U.S. DEPARTMENT OF THE INTERIOR
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PRELIMINARY GEOLOGIC DESCRIPTION OF THE SAN JOSE 30 X 60 MINUTE QUADRANGLE. CALIFORNIA

By

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INTRODUCTION

The San Jose 30 x 60 minute quadrangle (figure 1), which contains the city of San Jose near its northwest corner, straddles the central California Coast Ranges and much of the San Andreas fault system southeast of San Francisco. The quadrangle extends from near the town of Santa Cruz on the southwest (long. -122°, lat. 37°) to the San Joaquin River in the San Joaquin Valley on the northeast (long. -121°, lat. 37.5°), a diagonal distance across the structural grain of the area of just over 100 km (65 mi).

This new geologic compilation is based on extensive previous work by many authors and a great deal of new mapping, largely at a scale of 1:24,000, much of which is previously unpublished. The report remains preliminary because of the absence of structural data including attitudes and concealed faults beneath the Santa Clara and San Joaquin Valleys, the inconsistent treatment of landslides, and the need for further modification, particularly in the Quaternary of the Santa Clara Valley.

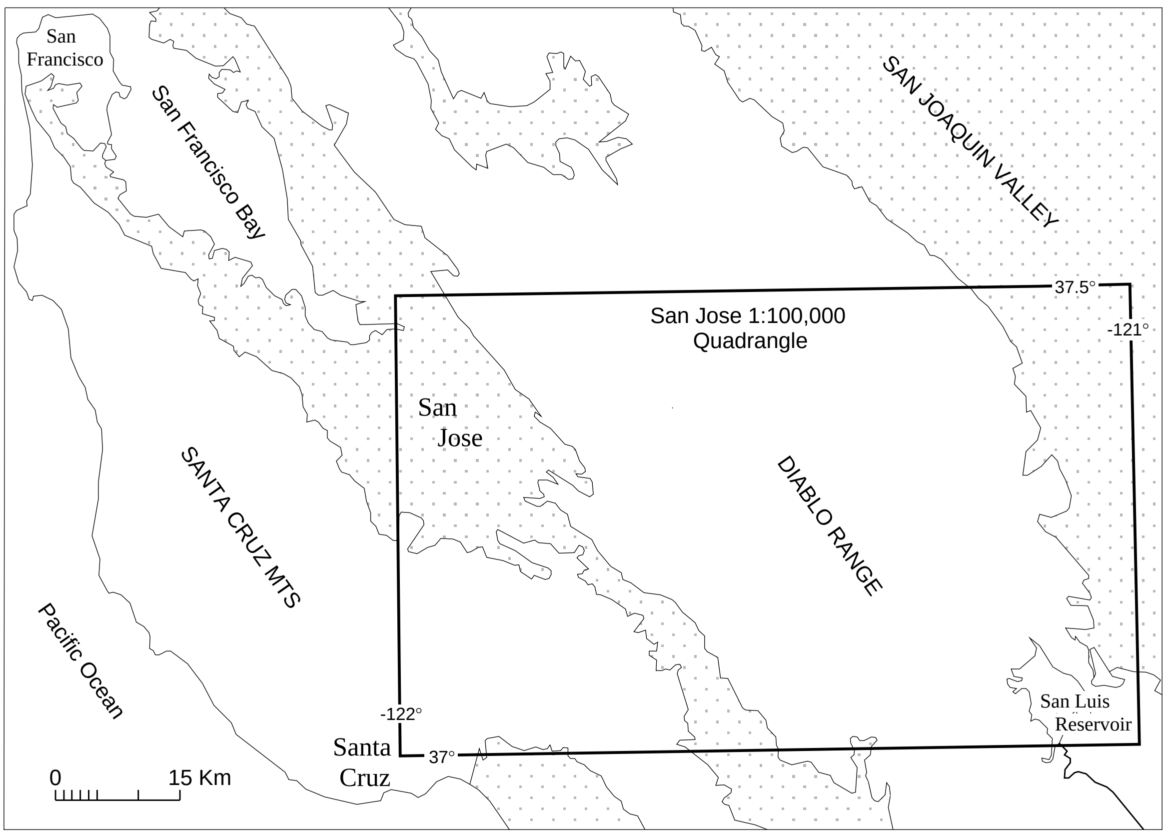

Figure 1. Location of the San Jose 60 X 30 minute, 1:100,000 quadrangle.

This report provides the geologic framework for a number of other reports about the San Jose 30 x 60 minute quadrangle, including summaries of micro- and macrofossil localities (Elder and Miller, 1990; Elder and Miller, 1993; Sliter and others, 1993), a description of new radiometric ages and tephra correlations (Nakata and others, 1993), a map of isostatic residual gravity (Chuchel and Jachens, 1990), an aeromagnetic map (Roberts and Jachens, 1993), and a delineation of landform types (Pike and others, 1992).

The geology of the map area includes large Quaternary alluvial complexes in the Santa Clara and western San Joaquin Valleys, several contrasting Cenozoic sedimentary sequences that include Miocene and Pliocene volcanics and strongly deformed Plio-Pleistocene gravels, and fundamentally different basement terranes. Southwest of the San Andreas fault in the Santa Cruz Mountains the basement consists of granitic and mafic crystalline rock, whereas northeast of the fault in the Santa Cruz Mountains, beneath the Santa Clara Valley, and in the Diablo Range the basement consists of accreted Franciscan Complex structurally overlain by Coast Range ophiolite and marine clastics of the Mesozoic Great Valley sequence. These rocks are transected by the active San Andreas fault in the Santa Cruz Mountains and the active Calaveras and Hayward faults along the southwestern border of the Diablo Range, together with numerous other young faults of the San Andreas system.

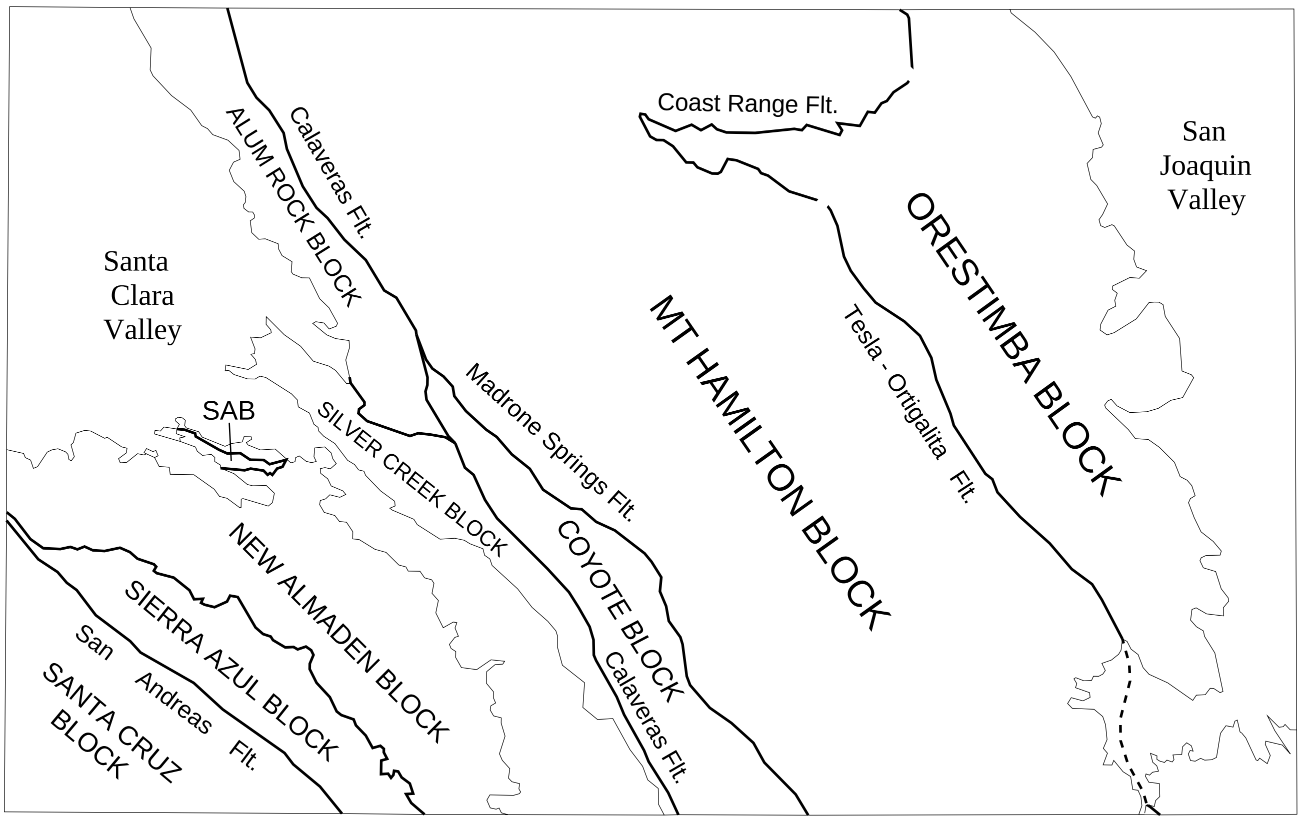

Figure 2. Major alluvial valleys, bedrock blocks, and bounding faults. SAB marks the outlier of the Sierra Azul block in the Santa Teresa Hills.

We divide the bedrock of the map area into eight structural blocks (figure 2) that are distinguished by differing stratigraphic sequences and geologic histories, and separate the Quaternary sequences of the two large alluvial valleys (Santa Clara Valley and part of the western margin of the San Joaquin Valley). The explanation of map units on the geologic map (Sheet 1), the description of the map units in this text, and the correlation diagram for bedrock units (Sheet 2) are all organized accordingly. The thirty-two 7.5-minute quadrangles composing the 1:100,000 San Jose quadrangle are shown on figure 3.

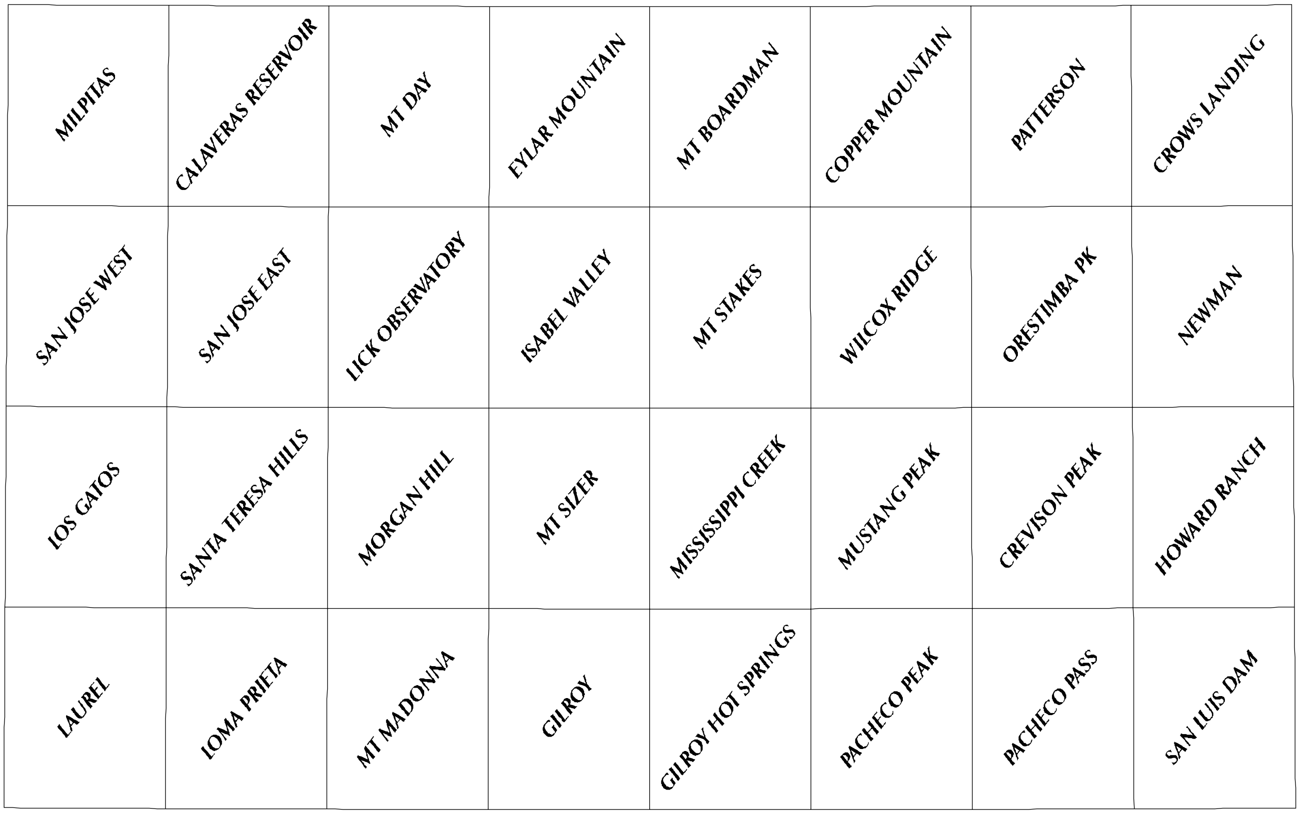

Figure 3. The thirty two 7.5-minute quadrangles composing the San Jose 30 X 60 minute quadrangle.

