Geologic Map and Map Database of Eastern Sonoma and Western Napa Counties, California

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Introduction

This report contains a new 1:100,000-scale geologic map, derived from a set of geologic map databases (Arc-Info coverages) containing information at 1:62,500-scale resolution, and a new description of the geologic map units and structural relations in the map area. Prepared as part of the San Francisco Bay Region Mapping Project, the study area includes the north-central part of the San Francisco Bay region, and forms the final piece of the effort to generate new, digital geologic maps and map databases for an area which includes Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma Counties. Geologic mapping in Lake County in the north-central part of the map extent was not within the scope of the Project. The map and map database integrates both previously published reports and new geologic mapping and field checking by the authors (see Sources of Data index map on the map sheet or the Arc-Info coverage eswn-so and the textfile eswn-so.txt). This report contains new ideas about the geologic structures in the map area, including the active San Andreas Fault system, as well as the geologic units and their relations.

Together, the map (or map database) and the unit descriptions in this report describe the composition, distribution, and orientation of geologic materials and structures within the study area at regional scale. Regional geologic information is important for analysis of earthquake shaking, liquifaction susceptibility, landslide susceptibility, engineering materials properties, mineral resources and hazards, as well as groundwater resources and hazards. These data also assist in answering questions about the geologic history and development of the California Coast Ranges.

The spatial scale of the map or map database, however, is not sufficiently detailed for site-specific investigations. Those seeking detailed information of that kind should consult the earthquake-hazards maps produced by the California Geological Survey or contact a licensed geologist or engineering-geologist.

The digital nature of the geologic map information is important for three reasons. First, the digital geologic map data can be combined with other digital map datasets (topography, groundwater information, landslide distribution) for rapid and complex analysis of geologic resources and hazards. Second, digital maps are more easily updated than printed maps. Third, the digital data is readily available to regional planners, local, state, and federal agencies, teachers, consultants, and others who are interested in the geologic data of the region.

The map area includes most of eastern Sonoma County and western Napa County, and small parts of Lake and Yolo Counties to the north. The map area is dominantly north-northwest trending valleys and ridges of mountains of modest height (mostly less than 800 m); there are low rolling hills in the southwestern corner. The northern and eastern mountains are largely uninhabited but the valley lands are the heart of the California premium wine industry (see Swinchatt and Howell, 2004, for a discussion of the relationship between wine and geology). The southwestern part of the map area is undergoing rapid suburban development.

This map is modified from and supercedes U.S. Geological Survey Miscellaneous Field Studies Map MF-483 (Fox and others, 1973). Two factors led to the decision to remap the area. First, there is new geologic information gathered in the area over almost 30 years, and second, tectonic theories for the California Coast Ranges have changed since the publication of the earlier map. The new tectonic theories have a strong influence on the depiction of through-going active faults, volcanic fields, folds, and other mapped features. Changes in the map include:

1) an updated depiction of the active Rodgers Creek, West Napa, and Maacama Fault Zones, as well as other dormant faults;
2) Quaternary surficial deposits throughout the map;
3) new mapping in Aetna Springs, Walter Springs, St. Helena, Chiles Valley, Rutherford, Kenwood, and Cotati quadrangles; and
4) reinterpretation of the Early Cretaceous section in the northeastern part of the map area.

This pamphlet also includes enhanced unit descriptions, and a discussion of the stratigraphy and structure of the map area not present in the earlier MF.

Stratigraphy

Mesozoic terrane complexes

The rock units in the San Francisco Bay region are made up of two components: 1) older rocks comprised of amalgamated, highly deformed tectonostratigraphic terranes that are displaced, at least in part, from hundreds to thousands of kilometers from their position of origin (allocthonous or parautochthonous); and 2) younger, less deformed rocks that overlie the amalgamated terranes and are roughly in their original position (except for San Andreas Fault system offsets and smaller dislocations described below). Throughout the map area, the older set of rocks are Mesozoic and the younger are Cenozoic.

The amalgamated older terranes are grouped into three related rock **complexes**, two of which crop out in the map area. One of these, the Great Valley complex, is made up of the Coast Range ophiolite and the Great Valley sequence. The Jurassic Coast Range ophiolite in the map area consists mostly of serpentinite, serpentinite-matrix mélange, gabbro, diabase, and basalt. The Great Valley sequence is composed of Jurassic and Cretaceous age sandstone, conglomerate, and shale. Although the sedimentary rocks and ophiolite have been tectonically separated almost everywhere in the map area, the Great Valley sequence was originally deposited on top of the ophiolite. This depositional relationship is preserved locally in the Chiles Valley and St. Helena quadrangles. The Great Valley complex represents the accreted and deformed remnants of arc-related Jurassic oceanic crust with a thick sequence of overlying turbidites, at least in part, related to the North American fore arc (parautochthonous).

The second set of amalgamated terranes, the Franciscan Complex, is composed of weakly to strongly metamorphosed graywacke, argillite, basalt, serpentinite, chert, limestone, and other rocks. The rocks of the Franciscan Complex in the map area are mostly derived from Jurassic to Cretaceous oceanic crust and pelagic deposits overlain by Late Jurassic to Late Cretaceous turbidites. Most Franciscan Complex rocks are little metamorphosed, but high-pressure, low-temperature metamorphic minerals are common in rocks that crop out as mélange blocks (Bailey and others, 1964) and in several fault-bounded lenses within the map area. High-grade metamorphic blocks in sheared but relatively unmetamorphosed argillite matrix (Blake and Jones, 1974) reflect the complicated history of the Franciscan Complex. The parts of the complex that crop out in the map area were subducted beneath the Coast Range ophiolite, a process that continued through Late Cretaceous time, after the deposition of the Franciscan Complex sandstone containing Campanian (Late Cretaceous) fossils that crops out just south of the map area (Blake and others, 2000). The youngest parts of the Franciscan Complex don't crop out in the map area, but are well exposed to the northwest in Sonoma and Mendocino Counties. These younger terranes include Eocene and younger sedimentary rocks (the Coastal Belt of the Franciscan Complex), so accretion of Franciscan Complex terranes in the region must have continued into Cenozoic time. However, the original relationship between the Coastal Belt Franciscan Complex terranes to the west and older Franciscan Complex and Great Valley complex rocks in the map area is not well understood. Because the Great Valley complex, including the Coast Range ophiolite, formed the hanging wall of the subduction zone where the Franciscan Complex terranes accreted, the contact between the two Mesozoic complexes is everywhere faulted (Bailey and others, 1964), and the Franciscan Complex presumably underlies the entire San Francisco Bay area east of the San Andreas Fault.

The third older rock complex, the granitic rocks of the Salinian complex, crops out only west of the San Andreas Fault Zone west of the map area.

Both the Franciscan Complex and the Great Valley complex have been further divided into a number of fault-bounded tectonostratigraphic terranes (Blake and others, 1982, 1984). When the terranes were first established, the prevailing methodology was to identify separate terranes if there was any doubt about stratigraphic linkage between structurally separated entities. As a result of further research, additional data, and, in particular, new fossil localities, the distribution and nature of the originally mapped terranes have been greatly modified (see Blake and others, 2000, 2002).

Terranes in the map area are shown in an index map on the map sheet (and in the map database eswn-terr.e00). See Blake and others (2002) for a detailed description of the Mesozoic terranes, a recent discussion of the origin of the Coast Range ophiolite and the Franciscan mélange, as well as a description of the terranes listed above.

Strata of two terranes in the Great Valley complex crop out within the map area. The strata and ophiolitic rocks in the Napa, Sonoma, and Rutherford quadrangles are probably part of the Del Puerto terrane, based on the presence of large masses of keratophyre in rocks of similar structural position along strike southeast of the map area (Graymer and others, 2002). The extensive outcrops of Great Valley complex rocks north and east of Napa Valley are laterally equivalent to the type area of the Elder Creek terrane, which is characterized by the absence of keratophyre and the presence of ophiolite breccia in the basal sedimentary strata (Blake and others, 1984). There are also some outcrops of Great Valley complex rocks within, just east, and just west of Napa Valley that lack distinguishing characteristics, and remain undifferentiated.

The Franciscan Complex in the map area comprises two terranes as well as mélange. A tiny fault-bounded sliver of graywacke (Kfss) in the northwesternmost part of the map area is tip of one of several much larger bodies of coherent sandstone that make up the Devils Den terrane (Blake and others, 2002). Metagraywacke (Kfm) of the Yolla Bolly terrane forms two large bodies northeast of Napa Valley, although the body in the Walter Springs and Aetna Springs quadrangles is somewhat disrupted by faults and obscured in places by a structurally overlying slab of Great Valley complex serpentinite (sp). Franciscan Complex mélange (fsr), which is not a true terrane but is formed by tectonic mixing of rocks of several terranes, crops out throughout the map area.

Tertiary Stratigraphy

In the San Francisco Bay area, Franciscan detritus in the Paleocene strata overlying Great Valley complex rocks in Rice Valley and the eastern Diablo Range (Bartow, 1985), as well as unmetamorphosed early Eocene quartzofeldspathic strata overlying Franciscan Complex metamorphic rocks (Pampeyan, 1993), indicate that much of the tectonic activity that brought the two Mesozoic complexes together was complete by early Tertiary time.

In the map area, most Paleogene strata was probably eroded prior to the Miocene and Pliocene eruption of the Sonoma Volcanic field, as little early Tertiary strata is exposed at the base of the volcanic deposits. A large fault-bounded block of Eocene and Paleocene strata (Td) is preserved in the area west of Napa Valley in the Napa quadrangle, which is in the same structural block as a thick section of Eocene strata that unconformably overlie Late Cretaceous strata southeast of the map area in the Cordelia quadrangle (Graymer and others, 2002). A very small body of Paleogene(?) strata (Ts), at the border of Chiles Valley and Walter Springs quadrangles, in angular unconformity on lower Great Valley sequence strata (KJgvl), has been tentatively correlated (Wagner, 1975) with Paleogene strata that conformably overlie the Late Cretaceous rocks northwest of Vacaville, east of the map area. In the western part of the map area, rocks of the Franciscan Complex and the Great Valley complex are unconformably overlain by Miocene sedimentary and volcanic rocks.

Tertiary stratigraphic relations in the area also reveal significant late Tertiary and Quaternary fault offset. For example, in the southwest part of the Napa quadrangle Sonoma Volcanics overlie more than 850 m (2800 ft) of Oligocene to late Miocene marine strata (Tkt, Tms, Tci, Tn) that are completely missing just to the east where Sonoma Volcanics overlie Eocene strata (Td). This juxtaposition suggests that many kilometers of offset along the Carneros Fault moved deposits from different depositional basins or from widely separated parts of the same basin. In the same way, the informally named (Graymer and others, 2002) Burdell Mountain volcanics (Tbm), which are correlated with the Quien Sabe Volcanics in San Benito County, have been offset about 175 km (Jones and Curtis, 1991) by the faults of the East Bay Fault system.

Structure

The mapped structures are divided here into two general categories, younger and older. The younger structures are north-northwest trending faults and associated folds generated by the transpressional Pacific-North American plate margin. The faults have a predominately right-lateral strike-slip offset, but also have a component of fault-normal compression, as shown by the uplift of fault-parallel ridges and the formation of fault-parallel folds (Jones and others, 1994). These younger structures probably initiated with the establishment of the transpressional plate margin in the region in the wake of the northward migration of the Mendocino Triple Junction, which passed through the San Francisco Bay region between about 12 and 4 Ma. The structures therefore cut and deform late Miocene and younger rocks.

Important among these younger structures in the map area are the Quaternary-active, including Holocene-active, faults of the San Andreas Fault system, such as the Maacama, Healdsburg, Rodgers Creek, and West Napa Faults, shown as magenta (Holocene-active; Hart and Bryant, 1999) and orange (Quaternary-active) on the map. The West Napa Fault was previously not mapped as Holocene-active in the map area, but it is mapped as Holocene-active south of the map area in the Cuttings Wharf quadrangle (California Division of Mines and Geology, 1983), and recent work by Langenheim and others (2006) shows that the 2000 M 5.2 Yountville earthquake probably occurred on the West Napa Fault. In the Rutherford quadrangle along the western margin of Napa Valley we map right-deflected streams that could result from right-lateral offset associated with Holocene activity on the West Napa Fault. However, the detailed paleoseismic work required to prove Holocene activity on the West Napa Fault in the map area was beyond the scope of this study.

The mountainous topography west of Napa Valley resulted from latest Pliocene and Quaternary uplift associated with the younger structures. The mountain range was absent in Pliocene time when obsidian pebbles from the Sonoma Volcanics at Glass Mountain, north of Saint Helena, were transported west-southwest and deposited in the alluvial fans that formed the Glen Ellen Formation (McLaughlin and others, 2004). Thus, there has been at least 650 m of uplift since Glen Ellen Formation deposition (about 2.78 Ma or less, based on the isotopic age of the Glass Mountain obsidian; McLaughlin and others, 2004).

