Geologic maps and structure sections of the southwestern Santa Clara Valley and southern Santa Cruz Mountains, Santa Clara and Santa Cruz Counties, California

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GEOLOGIC MAPS AND STRUCTURE SECTIONS OF THE SOUTHWESTERN SANTA CLARA VALLEY AND SOUTHERN SANTA CRUZ MOUNTAINS, SANTA CLARA AND SANTA CRUZ COUNTIES, CALIFORNIA

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INTRODUCTION

This report depicts the geologic framework and structure of the San Francisco Bay region in the vicinity of southwestern Santa Clara Valley and the southern Santa Cruz Mountains. The maps encompass parts of Santa Clara and Santa Cruz Counties and include new and revised geologic mapping of the Los Gatos, Santa Teresa Hills, Laurel, Loma Prieta, and Mount Madonna 7.5' quadrangles and parts of the Morgan Hill and Gilroy 7.5' quadrangles. The mapping was carried out under the National Cooperative Geologic Mapping and Earthquake Hazards Reduction Programs of the U.S. Geological Survey between 1988 and 1997 as part of projects to map the geology of the 1:100,000 San Jose quadrangle (fig. 1) and to investigate the geology of the epicentral region of the October 17, 1989 Loma Prieta Earthquake. Some mapping is compiled from older sources. The various sources of geologic map data are indexed in Figure 2.

The description of rock units and structure are arranged by major fault blocks of different basement composition that are separated by the San Andreas fault. The Salinian terrane, which lies southwest of the San Andreas fault, is a regionally extensive Mesozoic rock assemblage, largely of continental affinity, composed of granitic to gabbroic rocks with roof pendants of high temperature metasedimentary rocks. Northeast of the San Andreas fault, the basement is a composite of the Franciscan Complex, the Coast Range ophiolite, and parts of the Great Valley Sequence, a disrupted assemblage of rocks which originally formed the Mesozoic convergent continental margin.

The Santa Cruz fault block of this report is comprised entirely of rocks of the Salinian terrane. The Santa Cruz block, in turn, is divided into the subsidiary Ben Lomond and La Honda fault blocks by the Zayante fault. Northeast of the San Andreas fault the Mesozoic composite basement is broken into the subsidiary Sierra Azul and New Almaden blocks along a complex fault boundary consisting of locally merged segments of the Sargent, Berrocal, Sierra Azul, and Aldercroft faults. This complex block boundary is further considered to represent a part of the regionally extensive Coast Range fault, which everywhere separates Mesozoic forearc strata of the Great Valley Sequence from the Franciscan Complex. The Coast Range fault has been interpreted as a major attenuation fault associated with Late Cretaceous to early Tertiary unroofing of the Franciscan Complex (Jayko and others, 1987; Harms and others, 1992). An alternative model interprets the Coast Range fault as the roof thrust of a thick, regionally extensive system of tectonic wedges (Godfrey and others, 1997).

Rocks between the San Andreas fault zone and the Sargent-Berrocal-Sierra Azul-Aldercroft fault zone are a part of the Sierra Azul block. Rocks in the Santa Teresa Hills that have a stratigraphy similar to that of the Sierra Azul area are considered a thrust klippe of the Sierra Azul block. The relative amounts and timing of strike slip, uplift, and shortening along fault block boundaries are generally determined or constrained by contrasting stratigraphic and structural relationships of rock units that compose each of the major and subsidiary fault blocks.

SUMMARY OF GEOLOGIC AND STRUCTURAL HISTORY

The map area covered in this report consists of 5 map sheets encompassing the Los Gatos, Laurel, Loma Prieta, Santa Teresa Hills, Mount Madonna and southwestern half of the Morgan Hill, and southwestern corner of the Gilroy 7.5' quadrangles (fig. 3). The pre-late Pliocene stratigraphy and structure is first divided into rocks with stratigraphic and structural settings that were initially widely separated northeast and southwest of the San Andreas fault. Secondly, these rocks are further subdivided into a number of separately described fault blocks and subsidiary fault blocks, also having significantly different stratigraphic and structural histories.

NORTHEAST OF THE SAN ANDREAS FAULT

New Almaden Block

The New Almaden block is bounded northeast of the map area (delineated in fig. 3) by the largely covered San Jose fault of Brabb and Hannah (1981) and by faults of the Hayward fault system. To the southwest, the New Almaden block is bounded in the map area by the Sierra Azul block along Late Cenozoic faults including the Aldercroft, Sierra Azul, Berrocal, and Sargent faults (fig. 3) that are superposed on the Coast Range fault. The structurally lowest exposed rocks of the New Almaden block consist of a composite Mesozoic basement of rocks of the Coast Range ophiolite and Franciscan Complex, which were tectonically imbricated, interleaved, and then unroofed and eroded between the Late Cretaceous and the early Eocene. Following their unroofing and erosion, the interleaved Franciscan and ophiolitic rocks were unconformably overlain by early Eocene marine strata and, later, by Miocene marine strata, followed by unconformable deposition of Pliocene and Pleistocene fluvial strata. Since the middle Pleistocene, Miocene and younger strata of the New Almaden block locally have been tilted, overturned, compressed into open to tightly-appressed folds, and repeated along northeast-vergent reverse faults of the Sargent, Berrocal, and Shannon fault zones.

In the northern part of the Los Gatos 7.5' quadrangle, a 3 km-deep structural depression in the Mesozoic basement of the New Almaden block defined by gravity data (Roberts and Jachens, 1993), is bounded on its southwest side by faults of the Shannon and Berrocal fault zones. The depression extends northwestward into the adjacent quadrangles and is buried beneath Quaternary deposits of the Santa Clara Valley. At least 800 m of Miocene strata are present below the Quaternary section, based on subsurface data (Stanley and others, 1996). Geochemical data from Miocene oil in a well drilled over the buried basin suggest that the Miocene section could be much thicker (Stanley and others, 1996; Roberts and Jachens, 1993). The presence of this deep basin is here considered indicative of major Miocene extension that pre-dated thrusting along the Berrocal-Shannon fault system. Dacitic volcanic rocks interleaved in the Miocene marine section and radiometrically dated at 15.6 Ma (Nakata and others, 1993) may be related to this extensional tectonism.

Elsewhere in the New Almaden block, strata as young as Holocene are involved in surface faulting. The Santa Clara Formation and possibly overlying terrace deposits are cut by the Lexington fault zone in the vicinity of Lexington Reservoir. Southwest of Lexington Reservoir, Santa Clara Formation strata and several gigantic Pleistocene to Holocene landslides are cut by the San Andreas fault. Some of the landslide deposits in this area consist of intact blocks derived from rock units southwest of the San Andreas fault. Similarly, along the northeast side of the New Almaden block, strata of the Santa Clara Formation are cut by southwest-vergent reverse- and right-lateral faults of the Piercy fault zone, which at depth may merge with the Hayward-Calaveras fault system northeast of the map area.