LANDSLIDES

Large landslides are shown on the map as integral parts of the areal geology that constitute distinctive surficial deposits and interrupt and obscure the bedrock identity and relations. For the most part only the larger landslides are shown, that is, those greater than 200-300 m across. Locally, some bedrock patches are distinguished within landslides where it is important to show the presence of the rock unit despite its displacement by sliding. The landslides are compiled variously from individual geologic sources, photointerpretive landslide mapping at 1:24,000 by T.H. Nilsen (Nilsen and others, 1975), and original photointerpretation by Wentworth from 1:80,000 areal photographs (see SOURCES). This geologic map is not a thorough or uniform statement of the distribution of landslides or a representation of landslide hazard in the map area. For such information, consult particularly the sources listed in the index to detailed landslide maps in the region assembled by Pike (1997), the comprehensive study of landslides in the San Francisco Bay region by Nilsen and others (1979), the studies of debris flows assembled by Ellen and Wieczorek (1988), the digital reports by Ellen and others (1997) on debris flows and Wentworth and others (1997) on slides and earthflows, or other more specific or detailed studies.

FAULTS

Faults are shown on the map that bound and offset bedrock units as compiled and/or modified from the various sources. Concealed faults in the interior of large areas of alluvium (such as beneath the Santa Clara Valley and San Francisco Bay) are not included, however, and the current activity of faults is not addressed. Thrust, reverse, and attenuation faults, which are common throughout the map area, are not separately indicated by symbol on the map, but are discussed in the text.

For information on active faults and fault hazards, see the comprehensive discussion of the San Andreas Fault System edited by Wallace (1990), the California State map of fault activity (Jennings, 1994), the recent compilation of earthquake sources in the San Francisco Bay region (Working Group on California Earthquake Probabilities, 1999), the 1:24,000 fault strip maps along the San Andreas and Hayward faults (Sarna-Wojcicki and others, 1975; Lienkaemper, 1992), the 1:24,000 maps of Alquist-Priolo Special Studies Zones (Hart and Bryant, 1997), or more specific or detailed studies, including various U. S. Geological Survey Professional Papers describing the Loma Prieta earthquake.

BEDROCK STRUCTURAL BLOCKS

The distinguishing structural and stratigraphic characteristics and bounding faults of the bedrock structural blocks are briefly described below in sequence from southwest to northeast (see figure 2). We begin southwest of the San Andreas fault, continue across the northeastern flank of the southern Santa Cruz Mountains and the southern Santa Clara Valley to the west flank of the Diablo Range, then cross the Diablo Range to its eastern flank adjacent to the San Joaquin Valley. The extent and geologic details of these blocks outside the map area are not addressed.

Santa Cruz Block

The southwestern corner of the map area includes a small part of the Santa Cruz block, which extends inland from the San Gregorio fault at the Pacific coast to the San Andreas fault and forms part of the Salinian terrane of coastal California. The block differs from the region northeast of the San Andreas fault in having a basement of granitic and mafic crystalline rock, rather than accreted Franciscan Complex. The Salinian and Franciscan basements have been juxtaposed by large right-lateral offset along the San Andreas fault system.

The block is bisected within the map area by the Zayante fault, southwest of which granitic and local metamorphic basement rocks of the Ben Lomond mass are exposed. Northeast of that fault, basement of mafic composition lies buried at a depth of about 6 km, based on interpretation of aeromagnetic data (Jachens and Griscom, in press). This mafic basement is considered to be a subsurface continuation of Jurassic gabbroic rocks exposed at Logan quarry a few kilometers south of the map area along the San Andreas fault (Brabb and Hanna, 1981), and has been correlated across faults of the San Andreas system with mafic basement in the Gualala block to the northwest (Jachens and others, 1998) and with mafic rocks in the western Tehachapi Mountains to the southeast (Ross, 1970).

The granitic basement within the map area is unconformably overlain by Eocene and younger marine strata (and Paleocene marine strata farther west). A more severely deformed Eocene and younger marine section is exposed northeast of the Zayante fault. No Mesozoic sedimentary rocks are exposed, in contrast to blocks northeast of the San Andreas fault, although they could exist in the subsurface. The contrasting basements and differences in stratigraphic sequences have led Brabb and others (1998) to subdivide rocks of the Santa Cruz block just west of the map area into several different stratigraphic asemblages.

The rocks between the Zayante and San Andreas faults comprise the La Honda depositional basin, which consists largely of marine strata ranging in age from Eocene (Narizian) through Pliocene. This section is particularly unusual because the Oligocene strata are largely marine. The rocks are tightly compressed into northwest-trending, southeast-plunging folds above an inferred detachment at the top of the gabbroic basement (McLaughlin and Clark, in press).

The Zayante fault in its present form is a northeast-vergent, dextral-reverse fault that dips moderately to steeply southwestward at the surface. Aeromagnetic and gravity data indicate that the fault must steepen with depth and may terminate along a southwestwardly-dipping low-angle fault at the top of the buried gabbroic basement (Jachens and Griscom, in press). Recognizable displacement has been predominantly dip-slip, with a minor component of right-lateral strike-slip indicated in its later history (McLaughlin and Clark, in press). Stratigraphic relations across the fault indicate that most vertical displacement occurred in the Oligocene to early Miocene in conjunction with marine to non-marine deposition in La Honda basin. Although the present geometry of the fault indicates a reverse fault, this pre-San Andreas offset may well have been extensional, although juxtaposition of the contrasting basements may involve large strike slip along the boundary as well.

The San Andreas fault in the map area consists of a zone of anastomosing faults as wide as 2 km, with the main bedrock boundary located at the northeast side of the zone. This fault has absorbed 127 km of the total 301-km offset attributed to the San Andreas fault in central California (Jachens and others, 1998), resulting in the juxtaposition of the mafic basement against Franciscan rocks to the northeast. The San Andreas is active and experienced offset here in both 1906 and 1989, although details of surface rupture are poorly known (1906) or largely attributable to ridge-top spreading and slope failure, rather than primary fault offset (1989) (Ponti and Wells, 1991). Younger Pleistocene and Holocene terrace deposits are tilted and cut by faults in the zone, and fault topography is evident. Very large landslides in the rift zone, some consisting of gigantic intact blocks, have slid northeastward and locally across the San Andreas fault to place rocks of the Santa Cruz block onto the Sierra Azul and New Almaden blocks.

Sierra Azul Block

The Sierra Azul block is a narrow, elongate thrust block that extends along the northeast side of the San Andreas fault and structurally overlies the New Almaden block along a now complexly modified Coast Range fault. The block consists of a thick sequence of marine Mesozoic through early Tertiary strata that is floored by ophiolite. A separate outlier of the block is located farther northeast in the Santa Teresa Hills (see fig. 2).

Local remnants of the Coast Range fault at the base of the block are marked by basal ophiolite faulted over Franciscan Complex of the New Almaden block. Attenuation faulting along the Coast Range fault here involved rocks as young as Eocene (see also Jayko and others, 1987), and Franciscan rocks were exposed by early Eocene time to shed debris into the basal sandstone of the Mount Chual section (Tcm). The Coast Range fault was greatly modified by several younger, northeast-vergent reverse faults (including the Berrocal, Sierra Azul, and Sargent faults), which trend northwestward, have unknown components of right slip, and join the boundary obliquely from both within and northeast of the block. The Sierra Azul section has been repeated at least three times by these faults.

This younger thrusting of the Sierra Azul block over Franciscan basement to the northeast partially postdates shallow-marine Miocene strata deposited on that basement, and offset of the Santa Clara Formation by the Berrocal fault indicates that northeast-bounding faults of the Sierra Azul block were active at least until the middle Pleistocene (McLaughlin and others, 1999). Post-Miocene crustal shortening across the northeast boundary of the Sierra Azul block was accomplished by oblique strike-slip. Structural data suggests that this shortening is only a few kilometers, and folds in Miocene and younger rocks northeast of the boundary define a shortening of about 20 percent (McLaughlin and Clark, in press; McLaughlin and others, 1999). Earlier contraction is evident along the northwestern reach of the Sargent fault, where thrusting was largely complete by about 10 Ma and was later overprinted by right slip associated with the San Andreas fault.

Immediately adjacent to the San Andreas fault, a long, narrow sliver of lower Miocene to lower Eocene strata is separated by another northwest-trending, northeast-vergent fault from age-overlapping but lithologically distinct strata farther northeast in the Sierra Azul block. The relation of this sliver to the remainder of the Sierra Azul block is uncertain; it may be a separate San Andreas sliver or may even have been thrust across the San Andreas from the southwest.

The Sierra Azul outlier in the Santa Teresa Hills structurally overlies Franciscan rocks of the New Almaden block in a synformal warp on the disrupted northeast flank of a major antiform in the New Almaden block, although in detail rocks of the outlier are locally interleaved with the Franciscan. The outlier shares its early history with the main Sierra Azul block. The broad warps in the older rocks are truncated by the basal early to middle Miocene unconformity, and the overlying strata contain locally derived detritus. Miocene dacitic volcanics interbedded in the Temblor Sandstone may locally intrude Eocene strata in the southwestern Santa Teresa Hills (Bailey and Everhart, 1964).

New Almaden Block

The New Almaden structural block forms the northeastern flank of the southern Santa Cruz Mountains between the Sierra Azul block and the southern Santa Clara Valley, with its northeastern boundary concealed beneath the valley and probably close to its northeastern margin. It abuts the San Andreas fault northwest of the Sierra Azul block. The block consists largely of masses of Franciscan greenstone and graywacke of the Permanente and Marin Headlands terranes that are immersed in abundant melange, all belonging to the Franciscan Central belt. These rocks, together with long seams and patches of serpentinite here considered part of the Coast Range ophiolite, have been tectonically imbricated and interleaved. Subsequently, within the last 3-5 MY, these rocks and unconformably overlying marine Miocene and nonmarine Plioene to middle-Pleistocene Santa Clara Formation were folded into a series of open to tightly-compressed folds and repeated across northeast-vergent reverse faults of the Sargent, Berrocal, and Shannon fault zones.

Much of the New Almaden block is broadly warped into a major southeast-plunging antiform cored by melange and with a structurally complex northeastern flank that extends nearly the length of the block. Northeast-southwest compression reactivated these structures probably beginning in the Pliocene and continuing at least into the late Pleistocene (< 50 Ka, McLaughlin and others, 1999). Quaternary faulting is also evident along the San Andreas fault and along faults at the boundary with the Silver Creek block on the northeast.

A 3-km-deep sedimentary basin is inferred beneath Quaternary cover across the west margin of the map area from gravity data (Roberts and Jachens, 1993). It is bounded on its southwest side by faults of the Shannon and Berrocal fault zones and overlies presumed northward continuation of New Almaden basement in the subsurface. It contains a Miocene sedimentary section that is at least 800 m thick, but that could be much thicker, based on geochemical data for Miocene oil from an old well (Stanley and others, 1996). The basin probably resulted from Miocene extension that pre-dated thrusting along the Berrocal-Shannon fault system. Dacitic volcanic rocks dated at 15.6 Ma (Nakata and others, 1993) that are interleaved in the marine Miocene section exposed nearby may be related to this extension.

Silver Creek Block

The Silver Creek block is exposed northeast of the southern Santa Clara Valley and extends from the concealed northeast boundary of the New Almaden block to the Calaveras fault. That concealed boundary is locally exposed at the narrowest part of the Valley, where Pliocene Silver Creek Gravels are faulted between serpentinite and Franciscan melange. To the north, the block is bounded on the northeast by faults of the Hayward fault system of Graymer and others (1995), including the Evergreen and Clayton faults, and to the northwest the block extends an unknown distance beneath the San Francisco Bay plain.

The block is composed of a structural duplex, the structurally lowest and highest rocks both being composite basement rocks of the Franciscan Complex and the Coast Range ophiolite. Structurally interleaved between the basement rocks are tightly folded Jurassic through Tertiary strata, including the Pliocene Silver Creek Gravels. The basement rocks were thrust over these strata along the Silver Creek thrust. The vergence of the thrust fault is uncertain, but is probably westward because of the general style of structures farther east. The thrust fault itself was subsequently folded, planed off by erosion, and overlain by the Plio-Pleistocene Packwood Gravels. The timing of this thrusting and folding occurred between the deposition of the Silver Creek Gravels, which have been dated as young as 2.6 Ma (Nakata and others, 1993), and the Packwood Gravels, which are undated where they overlap the Silver Creek thrust. The entire duplex and the overlying Packwood Gravels are deformed along the east side by both the bounding Hayward and Calaveras fault systems and internal faults such as the Thompson Creek fault (Graymer and DeVito, 1993).

In addition to its structural style, the Silver Creek block contrasts with surrounding blocks in its Tertiary stratigraphy. The locally exposed Miocene rocks in the block are quite different from the Miocene sections in the adjacent Alum Rock, Coyote, and New Almaden blocks, being composed of mica-rich sandstone and 9.3-10.5 Ma andesite and basalt instead of fossiliferous quartz-lithic sandstone, siliceous shale, and polymictic conglomerate. The large volume of Pliocene volcanic rocks is also unique to the Silver Creek block.

Alum Rock Block

The Alum Rock block is exposed between the San Francisco Bay plain and the Calaveras fault farther east, and on the south abuts the Silver Creek block across faults of the Hayward fault system of Graymer and others (1995). The western boundary beneath the Bay plain probably consists of unmapped strands of the Hayward fault system.

The block is composed of an imbricate stack of steeply east-dipping strata that are repeated by steeply-dipping, west-vergent, reverse-right-lateral faults (transpressional faults). These oblique faults form the southern part of the Hayward fault system, and their compressional component represents the transpressional cross-over of offset between the Calaveras fault and the Hayward fault together with the fault-normal compression common throughout the area. The faults in this block cut, and therefore postdate deposition of the Pleistocene and Pliocene(?) Irvington Gravels. The bounding faults on the south cut the Packwood Gravels, and some of the faults in this block show geomorphic evidence of late Quaternary offset, such as offset streams, linear valleys, and offset surficial deposits (Dibblee, 1972a,c).