The structures in the mountains east of Napa Valley are more complex. Extensive compressional deformation of Mesozoic rocks in this area resulted in imbricate faulting and overturned folds (see cross section A-A' on the map sheet and discussion below). Some of these structures have evidence of Pliocene or younger activity, whereas others are mapped as overlapped by young (<4 Ma) Sonoma Volcanics. Swinchett and Howell (2004) hypothesized that uplift of the mountains east of Napa Valley was caused by Neogene thrusting on these structures that has continued into the Quaternary, and has generated massive landslides. However, there are also normal faults that cut the Sonoma Volcanics in the area (fig. 1), and the regional gravity expression (Langenheim and others, 2003; Langenheim, written commun.) indicates there may be basins, now filled with volcanic rock, that could be grabens. Resolution of all the details of the structural history of this area is beyond the scope of this regional study. However, the overall picture (fig. 2) is consistent with Pliocene and Quaternary compressional deformation superimposed on earlier extensional deformation.

Correlation of the Oligocene to Miocene strata (Tkt, Tms, Tci, Tn) in Carneros Valley (Napa and Sonoma quadrangles) with a similar sequence in central Contra Costa County (Fox, 1983) suggests there has been about 45 km of long-term right-lateral offset along the Carneros Fault since Neroly Sandstone deposition (about 10 Ma, Graymer and others, 1994). The Carneros Fault appears to be truncated by the Saint John Mountain Thrust, which is probably a compressional structure related to the post-Glen Ellen Formation compression and uplift described above. This truncation suggests that the Carneros Fault offset was largely complete by 2.8 Ma, the maximum age of the top of the Glen Ellen Formation.

The Petaluma Valley Fault is probably also largely a late Miocene to Pliocene structure. The fault cuts and offsets by about 35 km the Roblar tuff of Sarna-Wojcicki (1992); the tuff is about 6 Ma (Graymer and others, 2002). By mid-Pliocene time, however, fault offset had largely transferred east to the Rodgers Creek, Healdsburg, and Maacama Faults (Graymer and others, 2002; McLaughlin and others, 2004).

The older structures in the map area, which are cut and deformed by the late Miocene and younger structures, are of two types. The first type are exposed in the area northeast of Napa Valley, where Great Valley complex and Franciscan Complex rocks are imbricated along northwest trending to west-northwest trending reverse faults and associated folds. These structures are possibly the remnants of deformation associated with Cretaceous accretion of Franciscan Complex rocks (Phipps, 1984). The second type of older structure in the map area is a broad, regional deformation manifested as a somewhat disrupted east-dipping homocline northeast of Lake Berryessa and reverse fault repetition of Great Valley sequence strata in the eastern part of the map area. These older structures probably formed between Eocene and middle-Miocene, as shown by the large angular unconformity at the base of the Putnam Peak Basalt east of the map area (Graymer and others, 2002). However, the more modest deformation of the Pliocene Tehama Formation in that same homocline, also east of the map area (Graymer and others, 2002), as well as the uplift of early to late Pleistocene alluvial deposits in the map area (QTc, Qoa), suggest that deformation on the second type of older structures may have continued into the Quaternary. The young deformation probably results from the same compression that may have formed the mountains east of Napa Valley. This compression also causes the ongoing eastward-directed wedging of Franciscan Complex rocks beneath the upturned western portion of the Great Valley complex (fig. 2).

Figure 1. West-dipping normal faults within Sonoma Volcanics in the mountains east of Napa Valley. These faults, with a maximum offset of about one meter, are subparallel to the west-dipping normal fault contact between the Sonoma Volcanics and structurally underlying serpentinite. Normal faults in this area are overlapped by younger parts of the Sonoma Volcanics and are overprinted by younger compressional deformation.

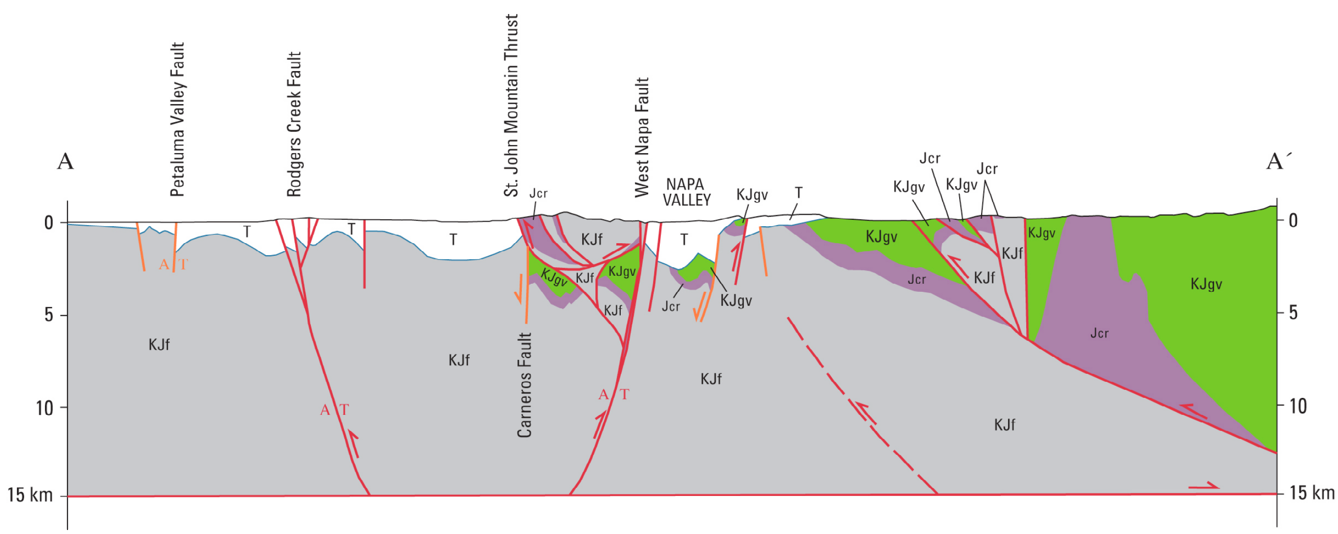

Figure 2. Generalized and downward-expanded interpretive version of cross section A-A′. Geologic units are grouped into four categories: T, Tertiary rocks; KJf, Franciscan Complex rocks; Jcr, Coast Range ophiolite; KJgv, Great Valley sequence. Quaternary- and late Pliocene-active faults are shown in red, Pliocene and Miocene faults are shown in orange, the base of the Tertiary strata is shown in blue. A/T symbol denotes the direction of strike-slip offset (A, away from the viewer; T, toward the viewer). The horizontal fault at 15 km depth is a simplified representation of the midcrustal decollement at the brittle-ductile transition (Jones and others, 1994). Note that older extensional faults (orange) are overprinted by younger compressional structures both east and west of Napa Valley, that uplift and compression east of Napa Valley is associated with a blind thrust (shown as dashed), and that Franciscan Complex rocks (KJf) have been wedged under Great Valley complex rocks (Jcr and KJgv) in late Pliocene to Quaternary time.

DESCRIPTION OF MAP UNITS

Unit descriptions are divided into three sections: 1) Quaternary surficial deposits (similar throughout the map area); 2) early Pleistocene and older rocks (because fault offset has juxtaposed depositional basins or parts of depositional basins that were once kilometers or tens of kilometers apart, the assemblage of these units in adjacent areas may be quite different); 3) Mesozoic rocks of the Great Valley complex and Franciscan Complex. Although there are few exposures of Franciscan Complex rocks in the map area, they probably underlie much of the map area at depth.

Throughout the description of map units we depart from U.S. Geological Survey standard usage, and use geochronologic nomenclature instead of chronostratigraphic nomenclature. The reason for this is that in tectonically active areas such as that described herein, the simple application of superposition inherent in chronostratigraphic nomenclature can be misleading. Older rock units are often found above younger units of similar type as the result of ongoing tectonic uplift or large-scale faulting. Therefore systematic use of the term upper (as in upper Pleistocene) to mean younger, and lower (as in lower Miocene) to mean older, is frequently at odds with the reality in the field. Some examples from the map area include Quaternary alluvial terrace deposits, which are always older in higher terrace levels, and Cretaceous Franciscan Complex rocks, which have been everywhere accreted below Jurassic Coast Range ophiolite.

SURFICIAL DEPOSITS

Descriptions of surficial deposits are modified from Knudsen and others (2000), Helley and Graymer (1997), Atwater (1982), and Helley and Barker (1979).

af **Artificial fill (Historic)**—Undifferentiated man-made deposit of various materials and ages, including some dredge spoils, levee fill, and fill over Bay mud and also road embankments, earthen dams, and railroad grades. Some are compacted and quite firm, but fills made before 1965 are nearly everywhere not compacted and consist simply of dumped materials. Much of this unit is mapped based on topographic expression on the most recent U.S. Geological Survey 7.5-minute quadrangle maps

afbm **Artificial fill over Bay mud (Historic)—**Artificial fill placed in the estuarine environment to create new land

alf **Artificial levee fill (Historic)**—Man-made deposit of various materials and ages forming artificial levees as much as 20 ft (6.5 m) high. Some are compacted and quite firm, but fills made before 1965 are almost everywhere not compacted and consist simply of dumped materials. Levees bordering waterways of the mudflats and large streams were first emplaced as much as 150 years ago. The distribution of levee fill conforms to levees shown on the most recent U.S. Geological Survey 7.5-minute quadrangle maps

Qhc **Stream channel deposits (late Holocene)—**Loose sand, gravel, and cobbles with minor clay and silt deposited within active, natural stream channels

Qhay **Younger alluvium (late Holocene)—**Loose sand, gravel, silt, and clay deposited in active depositional environments and judged to be less than 1000 years old based on geomorphic expression or historic records of deposition

Qhty **Terrace deposits (late Holocene)—**Moderately sorted to well-sorted, moderately bedded to well-bedded sand, gravel, silt, and minor clay deposited as point bar and overbank deposits and judged to be less than 1000 years old based on geomorphic expression, position relative to the modern river system, and historic records of deposition

Qha **Alluvium (Holocene)—**Sand, silt, and gravel deposited in fan, valley fill, terrace, or basin environment. Mostly undissected by later erosion. Typically mapped in smooth, flat valley bottoms in medium-sized drainages and other areas where geomorphic expression is insufficient to allow differentiation of depositional environment

Qht **Terrace deposits (Holocene)—**Moderately well sorted sand, silt, gravel, and minor clay deposited in point bar and overbank settings. Mostly undissected by later erosion

Qhf **Alluvial fan deposits (Holocene)**—Moderately to poorly sorted and moderately to poorly bedded sand, gravel, silt and clay deposited where streams emanate from upland regions onto valley floors or plains. Mostly undissected by later erosion. In places, Holocene deposits may only form a thin layer over Pleistocene and older deposits

Qhff **Fine-grained alluvial fan deposits (Holocene)**—Mostly silt and clay with interbedded lenses of sand and minor gravel deposited at the distal margin of large alluvial fan complexes

Qhl **Natural levee deposits (Holocene)**—Moderately sorted to well-sorted sand with some silt and clay deposited by streams that overtop their banks during flooding. Natural levees are often identified by their low, channel-parallel ridge geomorphology

Qhb **Basin deposits (Holocene)**—Very fine silty clay to clay deposits occupying flat-floored basins and flat areas

Qhbm **Bay mud (Holocene)**— Water-saturated estuarine mud, predominantly gray, green and blue clay and silty clay underlying marshlands and tidal mud flats of Napa River outlet. Contains lenses of well-sorted, fine sand and silt, a few shelly layers (oysters), and peat. Interfingers with and grades into fine-grained deposits at the distal edge of Holocene fans. Unit is time-transgressive and generally occupies the area between the modern shoreline and the historical limits of tidal marsh

Qa **Alluvium (Holocene and late Pleistocene)**—Sand, silt, and gravel deposited in fan, valley fill, terrace, or basin environments. Similar to unit Qha, this unit was deposited during either late Pleistocene or Holocene time

Qt **Terrace deposits (Holocene and late Pleistocene)**—Moderately sorted to well-sorted, moderately bedded to well-bedded sand, gravel, silt, and minor clay deposited on relatively flat, undissected stream terraces. Similar to unit Qht, this unit was deposited during either late Pleistocene or Holocene time

Qf **Alluvial fan deposits (Holocene and late Pleistocene)**—Poorly sorted, moderately bedded to poorly bedded sand, gravel, silt, and clay deposited in gently sloping alluvial fans. Similar to unit Qhf, this unit was deposited during either late Pleistocene or Holocene time

