U.S. GEOLOGICAL SURVEY
U.S. DEPARTMENT OF THE INTERIOR

OPEN-FILE REPORT 03-301

GEOLOGIC MAP AND DIGITAL DATABASE OF THE YUCAIPA 7.5' QUADRANGLE, SAN BERNARDINO AND RIVERSIDE COUNTIES, CALIFORNIA, version. 1.0

Summary Pamphlet

By

J.C. Matti[1], D.M. Morton[2], B.F. Cox[3], S.E. Carson[4], and T.J. Yetter[4]

2003

[1]U.S. Geological Survey, Tucson, Arizona
[2]U.S. Geological Survey, Riverside, California
[3]U.S. Geological Survey, Menlo Park, California
[4]U.S. Geological Survey, Menlo Park, California (when geologic mapping was contributed)

[This Summary Pamphlet accompanies the geologic map and digital database of the Yucaipa 7.5’ quadrangle, San Bernardino and Riverside Counties, California, version 1.0]

Table of Contents

GEOLOGIC OVERVIEW

The Yucaipa 7.5' quadrangle is located at the southeastern margin of the San Bernardino Basin, an extensional region situated within a right-step-over zone between the San Jacinto and San Andreas Fault zones. The quadrangle is traversed by several faults of the right-lateral San Andreas system, including (from oldest to youngest) the Banning Fault and the Wilson Creek, Mission Creek, Mill Creek, and San Bernardino strands of the San Andreas Fault.

The Mill Creek strand of the San Andreas Fault is the easternmost strand of the San Andreas. It separates granitic and metamorphic rocks of the San Bernardino Mountains block from a thin slice of similar crystalline rocks on Yucaipa Ridge, and thus has only a small amount of strike-slip displacement.

The Wilson Creek strand traverses Yucaipa Ridge and converges toward the Mill Creek strand in the Santa Ana river Canyon. The fault has juxtaposed an igneous and metamorphic complex (Wilson Creek block) and overlying nonmarine sedimentary rocks (Mill Creek Formation of Gibson, 1971) against rocks of San Bernardino Mountains-type, and thus has significant strike-slip displacement.

The Mission Creek strand is inferred to lie beneath Quaternary surficial deposits along the southwestern base of the San Bernardino Mountains. This fault is the major strand of the San Andreas Fault zone, and has juxtaposed crystalline rocks of San Gabriel Mountains-type (including Pelona Schist overlain by the Vincent Thrust and associated upper-plate crystalline rocks) against the Wilson Creek block and the San Bernardino Mountains.

The San Bernardino strand defines the modern trace of the San Andreas Fault. The strand forms primary fault features in all but the youngest Quaternary surficial unit, and is thought to have evolved in the last 125,000 years or so based on regional fault relations.

Complications within the San Andreas Fault system over the last several hundred thousand years created a landscape in which Quaternary surficial materials of the Yucaipa quadrangle have accumulated. The earliest of these is represented by early Quaternary deposits of the San Timoteo beds of Frick (1921). Following deposition of this unit, crustal extension throughout the San Bernardino Basin region led to uplift of the Crafton Hills horst and down-dropping of the Yucaipa Valley graben on northeast-trending faults that bound the Crafton Hills and Yucaipa Valley. Subsequent middle and late Quaternary streamflows deposited several generations of axial-valley and alluvial-fan sediment in the down-dropped lowlands. These deposits and the older San Timoteo beds they overlie record (1) an extensive early through late Quaternary alluvial system that probably included west-flowing streamflows of the ancestral San Gorgonio River and its tributaries and (2) the history of middle and late Quaternary fault movements in the Yucaipa quadrangle.

INTRODUCTION

This geologic database of the Yucaipa 7.5' quadrangle was prepared by the Southern California Areal Mapping Project (SCAMP), a regional geologic-mapping project sponsored jointly by the U.S. Geological Survey and the California Geological Survey. The database was developed as a contribution to the National Cooperative Geologic Mapping Program's National Geologic Map Database, and is intended to provide a general geologic setting of the Yucaipa quadrangle. The database and map provide information about earth materials and geologic structures, including faults and folds that have developed in the quadrangle due to complexities in the San Andreas Fault system.

The Yucaipa 7.5' quadrangle contains materials and structures that provide unique insight into the Mesozoic and Cenozoic geologic evolution of southern California. Stratigraphic and structural elements include: (1) strands of the San Andreas Fault that bound far-traveled terranes of crystalline and sedimentary rock; (2) Mesozoic crystalline rocks that form lower and upper plates of the regionwide Vincent-Orocopia Thrust system; and (3) late Tertiary and Quaternary sedimentary materials and geologic structures that formed during the last million years or so and that record complex geologic interactions within the San Andreas Fault system. These materials and the structures that deform them provide the geologic framework for investigations of geologic hazards and ground-water recharge and subsurface flow.

Geologic information contained in the Yucaipa database is general-purpose data that is applicable to land-related investigations in the earth and biological sciences. The term "general-purpose" means that all geologic-feature classes have minimal information content adequate to characterize their general geologic characteristics and to interpret their general geologic history. However, no single feature class has enough information to definitively characterize its properties and origin. For this reason the database cannot be used for site-specific geologic evaluations, although it can be used to plan and guide investigations at the site-specific level.

Previous investigations

Vaughan (1922) briefly discussed rocks and geologic structures in the Yucaipa area as part of his geologic reconnaissance of the San Bernardino Mountains. As part of his study of South Coastal hydrogeologic basins, Eckis (1934) discussed the geologic setting of the Redlands-Yucaipa area. Burnham (1952) wrote an unpublished report on a ground fissure that developed in Yucaipa Valley in the Winter of 1952. Burnham and Dutcher (1960) and Dutcher and Burnham (1964) described the geologic setting of the Yucaipa area as part of their extensive hydrogeologic investigations in the Redlands-Mill Creek-Yucaipa-Calimesa areas. These important reports defined the major geologic and structural features in the Yucaipa quadrangle, many of which we were able to duplicate and (or) refine in the current investigation. Dibblee (1967) mapped the Yucaipa 7.5' quadrangle as part of his geologic map of the Redlands 15' quadrangle (Dibblee, 1974). Several thesis investigations have examined the geology of sedimentary rocks of Yucaipa Ridge and Mill Creek Canyon (Smith, 1959; Owens, 1959; Gibson, 1964; Demirer, 1985; West, 1987). Reynolds and Reeder (1986, 1991) described the physical stratigraphy and vertebrate paleontology of the San Timoteo beds of Frick (1921), and Albright (1997, 1999) described the paleontology and magnetostratigraphy of these beds based in part on exposures in the Yucaipa quadrangle. Matti and others (1992) produced a geologic map of the Yucaipa quadrangle that is the basis for much of the information in the current report. Most recently, Spotila and others (2001) used (U-Th)/He dating to examine the uplift history of crystalline rocks of Yucaipa Ridge as a way of testing strain distribution within the San Andreas Fault zone.

Acknowledgments

Geologic mapping for this study was sponsored by three U.S. Geological Survey (USGS) programs: the National Cooperative Geologic Mapping Program, the Earthquake Hazards Program, and the Mineral Resources Program. The mapping was coordinated with the California Geological Survey, and was conducted in cooperation with three agencies that cost-shared digitization of v. 1.0: (1) the U.S. Army Corps of Engineers (Seven Oaks Dam Flood Control Project); (2) the San Bernardino Valley Municipal Water District (SBVMWD; we especially would like to thank Ms. Melissa Zoba, who provided us with copies of hard-to-obtain reports by Burnham and Dutcher, 1960 and Dutcher and Burnham, 1964); (3) The U.S. Forest Service (San Bernardino National Forest; Mr. Raj Daniel of the Forest facilitated interagency coordination). The map and report benefited from technical reviews by R.F. Yerkes, P. Stone, and F.K. Miller of the USGS; the digital database was reviewed by D. Bedford of the USGS. We thank P.M. Sadler and M.O. Woodburne for discussions of the stratigraphy and structure of rocks in the Yucaipa Quadrangle.

CRYSTALLINE BASEMENT ROCKS

Crystalline basement rocks in the Yucaipa quadrangle represent two distinctive packages that are widespread in southern California:

- crystalline rocks of San Bernardino Mountains-type
- crystalline rocks of San Gabriel Mountains-type

These terranes are separated by strands of the San Andreas Fault system (fig. 2). Rocks of San Bernardino Mountains type occur east of the Mission Creek strand of the San Andreas Fault; rocks of San Gabriel Mountains-type occur between the Mission Creek strand and the Banning Fault.

Crystalline Rocks of San Bernardino Mountains-type

Rocks east of the San Andreas Fault

In the Yucaipa quadrangle, two crystalline-rock units occur east of the San Andreas Fault zone:

Hornblende monzogranite and quartz monzonite.—This rock (unit Ʀm) is distinguished by large euhedral potassium-feldspar phenocrysts (Frizzell and others, 1986, fig. 2-4). The unit is Triassic in age (215 m.y. old; Frizzell and others, 1986), and is the oldest known from the Yucaipa quadrangle. Plutonic rocks of this age are found throughout southern California in parts of the San Gabriel and San Bernardino Mountains and in the Mojave and Sonoran Desert provinces; however, they are volumetrically restricted compared to younger Jurassic and Cretaceous granitoids. Rocks of Triassic age are important because they record early episodes of plutonism that became so voluminous throughout the Mesozoic in southern California. Some of the Triassic granitoids, like those studied by Miller (1977, 1978) in the north-central San Bernardino Mountains, have distinctive alkalic chemistries that provide insight about how early Mesozoic plutonism in southern California differed from later Mesozoic episodes that typically were more calc-alkalic in composition. Triassic granitoid rocks of unit Ʀm in the Yucaipa quadrangle provide another piece of this puzzle, and are significant because their calc-alkalic composition (Frizzell and others, 1986) contrasts with alkalic rocks of comparable age nearby in the San Bernardino Mountains (Miller, 1977, 1978; Miller and others, 1998, 2000).

Granodiorite of Angeles Oaks.—This unit of biotite-hornblende granodiorite forms only a small outcrop in the northwest corner of the Yucaipa quadrangle but is widespread to the north and northeast (Morton and Miller, in press). Hornblende and biotite from a sample 15 km northeast of the Yucaipa quadrangle yielded conventional potassium-argon ages of 71 Ma and 72 Ma, respectively (Miller and Morton, 1980, sample 90), which probably are cooling ages, not emplacement ages.

Monzogranite of City Creek.—This unit of leucocratic biotite monzogranite forms only a small outcrop in the northwest corner of the Yucaipa quadrangle but is widespread to the north and northwest (Morton and Miller, in press). Biotite from a sample 20 km northwest of the Yucaipa quadrangle yielded a conventional potassium-argon age of 66 Ma respectively (Miller and Morton, 1980, sample 59A), which probably is a cooling age, not an emplacement age.

Rocks between Wilson Creek and Mill Creek strands, San Andreas Fault

In the Yucaipa quadrangle, a small fault-bounded slice of granodioritic rock we informally name the orthogneiss of Alger Creek (unit Mzga) occurs between the Mill Creek and Wilson Creek strands of the San Andreas. The orthogneiss is similar to rocks north of the Mill Creek strand in the Alger Creek area of the adjacent Forest Falls quadrangle, and is part of the evidence cited by Matti and others (1985, 1992b; Matti and Morton, 1993) for no more than 8 to 10 km of right-lateral displacement on this strand of the San Andreas. In the Forest Falls quadrangle the orthogneiss of Alger Creek intrudes Proterozoic gneiss and probably intrudes unit ŦRm, but is intruded by late Cretaceous plutonic rock (B.F. Cox, unpublished mapping, 1979); the unit probably is Cretaceous or Jurassic in age. The origin of its ductile fabric is unknown.

Rocks between Mission Creek and Wilson Creek strands, San Andreas Fault

Between the Mission Creek and Wilson Creek strands of the San Andreas Fault occurs a distinctive crystalline terrane that Matti and others (1985, 1992b) named the Wilson Creek block. Although this block is separated from the main mass of the San Bernardino Mountains by the Wilson Creek strand of the San Andreas, we believe crystalline rocks in the block are compatible with comparable rocks that fringe the southwest margin of the San Bernardino and Little San Bernardino Mountains. Hence we associate them with rocks of San Bernardino Mountains-type (fig. 2; Matti and others, 1992b).

Crystalline rocks of the block are a heterogeneous suite of gneissose, foliated, and texturally massive granitoid rocks (units gg, Mzc, Mzi, Mzgr, and Mzg) that represent a metamorphic and plutonic complex. The origin and age of this complex is problematical. Previous workers interpret it as a Precambrian metamorphic terrane intruded by Mesozoic plutons like the Diorite of Cram Peak (see Rogers, 1967, who compiled the unpublished work of T.W. Dibblee, Jr.; Dibblee, 1964, 1968, 1975, 1982). Fabrics in the gneissose rocks (unit gg) clearly reflect deformation and recrystallization of rocks that originally were texturally and compositionally more homogeneous. However, on outcrop scales the deformational fabrics pass transitionally into equigranular fabrics that show little evidence of deformation. Moreover, some gneissose rocks appear to be transitional locally into the Diorite of Cram Peak (unit Mzc), suggesting that the gneissose rocks may be deformed versions of that body. Cross-cutting relations between deformed and undeformed rocks are not common. Instead, the two fabric types commonly are interlayered. This suggests either (1) intermingling of rocks having metamorphic and magmatic origins or (2) intermingling of rocks having different rheologic response to strain. We presently cannot resolve whether texturally massive fabrics in unit gg represent high-strain metamorphic rocks having granoblastic texture or low-strain rocks having original plutonic fabrics.

We interpret unit gg to be a metamorphic and plutonic complex of mixed origin. Some of the gneiss bodies formed under regional dynamothermal conditions, and may be orthogneisses and paragneisses of Proterozoic and (or) Paleozoic age. Other gneissose rocks may represent plutonic bodies that were deformed and recrystallized during or subsequent to intrusion; these rocks probably are Cretaceous in age, based on comparison with similar rocks in the region that have been dated. Such comparisons can be made after strike-slip displacements on the San Andreas Fault are reconstructed by the scheme proposed by Matti and others (1992b; Matti and Morton, 1993). If crystalline rocks of the Wilson Creek block are restored using displacements on the Mill Creek and Wilson Creek strands, the block ends up adjacent to the northwestern Little San Bernardino Mountains (Matti and Morton, 1993, Figs. 7A-7E, Plate IIIB). There, across the San Andreas Fault, occurs a suite of gneissose and foliated rocks generally similar to those in the Wilson Creek block. Isotopic and geochronologic studies indicate that some of the gneissose rocks and most of the plutonic rocks are late Cretaceous in age (Matti and others, 1994; Fleck and others, 1997). This belt extends northwestward along the San Bernardino Mountains all the way to Cajon Pass, where similar gneissose plutonic rocks have been dated as late Cretaceous (Silver and others, 1988).

Crystalline rocks of the Wilson Creek block are highly fractured locally, especially in the west part of the Yucaipa quadrangle. There, along the Santa Ana fire road, brittle deformation includes low-angle faults that dip shallowly toward the San Bernardino Valley.

Crystalline Rocks of San Gabriel Mountains-type

Crystalline rocks of San Gabriel Mountains-type crop out extensively in the Yucaipa quadrangle, southwest of the Mission Creek strand of the San Andreas Fault. The rocks consist of two suites separated by a low-angle thrust fault—the region-wide Vincent Thrust. Lower-plate rocks consist of Pelona Schist locally intruded by granitoid rock; upper-plate rocks comprise a variety of highly deformed granitoid rocks. These structural relations are similar to those in the southeastern San Gabriel Mountains, where the Vincent Thrust separates Pelona Schist in the lower plate from various deformed granitoid rocks in the upper plate (Ehlig, 1981; Morton, 1975).

Lower-plate rocks

Pelona Schist in the lower plate of the Vincent Thrust crops out extensively in the Crafton Hills, and consists mainly of quartzofeldspathic muscovite schist whose protolith was sandstone and sandy mudrock. Just beneath the Thrust in the Crafton Hills the Pelona also includes chlorite-albite-actinolite greenstone that represents mafic lavas or sills. A small mappable body of greenstone occurs on Yucaipa Ridge (unit Mzpsg), but these outcrops do not resemble those in the Crafton Hills. All Pelona Schist protoliths were metamorphosed to greenschist grade in late Mesozoic or early Paleocene time, presumably as they were overthrust by the upper-plate rocks (Jacobson, 1990, 1997; Jacobson and Dawson, 1995; Jacobson and others, 1996).