Although the structural style of this block is similar to, but apparently younger than structure of the adjacent Coyote block, the stratigraphic relationships are different. The Alum Rock block consists of a stack of Jurassic to Quaternary strata that was originally deposited on Jurassic Coast Range ophiolite and associated intermediate and silicic volcanic rocks. There are no lower Tertiary rocks in the Alum Rock block in the map area, and the middle Miocene Claremont Formation unconformably overlies the Late Cretaceous Berryessa Formation along a contact that is exposed east of Milpitas. Rocks of the Berkeley-Oakland hills north of the map area lie in a structurally similar position, but are distinct in including lower Tertiary strata. Franciscan rocks are present in the Alum Rock block, but only as small fault slivers of melange.

Coyote Block

The Coyote block is bounded on the west by the Calaveras fault and on the east by the Madrone Springs fault. It pinches out northward where these faults converge in San Felipe Valley east of San Jose. The block is composed of steeply east-dipping strata that are imbricated and cut by steep, west-vergent reverse faults with an unknown component of strike-slip offset. The Calaveras fault is known to be active, but there is no evidence for offset on the interior faults more recent than late Miocene.

The rock units in the Coyote block consist of Jurassic Coast Range ophiolite and overlying Cretaceous and Tertiary strata. Although the Cretaceous strata are the same throughout the block, there are three different Tertiary sequences. In the northernmost part of the block, the Tertiary sequence consists of Eocene mudstone, middle Miocene Claremont Formation, and middle to upper Miocene Briones Formation. In the east-central part of the block, in contrast, the sequence is composed of lower to middle Miocene Temblor sandstone overlain by Claremont Formation. In the west-central and southern part of the block, the Tertiary rocks are upper Paleocene and/or lower Eocene glauconitic sandstones and mudstones. The Paleocene and/or Eocene section need not be distinct, as it could originally have been part of one or both of the others and then been separated by faulting, but the two sequences containing Miocene strata are clearly distinct. We have not tried to subdivide the Coyote block to separate these two different Tertiary sections; their near juxtaposition must result from transpressional fault offset after the middle Miocene.

Mt. Hamilton Block

The relatively large Mt. Hamilton block is bounded on the west by the Calaveras and Madrone Springs faults and on the east by the Coast Range and Tesla-Ortigalita faults. The block consists almost entirely of rocks of the Franciscan Eastern belt together with several small bodies of serpentinite that are tentatively assigned to the Coast Range ophiolite. The Franciscan rocks near the southern margin of the map area are unconformably overlain by marine Miocene sandstone and overlying basalt-rhyolite flows at the northern fringe of the Quien Sabe volcanic field, which has been dated at 9.3-11.6 Ma (Nakata and others, 1993).

Unlike the volcanic-rich rocks of the Franciscan Central belt to the west, the coherent Franciscan rocks of the Mt. Hamilton block consist largely of metagraywacke with thin, locally preserved basal chert and greenstone layers. Of equal importance in the block are interleaved zones of Franciscan melange which occur as thin slices within the metagraywacke and as thicker slabs that separate the coherent units.

Most of the coherent metagraywacke has an incipient to pronounced cleavage (textural zone TZ-2A to TZ-2B[1]) and contains high-pressure, low-temperature metamorphic minerals including pumpellyite, lawsonite, jadeitic pyroxene, and aragonite. The scarce greenstone and chert layers are also metamorphosed, and in some places contain abundant crossite or glaucophane, such that the rock has been called bluestone (Ernst, 1993b).

Detailed mapping and paleontologic studies indicate that two distinctive Franciscan terranes are present, each of which is subdivided into three subunits. The Cretaceous Burnt Hills terrane consists largely of arkosic metagraywacke, whereas the Jurassic Yolla Bolly terrane consists largely of lithic, quartzofeldspathic metagraywacke. The melanges also differ from those of the Central belt in that the

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1 Degree of development of metamorphic foliation in the Franciscan graywackes is described in terms of the textural zones of Jayko and others (1986), and is abbreviated TZ-[zone], such as TZ-1 (no fabric) and TZ-3A (schistose and segregated).

matrix metagraywacke and argillite contain blueschist-facies minerals such as lawsonite, pumpellyite, and aragonite. In the southeastern corner of the block in the map area, melange occurs along the boundaries of the three Yolla Bolly subunits. Because there is a pronounced step in metamorphic grade across each of these melanges and the increase in textural grade is structurally upward, we believe that these melanges formed after subduction and probably during Cenozoic thrusting (Blake and others, 1994; Blake and Wentworth, 1999).

Ar-Ar dating of jadeite- and lawsonite-bearing metagraywacke from the Burnt Hills terrane yields plateau ages of 82-85 Ma (Blake and Lanphere, 1992). This age for the metamorphism is very close to the fossil ages, and indicates that subduction was nearly contemporaneous with deposition. Radiometric dates of blueschist-facies rocks from the older Yolla Bolly terrane range from about 125 to 78 Ma (Lindquist and Morganthaler, 1991; Blake and Lanphere, 1992). The younger metamorphic ages are probably the result of overprinting during subduction of the Burnt Hills terrane.

Orestimba Block

The Orestimba block lies east of the Mt. Hamilton block and is separated from it by the Coast Range and Tesla-Ortigalita faults. The rocks consist of the Jurassic Coast Range ophiolite (Bailey and others, 1970; Hopson and others, 1981) overlain by Jurassic and Cretaceous Great Valley sequence, which in turn is overlain by Cenozoic sedimentary rocks and subordinate, local volcanic rocks. Although partially dismembered by faulting, the rocks of the Orestimba block form an east-dipping homocline that is overlapped on the east by nearly flat-lying Quaternary sediments.

The stratigraphy of the Coast Range ophiolite and the Great Valley sequence is very different from that of coeval rocks to the west in the Mt. Hamilton block. Whereas only serpentinized harzburgite and dunite are present in the Mt. Hamilton block, here the elements of a more complete ophiolite are present. Intrusive gabbros are cut by numerous dikes of tonalite and quartz diorite, some of which have yielded hornblende $^{40}Ar/^{39}Ar$ ages as young as 150 Ma (Evarts and others, 1992). The volcanic portion of the ophiolite is characterized by abundant sills of quartz keratophyre and greatly subordinate pillowed flows of basalt and keratophyre. The overlying Lotta Creek Formation contains many coarse-grained clastic rocks that were largely derived from a nearby andesitic volcanic arc (Hopson and others, 1981; Robertson, 1989).

Above the Lotta Creek Formation, sedimentary rocks of the Jurassic and Cretaceous Great Valley sequence contrast with metamorphic Franciscan rocks of similar age in the Mt. Hamilton block. The basal strata consist of a thin, discontinuous Jurassic Hawk Shale overlain by another thin, discontinuous, Lower Cretaceous shale unit, and these in turn are overlain by thousands of feet of shale, sandstone, and conglomerate of the Upper Cretaceous Panoche Formation. The contacts between these units have generally been considered to be disconformities (Schilling, 1962), although they could also be knife-sharp attenuation faults. Some are shown as such on the geologic map, but others show no evidence of faulting and in some instances contain intervening thin conglomerates that support the existence of local disconformities (B.F. Cox, written commun., 1996).

In contrast to the blocks to the west, the rocks of the Orestimba block probably formed not far from where they are today. This conclusion is based on the petrology of the sandstone and conglomerate (Ingersoll, 1983; Seiders, 1988; Jayko and Blake, 1993).

Structures within the Coast Range ophiolite and the lower part of the Great Valley sequence record a Late Cretaceous(?) period of attenuation faulting (Jayko and others, 1987; Harms and others, 1992), with the Coast Range fault serving as the basal detachment. This was followed in the early Tertiary by eastward underthrusting of a wedge of Franciscan rock beneath the overriding Coast Range ophiolite and Great Valley sequence (Wentworth and others, 1984; Wentworth and Zoback, 1989). The present through-going Tesla-Ortigalita fault raises the Franciscan terrane relative to the rocks to the east.

Basalt dated at 7.4-9.0 Ma (Nakata and others, 1993) was locally erupted onto the Miocene topographic surface and is preserved adjacent to San Luis Reservoir on both sides of the Tesla-Ortigalita fault. This rock contrasts with the older and more highly differentiated Quien Sabe volcanics in the core of the Diablo Range. The latest deformation along part of this complex boundary involves dextral strike-slip faulting with an offset of probably 1-6 km (Manson, 1985; Anderson and LaForge, 1990).

DESCRIPTION OF MAP UNITS

The geologic units shown on the geologic map, of which there are 140, are organized here, first, by separating the surficial deposits from the deformed bedrock and, second, by valley or bedrock block. Those surficial units that are not discriminated by valley -- either occurring in various places or in the mountains -- are included under the General heading. Deformed Plio-Quaternary gravels such as the Santa Clara Formation are included in the bedrock blocks.

General

af Artificial fill (Modern) -- principally a large sanitary land fill at the margin of San Francisco Bay in the northwest corner of the map, but also including several dams and local areas of fill.

Qhc Stream channel deposits (Holocene) -- largely unconsolidated sand and gravel along mountain streams.

Qha Alluvium (Holocene) -- unconsolidated, moderately sorted sand, gravel, and some silt and clay (modified from unit Qhac of Helley and Lajoie, 1979); located largely on low terraces along mountain stream courses.

Qls Landslide deposits (Quaternary) -- locally derived bedrock materials that range from rubble to nearly intact rock displaced downslope by slumping and sliding; only larger landslides are shown (typically with diameters greater than about 350 m or areas greater than about 0.1 km^2).

Qa Alluvium, undivided (Quaternary) -- sand, gravel, and clay of stream channel, fan, and terrace deposits undivided by age or genesis in upland areas, and including many fringing colluvial deposits.

Qc Colluvium (Quaternary) -- clay, silt, and sand, locally derived, underlying smooth, gently inclined slopes at the margins of alluvial deposits and filling broad swales and hollows; locally distinguished.

Qt Stream terrace deposits (Quaternary) -- unconsolidated, moderately to poorly sorted sand, gravel, and silt and clay; located low in the local topography along streams; locally distinguished.

Qpa Alluvium (upper Pleistocene) -- poorly consolidated, poorly sorted sand, gravel, and some silt and clay (modified from unit Qpa of Helley and Lajoie, 1979); located largely along mountain stream courses.

Qoa Older alluvium (lower-middle Pleistocene?) -- located relatively high in the local topography and/or considerably dissected; partially consolidated sand, gravel, and clay.

South flank of Santa Cruz Mountains

Qmt Marine terrace deposits (Pleistocene) -- partially consolidated, moderately well sorted, marine sand and local gravelly lenses; overlying alluvial and colluvial sand, silt, and clay, especially near the inland terrace margins.

Qar Aromas Sand (Pleistocene) -- undivided fluvial and dune deposits; mostly partially consolidated, moderately to poorly sorted clay, silt, sand, and gravel; locally moderately well-sorted dune sand; multiple paleosols.

QTn Nonmarine deposits (Pleistocene and Pliocene?) -- oxidized and partially consolidated fine-grained sand and silt; mapped locally beneath fluvial Aromas Sand.

Santa Clara Valley

PP, GP Percolation pond, gravel pit (Modern) -- excavated in or through surrounding map unit.

Qhbm Bay Mud (Holocene) -- dark colored plastic clay and silty clay, unconsolidated and water saturated, rich in organic material; locally contains beds of peat and lenses of well-sorted silt and sand; contains Holocene and (at top) modern molluscs; dated as old as 9,600 years in the Bay basin, but probably 5,000-6,000 years old and younger within the map area (Helley and others, 1979). Underlies the Bay and the salt evaporators, and thins to a presumed edge at the pre-development shoreline (Helley and Westling, 1989; Nichols and Wright, 1971).

Qhb Basin deposits (Holocene) -- dark-colored clay and very fine silty clay, rich in organic material, deposited beyond the levees and flood plains in the flood basins where stilling flood waters drop their finest sediment.

Qhfp Flood plain deposits (Holocene) -- gray, dense, sandy to silty clay, may locally contain lenses of silt and fine gravel.

Qhl Levee deposits (Holocene) -- sandy and clayey silt ranging to sandy and silty clay, loose and moderately to well sorted, coarser along Coyote Creek than along the smaller streams, generally well drained; deposited adjacent to the stream courses where spreading flood waters first slow and begin to deposit suspended sediment, thereby building natural levees that stand higher than the adjacent streams and flood plains and basins.

Qhc Stream channel deposits (Holocene) -- unconsolidated sand, silt, and gravel, poorly to well sorted, decreasing in coarseness downstream and with decreasing stream gradient, hence ranging from sand and gravel in the uplands and near fan heads to sandy silt in the lower reaches of the Santa Clara Valley streams.

Qht Stream terrace deposits (Holocene) -- largely along Coyote Creek, where strath terraces are cut in levee deposits and bear thin (1 m) deposits containing such modern artifacts as automobile tires (suggested by Helley and Wesling [1990] to have resulted from controlled hydraulic releases upstream from Coyote Dam following its closure in 1936).

Alluvial fan deposits (Holocene) -- brown gravelly sand and sandy and clayey gravel, grading upward to sandy and silty clay, moderately dense to dense, coarser near the fan heads and upstream, deposited by flooding streams where they emerge from constrained channels of the uplands; include terrace deposits within some upland valleys; merge downslope into flood plain and basin deposits. Subdivided into:

Qhf1 Younger -- morphologically distinct young fans that overlie larger Holocene or older deposits; locally distinguished.

Qhf2 Older -- The principal Holocene fans and associated terraces.

Qpf Alluvial fan deposits (Upper Pleistocene)-- tan to reddish brown gravel, clast supported, clasts typically cobble sized, clayey and sandy matrix, crudely bedded; spatial relation to depositing streams typically still evident.