Qls **Landslide deposits (Holocene and late Pleistocene)**—Chaotic deposits of sand, silt, clay, angular boulders, and blocks of bedrock up to hundreds of meters long deposited by gravity driven sliding and flow. These deposits are mostly mapped based on their characteristic geomorphic expression. Only some of the larger landslide deposits are mapped, mostly where the deposits obscure the underlying bedrock relations. Locally, landslide deposits are composed primarily of volcanic rocks and are subdivided into the following subunits:

Qlsa **Andesitic composition**

Qlsr **Rhyolitic composition**

Qpa **Alluvium (late Pleistocene)**—Poorly sorted to moderately sorted sand, silt, and gravel. This unit is mapped on gently sloping to level alluvial fan or terrace surfaces where separate fan, terrace, and basin deposits could not be delineated. Late Pleistocene age is indicated by depth of stream incision, development of alfisols, and lack of historical flooding

Qpt **Terrace deposits (late Pleistocene)**—Moderately sorted to well-sorted, moderately bedded to well-bedded sand, gravel, silt, and minor clay deposited on relatively flat, undissected stream terraces. Late Pleistocene age is indicated by development of alfisols and height of the terrace above stream level

Qpf **Alluvial fan deposits (late Pleistocene)**—Poorly sorted, moderately bedded to poorly bedded sand, gravel, silt, and clay deposited in gently sloping alluvial fans. Late Pleistocene age is indicated by erosional dissection and development of alfisols. These deposits are about 10 percent denser and have 50 percent greater penetration resistance than unit Qhf (Clahan and others, 2000)

Qoa **Alluvium (late and early Pleistocene)**—Sand, silt, clay, and gravel deposits with little or none of the original geomorphic expression preserved. Moderately to extremely dissected, in places tens or hundreds of meters above the current depositional surface, and capped by well-developed soils

Qlso **Landslide deposits (late and early Pleistocene)**—Chaotic deposits of sand, silt, clay, angular boulders, and blocks of bedrock up to hundreds of meters long deposited by gravity driven sliding and flow. These deposits are mostly mapped based on their characteristic geomorphic expression. The older age of these deposits is indicated by characteristic degradation of landslide geomorphic expression. Only some of the larger landslide deposits are mapped, mostly where the deposits obscure the underlying bedrock relationships

EARLY QUATERNARY AND TERTIARY STRATA

Clear Lake Volcanics

A few outliers of the large volcanic complex around Clear Lake, that crops out mostly in Lake County to the north of the map area, are exposed in the northern part of the map area. This very young volcanic center (Holocene to Pliocene) is the northernmost manifestation of northward younging volcanism thought to be related to the initiation of the San Andreas Fault system (Fox and others, 1985b). The near-surface magma and remnant heat from plutonic rocks related to the volcanic center is probably driving the hydrothermal activity at The Geysers geothermal field northwest of the map area. For a more complete look at the Clear Lake Volcanics, see Hearn and others (1995). In the map area, the Clear Lake volcanics are informally subdivided into the following units:

Qr **Rhyolite (Pleistocene)**—Thick flows of biotite rhyolite. Mapped as part of the rhyolite of Alder Creek by Hearn and others (1995), which has yielded 3 K/Ar ages averaging 1.12 ± .02 Ma

QTob **Olivine basalt (Pleistocene and Pliocene)**—Dark-gray and black olivine-porphyry basalt and basalt, and gray to brownish-gray basaltic andesite and andesite. This unit also includes some interlayered rhyolite, rhyolite tuff, and conglomerate. Rocks from this unit at Table Mountain (Detert Reservoir quadrangle) have yielded a K/Ar age of 1.96 ± .06 Ma (Donnelly-Nolan and others, 1981), and those from the southeast quarter of Middletown quadrangle have yielded K/Ar age of 1.45 ± .12 Ma (Hearn and others, 1995). Correlated rocks north of the map area have yielded K/Ar ages as young as 1.33 ± .53 Ma, and as old as 2.2 ± .2 Ma (Hearn and others, 1995)

QTt **Tuff (Pleistocene and (or) Pliocene)**—White rhyolite tuff, interbedded with unit QTob, mapped locally where outcrop extent is large enough

Tr **Rhyolite (Pliocene)**—Mostly white, altered rhyolite dome and flow rock, with some blocks of black, glassy rhyolite. Mapped as rhyolite of Pine Mountain by Hearn and others (1995), this unit has yielded a K/Ar age of 2.06 ± .02 Ma

QTc **Cache Formation (Pleistocene and (or) Pliocene)**—Nonmarine pebbly sandstone, conglomerate, siltstone, and tuff. Only mapped in small outcrops interbedded with Clear Lake Volcanics (QTob) northwest of Lake Berryessa in the Walter Springs quadrangle

QTge **Glen Ellen Formation (early Pleistocene? and Pliocene)**—Brown- to buff-weathering, interbedded siltstone, fine- to coarse-grained sandstone, pebbly and cobbly sandstone, conglomerate, and tuff. Sandstone is tuffaceous or feldspathic arenite. Coarse clasts include mafic to silicic volcanics, obsidian, pumice, varicolored chert, and graywacke. The northwestern part of the Glen Ellen Formation contains more interbeds of tuff. Radiometric ages from interbedded tuff show that the Glen Ellen Formation is 3.1 Ma or younger (McLaughlin and others, 1999). Some obsidian pebbles within the Glen Ellen Formation have been correlated with obsidian in the rhyolite of the Sonoma Volcanics (Tsr) at Glass Mountain north of the town of Saint Helena, which has yielded an Ar/Ar age of about 2.8 Ma (McLaughlin and others, 2004), indicating that the Glen Ellen Formation is at least in part younger than that. The basal part of the Glen Ellen Formation is coeval with and interfingers with the upper part of the Sonoma Volcanics

QThg **Huichica and Glen Ellen Formations, undivided (early Pleistocene? and Pliocene)**—The Huichica Formation in its type area south of the map area (Graymer and others, 2002) is composed of massive, yellow siltstone, well-sorted quartz-lithic sandstone, and poorly consolidated gravel. Detritus includes varicolored chert, quartz-lithic sandstone, biotite wacke, rhyolite, metachert, and tuff reflecting derivation from Franciscan Complex, Great Valley complex, and older Tertiary rocks. The Huichica Formation also includes a tuff bed near the base that is correlated with the 4.0 ± .2 Ma Lawlor Tuff (Sarna-Wojcicki, 1976). The Huichica and Glen Ellen Formations are similar and cannot be distinguished in much of the map area

Sonoma Volcanics (Pliocene And late Miocene)

The Sonoma Volcanic field includes rhyolite, dacite, andesite, and basalt tuff, glass, flow rock, pyroclastic breccia, and intrusives that were probably derived from several eruptive centers, along with interbedded volcaniclastic sedimentary rocks. Radiometric ages of the Sonoma Volcanics range from 2.6 ± .3 Ma to 8.24 ± .22 Ma (Fox, 1983; Fox and others, 1985b; Youngman, 1989). The Sonoma Volcanics, along with the Clear Lake Volcanics, Donnell Ranch Volcanics, and the informally named Burdell Mountain volcanics, are thought to have formed as part of the northward younging series of volcanic centers related to initiation of the San Andreas Fault system (Fox and others, 1985a). For more about the Sonoma Volcanics, see Fox (1983) and Sarna-Wojcicki (1976).

Tsv **Sonoma Volcanics, undivided (Pliocene and late Miocene)**

Tsr **Rhyolite flows**—Includes intercalated rhyolite tuff in places

Tsri **Rhyolite plugs**—Also includes dikes, and may be in part extrusive

Tsrs **Soda rhyolite flows**—May also include minor intrusive rocks

Tsrp **Perlitic rhyolite**—Includes intrusive and extrusive rocks

Tsrb **Rhyolite breccia**

Tsa **Andesite to basalt lava flows**

Tsai **Andesite to dacite plugs**—Also includes areas of small plugs and dikes not mapped separately

Tsb **Basalt flows**—Includes areas of columnar basalt

Tsfd **Basalt or andesite lava flows and sediments**—Thin flows and interlayered diatomite and fine-grained sedimentary rocks

Tst **Pumiceous ash-flow tuff**—Pumiceous tuff, locally welded, and aglomeratic tuff, andesite and basalt flow rocks, tuff breccia, and bedded tuff

Tswt **Welded ash-flow tuff**—Also includes minor partly welded and unwelded ash-flow tuff

Tstx **Tuff(?)**—Massive, hard, xenolithic rock, probably welded tuff

Tsag **Agglomerate**—Also contains volcanic breccia and tuff breccia

Tslt **Tuff breccia**—Also contains interlayered agglomerate and tuff

Tsft **Tuff**—Similar to unit Tst, thinly interlayered with basalt or andesite lava flows

Tss **Volcanic sand and gravel**—Crossbedded, coarse-grained volcanic sandstone, and cobble conglomerate with well-rounded to angular andesite and basalt clasts. Also includes tuffaceous silt, bedded tuff, clay, and diatomite

Tssd **Diatomite**—Also includes interbedded sand, gravel, and tuff

Twg **Wilson Grove Formation (late Pliocene to late Miocene)**—Mostly massive or thick-bedded, buff-weathering, light-gray, fine-grained quartz-lithic arenite. Also includes locally beds of mollusk- and gastropod-shell hash, pebble to boulder conglomerate, and tuff. Fossils range in age from late Miocene to late Pliocene (Travis, 1952; Naidu, 1999, Powell and others, 2004). The lower part of the unit west of the map area overlies and is interbedded with late Miocene and early Pliocene basalt flow rock and rhyolite tuff. The volcanic rocks yielded radiometric ages ranging from 4.26 ± .27 Ma to 7.83 ± .29 Ma (Fox and others, 1985b, Bartow and others, 1973, Sarna-Wojcicki, 1976). Unit is probably, at least in part, the marine equivalent of the informally named estuarine sand and gravel of Cotati (Tc) and the alluvial Petaluma Formation (Tp).

Tc **Sand and gravel of Cotati (Pliocene and late Miocene)**—Informally named, thick-bedded to massive, white quartz arenite, buff-weathering siltstone, and pebble conglomerate. Coarse clasts include varicolored chert, gray or brown laminated chert, red, gray, and white quartz- and plagioclase porphyry volcanics, black basalt, blueschist, graywacke, greenstone, quartz, and black hornfels. Locally present within the sandstone beds are estuarine bivalve, crustacean, and gastropod fossils. The laminated chert clasts may be derived from middle Miocene Claremont Formation cherts (Fox, 1983), although the nearest outcrop of these rocks is several tens of kilometers to the southeast. However, offset on the Hayward-Rodgers Creek/Healsdburg and the Hayward-Petaluma Valley Faults have probably moved this unit and the Wilson Grove Formation (Twg) at least 60 km from the southeast since deposition (Graymer and others, 2002). The sand and gravel of Cotati overlies and is interbedded with late Miocene and early Pliocene basalt and andesite flow rock of the Sonoma Volcanics (Tsv, Tsa). In the map area, outcrops of interbedded Sonoma Volcanics yielded K/Ar ages of 4.26 ± .27 Ma, whereas just to the west a volcanic body interbedded in the unit is dated 7.83 ± .29 Ma (Fox and others, 1985b). The sand and gravel of Cotati overlies the Donnell Ranch Volcanics (Tdr), and interfingers on the west with the marine Wilson Grove Formation (Twg). The age of the sand and gravel of Cotati is not as well constrained as that of the Wilson Grove Formation, but must postdate the underlying volcanics and include the age of interlayered basalt and andesite (Tsv, Tsa). Because the sand and gravel of Cotati interfingers with the Wilson Grove Formation, we consider it to be the estuarine equivalent to, at least part of, the Wilson Grove. The sand and gravel of Cotati is in places indistinguishable from the Petaluma Formation (Tp), although some beds of unit Tc may be distinguished by having estuarine fossils or by having small, very spherical pebbles in conglomerate. As described below, unit Tc is probably the estuarine equivalent of at least part of the alluvial Petaluma Formation (Tp). Because the sand and gravel of Cotati is so similar in places to the Petaluma Formation, we have mapped the boundary between the two units in the Cotati quadrangle at the Petaluma Valley Fault, which separates verifiable sand and gravel of Cotati outcrops from the main extent of Petaluma Formation. However, the two formations probably interfingered during deposition, and therefore some of what is mapped herein as sand and gravel of Cotati might actually be Petaluma Formation