The New Almaden block is broadly warped along weakly defined structural axes into a major antiform and synform. The antiformal and synformal structures are weakly defined by the map distribution of distinctive northwest-southeast-trending lithic elements of the Franciscan Complex and by dips of bedding, shear foliation, and phacoid orientations in the Franciscan rocks and interleaved rocks of the Coast Range ophiolite. The axis of the antiform trends approximately southeastward from Guadalupe Reservoir near New Almaden, through the divide between Uvas and Llagas Creeks south of Morgan Hill. In the Morgan Hill area, the southeastward plunge of the antiform is well defined in a large intact slab of basaltic volcanic rocks assigned to the Permanente terrane of the Franciscan Complex (see geologic map of Mount Madonna 7.5' quadrangle). The northeast limb of the antiform is downwarped into a synform, which underlies much of the area northeast of New Almaden (fig. 3).

Northeast-southwest compression associated with the warping of the New Almaden block probably began in the Pliocene and continued at least into the late Pleistocene (< 50 ka) (McLaughlin and others, 1997, 1999).

Sierra Azul Block and Santa Teresa Hills Outlier

The Sierra Azul structural block is composed of a thick sequence of ophiolitic and marine Mesozoic through early Tertiary strata that structurally overlies the New Almaden block northeast of the San Andreas fault. In the map area, the Sierra Azul block extends for about 28 km in a northwest-southeast direction. The maximum width of the block is about 7 km.

The block is bounded on the northeast by faults that are superimposed on the older Coast Range fault. These bounding faults separate the basal ophiolitic section of the Sierra Azul block from the Franciscan Complex. The faults include the Aldercroft, Soda Springs, Sierra Azul, Berrocal, and Sargent faults, all of which merge along the Sierra Azul block boundary in a southeastward direction, but they also extend either into the Franciscan Complex or into the interior of the Sierra Azul block. The detailed extent of each fault is shown on the 7.5' geologic map sheets. However, only the Sierra Azul block-bounding segments of these faults are shown in Figure 3. The southwestern boundary of the Sierra Azul block is the San Andreas fault, which separates the Sierra Azul rocks from the Santa Cruz block to the southwest (fig. 3).

The Sierra Azul block is transected by northwest-trending, northeast-vergent reverse faults with unknown components of right-lateral slip, which have obliquely stacked the section of the block into at least three repeated subsidiary blocks. These faults include the Hooker Gulch, Sierra Azul, and Sargent faults (fig. 3). As noted above, local segments of the Sargent and Sierra Azul faults also bound the Sierra Azul block.

Another northwest-trending, northeast-vergent fault of the Sierra Azul block separates strata of early Miocene to early Eocene age on the southwest side, from early Eocene and older marine rocks to the northeast. The relation of the rocks in the southwest fault sliver (the shale and sandstone of Highland Way) to other rocks of overlapping age in the Sierra Azul block is uncertain. The shale and sandstone of Highland Way possibly has been translated along or has been thrust in from southwest of the San Andreas fault.

A northeastern boundary fault, the Berrocal fault, which also cuts the New Almaden block (fig. 3), thrusts the Sierra Azul and New Almaden blocks northeastward, locally juxtaposing the Sierra Azul block with near-shore to inner-slope facies Miocene to Pleistocene strata of the New Almaden block (see for example, the Mount Madonna quadrangle). The near-shore depositional setting of exposed Miocene strata in the New Almaden block (the Temblor Sandstone) contrasts sharply with the deep-marine depositional setting of partially coeval strata in the Sierra Azul block. Structural data from fault and fold reconstructions and gravity and aeromagnetic models, furthermore, suggest that Miocene and younger crustal shortening between the San Andreas fault and the southwest margin of the Santa Clara Valley is no more than a few kilometers (about 20 percent) (McLaughlin and Clark, in press; McLaughlin and others, 1997, 1999). The contrast in coeval depositional facies, therefore, is not merely the result of shortening, but it may also reflect oblique strike slip and, alternatively, significant pre-Miocene submarine relief (McLaughlin and others, 1999).

The timing and mode of deformation of the Sierra Azul block are partially constrained by structural relations along the northwest segment of the Sargent fault, between Loma Prieta Peak and the San Andreas fault, and also along the Berrocal fault in the Mount Madonna 7.5' quadrangle. Most northeast vergent thrusting along the Sargent and Berrocal faults probably occurred in the middle Miocene (between about 18 and 10 Ma) based on the ages of rocks juxtaposed along the faults, kinematic indicators, and the radiometric ages and paragenesis of hydrothermal adularia deposited in veins in the fault zones (McLaughlin and Clark, in press; McLaughlin and others, 1996; McLaughlin and others, 1999). Since 10 Ma, the Sargent fault has been reactivated as an oblique, right-lateral, strike-slip fault associated with the modern San Andreas fault system. Apatite fission track ages (Bürgmann and others, 1994) and fault and fold reconstructions (McLaughlin and others, 1999) suggest 3 to 4 km of unroofing of the Sierra Azul block along the Berrocal, Shannon, and Monte Vista faults of the New Almaden block since about 5 Ma. All of these oblique-reverse faults root toward the San Andreas fault (fig. 3 and structure sections).

A large outlier of the Sierra Azul block structurally overlies the New Almaden block in the Santa Teresa Hills and Los Gatos 7.5' quadrangles. This outlier occupies a synformal structure northeast of New Almaden (fig. 3 and structure sections). The southeast side of the Santa Teresa Hills thrust outlier appears to be imbricated with the Franciscan Complex. Structural and stratigraphic relations suggest that emplacement of the Sierra Azul-Santa Teresa Hills block followed deposition of the Eocene marine section and preceded early Miocene (Saucesian) deposition of marine strata on the New Almaden block.

Younger-over-older faults in the Sierra Azul block, that down-drop Eocene and Cretaceous strata onto the Eocene, Cretaceous, and Jurassic sedimentary section, the underlying Coast Range ophiolite, and the Franciscan Complex, are interpreted to be low-angle attenuation or detachment faults. This attenuation faulting was initiated along the Coast Range fault in the late Campanian or Paleocene. The faulting probably occurred during emplacement of the Central belt of the Franciscan Complex beneath older Franciscan rocks, the Coast Range ophiolite, and the Great Valley sequence. The attenuation faulting may have continued into Oligocene (pre-Zemorrian) time. Mechanisms proposed to explain this faulting include extension in the midcrust and (or) structural thinning in the roof-thrust zone of a tectonic wedge system (Jayko and others, 1987; McLaughlin and Clark, in press).

SOUTHWEST OF SAN ANDREAS FAULT

Santa Cruz Block

The Santa Cruz structural block extends southwestward from the San Andreas fault to beyond the map area, at least to the San Gregorio fault in the offshore region of Monterey Bay. The basement of the block is composed predominantly of Cretaceous plutonic rocks and minor metamorphic rocks of the Sur Series that are present locally as roof pendants and wallrock inclusions in the Cretaceous plutonic rocks and of unexposed magnetic basement interpreted to be largely Jurassic gabbro. These basement rocks are overlain by a section of early Tertiary through Pleistocene marine and nonmarine strata. The strata of early Tertiary through early Pleistocene age are deformed by faulting and folding, whereas younger Pleistocene and Holocene deposits are deformed by tilting and, locally, by faulting.