Qof Alluvial fan deposits (middle to upper Pleistocene)-- tan to reddish brown gravelly and clayey sand and clayey gravel, grades upward to sandy clay, dense; typically little or no relation to modern drainages.

San Joaquin Valley and adjacent Coast Ranges

Qhc Stream channel deposits (Holocene) -- unconsolidated sand and silt. Includes:

Qhcj Channel deposits of the San Joaquin River (Holocene) -- unconsolidated sand and silt derived largely from the Sierra Nevada and characterized by mica, quartz, and feldspar.

Qhb Basin deposits of the San Joaquin River (Holocene) -- unconsolidated silt and clay of mixed Sierran and Coast Range origin; finer-grained overbank deposits located in the topographic lows adjacent to the river.

Qhlj Levee deposits of the San Joaquin River (Holocene) -- unconsolidated sand and silt of mixed Sierran and Coast Range origin; coarser-grained overbank deposits located adjacent to the active river channel.

Qhr Basin rim and distal fan deposits (Holocene) -- unconsolidated fine-grained sand, silt, and clays; located in the distal part of alluvial fan.

Qap Alluvium of Patterson (upper Holocene) -- Unconsolidated, poorly to well-sorted gravel, sand, silt, and silty clay of modern stream channels and low terraces and forming thin deposits over parts of older alluvial fans; includes spatially equivalent Holocene fan and levee deposits of Sowers and others (1993) in Crows Landing 7.5-minute quadrangle; unit is as old as 2,850 and younger than 8,230 yrs, based on radiocarbon dates from wood, charcoal, and shells; historic flooding indicates that age ranges almost to the present.

Qfc Alluvial fan complex (Holocene and upper Pleistocene) -- Undeformed, generally unweathered, and unconsolidated; poorly to moderately sorted and bedded coarse sandy gravel and gravelly coarse sand as stream terraces and valley fills and at fan heads, grading downstream to well sorted and bedded silt, clay, and fine sand on lower fans. Forms much of the main alluvial fan surface along the east front of the Diablo Range and consists of (1) in the south, upper San Luis member mapped by Lettis (1982) and, northwest of O'Neil Forebay, an area mapped by him as Qsm? but not otherwise described, (2) farther north, of his undivided San Luis and Patterson alluvium, and (3) on the north in the Crows Landing 7.5-minute quadrangle, of the alluvial fan and terrace deposits of Sowers and others (1993) not here assigned to the Patterson alluvium (Qap). Age assignments of these parts range from the lower? Holocene and uppermost Pleistocene of the upper San Luis through the lower Holocene age of Lettis' undivided unit to unmodified Holocene of the Crows Landing fans. The combined fan complex is thus best considered to be lower Holocene and uppermost Pleistocene.

Alluvium of San Luis Ranch (lower? Holocene and upper Pleistocene) -- Undeformed, generally unweathered, and unconsolidated; poorly to moderately sorted and bedded coarse sandy gravel and gravelly coarse sand as stream terraces and valley fills and at fan heads, grading downstream to well sorted and bedded silt and fine sand on lower fan. Clasts are of chert, graywacke, sandstone, and other rock types from the Diablo Range. Entrenched within alluvium of Los Banos upstream and overlying that unit downstream on the fans. Lettis (1982) estimates deposition of the two members during the intervals 7-20 and 30-60 Ka: the upper member yielded fragments of *Equus* sp. bone with a U/Th date of 16.6 Ka, the lower member overlies wood with radiocarbon dates of 31.3 and 43.8 Ka, as well as the the ~ 80 Ka top of the Los Banos alluvium, and time must be provided for formation of soils developed on the upper Los Banos and lower San Luis members.

Subdivided stratigraphically by soils and topographic position into two cut-and-fill events:

Qsu Upper member -- Here distinguished only as stream terraces and valley fills isolated from the main fan complex at the range front. The upper member as originally mapped by Lettis (1982) on the open fans as far north as Mustang Creek (middle of Howard Ranch 7.5-minute quadrangle) is here incorporated into the alluvial fan complex (Qfc).

Qsl Lower member (oldest)

Alluvium of Los Banos (upper and middle Pleistocene) -- Weathered but relatively unconsolidated, poorly bedded, poorly sorted, largely coarse sandy gravel and gravelly coarse sand; clasts are of chert, graywacke, sandstone, and other rock types from the Diablo Range; fluvial; top marked by a well-developed soil. Deposited on remnants of broad pediments along the east front of the Diablo Range and upstream as terraces along the larger creeks. Lettis (1982) estimates deposition between about 80 and 535 Ka: the upper member yielded bone fragments of late Rancholabrean (<140 Ka) *Bison* sp. and U/Th dates of 95.2 and 81.7 Ka on that bone and on tooth fragments of *Equus* sp., and the maximum age is limited by the time required for formation of the strongly developed soil over the underlying 615-Ka Corcoran Clay in the San Joaquin Valley. Subdivided stratigraphically by relative topographic position into:

Qlu Upper member (youngest)

Qlm Middle member

Qll Lower member (oldest)

Santa Cruz Block

Tp Purisima Formation (Pliocene and Upper Miocene) -- Thick-bedded to massive, locally cross-bedded, bluish-gray, fine- to medium- grained sandstone, with abundant andesitic grains, and very thick-bedded, yellowish-gray, tuffaceous and diatomaceous siltstone. Locally contains marine vertebrate and molluscan fossils indicative of neritic depths and a Pliocene age (see also Powell, 1998). In Nisene Marks State Park, the Purisima locally includes a tuff bed correlated with the late Pliocene (3.4 Ma) Nomlaki Tuff (Clark and others, 1989; McLaughlin and Clark, in press).

Tsc Santa Cruz Mudstone (Upper Miocene) -- Medium-bedded and faintly laminated, pale-yellowish-brown, siliceous organic mudstone. Benthic foraminifers from the upper part of the section indicate deposition at neritic depths and a late Miocene age (*Bolivina obliqua* zone of Clark, 1981).

Tsm Santa Margarita Sandstone (Upper Miocene) -- Very thick-bedded, yellowish-gray to white, friable, medium- to fine-grained arkosic sandstone with granitic conglomerate locally at base. Sandstone is unconformable on older units, and locally contains vertebrate and invertebrate fossils indicative of shallow-marine conditions.

Tm Monterey Formation (Middle Miocene) -- Thin- to medium-bedded, brownish-black to pale-yellowish- brown, micaceous siltstone and subsiliceous organic mudstone. *Anadara obispoana* and benthic foraminifers indicate neritic depths and a middle Miocene (Luisian) age.

Tlo Lompico Sandstone (Middle and Lower Miocene) -- Thick-bedded to massive, yellowish-gray, fine- to medium-grained arkosic sandstone, locally calcareous. Locally unit includes a thick coquina bed containing mollusk fragments and *Balanus,* together with foraminifers indicative of shallow marine conditions. Invertebrate fossils indicate a middle Miocene age. Sandstone is unconformable on older units.

Tla Lambert Shale (Lower Miocene) -- Thin- to medium-bedded and faintly laminated olive-gray organic, locally phosphatic mudstone and thin-bedded sandy siltstone with interbedded micaceous, fine-to medium-grained arkosic sandstone. Mudstone commonly contains fish scales and fragments and benthic foraminifers indicative of bathyal depths and an early Miocene (Saucesian) age (K. McDougall, written commun., 1989).

Tvq Vaqueros Sandstone and volcanic rocks (Lower Miocene and Oligocene) -- Thick-bedded to massive, yellowish-gray, fine- to coarse-grained arkosic sandstone with a thick glauconitic sandstone bed in lower part. Upper beds contain *Dosinia* and *Ostrea* biostromes indicating shallow-marine conditions. Benthic foraminifers in lower part of unit indicate bathyal depths and an early Zemorrian (Oligocene) age. Basaltic flows locally present near base of unit have been radiometrically dated at 23.7 ± 0.7 Ma (Fox and others, 1985; Turner, 1970). Locally, the Vaqueros Sandstone includes:

Tvz Zayante Sandstone (Lower Miocene and Oligocene) -- Thick- to very thick-bedded, poorly sorted, reddish muddy sandstone, greenish sandy siltstone, and cobble conglomerate with abundant granitic detritus, probably non-marine. Locally intertongues with marine beds of Vaqueros Sandstone.

Tvb Basalt, probably equivalent to basalt west of the map area dated at 23.7 Ma (Tuerner, 197; Fox and others, 1984).

San Lorenzo Formation (Oligocene and Eocene) -- Divided into:

Tsr Rices Mudstone Member -- Nodular light-gray mudstone, locally bioturbated and glauconitic. Contains fish scales and benthic foraminifers indicative of middle bathyal depths and and Oligocene (early Zemorrian) age (K. McDougall, written commun., 1989). Lower part of unit in Loma Prieta Quadrangle is massive fine- grained glauconitic arkosic sandstone containing locally abundant mollusks indicative of neritic depths and a late Eocene (Refugian) age.

Tst Twobar Shale Member -- Thin-bedded and laminated olive-gray shale with lenses and laminae of very fine arkosic sandstone. Shale contains benthic foraminifers indicative of bathyal deposition and a late Eocene (Narizian) age.

Butano Sandstone (Eocene) -- Divided into:

Tbu Sandstone and mudstone, undivided -- Upper part of unit consists of yellowish-gray, medium-bedded to massive, fine-to medium-grained arkosic sandstone with thin interbeds of olive-gray siltstone and shale. Lower part of unit consists of dark gray, thin-bedded nodular mudstone commonly with fish scales along bedding planes, with interbedded thin to thick, locally graded, arkosic sandstone. Thick bedded to massive, fine-to coarse-grained arkosic sandstone is exposed locally at base of unit. Upper part of unit contains benthic foraminifers indicative of bathyal depths and a late to middle Eocene (Narizian or older) age. Mudstone in the middle part of unit also contains planktic and benthic foraminifers indicative of bathyal depths and a probable late Eocene (Narizian) age. Mudstone overlying sandstone and conglomerate in lower part of the Butano Sandstone contains foraminifers indicative of bathyal depths and an early Eocene (Planktic Zone P8) age.

Tbc Conglomerate -- Very thick-bedded to massive, light-gray, granular, medium- to coarse-grained arkosic sandstone with thick to very thick interbeds of sandy pebble conglomerate containing granitic boulders as long as 1 m. Conglomerate locally rests on Salinian granitic basement southwest of Zayante fault. Conglomerate may be underlain between the Zayante and San Andreas faults by Paleocene strata of the Locatelli Formation (see Clark, 1981).

Kgr Granitic and Metamorphic Rocks (Cretaceous and older) -- Granitic rocks ranging in composition from granodiorite to quartz diorite (Ross and Brabb, 1973). Radiometric ages and structural data suggest that these rocks were emplaced 95-120 Ma. Locally, unit includes metamorphosed pendants and inclusions of undated pelitic schist and marble, probably correlative with the Sur Series of Trask (1926).

Sierra Azul Block

sc Silica-carbonate rock (Miocene?) -- Present locally along the Sargent and Berrocal faults, associated with hydrothermal alteration of serpentinized ultramafic rocks. Miocene age based on 10-Ma radiometric age of associated hydrothermal alteration (McLaughlin and others, 1996).

Tme Shale and sandstone of Highland Way (lower Miocene to lower Eocene) -- Hard, black, siliceous, carbonaceous marine shale and interbedded shale and arkosic sandstone. Includes beds with bathyal to abyssal foraminiferal fauna of early Eocene age (P8-P9, CP-11) in lower part and beds with late Oligocene (Zemorrian) to early Miocene (Saucesian) foraminifers in upper part. Unit is fault bounded and present only along northeast side of San Andreas fault.

Sandstone and shale of Loma Chiquita Ridge (Eocene) -- Age based on scattered foraminifer localities, and sparse molluscan fossils. Includes:

Tls Sandstone and mudstone -- Thickly to thinly bedded, locally pebbly, quartzofeldspathic and arkosic sandstone and interbedded micaceous carbonaceous mudstone. Upper part of unit locally includes thin-bedded, fissile, brown siliceous mudstone.

Tcm Mottled mudstone and sandstone of Mount Chual (lower Eocene) -- Maroon red to olive green, mottled foraminiferal mudstone, locally with glauconitic, bioclastic, conglomeratic lithic sandstone at base. Basal bioclastic sandstone includes detritus from Franciscan Complex and Coast Range ophiolite. Strongly cemented bioclastic beds in the Santa Teresa Hills were mapped as limestone (Bailey and Everhart, 1964). The bioclastic debris includes transported fragmental, shallow marine macrofossils and large Discocyclinnid foraminifers. The overlying mottled mudstone contains a deep marine foraminiferal fauna (bathyal to abyssal) of early Eocene age (P8-P9). Mottled mudstone is overlain by quartzo-feldspathic sandstone and interbedded carbonaceous green to brown mudstone.

Great Valley sequence (Cretaceous and Jurassic)

Kus Sandstone and shale (Upper Cretaceous) -- Arkosic to feldspathic wacke, lithic, laumontized, locally massive or rhythmically interbedded with dark gray to green shale. Upper part of sandstone and shale unit is massive shale with carbonate concretions locally containing macrofossils of Late Cretaceous (Campanian) age (Elder, 1990). Lower and middle parts of unit locally include:

Kuc Conglomerate (Upper Cretaceous) -- Massive to thick-bedded, pebble to boulder conglomerate, composed predominantly of well rounded clasts of mafic to intermediate porphyritic volcanic and intrusive rocks and granitic to gabbroic plutonic rocks. Conglomerate beds locally contain a Late Cretaceous (Campanian) macrofossil assemblage (Elder, 1990).