Upper-plate rocks

Upper-plate rocks of the Vincent Thrust consist of strongly foliated Mesozoic granitoid rocks (units Mzmg, and Mzfg) that mainly are granodiorite and tonalite in composition. The terrane includes small bodies of porphyritic granodiorite and monzogranite lithologically similar to the Triassic Mount Lowe intrusion of the San Gabriel Mountains (described by Joseph and others, 1982; Barth and Ehlig, 1988). These small bodies are remnants of a formerly widespread Triassic plutonic suite that subsequently was intruded and enveloped by younger Mesozoic granitoids.

Much of the upper-plate rock has mylonitic and cataclastic fabrics that were created when the rock was deformed by ductile and brittle-ductile shearing, squeezing, and stretching. These fabrics are most pronounced near the Vincent Thrust, and presumably were developed as a result of the thrusting. In the southwest corner of the quadrangle, a body of texturally massive to slightly foliated diorite (unit Mzd) is associated with mylonitic rocks of unit Mzmg, and appears to intrude them. This relation is reinforced by the massive to slightly deformed fabric of unit Mzd in comparison to unit Mzmg. However, intrusive relations between the two units are ambiguous, and fabric contrasts between them cannot be used alone to demonstrate sequencing relations: the less deformed dioritic rocks could be older, and the stronger deformation fabrics in younger unit Mzmg could reflect the more quartz-rich composition of its plutonic protoliths.

CENOZOIC ROCKS

Tertiary and Quaternary sedimentary materials crop out in three areas within the south part of the Redlands quadrangle: (1) in the San Timoteo Badlands, (2) along the north flanks of San Timoteo and Live Oak Canyons, and (3) in the Reche Canyon area. The materials all are part of the San Timoteo sedimentary sequence, named by Frick (1921) for exposures in the San Timoteo Badlands.

Sedimentary rocks between the Mill Creek and Wilson Creek strands

The formation of Warm Springs Canyon (unit Tw) is a poorly exposed sequence of nonmarine sandstone, conglomerate, and mudrock whose internal stratigraphy is disrupted by faults and whose east and west boundaries are the Mill Creek and Wilson Creek strands of the

San Andreas Fault. No age has been determined for the succession, but lithologic comparison with other nonmarine sedimentary rock sequences in the region suggests that it probably is late Miocene. If evidence for no more than 10 km of right-slip on the Mill Creek strand of the San Andreas based on crystalline rocks is correct, then the formation of Warms Springs Canyon was deposited on rocks of San Bernardino Mountains type in the Mill Creek region (but see alternative proposals by Sadler and Demirer, 1986, Hillenbrand, 1990, and Sadler and others, 1993).

Sedimentary rocks of the Wilson Creek block

Within the Wilson Creek block, crystalline rocks are overlain depositionally by nonmarine sedimentary rocks of the Mill Creek Formation of Gibson (1964, 1971) (unit Tm). The formation consists of mudrock, sandstone, and conglomerate deposited in alluvial-fan, riverine, and lacustrine settings; the depositional setting included sand-bearing turbidity currents flowing into a lake basin (Gibson, 1964, 1971; Sadler and others, 1993). Woodburne (1975) reviewed permissive evidence supporting a late Miocene age for the unit, but its age is not well established. The Mill Creek basin is viewed as a syntectonic pull-apart basin that evolved in the late Miocene within the San Andreas Fault system (Sadler and others, 1993).

Stratigraphic relations between the Mill Creek Formation and the formation of Warm Springs Canyon (unit Tw) east of the Wilson Creek fault are problematical, and are interpreted in different ways by different workers. Most investigators suggest a stratigraphic and paleogeographic link between the two units. For example, Dibblee (1982, fig. 7) grouped the two units together within the Mill Creek Formation, and implied that they were deposited together elsewhere in southern California before being displaced jointly into the Mill Creek region by his north branch of the San Andreas Fault (Mill Creek strand of our usage). Demirer (1985), Sadler and Demirer (1986), and West (1987) elaborated this concept by proposing that the two sedimentary sequences are halves of a two-sided depositional basin that developed within a rift zone of the ancient San Andreas Fault (also see Sadler and others, 1993). Alternatively, we maintain that sedimentary rocks we assign to the Mill Creek and Warm Springs formations are two distinct and different sequences separated by the Wilson Creek fault. We acknowledge lithologic similarities between them, but we emphasize three points that in our judgment warrant separation of the two units: (1) the formation of Warm Springs Canyon is a sequence that overall is compositionally and texturally more immature than the Mill Creek Formation; (2) the geometry and pattern of sedimentary facies in the Mill Creek Formation is more orderly than in the formation of Warm Springs Canyon; and (3) we have not observed the two sequences to interfinger with each other as indicated by Demirer (1985) and West (1987).

Cenozoic rocks west of the Mission Creek strand

Cenozoic geologic units west of the Mission Creek strand of the San Andreas Fault include Tertiary igneous rocks and upper Tertiary and Quaternary sedimentary materials of the San Timoteo beds of Frick (1921).

Igneous rocks

Igneous rocks intrude both the lower and upper plates of the Vincent Thrust. In the lower plate, granodiorite and quartz-porphyry (unit Tgr) intrude Pelona Schist. North of Mill Creek near Mentone, the granodiorite forms a small hypabyssal body. South of Mill Creek in the Crafton Hills, granodiorite and quartz porphyry form sill-like masses parallel to foliation in Pelona Schist. In the upper plate, especially in the hills along the east margin of the Yucaipa quadrangle, andesite to dacite dikes have intruded Mesozoic rock units; some of these dikes are mappable (unit Ta).

We infer that these igneous rock units are middle or late Tertiary in age (Oligocene and [or] Miocene) based on their lithologic similarity to rocks of that age identified in the lower and upper plates of the Vincent Thrust in the southeastern San Gabriel Mountains (Morton, 1975; Morton and Matti, 1987), in the southeastern San Bernardino Mountains (Farley, 1977), and elsewhere in southern California (Miller and Morton, 1977).

Sedimentary materials

The main Cenozoic map unit west of the San Andreas Fault in the Yucaipa quadrangle is consolidated and unconsolidated sedimentary materials that we group within the San Timoteo beds of Frick (1921) (our upper member, unit QTstu).

The San Timoteo beds are named from exposures in the San Timoteo Badlands, which parallel the San Jacinto Fault and extend more than 40 km from the Loma Linda area southeastward to the San Jacinto Mountains (fig. 1). Canyons and arroyos eroded into the Badlands during the last million years or so (Morton and others, 1990; Kendrick, 1999; Kendrick and others, 2002) reveal a gently- to moderately-dipping sequence of nonmarine sediment and sedimentary rock that have been deformed into a major anticlinal fold that for much of its length plunges gently to the northwest (Morton, 1999). Due to this gentle tilting, older strata in the sequence crop out in the southeastern San Timoteo Badlands while younger strata crop out in the northwestern Badlands, mainly in the Redlands, San Bernardino South, and Yucaipa quadrangles (fig. 1, 2).

The Badlands sequence first was examined by Frick (1921), who separated it into his "upper San Timoteo deposition" and "lower San Timoteo deposition" (Frick, 1921, p. 317, 335). To the "upper San Timoteo deposition" Frick applied the name "San Timoteo beds"; to the "lower San Timoteo deposition" he applied the name "Eden beds" (Frick 1921, p. 283). Despite many subsequent investigations, a type section and formal stratigraphic names have not been proposed for sedimentary units in the Badlands sequence; thus, their stratigraphic relations internally and with other sedimentary units have not been formally documented. For this reason, in the Yucaipa quadrangle we use the name "San Timoteo beds of Frick (1921)" informally.

We subdivide the San Timoteo sequence according to the scheme of Matti and Morton (1975) and Morton (1999), who separated the formation into informal members based on mapping by Matti and Morton (in press).

San Timoteo beds, upper member (unit QTstu)

Stratigraphic boundaries—The upper member forms the upper part of Frick's San Timoteo beds. Its lower contact is not exposed in the Yucaipa quadrangle, but to the south in the adjacent Sunnymead quadrangle the upper member transitionally overlies the middle member of the San Timoteo beds (Morton and Matti, 2001).

The contact between unit QTstu and overlying sedimentary materials is not as well documented, and relations depicted on the geologic map are provisional. In part this is due to poor exposures, but in part it is because sedimentary materials in this part of the stratigraphic section have generally similar lithologic characteristics, and we have not everywhere confirmed where the boundaries between map units should be placed. In particular, we have difficulty distinguishing the contact between unit QTstu and overlying units $Qvoa_3$ and Qoa_1 in the vicinity of Live Oak Canyon in the southwest corner of the quadrangle.

In the hills north of Live Oak Canyon, yellowish-gray strata of unit QTstu pass upward into reddish-colored deposits we refer to unit $Qvoa_3$. The contact occurs somewhere between these two distinctly colored intervals, but its placement is subject to interpretation. We agree with many of the observations by Burnham and Dutcher (1960, p. 64-66) regarding the lithology of materials in this area, including the presence of buried paleosols and the presence of calcareous concretions and fracture fillings throughout the troublesome interval. However, in v. 1.0 of this database we place the contact between our units QTstu and Qvoa$_3$ at a different position than Burnham and Dutcher (1960, fig. 3) did between their units QTs and Qrg ("old red gravel"). This difference of interpretation does not negate the fact that two geologic units exist in this vicinity, nor does it significantly affect the interpretation of geologic setting and geologic history in this part of the stratigraphic section. However, careful follow-up mapping and investigation north of Live Oak Canyon are required in order to resolve stratigraphic details and to bring more clarity to the sequence of map units and their boundary relations.

Southeast of Live Oak Canyon stratigraphic relations between unit QTstu and overlying units are equally troublesome, and our mapping there also is provisional. In general, we agree with Burnham and Dutcher (1960, fig. 3) that the upper member of the San Timoteo beds is overlain by alluvial deposits, and that these deposits (unit Qoa$_1$ of our map, unit Qoa of Burnham and Dutcher, 1960, fig. 3) comprise a unit that is lithologically different from and younger than alluvial deposits that overlie unit QTstu north of Live Oak Canyon (unit Qvoa3). However, our geologic map shows this contact at a different position than depicted by Burnham and Dutcher. Again, this difference of interpretation does not negate the fact that two geologic units exist in this vicinity; however, it does potentially affect the subsurface thickness and extent of unit Qoa$_1$, and careful follow-up mapping and investigation here are required to resolve stratigraphic details.

Lithology—The upper member of the San Timoteo beds of Frick (1921) consists of both consolidated and unconsolidated sedimentary materials (see Table 1 for distinctions between these two consolidation states). As discussed by Burnham and Dutcher (1960, p. 57-63), the upper member (our unit QTstu) is lithologically variable, and from place to place has different ratios between finer-grained (sandy, silty, and clay-bearing) and coarser-grained (gravel-bearing) sedimentary materials. In general, sand, gravelly sand, and gravel and their consolidated equivalents (sandstone, conglomeratic sandstone, conglomerate) are far more common than muddy materials and their consolidated equivalents (mudstone, claystone, siltstone). The sedimentary materials are grayish- to yellowish-colored lower in the sequence but tend to be brownish colored higher in the sequence, thus complicating the distinction between unit QTst and overlying alluvial map units. Clasts in gravel and conglomerate layers include most of the basement rocks in the Yucaipa quadrangle, including granitoids from the upper plate of the Vincent Thrust and granitoid and gneissic rocks of San Bernardino Mountains-type derived from Yucaipa Ridge. Paleocurrents generally point to the south and southwest, and for this part of the stratigraphic section are consistent with streamflows sourced from rocks of both San Gabriel Mountains-type and San Bernardino Mountains type. These streams were part of a drainage system probably much like that formed currently by the Oak Glen Creek-Yucaipa Creek network, except that we have not observed clasts of the Mill Creek Formation (of Gibson, 1964) in unit QTstu (an observation shared by Burnham and Dutcher, 1960, p. 60, who refer to these as "Potato Sandstone" of Vaughan, 1922). This implies that the current Wilson Creek drainage did not provide much sediment, if any, from the part of Yucaipa Ridge underlain by the Mill Creek beds—an interpretation that may have implications for the timing and amount of displacement on the San Bernardino strand of the San Andreas Fault.

Age and correlation—Throughout its regional outcrop belt in the San Timoteo Badlands the San Timoteo beds of Frick (1921) range from early Pliocene through early Quaternary in age (Albright, 1997, 1999). However, in the Yucaipa quadrangle only the Quaternary part of the formation is exposed. The upper part of the unit contains the middle Pleistocene (Irvingtonian-II) Shutt Ranch vertebrate local fauna dated as about 780 to 990 Ka (Albright, 1999, who re-evaluated the work of Repenning, 1987, and Reynolds and Reeder, 1986, 1991). In the adjacent Redlands quadrangle, magnetostratigraphic data (Albright, 1997, 1999) indicate that uppermost part of the San Timoteo beds post-date the Brunhes-Matuyama magnetic reversal, and thus are younger than about 780 Ka.

Depositional origin—Sediments of the upper member of the San Timoteo beds in the Yucaipa quadrangle represent alluvial deposits that were laid down by streams flowing south and southwest down an ancestral valley between the Crafton Hills and hills east of Yucaipa and Calimesa (Matti and Morton, 1993). This paleographic reconstruction is indicated by depositional structures and paleocurrent indicators, and by clast compositions in gravelly and conglomeratic beds.

QUATERNARY SURFICIAL MATERIALS

Quaternary surficial materials—geologic materials that have accumulated at the land surface over the last 750,000 years or so—are widespread throughout the Yucaipa quadrangle. These are mainly unconsolidated materials that mantle the ground surface of valleys and hillslopes, or that form the uppermost fillings of alluvial fans and valleys.

The transition between "unconsolidated" and "consolidated" (lithified) is not easy to define. In general, sedimentary materials that have begun to consolidate (lithify) will have some degree of compaction and (or) cementation that yields a stiff, firm, or coherent mass that resists breakage. This consolidation process leads to decreased pore space and increased relative density. The consolidation (lithification) process is influenced by sediment grain size, sorting, cohesiveness (cohesionless materials *versus* cohesive materials), overburden load, and circulating fluids. With increased consolidation, lithification and progressive hardening (induration) results. For the Yucaipa quadrangle, we used the criteria listed in Table 1 to describe the consolidation state of surficial materials. In general, consolidation increases with increasing age of the sedimentary material.

	Lithification State	**Field Criterion**	**Relative Density (D_r)[1]**
Unconsolidated	Very slightly consolidated	Easily indented with fingers	0.00—0.20
	Slightly consolidated	Somewhat less easily indented with fingers. Easily shoveled	0.20—0.40
	Moderately consolidated	Shoveled with difficulty	0.40—0.70
Consolidated	Well consolidated	Requires pick to loosen for shoveling	0.70—0.90
	Lithified	Requires blasting or heavy equipment to loosen	0.90—1.00
	Indurated	Rings to the blow of a hammer	1.00

Table 1: Criteria for the recognition of consolidation state in surficial materials (modified from Bowles, 1984, Table 5-2)

We classify surficial materials in the Yucaipa quadrangle into various map units using three kinds of information:

- physical properties and lithologic features (including consolidation, depositional fabric, particle size and particle sorting, particle composition, matrix support versus grain support);
- genesis and geomorphic setting (physiographic setting) and mode of origin (alluvial-fan, colluvial, slope failure, etc.);

---

[1] As translated by Bowles (1984, p. 151-152), relative density is an engineering parameter that relates void space determined in the laboratory to a ratio involving index values of minimum and maximum void space for specified materials under specified conditions. Void space in turn is related to *in situ* dry unit weight. The *Glossary of Geology* definition of relative density is: "The ratio of the difference between the void ratio of a cohesionless soil in the loosest state and any given void ratio to the difference between its void ratios in the loosest and in the densest states (ASCE, 1958, term 296)" (Jackson, 1997, p. 540).

- age (as interpreted mainly from pedogenic-soil characteristics, but also by degree of erosional dissection).

Our inclusion of genesis as a factor in mapping surficial materials runs counter to the way map units of other materials in the quadrangle are classified. According to the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983), surficial geologic-map units—like map units of consolidated materials—are lithostratigraphic and (or) allostratigraphic units that should be defined on the basis of descriptive lithologic and stratigraphic features alone; highly interpretive and derivative criteria such as genesis typically should be avoided. Despite these guidelines, use of genetic criteria as a basis for classifying and mapping surficial materials seems intuitive because they are forming right before our eyes: we can observe how the physiographic setting and geologic origin of the materials determines their physical properties and contributes to the overall characterization of a map unit. Thus, it is useful to include genetic factors in the mapping of these materials, and in the Yucaipa quadrangle surficial materials that have the same genesis are candidates for inclusion within the same geologic-map unit—assuming they are about the same age (discussed below).

