cow Canyon landslide. Incipient landslide scarps east of Mount

San Antonio confirm active landsliding in this area, and attest to the potential for catastrophic slope failures in the upper part of San Antonio Canyon.

Landslides, excluding avalanche-type deposits, are pervasive in the Pelona Schist and are especially abundant in the Pelona Schist body located between the San Andreas and Punchbowl fault zones. Most landslides located within the Pelona Schist lack classic landslide morphology. Many of these landslides are produced by slowly spreading snouts of ridges. Sackungen and sackungen-like features, such as side-hill and ridge-top trenches, are common (Morton and Sadler, 1989). Many of the sackungen-like ridge-top trenches lack any readily visible deformed material below the trenches. Sackungen-like scarps occur in rocks other than the Pelona Schist, such as the scarps southeast of Circle Mountain on the north side of Lone Pine Canyon. Pelona Schist landslide debris can form mudflows when properly saturated either by intense summer-storm rainfall or melting snowpack (Morton and Campbell, 1974; Morton and others, 1978; Morton and Kennedy, 1978).

Geologic structures

San Jacinto Fault Zone

The San Jacinto fault, a major fault of the San Andreas fault system, originates at the southeast end of the San Gabriel Mountains and extends southward with a more southerly strike than the San Andreas fault zone. The San Jacinto fault zone is seismically the most active in California, and has generated a large number of destructive earthquakes in historic time. In contrast to the relatively continuous and singular trace of the San Andreas fault, the San Jacinto fault zone consists of a series of relatively short en echelon faults that constitute a zone up to 15 km wide (Sharp, l975). Most of these faults have numerous surface features (e.g, scarps, sagponds, and offset drainages) indicative of recent ground rupture.

Where it enters the southeastern San Gabriel Mountains from the south, the San Jacinto fault zone loses its identity as an easily mappable thoroughgoing strike-slip fault. In the San Gabriel Mountains, faults traditionally assigned to the San Jacinto fault usually are depicted as either branching directly off the San Andreas fault on the north side of the Mountains or merging with the inactive Punchbowl fault. However, geologic mapping by Morton (1975; Morton and Matti, 1990a, 1990b; Morton and others, l990) indicates that the San Jacinto fault zone at the surface does not connect either with the Punchbowl or San Andreas faults but instead interacts in some fashion with east-to northeast-striking faults in the interior of the eastern San Gabriel Mountains.

Where it penetrates the southeastern corner of the San Gabriel Mountains near the mouth of Lytle Creek, the fault zone generally identified as the "San Jacinto fault zone" is a 300-m wide zone consisting of three nearly vertical faults. From west to east, these three faults bound four mappable blocks of biotite gneiss, mylonitic leucogranite, Pelona Schist, and Miocene granodiorite. The fault with the greatest width of crushed rock is overlain by apparently unfaulted alluvium thought to be 200-500 ka old (Morton and Matti, 1987). Four kilometers into the range, the "San Jacinto fault zone" consists of a relatively homogeneous zone of gouge and crushed rock, 200-300 m thick, bordered on the east by a thrust fault. Here, also, apparently unfaulted alluvium considered to be 200-500 ka (Morton and Matti, 1987), overlies the broad crush zone, but is offset along the eastern edge by the thrust fault.

Two faults, the Lytle Creek and Glen Helen, commonly thought to be branches of the "San Jacinto fault zone", parallel the San Jacinto fault zone near the mountain front. The Glen Helen fault, exposed along the west side of Cajon Canyon, is the only fault within the eastern San Gabriel Mountains that has a variety of more-or-less continuous youthful fault features, such as sag ponds and scarps. Morton and Matti (l987) indicate that these fault features are developed in alluvium capped by soils whose degree of development is comparable to the S4 to S5 soil stage of McFadden (1982), soils whose age probably falls between 4 and 70 ka. The Lytle Creek fault forms scarps in alluvial deposits capped by soils that also are consideredto the S4 or S5 soil stage (Morton and Matti, 1987). These are apparently the same as the ones considered to be 50 to 60 ka by Mezger and Weldon (1983).

Six kilometers northwest of the mountain front, the 200-300-m-wide "San Jacinto fault zone" coalesces with three north-dipping faults, each traversing a separate fork of Lytle Creek. West of this junction, these three faults branch and progressively change in strike counterclockwise until they are all orientated in a northeast direction. These northeast-striking faults converge to the west near the mountain front at the mouth of San Antonio Canyon, just west of the San Bernardino Forest. Just west of San Antonio Canyon, two faults seem to coincide with the San Gabriel fault zone in Cow Canyon. Based on the distribution of basement rocks, separation on the northwest-striking faults appears to be oblique-right-reverse, that on the east-striking faults appears to be thrust, and that on the northeast-striking faults is oblique-left-reverse. This is similar to the generalized sense of displacement determined from a recent microearthquake study (Cramer and Harrington, 1987). The overall geometry and sense of displacement of the faults is an antiformal schuppen-like structure.

Punchbowl Fault

The Punchbowl fault zone, located just south of the San Andreas fault in the eastern San Gabriel Mountains, is a deformed early strand of the San Andreas fault. It consists of two closely spaced faults separated at most places by a sliver of intensely deformed tonalitic and gneissic rocks. In some places recognizable gneiss and tonalite is missing and the two metamorphic facies of the Pelona Schist are separated by thoroughly sheared basement rock of uncertain parentage.

Secondary faults in the area of the San Gabriel Mountains commonly have reverse slip (Weldon and Matti, 1986) and analysis of current seismicity gives a mix of reverse and strike-slip fault plane solutions (Jones, 1988).

Cucamonga fault zone

The Cucamonga fault zone is located along the southern margin of the eastern San Gabriel Mountains, and marks the eastern end of the frontal-fault system of the San Gabriel Mountains. The Cucamonga fault zone consists of numerous anastomosing, east-striking, north-dipping thrusts that separate crystalline basement rocks of the eastern San Gabriel Mountains from alluvium of upper Santa Ana valley to the south. Some thrust faults of the zone lie entirely within alluvium (Morton and Matti, 1987). Slickensides in the basement rocks are consistently oriented down-dip, indicating the most recent displacements along the Cucamonga fault zone have been pure thrust.

Faulting has occurred throughout the Quaternary, with individual faulting events estimated at about 6.7 M with a recurrence of about 625 years for the past 13,000 years (Morton and Matti, 1987). The average north-south convergence across the Cucamonga fault zone is estimated to have been in the range of 3 mm/yr (Weldon, 1986) to 5 mm/yr (Matti and others, 1982; Morton and Matti, 1987).

San Andreas fault

On the north side of the San Gabriel Mountains, the San Andreas fault forms a nearly linear, relatively simple break, slightly concave to the south. Within Lone Pine Valley, the San Andreas forms a linear "rift valley" that reflects long-term activity on the fault. This trace of the fault along the north flank of the San Gabriel Mountains represents the Mojave Desert segment of the San Andreas; to the southeast, the Mojave Desert segment passes into the San Bernardino strand that lies along the base of the San Bernardino Mountains.

Other faults in the San Gabriel Mountains

Located north of the Cucamonga fault zone between Lytle Creek and San Antonio Canyon are three northwest-striking right-lateral faults, the Duncan Canyon, Morse Canyon, and Demens Canyon faults (Morton and Matti, 1987). They appear to be terminated on the south by the Cucamonga fault zone and on the north by the South Fork Lytle Creek fault. All three show right-lateral separation, the 1.5-km separation along the Duncan Canyon fault being the greatest.

GEOLOGY OF THE CAJON VALLEY AREA

The San Bernardino National Forest encompasses part of the Cajon Valley area located north of the San Andreas fault between the northeastern San Gabriel Mountains and the western San Bernardino Mountains. In contrast to the extensive exposures of crystalline rocks in the two mountain ranges, the Cajon Valley area is dominated by Tertiary and Quaternary sedimentary rocks.

Crystalline basement rocks

Crystalline basement rocks occur in eastern and the western parts of the Cajon Valley area (Dibblee, 1967b; Ross, 1972). To the east, the basement is similar to that of the western San Bernardino Mountains, and consists of a metamorphic complex intruded by granitoid plutonic rocks (Ehlig, 1988). The granitoids consist of light-colored rocks of granodioritic composition that are late Cretaceous in age (Silver and others, 1988); the metamorphic complex consists of gneissose granitoid rocks and associated metasedimentary screens. To the west, the basement complex consists of highly deformed tonalitic rocks, with variable amounts of included gneiss, schist, marble, and calc-silicate marble (Dibblee, 1967b; Ross, 1972) . Here, larger marble pods have been prospected and mined to a limited extent for decorative rock. The plutonic rocks are mineralogically and texturally heterogeneous, and consist mainly of biotite-hornblende granodiorite to tonalite (Ross, 1972). In many places they are intensely fractured and sheared. Good exposures of intensely sheared rock along Highway 138 are on the east side of Sheep Creek northeast of Wrightwood.

Mesozoic and Tertiary sedimentary rocks

The oldest sedimentary rocks in the Cajon Valley area belong to the marine San Francisquito(?) Formation of Cretaceous and(or) Paleocene age. On the basis of overall lithologic similarity, these sedimentary rocks are correlated with the San Francisquito Formation in the Devils Punchbowl 25 mi west of the Cajon Valley area area (Dibblee, 1967b; Kooser, l980, 1982). A single vertebrae of a plesiosaur was found in the Cajon Valley area (Kooser, 1985). The San Francisquito Formation occurs in a number of complex fault blocks on both sides of Interstate 15 in the southern part of the Cajon Valley area (Weldon, 1986); most of these fault blocks are too small to be shown on the accompanying geologic map (plate 1). The San Francisquito Formation consists of a basal conglomerate overlain by sandstone and siltstone. The conglomerate consists of unsorted subrounded cobbles of gneiss and light-colored granitic rock. The buff to nearly black sandstone and siltstone are well bedded, with alternating sandstone and siltstone beds. The San Francisquito Formation is in fault contact with younger sedimentary units.

Coarse arkosic sandstone and minor siltstone in several small fault blocks have been correlated with the marine Vaqueros(?) Formation. Based on marine invertebrate fossils, these rocks are considered to be lower Miocene (Woodburne and Golz, l972). The Vaqueros(?) Formation rests depositionally on granitic basement or is faulted against the San Francisquito(?) Formation, and is unconformably overlain by nonmarine Miocene sedimentary rocks.

Cajon Valley is flanked by an 8000-ft thick sequence of nonmarine clastic rocks, here called the rocks of Cajon Valley (Cajon Formation of Meisling and Weldon, 1989). This sequence previously has been termed Punchbowl Formation (see Noble, 1953, 1954a), a formational name applied to a somewhat similar-appearing sequence of rocks in the Devils Punchbowl area 25 mi west of Cajon Valley. Detailed biostratigraphic studies by Woodburne and Golz (1972) showed that the rocks in Cajon Valley are older than the youngest rocks of the Punchbowl Formation in the type locality. In Cajon Valley, these rocks have yielded a vertebrate fauna indicating a middle to late Miocene age. In this report, the informal name "rocks of Cajon Valley", suggested by M. O. Woodburne (personal communication, 1989), is used to distinguish these rocks from the type Punchbowl Formation.

The rocks of Cajon Valley consist of a lower sequence of tan conglomerate and conglomeratic sandstone and an upper sequence of finer-grained conglomeratic sandstone and reddish to grayish sandstone, and with local gray siltstone. Parts of the lower sequence weather to form scenic hogbacks (e.g., near Mormon Rocks Ranger Station). The western boundary of the unit is the Cajon Valley fault that juxtaposes the rocks of Cajon Valley against heterogeneous tonalite. Movement on this fault is interpreted to have occured mainly during the late Miocene (Woodburne and Golz, 1972). The eastern boundary of the rocks of Cajon Valley is the Squaw Peak fault that juxtaposes the unit against the Crowder Formation of Dibblee (1967b).

The Crowder Formation consists of a thick section of light-gray conglomerate and conglomeratic sandstone that typically is less well lithified than the rocks of Cajon Valley. Dibblee (1967) considered that the Crowder Formation was Pliocene in age and rested unconformably above the rocks of Cajon Valley. More recently, Weldon (1984b, 1986; Meisling and Weldon, 1989) and Reynolds (1984) recognized that the Crowder Formation is the same age (Miocene) as the rocks of Cajon Valley and that the two units have been juxtaposed by the Squaw Peak thrust fault and associated structures (Meisling and Weldon, 1989; however, Ehlig, 1988b, offers an alternative view of these structural relations).