La Honda and Ben Lomond Subsidiary Blocks

The Santa Cruz block is divided into two subsidiary fault blocks by the northeast-vergent, dextral-reverse Zayante fault (fig. 3). The La Honda subsidiary block lies northeast of the Zayante fault and southwest of the San Andreas fault. The Ben Lomond subsidiary lies southwest of the Zayante fault.

The exposed sedimentary section of the La Honda subsidiary block consists of a thick Pliocene through Eocene sequence of strata. Paleocene and older marine rocks are speculatively present in the subsurface of the La Honda block (McLaughlin and Clark, in press; Wentworth and others, 1998; Jachens and others, 1998). The Tertiary section of the La Honda subsidiary block is as much as 6 km thick, defining a major depositional basin (La Honda basin) (McLaughlin and Clark, in press). Based on aeromagnetic data (Jachens and Griscom, in press), the unexposed basement beneath La Honda basin and northeast of the Zayante fault is of mafic composition and is probably a continuation of Jurassic gabbroic rocks exposed at the surface along the San Andreas fault at Logan, about 30 km southeast of Loma Prieta peak.

The Zayante fault dips moderately to steeply southwestward at the surface but steepens at depth. Aeromagnetic and gravity data suggest that the Zayante fault roots into a buried southwest-dipping low-angle fault along the top of the gabbroic basement of the La Honda block (Jachens and Griscom, in press).

Displacement on the Zayante fault is predominantly dip slip with a minor component of right-lateral strike-slip recognized in the late stages of the faulting. The contrast in composition and age of crystalline basement rocks beneath rocks mapped as the same Eocene sequence (Butano Sandstone) northeast and southwest of the Zayante fault possibly results from major Paleocene to Late Cretaceous right- or left-lateral strike slip (McLaughlin and Clark, in press). Much of the Eocene section northeast of the Zayante fault, however, is also buried beneath younger deposits and, therefore, may not correlate with the Butano Sandstone southeast of the fault (Wentworth and others, 1998; Jachens and others, 1998). Stratigraphic relations across the Zayante fault zone in La Honda basin indicate that most vertical displacement occurred in the Oligocene to early Miocene in conjunction with a transition from marine to nonmarine deposition. Although the present geometry of the fault indicates that it is a reverse fault, the variation in fault geometry with depth, the major influence of fault growth on the depth of sedimentary deposits in La Honda basin of the La Honda subsidiary block, and the occurrence of early Miocene basaltic volcanic rocks in the basin deposits may indicate that the Zayante fault was an extensional feature prior to late Tertiary initiation of transpression in the Coast Ranges.

Southwest of the Zayante fault, granitic, granodioritic, and quartz-dioritic rocks of the Ben Lomond subsidiary block of the Santa Cruz block are exposed at the surface. Conglomeratic Eocene strata of the Butano Sandstone overlie the granitic basement, and younger Tertiary marine strata locally overlap the Eocene section.

The thick stratigraphic section of the La Honda subsidiary block is compressed into several northwest-trending, southeast-plunging folds above the low-angle detachment at the top of the gabbroic basement of La Honda basin. In this area, Pliocene strata of the Purisima Formation are tightly folded and truncated against the San Andreas fault, and younger Pleistocene and Holocene terrace deposits are tilted and cut by faults in the San Andreas fault zone. In the Ben Lomond subsidiary block, the thinner Tertiary section, which overlies granitic rocks exposed at the surface, is less intensely deformed.

THE SAN ANDREAS FAULT AND LOMA PRIETA EARTHQUAKE

The San Andreas fault within the study area consists of a complex zone of right-lateral faulting up to 2 km wide. The main trace of the fault, along which most slip occurred, is along the northeast side of the fault zone. The San Andreas zone in this area has been active since the Miocene and has accomodated at least 150 km of right slip, of which up to 27 km occurred since 3 Ma (McLaughlin and others, 1996; McLaughlin and Clark, in press).

Extensive surface fissuring occurred along this part of the San Andreas fault zone during the Loma Prieta earthquake of October 17, 1989. Some surface fissures that occurred during the San Francisco earthquake of 1906 were reactivated in the 1989 earthquake (Prentice and Schwartz, 1991). Much of the surface deformation during these earthquakes, however, was on northwest-trending fissures that were left lateral and extensional, inconsistent with dextral slip expected from this fault orientation. These sinistral northwest-trending deformation features were considered to be related to slope-failure processes (Ponti and Wells, 1991).

During the Loma Prieta earthquake, major surface deformation was concentrated along the southwest (La Honda basin/subsidiary block) side of the San Andreas fault. Much of this surface deformation in the Skyland Ridge and Summit Road areas was the result of ridge-top spreading and slope failure induced by seismic shaking (Ponti and Wells, 1991). Concentration of this deformation over the La Honda basin side of the San Andreas fault zone was likely influenced by the contrast in thickness of the Tertiary sections across the San Andreas fault. Very large landslide deposits, some consisting of gigantic intact blocks, have moved northeastward across the San Andreas fault locally, depositing rocks of the Santa Cruz block onto the Sierra Azul and New Almaden blocks. Some of these landslides were probably seismically induced.

DESCRIPTION OF MAP UNITS

QUATERNARY TO LATE TERTIARY UNITS

md **Mine dump (Holocene)**—Mine tailings, largely from mercury mines in the New Almaden area

gp **Gravel pit (Holocene)**—Gravel quarries in Quaternary gravels of Santa Clara Valley floor

pp **Percolation pond (Holocene)**—Man-made ponds in Santa Clara Valley created to recharge Quaternary aquifers

af **Artificial fill (Holocene)**—Major fill areas at dam sites and along roadways

Qal **Alluvium, undivided (Holocene and Pleistocene)**—Unconsolidated boulders, gravel, sand, and silt deposited in stream channels, alluvial fans, and terraces

Qls **Landslide deposits, undivided (Holocene and Pleistocene)**—Unconsolidated and intact blocks of rock and soil debris that have moved by gravitational processes downslope. Movement may be extremely rapid or slow and vary with time. Landslides often move along slip planes, and movement may be enhanced by water infiltration. Landslides may also include debris flows. Landslides range from meter-size blocks too small to show at map scale to large composite landslides greater than a kilometer long. Many landslides along or near the San Andreas fault were activated during the Loma Prieta earthquake. Some large composite landslides exhibit youthful fault features, suggesting that they are offset by the San Andreas fault. Some of these large landslides also consist of rocks that have moved northeastward from source areas southwest of the San Andreas fault. Ancient Pleistocene landslides may be deeply and intricately dissected

Qt **Alluvial terrace deposits, undivided (Holocene and Pleistocene)**—Boulders, gravel, sand, silt, and soil deposited in Holocene and (or) Pleistocene stream and alluvial fan settings

Qhf **Alluvial fan deposits (Holocene)**—Unsorted boulders, gravel, sand, silt, and soil deposited in Holocene alluvial fans

Qhb **Basin deposits (Holocene)**—Mud, silt, and sand, locally thinly laminated, deposited in closed nonmarine depressions and related lacustrine settings