Figure 3 illustrates the hierarchical framework for classifying surficial geologic-map units in the Yucaipa quadrangle, showing how physiographic setting and genesis figure into identifying and naming the units. Most surficial units in the quadrangle are classified into two major alluvial categories: *axial-valley materials* deposited in lowlands by through-going rivers and streams that flow down valley axes (units Qvya, Qya, Qoa, and Qvoa) and *alluvial-fan materials* deposited in cone-shaped aprons that flank the margins of hills and mountains or that build down onto through-going axial-valley plains from lateral tributaries (units Qvyf, Qyf, Qof, and Qvof).

Both *axial-valley* and *alluvial-fan* deposits are categories of alluvium: that is, they consist of sediment deposited mainly by stream flows (although alluvial-fan deposits locally include sediment-gravity-flow deposits). For this reason, the two alluvial deposit types generally have similar lithologic characteristics and physical properties. For example, axial-valley deposits have physical properties that are very similar to those of distal alluvial-fan deposits. How, then, can the two deposit types be distinguished by other than original physiographic setting and genesis, especially for older materials where information about such factors may have become obscured by erosion, deformation, and burial by younger units? Materials in *axial-valley* and *alluvial-fan* categories differ in the following general ways:

- alluvial-fan deposits typically are coarser grained and more poorly sorted than axial-valley deposits, being gravel-rich in comparison with sand-rich axial-valley deposits;
- axial-valley deposits typically have more layers of clay, silt, and organic-rich material (peat) associated with sand-and-gravel layers than do alluvial-fan deposits;
- where axial-valley and alluvial-fan deposits at the surface or in the subsurface are traced in a known or inferred upstream direction, alluvial-fan deposits tend to coarsen in grain size and lose fine-grained interbeds more rapidly than do their axial-valley counterparts.

Our classification of surficial geologic-map units also incorporates geologic age as a basis for assigning a map-unit name. This is because relative age position among bodies of surficial earth material is an obvious aspect that has an immediate impact on the observer. For example, during the Quaternary Epoch Southern California witnessed the cyclic development of multiple generations of surficial deposits:

- Mountain canyons display flights of alluvial terraces, each formed by different pulses of canyon-filling alluvium or down-cutting stream events;
- Alluvial fans flanking the mountains consist of different-aged units nested one into another;

- The coastal strip has flights of marine terraces that march upslope from present sea level.

These cycles developed because geologic and climatic conditions vary with the passage of time, and such changes trigger responses in the geologic and geomorphic processes that operate at the earth's surface. As a result, one package (map unit) of surficial materials can give way abruptly to another. If these packages have not been stripped away by erosion or concealed by younger materials, a succession of surficial units will be preserved.

This succession is age-sequenced: that is, the succession of alluvial map units on hillslopes or in canyons or on valley bottoms is arrayed in a chronologic sequence. As part of the geologic-mapping process, the geologist confirms how the sequence of deposits in one area relates temporally to the sequence in another area. Geologic age thus is a critical criterion in the classification and mapping of surficial geologic materials, and surficial deposits of the same age are candidates for inclusion within the same geologic-map unit—as long as they have the same origin and generally similar physical properties.

Figure 4 illustrates regional and global chronologies within which surficial materials of the Yucaipa quadrangle can be compared. Figures 5 and 6 indicate where we think surficial map units in the Yucaipa quadrangle fit within this chronology, especially in comparison with the succession of alluvial-terrace fills recognized by Bull (1991) in the San Gabriel Mountains and in the desert regions of southern California. Our classification scheme breaks out four major age-based surficial families:

- *Very young* surficial deposits (Qvy units; these are the most recent surficial deposits spanning the last few hundred years or so of Holocene time);
- *Young* surficial deposits (Qy units; these are Holocene and latest Pleistocene deposits that formed since the last major glacial period—since the late Wisconsin of Figures 4 and 5);
- *Old* surficial deposits (Qo units; these are surficial deposits that formed during the last few hundred thousand years. We currently do not have good age control on these units);
- *Very old* surficial deposits (Qvo units; these are the oldest surficial deposits that accumulated in the Yucaipa quadrangle since the deposition of the San Timoteo beds of Frick, 1921).

Currently, we cannot correlate very confidently surficial geologic-map units in the Yucaipa quadrangle with the global climatically-driven chronology. For one reason, our only way to estimate geologic age is the textural and mineralogic maturity of pedogenic-soil profiles that cap each surficial deposit. In general, this allows us to compare the age of the surficial units relative to each other, and allows us to speculate about where each unit falls relative to the provisional chronology developed by Bull (1991). Unfortunately, soil profiles in the Yucaipa quadrangle have only been studied carefully in a few areas (Harden and Matti, 1989; also see Woodruff and Brock, 1980). Moreover, during our geologic mapping we were able to examine soil profiles only in a perfunctory way. Until careful investigations of the pedogenic soils are conducted, or until numerical geochronologic data are obtained using radiometric-age determinations (see the work by Kendrick, 1999 and Kendrick and others, 2002 in the adjacent Redlands quadrangle), our classification and correlation of surficial materials in the Yucaipa quadrangle is provisional and subject to modification and revision.

Although the general character of the surficial map units persists throughout the map area, in detail their character varies both horizontally and vertically. Thus, details of sediment interlayering, consolidation, grain-size variation, and permeability for a given map unit may change markedly between localities only a few tens of meters apart. Similar variations also occur vertically at a specific site: physical properties observed in the upper meter or two of a unit may not persist very far into the subsurface, and the surface unit may be underlain in the subsurface by an older unit (Qya_5 at the surface may be underlain within a few meters by units Qya_4, and Qya_3). Finally, because stream channels migrate from season to season and year to year and because the interface between alluvial-fan and axial-valley environments changes in location with the passage of geologic time, alluvial-fan and axial-valley deposits interfinger in the subsurface throughout the map area. These factors all contribute to lithologic variability both laterally and vertically within and between surficial geologic units.

Because the Yucaipa quadrangle has only some of the units recognized regionally, and because the dataset authors have attempted to correlate these units within the region-wide classification scheme, surficial units recognized in the quadrangle appear to be identified out of context: for example, unit $Qvof_3$ is recognized even though older units $Qvof_2$ and $Qvof_1$ are not. Figures 4-6 illustrate the main region-wide surficial units.

From younger to older, we recognize the following categories of surficial deposits in the Yucaipa quadrangle:

Very young deposits (Qvyw, Qvyf, Qvyc, Qvyls)

Within the San Bernardino Mountains, mappable bodies of very young colluvium (unit Qvyc) mantle some hillslopes. Canyon bottoms are veneered with deposits of active streamflows (unit Qvyw) and flanked by older deposits of streams and alluvial fans that form step-like terraces rising above the active washes. Lowlands of Yucaipa Valley and the San Bernardino Valley are the locus of very young wash deposits, including those that are active (unit Qvyw) and progressively less active to abandoned (units $Qvyw_2$ and $Qvyw_1$).

Landslides occur throughout the mountain region, but are most abundant on hillslopes underlain by the Mill Creek Formation, particularly where mudrock is a large component of the formation (units Tmm and Tms) . Youthful (and older landslides) are particularly prominent west and east of State Route 38 in Mill Creek Canyon, and along the southwest base of Yucaipa Ridge east of the mouth of Mill Creek. The landslides include both loose cohesionless masses of rubble and intact blocks of bedrock that have slumped downhill. Some landslides are active, like those along the west side of State Route 38 near the mouth of Mill Creek Canyon; other slides are older and inactive under current climatic and tectonic conditions. All landslides are susceptible to reactivation under severe earthquake-generated ground-shaking conditions or high-rainfall conditions.

Young deposits (Qya, Qyf, Qyls)

Surficial deposits of this family are sandy and gravelly deposits characterized by pedogenic-soil profiles having minimal soil-profile development: the $A/C_{ox}/C$ profiles are no thicker than 1 or 2 m, with the most mature profiles having Bcambic horizons that lack illuvial clay. These soils are Holocene to latest Pleistocene in age, coincide with soil-stages S6 and S7 of McFadden (1982) and Bull (1991), and are between 15,000 and 1,000 years old (Figures 5, 6).

Young surficial deposits in the Yucaipa quadrangle are not so widespread as old and very old surficial deposits. This pattern reflects a major contrast between paleogeographic settings for older Quaternary and latest Quaternary deposits: old and very old units resulted from major aggradational pulses that distributed sediment across a landscape that appears to have been relatively smooth, whereas young units have resulted from minor aggradational pulses that deposited sediment locally on a landscape that is tectonically active and that mainly is undergoing erosional dissection. The young deposits also have been subjected to local base-level influences more frequently than were older deposits. For example, several areas of young alluviation occur adjacent to fault scarps of the Yucaipa Valley graben complex, and are accumulating on down-thrown blocks while sediment is being eroded from up-thrown blocks. These tectonic influences on sedimentation patterns for the last 15,000 years or so allow us to interpret the recency of faulting in the Yucaipa quadrangle.

Old deposits (Qoa, Qof, Qols)

Alluvial deposits of this age are widespread west of the San Andreas Fault. The deposits are characterized by pedogenic-soil profiles having red B horizons as thick as 2 m; soils having this degree of rubification are comparable to soil-stages S3, S4, and S5 of McFadden (1982) and Bull (1991), and probably are between 500,000 and 50,000 years old (Figures 5, 6). They represent the "older alluvium" of Burnham and Dutcher (1960, p. 77-78).

Various units of Qoa in Yucaipa Valley and in the valley of Oak Glen Creek are axial-valley deposits laid down by through-going streamflows of ancestral Oak Glen and Yucaipa Creeks. These deposits are physically continuous with equally extensive deposits that occupy intermontane canyons in the adjacent Forest Falls quadrangle (Matti and others, 1992b; J.C. Matti, B.F. Cox, and K.J. Kendrick, unpublished geologic mapping). Together, these deposits represent a significant volume of sediment that seems anomalously large with respect to the size and discharge potential of catchment basins on Yucaipa Ridge that source the creeks currently flowing down the canyons (Figure 1). To explain this discrepancy, we propose that units of Qoa in the Yucaipa quadrangle were deposited in a large, regional, integrated drainage system that headed to the east and northeast, via Oak Glen Valley and via Little San Gorgonio and Noble Creeks. The main trunk of this drainage system ultimately may have been San Gorgonio River, which today flows southward and southeastward into the Coachella Valley (Figure 1) but during Qoa time may have flowed westward down Oak Glen Valley and Wildwood Canyon and thence into Yucaipa Valley. This paleogeographic pattern seems more likely when about 3 km of late Pleistocene right-slip is reconstructed on the San Bernardino strand of the San Andreas Fault (Matti and others, 1992b; Matti and Morton, 1993, fig. 7K). This restoration places the Yucaipa quadrangle closer to the head of San Gorgonio River in the southeastern San Bernardino Mountains, and provides a paleogeographic association between the large volumes of older axial-valley alluvium in the greater Yucaipa-Oak Glen regions and a large river that could have generated the high-discharge streamflows capable of transporting and depositing large sediment volumes. The distribution of unit Qoa in the vicinity of Live Oak Canyon suggests that streamflows depositing various subunits in Yucaipa Valley ultimately flowed down ancestral Live Oak Canyon to meet ancestral San Timoteo Creek. They were confined to this paleo-drainage pattern by the high-standing Crafton Hills-Sand Canyon area that, by this time, had been uplifted to form a barrier between Yucaipa Valley and the San Bernardino Valley to the northwest.

During this same time period, axial-valley streamflows of ancestral Oak Glen Creek were flanked on the north by alluvial fans emanating from canyons heading north into Yucaipa Ridge. This paleogeographic configuration led to distinct cobble populations for the two different depositional regimes: (1) axial-valley deposits of Qoa that accumulated in ancestral Oak Glen Valley have clasts derived mainly from crystalline bedrock units cropping out on Yucaipa Ridge east of the Yucaipa quadrangle; (2) within the quadrangle, alluvial-fan deposits of Qof flanking Yucaipa Ridge have clasts derived mainly from the Mill Creek Formation. This difference in clast populations is the main basis for distinguishing units of Qoa from units of Qof in the northern Yucaipa Valley area, and were used by Harden and Matti (1989) to estimate slip rates for the San Bernardino strand of the San Andreas Fault (discussed below).

We assign large landslide deposits that occur on Yucaipa ridge to unit Qols. These deposits typically are slightly to moderately dissected, and lack the youthful geomorphic features displayed by landslides along State Route 38 in Mill Creek Canyon. The Qols deposits are particularly extensive east of the mouth of Mill Creek Canyon, where a large landslide complex has been shed from the Mill Creek Formation across the San Bernardino strand of the San Andreas Fault.

Very old deposits (Qvoa, Qvof)

Very old Quaternary deposits occur in two main areas: flanking the San Bernardino strand of the San Andreas Fault between Mill Creek and Santa Ana River (unit Qvof$_3$), and on the southwest part of the Crafton Hills horst (unit Qvoa$_3$). Both deposits are characterized by pedogenic-soil profiles having very red B horizons as thick as 3 m. Soils of this maturity are comparable to soil-stage S2 of McFadden (1982) and Bull (1991), and probably are greater than 500,000 years old. These deposits coincide with the "old red gravel" of Burnham and Dutcher (1960, p. 72-77).

Adjacent to the San Andreas Fault, deposits of unit Qvof$_3$ consist of sand-and-gravel deposits that have been tilted as steeply as 65° toward the San Bernardino Valley. This area is referred to as "Morton Ridge" by Burnham and Dutcher (1960), who correlate the deposits with their "old red gravel". Burnham and Dutcher (1960, p. 75) interpret the deposits as "...the accumulation of slope-wash debris and fan material along the San Andreas fault at or near the base of the rising San Bernardino Mountains". Although some parts of the Quaternary stratigraphy between Mill Creek and Santa Ana River contain detritus derived from local hillslopes to the north, deposits we map as unit Qvof$_3$ contain abundant cobbles and boulders derived from bedrock units east of the San Bernardino strand, including the Mill Creek Formation of Gibson (1971), units TRm and Mzga, and various crystalline rock units that crop out in the Mill Creek drainage beyond the borders of the Yucaipa quadrangle. We interpret unit Qvof$_3$ here to be mainly alluvial-fan deposits that originally accumulated at the canyon mouth of Mill Creek and since have been displaced right-laterally about 2 to 3 km by the San Bernardino strand of the San Andreas Fault.

In the Sand Canyon area of the southwestern Crafton Hills horst, unit Qvoa$_3$ consists of sand and gravel beds and interlayered paleosols (see the excellent description by Burnham and Dutcher, 1960, p. 75-76 of their "old red gravel" in this area). The deposits here contain more sand than gravel and have textural and bedding features and depositional fabrics that are more typical of fluvial-plain deposits rather than alluvial-fan deposits; hence, we map them as axial-valley deposits (unit Qvoa$_3$) rather than as alluvial-fan deposits (unit Qvof$_3$). The deposits contain granitoid and gneissose clasts of both San Gabriel Mountains-type and San Bernardino Mountains-type, but are rich in clasts of the latter derived from the Yucaipa Ridge area east of the quadrangle. In this regard the Sand Canyon deposits are very similar to deposits in Section 29 at the east margin of the Yucaipa quadrangle along the south wall of Wilson Creek. There, unconformably beneath overlying deposits of unit Qoa$_2$, deposits we assign to unit Qvoa$_3$ consist of gravel and gravelly sand containing highly weathered gneissose and granitic clasts derived from crystalline rocks of San Bernardino Mountains-type. The paleogeographic picture that emerges from these correlations is that during Qvo time, axial-valley streamflows coursed down Oak Glen Canyon through the Yucaipa Valley and westward through the Sand Canyon area into the San Bernardino Basin. As with younger deposits of Qo age (discussed above), discharge rates required to transport and deposit this prodigious amount of alluvial sediment seem anomalous relative to the size of catchment basins on Yucaipa Ridge. As with the Qo deposits, we suspect that unit Qvoa$_3$ was deposited by streamflows of San Gorgonio River that formerly flowed down Oak Glen Valley prior to late Quaternary displacements on the San Bernardino strand of the San Andreas Fault.