KJs Mudstone (Lower Cretaceous and Upper Jurassic) -- Dark gray to green, locally siliceous, laumontized argillite and mudstone and minor thinly interbedded lithic arkosic wacke with minor carbonate concretions. Locally includes up to 60 m of angular mafic-clast breccia and altered tuff on south flank of Mount Umunhum. Mudstone commonly contains macrofossils (mostly *Buchia*) of Early Cretaceous (Valanginian) to Late Jurassic (Tithonian) age. Tuffaceous chert in lower beds contains a Late Jurassic radiolarian fauna. Serpentinitic mudstone and sandstone containing Tithonian megafossils (Elder and Miller, 1993) in the Santa Teresa outlier north of Calero Reservoir is embedded in serpentinite together with interleaving fault slices of Franciscan melange. This clastic serpentinitic rock is here considered part of the lowermost Great Valley sequence like other detrital serpentinites in that stratigraphic position in the Coast Ranges, in contrast to earlier assignments to the Franciscan (Bailey and Everhart, 1964; Elder and Miller, 1993).

Jsl Slate of Loma Prieta Peak (Jurassic?) -- Slaty to phyllitic rocks locally exposed along thrust fault on northwest side of Loma Prieta Peak. Unit includes siliceous, tuffaceous metasedimentary rocks with minor metaconglomerate having flattened clasts of metachert, quartzite, metatuff, and porphyritic granite. Slate is metamorphosed to low greenschist facies, lacks high-pressure metamorphic minerals, and resembles Jurassic metaclastic rocks in the western foothills of the Sierra Nevada.

Coast Range Ophiolite (Jurassic)

Jbk Basalt, andesite, and quartz keratophyre (Upper to Middle Jurassic) -- Consists from top to base of quartz-keratophyre breccia, banded tuff, and dacitic to basaltic flows and breccias. Radiolarians in tuffaceous chert in upper part of sequence indicate Upper Jurassic (Oxfordian) to Middle Jurassic or older age (Murchey, oral commun., 1993; Sliter and others, 1993), and the underlying volcanics are thus Middle Jurassic or older.

Jic Intrusive complex (Upper Jurassic?) -- Dioritic to diabasic dikes and sills, locally including pegmatitic hornblende-albite dikes and dikelets with radiometric age (Pb/U-zircon) ≥ 168 Ma (J. Wooden, written commun., 1992).

Jdw Cumulate rocks -- Layered gabbroic through ultramafic rocks with cumulate textures, including wehrlite and dunite; partially to extensively serpentinized.

New Almaden Block

QTsc Santa Clara Formation (Pleistocene and Pliocene) -- Fluvial boulder to pebble gravel, sandstone, and siltstone, and minor thin-bedded lacustrine mudstone, locally with abundant plant fossils and woody debris. Lower beds locally include fresh water oysters, clams, and gastropods, plant fossils, and vertebrate fossils of Late Pliocene (Blancan) age (Sorg and McLaughlin, 1975; Adam and others, 1982). Upper beds locally include the Rockland ash, dated at 0.4-0.6 Ma (Sarna-Wojcicki and others, 1991; Lanphere and others, 1999). The age range of the Santa Clara Formation overlaps that of the Silver Creek Gravels, the Packwood Gravels, and the Irvington Gravels northeast of the Santa Clara Valley.

sc Silica Carbonate rock (Miocene?) -- Siliceous and calcareous sinter deposits resulting from hydrothermal alteration of serpentinite; widely distributed in the area, especially associated with mercury mineralization in the New Almaden mining district. Miocene age of the silica carbonate is inferred from radiometrically dated volcanic rocks nearby and hydrothermal K-feldspar from mineralized areas (McLaughlin and others, 1996).

Tms Monterey Shale (Middle to Lower Miocene) -- Predominantly siliceous mudstone, diatomite, and porcellanite. Siliceous and diatomaceous mudstones contain foraminifers of middle Miocene (Luisian) age in northwestern exposures. At the southeastern end of exposures in the vicinity of Morgan Hill and Gilroy, contains foraminifers of early Miocene (Saucesian) age, suggesting marine transgression from southeast to northwest, and an overlap in age with the underlying Temblor Sandstone. The Monterey Shale locally includes:

Tus Sandstone -- Quartzofeldspathic sandstone or lithic arkose, present in upper part of the unit.

Tts Temblor Sandstone (Middle Miocene to Oligocene?) -- Pebbly, lithic arkosic sandstone, fossiliferous conglomerate, and bioclastic grit. Mudstone in lower part of unit locally contains foraminifers of late Oligocene (Zemorrian) age. Locally includes:

Ttv Dacitic volcanic and intrusive rocks (middle Miocene) -- in the upper part of the Temblor Sandstone; radiometrically dated at 15.6 Ma (Nakata and others, 1993) and equivalent to the Luisian benthic foraminiferal stage of the Middle Miocene.

Jsp Serpentinized ultramafic rocks (Jurassic) -- includes serpentinized harzburgite, dunite, and peridotite. Individual bodies typically are interleaved with Franciscan rocks and could be either Coast Range ophiolite or Franciscan basement. Although the protolith is Jurassic, some of the serpentinization is much younger, and some may still be underway (Barnes and O’Neil, 1969).

CENTRAL BELT, FRANCISCAN COMPLEX (CRETACEOUS AND JURASSIC)

fm Melange (Lower Tertiary? and Upper Cretaceous) -- Melange of the Central belt, with a matrix that consists of penetratively sheared argillite and lithic metasandstone, metamorphosed to pumpellyite- and, locally, lawsonite-bearing assemblages. Metasandstone of matrix locally exhibits a moderate cataclastic fabric (TZ-2A). Melange may contain blocks of high grade blueschist, amphibolite, chert, or mafic igneous rocks. Blocks of blueschist consist of glaucophane-, lawsonite-, and (or) jadeite-bearing schist, locally containing garnet. Amphibolite blocks consist of hornblende-bearing, foliate metamorphic rocks, largely of mafic composition, that also locally contain garnet. Hornblende in amphibolite blocks may be partially retrograded to sodic amphibole. Blueschist and amphibolite blocks commonly are sheared, subround to oblate, and may have external rinds composed of fine- to coarse-grained actinolite, talc, and antigorite, suggesting tectonic transport in serpentinite. Premetamorphic protoliths of blueschist blocks include eclogite, basalt, siliceous tuff, and tuffaceous metasedimentary rocks. Radiometric ages from elsewhere in Coast Ranges indicate Middle to Late Jurassic metamorphic ages (150-170 Ma) for these rocks. Blocks of chert are red, white or green, radiolarian-bearing, and locally tuffaceous. Chert may be locally foliated and contain blueschist metamorphic minerals, including lawsonite, sodic amphibole, jadeitic pyroxene, and stilpnomelane.

Metavolcanic rocks of Bailey and Everhart (1964) that are not assigned to the Permanente or Marin Headlands terranes are shown as greenstone (gs) blocks in melange.

In each of the structural blocks where melange occurs, its age is limited by the age of the youngest rocks incorporated in the melange. In most cases the resultant time of formation of the melange is younger than Middle to Late Cretaceous, and may extend into the early Tertiary.

Permanente terrane (Cretaceous) -- Divided into:

fpl Foraminiferal Limestone (Upper to Lower Cretaceous) -- Pelagic gray to pink foraminiferal limestone and minor intercalated black to red radiolarian chert. Foraminifer assemblages indicate that limestone formed at equatorial latitudes between Late Cretaceous (Turonian) and late Lower Cretaceous (Barremian) (Sliter and others, 1991).

fpv Basaltic volcanic rocks (Lower Cretaceous) -- Pillowed basalt flows and flow breccias, locally with siliceous tuff near top of sequence (notably near Uvas Reservoir). $^{87}Sr/^{86}Sr$ values and geochemical data (McLaughlin and others, 1991, 1996) suggest a late Early Cretaceous age (135-120 Ma) and an oceanic plateau or seamount origin.

Marin Headlands terrane (Cretaceous and Jurassic) -- Divided into:

fms Graywacke (Lower Cretaceous) -- Coherent, bedded, locally conglomeratic, lithic graywacke sandstone with conspicuous chert and volcanic detritus. Locally includes areas of melange and pebbly to bouldery mudstone. Age is younger than late Early Cretaceous (Hauterivian), based on radiolarians in chert clasts in conglomeratic beds. Sandstone is weakly reconstituted (TZ-1, and locally to TZ-2A) and commonly contains incipient pumpellyite. Radiolarian chert and basalt locally present at base.

fmc Radiolarian chert (Lower Cretaceous to Lower Jurassic) -- Red to green radiolarian chert. Radiolarian faunas indicate an Early Jurassic (Pliensbachian) to Early Cretaceous (Valanginian or younger) age for large tectonic blocks of chert (Hagstrum and Murchey, 1993). Olistoliths and pebbly chert detritus in mudstones and in associated melange contain radiolarian faunas of Late Jurassic (Tithonian) to Early Cretaceous (Hauterivian) age (McLaughlin and others, 1991; Sliter and others, 1993).

fmv Basaltic volcanic rocks (Lower Jurassic) -- Basaltic flows, massive to pillowed, locally vesicular, with minor tuff and pillow breccia. Geochemistry suggests a mid-ocean ridge (MORB) or an off-ridge origin. Age is late Early Jurassic (Pliensbachian) or older, based on age of overlying radiolarian cherts.

Silver Creek Block

QTp Packwood Gravels of Crittenden (1951) (Pleistocene? and Pliocene) -- Generally consists of gravel rarely as coarse as cobbles, silty and fine sandy conglomerate, fine silty sandstone, gravely to fine sandy siltstone, and minor olive-green claystone beds. Numerous nonmarine red mudstone beds are noteworthy. Differs from other gravels in the map area in having clasts composed almost entirely of detritus from conglomerate and sandstone of the Cretaceous Great Valley sequence. Base is interbedded and coeval with the Silver Creek Gravels (M. Wills and D. Andersen, California State Univ. San Jose, personal comm., 1995), but the top is younger, as it postdates and overlaps the Silver Creek thrust, which postdates the deposition of the Silver Creek Gravels.

Tsg Silver Creek Gravels of Graymer and DeVito (1993) (Pliocene) -- Interbedded conglomerate, sandstone, siltstone, tuffaceous sediment, tuff, and basalt. This unit is distinguished from other gravels in the map area by the presence of interbedded volcanic rocks and interbeds of nonmarine green and red mudstone, by its relatively well consolidated nature, and by its clast composition: about 75% Franciscan rocks and 25% volcanic rocks, Claremont chert, and other Cenozoic rocks. An interbedded basalt has been dated at 2.6 Ma (Nakata and others, 1993), and an interbedded tuff in Silver Creek Valley has been dated at about 3 to 4 Ma (M. Wills, California State. Univ. San Jose, personal comm., 1995). The base is nowhere exposed, and the section terminates upward at the Silver Creek thrust.

Tba Basalt of Anderson and Coyote Reservoirs (Pliocene) -- Pyroclastic andesite and alkali olivine basalt flows. The basalt contains mafic and ultramafic xenoliths (Nakata, 1980; Wilshire and others, 1988; Jové, 1992). K/Ar dating indicates two periods of volcanism that cluster around 2.5 and 3.6 Ma (Nakata and others, 1993).

Tvo Andesite of Silver Creek (Miocene) -- Andesite and basalt dikes and flows, interbedded with tuff. K/Ar dating has yielded ages of 10.5 and 9.3 Ma from an andesite dike in the unit (Nakata and others, 1993). This unit overlies the sandstone of Silver Creek (Tso) and, like that unit, crops out only in a small area in Silver Creek valley in the southeast part of the San Jose East 7.5-minute quadrangle.

Tso Sandstone of Silver Creek (Miocene). Biotite-rich sandstone containing a thin layer of peat near the top. Also contains a thin layer of silicic tuff, which has yielded a K/Ar age of 13.9 Ma (Nakata and others, 1993). Overlain by the andesite of Silver Creek (Tvo) and, like that unit, crops out only in a small area in Silver Creek Valley in the southeast part of the San Jose East 7.5-minute quadrangle.

sc Silica-carbonate rock (Miocene?) -- Product of hydrothermal alteration of serpentinite; especially prominent along the fault contact between serpentinite and Franciscan melange.

KJk Knoxville Formation (Lower Cretaceous and Upper Jurassic) -- Mainly dark, greenish-gray silt or clay shale with thin sandstone interbeds. Locally includes thick pebble to cobble conglomerate beds in its lower part. Locally at the base includes beds of angular, volcanoclastic breccia derived from underlying ophiolite and silicic volcanic rocks. In the Silver Creek block, the Knoxville contains fossils (*Buchia*) of late Jurassic (Tithonian) and late Jurassic to early Cretaceous (Oxfordian to Valanginian) age.

Coast Range Ophiolite (Jurassic)

Jsp Serpentinite -- Mainly sheared serpentinite, but also includes massive serpentinized harzburgite. Although the protolith is Jurassic, some of the serpentinization is much younger, and some may still be underway (Barnes and O'Neil, 1969).

CENTRAL? BELT, FRANCISCAN COMPLEX

fm Melange (Lower Tertiary? and Upper Cretaceous) -- Sheared black argillite, graywacke, and metagraywacke containing blocks and slabs of metagraywacke and shale (mw), chert and metachert (ch), serpentinite (sp), greenstone (gs), amphibolite, tuff, eclogite, quartz schist, greenschist, basalt, marble, conglomerate, and blueschist (bl). Blocks range in length from a few millimeters to several hundred meters. Only some of the largest blocks and slabs are distinguished on the map.

In each of the blocks where melange occurs, its age is limited by the age of the youngest rocks incorporated in the melange. In most cases the resultant time of formation of the melange is younger than Middle to Late Cretaceous, and may extend into the early Tertiary.