Sedimentary rocks on the north side of Cajon Valley formerly were included within the Crowder Formation (Dibblee, 1967; Foster, 1980 referred to these as the western facies of his upper Crowder Formation) but now are referred to informally as the Phelan formation (Meisling, 1984; Weldon, 1984b, 1986) or Phelan Peak deposits (Meisling and Weldon, 1989). We informally refer to these as "the rocks of Phelan Peak". These rocks, of fluvial origin, consist of unconsolidated to moderately indurated, light brownish to orangish coarse sandstone, conglomeratic sandstone, and conglomerate. The age of deposition is from 1.4 to 4.1 Ma (Weldon, 1984, 1986). As now used, this unit unconformably overlies the rocks of Cajon Valley and the Crowder Formation as well as the tectonic structures that separate these two older units.

Quaternary deposits

The most conspicuous and widespread assemblage of Quaternary surficial materials in the Cajon Valley region underlies and caps the so-called "inface bluffs" that rise above Cajon Valley and face southward (Noble, 1954a). The bluffs display three successive Pleistocene rock units that together record the history and evolution of the Victorville fan--an ancient, now-abandoned Quaternary alluvial-fan complex of sand and gravel that spread northward onto the high desert from various stream-canyon sources in the crystalline San Gabriel Mountains (Meisling and Weldon, 1989; Weldon and others, 1993). Two rock units form the lower part of the Victorville fan: the Harold Formation (of Noble, 1953) and the Shoemaker Gravel (of Noble,1954b). The Harold Formation is a thin (less than 120 ft) nearly continuous section of unconsolidated, fluvial sandstone and pebbly sandstone exposed along the lower part of the "inface bluffs" (Foster, 1980, 1982). The Harold Formation grades upward into the Shoemaker Gravel, an unconsolidated section of thick and poorly bedded, fluvial coarse sand, conglomeratic sand, and conglomerate. North of Cajon Valley the Shoemaker Gravel is about 200 ft thick. The top of the Victorville fan is capped by unnamed, dissected brownish sand-and-gravel units that represent the youngest deposits of the ancient alluvial fan (Foster, 1980, 1982; Meisling, 1984; Weldon,1986).

In the Cajon Valley area, several large landslide deposits carry gneiss, marble, and tonalitic rocks over the Cajon fault and sedimentary rocks of Cajon Valley.

GEOLOGY OF THE SAN BERNARDINO MOUNTAINS

The San Bernardino Mountains consist of a high, east-trending elongate block that has been uplifted to its present elevation during the last few million years. The mountains are bounded on their steep north side by a series of south-dipping thrust faults commonly referred to as the north-frontal fault system (Meisling, 1984; Miller, 1987). The interior of the range is traversed by the east-trending north-dipping Santa Ana reverse fault that separates the mountain geomorphology into two main terrains: to the north, an extensive, partly dissected plateau that forms the main mass of the San Bernardino Mountains; to the south, a more strongly dissected terrain that has been deeply eroded by major stream canyons that head into the interior away from the south edge of the mountains. The highest summits of the San Bernardino Mountains occur in this terrain, including San Gorgonio Peak (11,485 ft).

The southwestern and southeastern margins of the San Bernardino Mountains are traversed by several strands of the San Andreas fault zone that in part form the geomorphic and structural boundary of the range (Matti and others, 1992). These faults partition the geologic materials and geologic structures of the San Bernardino Mountains into three main terranes: (1) rocks outboard (west and southwest) of the Mission Creek strand; (2) rocks between the Mission Creek strand and the Wilson Creek strand; and (3) the main San Bernardino Mountains terrane inboard (east) of the Mill Creek strand.

Geologic setting southwest of the Mission Creek strand,
San Andreas fault

The Mission Creek strand of the San Andreas fault separates a distinctive terrane of crystalline rocks in the southeastern San Bernardino Mountains from Mojave Desert-type rocks in the main mass of the mountains. The Mission Creek strand enters the San Bernardino Mountains from the Coachella Valley, curves west and southwest to the headwaters of San Gorgonio River, and continues northwest along the margin of the mountains along a trace that is obscurred beneath alluvium of the San Bernardino Valley (Matti and others, 1985, 1992). This older trace has been reactivated by the modern San Bernardino strand of the San Andreas that lies along the base of the San Bernardino Mountains. Rocks outboard (south and west) of the Mission Creek fault are not native to the San Bernardino Mountains; instead, they have been faulted against the main mass of the range by displacements on the San Andreas fault that brought the rocks into the region from their original position about 140 km farther southeast in the Coachella Valley (Matti and others, 1985, 1992; Matti and Morton, 1993). In San Gorgonio Pass, the Banning fault separates these rocks from Peninsular Ranges rocks of the San Jacinto Mountains.

Crystalline rocks in the southeastern San Bernardino Mountains are like those in the eastern San Gabriel Mountains (Matti and others, 1983). They form two distinct terranes separated by a steeply dipping thrust fault that is part of the region-wide Vincent-Orocopia-Chocolate Mountains thrust sytem (Ehlig, 1981, p. 266-277):

Lower-plate rocks.--Lower-plate rocks of the Vincent-Orocopia thrust crop out in a restricted area in the headwaters of San Gorgonio River. There, the rocks consist mainly of albite-actinolite-chlorite-epidote greenstone that probably represents basaltic flows and tuffs that have been metamorphosed to greenschist facies. Subordinate lithologies include metachert, metasiltstone, metasandstone, and minor carbonate rock. These rocks are similar to the Pelona Schist of the southeastern San Gabriel Mountains.

Upper-plate rocks.--Upper-plate rocks of the Vincent-Orocopia thrust are a lithologically monotonous assemblage that includes foliated and gneissose granitoid rocks, compositionally layered granitic gneiss, and pegmatite. Abundant epidote characterizes many of these rocks. The granitoid rocks and their gneissose equivalents have a range of compositions that includes leucocratic biotite granodiorite, hornblende-biotite quartz diorite and tonalite, granodioritic orthogneiss, and distinctive hornblende- and potassium-feldspar-bearing porphyritic granodiorite and monzogranite that is lithologically similar to the Mount Lowe Intrusion of the San Gabriel Mountains (Barth and Ehlig, 1988; Joseph and others, 1982; Ehlig, 1981, p. 262-263, discusses the petrology and regional correlation of the unit). Most of the plutonic rocks and most of the plutonic protoliths for the layered gneisses probably are Mesozoic in age, although bodies of Precambrian orthogneiss may be present. These crystalline rocks have been affected by one or more penetrative deformations that have crushed and sheared the rocks and have produced pervasive planar fabrics that include textural foliation, cataclastic and mylonitic foliation, and gneissose compositional layering. Mylonitic fabrics are especially well developed structurally low in the terrane near the Vincent-Orocopia thrust. Following the last episodes of penetrative deformation, the crystalline rocks were intruded by dikes of hypabyssal dacite porphyry and porphyritic basalt.

Geologic setting between the Mission Creek and Mill Creek strands,
San Andreas fault

A thin slice of crystalline basement rocks and overlying Tertiary sedimentary rocks occurs between the Mission Creek strand of the San Andreas and the Wilson Creek strand--a sinuous fault that occurs between the Mission Creek and Mill Creek strands from San Gorgonio River to the vicinity of San Bernardino. The crystalline rocks mainly are gneissose to foliated granodiorite that is associated with texturally massive plutonic rock that is dioritic to monzogranitic in composition (Matti and others, 1983a, 1992b). These rocks locally are overlain nonconformably by upper Cenozoic nonmarine sandstone and conglomerate of the Mill Creek Formation (of Gibson, 1971, as used by Matti and others, 1992b). As with rocks outboard (southwest) of the Mission Creek strand, rocks outboard of the Wilson Creek strand are not native to the San Bernardino Mountains; they are generally similar to rocks in the Little San Bernardino Mountains, and appear to have been faulted against the San Bernardino Mountains by about 50 km of displacement on the Wilson Creek and Mill Creek strands of the San Andreas fault (Matti and Morton, 1993).

Geologic setting of the San Bernardino Mountains east of the San Andreas fault zone

The main mass of the San Bernardino Mountains occurs east of the San Andreas fault zone, although a thin slice of rocks native to the mountains occurs outboard (southwest) of the Mill Creek strand of the San Andreas and has been displaced about 8 km northwest of its original position (Matti and others, 1985; Matti and Morton, 1992). Rocks of the main San Bernardino Mountains are similar to those in the Mojave Desert Province. They span a broad range of compositions and geologic ages and have beed deformed by a variety of geologic structures. We describe these geologic materials and structures in terms of their relation to major Mesozoic batholithic intrusions.

Prebatholithic rocks

Prebatholithic rocks in the San Bernardino Mountains can be grouped into two packages: (1) very old crystalline rocks that represent the ancient Proterozoic North American continental crust as it existed more than 1.5 billion years ago, and (2) very old sedimentary rocks that were deposited in marine environments that lapped over the ancient Proterozoic continental mass.

Proterozoic crystalline rocks.--These rocks consist of granitoid and gneissose rocks that form the Baldwin Gneiss of Guillou (1953). Three major rock types occur: (1) well foliated to compositionally layered granitic gneiss rocks that include augen gneiss having "eye-shaped" crystals of potassium feldspar and (or) clots of quartzofeldspathic minerals; (2) bodies of texturally massive to foliated equigranular to porphyritic plutonic rock; and (3) biotite-rich well-foliated compositionally layered gneiss that probably is metasedimentary in origin. The first two rock types mainly are biotite-bearing and granodioritic in composition, are plutonic and metaplutonic in origin, and locally are cut by pegmatitic and quartz-rich dikes and veins. The plutonic rocks have a minimum age of 1,750±15 billion years (Silver, 1971); the gneissose rocks they intrude are even older.

Proterozoic and Paleozoic metasedimentary rock.--A thick sequence of metasedimentary rock crops out locally in the San Bernardino Mountains. In the eastern part of the range, basal units of these rocks rest depositionally on top of the Baldwin Gneiss; elsewhere, the metasedimentary rocks occur as thin screens to thick pendants surrounded by Mesozoic granitoid rocks, and their depositional relation with the Baldwin gneiss can only be inferred. The metasedimentary rocks consist generally of a lower metaquartzite sequence and an upper metacarbonate sequence, both deposited in relatively shallow marine environments of the ancient North American continental shelf. The metaquartzite sequence ranges in age from late Proterozoic to early Cambrian; the carbonate sequence ranges in age from early Cambrian through Pennsylvanian.

Metaquartzite sequence: Metaquartzites in the San Bernardino Mountains first were studied by Vaughan (1922) who grouped them within his Saragossa Quartzite. Working in the north-central part of the range, Guillou (1953) applied the name Chicopee Formation to the upper part of Vaughan's Saragossa Quartzite in order to distinguish distinctive quartzite and non-quartzite rock types that occur in that part of the sequence. Richmond (1960) adopted Guillou's nomenclature in revised form (Chicopee

Canyon Formation), but for purposes of his regional mapping Dibblee (1964a) continued to apply the name Saragossa Quartzite to all the quartzitic rocks. Stewart and Poole, 1975) recognized affinities between the San Bernardino Mountains quartzite sequence and similar rocks in the Great Basin and Mojave Desert Provinces, and later workers applied some of the southern Great Basin rock names in the San Bernardino Mountains (Tyler 1975, 1979; Cameron, 1981, 1982). However, lithologic and thickness differences between parts of the quartzitic sections in the San Bernardino Mountains and those in the southern Great Basin led Cameron (1981, 1982) to break out several new quartzitic formations within Vaughan's (1922) old Saragossa Quartzite, and Cameron (1982) grouped these formations within his Big Bear Group.

Although workers don't all agree about the nomenclature applied to the quartzitic sequences, all recent workers have split out multiple rock units in order to portray the considerable lithologic variation present within Vaughan's (1922) Saragossa Quartzite. In ascending order, this variation includes: (1) thick basal units of light-colored metaquartzite and conglomeratic quartzite, an interval of dark-colored phyllite, metasiltstone, and metaquartzite, and a light-colored sequence of quartz-sand-bearing limestone and dolomite and ripple-laminated quartz-rich metaquartzite and conglomeratic quartzite (some parts of this sequence are lithologically similar to the Stirling Quartzite as used by Stewart , 1970, in the southern Great Basin); (2) an interval of dark-colored metasiltstone and phyllite interlayered with light-colored laminated and cross-laminated metaquartzite (lithologically correlative with the Wood Canyon Formation as proposed by Stewart and Poole, 1975); (3) an interval of white, texturally massive metaquartzite (lithologically correlative with the Zabriskie Quartzite as proposed by Stewart and Poole, 1975). This sequence and nomenclature is usable mainly in the central San Bernardino Mountains where the quartzitic sections are relatively well preserved (Sadler, 1981; plate 2 of this report); elsewhere in the range, the metaquartzite sections are highly intruded by Mesozoic plutonic rocks and are less complete and structurally more complex.