In the hills north of Live Oak Canyon, we have difficulty distinguishing deposits of unit Qvoa$_3$ from deposits of the underlying upper member of the San Timoteo beds of Frick (1921). For one reason, upper beds of unit QTstu here are brownish colored, and are difficult to separate from brownish colored deposits of unit Qvoa$_3$. For a second reason, a series of reddish paleosols occur in strata we assign to unit QTstu, just as they do in unit Qvoa$_3$ in the Sand Canyon area. Not only does this complicate differentiation of one unit from another, but in some areas north of Live Oak Canyon the paleosol succession in unit QTstu seems to culminate in a capping paleosol, without the occurrence of an actual stratigraphic fill of unit Qvoa$_3$. Some materials we assign to unit Qvoa$_3$ here may simply be paleosol or residuum developed on a landscape surface of unit QTstu. A similar problem occurs in the hills south of Live Oak Canyon (El Casco quadrangle) and east of the map area (Redlands quadrangle): in those areas, rubified argillic zones that cap ridges underlain by unit QTstu are mapped as very old residuum and paleosol (unit Qvor of Matti and Morton, in press; Matti and others, 2003) More mapping and investigation in the southwest corner of the Yucaipa quadrangle is required to resolve these ambiguities.

If it turns out that areas of Qvoa$_3$ in the southwest corner of the Yucaipa quadrangle are not actual alluvial deposits but instead are residuum and paleosol capping a landscape surface developed on unit QTstu, this has significant implications for the paleogeographic setting of the Yucaipa quadrangle during Qvo time. It would imply that areas north of Live Oak Canyon were subaerially exposed and developing weathering surfaces at the same time as alluvium was being deposited in the Sand Canyon area to the north. This might have implications for the timing of fault movements in the Crafton Hills Fault zone and the Live Oak Canyon Fault zone in the adjacent Redlands quadrangle (Matti and others, 2003) and the paleogeographic evolution of the ancestral San Timoteo Canyon drainage system.

STRUCTURAL GEOLOGY

Vincent Thrust

On the north-facing slope of the Crafton Hills, a low-angle fault separates Pelona Schist from overlying mylonitic and strongly foliated crystalline rocks. This relation is similar to that occurring in the southeastern San Gabriel Mountains, where the Vincent Thrust separates greenschist-facies rocks of Pelona Schist from a suite of mylonitic crystalline rocks in the upper plate of the thrust (Ehlig, 1958; Morton, 1975). We follow Ehlig (1968, 1981, 1982) who correlated the low-angle fault in the Crafton Hills with the Vincent Thrust, thereby extending this structure throughout the greater Inland Empire region and elsewhere in southern California (fig. 2; Ehlig, 1968; Matti and others, 1985, 1992b).

In the Crafton Hills, the Vincent Thrust is not conspicuously exposed. Within the Pelona Schist, intensity of foliation within the muscovite schist (unit Mzpsm) increases approaching the fault, and is succeeded by a thin interval of strongly foliated albite-actinolite schist (greenstone) that in turn is overlain by mylonitic granitoid rock. The foliated greenstone and mylonitic granitoid rock superficially resemble each other, and early workers (e.g., Dibblee, 1967) did not place the tectonic boundary at the same topographic or structural position that we recognize. The Vincent Thrust trends southwest across the Crafton Hills for a few miles, but eventually is concealed by Quaternary alluvial units. The concealed trace of the thrust projects toward the Redlands quadrangle, where it can be inferred in the subsurface as well as throughout the San Bernardino Basin (fig. 2; Matti and others, 2003). A small outcrop of upper-plate crystalline rock occurs in Mill Creek Wash in Section 17 north of Mentone (unit Mzfg). This body has been downdropped from equivalent upper-plate rocks in the Crafton Hills by normal faults responsible for developing the San Bernardino Basin; ostensibly, the Vincent Thrust underlies this isolated body of upper-plate rock.

Northeast of the Crafton Hills the Vincent Thrust is not exposed again in the Yucaipa quadrangle, but it ostensibly continues northeastward in the subsurface toward the concealed trace of the Mission Creek strand of the San Andreas Fault. Along the east edge of the quadrangle a small exposure of Pelona Schist greenstone (unit Mzpsg, first recognized by Smith,

1959) represents the lower plate of the Vincent Thrust system; however, these outcrops do not bear on the distribution of the Vincent Thrust eastward from the Crafton Hills because they occur east of the Mission Creek strand of the San Andreas Fault and are in a different structural block. East of the Yucaipa quadrangle the Vincent Thrust is next exposed in the headwaters of San Gorgonio River in the southeastern San Bernardino Mountains (fig. 2; Allen, 1957; Ehlig, 1968, 1981, 1982; Farley, 1977; Matti and others, 1985, 1992b).

San Andreas Fault zone

The San Andreas Fault zone is the most conspicuous structural element in the Yucaipa quadrangle, and is of particular interest because of its potential for generating large earthquakes. The four strands recognized by Matti and others (1985, 1992b) occur in the quadrangle, and are shown on the geologic map and in Figure 2. We discuss these faults from east to west, concluding with the modern trace of the fault (San Bernardino strand).

Mill Creek strand

From southeast to northwest, the Mill Creek strand traverses Mill Creek and Warm Springs Canyons and crosses Santa Ana River Canyon before exiting the Yucaipa quadrangle (fig. 2). Throughout much of this extent the fault is concealed beneath young Quaternary alluvium and colluvium, but where it traverses bedrock the fault forms a zone of sheared and crushed rock as much as 10 m wide.

Most workers agree that the Mill Creek strand is a right-lateral strike-slip fault of the San Andreas zone, but disagreement exists regarding its tectonic significance. Early workers interpreted the fault as a major San Andreas strand having right-slip displacements in excess of 100 km. Initially, Gibson (1964, 1971) concluded that 120 km of right-slip on the fault has displaced the Mill Creek Formation into the Yucaipa area from its original depositional position in the vicinity of the Orocopia Mountains northeast of the Salton Sea. Dibblee (1968, p. 269) concluded that, if strands of the San Andreas Fault in the southeastern San Bernardino Mountains have contributed to the 210 km of right-slip proposed for the San Andreas in southern California by Crowell (1962), then the largest movement probably occurred along the Mill Creek strand (his "north branch of the San Andreas Fault"). Later, Dibblee (1975, p. 134) proposed that his north branch generated about 96 km of right slip and displaced crystalline rocks in the southeastern San Bernardino Mountains from unspecified counterparts in the Orocopia Mountains. Dibblee (1982, p. 164) subsequently increased this value to 120 km—a displacement identical to Gibson's (1964, 1971) and presumably based on Gibson's palinspastic restoration of the Mill Creek Formation to the Orocopia Mountains region. Sadler and Demirer (1986; Sadler and others, 1993) used paleogeographic reconstructions for the Mill Creek Formation to conclude that the Mill Creek strand has displaced the formation from a depositional position between the Little San Bernardino and Orocopia Mountains—a distance of more than 110 km. Most recently, Hillenbrand (1990) proposed that the Mill Creek fault has displaced the formation of Warm Springs Canyon only about 40 km from a presumed cross-fault source for diorite-gabbro clasts that occur in conglomerate beds of the unit.

Other workers view the Mill Creek strand as a minor element of the San Andreas Fault based on geologic relations immediately east of the Yucaipa Quadrangle. There, Farley (1979) and Matti and others (1983, 1985) showed that crystalline rocks directly outboard (west) of the Mill Creek strand are similar to those directly inboard (east) of the strand. We have observed similar relations in the Yucaipa quadrangle where unit Mzga—a foliated orthogneiss outboard of the Mill Creek strand—is lithologically similar to rocks we have mapped inboard of the fault a few kilometers to the southeast in the Alger Creek area in the Forest Falls quadrangle. These and other relations led Matti and others (1985) to propose that the Mill Creek strand is a minor element of the San Andreas Fault having no more than 8 or 9 km of right slip—an interpretation we retain in this report.

The age of faulting on the Mill Creek strand is not well constrained in the Yucaipa quadrangle. The fault is younger than the Miocene formation of Warm Springs Canyon, but evidence for Quaternary movement on the fault is not definitive. The fault does not break young surficial materials like those on the divide between Mill Creek and Warm Springs canyons and on the north wall of Warm Springs Canyon; there, a large landslide mass of poorly-constrained age also conceals the trace of the fault. In Santa Ana Canyon, on the bedrock divide between Government Creek and Santa Ana River, deposits of Qoa appear to be broken by fault planes of the Mill Creek zone; however, the terrace surfaces of the deposits do not show primary fault features, and we have not confirmed whether these breaks reflect right-slip movements on the Mill Creek strand or extensional reactivation of the strand by dip-slip movements (Weldon and Matti, 1986). The bedrock canyon of Santa Ana River is deflected right laterally where it is crossed by the Mill Creek strand, and late Quaternary alluvial deposits nested down into this deflection could be interpreted as having been displaced westward as it evolved due to strike-slip faulting. However, these relations do not provide definitive information about the age of movements on the Mill Creek fault for two reasons: (1) the deflection may be due to erosional vagaries of the Santa Ana River rather than to right-lateral movements on the fault (the bedrock canyon of Government Creek is not deflected, for example), and (2) if it is the result of strike-slip displacements, the deflection of Santa Ana River canyon could have occurred before or since backfilling of late Quaternary gravels in the canyon. Matti and others (1985, 1992b) concluded that major episodes of right-slip on the Mill Creek strand occurred in the middle Pleistocene, after displacements on the Mission Creek strand but before displacements on the late Pleistocene San Bernardino strand. We accept this interpretation here.

Wilson Creek strand

The Wilson Creek strand traverses Yucaipa Ridge and converges toward the Mill Creek strand in Santa Ana River Canyon (fig. 2). The fault juxtaposes crystalline rocks of the Wilson Creek block and the overlying Mill Creek Formation against the formation of Warm Springs Canyon. The fault trace is poorly exposed in most areas, but generally dips moderately southward and has a curving, locally sinuous trace. In the adjacent Forest Falls quadrangle, beds of the formation of Warm Springs Canyon are deformed into an overturned syncline beneath the south-dipping Wilson Creek strand (J.C. Matti, unpubl. mapping, 1985-1992). A similar relation may exist in the Yucaipa quadrangle, where beds of the formation of Warm Springs Canyon dip steeply to moderately south against the Wilson Creek Fault; however, we have not identified facing criteria in these beds to confirm their overturned configuration.

The distribution, movement sense, and importance of the Wilson Creek fault are interpreted in different ways by different workers. Faults we assign to the Wilson Creek strand were mapped by Owens (1959) and by Smith (1959); the latter identified two fault segments (his South fault and Yucaipa Ridge fault) that he thought were unrelated. Matti and others (1985) combined Smith's South and Yucaipa Ridge faults into the through-going Wilson Creek strand. The distribution and displacement history of the fault were examined by Demirer (1986) and by West (1987), who referred to the structure as the Yucaipa Ridge fault and restricted the name "Wilson Creek" to another fault zone in the adjacent Forest Falls quadrangle. All previous workers conclude that faults we assign to the Wilson Creek fault are minor structures having reverse dip-slip movement.

Investigators who view the Wilson Creek fault as a minor structure have invoked stratigraphic comparisons between the Mill Creek Formation and the formation of Warm Springs Canyon. Most workers (Dibblee, 1982; Demirer, 1986; Sadler and Demirer, 1986; West, 1987) interpret the two units to be stratigraphically similar, and therefore see no need to juxtapose them along a fault having significant strike-slip movement. For reasons discussed above, we maintain that stratigraphic differences between the Mill Creek and Warm Springs formations outweigh stratigraphic similarities between them. More significantly, basement rocks of the Wilson Creek block that underlie the Mill Creek Formation are dissimilar to those in the San Bernardino Mountains east of the Wilson Creek and Mill Creek faults: if the Mill Creek strand is a relatively minor strand of the San Andreas (as we propose), then either the Wilson Creek strand or some other (unrecognized) fault is required to bring the Wilson Creek block into the region.

We interpret the Wilson Creek strand as a major strand of the San Andreas Fault. Originally, Matti and others (1985) proposed that the strand has about 110 km of right slip. This estimate was based on a model where the Wilson Creek and Mission Creek faults (fig. 2) are major strands of the San Andreas that, in combination, have brought exotic rocks into the San Bernardino Mountains from their original positions as much as 150 km farther southeast in the Coachella Valley region. In this model, the Wilson Creek strand contributed considerably more of this 150-km displacement than did the Mission Creek strand. This model had uncertainties, however, and Matti and others (1985) pointed out that an equally likely reconstruction of displaced crustal blocks could be achieved if the Mission Creek strand, rather than the Wilson Creek strand, had the larger displacement. Matti and Morton (1993) adopted this role reversal between the two fault strands based on their speculation that the Wilson Creek strand is a segment of the Punchbowl Fault in the San Gabriel Mountains (fig. 1), an old strand of the San Andreas Fault for which about 40 to 45 km of right-slip has been documented (Ehlig, 1981; Barrows and others, 1985, 1987). Matti and Morton (1993) proposed that the through-going Wilson Creek-Punchbowl Fault was deformed into a sinuous trace following its right-lateral history, and that the Wilson Creek segment of this fault became stranded against the San Bernardino Mountains and was bypassed as movements on the younger Mission Creek strand displaced the northwest end of the Punchbowl fault (now near Palmdale) away from the southeast end of the Wilson Creek fault in the San Bernardino Mountains (Matti and Morton, 1993). If this speculation is correct, then the Wilson Creek strand has the same amount of right slip (40 to 45 km) documented for the Punchbowl Fault in the San Gabriel Mountains.

Mission Creek strand

Matti and others (1985, 1992b) inferred the existence of the Mission Creek strand in the Yucaipa quadrangle and elsewhere along the southwestern base of the San Bernardino Mountains in order to explain the juxtaposition of San Gabriel Mountains-type basement rocks (upper- and lower-plate rocks of the Vincent Thrust) against the Wilson Creek block and against basement rocks of San Bernardino Mountains-type (fig. 2). The role of the Mission Creek strand in juxtaposing these distinctive terranes had been documented in the southeastern San Bernardino Mountains (Farley, 1979; Matti and others, 1983, 1985), where the fault separates rocks of San Gabriel Mountains-type from the Wilson Creek block and from rocks native to the San Bernardino Mountains. Matti and others (1985) reasoned that the Mission Creek strand must continue in the subsurface along the southwestern base of the San Bernardino Mountains, where a major strike-slip structure other than the San Bernardino strand is required to separate rocks of San Gabriel Mountains-type underlying the San Bernardino basin from rocks of San Bernardino Mountains-type and the Wilson Creek block. The San Bernardino strand could not play this significant role, because Matti and others (1985, 1992b) demonstrated that this structure has no more than a few kilometers of displacement since its inception in the last 125,000 years or so (discussed below). Inferred continuation of the Mission Creek strand northwestward from its documented occurrence in the southeastern San Gabriel Mountains is the only logical explanation for basement-rock contrasts between the San Bernardino Basin and the San Bernardino Mountains (fig. 2).

Within the Yucaipa quadrangle, the position of the Mission Creek strand is concealed beneath all generations of Quaternary surficial deposits. In the eastern half of the quadrangle the geologic map shows only surface breaks of the San Bernardino strand: no concealed trace of the Mission Creek strand is indicated because we infer that the younger fault (San Bernardino strand) evolved through re-activation of the older fault (Mission Creek strand), and the two structures occupy the same trace. Cartographically, this relation cannot be displayed (although fig. 1 conveys it schematically). Just west of the mouth of Mill Creek, the geologic map shows the concealed trace of the Mission Creek strand diverging from the San Bernardino strand by as much as 0.5 km at the west margin of the quadrangle. This interpretation is based on relations in the adjacent Redlands quadrangle, where newly identified outcrops of the Wilson Creek block outboard (southwest) of the San Bernardino strand indicate that the major strand of the San Andreas zone lies slightly outboard of the modern San Andreas trace (Matti and others, 2003).

The age of faulting on the Mission Creek strand is not well constrained in the Yucaipa quadrangle. The fault is older than all Quaternary surficial units, including deposits of unit Qvof_3 that are at least 500,000 years old and may be as old as 600 Ka to 700 Ka. Matti and others (1985, 1992b) observed similar relations in the southeastern San Bernardino Mountains (Raywood Flat area) and in the northwestern Coachella Valley. Thus, regionally the Mission Creek strand probably has not been a significant right-lateral component of the San Andreas system since early Pleistocene time.

San Bernardino strand

The San Bernardino strand defines the modern trace of the San Andreas Fault in the Yucaipa quadrangle and elsewhere along the southwest margin of the San Bernardino Mountains. The fault breaks all but the youngest surficial materials. Northwest of Mill Creek the fault trends N 70° W, a trend it maintains throughout much of the San Bernardino Valley; southeast of Mill Creek, individual segments of the strand have a more northwesterly trend that averages N 55° W.