Coyote Block

sc Silica-carbonate rock (Miocene?)

Tbr Briones Formation (upper Miocene) -- The basal part consists of distinctly bedded, gray to white, fine-grained sandstone and siltstone. Sandstone beds are as thin as 5 to 10 cm, with 2- to 10-cm-thick shale interbeds. These are interbedded with massive, fine-grained sandstone beds as thick as five meters. The middle part consists of indistinctly bedded, white, fine- to coarse-grained sandstone, conglomeratic sandstone, and massive shell-hash conglomerate (shell beds). Shell-hash conglomerate is made up of interlocking mollusk and barnacle shells and shell fragments in a white, calcareous sandstone matrix. The upper portion consists of distinctly to indistinctly bedded, massive to cross-bedded, fine- to coarse-grained white sandstone. For the most part the Briones Formation unconformably overlies the Claremont Formation.

Tcc Claremont Formation (upper to middle Miocene) -- Chert and siliceous shale. Chert occurs as distinct, massive to laminated, gray or brown beds as thick as 10 cm with thin shale partings. Siliceous shale is dark brown to gray, finely laminated, with grains as large as silt. Some of the shale contains abundant foraminifers and fish scales. The shale also contains prominent interbedded lenses as long as one meter of massive, tan, foraminifer-bearing dolomite that weathers to a distinctive yellowish orange color. Light brown, gray, and white, fine-grained quartz sandstone and siltstone are locally present.

Tts Temblor Sandstone (middle to lower Miocene) -- Thickly and indistinctly bedded, olive, fine- to coarse-grained sandstone and pebble conglomerate. Vertebrate and invertebrate fossils of middle Miocene age are common.

Tbm Brown-weathering mudstone (Eocene) -- Brown and green weathering, brown and gray, foraminifer-bearing mudstone, locally interbedded with brown and gray, fine-grained, quartz-lithic sandstone. One outcrop in the Morgan Hill 7.5-minute quadrangle also contains coarse-grained, glauconitic sandstone. This unit has yielded foraminifers of middle Eocene age.

Tgs Glauconitic sandstone and red mudstone (lower Eocene and/or upper Paleocene) -- Coarse-grained, green and black, glauconitic-lithic sandstone interbedded with pink-brown siliceous mudstone with zones rich in coarse glauconite grains; brown, thin-bedded, siliceous shale; light brown, mica-rich siltstone with much plant debris; clean, white, quartz sandstone; and foraminifer-rich olive-gray, green, and red mudstone. This unit has yielded foraminifers of late Paleocene and/or early Eocene age.

Kcu Sandstone, mudstone, and conglomerate (Cretaceous) -- Indistinctly bedded, massive, fine- to coarse-grained, biotite-lithic wacke interbedded with dark brown to dark gray, biotite-rich siltstone and dark olive to dark gray mudstone. Foraminifers may be present but are poorly preserved. Plant debris is locally common. Shale chips, mostly sand size but as long as 5 cm, are locally common. Conglomerate crops out in thick (10 meters or more) beds of pebble to boulder conglomerate containing well-rounded clasts of silicic to intermediate volcanic rocks, limestone, black metavolcanics, and rip-up clasts of mica-rich sandstone.

Coast Range Ophiolite (Jurassic)

Jsp Serpentinite -- Mainly sheared serpentinite, but also includes massive serpentinized harzburgite. Although the protolith is Jurassic, some of the serpentinization is much younger, and some may still be underway (Barnes and O'Neil, 1969).

Alum Rock Block

QTi Irvington Gravels of Savage (1951) (Pleistocene and Pliocene?) -- Poorly to well consolidated, distinctly bedded cobble conglomerate, gray conglomeratic sandstone, and gray, coarse-grained, cross-bedded sandstone. Clasts consist about half of micaceous sandstone derived from the Great Valley sequence and the Franciscan Complex and half of chert, metamorphic and volcanic rocks derived from the Franciscan Complex. The gravels also include rare but distinctive clasts of laminated black chert from the Claremont Formation. A large number of Pleistocene (Irvingtonian) vertebrate fossils has been collected from this unit (Savage, 1951). The fossils are restricted to a relatively thin stratigraphic interval, making it possible that the unit could contain strata as old as Pliocene.

Tor Orinda Formation (upper Miocene) -- Distinctly to indistinctly bedded, non-marine, pebble to boulder conglomerate, conglomeratic sandstone, and coarse- to medium-grained lithic sandstone. Clasts are sub-angular to well rounded, and contain a high percentage of detritus from the Franciscan Complex. The Orinda Formation unconformably overlies the Briones Formation. Locally includes:

Torv Basalt and andesite -- interlayered with Orinda sandstone and conglomerate.

Tbr Briones Formation (upper Miocene) -- fine-grained sandstone and siltstone. Sandstone beds are as thin as 5 to 10 cm, with 2- to 10-cm-thick shale interbeds. These are interbedded with massive, fine-grained sandstone beds as thick as five meters. The middle part consists of indistinctly bedded, white, fine- to coarse-grained sandstone, conglomeratic sandstone, and massive shell-hash conglomerate (shell beds). Shell-hash conglomerate is made up of interlocking mollusk and barnacle shells and shell fragments in a white, calcareous sandstone matrix. The upper part consists of distinctly to indistinctly bedded, massive to cross-bedded, fine- to coarse-grained, white sandstone. For the most part, The Briones Formation unconformably overlies the Claremont Formation.

Tcc Claremont Formation (upper and middle Miocene) -- Chert occurs as distinct, massive to laminated, gray or brown beds as thick as 10 cm with thin shale partings. Distinctive black, laminated chert occurs in Alum Rock Canyon. Siliceous shale is dark brown to gray, finely laminated, with grains as large as silt. Some of the shale contains abundant foraminifers and fish scales and the shale also contains prominent interbedded lenses as long as one meter of massive, tan, foraminifer-bearing dolomite that weathers to a distinctive yellowish orange color. Light brown, gray, and white, fine-grained quartz sandstone and siltstone are locally present. The Claremont Formation unconformably overlies Cretaceous strata in the Milpitas area.

Berryessa Formation (Cretaceous) -- Divided into:

Kbs Sandstone and mudstone -- Interbedded layers of massive, indistinctly bedded, coarse- to fine-grained, mica-quartz-lithic wacke and mica-bearing siltstone and claystone. Fine-grained beds are well exposed for the most part only in canyons, whereas sandstone beds form resistant outcrops on ridge tops and in canyons. Includes local small, unmapped lenses of conglomerate.

Kbc Conglomerate -- Thick, indistinct beds of pebble, cobble, and less common boulder conglomerate interfingered with coarse-grained mica-quartz-lithic wacke. Clasts include silicic to intermediate volcanic rocks, black chert and argillite, quartz, mica schist, semi-gneissic meta-andesite, granodiorite and granite, black hornfels, and rip-up clasts of mudstone and lithic wacke.

Kau Sandstone, mudstone, and conglomerate (Upper Cretaceous) -- Indistinctly to distinctly bedded, fine- to coarse-grained, biotite-quartz-lithic wacke interbedded with thin, distinct beds of dark gray, biotite-rich, siltstone and claystone. Conglomerate crops out in thin (about one meter) lenses of pebble to boulder conglomerate containing well-rounded clasts of silicic to intermediate volcanic rocks, granite, green chert, quartzite, and limey nodules. One outcrop in the Calaveras Reservoir 7.5-minute quadrangle has yielded an invertebrate fossil of Late Cretaceous (Turonian) age.

KJk Knoxville Formation (Lower Cretaceous and Upper Jurassic) -- Mainly dark, greenish-gray silt or clay shale with thin sandstone interbeds. Locally includes thick pebble to cobble conglomerate beds in its lower part. Locally at the base includes beds of angular, volcanoclastic breccia derived from underlying ophiolite and silicic volcanic rocks.

Coast Range Ophiolite (Jurassic)

Jbk Basalt, keratophyre, and quartz keratophyre -- Pillow basalt, massive basalt, and basalt breccia interfingered with keratophyre and quartz keratophyre that consists of highly altered intermediate and silicic volcanic and hypabyssal rocks in which most feldspar is replaced by albite. Includes rocks previously mapped as Alum Rock rhyolite and erroneously considered to be Tertiary (Dibblee, 1973a; Crittenden, 1951). Recent biostratigraphic and isotopic analyses have revealed a Jurassic age for these rocks (Jones and Curtis, 1991). The keratophyre and quartz keratophyre are probably the altered remnants of a volcanic arc deposited on oceanic crust during the Jurassic and the basalt the uppermost part of the crust.

Jic Intrusive diabase, diorite, and gabbro -- Locally includes small lenses of serpentinite. This unit is a remnant of the lower part of the oceanic crust.

Jsp Serpentinite -- Mainly sheared serpentinite, but also includes massive serpentinized harzburgite. Although the protolith is Jurassic, some of the serpentinization is much younger, and some may still be underway (Barnes and O'Neil, 1969).

CENTRAL? BELT, FRANCISCAN COMPLEX

fm Melange (Lower Tertiary? and Upper Cretaceous) -- Sheared black argillite, graywacke, and metagraywacke containing blocks and slabs of metagraywacke and shale (fs), chert and metachert (fc), serpentinite (sp), greenstone (gs), amphibolite, tuff, eclogite, quartz schist, greenschist, basalt, marble, conglomerate, and blueschist. Blocks range in length from a few millimeters to several hundred meters. Only some of the largest blocks and slabs are distinguished on the map.

In each of the blocks where melange occurs, its age is limited by the age of the youngest rocks incorporated in the melange. In most cases the resultant time of formation of the melange is younger than Middle to Late Cretaceous, and may extend into the early Tertiary.

Mt. Hamilton Block

Tsl Basalt of San Luis Reservoir (upper Miocene) -- basalt flows plus minor pyroclastic deposits (see description under Orestimba block).

Tqs Quien Sabe Volcanics (upper Miocene) -- highly differentiated andesitic suite ranging from basalt to rhyolite as flows and dikes, plus minor tuffs and volcanic sedimentary rocks, at Pacheco Peak; represents the earliest recognized Quien Sabe volcanism with a K-Ar date of 11.6 Ma (Nakata and others, 1993; Drinkwater and others, 1992). Includes:

Tqi Intrusive Phase

Tv Volcanic rocks, undivided (upper Miocene?) -- Probably alkalic basalt along Mt. Hamilton Road and near Isabel Creek in Isabel Valley, and andesite in the Eylar Mt. and Mississippi Creek 7.5 -minute quadrangles (Crawford, 1976; Nakata and others, 1993).

Tlt Siltstone and sandstone (upper to middle Miocene) -- Thin-bedded, diatomaceous siltstone containing fish scales, twigs, and rare leaves and friable, arkosic sandstone forming a section about 33 m thick that unconformably overlies Franciscan rock beneath the Quien Sabe Volcanics at Pacheco Peak (Berkland, 1970); correlated by D. H. Sorg (written commun., 1993) with the Lone Tree unit in the Quien Sabe volcanic field farther south (Drinkwater, Sorg, and Russell, (1992), which occupies a similar stratigraphic position; age based on abundant molluscs from sandstone near the middle of the section (Berkland, 1970).

Tcc Claremont Formation (upper and/or middle Miocene) -- Distinctly bedded, massive, gray and black laminated chert and dark brown, gray, or black, finely laminated, siliceous shale, some of which contains poorly preerved fish scale and formainifers.

Tts Temblor Sandstone (middle Miocene) -- Thickly and indistinctlky bedded, olive green, fine-to coarse-grained sandstone and pebble conglomerate, commonly fossiliferous; unconformably overlies Franciscan melange (fm) at north end of Calaveras Reservoir.

Coast Range Ophiolite? (Jurassic)

Jsp? Serpentinite -- Undifferentiated ultramafic rocks now largely replaced by serpentine; probably pieces of Coast Range ophiolite, but are not directly associated with either other ophiolite rock types or Great Valley sequence. Although the protolith is Jurassic, some of the serpentinization is much younger, and some may still be underway (Barnes and O’Neil, 1969).

EASTERN BELT, FRANCISCAN COMPLEX (CRETACEOUS AND JURASSIC)

fm Melange (Lower Tertiary? and Upper Cretaceous) -- Melange of the Eastern Franciscan belt with a matrix of sheared argillite, lithic metagraywacke, and scarce but diagnostic "green tuff" (Brandon, 1989). The matrix metagraywacke usually has a weak cleavage (TZ-2A) and contains fine-grained lawsonite, pumpellyite, and veins of quartz and aragonite. It is clear in some places that the metamorphic cleavage predates a scaly, anastomosing cleavage characterized by numerous slickensided surfaces that is typical of melanges everywhere (Raymond, 1973a). In most outcrops, however, the scaly cleavage is predominant and the more penetrative cleavage is no longer present.

The melange occurs in two different modes that are evident on the geologic map. Thin melange zones occur within the coherent terranes (intra-wedge melange of Crawford, 1975), and thicker "inter-wedge" melanges separate the different terranes. Aside from the difference in scale, these two occurrences contain the same kinds of blocks and look the same in outcrop.

The matrix contains abundant blocks and slabs of greenstone (gs) and radiolarian chert (ch) that are of the same metamorphic grade as the matrix and could be the dismembered basement to those sedimentary rocks. There are also blocks and slabs of metagraywacke (mw), conglomerate (cg), and graywacke (gw) that appear to have been incorporated into the melange from the adjacent, more coherent Burnt Hills and Yolla Bolly terranes by either sedimentary or tectonic processes. Some blocks of unknown type (?) have been mapped from topographic expression. Blocks smaller than about 100 m in diameter are not distinguished (except blueschist and other high-grade blocks shown by symbol).

bl, ◆ Blueschist block -- tectonic blocks of medium- to high-grade blueschist (type 3 and 4 of Coleman and Lee, 1963) of around 160 ± 5 Ma and some blocks of eclogite and amphibolite; symbol used where block is too small to map at 1:100,000 (that is, less than about 100 m in diameter). These famous Franciscan blueschists, eclogites, and amphibolites have been the object of many recent studies (see, for example, Moore and Blake, 1989, and references therein), and dating of several in the Mt. Hamilton block by various techniques and has yielded metamorphic ages of around 160 ± 5 Ma (see Lindquist and Morganthaler, 1991).