Tp **Petaluma Formation (early Pliocene and late Miocene)**—Gray weathering, brown and green pebble and cobble conglomerate, gritstone, lithic and quartz-lithic arenite, and mudstone. Coarse clasts include varicolored chert, quartz- and plagioclase-porphyry rhyolite and andesite, vesicular andesite, laminated rhyolite, white tuff, basalt, quartz, graywacke, greenstone, and laminated chert. Land-mammal fossils are locally present within the sandstone and conglomerate, whereas lacustrine and estuarine ostracods, fish remains, and thin-shelled mollusks (Liniecki-Laporte and Anderson, 1988) have been found in the mudstone. Mammal fossils originally described as late Pliocene (Stirton, 1939) are now known to be late Miocene (late Hemphilian, McFadden, 1998). Early Pliocene mammal fossils have been found elsewhere within the unit, however (early Blancan, Bartow and others, 1973; Davies, 1986). South of the map area, the Petaluma Formation also includes a tuff bed correlated with the informally named Roblar tuff of Sarna-Wojcicki (1992), which yielded radiometric ages around 6 Ma (Sarna-Wojckici, 1976). Also south of the map area the Petaluma Formation contains a layer of basalt flow rock (8.52 ± .18 Ma, Fox and others, 1985b) probably equivalent to the mafic member of the Donnell Ranch Volcanics (Youngman, 1989; Graymer and others, 2002). A rock of similar composition and age has been reported in the subsurface of the map area from the Murphy Well near the south edge of the Glen Ellen quadrangle (Fox and others, 1985b; D. Wagner, California Geological Survey, oral commun., 2003)

Tdr **Donnell Ranch Volcanics (late Miocene)**—Rhyolite, andesite, and basalt. Along Highway 101 at Meacham Hill in the Cotati quadrangle the unit is vesicular andesite. The rocks at Meacham Hill yielded a K/Ar age of 13.62 ± 2.39 Ma (Fox and others, 1985b), and so were previously correlated with the Burdell Mountain volcanics (Graymer and others, 2002), but more recent Ar/Ar analysis yielded a more reliable age of about 8.5 Ma (D. Wagner, California Geological Survey, written commun.), which is more consistent with correlation to the Donnell Ranch Volcanics just south of the map area in the Sears Point and Petaluma River quadrangles (Youngman, 1989). Donnell Ranch Volcanics in that area have similar mixed volcanic lithology. A small body of rhyolite just west of the map area in the Two Rock quadrangle is also correlated with the Donnell Ranch Volcanics (Graymer and others, 2002). The type Donnell Ranch Volcanics have in turn been correlated with the Berkeley Hills volcanics (Fox and others, 1985a, Youngman, 1989) several tens of kilometers southeast of the map area in Alameda and Contra Costa Counties. The three correlated volcanic bodies were separated from each other by offset on the East Bay Fault System, including the Rodgers Creek and Petaluma Valley Faults in the map area (Graymer and others, 2002)

Tn **Neroly Sandstone (late Miocene)**—White- or buff-weathering, blue, blue-gray, gray, or brown, fine- to coarse-grained lithic and quartz-lithic sandstone and siltstone. Locally includes gray or pinkish-brown mudstone. In the Rutherford quadrangle, this unit also includes interlayered basalt and basaltic sandstone

Tci **Cierbo Sandstone (late Miocene)**—Outcrop in the map area is limited to the northern part of Carneros Valley (Napa and Sonoma quadrangles). Massive, fine-grained, white-weathering, light- to medium-gray quartz-lithic sandstone and mudstone. Locally contains lenses of pebbly shell hash. Pebbles include porphyry andesite and basalt, black hornfels argillite, quartz, and green chert

Tbm **Burdell Mountain volcanics (late and middle? Miocene)**—Informally named andesite and basalt flow rock, in places plagioclase and hornblende porphyry, locally vesicular. This unit in the map area yielded Ar/Ar ages of about 11.1 Ma (Ford and others, 2003) and a less reliable K/Ar age of 12.5 ± 1.4 Ma (Davies, 1986). It is part of a much larger volcanic complex that includes volcanic rocks of similar age (K/Ar ages of 11.76 ± 0.44 Ma to 12.47 ± 0.74 Ma; Fox and others, 1985b) and lithology as far south as Burdell Mountain in Marin County (see Blake and others, 2000). The Burdell Mountain volcanics are correlated with the Quien Sabe Volcanics, which lie about 175 km to the southeast (Jones and Curtis, 1991; McLaughlin and others, 1996; Graymer, 1999; Blake and others, 2000). The Burdell Mountain volcanics were brought to their current position by offset on the East Bay Fault System, including the Petaluma Valley, Rodgers Creek, Healdsburg, Carneros, and West Napa Faults within the map area (Graymer and others, 2002)

Tms **Unnamed sandstone (middle Miocene)**—Medium- to fine-grained, white to light-gray sandstone and shale with marine fossils. This unit forms very little outcrop in the map area, like the Cierbo Sandstone (Tc) limited to the northern part of Carneros Valley, but Weaver (1949) collected a distinctive fossil suite from it

Tkt **Kirker Tuff (early Miocene and(or) Oligocene)**—Bluish-gray, gray, or brown, fine- to coarse-grained quartz-lithic marine sandstone with conglomerate locally present in basal part. The sandstone is locally fossiliferous. In one outcrop at the top of the unit the sandstone contains small pebbles of pumice, suggesting that this unit may correlate to the tuffaceous sandstone that overlies the San Ramon Sandstone in its type area in central Contra Costa County (Graymer, 2000). The accepted age for the San Ramon Sandstone was early Miocene, based on Addicott (1970) who noted that Weaver and others (1944) had reclassified the molluscan zone of the San Ramon Sandstone fauna (*Echinophoria apta*) from late Oligocene to early Miocene. However, Kleinpell (1938) reported early Zemorrian foraminifera from the type area of the San Ramon Sandstone. Weaver and others (1944) classified the Zemorrian as early Miocene (probably based on the relationships in this unit), but more recent work on foraminiferal zonation by McDougall (1983) has shown the Zemorrian zone to be entirely Oligocene. In addition, the tuffaceous sandstone and tuff that overlies the San Ramon Formation in its type area is correlated with the Kirker Tuff in eastern Contra Costa County, which is considered to be Oligocene. The contradiction in accepted ages of the two units and the contradiction of foraminiferal and molluscan zonation caused Graymer (2000) to use the less restricted age indicated for both the San Ramon Sandstone and the overlying tuffaceous sandstone in central Contra Costa County, and we follow that usage here

Td **Unnamed sandstone (Eocene and Paleocene)**—Yellow-brown, red-brown, or gray-weathering, white, clean, quartz, quartz-lithic, and quartz-biotite sandstone, siltstone, and minor mudstone. This unit is distinctly bedded, and locally crossbedded or thin bedded. The sandstone is locally glauconitic. The mudstone, where exposed, contains foraminifers. A sparse molluscan fauna (Weaver, 1949) and unpublished oil-company microfossil data suggest that this unit may contain Paleocene beds at its base, but no mappable lithologic difference was found during this study

Ts **Unnamed sandstone (Eocene? or Paleocene?)**—Quartzose sandstone. Mapped only in two very small outcrops west of Lake Berryessa in the Walter Springs and Chiles Valley quadrangles. Correlated based on similar lithologies by Wagner (1975) with the Paleocene Martinez Formation mapped to the east and southeast of the map area, but Eocene quartz-rich sandstone is also known from those areas. No fossils are known from the outcrops in the map area

GREAT VALLEY COMPLEX

Great Valley sequence

KJgv **Sandstone, shale, and conglomerate (Late Cretaceous to Late Jurassic)**—Undivided strata of the Great Valley sequence. Mapped outcrop is limited to small areas in Yountville, Rutherford, and Saint Helena quadrangles where outcrops lack known age diagnostic fossils. Elsewhere in the map area, divided into:

Kgvu **Sandstone, shale, and conglomerate (Late Cretaceous)**—Medium-gray, hard, fine- to coarse-grained quartz-biotite wacke in thin to thick beds separated by layers of well-bedded, gray to black mudstone. This unit also contains minor pebble conglomerate. Late Cretaceous (probably Campanian) foraminifers were collected by the authors from an outcrop of this unit in the Sonoma quadrangle. Unit is distinguished from the older part of the Great Valley sequence (KJgvl) by a greater amount of sandstone and by its fossil content. However, in the Napa and Sonoma quadrangles exposures are limited by plant cover, so the contact between the two units is inferred and questionably located. In the northeasternmost part of the map area, as well as to the east of the map area, the Late Cretaceous part of the Great Valley sequence is further subdivided into formations, although only the Venado Formation crops out in the map area

Kv **Venado Formation (Late Cretaceous)**—Massive and thick-bedded, brown-weathering, greenish-gray, shale-chip bearing, biotite-lithic wacke. Includes minor siltstone, more common near the top, and conglomerate near the base. At Monticello Dam, east of the map area, the basal part also includes a layer of megabreccia, angular blocks of sandstone and siltstone up to 3.5 m in length in a conglomeratic mudstone matrix (see Peterson, 1965, Lowe, 1972). Unit contains sparse foraminifers of Late Cretaceous (Turonian) age

KJgvl **Sandstone and shale (Early Cretaceous and Late Jurassic)**—Mostly rhythmically thin-bedded fine-grained quarz-lithic wacke and greenish-gray to black mudstone and shale. Locally, unit contains beds of massive sandstone or conglomerate that can be tracked for several kilometers before pinching out. In the northeast part of the map area, unit was divided by Sims and others (1973) into three distinct stratigraphic units, but Weaver (1949) recorded Late Jurassic and Early Cretaceous *Buchias* in both the structurally lower and upper parts of the unit. In addition, Boyd (1956) reported Early Cretaceous (Albian) ammonites from an area east of the map area now covered by the southeasternmost part of Lake Berryessa. Because the fossils in the structurally upper parts of the unit are reported from concretions in shale beds, it is unlikely that the fossils have been redeposited as clasts. It is more likely that there are unmapped structures present that have disrupted the original stratigraphic sequence. These structures are not recognized, probably because of the similar lithology throughout most of this unit, and will probably only be mappable through the application of thorough paleontological studies. In the southeastern part of the map area unit is distinguished from the younger part of the Great Valley sequence (Kgvu) by a greater amount of claystone and mudstone and by the presence of *Buchia* near the Bella Oak Mine west of Oakville in the Rutherford quadrangle (Fix and Swinney, 1949). Locally subdivided into:

KJsp **Sedimentary serpentinite member**—Only crops out in the Knoxville quadrangle

Jk **Knoxville Formation (Late Jurassic)**—Distinctly bedded black shale and thin beds of biotite-lithic wacke. Although unit elsewhere has been mapped to include rocks that include Early Cretaceous fossils, Knoxville Formation in its type area in the Knoxville quadrangle includes only Late Jurassic fossils. Therefore, as used herein, this unit is limited to rocks that contain only Late Jurassic fossils. In the Knoxville quadrangle, this unit also includes, mapped locally:

Jsp **Sedimentary serpentinite member**

Jgvm **Mélange**—Highly sheared to moderately sheared and disrupted sandstone and shale identical to unit KJgvl with intercalated large lenses of basalt breccia (Jv). Deformation ranges from small scale isoclinal folds to slaty cleavage in the shale and complete disruption of the sandstone. Quartz and calcite veins are common. Northwest of Lake Berryessa this unit also contains large slabs of serpentinite and layers of sedimentary serpentinite. This unit has either undergone repeated imbrication along reverse or thrust faults that tectonically interleaved the sedimentary rocks with the previously underlying volcanic rocks; or the unit formed as an olistostrome from volcanic- and ultramafic-bearing submarine debris flows and has undergone considerable later deformation. This unit is mapped as depositionally underlying the Knoxville Formation (Jk), so must predate that unit

Coast Range ophiolite

Jv **Basaltic pillow lava and breccia (Jurassic)**—Mostly massive black basalt, also includes amygdaloidal and plagioclase-porphyry basalt, pillow basalt, basalt breccia, diabase, and keratophyre. Coast Range ophiolite volcanic rocks are distinguished from Franciscan Complex volcanic rocks by lack of metamorphism and alteration, by association with intrusive rocks, and by lack of associated ribbon chert

Jmi **Mafic intrusive complex (Jurassic)**—Fine- to coarse-grained gabbro and diorite

Jgb **Gabbro (Jurassic)**—Locally also contains plagioclase-porphyry diabase, pyroxenite, and serpentinite

sp **Serpentinite (Jurassic)**—Mainly sheared serpentinite, but also includes massive serpentinized harzburgite. Crops out as extensive fault-bounded slabs and sheets, smaller fault slivers, and blocks and lenses tectonically entrained into Franciscan Complex mélange (fsr). In places, also includes:

sc **Silica-carbonate rock**—Orange-weathering, pervasively altered serpentinite composed mostly of amorphous silica and dolomite

spm **Serpentinite-matrix mélange**—Sheared serpentinite matrix includes blocks, up to several kilometers in length, of pyroxenite, gabbro, basalt, and high-grade metamorphic rocks