Northwest of Santa Ana River the San Bernardino strand breaks surficial deposits we assign to units Qvos, Qof, and Qya; the trace is marked by scarps and lineaments, and by a steeply north-dipping fault plane and shear zone exposed in road cuts of the Santa Ana Truck Trail in the adjacent Redlands quadrangle (Matti and others, 2003). At the canyon mouth of Santa Ana River, the fault's trace is buried by young sediment of units Qvyf and Qvyw, but the fault forms scarps in surficial materials we assign to unit Qya_3. The fault's trace across Santa Ana Wash is marked by a vegetation lineament that is conspicuous on 1930-vintage aerial photographs.

Between Santa Ana River and the east boundary of the Yucaipa quadrangle, the structural setting of the San Bernardino strand becomes progressively more complex—a trend that seems to coincide with the change in average strike of the fault zone from its N 70° W average orientation to the NW and its N 55° W orientation to the SE. Northwest of this change in geometry the fault zone is simpler: to the southeast the zone is more segmented and has a tendency toward en-echelen strands.

West of the canyon mouth of Mill Creek, bedrock and surficial units are traversed by several parallel fault strands, some of which are part of the San Andreas zone; locally, these strands have north-facing scarps. None of these faults breaks youngest deposits of Mill Creek wash, but on the east side of the wash 1930-vintage aerial photographs reveal a scarp that disrupts surficial deposits we assign to unit Qyf_3. A soil-profile in this unit near the Mill Creek gauging station has attributes of soil-stage S6 or S7 of McFadden (1982) and Bull (1991), and the unit probably is middle to late Holocene in age.

Directly southeast of Mill Creek the San Bernardino strand becomes yet more complex, and is complicated by landslide masses that have been shed from Yucaipa Ridge. Between Mill

Creek and Spoor Canyon, these landslides have conspicuous crown scarps that resemble scarps created by faults, and it is difficult to differentiate between tectonic and landslide origins for the features. However, one of them is aligned with the fault scarp of the San Bernardino strand in Qyf$_3$ of Mill Creek wash, and we tentatively identify this feature and one a few hundred meters to the north as tectonic scarps associated with the fault zone. The large landslide mass directly west of the mouth of Spoor Canyon completely obscures the San Bernardino strand, and this displaced mass of Mill Creek Formation has a basal slide plane that has crushed and sheared the bedrock units. On the west wall of Spoor Canyon it is difficult to distinguish this deformation from that caused by the fault. The antiquity of the landslide masses between Spoor Canyon and Mill Creek is uncertain. Some are relatively young, but others are older dissected slides that have stabilized under current climatic and tectonic conditions. Whatever their precise age, the San Bernardino strand does not appear to have noticeably displaced them laterally. This apparent lack of displacement reflects either (1) the youthfulness of the landslides or (2) the fact that the San Bernardino strand may step left between Spoor Canyon and Mill Creek and lie mainly at the outer (southwest) margin of the landslide masses; this would require that most of the masses have not been disrupted from their place of origin on the Yucaipa Ridge block. We tentatively favor the second interpretation and depict it on the geologic map.

The left-stepping geometry of the San Bernardino strand continues southeastward to the boundary of the Yucaipa quadrangle and into the adjacent Forest Falls quadrangle (Harden and Matti, 1989, fig. 2). In plan view, the fault pattern consists of short northwest-trending fault segments that pass into east-trending fault-like scarps. The latter probably are reverse faults, but we have not confirmed this interpretation. In left-stepping right-lateral strike-slip fault zones, reverse dip-slip fault segments typically occur between en-echelen strike-slip segments (Aydin and Page, 1984; Christie-Blick and Biddle, 1985; Sylvester, 1988), and this geometry in the Yucaipa quadrangle would be compatible with the apparent left-stepping nature of the San Bernardino strand along this reach.

Directly southeast of Spoor Canyon, stream gullies and other geomorphic features have been displaced right-laterally by the northwest-trending fault segments. This evidence for youthful right-slip on the San Bernardino strand is complemented by convincing evidence for longer-term right-slip throughout the latest Pleistocene and Holocene (Harden and Matti, 1989).

In order to evaluate long-term slip rates for the San Bernardino strand, Harden and Matti (1989) examined soil profiles of Qof units in the Yucaipa and Forest Falls quadrangles that contain clast populations derived from various distinctive bedrock units that crop out on Yucaipa Ridge. During Holocene and latest Pleistocene time the San Bernardino strand has displaced these alluvial-fan units right-laterally away from their source areas. Within uncertainty limits posed by the soils data and by ambiguities in the displacement paths of the alluvial-fan deposits, Harden and Matti (1989) reached two main conclusions:

(1) Holocene slip rates on the San Bernardino strand probably are comparable to the 25 mm/yr rates proposed for the fault in the Cajon Pass region (Weldon and Sieh, 1985; McFadden and Weldon, 1987);

(2) late Pleistocene slip rates appear to be about 6 to 13 mm/yr, considerably lower than Holocene rates. These conclusions suggest that long-term slip on the San Bernardino strand has accelerated with time.

We believe that this slip-rate scenario is compatible with gradual inception of the San Bernardino strand by reactivation of the abandoned Mission Creek strand starting in late Pleistocene time, perhaps around 125,000 yr B.P. according to Matti and others (1985, 1992b; Matti and Morton, 1993).

Banning Fault

The Banning Fault is a major right-lateral strike-slip fault that was part of the San Andreas system in late Miocene time (Matti and others, 1992b; Matti and Morton, 1993). Southeast of the Yucaipa quadrangle in San Gorgonio Pass and in the El Casco quadrangle (fig. 2), the fault juxtaposes rocks of San Gabriel Mountains-type on the north against the San Timoteo beds of Frick (1921) to the south. Projected northwestward from its last outcrop in the El Casco quadrangle (fig. 2), the Banning Fault would cross the Yucaipa quadrangle approximately along the concealed trace we infer for the fault in the southwest part of the map. Along this trace we observed no evidence that the Banning fault breaks Quaternary alluvial deposits or the upper member of the San Timoteo beds of Frick (1921). Thus, we conclude that the Banning Fault has played no major role in the Quaternary structural history of the Yucaipa area.

Burnham and Dutcher (1960, p. 99-100, fig. 3) interpret relationships involving the Banning Fault somewhat differently. They (1960, p. 100) acknowledge that exposures in the Yucaipa quadrangle do not allow traces of the Banning Fault to be "...mapped with a high degree of accuracy", and they position the fault based on two lines of evidence:

(1) They use a zone of secondary calcium-carbonate accumulation (caliche) east of Live Oak Canyon to position the concealed trace of the fault: "The southern margin of these caliche beds is remarkably straight and is aligned with the westward projection of the fault trace from the [southeast in the El Casco quadrangle]. The caliche deposits occur only in the older alluvium and are believed by the authors to coincide with an area where, because of the barrier action of the Banning Fault, ground water evaporated near the land surface during late Pleistocene time." (Burnham and Dutcher, 1960, p. 100, fig. 3);

(2) They cite complicated stratigraphic and structural relations in the hills on the north side of Live Oak Canyon as a basis for identifying and locating the Banning Fault: "Northwest of Live Oak Canyon the elevated areas of Redlands Heights, Smiley Heights, and the elongate frontal ridge west of Smiley Heights across San Timoteo Canyon were uplifted along the Banning Fault, which was traced as far west as the Loma Linda fault by the presence of cemented fractures, discordant dips, and aligned troughs along the southern flanks of the uplifted areas. Everywhere in this reach the fault appears to be of the steep normal or reverse type having possible vertical displacements of several hundred feet" (Burnham and Dutcher, 1960, p. 100, fig. 3).

We agree with many of the observations by Burnham and Dutcher, although we interpret them differently.

First, we were not aware of the caliche deposits east of Live Oak Canyon. These may well have originated by the mechanism proposed by Burnham and Dutcher, and might be usable for positioning the concealed trace of the Banning Fault. Until we have examined these materials and evaluated their significance, v. 1.0 of this database places the concealed trace of the Banning Fault where inferred originally by Matti and others (1992) (slightly north of the trace inferred by Burnham and Dutcher, 1960, fig. 3).

Second, in the hills north of Live Oak Canyon (and north of San Timoteo Canyon in the adjacent Redlands quadrangle; see Matti and others, 2003) we also observed caliche-filled fractures and, especially, discordant bedding dips in areas of the upper member of the San Timoteo beds (unit QTstu). Because of poor exposures we were not able to observe the actual fault planes responsible for these discordant dips, but locations where faults probably occur invariably are associated with knickpoints and abrupt slope changes in the landscape profile. This tectonic geomorphology indicates that the faults are young enough to have influenced landscape evolution in this area. In the adjacent Redlands quadrangle the faults do not appear to break deposits we assign to unit Qvoa$_3$ (Matti and others, 2003), although they may have formed sags in which Qvoa$_3$ alluvium may have accumulated (the "aligned troughs" of Burnham and Dutcher, 1960, p. 100).

Rather than attribute faulting and resulting tectonic geomorphology on the north side of San Timoteo Canyon to the Banning Fault, Matti and others (2003) assign these structures to their Live Oak Canyon Fault zone. To attribute them to the Banning Fault seems misleading, because in the Yucaipa quadrangle and in the western San Gorgonio Pass region the Banning Fault has not played a significant role in middle and late Quaternary landscape evolution (witness difficulties in locating the fault beneath Quaternary deposits in the Calimesa and Beaumont areas; fig. 2; see Matti and others, 1992b). Moreover, faults Matti and others (2003) assign to the Live Oak Canyon complex in the Redlands quadrangle have distinctive curvilinear traces that wend their way toward the Yucaipa quadrangle, where they interact in some fashion with faults of the Crafton Hills horst-and-graben complex. This geometry seems incompatible with the regional E-W trend of the exposed and concealed Banning Fault. In short, although in the Yucaipa and Redlands quadrangles the concealed subsurface trace of the ancestral Banning Fault may play a role in localizing faults of the Live Oak Canyon zone, we prefer to assign these structures to a distinct complex of their own, having a geologic history younger than and not related to late Miocene strike-slip displacements on the ancestral Banning Fault. To a certain extent this may be a semantic issue. However, in order to better understand local fault relationships and fault history, we believe it is useful to distinguish two distinct structural domains having different names.

Crafton Hills horst-and-graben complex

In the Crafton Hills-Yucaipa Valley area, Matti and others (1985, 1992a,b) recognized a series of normal dip-slip faults that they named the Crafton Hills horst-and-graben complex. The complex consists of a series of generally northeast-trending faults that are responsible for uplifting the Crafton Hills horst and downdropping the Yucaipa Valley graben to the east and the San Bernardino Basin to the northwest (fig. 2). Faults associated with this complex in the Yucaipa quadrangle include the Reservoir Canyon Fault, the Crafton Hills Fault zone, and the Chicken Hill Fault; in the Redlands quadrangle the Redlands Fault marks the westernmost exposed strand of the horst-and-graben complex (Matti and others, 2003).

The structure and geometric pattern of the horst-and-graben complex indicates that the faults formed by normal dip-slip displacements. Focal-solution studies also indicate normal dip-slip mechanisms (Green, 1983; Jones, 1988), although a left-lateral component may be present (Nicholson and others, 1986). The existence of a normal dip-slip fault complex in a region characterized by right-lateral strike-slip faults of the San Andreas family and by contractional reverse and thrust faults of the Transverse Ranges Province seems anomalous. Matti and others (1985, 1992b; Matti and Morton, 1993; Morton and Matti, 1993) offered a solution to this paradox by proposing that normal faults of the Yucaipa-Crafton Hills area formed within an extensional domain that occupies the greater San Bernardino Basin area as the consequence of a regional right step between the San Jacinto Fault and the San Bernardino strand of the San Andreas Fault (fig. 2). This extensional domain has led to normal dip-slip faults that have downdropped the Yucaipa Valley graben and uplifted the Crafton Hills horst.

The timing of faulting in the horst-and-graben complex is known only generally. Faults bounding the Crafton Hills horst break surficial unit Qvoa$_3$ in the Live Oak Canyon and Sand Canyon areas, and are responsible for uplifting deposits of that unit and leading to their dissection. Unit Qvoa$_3$ may be as young as 500 Ka, and thus records a minimum age for Quaternary displacements within the horst-and-graben complex. We have not recognized older displacements within this complex.. Extensional faulting appears to have continued throughout the late Pleistocene and Holocene (discussed below), and influenced depositional patterns within all surficial units of that age.

Specific faults defining the horst-and-graben complex include:

Reservoir Canyon Fault

Although Burnham and Dutcher (1960, p. 113-114, fig. 3) referred to this structure as the Crafton Fault, we follow Morton (1978) who mapped it as the Reservoir Canyon Fault from relations in the Redlands quadrangle (Fig. 2). There, and in the Yucaipa quadrangle, the fault forms a distinctive scarp in alluvium we assign to unit $Qvoa_3$. Traced from the west margin of the Yucaipa quadrangle this scarp trends northeast for about a mile, then trends northward to form a questionable scarp in alluvium we assign to unit Qof_2. To the north, we infer the location of the Reservoir Canyon Fault beneath young Holocene alluvium east of Mentone, and project this inferred trace northward across the Mill Creek Wash to connect with the Greenspot Fault. Together, the two faults form the west boundary of the Crafton Hills horst, and have dropped lowlands of San Bernardino Basin down relative to the high-standing Crafton Hills.

Crafton Hills Fault zone

Matti and others (1992a) applied the name "Crafton Hills Fault zone" to a series of documented and probable, sub-parallel, northeast-trending normal faults that bound the east side of the Crafton Hills. The zone can be recognized in the southwest corner of the quadrangle north of Live Oak Canyon, and extends to the northeast end of the Crafton Hills.

In the Live Oak Canyon area, faults of the Crafton Hills zone form an en-echelon series of strands that drop the San Timoteo beds and overlying very old alluvium (units QTstu and $Qvoa_3$) down to the east. The faults are not well exposed, and we identify them mainly on the basis of (1) geomorphic evidence and (2) abrupt changes in orientation (dip and strike) of layering in unit QTstu. One fault of this complex probably formed the abrupt upgrade in US Interstate Highway 10 where the roadway climbs west out of Live Oak Canyon.

Northeast of Dunlap Acres, faults of the Crafton Hills complex form a series of confirmed and probable fault scarps that trend northeast toward Yucaipa Intermediate School. Northeast of the intersection of Sand Canyon Road and Yucaipa Boulevard, these scarps have influenced the geomorphic development of young Holocene alluvial deposits and probably reflect youthful syn-depositional tectonic displacements. The southernmost of these scarps also may reflect a break-away zone for low-angle landsliding by lateral-spread mechanisms, and on the geologic map we query this structure as a probable fault. In the Dunlop Acres area about a half mile south of these fault scarps, Burnham (1952) mapped a northeast-trending ground fissure that opened up in the Winter of 1952, but he attributed this fissure to erosion following heavy January rains that year.

For the remainder of it northeastern extent, the Crafton Hills Fault zone forms a conspicuous fault that separates crystalline rock of the Crafton Hills from downdropped alluvial deposits of Yucaipa Valley. The zone dips moderately to steeply toward the valley and locally forms a zone of hard fault gouge; one strand forms a scarp in very old alluvial deposits we assign to unit $Qvof_3$. In this vicinity, deposits of Qof_3 do not appear to be affected by the fault. The zone does not appear to extend northeast to the San Bernardino strand of the Andreas Fault, but instead interacts with normal faults of the Yucaipa graben complex.

Yucaipa graben complex

In the east-central part of the Yucaipa quadrangle, a series of discontinuous and locally arcuate fault scarps is developed in late Quaternary alluvial deposits of various ages. Many of the scarps are identifiable in the field and on all vintages of aerial photographs; other scarps, such as the arcuate features that trend from the southwesternmost corner of Section 19 into the northeasternmost corner of section 25, can be interpreted only from older-vintage (1938, 1952) aerial photographs that predate urban and agricultural development. The fault scarps have variable trends—some east-trending, others northeast-trending, some northwest-trending—but most have downdropped blocks that face inward toward Yucaipa Valley. We interpret these structures as normal faults that form the northeast termination of the Crafton Hills horst-and-graben structure, and refer to them as the "Yucaipa graben complex". We infer that eastern structures of this complex trend southwestward toward the Chicken Hill Fault, and probably are continuous with that structure.

One of the fault scarps we include within the Yucaipa graben complex is coincident with part of the Oak Glen Fault as mapped by Burnham and Dutcher (1960, fig. 3), who recognized that it forms a scarp in their older alluvium unit:

> "East of the Crafton Hills and the Chicken Hill fault [as mapped by Burnham and Dutcher], the trace of the Oak Glen fault is marked by a pronounced south-facing scarp in the older alluvium. Streams of the present drainage system have eroded this scarp near the eastern edge of the area. Near the west end, however, the scarp appears fresh and is about 30 to 40 feet high where it is crossed by Bryant Street" (Burnham and Dutcher, 1960, p. 105).