Burnt Hills terrane (Upper Cretaceous)

fb1 Lower Unit -- Predominantly thin-bedded, fine-grained sandstone and mudstone (turbidites) with local interbeds (channels) of coarse-grained, uncleaved arkosic sandstone (TZ-1). Rarely preserved is basal basaltic greenstone (fbg) and overlying radiolarian ribbon chert (fbc). Sandstone is locally cleaved (TZ-2A) and contains fine-grained metamorphic minerals including pumpellyite and lawsonite. Quartz-aragonite veins are locally present. Megafossils of Upper Cretaceous age have been found at several localities (Elder and Miller, 1990), and radiolarians from the underlying chert are also of Cretaceous age (Murchey and Jones, 1984; Sliter and others, 1993).

fb2 Middle Unit -- Predominantly thick-bedded, coarse grained, arkosic sandstone and minor mudstone (turbidites) with local interbeds of thin-bedded turbidites. Rarely preserved is basal basaltic greenstone (fbg) containing lenses of pinkish aragonite marble (not mapped), and overlying pink to white radiolarian ribbon chert (fbc). Sandstone is locally reconstituted to slaty or semischistose metagraywacke (TZ-2A) and contains fine-grained metamorphic minersls including pumpellyite, lawsonite, and glaucophane. Near the Rooster Comb (northwest corner of the Mustang peak 7.5-minute quadrangle) there is an increase in textural grade to TZ-2B and a jadeite-in isograd (see Dalle Torre and others, 1996 for details). No identifiable megafossils have been found in the clastic rocks, but radiolarians from the Rooster Comb are the same as those from cherts in the lower unit (fb1) farther south (Sliter and others, 1993).

fb3 Upper Unit -- Schistose (TZ-2B) jadetized metagraywacke and slate. Contains unmapped lenses of bluish-greenish, glaucophane-bearing metatuff (bluestone), and basal(?) metachert layers up to 30 m thick. No fossils have been found; correlation with the less metamorphosed lower and middle units (fb1 and fb2), is based on lithology and an Upper Cretaceous metamorphic age (Blake and Lanphere, 1992).

Yolla Bolly terrane (Cretaceous? and Jurassic)

fy1 Lower Unit -- uncleaved (TZ-1) lithic quartzofeldspathic metagraywacke, mudstone, and conglomerate. Includes scarce basal, basaltic greenstone (fyg) and Middle-Upper Jurassic radiolarian ribbon chert (fyc). Locally reconstituted to TZ-2A metagraywacke with pumpellyite, lawsonite, and aragonite; greenstone pebbles in conglomerate near Mt. Hamilton are replaced by fine-grained glaucophane. No megafossils are known, but cherts are well dated at Middle to Upper Jurassic (Sliter and others, 1993).

fy2 Middle Unit. TZ-2A to TZ-2B metagraywacke, slaty mudstone, and conglomerate containing pumpellyite and lawsonite plus local occurrences of incipient jadeitic pyroxene. Quartz-aragonite veins are widespread. Includes minor occurrences of greenstone and chert (unmapped) that may represent basal oceanic crust. A single Upper Jurassic *Buchia* was found in metagraywacke of this unit by Ken Crawford in the Mt. Day 7.5-minute quadrangle (Elder and Miller 1990).

fy3 Upper Unit -- TZ-2B metagraywacke, slaty mudstone, and minor metaconglomerate. Includes mapped lenses of basal bluestone (fyg) and bluish to pinkish metachert (fyc). Distinguished from other Yolla Bolly units by stronger metamorphic fabric, jadeite sprays (fine-grained but usually visible under the hand lens), and abundant quartz-aragonite or quartz-albite veins. These rocks have been well-studied, in particular near Pacheco Pass (see Ernst, 1993b, and Kimura and others, 1996 for details of the metamorphism and structure).

fys Metagraywacke, undivided -- Metagraywacke of TZ-1 to TZ-2B including undivided slabs of the lower, middle, and upper units (fy1, fy2, and fy3). Contains blueschist-facies metamorphic minerals as in the other Yolla Bolly units.

fyu Yolla Bolly terrane, undivided -- Metagraywacke of TZ-2A to TZ-2B, mudstone, and conglomerate, together with areas of mixed melange and metagraywacke and, north of the Del Puerto ophiolite, much greenstone and unmapped chert, some of which may be basal oceanic layers. Contains blueschist-facies metamorphic minerals as in the other Yolla Bolly units.

fws Ward Creek (?) terrane -- Glaucophane- and lawsonite-bearing metagraywacke and grayish mica schist (metamudstone) of TZ-2B and TZ-3A exposed just west of the serpentinite body at the boundary of the Mt. Day and Lick Observatory 7.5-minute quadrangles; closely resembles ca 140-Ma glaucophane-bearing schists in the Cazadero area of Sonoma County (Coleman and Lee, 1963; Blake and others, 1984; Wakabayashi, 1992), although no metamorphic ages have been obtained from these rocks.

Orestimba Block

QTt Tulare Formation (Pleistocene and Pliocene?) -- Fluvial pebbly sand and sandy pebble gravel, reddish brown and weakly indurated; exposed in the map area just north of the mouth of Quinto Creek. In contrast to the wide variety of Diablo-Range rock types present in the Tulare Formation elsewhere, this isolated patch consists largely (about 80%) of red and green Franciscan chert; strata dip eastward as much as 10-15 degrees; the original depositional top of the deposit has been removed by erosion; the unit occupies an intermediate structural and geomorphic position between the more steeply dipping bedrock units below and the adjoining younger surficial deposits. A Pleistocene (Irvingtonian or younger, < 1.9 Ma) age is locally indicated by the presence of a tibia of *Equus scotti* (Lettis, 1982; B. F. Cox, written commun., 1997).

Tfn Fanglomerate (lower Pliocene? and upper Miocene) -- Reddish-brown to gray conglomerate, sandstone, and siltstone, commonly containing crossbedding and channeling; conglomerate becomes more abundant toward the top of the unit; composed principally of detritus from the Franciscan Complex or Great Valley sequence. Within the map area, the fanglomerate lies unconformably on the Valley Springs Formation. The unit is considered to be late Miocene and early Pliocene(?) based on late Miocene (Late Clarendonian) vertebrates from the lower part and correlated lacustrine interbeds elsewhere that contain fresh-water diatoms of late Miocene or early Pliocene? age (Bartow and others, 1985).

Tsl Basalt of San Luis Reservoir (upper Miocene) -- High-alumina basalt flows and associated basaltic to andesitic pyroclastic deposits; occur as moderately deformed erosional remnants; 4 conventional K-Ar dates range from 7.4 to 9.0 Ma; erupted from local vents that may have been related to the Ortigalita fault, which separates the two small areas of occurrence near San Luis Reservoir (Nakata and others, 1993).

Tvs Valley Springs Formation (lower Miocene and upper Oligocene) -- Yellowish-gray and tan, clayey sandstone, sandy tuffaceous claystone, and light-gray vitric tuff; locally exhibits crude irregular bedding and poorly developed prismatic structure; correlation with the type locality in the Sierra Foothills, where the unit is considered to be late Oligocene and early Miocene, is based on similar lithology, equivalent stratigraphic position, and trace- and minor-element chemistry of the glass in vitric tuff interbeds, reinforced by its subsurface occurrence throughout the northern San Joaquin Valley; base is unconformable (Bartow and others, 1985).

Tpf Poverty Flat Sandstone (upper and middle Eocene) -- Principally gray, micaceous lithic sandstone interbedded with gray, fossiliferous claystone near the base, grading upward into whitish, crossbedded, quartz-kaolinite sandstone and siltstone near the top that contains anauxite; locally includes greenish-gray, sandy claystone and brown, carbonaceous siltstone; a chert-pebble conglomerate at the top is composed mostly of red, radiolarian chert pebbles derived from the Franciscan Complex; characteristically mottled red and orange in the upper part. Gradationally overlies the Kreyenhagen Shale and is unconformably overlain by the Valley Springs Formation. A middle and upper Eocene age is based on middle Eocene diatoms and late Eocene or early Oligocene molluscs from the basal claystone and association of the quartz-kaolinite composition of the upper part with tropical weathering believed limited to the Eocene (Bartow and others, 1985).

Tkr Kreyenhagen Shale (middle Eocene) -- Gray shale, diatomaceous shale, and diatomite with some interbedded sandstone in the lower part; white weathering, light-brown platy diatomite and gray shale in the upper part; contains common clastic dikes of gray lithic sandstone; locally more than 330 m thick, but is unconformably truncated by the overlying Valley Springs Formation in the northeast part of the map area. age of the unit in this area is restricted to the middle Eocene by diatoms from its top (Bartow and others, 1985).

Tds Domengine Sandstone (middle Eocene) -- Greenish gray, glauconitic quartz sandstone, weakly indurated and very poorly exposed; fine to medium grained (distinctly coarser than underlying Tesla sandstone); discontinuously present at the base of the middle Paleogene depositional sequence; age based on microfossils and sparse megafossils (Bartow and others, 1985; B. F. Cox, written commun., 1997).

Tesla Formation (Eocene and Paleocene)

Tte Sandstone and siltstone - Light-gray and tan, very fine-grained sandstone and siltstone, and tan micaceous sandstone. Locally contains thin carbonaceous layers; thins northward; correlated with the type Tesla at Corral Hollow to the north; molluscs of probable Paleocene age occur in the lower half of the unit and, although the upper part has yielded no datable fossils in the map area, molluscs from Corral Hollow suggest it to be late early to early middle Eocene in age (Bartow and others, 1985; B. F. Cox, written commun, 1997).

Ttq Quartzose sandstone - leached and variegated, generally white fine-grained sandstone about 30 m thick located in the lower half of the Tesla, laminated and crossbedded; fossil burrows, rootlets, and leaves indicate subaerial exposure; the unit is interpreted to represent a paleosol (B. F. Cox, written commun., 1997).

Great Valley sequence

The Great Valley sequence on the east flank of the Diablo Range consists of mudstone, sandstone and conglomerate about 8.5 km thick and ranging in age from uppermost Jurassic (Tithonian) to Late Cretaceous. Bedding is regular and facies change both laterally and vertically to define interleaved lenticular bodies.

Moreno Formation (Upper Cretaceous) -- a shoaling-upward sequence of marine sandstone and mudstone that gradationally overlies the Panoche Formation; contains abundant Late Cretaceous (Campanian and Maestrichtian) fossils; the Paleocene part that is present at the type locality has here been removed by erosion beneath the unconformably overlying Tesla Formation (Bartow and others, 1985; B. F. Cox, written commun., 1997). Subdivided into:

Kmm Shale -- Dark gray to brown shale and silty shale containing limestone concretions and thin sandstone interbeds; locally abundant microfossils.

Kms Sandstone -- Gray, medium-grained, arkosic sandstone; forms lenticular interbeds in the shale.

Panoche Formation (Upper Cretaceous) -- consists of turbiditic sandstone and interbedded mudstone, and in the lower half contains thick sequences of conglomerate as well; fossils range in age from Cenomanian in conglomerate locally present in the south near San Luis Reservoir to principally Turonian to

Campanian (Late Cretaceous) (Bartow and others, 1985; B. F. Cox, written commun., 1997). Subdivided into:

Kps Sandstone -- Interbedded fine- to medium-grained sandstone and siltstone containing prominent lenses of gray, massive, concretionary sandstone; many beds are graded and contain rip-up clasts (Bartow and others, 1985; B. F. Cox, written commun., 1997).

Kpc Conglomerate -- Cobble and pebble conglomerate with interbedded fine- to coarse-grained pebbly sandstone; clasts mostly rounded and less than about a half meter in diameter (locally angular and up to 4 meters) and composed mainly of felsic, intermediate, and mafic volcanic rocks, but including various felsic to mafic plutonic rocks (B. F. Cox, written commun., 1997).

Kpm Mudstone -- Silty, olive-gray mudstone and siltstone with thin, interbedded fine-grained sandstone; contains sparse calcareous concretions.

Km Mudstone (Upper Cretaceous) -- Dark gray to black mudstone and siltstone with thin, fine-grained sandstone interbeds, calcareous concretions, and local beds of pebble conglomerate about 1 m thick. West of the ophiolitic volcanics at Copper Mtn., these Upper Cretaceous (Turonian) mudstones are disconformable(?) on Upper Jurassic mudstone (KJm) without any of the intervening Lower Cretaceous "Horsetown beds" (Ksh) that are present just east of the volcanics. South of the volcanics, this mudstone (Km) was distinguished from the Panoche Formation to the east by Sonneman and Switzer (unpublished mapping, Exxon Corp., 1961-62), who erroneously considered it to be Franciscan.

Ksh Shale (Lower Cretaceous) -- Dark gray, silty shale containing thin sandstone interbeds and some calcareous concretions; occurs only just east of the ophiolitic volcanics at Copper Mtn.; equals the "Horsetown beds" of earlier workers and is considered by Bartow and others (1985) to be limited to the Albian.