FRANCISCAN COMPLEX

fsr **Mélange**—Sheared argillite and graywacke matrix enclosing blocks and lenses of graywacke, chert, metachert, greenstone, serpentinite, silica-carbonate rock, blueschist (metasediment and metabasalt), eclogite, amphibolite, limestone, and quartz-mica schist. Enclosed blocks and lenses range in size from pebbles to several hundred meters. The matrix graywacke has yielded Late Jurassic (Tithonian) fossils west of the map area. High-grade blocks northwest of the map area have yielded metamorphic ages of about 138-150 Ma (K/Ar, Kelley, 1982; Lee and others, 1964). Chert blocks in Marin County west of the map area are almost all similar to coherent chert of the Marin Headlands terrane (Murchey and Jones, 1984). Mélange blocks are probably derived from tectonic detachment of pieces of surrounding coherent Franciscan Complex and Great Valley complex terranes. Large blocks and lenses mapped locally include:

sp **Serpentinite**—Probably detached from the Coast Range ophiolite and structurally incorporated into the mélange (Blake and others, 2000)

fs **Graywacke**

ch **Chert**

fgc **Greenstone and chert**

gs **Greenstone**

m **High-grade metamorphic rocks**

Kfss **Sandstone (Late Cretaceous, Turonian?)**—Distinctly bedded, brown-weathering, greenish-gray, muscovite- and K-feldspar-bearing feldspathic-lithic wacke and dark-gray, mica-bearing siltstone and slate. The sandstone in this area has locally an incipient foliation (textural zone 2A of Jayko and others, 1986), bears muscovite instead of biotite, and has not yielded age-diagnostic fossils, but is otherwise similar to the Turonian fossil-bearing wacke near Lake Sonoma to the west of the map area (Blake and others, 2002)

Kfm **Metagraywacke (Late and Early Cretaceous)**—Brown-weathering, gray, foliated (textural zone 2A of Jayko and others, 1986), jadeite-bearing metagraywacke. Similar jadeite-bearing metagraywacke elsewhere in the Coast Ranges has yielded radiometric metamorphic ages of 90-110 Ma (Wakabayashi, 1999; Mattinson and Echevarria, 1980), and has yielded Late Jurassic (Tithonian) fossils (Crawford, 1976)

Kfmc **Metachert (Late and Early Cretaceous)**—Fine-grained banded chert and red ribbon chert, locally foliated. In places the metachert contains bluish bands or layers indicating the presence of blue amphibole. Radiolarians were observed, but not studied, in hand samples from the map area. Similar metachert outside the map area has yielded both Late Jurassic and Early Cretaceous radiolaraians and other fossils (Murchey and Jones, 1984)

Kfmg **Metagreenstone (Late and Early Cretaceous)**—Greenstone with patchy occurrence of blue amphiboles, locally folitated

KJfs **Graywacke and mélange (Early Cretaceous and Late Jurassic)**—Massive to distinctly bedded, brown-, orange-, and white-weathering, green to gray, lithic wacke and dark-gray or black siltstone, shale, and slate, grading into mélange consisting of sheared argillite and graywacke matrix enclosing blocks and lenses of sedimentary, metamorphic, and volcanic rocks (see fsr above for a more complete description of mélange). Because the contact between coherent graywacke and mélange is gradational (derived from different amounts of shearing), and because of the size of, and amount of cover in, the map area, it was not possible in this study to differentiate everywhere between coherent graywacke and mélange. Coherent graywacke bodies also locally include conglomerate and pebbly sandstone. Coarse clasts in the map area include quartz-porphyry rhyolite, volcanolithic gritstone and breccia, gray chert, plagioclase-porphyry basalt, and plagioclase-augite-porphyry andesite. West of the map area, coarse clasts also include black chert, quartzite, hornfels, granite, lithic wacke, blueschist, greenstone, green chert, marble, amphibolite, and quartz-mica schist. In many places, the graywacke contains conspicuous large chips of black and green shale. Coherent sedimentary rocks range from completely unfoliated to moderately foliated (Textural Zones 1-2A of Jayko and others, 1986). Late Jurassic (Tithonian) fossils have been found in both the coherent graywacke and the mélange matrix west of the map area (Bailey and others, 1964, D.L. Jones, USGS, written commun.). Interbedded chert in similar coherent graywacke in Marin County yielded Late Jurassic to Early Cretaceous microfossils (Murchey and Jones, 1984). Chert pebbles from conglomerate yielded Late Triassic to Early Jurassic microfossils (Seiders and Blome, 1984). This unit is distinguished from most other Franciscan Complex graywacke by its very high lithic content

KJfc **Chert (Cretaceous to Jurassic)**—Red chert and ribbon chert in coherent slabs, commonly associated with greenstone (KJfgs). Locally radiolarians are observed in hand-sample, but paleontological analysis of those fossils was beyond the scope of this project, and no studies of those fossils have been published. Franciscan Complex cherts elsewhere yielded radiolarians ranging in age from Middle Jurassic to Late Cretaceous

KJfgc **Greenstone and chert (Cretaceous to Jurassic)**—Coherent slabs of interleaved maroon-weathering pillowed greenstone, basalt breccia, and red chert and ribbon chert

KJfgs **Greenstone (Cretaceous to Jurassic)**—Coherent slabs of orange-brown- and maroon-weathering, dark gray, black, and green, massive and pillowed greenstone, basalt, and andesite. In some outcrops the basalt is plagioclase-porphyritic. Locally rocks of this unit are amygdaloidal and(or) vesicular

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Digital Publication and Database Description

Introduction

This publication includes, in addition to cartographic and text products, geospatial (GIS) databases and other digital files. These files are published on the Internet through the U.S. Geological Survey publication web site (http://pubs.usgs.gov). The database files are particularly useful because they can be combined with any type of other geospatial data for purposes of display and analysis. The other files include digital files that support the databases, and digital plot files that can be used to display and print the cartographic and text products included in this publication.

Following is the digital publication and database description. It contains information about the content and format of the digital geospatial databases used to create this digital geologic map publication. **This information is not necessary to use or understand the geologic information in the map and preceding geologic description.** This chapter mostly contains information useful for those who intend to use the geospatial databases. However, it also contains information about how to get digital plot files of the map and geologic pamphlet via the Internet, information about how the map sheet and pamphlet were created, and information about getting copies of the map sheet and text from the U.S. Geological Survey.

In addition, in 1999, the USGS adopted policies regarding revision of publications, introducing the concept of version numbers similar to those used in the computer industry. The following chapter contains information about the version system and about how to access a revision list explaining changes from version 1.0, if any have been made.

The digital map database, compiled from previously published and unpublished data, and new mapping by the authors, represents the general distribution and orientation of bedrock and surficial deposits in the mapped area. Together with the accompanying text file (eswnsim.txt, eswnsim.pdf, or eswnsim.ps), the database provides current information on the geologic structure and stratigraphy of the area covered. The database delineates map units that are identified by general age and lithology following the stratigraphic nomenclature of the U.S. Geological Survey. The scale of the source maps limits the spatial resolution (scale) of the database to 1:62,500 or smaller. The content and character of the database, as well as three methods of obtaining the database, are described below.

For those who don't use digital geologic map databases

For those interested in the geology of the mapped area who do not use an ARC/INFO compatible Geographic Information System (GIS), we have provided two sets of plotfiles (PostScript format and another in Adobe Acrobat PDF format); each set contains an image of a geologic map sheet and explanation, and an explanatory pamphlet (see the sections “PostScript plot files” and “PDF plot files” below).

Those interested who have computer capability can access the plot file packages in any of the three ways described below (see the section “Obtaining the digital database and plotfile packages”). However, it should be noted the plot file packages do require gzip and tar utilities to access the plot files. Therefore additional software, available free on the Internet, may be required to use the plot files (see section “Tar files”).

Those without computer capability can obtain plots of the map files through USGS Map-On-Demand service for digital geologic maps (see section “Obtaining plots from USGS Map On Demand Services”) or from an outside vendor (see section “Obtaining plots from an outside vendor”).

SIM 2956 Digital Contents

This report consists of three digital packages. The first is the PostScript Plotfile Package, which consists of PostScript plot files of a geologic map, explanation sheet, and geologic description. The second is the PDF Plotfile Package, and contains the same plotfiles as the first package, but in Portable Document Format (PDF). The third is the Digital Database Package, and contains the geologic map database itself and the supporting data, including base maps, map explanation, geologic description, and references.

PostScript plotfile package

This package contains the images described here in PostScript format (see below for more information on PostScript plot files):

eswnmap.ps	A PostScript plotfile containing an image of the geologic map and base maps at a scale of 1:100,000 along with a map key including terrane map, index maps, and correlation chart.
eswnsim.ps	A PostScript plotfile that contains an image of the pamphlet containing detailed unit descriptions and geological information, a description of the digital files associated with the publication, plus references cited.

PDF plotfile package

This package contains the images described here in PDF format (see below for more information on PDF plot files):

eswnmap.pdf	A PDF file containing an image of the geologic map and base maps at a scale of 1:100,000, along with a map key including terrane map, index maps, and correlation chart.
eswnsim.pdf	A PDF file that contains an image of the pamphlet containing detailed unit descriptions and geological information, a description of the digital files associated with the publication, plus references cited.

Digital database package

The database package includes geologic map database files for the map area. The digital maps, or coverages, along with their associated INFO directory have been converted to uncompressed ARC/INFO export files. ARC export files promote ease of data handling, and are usable by some Geographic Information Systems in addition to ARC/INFO (see below for a discussion of working with export files). The ARC export files and the associated ARC/INFO coverages and directories, as well as the additional digital material included in the database, are described below:

ARC/INFO export file	Resultant Coverage	Description of Coverage
eswn-geol.e00	eswn-geol/	Polygon and line coverage showing faults, depositional contacts, and rock units in the map area.
eswn-strc.e00	eswn-strc/	Point and line coverage showing strike and dip information and fold axes.
eswn-xsl.e00	eswn-xsl/	Line coverage showing the trend of the cross section (eswn-xsa described below)

The database package also includes the following ARC coverages, and files:

ARC Coverages, which have been converted to uncompressed ARC/INFO export files:

ARC/INFO export file	Resultant Coverage	Description of Coverage
eswn-quad.e00	eswn-quad/	Polygon, line, and annotation coverage showing index map of quadrangles in the map area.
eswn-corr.e00	eswn-corr/	Polygon and line coverage of the correlation table for the units in this map database. This database is not geospatial.

eswn-so.e00	eswn-so/	Polygon and line coverage showing sources of data index map for this map database.
eswn-terr.e00	eswn-terr/	Polygon and line coverage of the index map of tectonostratigraphic terranes in the map area. (Terranes are described eswnsim.txt or eswnsim.ps)
eswn-xsa.e00	eswn-xsa/	Polygon and line coverage of SW to NE trending cross section.

ASCII text files, including explanatory text, ARC/INFO key files, PostScript plot files, and a ARC Macro Language file for conversion of ARC export files into ARC coverages:

eswnsim.ps	A PostScript plotfile that contains an image of the pamphlet containing detailed unit descriptions and geological information, a description of the digital files associated with the publication, plus references cited.
eswnsim.pdf	A PDF version of eswnsim.ps
eswnsim.txt	A text-only file containing an unformatted version of eswnsim.ps without figures.
eswnfig1.tif	A TIFF file of Figure 1 from eswnsim.ps
eswnfig2.tif	A TIFF file of Figure 2 from eswnsim.ps
eswnso.txt	ASCII text-only file containing sources of data related to coverage eswn-so
import.aml	ASCII text file in ARC Macro Language to convert ARC export files to ARC coverages in ARC/INFO.
sim2956d.met	A parsable text-only file of publication level FGDC metadata for this report.
sim2956e.rev	A text-only file describing revisions, if any, to this publication.

The following supporting directory is not included in the database package, but is produced in the process of reconverting the export files into ARC coverages:

info/	INFO directory containing files supporting the databases.