We map these fault scarps somewhat differently than did Burnham and Dutcher (1960, fig. 3), and we do not associate them with the name "Oak Glen Fault" in order to avoid confusion between our interpretations in this vicinity and those of Burnham and Dutcher. As mapped by us, the east-trending scarp that crosses Bryant Street in the SW corner of Section 19 consists of two curvilinear en-echelen segments developed mainly in alluvial-fan deposits we assign to unit Qof_3. Where it crosses Bryant Street, the western segment turns abruptly south and splays into three scarps that form the west boundary of the Yucaipa Valley graben complex. The eastern scarp segment decreases in height eastward, and appears to disappear as it approaches other scarps that we associate with the Yucaipa graben complex. Along this reach, the variability in scarp height is due partly to the fact that the scarps are developed in two different-aged alluvial-fan units: the scarp is higher where developed in unit Qof_3 but no more than about 1 m high where developed in deposits we assign to unit Qyf_3 in the SE corner of Section 19. These relations indicate that the scarp was formed by recurring fault movements, with most scarp-forming activity occurring before the deposition of mid-Holocene unit Qyf_3 but at least one scarp-forming event after the deposition of unit Qyf_3. Dutcher and Burnham (1960, fig. 3) attributed these scarp patterns to their Oak Glen Fault, and extended this fault westward toward Mill Creek Wash on the north side of the Crafton Hills. By contrast, we map faults in this area only where we can see the scarps they have produced, and to us these are restricted to the Yucaipa Valley area where they form the Yucaipa Valley graben complex.

Chicken Hill Fault

The Chicken Hill Fault has long been known from hydrogeologic studies in the Yucaipa Valley area (Burnham and Dutcher, 1960, p. 117, fig. 3). We adopt the name "Chicken Hill Fault" in this report, but revise the fault's distribution and add new information about its geologic attributes and probable extent.

As mapped by us, the Chicken Hill Fault is a northeast-trending structure whose west-side is down. The fault presumably extends southwest down Live Oak Canyon, a relation we indicate on the geologic map. In this vicinity, the Chicken Hill fault seems to be a mirror image of the Crafton Hills Fault complex to the west; the two fault zones probably account for the localization of Live Oak Canyon as a downdropped graben. In the vicinity of Interstate Highway 10 at the intersection of Oak Glen Creek and Yucaipa Creek, 1938-vintage aerial photographs reveal a geomorphic feature we interpret as a fault scarp in surficial deposits of unit Qya_5 (ground-truth evidence for the scarp has been obliterated by cut-and-fill activities related to Interstate 10). We associate this scarp with the Chicken Hill Fault, and infer relatively youthful Holocene displacements on the fault in this vicinity.

From the vicinity of Interstate Highway 10, the Chicken Hill Fault trends northeast for about 1.5 miles and forms the western edge of the bench on which the original town of Yucaipa is built. This reach is the best-known extent of the fault, and here it forms a down-to-the-west scarp in sedimentary materials we assign to the upper member of the San Timoteo beds (unit QTstu) and old alluvium we assign to unit Qoa_2.

To the northeast, in the Oak Glen and Wilson Creek washes, we interpret the continuation of the Chicken Hill Fault differently than previous workers. Burnham and Dutcher (1960, fig. 3) map the fault northward across Oak Glen Creek to connect with faults we assign to the Crafton Hills Fault zone. Although this is possible, and can be used to explain a ground-water barrier in this vicinity, it would require that the Chicken Hill Fault reverse its displacement sense from down-on-the-west (along its southern extent) to up-on-the-west (along its northern extent). By our interpretation, the northeast trend of the Chicken Hill Fault continues up Oak Glen Creek and Wilson Creek, to eventually connect with faults of the Yucaipa graben complex. By this correlation, the Chicken Hill Fault maintains its down-on-the-west geometry, allowing the Yucaipa bench to be elevated on the east and the combined Oak Glen and Wilson Creek washes to be dropped down on the west and northwest.

Age of the Crafton Hills horst-and-graben complex

Faults of the Crafton Hills horst-and-graben complex are all late Quaternary in age, and some are youthful enough to have broken Holocene surficial units. Holocene displacements are indicated in four areas:

(1) in the southwest part of the map, where a scarp and vegetation barrier on the north side of Live Oak Creek are developed in Holocene deposits of unit Qvyf;
(2) at the intersection of Live Oak Creek and Yucaipa Creek in the vicinity of Interstate Highway 10, where 1938-vintage aerial photographs reveal a geomorphic feature we interpret as a fault scarp in surficial deposits of unit Qya_5 (ground-truth evidence for the scarp has been obliterated by cut-and-fill activities related to Interstate 10);
(3) northeast of Dunlap Acres in the southwest part of the quadrangle, where a series of documented and probable scarps disrupt deposits as young as unit Qyf_3;
(4) north of Wilson Creek in the east-central part of the quadrangle, where east- and northeast-trending faults form scarps in surficial materials we assign to unit Qyf_3. Field evidence for late Holocene faulting in the Yucaipa quadrangle is consistent with seismicity patterns that show abundant microseismicity beneath the Yucaipa Valley area (Green, 1983; Nicholson and others, 1986; Jones, 1988).

Greenspot Fault

Like Burnham and Dutcher (1960, p. 107), we apply the name Greenspot Fault to a scarp-like structure of probable tectonic origin east of Santa Ana Wash that disrupts deposits we assign to units $Qvof_3$ and Qof_2. This structure is flanked ½ km to the east by a sub-parallel scarp-like feature that probably also is tectonic in origin. The Greenspot Fault appears to be a normal dip-slip structure that drops Quaternary units down to the west. The fault probably is the northward continuation of the contemporaneous Reservoir Canyon Fault, in which case the Greenspot fault would be a bounding structure of the Crafton Hills horst.

Mill Creek Thrust

We apply the name Mill Creek Thrust to a low-angle reverse fault that breaks old and young surficial deposits west of the canyon mouth of Mill Creek. The thrust forms a scarp in deposits we assign to unit Qyf_1, and traverses units $Qvof_3$ and Qof_1. The fault has been trenched by Rasmussen and Associates (1978) who documented low to moderate north dips.

The tectonic role of the Mill Creek thrust is unclear. However, it occurs in an area where the San Bernardino strand of the San Andreas Fault changes regional strike from N 55° W to N 70° W. In effect, this is a left-stepping deflection that may trigger contraction outboard (west) of the San Bernardino strand due to angular convergence between the two right-lateral segments. A clearer picture of the origin and role of the Mill Creek Thrust must await more careful mapping in its poorly exposed outcrop belt.

REFERENCES CITED

Albright, L.B., 1997, Geochronology and vertebrate paleontology of the San Timoteo Badlands, southern California: Riverside, University of California, unpublished Ph.D. thesis, 328 p.

Albright, L.B., 1999, Magnetostratigraphy and biochronology of the San Timoteo Badlands, southern California, with implications for local Pliocene-Pleistocene tectonic and depositional patterns: Geological Society of America Bulletin, v. 111, p. 1265-1293.

Allen, C.R., 1957, San Andreas fault zone in San Gorgonio Pass, southern California: Geological Society of America Bulletin, v. 68, p. 319-350.

Aydin, A., and Page, B.A., 1984, Diverse Pliocene-Quaternary tectonics in a transform environment, San Francisco Bay region, California: Geological Society of America Bulletin, v. 95, p. 1303-1317.

Barrows, A.G., Kahle, J.E., and Beeby, D.J., 1985, Earthquake hazards and tectonic history of the San Andreas Fault zone, Los Angeles County, California: California Division of Mines and Geology Open-File Report 85-10LA, 139 p., scale 1:12,000.

Barrows, A.G., Kahle, J.E., and Beeby, D.J., 1987, Earthquake hazards and tectonic history of the San Andreas Fault zone, Los Angeles County, California, *in* Hester, R.L., and Hallinger, D.E., eds., San Andreas Fault-Cajon Pass to Palmdale: Pacific Section, American Association of Petroleum Geologists, Volume and guidebook no. 59, p. 1-92.

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.

Berggren, W.A., Hilgen, F.J., Langereis, C.J., and others, 1995a, Late Neogene chronology: new perspectives in high-resolution stratigraphy: Geological Society of America Bulletin, v. 107, p. 1272-1287.

Berggren, W.A., Kent, D.V., Swisher, C.C., III, and Aubry, M-P., 1995b, A revised Cenozoic geochronology and chronostratigraphy, *in* Berggren, W.A., Kent, D.V., Aubry, M-P., and Hardenbol, J., eds., Geochronology, time scales and global stratigraphic correlation: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists, Special Publication 54, p. 129-212.

Bowen, D.Q., Richmond, G.M., Fullerton, D.S., Sibrava, V., Fulton, R.J., and Velichko, A.A., 1986, Correlation of Quaternary glaciations in the northern hemisphere, *in* Sibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary glaciations in the northern hemisphere: Quaternary Science Reviews, v. 5, p. 509-510 (plus chart).

Bowles, J.E., 1984, Physical and geotechnical properties of soils: New York, McGraw-Hill Book Company, 2nd Edition, 578 p.

Bull, W.B., 1991, Geomorphic responses to climatic change: New York, Oxford University Press, 326 p.

Burnham, W.L., 1952, A preliminary report on the Yucaipa Valley crevice: unpublished manuscript, 44 p.

Burnham, W.L., and Dutcher, L.C., 1960, Geology and ground-water hydrology of the Redlands-Beaumont area, California, with special reference to ground-water outflow: United States Department of the Interior Geological Survey—Ground Water Branch, Open-File Report, 352 p. [This important report is very difficult to obtain. A good-quality copy is archived with the San Bernardino Valley Municipal Water District, from whom copies can be obtained].

Cande, S.C., and Kent, D.V., 1995, Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic: Journal of Geophysical Research, v. 100, no. B4, p. 6093-6095.

Christie-Blick, N., and Biddle, K.T., 1985, Deformation and basin formation along strike-slip faults, *in* Biddle, K.T. and Christie-Blick, N., eds., Strike-slip deformation, basin formation, and sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 37, p. 1-34.

Crowell, J.C., 1962, Displacement along the San Andreas Fault, California: Geological Society of America Special Paper 71, 61 p.

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, unpublished M.S. Thesis, 108 p.

Dibblee, T.W., Jr., 1964, 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.

Dibblee, T.W., Jr., 1967, Geologic map of the Yucaipa quadrangle, California: U.S. Geologic Survey Open-File Report, scale 1:24,000.

Dibblee, T.W., Jr., 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.

Dibblee, T.W., Jr., 1974, Geologic map of the Redlands 15-minute quadrangle, California: U.S. Geologic Survey Open-File Report 74-1022, scale 1:62,500.

Dibblee, T.W., Jr., 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.

Dibblee, T.W., Jr., 1982, 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.

Dutcher, L.C., and Burnham, W.L., 1964, Geology and ground-water hydrology of the Mill Creek area, San Bernardino County, California: U.S. Geological Survey Open-File Report, 226 p. plus figures [revises an earlier report by the authors, released in 1960. The 1964 report is archived with the San Bernardino Valley Municipal Water District, from whom copies can be obtained].

Eckis, R., 1934, South Coastal basin investigation—Geology and ground-water storage capacity of valley fill: California Department of Water Resources Bulletin 45, 273 p.

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.

Ehlig, P.L., 1958, 1968, Causes of distribution of Pelona, Rand, and Orocopia Schist along the San Andreas and Garlock faults, *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. 294-305.

Ehlig, P.L., 1958, 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.

Ehlig, P.L., 1958, 1982, The Vincent Thrust: its nature, paleogeographic reconstruction across the San Andreas Fault, and bearing on the evolution of the Transverse 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.

Farley, Thomas, 1979, Geology of a part of northern San Gorgonio Pass, California: Los Angeles, California State University, unpublished M.S. thesis, 159 p.

Fleck, R.J., Wooden, J.L., Matti, J.C., Powell, R.E., and Miller, F.K., 1997, Geochronologic investigations in the Little San Bernardino Mountains, California: Geological Society of America Abstracts with Programs, v. 29, no. 5, p. 12-13.

Frick, C., 1921, Extinct vertebrate faunas of the Badlands of Bautista Creek and San Timoteo Canon, southern California: Berkley, 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. 14080-14088.

Gibson, R.C., 1964, Geology of a portion of the Mill Creek area, San Bernardino County, California: Riverside, University of California, unpublished 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.

Green, S.M., 1983, Seismotectonic study of the San Andreas, Mission Creek, and Banning fault system: Los Angeles, University of California, unpublished M.S. thesis, 52 p.

Harden, J.W., and Matti, J.C., 1989, Holocene and late Pleistocene slip rates on the San Andreas Fault in Yucaipa, California, using displaced alluvial-fan deposits and soil chronology: Geological Society of America Bulletin, v. 101, p. 1107-1117.

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, University of California, unpublished M.S. thesis, 163 p.

Hopkins, D.M., 1975, Time-stratigraphic nomenclature for the Holocene Epoch: Geology, v. 3, p. 10.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, N.J., 1984, The orbital theory of Pleistocene climate: support from a revised chronology of the marine ^{18}O record, *in* Berger, A., Imbrie, J., Hays, J., Kukla, G., and Saltzman, B., eds., Milankovitch and Climate, Part I: Dordrecht, Reidel Publishing Co., p.269-305.

Jackson, J.A., 1997, Glossary of geology, 4th ed.: Alexandria, Virginia, American Geological Institute, 769 p.

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., 1982, The Lowe igneous pluton, *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. 307-309.

Kendrick, K.J., 1999, Quaternary geologic evolution of the northern San Jacinto fault zone: Understanding evolving strike-slip faults through geomorphic and soil stratigraphic analysis: Riverside, University of California, unpublished Ph.D. dissertation, 301 p.

Kendrick, K.J., Morton, D.M., Wells, S.G., and Simpson, R.W., 2002, Spatial and temporal deformation along the northern San Jacinto fault, southern California; implications for slip rates: Bulletin of the Seismological Society of America, v. 92, no. 7, pp. 2782-2802.

Lundelius, E.L., Jr., Downs, T., Lindsay, E.H., Semken, H.A., Zakrewski, R.J., Churcher, C.S., Harington, C.R., Schultz, G.E., and Webb, S.D., 1987, The North American Quaternary sequence, *in* Woodburne, M.O., ed., Cenozoic mammals of North America: Geochronology and biostratigraphy: Berkeley and Los Angeles, University of California Press, p. 211-235.

Martinson, D.G., Pisias, N.G., Hays, J.D., Moore, T.C., and Shackleton, N.J., 1987, Age dating and the orbital theory of the ice ages: high resolution 0 to 300,000-year chronostratigraphy: Quaternary Research, v. 27, p. 1-29.

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., 1993, 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., and Iverson, S.R., 1983, 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., 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., Morton, D.M., Cox, B.F., Carson, S.E., and Yetter, T.J., 1992a, Geologic map of the Yucaipa 7.5' quadrangle, California: U.S. Geological Survey Open-File Report 92-446, 14 p., scale 1:24,000.

Matti, J.C., Morton, D.M. and Cox, B.F., 1992b, 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., Wooden, J.L., and Powell, R.E., 1994, Late Cretaceous plutonic and metamorphic complex in the Little San Bernardino Mountains, southern California: Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 70-71.

Matti, J.C., Morton, D.M. Cox, B.F., and Kendrick, K.J., 2003, Geologic map and digital database of the Redlands 7.5' quadrangle, San Bernardino and Riverside Counties, California, version 1.0: U.S. Geological Survey Open-File Report 03-302, scale 1:24,000.

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

McFadden, L.D., and Weldon, R.J., 1987, Rates and processes of soil development on Quaternary terraces in Cajon Pass, California: Geological Society of America Bulletin, v. 98, p. 280-293

Miller, C.F., 1977, 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, 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, F.K., and Morton, D.M., 1980, Potassium-Argon geochronology of the eastern Transverse Ranges and southern Mojave Desert, southern California: U.S. Geological Survey Professional Paper 1152, 30 p.

Miller, F.K., Matti, J.C., Brown, H.J., and Powell, R.E., 1998, Digital geologic map of the Fawnskin 7.5' quadrangle, California, version 1.0: U.S. Geological Survey Open-File Report 98-579, scale 1:24,000.

Miller, F.K., Matti, J.C., and Brown, H.J., 2000, Digital geologic map of the Butler Peak 7.5' quadrangle, California, version 1.0: U.S. Geological Survey Open-File Report 00-145, scale 1:24,000.