Metacarbonate sequence: Metamorphosed limestone and dolomite in the San Bernardino Mountains first were studied by Vaughan (1922) who grouped them within his Furnace Limestone. Various informal units of the formation have been mapped by Guillou (1953), Richmond (1960, his Furnace Formation), Dibblee (1964), Hollenbaugh (1968), and Sadler (1981). Stewart and Poole (1975) indicated that parts of the Furnace Limestone are lithologically similar to Paleozoic carbonate rocks of the Mojave Desert and Basin and Range Provinces, and Tyler (1975, 1979) first applied nomenclature other than Furnace Limestone to some of these rocks. He proposed that the lower part of Vaughan's Furnace Limestone is lithologically correlative with the Carrara and Bonanza King Formations of the southern Great Basin, a precedent followed by Cameron (1981, 1982). Cameron (1981) also indicated that the Furnace Limestone above the Bonanza King Formation included rocks like those in Devonian and Carboniferous units in the southern Great Basin, and Brown (1984a,b, 1987, 1991) mapped these units and determined their stratigraphy and formational contacts.

From oldest to youngest, the metacarbonate sequence in the north-central San Bernardino Mountains includes (plate 2): (1) Lower Cambrian limestone, calc-silicate rock, phyllite, and schist of the Carrara Formation; (2) Lower and Middle Cambrian light-gray and dark-gray, laminated to texturally massive dolomite, dolomitic limestone, and limestone of the Bonanza King Formation; (3) the Middle Cambrian Nopah Formation, separated into a thin basal member of hornfels, phyllite, calc-silcate rock, and quartz-sand-bearing limestone of the Dunderberg Shale Member and white to buff colored laminated to texturally massive dolomite of the upper member; (4) the Devonian Sultan Limestone, including dark colored dolomite of the Ironsides Member, white to buff colored laminated and texturally massive dolomite of the Valentine Member, and generally white limestone of the Crystal Pass Member; (5) the Mississippian Monte Cristo Limestone, including interlayered dark- and light-gray limestones of the Dawn and Anchor Members, white limestone of the Bullion Member, and heterogeneous limestone and dolomite of the Yellowpine Member; and (6) the Mississippina and Pennsylvanian Bird Spring Formation, including a basal member of quartzite, siltstone, and impure limestone, a lower member of white coarsely crystalline limestone, a middle member of medium- and dark-gray, quartz-sand and chert-bearing limestone, and an upper member of light- and medium-gray limestone.

Structure and metamorphism.--Quartzite and carbonate rocks in the San Bernardino Mountains are complexly deformed, and have been metamorphosed to conditions that locally reach amphibolite grade. The rocks have been folded under ductile conditions and refolded into two- or more generations of open to isoclinal folds, and are cut by numerous low-angle faults that have both older-over-younger and younger-over-older geometries (Cameron, 1981; Sadler, 1981; plate 2). The Doble fault of Guillou (1953) and the Santa Fe thrust of Woodford and Harris (1928) are examples of such structures. These structures are preplutonic: although some faults have been reactivated during Quaternary uplift of the range, fold and fault structures in the pre-batholithic rocks generally do not affect adjacent Mesozoic plutonic rocks, including Triassic hornblende monzonite that is the oldest Mesozoic plutonic rock in the region. The Proterozoic Baldwin Gneiss locally is involved in the low-angle faults that cut the folded quartzite and carbonate rocks, but the unit appears to have been too competent to fold easily. As a result of these ductility contrasts, the quartzite section appears to have broken away from the underlying Baldwin Gneiss and has slid along the original depositional contact on a low-angle fault that can be mapped throughout the north-central San Bernardino Mountains (Cameron, 1981; Sadler, 1981; Powell and others, 1993).

Contact metamorphism locally affects the prebatholithic rocks adjacent to plutonic contacts Richmond, 1960). However, the ductile nature of the deformation, the persistent nature of the metamorphic recrystallization, and correlation of metamorphic mineralization with dynamic structures point to regional dynamothermal metamorphism as a process that accompanied deformation and preceded or accompanied plutonism (Cameron, 1981, 1982).

Batholithic rocks

Batholithic rocks in the San Bernardino Mountains can be grouped into two packages: (1) older Mesozoic plutonic and volcanic rocks, and (2) younger Mesozoic plutonic rocks.

Older Mesozoic rocks.--Older Mesozoic igneous rocks include granitoid rocks of Triassic and Jurassic age and hypabyssal volcanic rocks of presumed Jurasssic age. The Triassic plutonic rocks are quartz-poor alkalic and potassic rocks that occur in two main areas: (1) adjacent to the Mill Creek strand of the San Andreas fault in the south-central part of the range, where a megaporphyritic hornblende-biotite monzogranite has a U/Pb intrusive age of about 215 Ma (Frizzell and others, 1986); (2) in the north-central and northwest part of the range, where alkalic hornblende monzonite has yielded an 40Ar/39Ar minimum age of 214±2.9 Ma (Cameron, 1981). The Triassic rocks are lithologically and chemically distinct from younger Mesozoic granitoids, with the hornblende monzonite in the north part of the range representing a distinctive suite of alkalic rocks that developed along the continental margin of western North America during early Mesozoic time (C.F. Miller, 1977a,b, 1978; Smith, 1982a,b).

Jurassic plutonic rocks occur locally in the central San Bernardino Mountains, and these may be related to a hypabyssal dike complex that crops out in the same region. The plutonic rocks are dioritic, quartz dioritic, and tonalitic in composition, and yield 40Ar/39Ar minimum ages of 126.7±3.5 Ma and 148.1±3.1 Ma and model Ar-retention ages of about 156 to 158 Ma (Cameron, 1981, p. 334). The hypabyssal dike complex was mapped and described by Richmond (1960) and Smith (1982a), who concluded that it was emplaced at shallow crustal levels within a northwest-trending fault zone that developed in prebatholithic rocks. Cameron (1981, p. 177-179) observed textural and compositional similarities between andesitic components of the dike complex and tonalitic, dioritic, and quartz dioritic shallow-level Jurassic plutonic rocks that he and Richmond (1960) mapped north of Big Bear Lake; Cameron proposes that the dike complex and the shallow-level dioritic rocks may be coeval and comagmatic. If Cameron is correct, then the dioritic rocks and the hypabyssal dike complex in the north-central San Bernardino Mountains may be part of the Late Jurassic Independence dike swarm of the Owens Valley region that James (1989) has recognized elsewhere in southern California.

Younger Mesozoic rocks.--Younger Mesozoic igneous rocks include granitoid rocks of probable Cretaceous age that crop out extensively throughout the San Bernardino Mountains. In the east part of the range, the granitoid rocks typically are monzogranitic in composition and are biotite-bearing; in the west part of the range, comparable granitoid rocks are granodioritic to monzogranitic in composition and are biotite- and hornblende-biotite bearing. Most workers group these rocks within a single undifferentiated unit (quartz monzonite [qm] of Dibblee, 1964a,b, 1967a,b; Cactus Granite of Vaughan, 1922, and Guillou, 1953); however, detailed studies like those of MacColl (1964) and F.K. Miller (1987; unpublished mapping, 1974-1977) show that discrete phases and plutonic bodies can be differentiated within the monzogranitic terrane. A few of these are identified on plate 1 of this volume. Elsewhere, the large plutonic units locally include muscovite-garnet granite, granodiorite, tonalite, and alaskite bodies that have not been differentiated on plate 1.

Deformed Mesozoic plutonic and metamorphic complex.--A poorly understood belt of gneissose crystalline rocks crops out inboard (east) of the San Andreas fault zone in the western San Bernardino Mountains and along the south-central and southeast margins of the range. These rocks traditionally have been interpreted as a Precambrian gneiss complex (Dibblee, 1975, 1982b; Rogers, 1967, who compiled the work of Dibblee, 1964a,b, 1967a,b, and unpublished). The terrane consists mainly of fine- to coarse-grained, equigranular to porphyritic, gneissose to foliated to texturally massive crystalline rocks characterized by compositional and textural heterogeneity (Ehlig, 1988a; Matti and others, 1992b). The rocks mainly are granodioritic to tonalitic in composition, are biotite- and hornblende-biotite bearing, locally are sheared and fractured, and commonly have brittle to slightly ductile deformation fabrics (cataclasite and low-grade mylonite). The gneissose rocks locally are intermingled with small bodies of calcite marble, calc-silicate rock, metaquartzite, and garnetiferous biotite-silimanite schist. We interpret this terrane as a Mesozoic plutonic and metamorphic complex that contains deformed and migmatized variants of deformed plutonic rock types that occur elsewhere in the San Bernardino Mountains.

Upper Cenozoic sedimentary rocks

Isolated patches of upper Cenozoic sedimentary occur throughout the San Bernardino Mountains. The major outcrop belts occur in two main areas:

(1) Deposits of the nonmarine Santa Ana Sandstone (of Vaughan, 1922, as used by Sadler, 1982, 1993, and by Sadler and Demirer, 1986) crop out in an east-trending belt 3 km wide and about 30 km long in the Santa Ana River drainage on the south margin of the San Bernardino Mountains. This unit has several local facies that include poorly sorted sandstone, pebbly sandstone, conglomerate, reddish paleosols, green claystone and mudstone, and intervals dominated by distinctive basement-clast populations that include Pelona Schist and anorthosite (Sadler and Demirer, 1986; Sadler, 1993)). Basalt flows and dikes interlayered with the sequence yielded a K/Ar whole-rock age of 6.2 Ma (Woodburne, 1975), but the sequence probably ranges from about 18 Ma to less than 5 Ma (Sadler, 1985, 1993). Deposits similar to the Santa Ana Sandstone occur intermittently east of the main outcrop belt, and ultimately trend laterally toward outcrops of the Old Woman Sandstone that underlie extensive Upper Miocene basalt flows in the Pioneertown area of the eastern San Bernardino Mountains (Dibblee, 1967a). The Santa Ana Sandstone also trends west toward the Cajon Pass area and upper Miocene deposits of the Crowder Formation (as used by Meisling and Weldon, 1989) that crop out there. Meisling and Weldon (1989) view the Crowder and Santa Ana formations as part of a regionwide package of nonmarine upper Cenozoic sediment that originally blanketed much of the now-uplifted San Bernardino Mountains. Isolated patches of quartzite cobbles that occur locally throughout the San Bernardino Mountains (Sadler and Reeder, 1983) may be vestiges of this late Miocene blanket.

(2) Deposits of the nonmarine Old Woman Sandstone (of Shreve, 1968, as used by Sadler, 1981) crop out intermittently along the north front of the San Bernardino Mountains. The lithology of the unit varies geographically (Sadler, 1981), but generally it consists of sandstone and mudstone interlayered with pebble- and cobble-bearing sandstone having basement clasts derived from Mojave Desert sources to the north; these rocks locally are overlain by a conglomeratic unit having basement clasts derived from San Bernardino Mountains sources to the south. The unit ranges in age from possibly 10 Ma to probably less than 2 Ma (May and Repenning, 1982).

Quaternary materials

Alluvial deposits.--Quaternary sand-and-gravel deposits are extensive in parts of the San Bernardino Mountains, including the following major outcrops: (1) alluvial-fan deposits on the south margin of the mountains that accumulated in the intra-mountain drainages of City Creek, Plunge Creek, and Santa Ana River. In the Barton Flats area of upper Santa Ana River, the alluvial-fan deposits are interlayered with riverine deposits and glacial-outwash deposits, all of which have been deformed by landslide processes that have created a complex geomorphic setting of scarps and hummocky ground (Sadler and Morton, 1989); (2) the Big Bear Lake area, where lowlands now occupied by Big Bear and Baldwin Lakes have been the sites of Quaternary alluvial accumulation (note, however, that broad expanses of sedimentary material formerly interpreted as Quaternary in the Big Bear Lake region [for example, units interpreted by Richmond, 1960, as Quaternary talus deposits and by Sadler, 1981, as relict fanglomerate] are intrepreted by Matti and Morton [plate 1 of this report] as mainly Tertiary in age); and (3) multiple alluvial-fan units that extend north onto Lucerne Valley from the north front of the San Bernardino Mountains.