Qhl **Levee deposits (Holocene)**—Sand, silt, and mud deposited in natural levee settings adjacent to stream channels

Qhfp **Floodplain deposits (Holocene)**—Sand, silt, mud, and gravel deposited on floodplains of streams that drain into Santa Clara Valley

Qhc **Stream channel deposits (Holocene)**—Boulders, gravel, sand, and silt deposited in dissected stream channels

Qa **Aromas Sand (Pleistocene)**—Nonmarine and marine shoreline deposits mapped southwest of San Andreas fault, locally divided into:

Qad **Dune deposits**—Well-sorted, fine-grained, cross-bedded sand

Qaf **Fluvial deposits**—Poorly consolidated gravel, sandstone, siltstone, and mudstone

Qof **Old floodplain deposits (Pleistocene?)**—Sand, silt, mud, and gravel deposited on older floodplains. Unit mapped only southwest of San Andreas fault

Qmt **Marine terrace deposits (Pleistocene)**—Unconsolidated to poorly consolidated sand and gravel mapped southwest of San Andreas fault, moderately to well sorted, locally burrowed and fossiliferous, in places crossbedded; deposited on shoreline terraces. Unit probably interfingers with older floodplain deposits and (or) Aromas Sand to northeast

Qoa **Old alluvium, undivided (Pleistocene)**—Unconsolidated boulders, gravel, sand, and silt deposited in older stream channels, alluvial fans, and terraces

Qpf **Alluvial fan deposits (Pleistocene)**—Unsorted boulders, gravel, sand, silt and soil, deposited in older alluvial fans. Includes deposits of older Pleistocene alluvial fans incised by younger Pleistocene and Holocene alluvial deposits. Unit includes channel and overbank deposits of major Pleistocene fluvial systems as well as fan deposits of ephemeral tributary streams

QTf **Fluvial deposits, undivided (Pleistocene and Pliocene?)**—Gravel, sandstone, and siltstone mapped southwest of San Andreas fault in Loma Prieta quadrangle. Unit overlies Purisima Formation and is overlain by Aromas Sand

QTsc **Santa Clara Formation (Pleistocene and Pliocene)**—Fluvial boulder to pebble gravel, sandstone, and siltstone locally including thin bedded lacustrine mudstone. Contains abundant plant fossils and woody debris. Lower beds locally contain freshwater pelecypods, 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 between 0.4 and 0.61 Ma (Sarna-Wojcicki and others, 1991; Lanphere and others, 1999). The Santa Clara Formation is equivalent in age to the Pliocene gravels of the Silver Creek area

(Graymer and DeVito, 1993), the Pliocene and Pleistocene (?) Packwood gravels (Crittenden, 1951), and Irvington gravels (Savage, 1951) northeast of the Santa Clara Valley and outside of the map area. Also outside of the map area, along the northeast side of Santa Clara Valley, the Santa Clara Formation includes xenolithic basaltic and andesitic volcanic rocks (Nakata, 1980; Wilshire and others, 1988; Jové, 1992) that have been radiometrically dated at 3.6 - 2.5 Ma (Nakata and others, 1993)

TERTIARY AND OLDER ROCK UNITS

Northeast of San Andreas fault

New Almaden Block

sc **Silica-carbonate rock (Miocene?)**—Siliceous and calcareous deposits resulting from hydrothermal alteration of serpentinite, widely distributed in the area, especially associated with mercury mineralization in the New Almaden mining district. We describe this unit under the New Almaden block, although it also occurs at a few localities along the Sargent and Berrocal faults at the margin of or within the Sierra Azul block. Miocene age of the silica-carbonate rock is inferred from radiometric dates from volcanic rocks that were a Miocene heat source beneath the New Almaden area and from hydrothermal K-feldspar from nearby mineralized areas (Nakata and others, 1993; McLaughlin and others, 1996). Silica-carbonate mineralization is inferred to be older than Pliocene because rare clasts of silica-carbonate rock occur in lower gravels of the Santa Clara Formation near New Almaden (Bailey and Everhart, 1964)

Tus **Unnamed sandstone (middle Miocene or younger)**—Quartzo-feldspathic sandstone or lithic arkose, which locally overlies Monterey Shale. Includes lithic sandstone that locally overlies the Monterey Shale in the Los Gatos quadrangle, which is middle Miocene (Luisian) in age based on foraminifers from mudstone interbeds (R.G. Stanley and K. McDougall, written commun., 1998). Also includes quartzofeldspathic sandstone unit that overlies Monterey Shale strata of Saucesian age in the Mount Madonna quadrangle, but this sandstone is undated and could be older or younger than the sandstone in the Los Gatos area

Tms **Monterey Shale (middle and lower Miocene)**—Predominantly siliceous mudstone, diatomite, and porcellanite. Siliceous and diatomaceous mudstone beds contain foraminifers of middle Miocene (Luisian) age in northwestern exposures, near Los Gatos and New Almaden. At the southeastern end of exposures, in the vicinity of Morgan Hill and Gilroy, unit contains foraminifers of early Miocene (Saucesian) age, suggesting marine transgression from southeast to northwest, and an overlap of the age of the Monterey Shale with that of underlying Temblor Sandstone (McLaughlin and others, 1999). Unit was originally assigned to Monterey Formation in the New Almaden area by Bailey and Everhart (1964), and its age overlaps that of rocks of similar lithology southwest of the San Andreas fault, which are assigned to and presumably continuous with the the Monterey Formation of the Monterey area. Monterey Shale of the New Almaden block is also equivalent in part and overlaps the ages of units northeast of the San Andreas fault, which are outside the map area and are assigned in the Palo Alto and Cupertino 7.5' quadrangles to the Monterey Shale, Ladera Sandstone, and Page Mill Basalt (Pampeyan, 1993; Sorg and McLaughlin, 1975). Marine siliceous shale deposition was widespread along the California margin in the early and middle Miocene prior to inception of large-scale strike slip along the San Andreas fault. For this reason, and because the rocks are time transgressive, we consider the Monterey Shale of the New Almaden block to originally have been widely separated from the partly equivalent Monterey Formation of the Santa Cruz block southwest of the San Andreas fault

Tt **Temblor Sandstone (middle Miocene to Oligocene?)**—Pebbly, lithic arkosic sandstone, fossiliferous conglomerate, and bioclastic grit that unconformably overlie strata of Eocene to Cretaceous age and Jurassic to Cretaceous rocks of the Franciscan Complex and Coast Range ophiolite. Unit was correlated by Bailey and Everhart (1964) with sandstone of similar age in the Temblor Hills in southwestern San Joaquin Valley. Near Gilroy the sandstone contains *Vertipecten* sp. cf. *V. bowersi* (Arnold) of early Miocene age (C. Powell, written commun., 1996). Southwest of Morgan Hill, mudstone interbedded in the lower part of unit locally contains foraminifers of latest Oligocene or earliest Miocene (Zemorrian) age. To the northwest, near New Almaden and notably along Hicks Road, basal conglomeratic bioclastic beds include abundant clasts derived from the Franciscan Complex and from ophiolitic rocks. Along the north side of Kennedy Road, basal sandstone locally contains large discocyclinnid foraminifers of Eocene age, which could indicate that there is undifferentiated Early Eocene sandstone beneath the Temblor Sandstone or that Eocene detritus is reworked into the basal Temblor beds. The Temblor Sandstone locally includes:

Ttv **Volcanic and intrusive rocks (middle Miocene)**—Volcanic flows and intrusive rocks of dacitic composition, present in the upper part of the Temblor Sandstone, which are radiometrically dated near New Almaden at 15.6 Ma (Nakata and others, 1993). This age is equivalent to the Luisian benthic foraminiferal stage of the middle Miocene. Undated siliceous volcanic rocks are present locally in the Mount Madonna 7.5' quadrangle, faulted against the Monterey Shale northeast of Mount Madonna. If these volcanics were the heat source for a nearby occurrence of hydrothermal adularia radiometrically dated at 17.6 Ma (McLaughlin and others, 1996) these more southeasterly volcanics could be somewhat older than those dated near New Almaden

Jos **Serpentinized ultramafic rocks (Jurassic)**—In New Almaden block, includes harzburgite, dunite, and peridotite. Locally unit contains minor blocks and sheared inclusions of gabbro and diabase. These rocks are intimately interleaved with melange in the New Almaden block and were originally assigned to the Franciscan Complex by Bailey and Everhart (1964). Here we reassign the complexly sheared serpentinized ultramafic rocks of the New Almaden block to the Coast Range ophiolite and suggest they are related to the ophiolitic basement of the Sierra Azul block and its outlier in the Santa Teresa Hills. Thin melange-bounded lenticular bodies of the serpentinized ultramafic rocks in the New Almaden block are locally traceable into larger elongate bodies of serpentinite or are mapped as sheared tongues extending from the larger bodies into the Franciscan Complex. One of these larger ultramafic bodies in the Santa Teresa Hills 7.5' quadrangle forms the base of the Santa Teresa Hills outlier of the Sierra Azul block (fig. 3), which also includes tectonically imbricated melange and a lense of fossiliferous serpentinitic sandstone and mudstone assigned to the Great Valley sequence

Franciscan Complex (Cretaceous and Jurassic)—The Franciscan Complex of California is divided into three broad, regionally extensive structural belts that generally include increasingly younger rocks from east to west; these belts are referred to, respectively, as the Eastern, Central, and Coastal belts (Bailey and others, 1964). Each of the Franciscan belts are further subdivided into a series of distinctive tectonostratigraphic terranes, characterized here as mappable, deformed, fault-bounded rock bodies having lithologies, ages, and (or) structural relations that distinguish them from adjacent juxtaposed rocks (Blake and others, 1984; McLaughlin and Ohlin, 1984). The Franciscan Complex in the map area consists entirely of the Central belt, which is subdivided into the following tectonostratigraphic terrane units:

fm **Melange of the Central belt (Upper Cretaceous)**—Melange matrix consists of penetratively sheared argillite and lithic metasandstone metamorphosed to pumpellyite- and, locally, to lawsonite-bearing assemblages. Metasandstone of matrix exhibits a weak to moderate cataclastic texture (textural zones 1 to 2 of Blake and others, 1967). Age of blueschist metamorphism of the metaclastic rocks is middle Cretaceous or younger. Penetrative deformation of rocks composing melange of the Franciscan Central belt postdated metamorphism of the metaclastic rocks and predated deposition of overlying early Eocene strata that contain conglomerate derived from unroofed Franciscan rocks. The penetrative fabric of the melange is, therefore, latest Cretaceous to Paleocene in age (McLaughlin and Clark, in press). The melange encloses higher grade blueschist and amphibolite blocks (sodic amphibole, jadeite, omphacite, and garnet-bearing assemblages) metamorphosed in the Jurassic, as well as more weakly metamorphosed blocks (phengite, pumpellyite, and lawsonite-bearing assemblages) of chert, limestone, and mafic igneous rocks. The melange components include small meter-scale blocks and slabs up to several kilometers long. These melange components are delineated as:

bs **Blueschist blocks**—Sodic amphibole ± jadeitic or omphacitic pyroxene ± lawsonite ± garnet ± stilpnomelane-bearing assemblages. Protoliths include eclogite, amphibolite, ultramafic to mafic igneous rocks, cherty pelagic rocks, and tuffaceous sedimentary rocks

am **Amphibolite blocks**—Rocks composed chiefly of green to brown hornblende ± garnet ± plagioclase ± lower temperature secondary assemblages including sodic amphibole ± lawsonite ± jadeitic pyroxene. Rocks may be strongly to weakly foliated

ch **Chert blocks**—Radiolarian chert, typically veined and recrystallized, locally metamorphosed to blueschist assemblages; in many places derived from Marin Headlands terrane, but probably also from other less certain oceanic pelagic terranes

v **Basaltic volcanic rock blocks**—Derived in part from Permanente and Marin Headlands terranes, but also from less certain oceanic sources, contains pumpellyite and, locally, incipient lawsonite ± sodic amphibole ± jadeitic pyroxene

cg **Conglomerate block**—Rounded, quartzite and dark, chert-clast, pebble to cobble conglomerate in melange on north shore of Chesbro Reservoir, in northern Mt. Madonna 7.5' quadrangle

mdi **Metadiorite block**—Present at one locality in the northern Mt. Madonna quadrangle. Although here included as a melange block, rock possibly is not part of the Franciscan but might be a younger intrusive associated with hydrothermal alteration

Permanente terrane (Cretaceous)—Divided into:

fpl **Foraminiferal limestone (Upper and Lower Cretaceous)**—Pelagic gray, gray-green, black, and pink, locally bituminous and (or) oolitic, foraminiferal limestone and minor black to gray, nodular to lenticular radiolarian chert. Foraminifers and sparse megafossils indicate that limestone formed at equatorial latitudes between the Late Cretaceous (Turonian) and the late Lower Cretaceous (Hauterivian). Limestone was deposited in shallow to deep water, open-ocean, seamount, and (or) oceanic plateau settings (Sliter and others, 1991). Lower part of limestone section is typically tuffaceous or cherty with fissile partings. Locally, near Uvas Reservoir in Mt. Madonna quadrangle, limestone is interbedded with red radiolarian chert in lower part of section

fpv **Volcanic rocks (Lower Cretaceous)**—Pillowed basalt flows, flow breccias, and andesitic tuff; locally, at Uvas Reservoir, contains siliceous tuff near top of volcanic sequence. Rocks are metamorphosed to prehnite-pumpellyite-chlorite assemblage. Basaltic rocks are geochemically similar to volcanic rocks of oceanic seamounts and plateaus (high Ti relative to V, FeO/MgO, and Cr and high P_2O_5) and commonly contain prominent ilmenite and sphene, and clinopyroxene as augite or titanaugite. Flow rocks along southwest shoreline of Uvas Reservoir in Mt. Madonna quadrangle contain abundant large inclusions of olivine-orthopyroxene cumulate gabbro. Stratigraphically high andesitic tuff along the northeast shoreline of Uvas Reservoir is geochemically similar to volcanic rocks of island arcs and locally contains undated radiolaria. $^{87}Sr/^{86}Sr$ values and geochemical data (McLaughlin and others, 1991) suggest a late Early Cretaceous age (135-120 Ma) for these volcanic rocks

fpt **Siliceous radiolarian-bearing tuff**—Mapped locally in northern Loma Prieta quadrangle as a lense within basalt flows and breccias. Relation to andesitic tuff of Uvas Reservoir not established