KJm Mudstone, including Hawk Shale (Lower Cretaceous and Upper Jurassic) -- Dark gray to black mudstone more than 100 m thick containing Upper Jurassic *Buchias;* conformably overlies the Lotta Creek Formation (Maddock, 1964; Elder and Miller, 1993). Occurs both east and west of Copper Mountain and farther south. In the Crevison Peak 7.5-minute quadrangle, the unit is dark mudstone (locally fissile) containing some thin sandstone and conglomerate interbeds and locally abundant calcareous concretions; a central conglomerate (Klc, see below) separates a lower, Jurassic, part (Hawk Shale of Schilling, 1961) from an upper, Lower Cretaceous part (B.F. Cox, written commun., 1997).

Klc Conglomerate (Lower Cretaceous) -- Pebble and cobble conglomerate of rounded clasts composed principally of andesitic volcanic rock and chert; occurs discontinuously between the Jurassic and Lower Cretaceous parts of the enclosing mudstone (KJm).

Jlc Lotta Creek Formation (Upper Jurassic) -- Volcanogenic breccia, conglomerate, sandstone, siltstone, and fine-grained radiolarian tuff; depositionally overlies volcanics (Jbk) of the Coast Range ophiolite. Hornblende from an andesite boulder in conglomerate yielded a $^{40}Ar/^{39}Ar$ age of 150 ± 2 Ma (Evarts and others, 1992).

Coast Range Ophiolite (Jurassic) -- the rocks exposed in the Red Mountain-Del Puerto Canyon area constitute one of the more complete ophiolite seqeunces in the western U.S. (Evarts and others, 1999). Divided into:

Jbk Basalt, keratophyre, and quartz keratophyre -- Sills and dikes plus minor pillowed flows and breccias; equals Del Puerto Keratophyre of previous workers; a "rhyolite" near the top of the section yielded a $^{40}Ar/^{39}Ar$ hornblende age of 150 ± 2 Ma (Evarts and others, 1992).

Jic Intrusive diabase, diorite, and gabbro -- Dikes and irregular intrusive bodies; includes minor quartz diorite or plagiogranite; equals "plutonic complex" of previous workers; several radiometric dates range from a $^{40}Ar/^{39}Ar$ hornblende age of 157 ± 2 Ma to a zircon fission-track age of 149 ± 6 Ma (Evarts, 1978; Evarts and others, 1992; Evarts and others, 1999)

Jdw Dunite-wehrlite -- Cumulate layered ultramafic rocks and minor lenses of plagioclase peridotite and layered olivine gabbro. K-Ar hornblende age of 165 ± 5 Ma (Lanphere, 1971).

Jsp Serpentinite -- Undivided ultramafic rocks (chiefly harzburgite and dunite), now largely replaced by serpentine. In the Red Mountain area and along the Tesla-Ortigalita fault, these rocks represent the basal portion of the Coast Range ophiolite. Although the protolith is Jurassic, some of the serpentinization is much younger, and some may still be underway (Barnes and O’Neil, 1969).

as Antigorite schist -- Schistose serpentinite derived from unit Jsp; restricted to the basal contact with the underlying Yolla Bolly terrane; shares the same metamorphic fabric as a thin (< 10 m), strongly foliated margin of that Yolla Bolly metagraywacke (Harms and others, 1992).

MAP SOURCES

The sources used in compiling the geologic map are described here
by 7-1/2 minute quadrangle (see figure 3).

CALAVERAS RESERVOIR - Surficial deposits largely from Helley and others (1994) and Nilsen and others (1975); landslides from Wentworth photointerpretation; bedrock geology from unpublished mapping by Graymer, D.L. Jones, and E.E. Brabb, 1994-96, modifying Dibblee (1973a) and Cotton (1972).

COPPER MOUNTAIN - Surficial deposits in western half of quadrangle modified and photointerpretively extended from Evarts (1978), elsewhere after Bartow and others (1985); landslides largely from Wentworth photointerpretation; bedrock geology from Maddock (1964), Evarts (1978), unpublished mapping by M. Maddock and L. Raymond (written commun., 1994), Bartow and others (1985), and unpublished mapping by H. S. Sonneman and J. R. Switzer (Exxon Corp., 1961-62).

CREVISON PEAK - Compiled from unpublished mapping by B.F. Cox, 1988-96, and from Lettis (1982).

CROWS LANDING - Geology modified from Sowers and others (1993) in the context of adjacent mapping by Lettis (in Bartow and others, 1985).

EYLAR MOUNTAIN - Surficial deposits from Nilsen and others (1975); landslides from Wentworth photointerpretation; bedrock geology from Cotton (1972), Crawford (1976), and Soliman (1958), modified by unpublished mapping and photointerpretation by Graymer, Blake, D.L. Jones, and Wentworth, 1994-1996.

GILROY - Surficial deposits from Helley and Nakata (1991), modified locally by McLaughlin along upland boundaries on southwest side of Santa Clara Valley; landslides largely from Dibblee (1973d); bedrock geology on northeast side of Santa Clara Valley compiled from unpublished mapping by Graymer, D.L. Jones, E.E. Brabb, and Wentworth, 1994-96., and in southwest part of quadrangle from unpublished field work by McLaughlin, 1996, site visits by McLaughlin and E.E. Brabb, 1996, and Dibblee (1973d).

GILROY HOT SPRINGS - Surficial deposits in the Santa Clara Valley from unpublished mapping by E.J. Helley, 1993, and elsewhere modified from Nilsen and others (1975) and Helley and others (1979); landslides largely from Wentworth photointerpretation; bedrock geology compiled from unpublished mapping by Graymer, D.L. Jones, E.E. Brabb, and Wentworth, 1994-96, unpublished mapping by Blake, and from Cotton (1972) and Dibblee (1973f).

HOWARD RANCH - Compiled from unpublished mapping by B.F. Cox., 1988-96, and Lettis (1982).

ISABEL VALLEY - Surficial deposits and landslides modified by Wentworth from Cotton (1972) and Helley and others (1979); bedrock geology modified by Blake and Wentworth from Cotton (1972) and Soliman (1958).

LAUREL - Geology compiled principally from Clark and others (1989); San Andreas fault zone compiled from Sarna-Wojcicki and others (1975); other sources include Dibblee and others (1978), Dupré (1975), and Burford (1961).

LICK OBSERVATORY - Surficial deposits and landslides after Page (1999) and Helley and others (1979); bedrock compiled from unpublished mapping by Graymer, D.L. Jones, and E.E. Brabb, 1994-1996, mapping by Page (1999), Cotton (1972), Crawford (1975), and unpublished mapping by Steven Thornley, 1993.

LOMA PRIETA - Geology compiled principally from McLaughlin and others (1988); San Andreas fault zone modified from Sarna-Wojcicki and others (1975); other sources include Clark and Rietman (1973), Dibblee and Brabb (1980), Osbun (1975), Simoni (1974), Dupré (1975), McLaughlin and others (1971), and Jones and others (1994).

LOS GATOS - Bedrock and surficial geology compiled chiefly from McLaughlin and others (1991), together with Bailey and Everhart (1964), Sorg and McLaughlin (1975), and Dibblee and Brabb, (1978); other sources include reconnaissance field work by E.E. Brabb, 1969, field work by McLaughlin, E. J. Helley, E. E. Brabb, J. C. Clark, and R. G. Stanley, 1989-96; studies in the Skyland Ridge and Summit Road deformation zone of the 1989 Loma Prieta earthquake by Ponti and Wells (1991), Loma Prieta earthquake deformation data collected in the vicinity of Elsman Reservoir by McLaughlin, 1989, and a consulting report for a school site located within the San Andreas fault zone (Johnson and Associates, 1989); San Andreas fault zone partially compiled from Sarna-Wojcicki and others (1975).

MILPITAS - Surficial deposits from Helley and Wesling (1989) as encoded in Helley and others (1994); bedrock geology from unpublished mapping by Graymer, D.L. Jones, and E.E. Brabb, 1994-1996, modifying Dibblee (1972b).

MISSISSIPPI CREEK - Surficial deposits and landslides largely modified from Nilsen and others (1975), which covers the western two thirds of the quadrangle; remaining geology modified by Blake and Wentworth from unpublished mapping by Blake and R. Fisher, 1988-94, Cotton (1972), unpublished mapping by Dibblee (written commun., 1990), and Morrell (1978).

MORGAN HILL - Surficial deposits from unpublished mapping by E. J. Helley, 1988-89; landslides from Dibblee (1973b); bedrock geology northeast of Santa Clara Valley compiled from unpublished mapping by Graymer, D.L. Jones, and E.E. Brabb, 1994-96, and by R.G. Coleman, 1989-92, modified after Dibblee (1973b); bedrock geology southwest of Santa Clara Valley compiled from unpublished mapping by McLaughlin, 1996, which locally uses Dibblee (1973b).

MT BOARDMAN - Surficial deposits modified from Nilsen and others (1975), Evarts (1978), and Helley and others (1979); landslides from Wentworth photointerpretation; bedrock geology compiled from Maddock (1964), Evarts (1978), Cotton (1972) and unpublished mapping by M. Maddock and L. Raymond (written commun., 1994).

MT DAY - Surficial deposits from Nilsen and others (1975); landslides from Wentworth photointerpretation; bedrock geology from unpublished mapping by Blake, Graymer, D.L. Jones, and Wentworth, 1994-1996, modifying Cotton (1972).

MT MADONNA - Surficial deposits from unpublished mapping by E. J. Helley, 1988-89; bedrock geology in southern part compiled largely from McLaughlin and others (1971), modified by McLaughlin, 1988-96, and in northern two-thirds of quadrangle compiled from unpublished field work by McLaughlin, 1996, partly modifying unpublished mapping by C. F. Jové-Colon, 1991-92, and Dibblee (1973c).

MT SIZER - Surficial deposits modified from unpublished mapping by E.J. Helley, Nilsen and others (1975), and Helley and others (1979); landslides largely from Cotton (1972) and Dibblee (1973e) modified by Wentworth photointerpretation north and south of Anderson Reservoir; bedrock geology from unpublished mapping by Graymer, D.L. Jones, E.E. Brabb, and Wentworth, 1994-1996, modifying Dibblee (1973e), Wagner (1978), and Cotton (1972).

MT STAKES - Compiled by Blake and Wentworth from unpublished mapping by Blake, 1988-1994, and from Nilsen (1975), Cotton (1972), Maddock (1964), and Morrell (1978).

MUSTANG PEAK - Landslides largely from Wentworth photointerpretation; surficial deposits and bedrock geology compiled by Blake, Wentworth, and B.F. Cox from unpublished mapping by Blake, 1988-94, Cowan (1974), Cotton (1972), Morrell (1978), and unpublished mapping by H. S. Sonneman and J. R. Switzer (Exxon Corp., 1961-62).

NEWMAN - Compiled from Bartow and others (1985).

ORESTIMBA PEAK - Geology compiled from Bartow and others (1985); southern boundary of quadrangle modified by E. E. Brabb (1997) from unpublished geologic mapping by B.F. Cox, 1989-91, and by J. R. Lively and W. Beeson (Exxon Corp., 1962).

PACHECO PASS - Geology modified by B.F. Cox, Blake, and Wentworth from Ernst (1993a) and, in northeast corner of quadrangle, from unpublished compilation of Great Valley sequence by E. E. Brabb, 1997, from unpublished geologic mapping by B.F. Cox, 1989-91, and J. R. Lively and W. Beeson (Exxon Corp., 1962).

PACHECO PEAK - Modified by Blake and Wentworth from unpublished mapping by D.H. Sorg, 1988-93, and from Helley and others (1979).

PATTERSON - Geology modified from Bartow and others (1985) and Sowers and others (1993).

SAN JOSE EAST - Surficial deposits from Helley and Wesling (1990) as encoded in Helley and others (1994); landslides compiled from Wentworth photointerpretation, Dibblee (1972c), Nilsen and others (1975), and Helley and Wesling (1990); bedrock geology compiled from unpublished mapping by Graymer, D.L. Jones, and E.E. Brabb, 1994-96, and unpublished mapping by R.G. Coleman, 1989-1992, modifying Dibblee (1972c).

SAN JOSE WEST - Surficial deposits from Wesling and Helley (1989) as digitally encoded in Helley and others (1994).

SAN LUIS DAM - Surficial deposits largely from Lettis (1982), modified slightly by E.E. Brabb from interpretation of 1942, 1971, and 1982 aerial photographs and from the distribution of attitudes in bedrock; boundaries of artificial fill largely from Herd (1979); bedrock geology compiled by E.E. Brabb, 1997, at north edge of quadrangle from unpublished geologic mapping by B.F. Cox, 1989-91, unpublished mapping by A.P. Bennison (written commun., 1990), and unpublished mapping by J. R. Lively and W. Beeson (Exxon Corp., 1962), and in the remainder of the quadrangle from Herd (1979) and Schilling (1962).

SANTA TERESA HILLS - Surficial deposits in the Santa Clara Valley from Helley and others (1994) and unpublished compilation by Helley, 1988-1989, modified slightly along boundaries with upland areas by McLaughlin; bedrock geology in New Almaden area compiled largely from Bailey and Everhart (1964); landslides and bedrock geology in southern and southeastern part of quadrangle compiled from mapping by McLaughlin, 1970-71 and 1988-91; fossil site visits north of Calero Reservoir by McLaughlin, W. P. Elder, and J. L. Nelson (Terratech Engineering), 1991; geology of the Santa Teresa Hills area modified after Short (1986); bedrock geology in northeast corner of quadrangle is from unpublished mapping by R. G. Coleman and C. F. Jové-Colón, 1991-92.

WILCOX RIDGE - Geology modified by Blake and Wentworth from unpublished mapping by Blake, 1988-1994, Maddock (1964), Cowan (1974), Morrell (1978), Cotton (1972), Dibblee (1982), and unpublished mapping by H. S. Sonneman and J. R. Switzer (Exxon Corp., 1961-62).

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