Glacial deposits.--Morainal glacial deposits of late Pleistocene and Holocene age occur on the north side of San Gorgonio Mountain and to the west on San Bernardino Ridge (Sharp and others, 1959). Fluvial-glacial detritus is common on the upper parts of Barton Flats where it forms a sedimentary veneer overlying the Santa Ana Sandstone.

Landslide deposits.--Landslides are common in the San Bernardino Mountains. Large landslide complexes occur locally along the steep south margin of the range (for examples see Miller, 1979, and Matti and others, 1992). Extensive landsliding has occurred in the Barton Flats area (Sadler and Morton, 1989) where older surficial gravel units that overlie the Santa Ana Sandstone have failed and slid northward toward the low-lying Santa Ana River, creating a complex pattern of crown scarps and depressions on the Barton Flats landscape. The steep terrane of Sugarloaf Mountain has shed numerous large landslide masses (McJunkin, 1978; Powell and others, 1983; Sadler and Morton, 1989), as has the precipitous west-facing slope of the Granite Peaks massif (Matti and others, 1982b). Spectacular landslides have originated on the north side of the San Bernardino Mountains. These include the well-known Blackhawk landslide, first recognized in the 1920's (Woodford and Harriss, 1928). This landslide travelled northward from the mountains a considerable distance onto the desert floor by riding a layer of compressed air (Shreve, 1968). Older landslides similar to the Blackhawk slide have been shed off of the north face of the San Bernardino Mountains throughout late Quaternary time (Sadler, 1981, 1982a; Matti and others, 1993, this volume).

Post-batholithic geologic structures

Post-batholithic geologic structures in and around the San Bernardino Mountains fall into three categories:

Late Miocene uplift structures.--These are associated with late Miocene uplift of the ancestral San Bernarino Mountains (Meisling and Weldon, 1982, 1989). These include the Squaw Peak thrust fault in the Cajon Valley region and east-trending north-dipping reverse faults and left-lateral faults in the western and central part of the mountains, including the Santa Ana fault. The Santa Ana fault is an east-striking reverse fault located in the interior of the range. Displacement on this fault has placed crystalline rocks against the Santa Ana Sandstone. The fault is obscured by landslides and colluvial debris along much of its length. Near the fault, the bedding of the Santa Ana Sandstone steepens and locally is overturned (Sadler, 1993).

San Andreas fault zone.--As discussed above, several strands of the San Andreas fault zone traverse the southeastern San Bernardino Mountains and flank the southwestern base of the range (plate 1 of this volume; Matti and others, 1992; Matti and Morton, 1993). Older strands of the zone include the Wilson Creek, Mission Creek, and Mill Creek faults; the modern trace of the fault in this region is represented by the San Bernardino strand. The older strands have generated considerable right-lateral displacements that over the last few million years have juxtaposed far-travelled crystalline basement rocks against the main mass of the San Bernardino Mountains. The modern San Bernardino strand is capable of generating large earthquakes, although the strand apparently did not rupture during the 1857 earthquake that occurred along the Mojave Desert segment to the northwest. Locally, as in the San Gorgonio Pass region and in the Yucaipa area, complexities in the San Andreas fault have created associated reverse and thrust-fault zones and normal dip-slip fault zones (Matti and others, 1992a,b).

Quaternary uplift structures.--Structures associated with Quaternary uplift of the range include the north-frontal fault zone (Meisling, 1984; Miller, 1987; Sadler, 1982a) and faults along the south part of the range that facilitated uplift (the San Gorgonio Pass fault zone of Matti and others, 1992). Meisling and Weldon (1989) indicate that uplift was accomplished in early Quaternary time by north-directed upward movements of the San Bernadino Mountains block along south-dipping low-angle structures that underlie the range. This uplift created the impressive topographic relief along the north face of the San Bernardino Mountains. Although largely complete by middle Quyaternary time (Meisling and Weldon, 1989), tectonism presumably associated with uplift of the range has continued into the late quaternary, giving rise to strike-slip and thrust-fault scarps that locally break late Quaternary alluvial deposits adjacent to the northern range front (Miller, 1987).

GEOLOGY OF THE SAN GORGONIO PASS AREA

San Gorgonio Pass is an east-trending lowland that intervenes between the two high-standing masses of the San Bernardino and San Jacinto Mountains. The surface of this lowland is covered by various generations of alluvial-fan deposits that mainly are derived from the San Bernardino Mountains. The northern foothills are underlain by upper Cenozoic nonmarine and marine sedimentary deposits that from oldest to youngest include sandstone and conglomerate of the Hathaway Formation (of Allen, 1957), marine mudstone and sandstone of the Imperial Formation, sandstone and conglomerate of the Painted Hill Formation (of Allen, 1957), and conglomeratic sandstone and conglomerate of the Cabazon Fanglomerate (of Vaughan, 1922, as used by Allen, 1957). Basalt flows and small intrusive bodies occur locally in the sedimentary sequence. The sedimentary section is folded, and is cut by north-dipping low-angle faults of the Quaternary San Gorgonio Pass fault zone (Matti and others, 1992). The east-trending right-lateral Banning fault separates the sedimentary section from crystalline rocks of the San Bernardino Mountains to the north. To the east, crystalline rocks of the San Bernardino Mountains block descend beneath the Coachella Valley and there, north of the Banning fault, are nonconformably overlain by a second occurrence of nonmarine and marine sedimentary rocks that includes from oldest to youngest the Coachella Fanglomerate (of Vaughan, 1922, as used by Allen, 1957, and Peterson, 1975), the Imperial Formation, and the Painted Hill Formation.

GEOLOGY OF THE SAN JACINTO MOUNTAINS BLOCK

The San Bernardino National Forest south of San Gorgonio Pass encompasses several mountain masses that we refer to collectively as the San Jacinto Mountains block. Included within this block are the San Jacinto Mountains themselves, with their topographic culmination of San Jacinto Peak (10,804 ft); the Santa Rosa Mountains; and the Cahuilla Mountain area. The San Jacinto Mountains form a high-standing massif tiered by several erosional levels that form a succession of relatively flat benches or plateaus that step up toward the summit apex. On the north and northeast, this massif drops precipitously into San Gorgonio Pass and into the Coachella Valley; to the south and southeast, the massif descends to the lowest erosional surface in the block, represented by Garner Valley and Pinon Flat. Southeast of Pinon Flat, the San Jacinto block rises again to form the Santa Rosa Mountains, which in turn drop off precipitously into Coachella Valley to the east and Borrego Valley to the southwest. The high-standing San Jacinto-Santa Rosa massif is separated from lower-standing uplands to the west by the San Jacinto fault, a right-lateral strike-slip zone that is part of the San Anderas fault family (Sharp, 1967). These uplands include local high points like Cahuilla Mountain and broad intermontane flats like Anza Valley. To the northwest, the Cahuilla-Anza upland drops off into the San Jacinto Valley and the Perris Block (of Woodford and others, 1971), which in turn are separated from the high San Jacinto Mountains on the east by the San Jacinto and Hot Springs faults.

In contrast to the geologic setting of the San Bernardino National Forest in the San Gabriel and San Bernardino Mountains, the San Jacinto Mountains block geologically is not very diverse. The region is underlain mainly by batholithic plutonic rocks of Mesozoic age that have invaded prebatholithic metasedimentary rocks; these rocks are generally similar to those elsewhere in the Peninsular Ranges Province of Jahns (1954). The crystalline units have been deformed by two major events (Sharp, 1979; Erskine, 1985): (1) a period of intense ductile shearing that produced the Eastern Peninsular Ranges mylonite zone and the associated Palm Canyon thrust fault; and (2) a period of brittle deformation that placed granitoid sheets on top of the upper plate of the Palm Canyon thrust. The batholithic and prebatholithic rocks and associated ductile and brittle structures locally are capped by Tertiary and Quaternary nonmarine sedimentary materials. All of these geologic materials and the older geologic structures are broken and displaced by young faults of the San Jacinto zone.

Preplutonic rocks

Prebatholithic rocks in the San Jacinto Mountains block are metasedimentary units that mainly consist of hornfels, biotite schist and phyllite, biotite-rich quartzofeldspathic gneiss, metaquartzite, and calcareous and dolomitic marble. These rocks represent accumulations of clay, silt, sand, and calcareous sediment that were deposited in the sea, probably during Paleozoic and (or) late Proterozoic time. This age span is supported by Rb-Sr isotopic evidence from metasedimentary rocks in the San Jacinto Mountains block (Hill, 1984, 1988) and by fossil evidence from similar metasedimentary rocks elsewhere in the Peninsular Ranges (Miller and others, 1983; Miller and Dockum, 1983). During Late Mesozoic time, high temperatures and pressures associated with emplacement of the batholithic rocks converted the sedimentary rock to metaquartzite, phyllite, schist, gneiss, and marble by metamorphic processes that recrystallized the sedimentary rocks, folded and sheared out the sedimentary layering, and produced new biotite-garnet-sillimanite mineral assemblages of the amphibolite facies.

Plutonic rocks

Plutonic rocks in the San Jacinto Mountains block include a variety of mafic to felsic plutonic units, although the most areally extensive plutonic bodies represent a narrow compositional range. According to Hill (1988, p. 10,327), the entire suite of plutonic rocks exposed in the San Jacinto Mountains massif was emplaced within a short 7-m.y. time span, with the youngest intrusives emplaced about 97 m.y. ago (Hill, 1981, 1984, plate 1). We describe these rocks in terms of their position in the lower and upper plates of the Palm Canyon thrust.

Lower-plate plutonic rocks

Plutonic rocks in the lower plate of the Palm Canyon thrust are typical of the Peninsular Ranges Province. Sparse mafic rocks include gabbro and diorite, with most occurrences located within and west of the San Jacinto fault zone. Mafic compositions include olivine gabbro, norite, and quartz gabbro that locally grades into mafic tonalite. Most of these rocks are dark-colored fine- to coarsely crystalline mixtures of hornblende, pyroxene, and plagioclase. Small bodies of biotite monzogranite occur locally, one in southeast Garner Valley (Penrod Granite of Brown, 1968, 1981) and another in the Cahuilla Mountain area that may have been displaced laterally from the Garner Valley body by right-slip displacement on the San Jacinto fault. A third distinctive monzogranite body occurs within the Eastern Peninsular Ranges mylonite zone (Matti and others, 1983) and has been strongly deformed along with enclosing granitoid rocks. The monzogranites typically are coarsely crystalline, commonly are muscovite-bearing, and locally are garnetiferous. Pegmatite veins and dikes are widespread but uncommon in the San Jacinto Mountains block; these are most abundant in the vicinity of Thomas Mountain, Cahuilla Mountain, and Bautista Canyon.

The most abundant granitoid rocks in the lower plate of the Palm Canyon fault are biotite granodiorite and hornblende-biotite tonalite to quartz diorite that crop out from the San Jacinto Mountains southeast to the Santa Rosa Mountains and in the Anza Valley area (Morton and others, 1980a). These rocks typically are coarsely crystalline, equigranular to porphyritic, and sphene-bearing. Careful mapping by Hill (1981, 1984, 1988) has documented three comagmatic tonalite plutons in the San Jacinto Mountains that have U/Pb intrusive ages of about 97±1 Ma (Hill, 1984, plate 1). These plutons probably are related temporally and petrologically to tonalite bodies elsewhere in the lower plate of the Palm

Canyon fault (like the Palm Canyon quartz diorite of Brown, 1968, 1981 and unnamed quartz diorite mapped by Matti and others, 1983b, and Erskine, 1985).

Upper-plate plutonic rocks

Plutonic rocks in the upper plate of the Palm Canyon thrust include (1) granitoid rocks in the Palm Canyon Complex of Erskine (1985) and (2) granitoid rocks in fault-bounded brittle sheets that overlie the Palm Canyon Complex.

Palm Canyon Complex.--Plutonic rocks in the Palm Canyon Complex consist of granitoids that occur either as extensive bodies or as small pods and zones intermingled with prebatholithic metasedimentary rocks. The more extensive rocks include bodies of hornblende-biotite tonalite, quartz diorite, and biotite granodiorite (Matti and others, 1983b). The more restricted bodies are dominated by leucocratic, garnetifierous, biotite-muscovite monzogranite that Erskine (1985; Todd and others, 1988) interprets as anatectic rocks that formed by assimilation and melting of the metasedimentary rocks. All of these plutonic rocks have affinities with plutonic rocks in the lower plate of the Palm Canyon fault.