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

fms **Sandstone (Upper and (or) Lower Cretaceous)**—Coherent, bedded, locally conglomeratic, lithic graywacke sandstone with conspicuous chert and volcanic detritus, weakly reconstituted (textural zone 1 of Blake and others, 1967) and locally in depositional contact with underlying radiolarian chert. Age is younger than chert clasts in the conglomerate and sandstone of Mount Umunhum area, which contain late Early Cretaceous (Hauterivian) radiolaria (McLaughlin and others, 1991; Sliter and others, 1993). Elsewhere in Coast Ranges, sandstone in upper part of Marin Headlands terrane and equivalent Geysers terrane to the north contains fossils of early Late Cretaceous (Cenomanian) age (Murchey and Jones, 1984; McLaughlin and Ohlin, 1984)

fmc **Radiolarian chert (Lower Cretaceous and Jurassic)**—Red to green radiolarian chert formed in an oceanic setting, present as mappable blocks in melange or as part of composite olistoliths and slabs tens of meters to kilometers in length, surrounded by melange. Composite chert-bearing blocks locally include depositionally overlying graywacke and (or) basaltic rocks that may depositionally underlie chert sections. Radiolarian faunas in chert indicate that the ages of chert blocks and slabs in map area range from late Early Cretaceous (Valanginian or younger) to Early Jurassic (middle Toarcian to late Pliensbachian) (I. Hattori, written commun., 1992; Y. Isozaki, written commun., 1991; B. Murchey, written and oral commun., 1991 and 1992; Hagstrum and Murchey, 1993). In the Marin Headlands area and elsewhere in northern California, the top of the chert sequence has been determined to be as young as early Late Cretaceous (Cenomanian) (McLaughlin and Pessagno, 1978; Murchey and Jones, 1984), substantially younger than in map area. Ages of chert detritus in overlying graywacke unit in map area suggests that significant erosion of the chert section occurred during and prior to deposition of the graywacke

fmv **Basaltic volcanic rocks (Lower Jurassic)**—Basalt flows, massive to pillowed, locally vesicular in upper part, and minor tuff and pillow breccia. Basalt is extensively spilitized and metamorphosed to prehnite-pumpellyite and low blueschist grade mineral assemblages. Locally, thin lenses and pods of thermally metamorphosed interpillow pelagic deposits, including recrystallized limestone altered to calc-silicate mineral assemblages (epidote, pumpellyite, calcite-aragonite, and hematite) and hydrothermal chert (orbicular jasper), are present. Basaltic rocks from the Marin Headlands area are geochemically similar to mid-ocean-ridge basalts (Shervais, 1982; Shervais and Kimbrough, 1987), in contrast to basaltic rocks of the Permanente terrane in the map area, which have a geochemistry similar to oceanic plateaus or seamounts (McLaughlin and others, 1991). Based on the age of the oldest overlying radiolarian cherts, the basaltic rocks of the Marin Headlands terrane are Early Jurassic (Pliensbachian) or older

Sierra Azul Block and related rocks in Santa Teresa Hills

Tme **Shale and sandstone of Highland Way (lower Miocene to lower Eocene)**—Marine, hard, black, siliceous, carbonaceous shale and interbedded shale and arkosic sandstone. Includes beds with bathyal to abyssal foraminiferal fauna of early Eocene age (planktic foraminiferal zones P8-P9; nannoplankton zone CP-11) in lower part and beds with late Oligocene (Zemorrian) to early Miocene (Saucesian) foraminifers in upper part (K. McDougall, written commun., 1988; Sliter and others, 1993). Unit is fault bounded and present only along northeast side of the San Andreas fault

Sandstone and shale of Loma Chiquita Ridge (Eocene)—Unit age is based on scattered foraminifer localities and sparse molluskan fossils. Consists of:

Tlm **Siliceous mudstone**—Thin-bedded, fissile, brown siliceous mudstone, locally present in upper part of unit. The occurrence of *Parvamussium cf. P. stanfordense* (Arnold) locally in Loma Prieta quadrangle suggests a late to middle Eocene age (Narizian), according to C. L. Powell (written commun., 1988)

Tls **Sandstone and mudstone**—Thick- to thin-bedded, locally pebbly, quartzo-feldspathic and arkosic sandstone and interbedded micaceous carbonaceous mudstone

Tcm **Mottled mudstone and sandstone of Mount Chual (lower Eocene)**—Maroon-red to olive-green, mottled foraminiferal mudstone, locally containing glauconitic, bioclastic conglomerate and lithic sandstone at base. Basal bioclastic strata include detritus eroded from Franciscan Complex and Coast Range ophiolite. In Santa Teresa Hills, bioclastic beds were mapped separately as limestone (Bailey and Everhart, 1964). The bioclastic debris includes transported fragmental shallow-marine macrofossils and large Discocyclinnid foraminifers. The overlying mottled mudstone contains deep-marine (bathyal to abyssal) foraminifers of early Eocene age, assigned to planktic zones P8-P9 (McDougall, 1989, 1991; Sliter and others, 1993). The mottled mudstone is overlain by quartzo-feldspathic sandstone and interbedded carbonaceous green to brown mudstone. Unit locally includes:

Tcms **Sandstone lenses**—Interbedded within mottled mudstone and sandstone of Mount Chual, mapped locally

Tcml **Limestone**—Mapped locally in Santa Teresa Hills as lenticular bodies, perhaps detached submarine slide blocks, consisting predominantly of reworked bioclastic debris, including Discocyclinnid foraminifers, of mixed shallow and deep marine origin (K. McDougall and W. Sliter, oral and written commun., 1988). Limestone is correlative with undifferentiated conglomeratic bioclastic beds at base of mottled mudstone and sandstone of Mount Chual in main Sierra Azul block

Great Valley Sequence (Cretaceous and Jurassic)—Consists of:

Kus **Sandstone and shale (Upper Cretaceous)**—Arkosic to feldspathic wacke, lithic, laumontitic, locally massive or rhythmically interbedded with dark-gray to green shale. Upper part of unit is massive shale with carbonate concretions locally containing macrofossils of Late Cretaceous (Campanian) age (Elder, 1990)

Kuc **Conglomerate (Upper Cretaceous)**—Massive to thick-bedded lenses of pebble to boulder conglomerate, interbedded with lower and middle parts of sandstone and shale unit, composed predominantly of well-rounded clasts of porphyritic volcanic and intrusive rocks of mafic to intermediate composition and of granitic to gabbroic plutonic rocks. Conglomerate beds locally contain a transported shallow marine Late Cretaceous (Campanian) macrofossil assemblage (Elder, 1990)