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., 1978, Geologic map of the Redlands 7.5' quadrangle, California: U.S. Geological Survey Open-File Report 78-21, scale 1:24,000.

Morton, D.M., 1999, compiler, Preliminary digital geologic map of the Santa Ana 30' x 60' quadrangle, Southern California, version 1.0: U.S. Geological Survey Open-File Report 99-172 (http://wrgis.wr.usgs.gov/open-file/of99-172/), scale 1:100,000.

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., 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 Matti, J.C., 2001, Geologic map of the Sunnymead 7.5' quadrangle, Riverside County, California, Version 1.0: U.S. Geological Survey Open-File Report 01-450, scale 1:24,000.

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 Miller, F.K., compilers, (in press), Preliminary Geologic Map of the San Bernardino 30' x 60' quadrangle, California, version 1.0: U.S. Geological Survey Open-File Report 03-xxx, 5 map sheets, scale 1:100,000.

Morton, D.M., Cox, B.F., and Matti, J.C. , 1980, 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., Matti, J.C., Miller, F.K., and Repenning, C.A., 1986, Pleistocene conglomerate from the San Timoteo Badlands, southern California; constraints on strike-slip displacements on the San Andreas fault: Geological Society of America Abstracts with Programs, v. 18, no. 2, p. 161.

Morton, D.M., Sadler, P.M., and Matti, J.C., 1990, Constant watershed growth and fault offset in the San Timoteo Badlands, southern California: Geological Society of America Abstracts with Programs, v. 22, no. 3, p. 70.

Nicholson, Craig, Seeber, Leonardo, Williams, Patrick, and Sykes, L.R., 1986, Seismicity and fault kinematics through the eastern Transverse Ranges, California: block rotation, strike-slip faulting and low-angle thrusts: Journal of Geophysical Research, v. 91, no. B5, p. 4891-4908.

North American Commission on Stratigraphic Nomenclature, 1983, North American stratigraphic code: American Association of Petroleum Geologists Bulletin, v. 67, no. 5, p. 841-875.

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

Phillips, F.M., Zreda, M.G., Smith, S.S., Elmore, D., Kubick, P.W., and Sharma, P., 1990, Cosmogenic chlorine-36 chronology for glacial deposits at Bloody Canyon, eastern Sierra Nevada: Science, v. 248, p. 1529-1532.

Pisias, N.G., Martinson, D.G., Moore, T.C., Jr., Shackleton, N.J., Prell, W., Hays, J., and Boden, G., 1984, High resolution stratigraphic correlation of benthic oxygen isotopic records spanning the last 300,000 years: Marine Geology, v. 56, p. 119-136.

Rasmussen, G.S., and Associates, 1978, Engineering geology investigation tentative Tract 9209, Lots 1-337, San Bernardino County, California: consulting report on file with San Bernardino County Planning Department, 29 p.

Repenning, C.A.., 1987, Biochronology of the microtine rodents of the United States, *in* Woodburne, M.O., editor, Cenozoic mammals of North America: Berkeley, University of California Press, p. 236-268.

Reynolds, R.E., and Reeder, W.A., 1986, Age and fossil assemblages of San Timoteo Formation, Riverside County, California, *in* Kooser, M.A. and Reynolds, R.E., editors, Geology around the margins of the eastern San Bernardino Mountains: Redlands, California, Publications of the Inland Geological Society, volume 1, p. 51-56.

Reynolds, R.E., and Reeder, W.A., 1991, The San Timoteo Formation, Riverside County, California: Redlands, California, San Bernardino County Museum Quarterly, v. 39, p. 44-48.

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

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., 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.

Shackleton, N.J., Berger, A., and Peltier, W.R., 1990, An alternative astronomical calibration of the lower Pleistocene timescale based on ODP site 677: Transactions of the Royal Society of Edinburgh, Earth Science, v. 81, p. 251-261.

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.

Smith, R.E., 1959, Geology of the Mill Creek area, San Bernardino County, California: Los Angeles, University of California, unpublished M.S. thesis, 95 p.

Spotila, J.A., Farley, K.A., Yule, J.D., and Reiners, P.W., 2001, Near-field transpressive deformation along the San Andreas fault zone in southern California, based on exhumation constrained by (U-Th)/He dating: Journal of Geophysical Research, v. 106, no. B12, p. 30,909-30,922

Sylvester, A.G., 1988, Strike-slip faults: Geological Society of America Bulletin, v. 100, no. 11, p. 1666-1703.

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., 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.

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.

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

Woodruff, G.A., and Brock, W.Z., 1980, Soil survey of San Bernardino County, southwestern part, California: U.S. Department of Agriculture, Soil Conservation Service, 64 p., scale 1:24,000.

Figure 1.--Index map showing location of Yucaipa quadrangle (red rectangle)

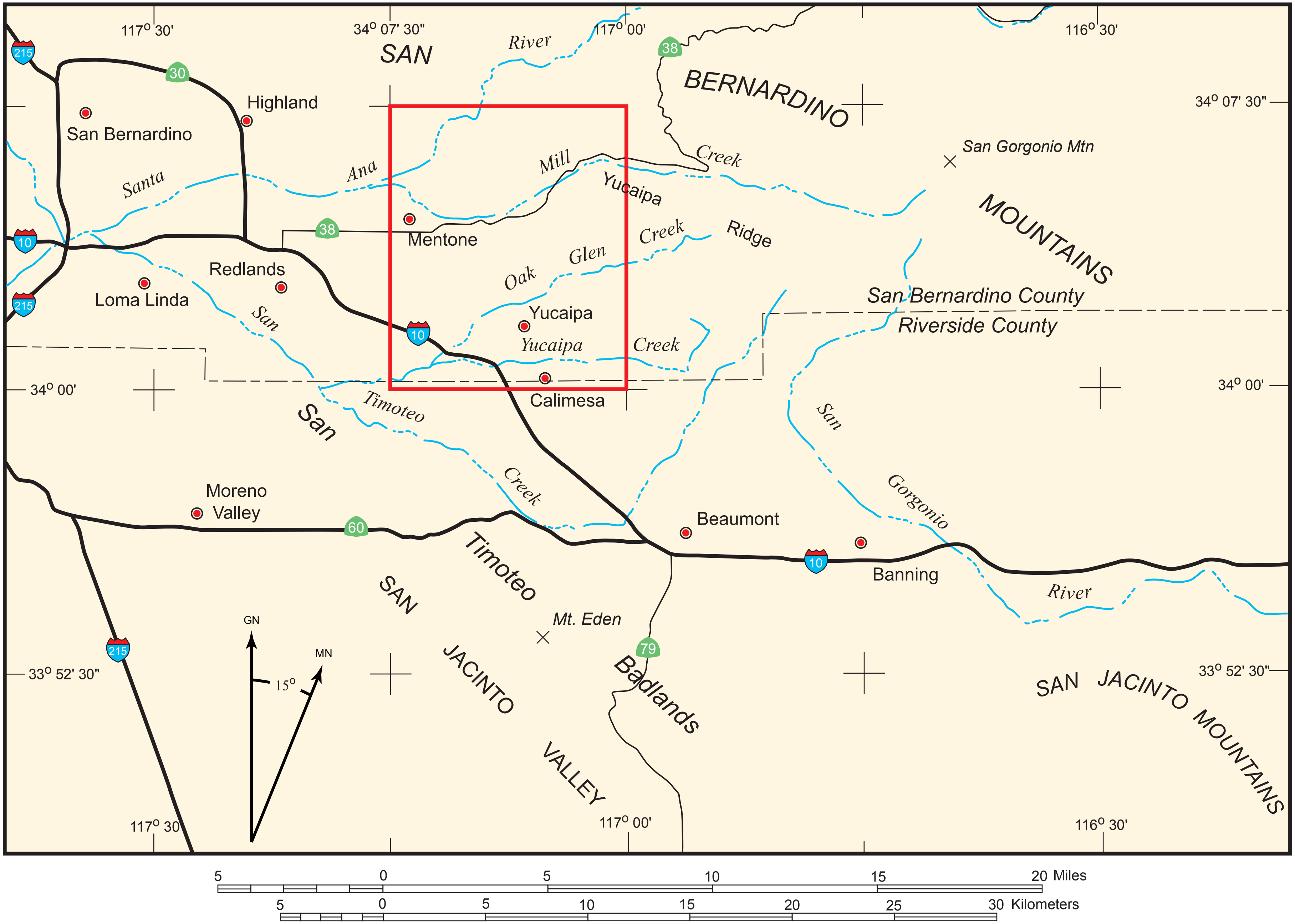
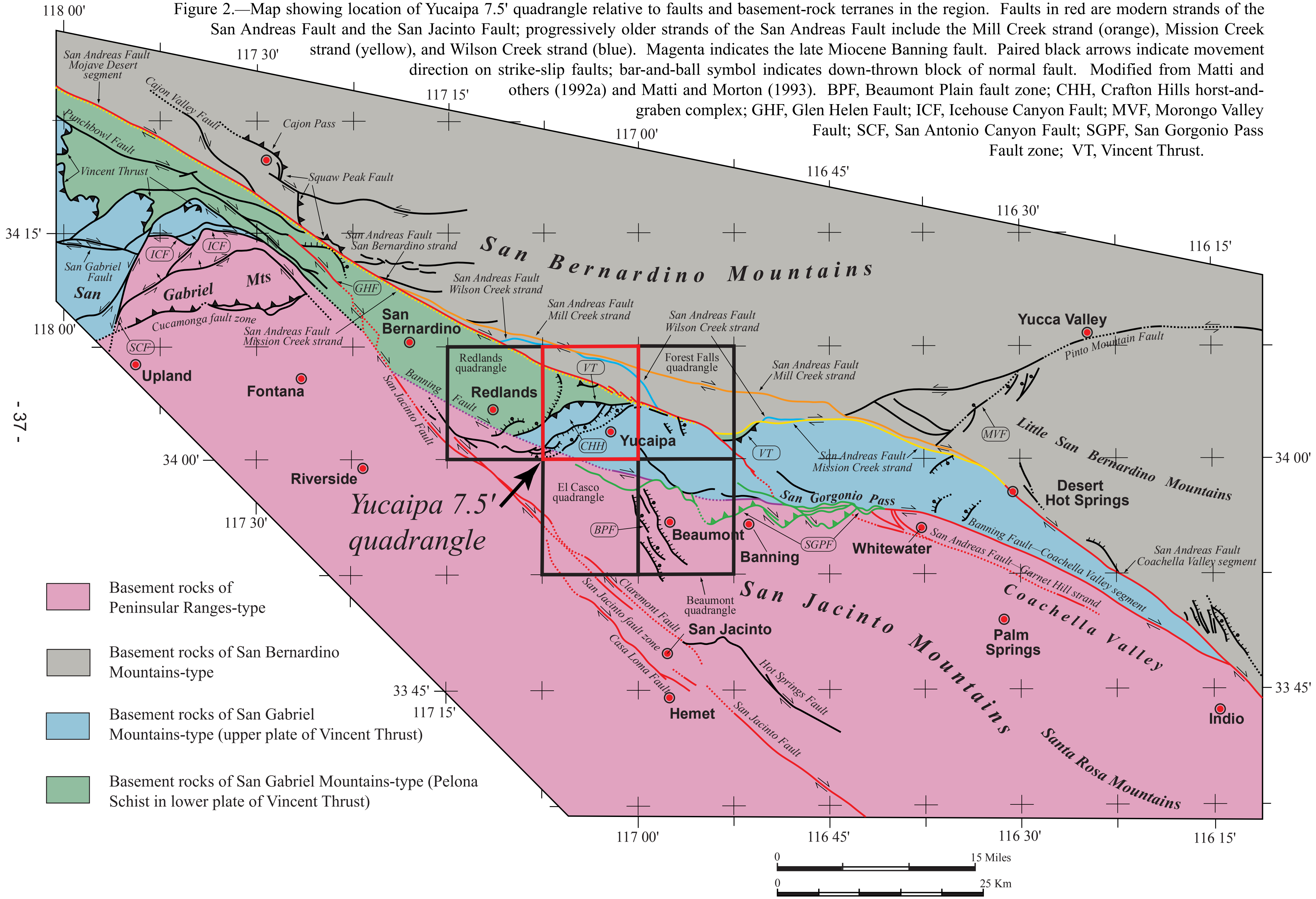


Figure 2.—Map showing location of Yucaipa 7.5' quadrangle relative to faults and basement-rock terranes in the region. Faults in red are modern strands of the San Andreas Fault and the San Jacinto Fault; progressively older strands of the San Andreas Fault include the Mill Creek strand (orange), Mission Creek strand (yellow), and Wilson Creek strand (blue). Magenta indicates the late Miocene Banning fault. Paired black arrows indicate movement direction on strike-slip faults; bar-and-ball symbol indicates down-thrown block of normal fault. Modified from Matti and others (1992a) and Matti and Morton (1993). BPF, Beaumont Plain fault zone; CHH, Crafton Hills horst-and-graben complex; GHF, Glen Helen Fault; ICF, Icehouse Canyon Fault; MVF, Morongo Valley Fault; SCF, San Antonio Canyon Fault; SGPF, San Gorgonio Pass Fault zone; VT, Vincent Thrust.



- 🟪 Basement rocks of Peninsular Ranges-type
- ⬜ Basement rocks of San Bernardino Mountains-type
- 🟦 Basement rocks of San Gabriel Mountains-type (upper plate of Vincent Thrust)
- 🟩 Basement rocks of San Gabriel Mountains-type (Pelona Schist in lower plate of Vincent Thrust)

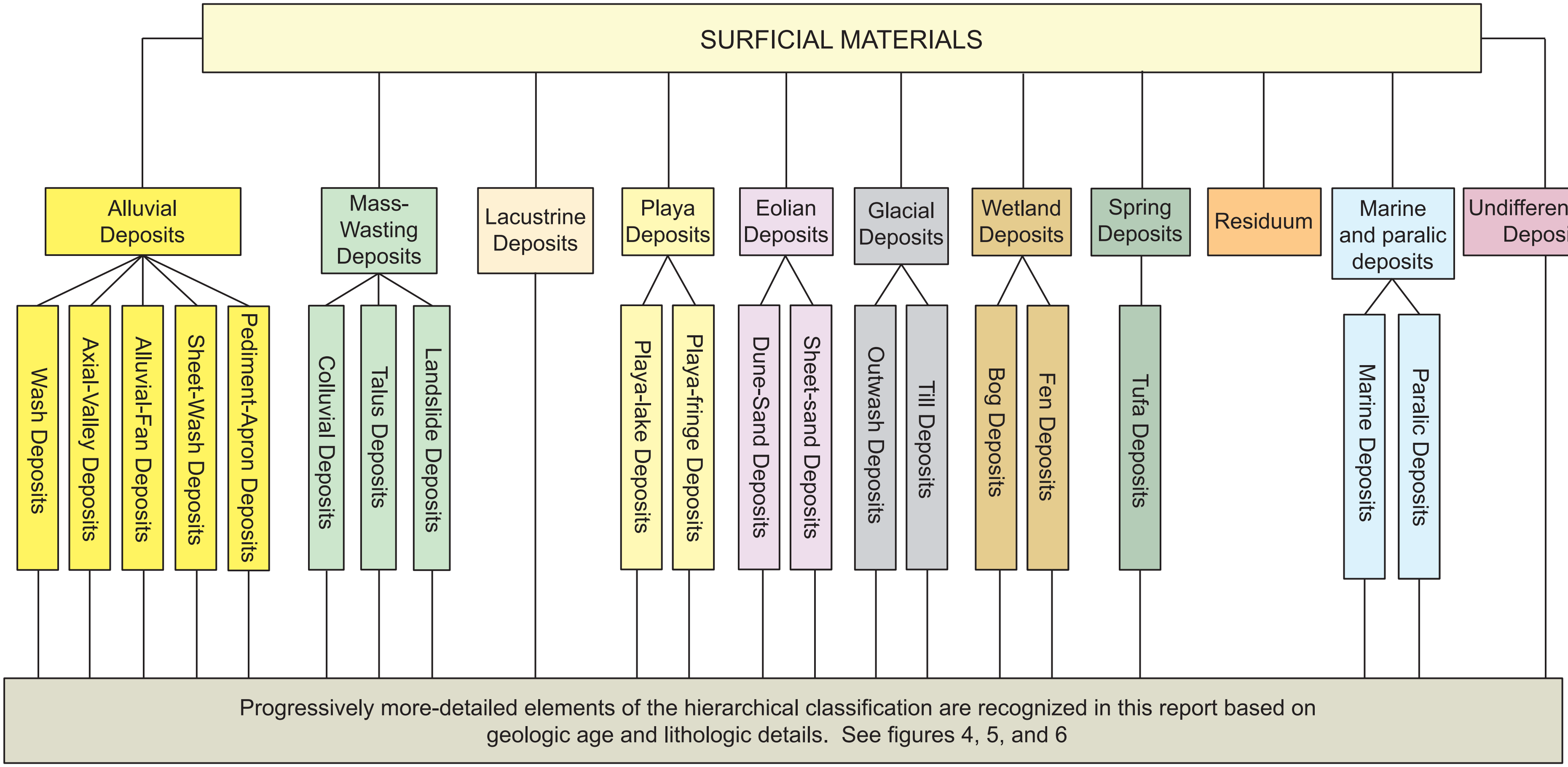


Figure 3.--Diagram illustrating hierarchical classification structure of surficial geologic-map units in the Yucaipa quadrangle, showing how physiographic setting and genesis figure into classifying and naming the units.