Fault-bounded granitoids.--Fault-bounded blocks that rest tectonically on the Palm Canyon Complex contain foliated to gneissose plutonic rocks that mainly are granodioite in composition but include tonalitic and quartz-dioritic rock. The granitoids are sphene-rich, and contain magnetite as the iron-oxide mineral phase rather than ilmenite as do plutonic rocks in the lower plate of the Palm Canyon fault (Erskine, 1985; Todd and others, 1988). These fault-bounded granitoids apparently originated at deeper crustal depths than did those in the lower plate of the Palm Canyon fault, judging from geobarometry studies by Ague and Brimhall (1989).

Tertiary and Quaternary Deposits

No rock-unit evidence exists for geologic events within the San Jacinto Mountains block for the long time period between emplacement of low-angle brittle sheets on the Palm Canyon Complex and deposition of late Cenozoic sedimentary materials on the block. Much of this period apparently involved degradational events that shaped the multiple erosion surfaces that occupy various topographic levels on the San Jacinto Mountains block and the adjacent Perris Block (Woodford and others, 1971). The onset of late Cenozoic and Quaternary sedimentation is poorly constrained because the ages of relevant sedimentary deposits are poorly known.

Apart from patchy local Holocene and Pleistocene surficial deposits, four main areas of late Tertiary and Quaternary sedimentary materials occur on the San Jacinto block (plate 1):

Bautists beds.--The Baistista beds are a sequence of Pleistocene fluvial deposits located in the lower parts of the San Jacinto River east and upstream from the confluence of the Middle and South Forks. Frick (1921) first used the name "Bautista beds" for these beds in the vicinity of the mouths of the San Jacinto River and Bautista Canyon; he collected vertebrate fossils that confirmed a Pleistocene age for much of the sequence. Most of the deposits consist of unconsolidated to moderately indurated, grayish to brownish, biotite-bearing, arkosic, coarse-grained to conglomeratic sandstone with some discontinuous cobble and boulder beds. Fine-grained sandstone and silty and clayey beds locally are common. The deposits are composed almost entirely of detritus from the San Jacinto pluton.

Garner Valley area.--Garner Valley is flanked by well-dissected, consolidated sand and gravel deposits that Fraser (1931) and Sharp (1967) correlated with the Pleistocene Bautista beds. These deposits were derived from adjacent crystalline bedrocks, but they have no obvious alluvial-fan geomorphology. Although they may in part be Quaternary in age, we suspect that they are as old as Pliocene or Miocene in age (plate 1 of this report). Hill (1984, 1988) has proposed that the deposits accumulated in a rift basin associated with early right-lateral strike-slip movements on structures of the San Jacinto fault zone.

San Jacinto fault zone.--Various generations of poorly consolidated to well consolidated sand and gravel deposits occur throughout the the San Jacinto fault zone from the San Jacinto Valley region southeast to Anza and beyond. Many of these are dominated by brownish colored, coarse, poorly sorted sand Many of these deposits are Quaternary in age (Sharp, 1967), but some could be as old as Pliocene or Miocene.

Desert-side alluvial-fans.--Large, deeply dissected canyons that embay the north and east margins of the San Jacinto Mountains block are floored by alluvial-fan deposits that consist of coarse bouldery fanglomerate..These fans prograde into San Gorgonio Pass and the northern Coachella Valley, and probably are mainly Pleistocene in age with only a minor Holocene component.

Locally in the San Jacinto Mountains block, Holocene deposits of unconsolidated alluvium are widespread. Most of the Holocene sediment from the west side of the San Jacinto Mountains was deposited into a rapidly subsiding pull-apart basin in the San Jacinto fault zone along the east side of San Jacinto Valley. Most of the Holocene sediments consist of cobble to boulder sized alluvial fan deposits. Deposits of coarse-grained sand are abundant on the modern floors of Garner and Anza Valleys.

Landslide deposits.--Slope-failure deposits occur locally on precipitous slopes of the San Jacinto Mountains block. Several large landslide masses are developed on the north face of San Jacinto Mountain overlooking San Gorgonio Pass (Morton and others, 1980a; plate 1 of this volume) and on the slopes of Martinez Mountain (Matti and others, 1983b). A large rock avalanche has been shed from Martinez Mountain eastward onto the Coachella Valley desert floor several thousand feet below (Bock, 1977; Baldwin, 1980, 1987; Morton and Sadler, 1989)

Geologic structures

Late Mesozoic ductile and brittle structures

During or following latest stages of granitoid plutonism in the San Jacinto block, the batholithic and prebatholithic rocks were subjected to a period of intense ductile shearing that squeezed, flattened, and sheared the rocks and created strongly foliated, layered, and lineated mylonitic fabrics of the Eastern Peninsular Ranges mylonite zone (Sharp, 1979; Matti and others, 1983b; Erskine, 1985). The mylonite zone is developed in tonalite and quartz diorite that now form the lower plate of the Palm Canyon fault. Sharp (1979) suggested that the mylonite represents a zone of ductile convergence along which rocks structurally above the zone were thrust west over typical Peninsular Ranges granitoids. Erskine (1985) documented this hypothesis and showed that the low-angle Palm Canyon fault probably is the culmination of west-directed thrusting that ultimately emplaced the Palm Canyon Complex against typical Peninsular Ranges rocks (Todd and others, 1988, fig. 32-6). However, prebatholithic and granitoid rocks of the Palm Canyon complex are generally similar to those in the underlying Peninsular Ranges terrane, and convergence along the mylonite zone and associated Palm Canyon fault probably was not great enough to juxtapose rocks having totally different provincial affinities (Erskine, 1985; Todd and others, 1988). Instead, the Palm Canyon Complex appears to be deep-seated equivalents of prebatholithic and batholithic rocks now occurring in the lower plate of the Eastern Peninsular Ranges mylonite zone and Palm Canyon fault (Matti and others, 1983b; Todd and others, 1988).

Ductile deformation associated with convergence was followed by a period of brittle deformation during which rock units in the upper plate of the Palm Canyon thrust were reshuffled by large-scale lateral displacements on low-angle structures like the Asbestos Mountain, Deep Canyon, and Martinez Mountain faults (Matti and others, 1983b; Erskine, 1985). According to Erskine (1985; Todd and others, 1988), movement indicators associated with these structures provide conflicting evidence of west-directed transport that may be related to earlier episodes of ductile convergence and east-directed transport that may reflect extensional dip-slip tectonics (Erskine and Wenk, 1985). Todd and others (1988) propose that this conflicting structural evidence may reflect reactivation of early contractional structures by later extensional events.

San Jacinto fault

In the vicinity of the San Jacinto Mountains block, the San Jacinto fault zone consists of several large faults, including the Hot Springs, Thomas Mountain, Buck Ridge, and Casa Loma faults (Sharp, 1967; Hill, 1984). These faults displace crystalline bedrocsk by as much as 25 to 30 km (Sharp, 1967), a movement history that may have developed entirely in the Quaternary. Locally, complications within the right-lateral fault zone have led to the formation of thrust-fault complexes.

REFERENCES CITED

Ague, J.J., and Brimhall, G.H., 1988b, Magmatic arc asymmetry and distribution of anomalous plutonic belts in the batholiths of California: effects of assimilation, crustal thickness, and depth of crystallization: Geological Society of America Bulletin, v. 100, p. 912-927.

Baird, A.K., McIntyre, D.B., and Welday, E.E., 1967, Geochemical and structural studies in batholithic rocks of southern California: Part II, Sampling of the Rattlesnake Mountain pluton for chemical composition, variability, and trend analysis: Geological Society of America Bulletin, v. 78, p. 191-222.

Baird, A.K., Baird, K.W., and Welday, E.E., 1979, Batholithic rocks of the northern Peninsular Ranges, southern California, in Abbott, P.L., and Todd, V.R., eds., Mesozoic crystalline rocks: San Diego, California State University, Department of Geological Sciences, p. 111-132.

Baird, A.K. and Miesch, A.T., 1984, Batholithic rocks of southern California - A model for the petrochemical nature of their source materials: U.S. Geological Survey Professional Paper 1284, 42 p.

Baldwin, J.E., 1980, The Martinez Mountain rock avalanche: Los Angeles, California State University, unpublished M.S. thesis, 58 p.

-----1987, The Martinez Mountain rock avalanche, in Guptil, P.D., Gath, E.M., and Ruff, R.W., eds., Geology of the Imperial Valley, California: Santa Ana, California, South Coast Geological Society Annual Field Trip Guidebook, v. 14, p. 37-48.

Barth, A.P., and Ehlig, P.L., 1988, Geochemistry and petrogenesis of the marginal zone of the Mount Lowe Intrusion, central San Gabriel Mountains, California: Contributions to Mineralogy and Petrology, v. 100, p. 192-204.

Bock, C.G., 1977, The Martinez Mountain rock avalanche, in Coates, D.R., ed., Landslides: Geological Society of America Reviews in Engineering Geology, v. 3, p. 155-168.

Bortugno, E.J., and Spittler, T.E., 1986, Geologic map of the San Bernardino Quadrangle: California Division of Mines and Geology, Regional Geologic Map Series, Map No. 3A, scale 1:250,000.

Brown, A.R., 1968, Geology of a portion of the southeastern San Jacinto Mountains, Riverside County, California: Riverside, University of California, M.S. thesis, 95 p.

Brown, A.R., 1980, Limestone deposits of the Desert Divide, San Jacinto Mountains, in Fife, D.L., and Brown, A.R, eds., Geology and mineral wealth of the California Desert: Santa Ana, California, South Coast Geological Society, p. 284-293.

Brown, A.R., 1981, Structural history of the metamorphic, granitic, and cataclastic rocks in the southeastern San Jacinto Mountains, in Brown, A.R., and Ruff, R.W., eds., Geology of the San Jacinto Mountains: Santa Ana, California, South Coast Geological Society Annual Field Trip Guidebook No. 9. p. 100-138.

Brown, H.J., 1984, Summary of the geology of the north range front of the San Bernardino Mountains, Lucerne Valley, California, in Kupferman, S., McIver, D., and Morton, P., eds., Major limestone producers of the western Mojave Desert, California: American Institute of Mining Engineers, 112th Annual Meeting, Los Angeles, Field Trip Guidebook, p. 12-19.

Brown, H.J., 1984, Paleozoic carbonate stratigraphy of the San Bernardino Mountains, southern California: Geological Society of America Abstracts with Programs, v. 16, p. 456.

Brown, H.J., 1986, Stratigraphy and paleogeographic setting of Paleozoic rocks in the northern San Bernardino Mountains, California, in Koozer, M.A., and Reynolds, R.E., eds., Geology around the margins of the eastern San Bernardino Mountains: Inland Geologic Society Publication, v. 1, p. 105-115.

Brown, H.J., 1987, Geologic setting and operations overview, Lucerne Valley limestone mining district, Lucerne Valley, California, in Pierce, W., ed., 21st Annual Industrial Mineral Conference Proceedings: Arizona Bureau of Mines Special Report 4, p. 44-54.

Brown, H.J., 1991, Stratigraphy and paleogeographic setting of Paleozoic rocks in the San Bernardino Mountains, California, in Cooper, J.D., and Stevens, C.H., eds., Paleozoic Paleogeography of the western United States-II: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 67, p. 193-207.

Cameron, C.S., 1981, Geology of the Sugarloaf and Delamar Mountain areas, San Bernardino Mountains, California: Cambridge, Massachusetts Institute of Technology, Ph.D. Thesis, 399 p.

Cameron, C.S., 1982, Stratigraphy and significance of the Upper Precambrian Big Bear Group, in Cooper, J.D., Troxel, B. , and Wright, L., Geology of selected areas of the San Bernardino Mountains and western Mojave Desert, and southern Great Basin of California: Geological Society of America, Cordilleran Section, Field Trip n. 9, p. 5-20.

Clark, M. M., 1984, Map showing recently active breaks along the San Andreas fault and associated faults between Salton Sea and Whitewater River-Mission Creek, California: U. S. Geological Survey Miscellaneous Investigations Map I-1483, scale 1:24,000.