KJm **Mudstone (Lower Cretaceous and Upper Jurassic)**—Dark-gray to green, locally siliceous, laumontized argillite and mudstone and minor thinly interbedded lithic arkosic wacke and carbonate concretions. Mudstone commonly contains macrofossils (mostly *Buchia*) of Early Cretaceous (Valanginian) to Late Jurassic (Tithonian) age (Elder and Miller, 1993). Tuffaceous chert in lower beds contains a Late Jurassic radiolarian fauna (B. Murchey, oral commun., 1990)

Jssp **Sedimentary serpentinite (Upper Jurassic)**—Serpentinitic sandstone and mudstone containing a diverse assemblage of fossils (including *Buchia* and ammonites) of Late Jurassic (Middle to Late Tithonian) age (Elder and Miller, 1993). Unit is present only in one small, fault-bounded lenticular outcrop area in Santa Teresa Hills quadrangle north of Calero Reservoir, interleaved with serpentinized ultramafic rocks of the Coast Range ophiolite. Lenticular screens of melange of the Franciscan Complex are also interleaved with the ultramafic rocks. The sedimentary serpentinite and the enclosing ultramafic rocks are continuous with and herein assigned to the Santa Teresa Hills outlier of the Sierra Azul block. The sedimentary serpentinite was originally assigned to the Franciscan Complex (Bailey and Everhart, 1964; Elder and Miller, 1993). The similarity in the lithology and age of the unit to extensive sedimentary serpentinites described in the Great Valley Sequence of western Sacramento Valley (Moiseyev, 1970), however, and association of the locality with ophiolitic rocks of the Santa Teresa Hills outlier lead us here to reassign the outcrop area to the lower part of the Great Valley sequence

Jt **Altered tuff of Mount Umunhum (Jurassic?)**—Deeply weathered, laumontized and hydrothermally altered tuffaceous volcanic rocks, less than 30 m thick, exposed locally on southwest side of Mount Umunhum. Composition of volcanic rocks ranges from basalt to dacite, with extensive alteration to chlorite and uralitic amphibole and with veins of quartz and epidote. Tuff is cut by fine-grained dioritic to microgabbroic dikes and sills. Entire unit is extensively sheared and bounded by attenuation faults, which cut flows at a low angle

Jdb **Diabase breccia of Mount Umunhum (Jurassic?)**—Up to 60 m of breccia composed of angular clasts of diabasic and dioritic composition, derived from underlying dikes and sills of the Coast Range ophiolite, exposed locally on southwest flank of Mount Umunhum. Breccia forms a thin, fault-bounded sheet conformable with overlying altered tuff and shale and sandstone of lower Great Valley sequence. Breccia may be tectonic, formed during attenuation faulting, or it may represent a sedimentary breccia formed as fault scarp talus in the Jurassic, during uplift and unroofing of the Coast Range ophiolite

Coast Range Ophiolite (Jurassic)—Consists of:

Jovb **Quartz-keratophyre breccia and siliceous tuff (Upper and Middle Jurassic)**—Unit is about 34 m thick. Breccia near top of unit is gray to white, coarsens upward, and is unsorted. In upper part, breccia consists of clasts up to boulder size of glassy, albite- and quartz- phenocryst-rich flow rock in a dark aphanitic tuff matrix, grading downward into centimeter-size clasts at base. Breccia is sharply underlain by fine-grained, flow-banded andesitic to dacitic tuff that displays grading, plane-laminar and cross-laminar structure, and loading features. Light-gray to reddish-black cherty tuff and radiolarian chert, in beds 1 to 6 cm thick, locally occurs between 2 and 5 m above the base of unit. Radiolaria in the chert suggest an Upper Jurassic (Oxfordian) age for upper chert beds and a Middle Jurassic (Bathonian or older) age for lower part of the banded tuff sequence (B. Murchey, oral commun., 1993; Sliter and others, 1993)

Jov **Basalt, andesite, and dacite (Middle Jurassic or older)**—Spilitic, pillowed basaltic to dacitic flows, breccias, and tuff, locally intruded by diabase sills

Joi **Intrusive complex (Jurassic)**—Dioritic to diabasic sheeted dikes and sills. Locally includes pegmatitic hornblende-albite dikes and dikelets with radiometric age (Pb/U-zircon) ≥168 Ma (J. Wooden, written commun., 1992)

Jog **Gabbro cumulates (Jurassic)**—Layered gabbro, with pyroxene-feldspar segregation layering and prominent uralitic and saussuritic alteration. Locally grades downward to ultramafic cumulates (Jou) but in most places unit is faulted above and below

Jou **Ultramafic cumulates (Jurassic)**—Layered ultramafic rocks with a cumulate texture, mapped locally in Sierra Azul block, commonly exhibiting residual interstitial plagioclase and segregation layering; consisting predominantly of pyroxene and olivine partially to extensively serpentinized. Rocks are locally cut by rodingitic gabbro dikes or enclose sheared gabbroic segregations

Jos **Serpentinized ultramafic rocks (Jurassic)**—Ultramafic rocks, including harzburgite and peridotite and ultramafic cumulates, generally serpentinized and sheared extensively. In Sierra Azul block, serpentinized ultramafic rocks commonly contain minor to trace amounts of residual feldspar, suggesting unit is partly correlative with the structurally overlying ultramafic cumulates unit. However, in New Almaden block and in Santa Teresa Hills outlier of the Sierra Azul block, serpentinized ultramafic rocks unit consists predominantly of harzburgite and peridotite exhibiting no evidence of a cumulate origin. The relative abundance of ultramafic cumulate rocks in the Sierra Azul block, compared to New Almaden block and the Santa Teresa Hills, may be the consequence of late Mesozoic to middle Tertiary attenuation faulting

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 unit is metamorphosed to low greenschist facies, lacks high pressure metamorphic minerals and, although undated, resembles Jurassic metaclastic rocks in western Sierra Nevada foothills (Mariposa Formation). Unit is tentatively regarded as a fault sliver of basement exhumed from beneath Franciscan Complex and Coast Range ophiolite (McLaughlin and Clark, in press) dbc **Diabase of Corralitos Creek (lower Miocene or Jurassic)**—Fault-bounded, altered intrusive diabase, basalt, and gabbro along northeast side of principal trace of the San Andreas fault, in headwaters of Corralitos Creek. Rock is mostly a breccia of diabase and gabbro inclusions in fine-grained olivine-augite-basalt matrix. Olivine and augite are extensively replaced by chlorite and rock is metamorphosed to prehnite-pumpellyite grade and cut by quartz and plagioclase veinlets. Augite is locally titaniferous. Age of unit is unknown but may be Jurassic and a part of the Coast Range ophiolite. Alternatively, the unit could be early Miocene in age and originally could have intruded the shale and sandstone of Highland Way, with which the diabase is now in fault contact