Tar files

The three data packages described above are stored in tar (UNIX tape archive) files. A tar utility is required to extract the database from the tar file. This utility is included in most UNIX systems, and can be obtained free of charge over the Internet from Internet Literacy's Common Internet File Formats Webpage (http://www.matisse.net/files/formats.html). Both tar files have been compressed, and may be uncompressed with **gzip**, which is available free of charge over the Internet via links from the USGS Public Domain Software page (http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/public.html). In addition, several common proprietary freeware programs such as Stuffit Expander (http://www.aladdinsys.com/expander/index.html) and shareware programs such as WinZip (http://www.winzip.com) can handle both tar file extraction and gzip uncompression. When the tar file is uncompressed and the data is extracted from the tar file, a directory is produced that contains the data in the package as described above. The specifics of the tar files are listed below:

Name of compressed tar file	Size of compressed tar file (uncompressed)	Directory produced when extracted from tar file	Data package contained
-----------	---------------------	----------------------	----------------------------
sim2956a.tgz	17 MB (48 MB)	eswnps	PostScript Plotfile Package
sim2956b.tgz	28 MB (29 MB)	eswnpdf	PDF Plotfile Package
sim2956c.tgz	59 MB (82 MB)	eswngeo	Digital Database Package

PostScript plot files

For those interested in the geology of the map area who don't use an ARC/INFO compatible GIS system we have included a digital data package containing two PostScript plot files. One file (eswnmap.ps) contains a color plot of the geologic map at 1:100,000 scale, along with a terrane map, index maps, correlation chart, and map key. A second file (eswnsim.ps) contains the geologic and digital publication description and discussion (this pamphlet).

The PostScript image of the geologic map and map explanation is 36 inches wide by 50 inches high, so it requires a large plotter to produce paper copies at the intended scale. In addition, some plotters, such as those with continual paper feed from a roll, are oriented with the long axis in the horizontal direction, so the PostScript image will have to be rotated 90 degrees to fit entirely onto the page. Some plotters and plotter drivers, as well as many graphics software packages, can perform this rotation. The pamphlet is on 8.5 by 11 inch pages.

The PostScript plotfiles for maps were produced by the ‘postscript’ command with compression set to zero in ARC/INFO version 8.1. The PostScript plotfiles for pamphlets were produced in Microsoft Word 10, Adobe Illustrator CS, and Adobe Arcrobat 6.0 on a Macintosh computer using the Destination PostScript File option from the Print command.

PDF plot files

A second digital package contains PDF versions of the map sheet and pamphlet described above. Adobe Acrobat PDF (Portable Document Format) files are similar to PostScript plot files in that they contain all the information needed to produce a paper copy of a map or pamphlet and they are platform independent. PDFs require less memory to store than PostScript files and are therefore quicker to download from the Internet. In addition, PDF files allow for printing of portions of a map image on a printer smaller than that required to print the entire map without the purchase of expensive additional software. All PDF files in this report have been created from PostScript plot files using Adobe Acrobat Distiller. In test plots we have found that paper maps created with PDF files contain almost all the detail of maps created with PostScript plot files. We would, however, recommend that those users with the capability to print the large PostScript plot files use them in preference to the PDF files.

To use PDF files, the user must install a copy of Adobe Acrobat Reader, which is available **free** from the Adobe website (http://www.adobe.com). Please follow the instructions given at the website to download and install this software. Once installed, the Acrobat Reader software contains an on-line manual and tutorial.

There are two ways to use Acrobat Reader in conjunction with the Internet. One is to use the PDF reader plug-in with your Internet browser. This allows for interactive viewing of PDF file images within your browser. This is a very handy way to quickly look at PDF files without downloading them to your hard disk. The second way is to download the PDF file to your local hard disk, and then view the file with Acrobat Reader. **We strongly recommend that large map images be handled by downloading to your hard disk**, because viewing them within an Internet browser tends to be very slow.

To print a smaller portion of a PDF map image using Acrobat Reader, it is necessary to cut out the portion desired using Acrobat Reader and the standard cut and paste tools for your platform, and then to paste the portion of the image into a file generated by another software program that can handle images. Most word processors (such as Microsoft Word) will suffice. The new file can then be printed. Image conversion in the cut and paste process, as well as changes in the scale of the map image, may result in loss of image quality. However, test plots have proven adequate. The full version of Adobe Acrobat (not free) can crop out a section of a PDF map image without loss of resolution.

An alternative that maintains the high resolution of the PDF map image is to use a raster image editor (such as Photoshop Elements) that can handle PDF files. This can take a long time and produces a large file (>100 MB), but results in a raster image file that can be cropped as desired. Tests with this method have provided excellent results.

Obtaining the Digital Database and Plotfile Packages

The U.S. Geological Survey now supports a set of graphical pages on the World Wide Web. Digital publications (including this one) can be accessed via these pages. The location of the main Web page for the entire USGS is:

http://www.usgs.gov

The Web server for digital publications from the Western Region is:

http://geopubs.wr.usgs.gov

Go to:

http://pubs.usgs.gov/sim/2007/2956

to access this publication. This web page provides access to the digital dabase files, and also affords easy access to the PostScript and PDF plot files for those who do not use digital databases.

Obtaining plots from a commercial vendor

Those interested in the geologic map, but who use neither a computer nor the Internet, can still obtain the information. Many vendors can download the plotfiles via the Internet. Important information regarding file formats is included in the sections "Tar files," "PostScript plot files," and "PDF plot files" above, so be certain to provide a copy of this document to your vendor.

Obtaining plots from USGS Map On Demand Services

U.S. Geological Survey provides a plot-on-demand service for maps. In order to obtain plots of this map, contact Map On Demand Services at:

U.S. Geological Survey
Information Services
Box 25286
Federal Center
Denver, CO 80225-0046

(303) 202-4200
1-888-ASK-USGS

FAX: (303) 202-4695

e-mail: infoservices@usgs.gov

Be sure to include with your request the SIM number **and** the exact names, as listed in the Database Contents section above, of the plotfiles you require.

Revisions and version numbers

From time to time, new information and mapping, or other improvements, will be integrated into this publication. Rather than releasing an entirely new publication, the USGS has adopted a policy of using version numbers similar to that used in the computer industry. The original version of all publications will be labeled Version 1.0. Subsequent small revisions will be denoted by the increase of the numeral after the decimal, while large changes will be denoted by increasing the numeral before the decimal. Pamphlets and map products will be clearly marked with the appropriate version number. Information about the changes, if any, that have been made since the release of Version 1.0 will be listed in the publication revision file. This file will be available at the publication web site (see above), and will also be included in the digital database package. A simplified version of the revision list will be included in the publication metadata.

Digital database format

The databases in this report were compiled in ARC/INFO, a commercial Geographic Information System (Environmental Systems Research Institute, Redlands, California), in part with version 3.0 of the menu interface ALACARTE (Fitzgibbon and Wentworth, 1991, Fitzgibbon, 1991, Wentworth and Fitzgibbon, 1991). The files are in either GRID (ARC/INFO raster data) format or COVERAGE (ARC/INFO vector data) format. Coverages are stored in uncompressed ARC export format (ARC/INFO version 7.x). ARC/INFO export files (files with the .e00 extension) can be converted into ARC/INFO coverages in ARC/INFO (see below) and can be read by some other Geographic Information Systems, such as MapInfo via ArcLink and ESRI's ArcView (version 1.0 for Windows 3.1 to 3.11 is available for free from ESRI's web site: http://www.esri.com). The digital compilation was done in version 8.1 of ARC/INFO.

Converting ARC export files

ARC export files are converted to ARC coverages using the ARC command IMPORT with the option COVER. To ease conversion and maintain naming conventions, we have included an ASCII text file in ARC Macro Language that will convert all of the export files in the database into coverages and create the associated INFO directory. From the ARC command line type:

```
Arc: &run import.aml
```

ARC export files can also be read by some other Geographic Information Systems. Please consult your GIS documentation to see if you can use ARC export files and the procedure to import them.

Digital compilation

The geologic map information was digitized from stable originals of the geologic maps at 1:62,500 scale. The author manuscripts (pen on mylar) were scanned using a Altek monochrome scanner with a resolution of 800 dots per inch. The scanned images were vectorized and transformed from scanner coordinates to projection coordinates with digital tics placed by hand at quadrangle corners. The scanned lines were edited interactively by hand using ALACARTE, color boundaries were tagged as appropriate, and scanning artifacts visible at 1:24,000 were removed. The maps were further edited and new information was added by on-screen digitizing using 1:24,000 scale raster images of standard U.S. Geological Survey topographic maps (DRGs) for reference. Structural data was digitized by on-screen digitizing using scanned and vectorized 1:62,500-scale maps described above or by digitizing from 1:24,000-scale field sheets using a digitizing table or on-screen using 1:24,000-scale DRGs for reference.

Base maps

Base Map layers were derived from published digital maps (Aitken, 1997) obtained from the U.S. Geological Survey Geologic Division Website for the Western Region (http://wrgis.wr.usgs.gov). Please see the website for more detailed information about the original databases. Because the base map digital files are already available at the website mentioned above, they are not included in the digital database package.

Faults and landslides

This map is intended to be of general use to engineers and land-use planners. However, its small scale does not provide sufficient detail for site development purposes. In addition, this map does not take the place of fault-rupture hazard zones designated by the California State Geologist (Hart and Bryant, 1999). Similarly, because only some of the landslides in the mapped area are shown, the database cannot be used to completely identify or delineate landslides in the region. For a more complete depiction of landslide distribution, see Nilsen and others (1979), Ellen and others (1997), and Wentworth and others (1997).

Spatial resolution

Uses of this digital geologic map should not violate the spatial resolution of the data. Although the digital form of the data removes the constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. The fact that this database was edited at a scale of 1:62,500 means that higher resolution information is not present in the dataset. Plotting at scales larger than 1:62,500 will not yield greater real detail, although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data.

Database specifics

What follows is a brief and simple description of the databases included in this report and the data in them. For a comprehensive look at the database structure and content, please see the FGDC Metadata file, sim2956d.met, included in the database package and available separately at the publication web page.

The map databases consist of ARC coverages and supporting INFO files, which are stored in a Universal Transverse Mercator (UTM) projection (Table 1). Digital tics define a 2.5 minute grid of latitude and longitude in the geologic coverages corresponding with quadrangle corners and internal tics.

Table 1. Map Projection File
The maps are stored in UTM projection. The following is a projection file of the type used in Arc/Info.

```
PROJECTION UTM
UNITS METERS
ZONE 10
DATUM NAD27
SPHEROID CLARKE1866
PARAMETERS
END
```

The content of the geologic database can be described in terms of the lines, points, and areas that compose the map. Each line, point, or area in a map layer or index map database (coverage) is associated with a database entry stored in a feature attribute table. Each database entry contains both a number of items generated by Arc/Info to describe the geometry of the line, point, or area, and one or more items defined by the authors to describe the geologic information associated with that entry. Each item is defined as to the amount and type of information that can be recorded. Descriptions of the database items use the terms explained in Table 2.

Table 2. Field Definition Terms

ITEM NAME	name of the database field (item)
WIDTH	maximum number of digits or characters stored
OUTPUT	output width
TYPE	B-binary integer, F-binary floating point number, I-ASCII integer, C-ASCII character string
N. DEC.	number of decimal places maintained for floating point numbers

Because some of the database structure for is similar for all coverages, some descriptions apply to all coverages in the publication. In that case, the notation <coverage> has been used to indicate the description is valid for any included coverage. The precise description for a particular coverage can be made by substituting the name of the coverage for <coverage>. For example, <coverage>-ID means that the description is the same for every coverage. The specific notation for a single coverage can be derived by replacing <coverage> with the coverage name (ie. ESWN-GEOL-ID for the coverage eswn-geol).

Lines

The lines (arcs) are recorded as strings of vectors and are described in the arc attribute table (the format of the arc attribute table is shown in Table 3). They define the boundaries of the map units, the boundaries of open bodies of water, and the map boundaries. These distinctions, including the geologic identities of the unit boundaries, are recorded in the LTYPE field according to the line types listed in Table 4.

Table 3. Content of the Arc Attribute Tables

ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	
FNODE#	4	5	B		starting node of arc (from node)
TNODE#	4	5	B		ending node of arc (to node)
LPOLY#	4	5	B		polygon to the left of the arc
RPOLY#	4	5	B		polygon to the right of the arc
LENGTH	4	12	F	3	length of arc in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
LTYPE	35	35	C		line type (see Table 4)
FAULTNAME	35	35	C		records the name of some faults (eswn-geol.aat only)

Table 4. Line Types Recorded in the LTYPE Field

eswn-geol and eswn-terr	eswn-strc	eswn-so and eswn-quad	eswn-corr
contact, approx. located	anticline, approx. located	contact, certain	age, bracket
contact, certain	anticline, certain	map boundary	box
contact, concealed	anticline, concealed	quad boundary	bracket
contact, inferred	syncline, approx. located	source boundary	leader
fault, active	syncline, concealed		outline
fault, active_p			protolith
fault, approx. located			
fault, certain			
fault, concealed			
fault, concealed, queried			
fault, inferred			
fault, inferred, queried			
map boundary			
reverse fault, certain			
scratch boundary			
thrust fault, approx. located			
thrust fault, certain			
thrust fault, concealed			
thrust fault, concealed, queried			
thrust fault, inferred			
thrust fault, inferred, queried			
water boundary			

Note, not every line type listed is present in every coverage. For example, eswn-terr only has some of the fault types listed.