Conrad, R.L., and Davis, T.E., 1977, Rb/Sr Geochronology of cataclastic rocks of the Vincent thrust, San Gabriel Mountains, southern California (abs.): Geological Society of America Abstracts with Programs, v. 9,. no. 4, p. 403-404.

Cox, B.F., Matti, J.C., Oliver, H.W., and Zilka, N.T., 1983, Mineral resource potential map of the San Gorgonio Wilderness, San Bernardino County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1161-C, scale 1:62,500.

Cramer, C.H., and Harrington, J.M., 1987, Seismicity and tectonics of the Cucamonga fault and the eastern San Gabriel Mountains, San Bernardino County, California, in Morton, D.M., and Yerkes, R.F., eds., Recent reverse faulting in the Transverse Ranges, California: U.S. Geological Survey Professional Paper 1339, p. 7-26.

Demirer, Ali, 1985, The Mill Creek Formation--a strike-slip basin filling in the San Andreas fault zone, San Bernardino County, California: Riverside, University of California, M.S. Thesis, 108 p.

Dibblee, T.W., Jr., 1964a, Geologic map of the Lucerne Valley quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-426, scale 1:62,500.

-----1964b, Geologic map of the San Gorgonio Mountain quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-431, scale 1:62,500.

-----1964c, Geologic Map of the Cajon Quadrangle, San Bernardino County, California: U.S. Geological Survey Open-file Map 64-42, scale 1:24,000.

-----1967a, Geologic map of the Morongo Valley quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-517, scale 1:62,5OO.

-----1967b, Areal geology of the western Mojave Desert, California: U.S. Geological Survey Professional Paper 522, 153 p.

-----1967c, Geologic map of the Old Woman Springs quadrangle, San Bernardino County, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-518, scale 1:62,5OO.

-----1968, Displacements on San Andreas fault system in San Gabriel, San Bernardino, and San Jacinto Mountains, southern California, in Dickinson, W.R., and Grantz, Arthur, eds., Proceedings of conference on geologic problems of San Andreas fault system: Stanford University Publications in Geological Sciences, v. XI, p. 269-278.

-----1974, Geologic Map of the Lake Arrowhead Quadrangle, San Bernardino County, California: U.S. Geological Survey Open-File Report 74-56, scale 1:62,500.

-----1975, Late Quaternary uplift of the San Bernardino Mountains on the San Andreas and related faults, in Crowell, J.C., ed., San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, p. 127-135.

-----1982a, Geology of the San Gabriel Mountains, southern California, in Fife, D.L., and Minch, J.A., eds., Geology and mineral wealth of the California Transverse Ranges: South Coast Geological Society Guidebook no. 10 (Mason Hill volume), p. 131-147.

-----1982b, Geology of the San Bernardino Mountains, southern California, in Fife, D.L., and Minch, J.A., eds., Geology and mineral wealth of the California Transverse Ranges: South Coast Geological Society Guidebook no. 10 (Mason Hill volume), p. 148-169.

Ehlig, P.L., 1958, Geology of the Mount Baldy region of the San Gabriel Mountains, California: Los Angeles, University of California, Unpublished Ph.D. dissertation, 153 p.

-----1981, Origin and tectonic history of the basement terrane of the San Gabriel Mountains, central Transverse Ranges, in Ernst, W.G., ed., The geotectonic development of California (Rubey Volume I): Englewood Cliffs, New Jersey, Prentice-Hall, Inc., p. 253-283.

-----1982, The Vincent thrust: its nature, paleogeographic reconstruction across the San Andreas fault, and bearing on the evolution of the Tranverse Ranges, in Fife, D.L., and Minch, J.A., eds., Geology and mineral wealth of the California Transverse Ranges: South Coast Geological Society Guidebook no. 10 (Mason Hill volume), p. 370-379.

-----1988a, Characteristics of basement rocks exposed near the Cajon Pass scientific drill hole, in Zoback, M.D., Silver, L.T., Henyey, Thomas, and Thatcher, Wayne, eds., Scientific drilling near the San Andreas fault: Geophysical Research Letters, v. 15, no. 9 (supplement), p. 949-952.

-----1988b, Geologic structure near the Cajon Pass scientific drill hole, in Zoback, M.D., Silver, L.T., Henyey, Thomas, and Thatcher, Wayne, eds., Scientific drilling near the San Andreas fault: Geophysical Research Letters, v. 15, no. 9 (supplement), p. 953-956.

Erskine, B.E., 1985, Mylonitic deformation and associated low-angle faulting in the Santa Rosa mylonite zone, southern California: Berkeley, University of California, unpublished Ph.D. thesis, 247 p.

Erskine, B.E., and Wenk, H.-R., 1985, Evidence for late Cretaceous crustal thinning in the Santa Rosa mylonite zone, southern California: Geology, v. 13, p. 274-277.

Evans, J.G., 1982, Mineral resources of the Sheep Mountain Wilderness Study Area and the Cucamonga Wilderness and additions, Los Angeles and San Bernardino Counties, California: US.Geological Survey Bulletin 1506, 92 p.

Fairbanks, H. W., The San Andreas rift as a geomorphic feature; Pajaro River to the north end of the Colorado Desert, in Lawson, A. C., chairman, The California earthquake of April 18, 1906, Report of the state earthquake investigation commission: Carnegie Institution of Washington, v. 1, p. 38-52.

Foster, J.H., 1980, Late Cenozoic tectonic evolution of Cajon Valley, southern California: Riverside, University of California, Ph.D. thesis, 241 p.

Foster, J.H., 1982, Late Cenozoic tectonic evolution of Cajon Valley, southern California, in Sadler, P.M., and Kooser, M.A., eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges, southern California: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., 1982, Volume and Guidebook, p. 67-73.

Fraser, D.M., 1931, Geology of San Jacinto Quadrangle south of San Gorgonio Pass: California Journal of Mines and Geology, v. 27, no. 4, p. 494-540.

Frick, C., 1921, Extinct vertebrate faunas of the Badlands of Bautista Creek and San Timeteo Canon, southern California: University of California Publications in Geology, v. 12, no. 5, p. 277-424.

Frizzell, V.A., Jr., Mattinson, J.M., and Matti, J.C., 1986, Distinctive Triassic megaporphyritic monzogranite: evidence for only 160 km offset along the San Andreas fault, southern California: Journal of Geophysical Research, v. 91, no. B14, p. 14,080-14,088.

Gibson, R.C., 1964, Geology of a portion of the Mill Creek area, San Bernardino County, California: Riverside, University of California, M.S. thesis, 50 p.

Gibson, R.C., 1971, Nonmarine turbidites and the San Andreas fault, San Bernardino Mountains, California, in Elders, W.A., ed., Geological excursions in southern California: Riverside, University of California Campus Museum Contributions, no. 1, p. 167-181.

Guillou, R.B., 1953, Geology of the Johnston Grade area, San Bernardino County, California: California Division of Mines Special Report 31, 18 p.

Haxel, Gordon, and Dillon, John, 1978, The Pelona-Orocopia Schist and Vincent-Chocolate Mountain thrust system, southern California, in Howell, D.G., and McDougall, K.A., eds., Mesozoic Paleogeography of the Western United States: Pacific Section, Society of Economic Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 2, p. 453-469.

Hewett, D.F., and Stone, Jerome, 1957, Uranothorite near Forest Home, San Bernardino County, California: American Mineralogist, v. 42, p. 104-107.

Hill, R.I., 1981, Field, petrological and isotopic studies of the intrusive complex of San Jacinto Mountain, in Brown, A.R., and Ruff, R.W., eds., Geology of the San Jacinto Mountains: Santa Ana, California, South Coast Geological Society Annual Field Trip Guidebook No. 9. p. 76-89.

Hill, R.I., 1984, Petrology and petrogenesis of batholithic rocks, San Jacinto Mountains, southern California: Pasadena, California Institute of Technology, Ph.D. thesis, 660 p.

Hill, R.I., 1988, San Jacinto intrusive complex: 1. Geology and mineral chemistry, and a model for intermittent recharge of tonalitic magma chambers: Journal of Geophysical Research, v. 93, no. B9, p. 10325-10348.

Hill, R.I., Chappell, B.W., and Silver, L.T., 1988, San Jacinto intrusive complex: 2. Geochemistry: Journal of Geophysical Research, v. 93, no. B9, p. 10349-10372.

Hill, R.I., and Silver, L.T., 1988, San Jacinto intrusive complex: 3. Constraints on crustal magma chamber processes from strontium isotope heterogeneity: Journal of Geophysical Research, v. 93, no. B9, p. 10373-10388.

Hillenbrand, J. M., 1990, The Potato Sandstone between the Santa Ana River and Badger Canyon, San Bernardino County, southern California: implications for displacement in the San Andreas fault zone: Riverside, California, University of California, unpublished M.S thesis, 163 p.

Hollenbaugh, K.M., 1968, Geology of a portion of the north flank of the San Bernardino Mountains, California: Moscow, University of Idaho, Ph.D. thesis, 109 p.

Hsu, K.J., 1955, Granulites and mylonites of the region about Cucamonga and San Antonio Canyons, San Gabriel Mountains, California: University of California Publications in Geological Sciences, v. 30, p. 223-324.

Hsu, K. J., Edwards, G, and McLaughlin, W. A., 1963, Age of intrusive rocks of the southeastern San Gabriel Mountains, California: Geological Society of America Bulletin, v. 74, p. 507-512.

International Union of Geological Sciences Subcommission on the Systematics of Igneous Rocks, 1973, Plutonic rocks: Geotimes, v. 18, no. 10, p. 26-30.

Jahns, R.H., ed., 1954, Geology of southern California: California Division of Mines Bulletin 170.

Jahns, R.H., 1954, Geology of the Peninsular Range province, southern California and Baja California, in Jahns, R.H., ed., Geology of southern California, Chapter II, Geology of the natural provinces: California Division of Mines Bulletin 170, p. 29-52.

James, E.W., 1989, Southern extension of the Independence dike swarm of eastern California: Geology, v. 17, p. 587-590.

Jones, L.M., 1988, Focal mechanisms and the state of stress on the San Andreas fault in southern California: Journal of Geophysical Research, v. 93, no. B8, p. 8869-8891.

Joseph, S.E., Criscione, J.J., Davis, T.E., and Ehlig, P.L., 1982a, The Lowe igneous pluton, in Fife, D.L., and Minch, J.A., eds., Geology and mineral wealth of the California Tranverse Ranges: South Coast Geological Society Guidebook no. 10 (Mason Hill volume), p.

Kooser, M.A., 1980, Stratigraphy and sedimentology of the San Francisquito Formation, Transverse Ranges, California: Riverside, University of California, Ph.D. thesis, 201 p.

-----1982, Stratigraphy and sedimentology of the type San Francisquito Formation, southern California, in Crowell, J.C., and Link, M.H., eds., Geologic history of Ridge Basin, southern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, Field trip guide and volume, p. 53-61.

MacColl, R.S., 1964, Geochemical and structural studies in batholithic rocks of southern California: Part 1, structural geology of Rattlesnake Mountain pluton: Geological Society of America Bulletin, v. 75, p. 805-822.

Matti, J.C., and Morton, D.M., 1975, Geologic history of the San Timoteo Badlands, southern California: Geological Society of America Abstracts with Programs, v. 7, no. 3, p. 344.

Matti, J.C., and Morton, D.M., 1992, Paleogeographic evolution of the San Andreas fault in southern California: a reconstruction based on a new cross-fault correlation, in Powell, R.E., Weldon, R.J., and Matti, J.C., eds., The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution: Geological Society of America Memoir 178, p. 107-159.

Matti, J.C., Cox, B.F., Obi, C.M., Powell, R.E., Hinkle, M.E., Griscom, Andrew, and McHugh, E.L., 1982a, Mineral resource potential map of the Whitewater Wilderness Study Area, Riverside and San Bernardino Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1478, scale 1:24,000.

Matti, J.C., Cox, B.F., Rodriguez, E.A., Obi, C.M., Powell, R.E., Hinkle, M.E., Griscom, Andrew, Sabine, Charles, and Cwick, G.J., 1982b, Mineral resource potential map of the Bighorn Mountains Wilderness Study Area (CDCA-217), San Bernardino County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1493-A, scale 1:48,000.

Matti, J.C., Cox, B.F., and Iverson, S.R., 1983a, Mineral resource potential map of the Raywood Flat Roadless Area, San Bernardino and Riverside Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1563-A, scale 1:62,500.