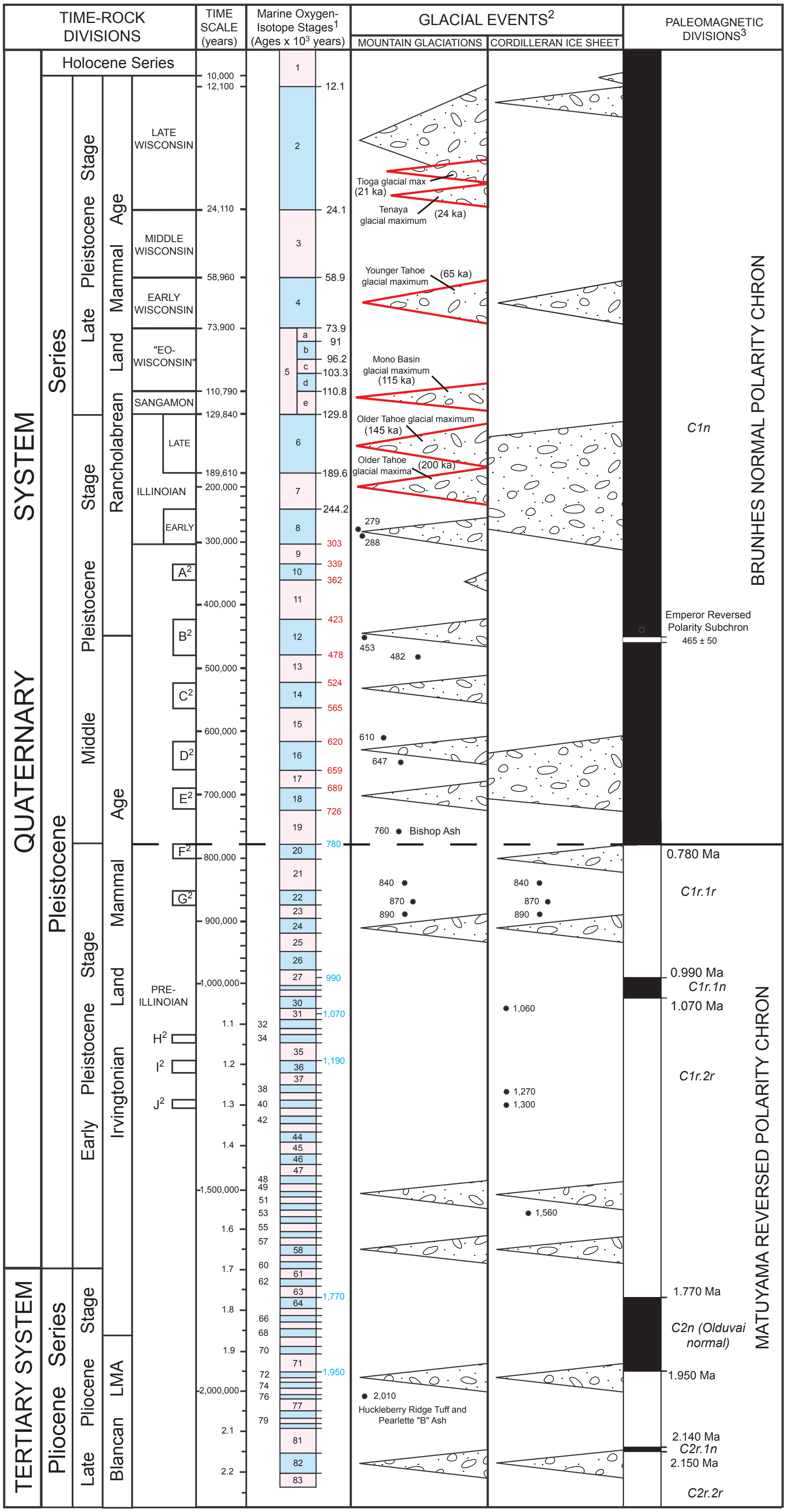


Figure 4.—Chart showing relations among Quaternary time-rock divisions, marine oxygen-isotope stages, glacial events, and paleomagnetic chronology. Figures 5 and 6 show how surficial materials in the Yucaipa quadrangle are correlated with the chronologies in this figure.

North American Land Mammal Ages adapted from Repenning (1987) and Lundelius and others (1987). North American glacial stages adapted from Bowen and others (1986). Time-rock divisions for Pleistocene Series from Berggren and others (1995a,b). Timescale is not linear: (a) for the interval dating from the present to 200,000 years before present (ybp), the span of time increments is adjusted to accommodate other information on the chart; (b) for the interval between 200,000 ybp to 1,000,000 ybp, the time increments are equal; (c) for the interval between 1,000,000 ybp and 2,300,000 ybp the time increments are equal, but not the same as (b).

[1] Marine oxygen-isotope stages adapted from several sources. (a) Stages 1 through base of 7, from Martinson and others, 1987 (black age annotations) based on orbital-tuning of results by Pisias and others (1984); (b) base of Stage 8 through base of Stage 18 from Imbrie and others, 1984 (red age annotations); (c) base of Stage 19 through base of Stage 83 interpolated by us from Figure 2 and Tables 3 and 4 of Shackleton and others, 1990 (blue age annotations from their Table 4).

[2] Sequencing of glacial events (gravel pattern) adapted from two sources. (a) Cordilleran Ice Sheet events and most mountain glaciations (including selected geochronologic age determinations) adapted and modified from Bowen and others (1986, Figure 1); (b) glaciations in the eastern Sierra Nevada Mountains along the southeast boundary of Yosemite National Park adapted from Phillips and others (1990; red outlines and geochronologic dates in parentheses).

[3] Paleomagnetic divisions adapted from Cande and Kent (1995), with age of Bruhnes-Matuyama boundary and selected Matuyama events determined by Shackleton and others (1990). Age of Emperor Reversed-polarity Subchron from Bowen and others (1986, Figure 1).

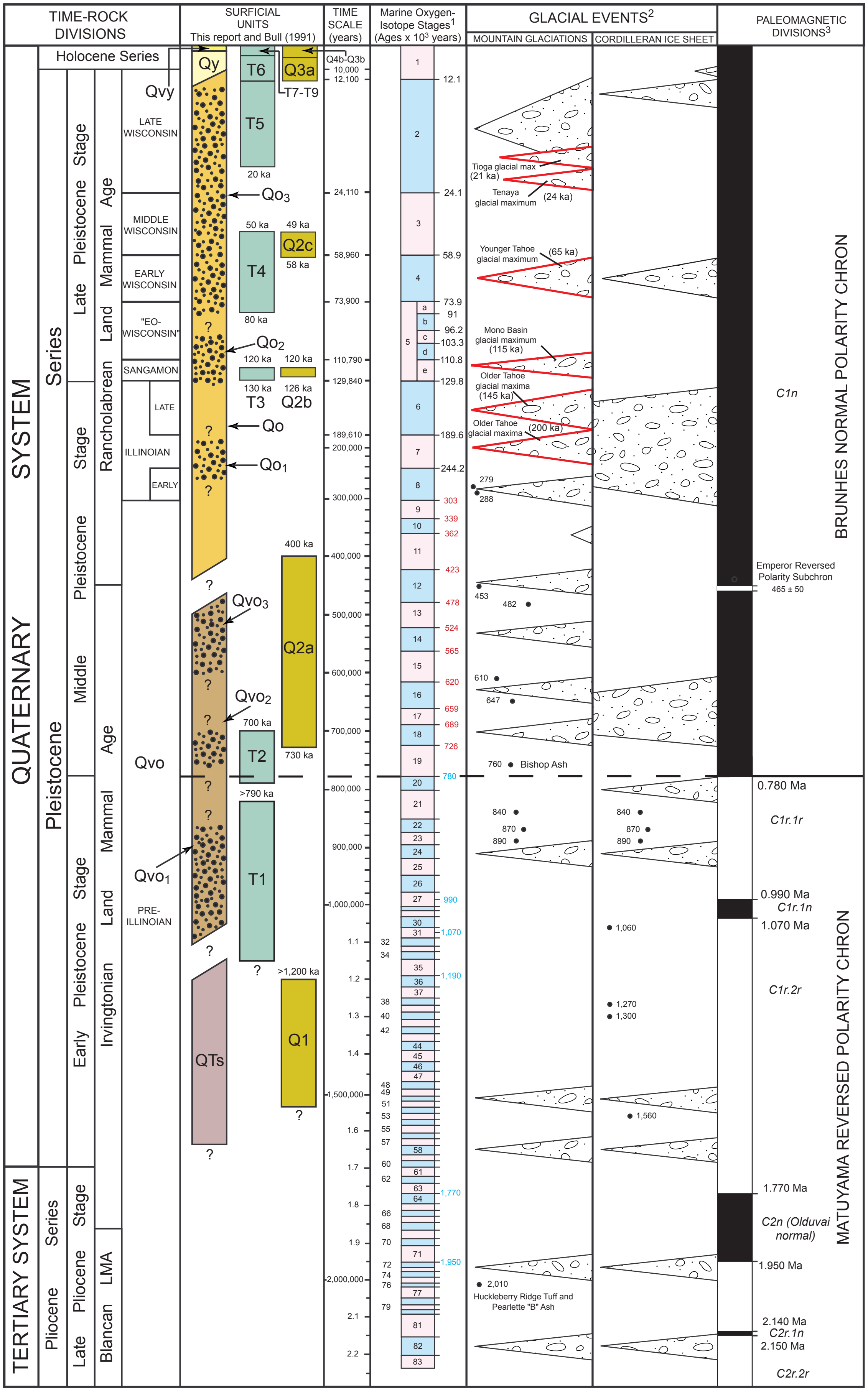


Figure 5.--Chart showing stratigraphic position of surficial geologic-map units mapped in this report (Qvy, Qy, Qo, Qvo) compared to alluvial-terrace units (T1-T9) and alluvial surfaces Q1-Q4b) defined by Bull (1991). Diagonal boundaries between Yucaipa map units indicate (a) time-transgressive nature of unit boundaries and (b) our uncertainty about the exact age of these boundaries locally.

Age ranges for alluvial-terrace units T1-T9 in the San Gabriel Mountains interpreted by us from Bull's Tables 4-1 and 6-2 and from our reading of his text (Bull, 1991, p. 232-254). Age ranges for alluvial-surfaces Q1-Q4b in the Mojave and Sonoran Deserts interpreted by us from Bull's Tables 4-1 and 6-2 and from our reading of his text (Bull, 1991, p. 232-254). See Figure 4 for explanation of Quaternary time-rock divisions, marine oxygen-isotope stages, glacial events, and paleomagnetic chronology.

Gravelly patterns within map categories of this report indicate where we currently interpret the stratigraphic position of subunits based on our mapping in the Inland Empire region. Future investigations might show the stratigraphic position of these subunits to be different than indicated in the figure; moreover, additional subunits might be recognized within the parent categories at positions for which map units currently are not identified. See Figure 6 for detailed map units within the Qy and Qvy Series.

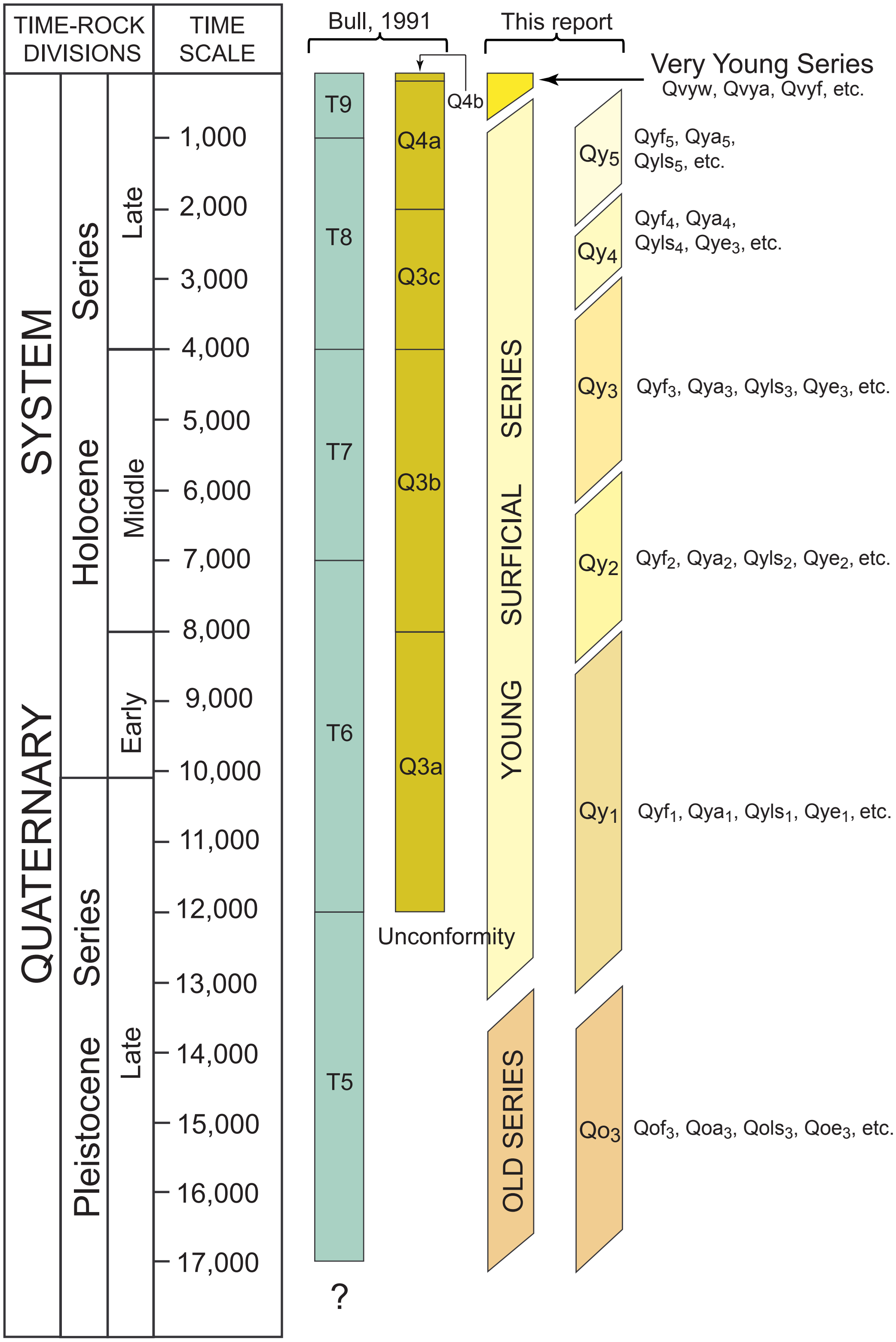


Figure 6.--Chart showing stratigraphic position of surficial geologic-map units for the latest Pleistocene and Holocene Series in the Yucaipa quadrangle; also shown are alluvial-terrace units T5-T9 and alluvial surfaces Q3a-Q4b defined by Bull (1991) in the San Gabriel Mountains and Mojave-Sonoran Deserts, respectively. Age ranges for alluvial-terrace units T5-T9 interpreted by us from Bull's Tables 4-1 and 6-2 and from our reading of his text (Bull, 1991, p. 232-254). Age ranges for alluvial-surfaces Q3a-Q4b interpreted by us from Bull's Tables 4-1 and 6-2 and from our reading of his text (Bull, 1991, p. 232-254). Time-rock divisions for Holocene Series from Hopkins (1975). Geologic timescale is linear. Diagonal boundaries between Yucaipa map units indicate (a) time-transgressive nature of unit boundaries and (b) our uncertainty about the exact age of these boundaries locally. Future investigations might show the stratigraphic position of subunits to be different than indicated in the figure; moreover, additional subunits might be recognized within the parent categories at positions for which map units currently are not identified.