The geologic linetypes are ALACARTE line types that correlate with the geologic line symbols in the ALACARTE line set GEOL.LIN according to the ALACARTE lines lookup table (GEOL.LUT). For more information on ALACARTE and its linesets, see Wentworth and Fitzgibbon (1991).

Areas

Map units (polygons) are described in the polygon attribute table (the format of the polygon attribute table is shown in Table 5). In the geologic coverage (eswn-geol) and the correlation coverage (eswn-corr), the identities of the map units are recorded in the PTYPE field by map label (Table 6). Map units are described more fully in the accompanying text file. In other coverages, various areal information is recorded in the PTYPE field (data source region number, assemblage number, terrane label, quadrangle name). Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with polygon information will have a polygon attribute table, and these coverages will not have a point attribute table.

Table 5. Content of the Polygon Attribute Tables

ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	
AREA	4	12	F	3	area of polygon in square meters
PERIMETER	4	12	F	3	length of perimeter in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTYPE	35	35	C		unit label

Table 6. Unit labels (see the "Geologic explanation and acknowledgements" section for a description of map units)

Jgb	Qhay	Tsa
Jgvm	Qhb	Tsag
Jgvm?	Qhbm	Tsai
Jk	Qhc	Tsb
Jmi	Qhf	Tsft
Jsp	Qhff	Tslt
Jv	Qhl	Tsr
KJfc	Qht	Tsrb
KJfgc	Qhty	Tsri
KJfgs	Qls	Tsrp
KJfgs?	Qlsa	Tsrs
KJfs	Qlso	Tss
KJgv	Qlsr	Tssd
KJgvl	Qoa	Tst
KJsp	Qoa?	Tstx
Kfm	Qpa	Tsv
Kfm?	Qpf	Tswt
Kfmc	Qpt	Twg
Kfmg	Qr	af
Kfss	Qt	afbm
Kgvu	Tbm	alf
Kv	Tbm?	ch
QTc	Tc	fgc
QTc?	Tci	fs
QTge	Td	fsr
QThg	Tdr	gs
QTob	Tkt	gs?
QTt	Tms	m
Qa	Tn	sc
Qf	Tp	sp
Qha	Tp?	sp?
	Tr	spm
	Ts	water

Note, not every unit label listed is present in every coverage. For example, queried units are not present in the correlation table coverage.

Points

Data gathered at a single locality (points) are described in the point attribute table (the format of the point attribute table is shown in Table 7). The identities of the points from compilation sources are recorded in the PTTYPE field by map label (Table 8 and 9). Note that ARC/INFO coverages cannot contain both point and polygon information, so only coverages with point information will have a point attribute table, and these coverages will not have a polygon attribute table.

Table 7. Content of the Point Attribute Tables

ITEM NAME	WIDTH	OUTPUT	TYPE	N. DEC	
AREA	4	12	F	3	area of polygon in square meters
PERIMETER	4	12	F	3	length of perimeter in meters
<coverage>#	4	5	B		unique internal control number
<coverage>-ID	4	5	B		unique identification number
PTTYPE	35	35	C		unit label
DIP	3	3	I		dip of bedding or foliation (structure coverage only)
STRIKE	3	3	I		strike of bedding or foliation (structure coverage only)

Table 8. Point Types Recorded in the PTTYPE Field for structure coverage (eswn-strc)

eswn-struc
----
air photo attitude
approx bedding
bedding
bedding w/tops
crumpled bedding
flat bedding
foliation
foliation and bedding
joint
joint unmineralized
ot bedding
ot bedding w/tops
vert bedding
vert foliation and bedding

The geologic point types in the structure coverage are mostly ALACARTE point types that correlate with the geologic point symbols in the ALACARTE point set ALCGEOL.MRK according to the ALACARTE point lookup table. For more information on ALACARTE and its pointsets, see Wentworth and Fitzgibbon (1991).

References Cited

Addicott, W.O., 1970, Miocene gastropods and biostratigraphy of the Kern River area, California: U.S. Geological Survey Professional Paper 642, 174 p.

Aitken, D.S., 1997, A digital version of the 1970 U.S. Geological Survey topographic map of the San Francisco Bay region, three sheets, 1:125,000 scale: U.S. Geological Survey Open-File Report 97-500.

Angel, L.H., 1948, Geology of a portion of the St. Helena quadrangle, California: Berkeley, University of California, M.A. thesis.

Atwater, B.F., 1982, Geologic maps of the Sacramento-San Joaquin Delta, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1401, 21 sheets, scale 1:24,000, 15 p.

Averitt, Paul, 1945, Quicksilver deposits of the Knoxville district, Napa, Yolo, and Lake Counties, California: California Journal of Mines and Geology, v. 41, p. 65-89, 1 sheet, scale 1:48,000.

Bailey, E.H., 1946, Quicksilver deposits of the western Mayacamas district, Sonoma County, California: California Journal of Mines and Geology, v. 42, p. 199-230, 1 sheet, scale 1:62,500.

Bailey, E.H., Irwin, W.P., and Jones, D.L., 1964, Franciscan and related rocks and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Bartow, J.A., 1985, Map showing Tertiary stratigraphy and structure of the northern San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1761, 2 sheets, scale 1:250,000.

Bartow, J.A., Sarna-Wojcicki, A.M., Addicott, W.O., and Lajoie, K.R., 1973, Correlation of marine and continental Pliocene deposits in northern California by tephrochronology: American Association of Petroleum Geologists Bulletin, v. 57, no. 4, p.769.

Blake, M.C., Jr., and Jones, D.L., 1974, Origin of Franciscan mélanges in northern California: Society of Economic Paleontologists and Mineralogists, Special Paper no. 19, p. 255-263.

Blake, M.C., Jr., Graymer, R.W., and Jones, D.L., 2000, Geologic map and map database of parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2337, 29 p., 2 sheets, scale 1:62,500, 8 Arc/Info coverages and associated files [http://geopubs.wr.usgs.gov/map-mf/mf2337].

Blake, M.C., Jr., Graymer, R.W., and Stamski, R.E., 2002, Geologic map and map database of western Sonoma, northern Marin, and southern Mendocino Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2402, 42 p., 1 sheet, scale 1:100,000, 11 Arc/Info coverages and associated files [http://geopubs.wr.usgs.gov/map-mf/mf2402].

Blake, M.C., Jr., Howell, D.G., and Jayko, A.S., 1984, Tectonostratigraphic terranes of the San Francisco Bay Region, *in* Blake, M.C., ed., 1984, Franciscan geology of northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 43, p. 5-22.

Blake, M.C., Jr., Howell, D.G., and Jones, D.L., 1982, Preliminary tectonostratigraphic terrane map of California: U. S. Geological Survey Open-File Report 82-593, 9 p., 3 map sheets, scale 1:750,000.

Boyd, H.A., 1956, Geology of the Capay quadrangle, California: Berkeley, University of California, Ph.D. thesis, 201 p.

Brice, J.C., 1953, Geology of the Lower Lake quadrangle, California: California Division of Mines Bulletin, v. 166, 72 p., 1 sheet, scale 1:62,500.

California Division of Mines and Geology, 1983, Cuttings Wharf quadrangle: State of California Special Studies Zones Map, 1 sheet, scale 1:24,000.

Cardwell, G.T., 1958, Geology and ground water in the Santa Rosa and Petaluma Valley areas, Sonoma County, California: U.S. Geological Survey Water-Supply Paper 1427, 273 p., 1 plt., scale 1:62,500.

Clahan, K.B., Mattison, E., and Knudsen, K.L., 2000, Liquefaction zones in the San Jose East 7.5-minute quadrangle, Santa Clara County, California *in* Seismic hazard evaluation of the San Jose East 7.5-minute quadrangle: California Division of Mines and Geology Open-File Report 2000-010.

Clark, A.W., 1948, Geology of a portion of the St. Helena quadrangle, California: University of California, Berkeley, M.A. thesis, 1 sheet, scale 1:62,500.

Conrey, B.L., 1948, Geology of the southern portion of the Morgan Valley quadrangle, California: University of California, Berkeley, M.A. thesis, 1 sheet, scale 1:62,500.

Crawford, K.E., 1976, Reconnaissance geologic map of the Eylar Mountain quadrangle, Santa Clara and Alameda Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-764, scale 1:24,000.

Crutchfield, W.H., Jr., 1953, The geology and silver mineralization of the Calistoga district, Napa County, California: University of California, Berkeley, M.A. thesis, 1 sheet, scale 1:62,500.

Davies, E.A., 1986, The stratigraphic and structural relationships of the Miocene and Pliocene formations of the Petaluma Valley area of California: Berkeley, University of California, M.S. thesis, 96 p.

Donnelly-Nolan, J.M., Hearn, B.C., Jr., Curtis, G.H., and Drake, R.E., 1981, Geochronology and evolution of the Clear Lake Volcanics, *in* McLaughlin, R.J., and Donnelly-Nolan, J.M., eds., Research in the Geysers-Clear Lake geothermal area, northern California: U.S. Geological Survey Professional Paper 1141, p. 47-60.

Ellen, S.D., Mark, R.K., Wieczorek, G.F., Wentworth, C.M., Ramsey, C.W., and May, T.E., 1997, Principal debris-flow source areas in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 97-745E, scale 1:275,000 and 1:125,000.

Fitzgibbon, T.T., 1991, ALACARTE installation and system manual (version 1.0): U.S. Geological Survey Open-File Report 91-587B.

Fitzgibbon, T.T., and Wentworth, C.M., 1991, ALACARTE user interface-AML code and demonstration maps (version 1.0): U.S. Geological Survey Open-File Report 91-587A.

Fix, P.F., and Swinney, C.M., 1949, Quicksilver deposits of the Oakville district, Napa County, California: California Journal of Mines and Geology, v. 45, no. 1, p. 31-46, 3 pls.

Ford, E.W., Caskey, S.J., Wagner, D.L., and Fleck, R.J., 2003, Miocene volcanic rocks at Burdell Mountain and implications for slip along the East Bay Fault System [abs.]: Geological Society of America Abstracts with Programs, v. 34, no. 7, p. 73.

Fox, K.F., Jr., 1983, Tectonic setting of late Miocene, Pliocene, and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S. Geological Survey Professional Paper 1239, 33 p.

Fox, K.F., Jr., Fleck, R.J., Curtis, G.H., and Meyer, C.E., 1985a, Implications of the northwestwardly younger age of the volcanic rocks of west central California: Geological Society of America Bulletin, v. 96, p. 647-654.

Fox, K.F., Jr., Fleck, R.J., Curtis, G.H., and Meyer, C.E., 1985b, Potassium-argon and fission track ages of the Sonoma Volcanics in an area north of San Pablo Bay, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1753, 9 p., 1 sheet, scale 1:125,000.

Fox, K.F., Jr., Sims, J.D., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of eastern Sonoma County and western Napa County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-483, 4 sheets, scale 1:62,500.

Goss, C.R., 1948, Geology of the southwest corner of the Calistoga quadrangle: University of California, Berkeley, M.A. thesis, 1 sheet, scale 1:31,680.

Graymer, R.W., 1999, Offset history of the Hayward Fault zone, San Francisco Bay region, California [abs.]: Geological Society of America Abstracts with Programs, v. 31, no. 6, p. 59.

Graymer, R.W., 2000, Geologic map and map database of the Oakland metropolitan area, Alameda, Contra Costa, and San Francisco Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2342, 31 p., 1 sheet, scale 1:50,000 [http://geopubs.wr.usgs.gov/map-mf/mf2342].

Graymer, R.W., Brabb, E.E., and Jones, D.L, 1999, Geology of the Cordelia and the northern part of the Benicia 7.5 minute quadrangles, California; a digital map database: U.S. Geological Survey Open-File Report 99-162, includes plotfiles for 1 sheet, scale 1:24,000, database description pamphlet, 11 p., geologic description and interpretation pamphlet, 8 p. [http://pubs.usgs.gov/of/1999/of99-162].

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1994, Preliminary geologic map emphasizing bedrock formations in Contra Costa County, California; a digital database: U.S. Geological Survey Open-File Report 94-622, includes plotfiles for 2 sheets, scale 1:75,000, database description pamphlet, 10 p., geologic description and interpretation pamphlet, 20 p. [http://pubs.usgs.gov/of/1994/of94-622].