Matti, J.C., Cox, B.F., Powell, R.E., Oliver, H.W., and Kuizon, Lucia, 1983b, Mineral resource potential map of the Cactus Spring Roadless Area, Riverside County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1650-A, scale 1:24,000.

Matti, J.C., Morton, D.M. and Cox, B.F., 1985, Distribution and geologic relations of fault systems in the vicinity of the central Transverse Ranges, southern California: U.S. Geological Survey Open-File Report 85-365, 27 p., scale 1:250,000.

Matti, J.C., Frizzell, V.A., and Mattinson, J.M., 1986, Distinctive Triassic megaporphyritic monzogranite displaced 160±10 km by the San Andreas fault, southern California: a new constraint for palinspastic reconstructions: Geological Society of America Abstracts with Programs, v. 18, no. 2, p. 154.

Matti, J.C., Morton, D.M. and Cox, B.F., 1992a, The San Andreas fault system in the vicinity of the central Transverse Ranges province, southern California: U.S. Geological Survey Open-File Report 92-354, 40 p., scale 1:250,000.

Matti, J.C., Morton, D.M., Cox, B.F., Carson, S.E., and Yetter, T.J., 1992b, Geologic map of the Yucaipa 7.5' quadrangle, California: U.S. Geological Survey Open-File Report 92-446, Scale 1:24,000.

May, D.J., 1986, Amalgamation of metamorphic terranes in the southeastern San Gabriel Mountains, California: Santa Barbara, University of California, unpublished Ph.D. thesis, 325 p.

May, D.J., 1989, Late Cretaceous intra-arc thrusting in southern California: Tectonics, v. 8, p. 1159-1173.

May, D.J., and Walker, N.W., 1989, Late Cretaceous juxtaposition of metamorphic terranes in the southeastern San Gabriel Mountains, California: Geological Society of America Bulletin, v. 101, p. 1246-1267.

May, S.R., and Repenning, C.A., 1982a, New evidence for the age of the Old Woman Sandstone, Mojave Desert, California, in Sadler, P.M., and Kooser, M.A. eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., Volume and Guidebook, p. 93-96.

McFadden, L.D., 1982, The impacts of temporal and spatial climatic changes on alluvial soils genesis in southern California: Tucson, University of Arizona, Ph.D. thesis, 430 p.

McJunkin, R.D., 1976, Geology of the central San Bernardino Mountains, San Bernardino County, California: Los Angeles, California State University, M.S. thesis, 102 p.

Meisling, K.E., 1984, Neotectonics of the north frontal fault system of the San Bernardino Mountains, southern California: Cajon Pass to Lucerne Valley: Pasadena, California Institute of Technology, unpublished Ph.D. thesis, 394 p.

Meisling, K.E., and Weldon, R.J., 1982, The late-Cenozoic structure and stratigraphy of the western San Bernardino Mountains, in Sadler, P.M., and Kooser, M.A., eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges, southern California: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., 1982, Volume and Guidebook, p. 75-82.

Meisling, K.E., and Weldon, R.J., 1986, Cenozoic uplift of the San Bernardino Mountains: possible thrusting across the San Andreas fault: Geological Society of America Abstracts with Programs, v. 18, no. 2, p. 157.

Meisling, K.E., and Weldon, R.J., 1989, Late Cenozoic tectonics of the northwestern San Bernardino Mountains, southern California: Geological Society of America Bulletin, v. 101, p. 106-128.

Mezger, LiLi, and Weldon, R.J., 1983, Tectonic implications of the Quaternary history of lower Lytle Creek, southeast San Gabriel Mountains: Geological Society of America Abstracts with Programs, v. 15, no. 5, p. 418.

Miller, C.F., 1977a, Alkali-rich monzonites, California: origin of near silica-saturated alkaline rocks and their significance in a calc-alkaline batholithic belt: Los Angeles, University of California, Ph.D. thesis, 283 p.

Miller, C.F., 1977b, Early alkalic plutonism in the calc-alkaline batholithic belt of California: Geology, v. 5, p. 685-688.

Miller, C.F., 1978, An early Mesozoic alkalic magmatic belt in western North America, in Howell, D.G., and McDougall, K.A., eds., Mesozoic paleogeography of the western United States: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 163-173.

Miller, E.L., and Cameron, C.S., 1982, Late Precambrian to late Cretaceous evolution of the southwestern Mojave Desert, California, in Cooper, J.P., Troxel, B.W., and Wright, L.A., eds., Geology of selected areas in the San Bernardino Mountains, western Mojave Desert, and southern Great Basin, California: Geological Society of America, Cordilleran Section, 78th annual meeting, Anaheim, Calif., 1982, Field Trip 9 Volume and Guidebook, p. 21-34.

Miller, F.K., 1979, Geologic map of the San Bernardino North 7.5' quadrangle: U.S. Geological Survey Open-File Report 79-770, scale 1:24,000.

Miller, F.K., 1987, Reverse-fault system bounding the north side of the San Bernardino Mountains, in Morton, D.M., and Yerkes, R.F., eds., Recent reverse faulting in the Transverse Ranges, California: U.S. Geological Survey Professional Paper 1339, p. 83-95.

Miller, F.K., and Morton, D.M., 1977, Comparison of granitic intrusions in the Pelona and Orocopia Schists, southern California: U.S. Geological Survey Journal of Research, v. 5, no. 5, p. 643-649.

Miller, R.H., and Dockum, M.S., 1983, Ordovician conodonts from metamorphosed carbonates of the Salton Trough, California: Geology, v. 11, p. 410-412.

Miller, R.H., Gastil, R.G., Anderson, P.V., Dockum, M.S., and Stevens, C.H., 1983, Uppermost Precambrian through Triassic rocks of southern and Baja California: Pacific Sections, AAPG, SEG, SEPM, Program and Abstracts, 58th Annual Meeting, Sacramento, p. 114.

Miller, W. J., 1934, Geology of the western San Gabriel Mountains of California: Los Angeles, University of California, Publications in Mathematical and Physical Sciences, v. 1, no. 1, 114 p.

Morton, D.M., 1975, Synopsis of the geology of the eastern San Gabriel Mountains, southern California, in Crowell, J.C., ed., San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, p. 170-176.

Morton, D.M., 1976, Geologic map of the Cucamonga fault zone between San Antonio Canyon and Cajon Creek, southern California: U.S. Geological Survey Open-File Report 76-726, scale 1:24,000.

Morton, D.M., and Campbell, R.H., 1974, Spring mudflows at Wrightwood, southern California: Quarterly Journal of Engineering Geology, v. 7, p.377-384.

Morton, D.M., and Kennedy, M.P., 1979, Part 1: Wright Mountain mudflows--1967 landsliding, in Landsliding and mudflows at Wrightwood, San Bernardino County, California: California Division of Mines and Geology Special Report 136, p.1-6.

Morton, D.M., and Matti, J.C., 1987, The Cucamonga fault zone: Geologic setting and Quaternary history, in Morton, D.M., and Yerkes R.F., eds., Recent reverse faulting in the Transverse Ranges, California: U.S. Geological Survey Professional Paper 1339, p. 179-203.

Morton, D.M., and Matti, J.C., 1990, Geologic map of the Cucamonga Peak 7.5' Quadrangle, California: U.S. Geological Survey Open-File Report 90-694, scale 1:24,000.

Morton, D.M., and Matti, J.C., 1990, Geologic map of the Devore 7.5' Quadrangle, California: U.S. Geological Survey Open-File Report 90-695, scale 1:24,000.

Morton, D.M., and Matti, J.C., 1993, Extension and contraction within an evolving divergent strike-slip fault complex: the San Andreas and San Jacinto fault zones at their convergence in southern California, in Powell, R.E., Weldon, R.J., and Matti, J.C., eds., The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution: Geological Society of America Memoir 178, p. 217-230.

Morton, D.M., and Miller, F.K., 1975, Geology of the San Andreas fault zone north of San Bernardino between Cajon Canyon and Santa Ana Wash, in Crowell, J.C., ed., San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, p. 136-146.

Morton, D.M., and Sadler, P.M, 1989a, The failings of the Pelona Schist: landslides and sackungen in the Lone Pine Canyon and Wrightwood areas, eastern San Gabriel Mountains, southern California, in Sadler, P.M., and Morton, D.M., eds., Landslides in a semi-arid environment: Redlands, California, Publications of the Inland Geological Society, v. 2, p. 301-322.

Morton, D.M., and Sadler, P.M, 1989b, Landslides flanking the northeastern Peninsular Ranges and in the San Gorgonio Pass area of southern California in Sadler, P.M., and Morton, D.M., eds., Landslides in a semi-arid environment: Redlands, California, Publications of the Inland Geological Society, v. 2, p. 338-355.

Morton, D.M., and Streitz, R., 1969, Reconnaissance map of major landslides, San Gabriel Mountains, California: California Division of Mines and Geology Map Sheet 15.

Morton, D.M., Matti, J.C., and Cox, B.F., 1980a, Geologic map of the San Jacinto Wilderness: U.S. Geological Survey Miscellaneous Field Studies Map MF-1159-A, scale 1:62,500.

Morton, D.M., Cox, B.F., and Matti, J.C., 1980b, Geologic map of the San Gorgonio Wilderness: U.S. Geological Survey Miscellaneous Field Studies Map MF-1164-A, scale 1:62,500.

Morton, D.M., Sadler, P.M., and Minnich, R.A., 1989, Large rock-avalanche deposits: examples from the central and eastern San Gabriel Mountains of southern Califorinia, in Sadler, P.M., and Morton, D.M., eds., Landslides in a semi-arid environment: Redlands, California, Publications of the Inland Geological Society, v. 2, p. 323-337.

Morton, D.M., Woodburne, M.O., and Foster, J., 1990, Geologic map of the Telegraph Peak Quadrangle, southern California: U.S. Geological Survey Open-File Report 90-693, scale 1:24,000.

Morton, D.M., Campbell, R.H., Barrows, A.G., Jr., Kahle, J.E., and Yerkes, R.F., 1979, Part 2: Wright Mountain mudflows--Spring 1969, in Landsliding and mudflows at Wrightwood, San Bernardino County, California: California Division of Mines and Ge~logy Special Report 136, p.7-21.

Morton, D.M., Rodriguez, E.A., Obi, C.M., Simpson, R.W., Jr., and Peters, T.J., 1983, Mineral resource potential map of the Cucamonga Roadless Areas, San Bernardino County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1646-A, scale 1:31,680.

Neville, S. L., 1983, Late Miocene alkaline volcanism, south-central Mojave Desert and northeast San Bernardino Mountains, California: Riverside, University of California, unpublished M.S. Thesis, 156 p.

Neville, S. L., and Chambers, J.M., 1982, Late Miocene alkaline volcanism, northeastern San Bernardino Mountains and adjacent Mojave Desert, in Sadler, P.M., and Kooser, M.A., eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges, southern California: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., 1982, Volume and Guidebook, p. 103-106.

Noble, L.F., 1953, Geology of the Pearland Quadrangle, California: U.S. Geological Survey Geologic Quadrangle Map GQ-24, scale 1:24,000.

Noble, L.F., 1954a, The San Andreas fault zone from Soledad Pass to Cajon Pass, California, in Jahns, R.H., ed., Geology of southern California: California Division of Mines Bulletin 170, p. 37-48, and Plate 5 of chapter IV, scale 1:125,000.

Noble, L.F., 1954b, Geology of the Valyermo Quadrangle and vicinity, California: U.S. Geological Survey Geologic Quadrangle Map GQ-50, scale 1:24,000.

Owens, G.V., 1959, Sedimentary rocks of lower Mill Creek, San Bernardino Mountains, California: Pomona, Pomona College, M.S. thesis,111 p.

Peterson, M.S., 1975, Geology of the Coachella fanglomerate, in Crowell, J.C., ed., San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, p. 119-126.

Powell, R.E., 1993, Balanced palinspastic reconstruction of pre-Late Cenozoic paleogeology, southern California: geologic and kinematic constraints on evolution of the San Andreas fault system, in Powell, R.E., Weldon, R.J., and Matti, J.C., eds., The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution: Geological Society of America Memoir 178, p. 1-106.

Powell, R.E., Matti, J.C., Cox, B.F., Oliver, H.W., Wagini, Alexander, and Campbell, H.W., 1983, Mineral resource potential of the Sugarloaf roadless area, San Bernardino County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1606-A, scale 1:24,000.