Southwest of San Andreas fault

Santa Cruz Block

Tp **Purisima Formation (Pliocene and upper Miocene)**—Thick-bedded to massive, locally crossbedded, bluish-gray, fine- to medium-grained sandstone, with abundant andesitic detritus 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 (Powell, 1998). In Nisene Marks State Park, the Purisima locally includes a tuff bed correlated with the late Pliocene (3.3 Ma) Nomlaki Tuff, which was erupted in the Cascade Range (A.M. Sarna-Wojcicki, oral commun., 1999)

Tsc **Santa Cruz Mudstone (upper Miocene)**—Medium-bedded and faintly laminated, pale-yellowish-brown siliceous organic mudstone. Benthic foraminifers from upper part of 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 granite-derived conglomerate locally at base. Sandstone is unconformable on older units and locally contains marine vertebrate and invertebrate fossils indicative of shallow-marine conditions (Clark, 1981)

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 are diagnostic of neritic depths and a middle Miocene (Luisian) age (Clark, 1981; Sliter and others, 1993)

Tlo **Lompico Sandstone (middle and lower Miocene)**—Thick-bedded to massive, yellowish-gray, fine- to medium-grained arkosic sandstone, locally calcareous and unconformable on older units. Locally includes a thick coquina bed containing mollusk fragments and *Balanus* (sessil barnacles) together with foraminifers, indicative of a shallow marine setting and middle Miocene age (Clark, 1981).

La Honda and Ben Lomond Subsidiary Blocks

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 bone fragments and benthic foraminifers indicative of bathyal depths and an early Miocene (Saucesian) age (K. McDougall, written commun., 1989). Present only north of the Zayante fault

Tv **Vaqueros Formation (lower Miocene and Oligocene)**—Thick-bedded to massive, yellowish-gray, fine- to coarse-grained arkosic sandstone with thick glauconitic sandstone bed in lower part. Upper beds contain *Dosinia* and *Ostrea* biostromes indicative of shallow-marine conditions. Benthic foraminifers in lower part of unit are diagnostic of bathyal depths and an early Zemorrian (Oligocene) age. Locally includes:

Tvb **Basalt flows (upper Oligocene)**—Locally present near base of unit. Radiometrically dated at 23.7 ± 0.7 Ma in the Felton quadrangle (Turner, 1970; Fox and others, 1985)

Tz **Zayante Sandstone (lower Miocene and Oligocene)`**—Thick-bedded to very thick bedded, poorly sorted, red muddy sandstone, green sandy siltstone, and cobble conglomerate with abundant granitic detritus, probably nonmarine. Locally intertongues with marine beds of Vaqueros Sandstone

San Lorenzo Formation (Oligocene and Eocene)—Consists of:

Tsr **Rices Mudstone Member (Oligocene and late Eocene)**—Nodular light-gray mudstone, locally bioturbated and glauconitic. Contains fish scales and benthic foraminifers indicative of middle bathyal depths and an 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 (late Eocene)**—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 (Clark, 1981; Sliter and others, 1993)

Butano Sandstone (Eocene)—Consists of:

Tbu **Undivided sandstone and shale (late to middle Eocene)**—Yellowish-gray, medium-bedded to massive, fine- to medium-grained arkosic sandstone with thin interbeds of olive-gray siltstone and shale, exposed between Zayante and San Andreas faults. Locally contains benthic foraminifers indicative of bathyal depths and a late to middle Eocene (Narizian) age (McDougall, 1989, 1991; Clark, 1981; Sliter and others, 1993; Wentworth and others, 1998). Base of unit is not exposed but surface exposures are probably underlain in subsurface between Zayante and San Andreas faults by unnamed older Eocene strata and, possibly, the Paleocene Locatelli Formation (McLaughlin and Clark, in press) and (or) Mesozoic sedimentary rocks. Interpretation of aeromagnetic and gravity data suggest these sedimentary rocks between San Andreas and Zayante faults are underlain by a gabbroic basement (McLaughlin and Clark, in press; Wentworth and others, 1998; Jachens and others, 1998).

Tbm **Mudstone (late Eocene)**—Dark-gray, thin-bedded nodular mudstone, commonly containing fish scales along bedding planes, and interbedded thin to thick, locally graded, arkosic sandstone beds. Unit is mapped locally between Zayante and San Andreas faults. Planktic and benthic foraminifers in unit are indicative of bathyal depths and a probable late Eocene (Narizian) age (McDougall, 1989, 1991)

Tbs **Sandstone (middle Eocene or younger)**—Thick-bedded to massive, fine- to coarse-grained arkosic sandstone mapped locally in lower exposed part of Butano Sandstone between Zayante and San Andreas faults (La Honda basin/subsidiary block). Base of unit not exposed

Tbc **Conglomerate (middle Eocene or younger)**—Very thick bedded to massive, light-gray, granular, medium- to coarse-grained arkosic sandstone with thick to very thick interbeds of sandy pebble conglomerate locally containing granitic boulders as long as 1 m. Mapped only in Ben Lomond subsidiary block southwest of Zayante fault, where it rests depositionally on Salinian granitic basement. Sandstone and conglomerate could be present in subsurface between the Zayante and San Andreas faults, underlain by older Tertiary and Mesozoic strata and gabbroic rocks (McLaughlin and Clark, in press; Wentworth and others, 1998; Jachens and others, 1998)

Kgr **Granitic and metamorphic rocks (Cretaceous and older)**—Granitic rocks ranging in composition from granodiorite to quartz diorite (Ross and Brabb, 1973), exposed southwest of the Zayante fault. 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)

Jmb **Mafic basement rocks (Jurassic)**—Subsurface basement unit present between the Zayante and San Andreas faults, shown only on structure sections. Unit is considered to be gabbro buried to a depth of 6 km, based on aeromagnetic and gravity models (Jachens and Griscom, in press; Jachens and others, 1998). These buried mafic rocks probably correlate with gabbroic rocks exposed along the San Andreas fault at Logan, California, about 30 km southeast of Loma Prieta Peak, radiometrically dated by U-Pb methods (zircon) at 160-165 Ma (Johnson and O'Neil, 1988; James and others, 1993)

dbm **Diabase and gabbro of Morrell Cutoff Road and Laurel Creek (lower Miocene or Jurassic)**—Undated, altered, coarse-grained, titanaugite-bearing diabase exposed beneath landslide debris in southern Los Gatos and northern Laurel quadrangles southwest of the San Andreas fault. Unit is faulted against Butano Sandstone, Rices Mudstone, and Vaqueros Sandstone. Pyroxenes in diabase are partly replaced by uralitic amphibole, plagioclase has undergone sodic alteration, rock is veined with laumontite and may contain pumpellyite. Diabase is compositionally similar to Diabase of Corallitos Creek in Loma Prieta quadrangle 12 km to the southeast, on the northeast side of the San Andreas fault. Unit may be Jurassic and related to gabbroic rocks of the Logan area near San Juan Bautista. Alternatively, the diabase and gabbro may be correlative with Oligocene volcanic rocks associated with the Vaqueros Sandstone southwest of the San Andreas fault.

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Geologic mapping was at a scale of 1:24,000, which is therefore the scale of maximum resolution. Enlargement of these maps to scales substantially less than 1:24,000 is here considered inappropriate.

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