Graymer, R.W., Jones, D.L., and Brabb, E.E., 2002, Geologic map and map database of northeastern San Francisco Bay region, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2403, 28 p., 1 sheet, scale 1:100,000, 9 Arc/Info coverages and associated files [http://pubs.usgs.gov/mf/2002/2403].

Graymer, R.W., Sarna-Wojcicki, A.M., Walker, J.P., McLaughlin, R.J., and Fleck, R.J., 2002, Controls on timing and amount of right-lateral offset on the East Bay fault system, San Francisco Bay region, California: Geological Society of America Bulletin, v. 114, no. 12, p. 1471-1479.

Hart, E.W., and Bryant, W.A., 1999, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 38 p. [revised 1997, supplements 1 and 2 added 1999].

Hearn, B.C., Jr., Donnelly-Nolan, J.M., and Goff, F.E., 1995, Geologic map and structure sections of the Clear Lake Volcanics, northern California: U.S. Geological Survey Miscellaneous Investigations Series I-2362, 3 sheets, scale 1:24,000.

Helley, E.J., and Barker, J.A., 1979, Preliminary geologic map of Cenozoic deposits of the Woodland quadrangle, California: U.S. Geological Survey Open-File Report 79-1606, 4 sheets, scale 1:62,500.

Helley, E.J., and Graymer, R.W., 1997, Quaternary geology of Contra Costa, and surrounding parts of Alameda, Marin, Sonoma, Solano, Sacramento, and San Joaquin Counties, California; a digital database: U.S. Geological Survey Open-File Report 97-98 [http://geopubs.wr.usgs.gov/open-file/of97-98].

Huffman, M.E., 1971, Geology for planning in the Sonoma Mountain and Mark West-Riebli Road areas, Sonoma County, California: California Division of Mines and Geology report to Sonoma County Planning Department, 20 p., scale 1:24,000.

Hurlbut, E.M., Jr., 1948, Geology of a portion of the Calistoga quadrangle: University of California, Berkeley, M.A. thesis, 53 p., 1 sheet, scale 1:62,500.

Jayko, A.S., Blake, M.C., Jr., and Brothers, R.N., 1986, Blueschist metamorphism of the eastern Franciscan Belt, northern California: Geological Society of America Memoir, v. 164, p. 107-123.

Johnston, Stedwell, 1948, The geology of a portion of the Calistoga quadrangle: University of California, Berkeley, M.A. thesis, 47 p., 1 sheet, scale 1:62,500.

Jones, D.L., and Curtis, G.H., 1991, Guide to the geology of the Berkeley Hills, central Coast Ranges, California, *in* Sloan, D., and Wagner, D.L., eds., Geologic excursions in northern California; San Francisco to the Sierra Nevada: California Division of Mines and Geology Special Publication 109, p. 63-74.

Jones, D.L., Graymer, R.W., Wang, Chi., McEvilly, T.V., and Lomax, Anthony, 1994, Neogene transpressive evolution of the California Coast Ranges: Tectonics, v. 13, p. 561-574.

Kelley, F.R., 1982, Thermal springs and wells and radiometric ages of rocks in the Santa Rosa quadrangle, California, *in* Wagner, D.L., and Bortugno, E.J., comps., Geologic map of the Santa Rosa quadrangle, California: California Division of Mines and Geology Regional Map Series, Map No. 2A, sheet 4, 28 p., scale 1:250,000.

Kleinpell, R.M., 1938, Miocene stratigraphy of California, IX: Tulsa, Okla., American Association of Petroleum Geologists, 450 p.

Knudsen, K.L., Sowers, J.M., Witter, R.C., Wentworth, C.M., and Helley, E.J., 2000, Preliminary maps of Quaternary deposits and liquifaction susceptibility, nine-county San Francisco Bay region, California; a digital database: U.S. Geological Survey Open-File Report 00-444, 2 sheets, scale 1:275,000, 2 pamphlets, 3 Arc/Info databases [http://pubs.usgs.gov/of/2000/of00-444].

Kunkel, Fred, and Upson, J.E., 1960, Geology and ground water in Napa and Sonoma Valleys, Napa and Sonoma Counties, California: U.S. Geological Survey Water-Supply Paper 1495, 252 p., 2 pls., scale 1:62,500.

Langenheim, V.E., Graymer, R.W., Jachens, R.C., 2006, Geophysical setting of the 2000 M_L 5.2 Yountville, California, earthquake; implications for seismic hazard in Napa Valley, California: Bulletin of the Seismological Society of America, v. 96, no. 3, p. 1192-1198.

Lee, D.E., Thomas, H.H., Marvin, R.F., and Coleman, R.G., 1964, Isotopic ages of glaucophane schists from the area of Cazadero, California; Article 142: U.S. Geological Survey Professional Paper 475-D, p. D105-D107.

Liniecki-Laporte, Margaret, and Andersen, D.W., 1988, Possible new constraints on late Miocene depositional patterns in west-central California: Geology, v. 16, no. 3, p. 216-220.

Lowe, D.R., 1972, Implications of three submarine mass-movement deposits, Cretaceous, Sacramento Valley, California: Journal of Sedimentary Petrology, vol. 42, no. 1, p. 89-101.

Mattinson, J.M., and Echeverria, L.M., 1980, Ortigalita Peak gabbro, Franciscan Complex; U-Pb dates of intrusion and high-pressure-low-temperature metamorphism: Geology, v. 8, no. 12, p. 589-593.

McFadden, B.J., 1998, Equidae, *in* Janis, C.M., Scott, K.M., and Jacobs, L.L., Evolution of Tertiary mammals of North America, Volume 1: New York, Cambridge University Press, p. 537-559.

McDougall, Kristin, 1983, Upper Eocene to lower Miocene benthic foraminifers from the Santa Cruz Mountains area, California, *in* Brabb, E.E., ed., Studies in Tertiary stratigraphy of the California Coast Ranges: U.S. Geological Survey Professional Paper 1213, p. 61-82.

McLaughlin, R.J., Sarna-Wojcicki, A.M., Fleck, R.J., Nilsen, T.H., Walker, J.P., Meyer, C.E., and Valin, Z.C., 1999, Initiation of active right-stepping dextral faults and implications for evolution of the San Andreas transform, northern San Francisco Bay region, California [abs.]: EOS, Transactions, American Geophysical Union, v. 80, no. 46, p. 735.

McLaughlin, R.J., Sarna-Wojcicki, A.M., Fleck, R.J., and Wright, W.H., Levin, V.R.G., and Valin, Z.C., 2004, Geology, tephrochronology, radiometric ages, and structure sections of the Mark West Springs quadrangle, Sonoma and Napa Counties, California: U.S. Geological Survey Scientific Investigations Map 2858, 2 sheets, scale 1:24,000 [http://pubs.usgs.gov/sim/2004/2858].

McLaughlin, R.J., Sliter, W.V., Sorg, D.H., Russell, P.C., and Sarna-Wojcicki, A.M., 1996, Large-scale right-slip displacement on the east San Francisco Bay region fault system; implications for location of late Miocene to Pliocene Pacific plate boundary: Tectonics, v. 15, p. 1-18.

Murchey, B.M., and Jones, D.L., 1984, Age and significance of chert in the Franciscan Complex in the San Francisco Bay region, *in* Blake, M.C., Jr., ed., Franciscan geology of northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 43, p. 23-30.

Naidu, G., 1999, Geology and paleontology of the Wilson Grove Formation, Sonoma-Marin Counties, California [abs.]: PaleoBios, v. 19, no. 1, Supplement, p. 6.

Nilsen, T.H., Wright, R.H., Vlasic, T.C., and Spangle, W.E., 1979, Relative slope stability and lands-use planning in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 944, 96 p.

Pampeyan, E.H., 1993, Geologic map of the Palo Alto and part of the Redwood Point 7.5-minute quadrangles, San Mateo and Santa Clara Counties, California: U.S. Geological Survey Miscellaneous Investigations Map I-2371, scale 1:24,000.

Peterson, G.L., 1965, Implications of two Cretaceous mass transport deposits, Sacramento Valley, California: Journal of Sedimentary Petrology, v. 35, no. 2, p. 401-407.

Phipps, S.P., 1984, Ophiolitic olistostromes in the basal Great Valley Sequence, Napa County, northern California Coast Ranges, *in* Raymond, L.A., ed., Melanges; their nature, origin and significance: Geological Society of America Special Paper, v. 198, p. 103-125.

Powell, C.L., II, Allen, J.R., and Holland, P.J., 2004, Invertebrate paleontology of the Wilson Grove Formation (late Miocene to late Pliocene), Sonoma and Marin Counties, California, with some observations on its stratigraphy, thickness, and structure: U.S. Geological Survey Open-File Report 2004-1017, 2 sheets, scale varies [http://pubs.usgs.gov/of/2004/1017].

Sarna-Wojcicki, A.M., 1976, Correlation of Late Cenozoic tuffs in the central Coast Ranges of California by means of trace- and minor-element chemistry: U.S. Geological Survey Professional Paper 972, 30 p.

Sarna-Wojcicki, A.M., 1992, Long-term displacement rates on the San Andreas fault system in northern California from the 6-Ma Roblar tuff, *in* Borchardt, Glenn, and others, eds., Earthquake hazards in the eastern San Francisco Bay area, Proceedings of the 2nd Conference on Earthquake Hazards in the eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 29-30.

Seiders, V.M., and Blome, C.D., 1984, Clast compositions of Upper Mesozoic conglomerates of the California Coast Ranges and their tectonic significance, *in* Blake, M.C., ed., 1984, Franciscan geology of northern California: Pacific Section, Society of Economic Paleontologists and Mineralogists, v. 43, p. 135-148.

Shouldice, J.R., 1947, Geology of part of the St. Helena quadrangle, California: Berkeley, University of California, M.A. thesis, 48 p., 1 sheet, scale 1:62,500.

Sims, J.D., Fox, K.F., Jr., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of Solano County and parts of Napa, Contra Costa, Marin, and Yolo Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-484, 5 sheets, scale 1:62,500.

Sowers, J.M., Noller, J.S., and Lettis, W.R., 1998, Quaternary geology and liquefaction susceptibility, Napa, California 1:100,000 quadrangle; a digital database: U.S. Geological Survey Open-File Report 98-460, 20 p., 1 sheet, scale 1:100,000 [http://pubs.usgs.gov/of/1998/of98-460].

Stirton, R.A., 1939, Cenozoic mammal remains from the San Francisco Bay region: University of California Publications in Geological Sciences, v. 24, no. 13, p. 339-409.

Swinchatt, Jonathan, and Howell, D.G., 2004, The winemaker's dance; exploring terroir in the Napa Valley: Berkeley, University of California Press, 243 p.

Travis, R.B., 1952, Geology of the Sebastopol quadrangle, California: California, Division of Mines and Geology Bulletin, v. 162, p. 1-33.

Wagner, D.L., 1975, Mesozoic geology of the Walter Springs area, Napa County, California: San Jose State University, M.S. thesis, 68 p., scale 1:12,000.

Wakabayashi, John, 1999, The Franciscan; California's classic subduction complex: Geological Society of America Special Paper, v. 338, p. 111-121.

Weaver, C.E., 1949, Geology of the Coast Ranges immediately north of the San Francisco Bay region, California: Boulder, Colo., Geological Society of America, Geological Society of America Memoir, 242 p., 14 pls.

Weaver, C.E., 1953, Eocene and Paleocene deposits at Martinez, California: Washington University Publications in Geological Science, v. 7, p. viii, 1-102.

Weaver, C.E., Beck, R.S., Bramlette, M.N., Carlson, S.A., Forrest, L.C., Kelley, F.R., Kleinpell, R.M., Putnam, W.C., Taliaferro, N.L., Thorup, R.R., VerWieke, W.A., Watson, E.A., 1944, Correlation of the marine Cenozoic formations of western North America [chart no. 11]: Geological Society of America Bulletin, v. 55, no. 5, p. 569-598.

Wentworth, C.M., and Fitzgibbon, T.T., 1991, ALACARTE user manual (version 1.0): U.S. Geological Survey Open-File Report 91-587C.

Wentworth, C.M., Graham, S.E., Pike, R.J., Beukelman, G.S., Ramsey, D.W., and Barron, A.D., 1997, Summary distribution of slides and earth flows in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 97-745C.

Yates, R.G., and Hilpert, L.S., 1946, Quicksilver deposits of eastern Mayacamas District, Lake and Napa Counties, California: California Journal of Mines and Geology, v. 42, p. 231-286, 1 sheet, scale 1:62,500.

Youngman, M.R., 1989, K-Ar and $^{40}Ar/^{39}Ar$ geochronology, geochemistry, and structural reinterpretation of the southern Sonoma Volcanic field, Sonoma County, California: Berkeley, University of California, M.S. thesis, 92 p., 1 plate.