Reynolds, R.E., 1984, Miocene faunas in the lower Crowder Formation: a preliminary discussion, in Hester, R.L., and Hallinger, D.E., eds., San Andreas fault--Cajon Pass to Wrightwood: American Association of Petroleum Geologists, Pacific Section, Volume and guidebook no. 55, p. 17-21.

Richmond, J.F., 1960, Geology of the San Bernardino Mountains north of Big Bear Lake, California, with a tabulated list of mines and mineral deposits by C.H. Gray, Jr.: California Division of Mines Special Report 65, 68 p.

Richmond, J.F., 1965, Chemical variation in quartz monzonite from Cactus Flat, San Bernardino Mountains, California: American Journal of Science, v. 263, p. 53-63.

Rogers, T.H., Compiler, 1965, Santa Ana sheet of Geologic map of California: California Division of Mines and Geology, scale 1:25O,OOO.

Rogers, T.H., Compiler, 1967, San Bernardino sheet of Geologic map of California: California Division of Mines and Geology, scale 1:250,000.

Ross, D.C., 1972, Petrographic and chemical reconnaissance study of some granitic and gneissic rocks near the San Andreas fault from Bodega Head to Cajon Pass, California: U.S. Geological Survey Professional Paper 698, 92 p.

Sadler, P.M., 1981, The structure of the northeast San Bernardino Mountains, California: notes to accompany 7.5 minute quadrangle maps submitted for compilation onto the San Bernardino 1¡x2¡ quadrangle: California Division of Mines and Geology Open File Report OFR 82-18 S.F., 26 p.

-----1982a, An introduction to the San Bernardino Mountains as the product of young orogenesis, in Sadler, P.M., and Kooser, M.A., eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges, southern California: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., 1982, Volume and Guidebook, p. 57-65.

-----1982b, Provenance and structure of late Cenozoic sediments in the northeast San Bernardino Mountains, in Sadler, P.M., and Kooser, M.A., eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges, southern California: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., 1982, Volume and Guidebook, p. 83-92

-----1985, Santa Ana Sandstone: its provenance and significance for the late Cenozoic history of the Transverse Ranges, in Reynolds, R.E., Compiler, Geologic investigations along Interstate 15, Cajon Pass to Manix Lake, California: San Bernardino County Museum Publication, p. 69-78.

-----1993, The Santa Ana Basin of the central San Bernardino Mountains: evidence of the timing of uplift and strike slip relative to the San Gabriel Mountains, in Powell, R.E., Weldon, R.J., and Matti, J.C., eds., The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution: Geological Society of America Memoir 178, p. 307-321.

Sadler, P.M., and Demirer, Ali, 1986, Geology of upper Mill Creek and Santa Ana Canyon, southern San Bernardino Mountains, California, field trip 12 of Ehlig, P.L., compiler, Neotectonics and faulting in southern California: Geological Society of America, Cordilleran Section, 82nd Annual Meeting, Los Angeles, California, 1986, Guidebook and Volume, p. 129-140.

Sadler, P.M., and Morton, D.M., 1989, Landslides of the uppermost Santa Ana River basin and the adjacent San Bernardino Mountains of southern California, in Sadler, P.M., and Morton, D.M., eds., Landslides in a semi-arid environment: Redlands, California, Publications of the Inland Geologic Society Publication, v. 2, p. 356-386.

Sadler, P.M., and Reeder, W.A., 1983, Upper Cenozoic quartzite-bearing gravels of the San Bernardino Mountains, southern California: recycling and mixing as a result of transpressional uplift, in Anderson, D.W., and Rymer, M.J., eds., Tectonics and sedimentation along faults of the San Andreas system: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 45-57.

Sadler, P.M., Demirer, Ali, West, David, and Hillenbrand, J.M., 1993, The Mill Creek Basin, the Potato Sandstone, and fault strands in the San Andreas fault zone south of the San Bernardino Mountains, in Powell, R.E., Weldon, R.J., and Matti, J.C., eds., The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution: Geological Society of America Memoir 178, p. 289-306.

Sharp, R.P., Allen, C.R., and Meir, M.F., 1959, Pleistocene glaciers on southern California mountains: American Journal of Science, v. 257, p. 81-94.

Sharp, R.V., 1967, San Jacinto fault zone in the Peninsular Ranges of southern California: Geological Society of America Bulletin, v. 78, p. 705-730.

Sharp, R. V., 1975, En echelon fault patterns of the San Jacinto fault zone, in Crowell, J.C., ed., San Andreas fault in southern California: California Division of Mines and Geology Special Report 118, p. 147-152.

Sharp, R.V., 1979, Some characteristics of the eastern Peninsular Ranges mylonite zone, in Analysis of actual fault zones in bedrock: U.S. Geological Survey Open-File Report 79-1239, p. 258-267.

Sharp, R.V., 1981, Variable rates of late Quaternary strike slip on the San Jacinto fault zone, southern California: Journal of Geophysical Research, v. 86, no. B3, p. 1754-1762.

Shreve, R.L., 1968, The Blackhawk landslide: Geological Society of America Special Paper 108, 47 p.

Silver, L.T., 1971, Problems of crystalline rocks of the Transverse Ranges: Geological Society of America Abstracts with Programs, v. 3, no. 2, p. 193-194.

Silver, L.T., James, E.W., and Chappell, B.W., 1988, Petrological and geochemical investigations at the Cajon Pass deep drill hole, in Zoback, M.D., Silver, L.T., Henyey, Thomas, and Thatcher, Wayne, eds., Scientific drilling near the San Andreas fault: Geophysical Research Letters, v. 15, no. 9 (supplement), p. 961-964.

Sims, S.J., 1960, Geology of part of the Santa Rosa Mountains, Riverside County California: Palo Alto, California, Stanford University, unpublished PhD thesis, 87 p.

Smith, D.K., 1982a, Petrology of Mesozoic alkaline and calc-alkaline igneous rocks northwest of Holcomb Valley, San Bernardino County, California: Riverside, University of California, M.S. thesis, 87 p.

Smith, D.K., 1982b, Petrology of Mesozoic alkaline and calc-alkaline igneous rocks northwest of Holcomb Valley, San Bernardino County, California, in Fife, D., and Minch, J.A., eds., Geology and mineral wealth of the California Transverse Ranges: South Coast Geological Society Guidebook no. 10 (Mason Hill volume), p. 321-329.

Smith, D.P., 1977, San Juan-St. Francis fault--hypothesized major middle Tertiary right-lateral fault in central and southern California, California Division of Mines and Geology, Special Report 129, p. 41-50.

Stewart, J.H., 1970, Upper Precambrian and lower Cambrian strata in the southern Great Basin, California and Nevada: U.S. Geological Survey Professional Paper 620, 206 p.

Stewart, J.H., and Poole, F.G., 1975, Extension of the Cordilleran miogeosynclinal belt to the San Andreas fault, southern California: Geological Society of America Bulletin, v. 86, p. 205-212.

Strathouse, E.C., 1982, The Santa Ana Sandstone (Miocene in part) and evidence for Late-Cenozoic orogenesis in the San Bernardino Mountains, in Sadler, P.M., and Kooser, M.A., eds., Late Cenozoic stratigraphy and structure of the San Bernardino Mountains, field trip 6 of Cooper, J.D., compiler, Geologic excursions in the Transverse Ranges, southern California: Geological Society of America, Cordilleran Section, 78th Annual Meeting, Anaheim, Calif., 1982, Volume and Guidebook, p. 97-102.

Strathouse, E.C., 1983, Late Cenozoic fluvial sediments in Barton Flats and evidence for orogenesis, San Bernardino Mountains, San Bernardino County, southern California: Riverside, University of California, M.S. thesis, 127 p.

Streckeisen, A., 1976, To each plutonic rock its proper name: Earth Science reviews, v. 12, p. 1-33.

Todd, V.R., Erskine, B.G., and Morton, D.M., 1988, Metamorphic and tectonic evolution of the northern Peninsular Ranges batholith, southern California, in Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States (Rubey Volume VII): Englewood Cliffs, Prentice-Hall, p. 894-937..

Todd, V.R., Erskine, B.G., and Morton, D.M., 1988, Metamorphic and tectonic evolution of the northern Peninsular Ranges batholith, southern California, in Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States (Rubey Volume VII): Englewood Cliffs, Prentice-Hall, p. 894-937..

Tyler, D.L., 1975, Stratigraphy and structure of the late Precambrian-early Cambrian clastic metasedimentary rocks of the Baldwin Lake area, San Bernardino Mountains, California: Houston, Rice University, M.S. thesis, 40 p.

Tyler, D.L., 1979, The Cordilleran miogeosyncline and Sevier(?) orogeny in southern California, in Newman, G.W., and Goode, H.D., eds., Basin and Range symposium and Great Basin field conference: Rocky Mountain Association of Geologists and Utah Geological Association, p. 75-80.

Vaughan, F.E., 1922, Geology of the San Bernardino Mountains north of San Gorgonio Pass: California University Publications in Geological Sciences, v. 13, p. 319-411.

Weldon, R.J., 1984a, Quaternary deformation due to the junction of the San Andreas and San Jacinto faults, southern California: Geological Society of America, Abstracts with Programs, v. 16, no. 6, p., 689.

Weldon, R.J., 1984b, Implications of the age and distribution of the late Cenozoic stratigraphy in Cajon Pass, southern California, in Hester, R.L., and Hallinger, D.E., eds., San Andreas fault--Cajon

Pass to Wrightwood: American Association of Petroleum Geologists, Pacific Section, Volume and guidebook no. 55, p. 9-16.

Weldon, R.J., 1986, The late Cenozoic geology of Cajon Pass; implications for tectonics and sedimentation along the San Andreas fault: Pasadena, California Institute of Technology, unpublished Ph.D. thesis, 382 p.

Weldon, R. J., and Matti, J. C., 1986, Geologic evidence for segmentation of the southern San Andreas fault: Transactions of the American Geophysical Union, v. 67, p 905-906.

Weldon, R.J., II, and Sieh, K.E., 1985, Holocene rate of slip and tentative recurrence interval for large earthquakes on the San Andreas fault, Cajon Pass, southern California: Geological Society of America Bulletin, v. 96, p. 793-812.

Weldon, Ray, and Humphreys, Eugene, 1986, A kinematic model of southern California: Tectonics, v. 5, no. 1, p. 33-48.

Weldon, R.J., II, Meisling, K.E., and Alexander, J., 1993, A speculative history of the San Andreas Fault in the central Transverse Ranges, California, in Powell, R.E., Weldon, R.J., and Matti, J.C., eds., The San Andreas fault system: displacement, palinspastic reconstruction, and geologic evolution: Geological Society of America Memoir 178, p. 161-198.

Wesnousky, S. G., 1988, Seismological and structural evolution of strike-slip faults: Nature, v. 335, No. 6188, p. 340-344.

West, D.L. 1987, Geology of the Wilson Creek-Mill Creek fault zone--the north flank of the former Mill Creek basin, San Bernardino County, California: Riverside, University of California, unpublished M.S. thesis, 94 p.

Willingham, R.C., 1968, A gravity survey of the San Bernardino Valley, southern California: Riverside, University of California, M.S. thesis, 96 p.

Woodburne, M.O., 1975, Cenozoic stratigraphy of the Transverse Ranges and adjacent areas, southern California: Geological Society of America Special Paper 162, 91 p.

Woodburne, M.O., and Golz, D.J., 1972, Stratigraphy of the Punchbowl formation, Cajon Valley, southern California: California University, Publications in Geological Sciences, v. 92, 73 p.

Woodford, A.O., and Harriss, T.F., 1928, Geology of Blackhawk Canyon, San Bernardino Mountains, California: California University Publications in Geological Sciences, v. 17, p. 265-304.

Woodford, A.O., Shelton, J.S., Doehring, D.O., and Morton, R.K., 1971, Pliocene-Pleistocene history of the Perris Block, southern California: Geological Society of America Bulletin, v. 82, p. 3421-3448.

Woodring, W.P., 1942, Marine Miocene mollusks from Cajon Pass, California: Journal of Paleontology, v. 16, p. 78-83.

Yerkes, R.F., 1951, The geology of a portion of the Cajon Pass area, California: Claremont, Claremont Graduate School, M.A. thesis, 96 p.

Yerkes, R. F., Levine, P., and Lee, W. H. K., 1987, Contemporary tectonics along south boundary of central and western Transverse Ranges, southern California: Transactions of the American Geophysical Union, v. 68, no. 44, p. 1510.