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Preliminary Geologic Map of the Napa and Bodega Bay 30’ x 60’ Quadrangles, California
Compiled by David L. Wagner and Carlos I. Gutierrez

Introduction

The Preliminary Geologic Map of the Napa and Bodega Bay 30’ x 60’ Quadrangles, California was compiled from new and existing geologic mapping covering the area between 38° and 38°30’ N. latitude and from 122° W. Longitude, to the coastline of the Pacific Ocean. This map was prepared by the Department of Conservation, California Geological Survey (CGS) and was supported in part by the U.S. Geological Survey (USGS) STATEMAP award No. G09AC00193. New geologic mapping by the CGS was completed for twenty-five of the thirty-five 7.5’ quadrangles during the period July 1998 to June 2009 under STATEMAP funding award numbers 1434-HQ-97-AG-0196, 01HQAG0092, 02HQAG0018, 03HQAG0085, 04HQAG0074, 05HQAG0080, 06HQAG0036, 07HQAG0143, and 08HQAG0102. This map is a product of an ongoing geologic mapping effort in the northern San Francisco Bay Area and represents a cooperative effort between the CGS, the USGS, as well as graduate students from San Jose State and San Francisco State universities. The Santa Rosa quadrangle was mapped by the USGS (McLaughlin and others, 2008).

Areal Geology

Introduction

This map covers an area of approximately 2000 square miles of the Coast Ranges geomorphic province of California (Figure 1). Most of the map area is north and west of the San Francisco Bay estuary, which consists of the San Pablo Bay, the Sacramento River delta and wetlands near Napa and the Fairfield-Cordelia area. The San Andreas Fault traverses the southwestern part of the map marking the active boundary between two lithospheric plates, the North American plate from the Pacific plate lying to the west. The Point Reyes Peninsula and Bodega Head are surface exposures of part of the Pacific plate known as the Salinian block. The Salinian block has been displaced tens to hundreds of kilometers from the southeast by movement along the faults of the San Andreas system. Rocks west of the San Andreas Fault are profoundly different than those exposed east of the fault. The overview of the geology of the Napa quadrangle that follows will address the areas west of the San Andreas Fault, within the fault zone and the area east of the fault respectively.

Geologic Setting West of the San Andreas Fault

The most comprehensive report on the geology of the Pt. Reyes Peninsula is by Galloway (1977) which established the basic stratigraphic framework. Clark and Brabb (1997) published a new geologic map of the peninsula which was compiled on the Napa 30’x 60’ quadrangle. The stratigraphy on the new map was substantially revised from Galloway (1977). The following description was adapted from Clark and Brabb (1997).

Granitic and metamorphic rocks form the basement of Point Reyes peninsula and Bodega Head. Metamorphic rocks of uncertain age (Paleozoic and or Mesozoic) are metasedimentary mica schist, quartzite, and marble that occur as inclusions or small roof pendants in the Mesozoic granitic rocks.
Figure 1. Index map showing the 7.5-minute quadrangles mapped within the Napa and Bodega Bay 30'x60'-minute quadrangles.
Granitic rocks are subdivided into the Tonalite of Tomales Point (94.3 Ma), the Granodiorite and the Granite of Inverness Ridge, and the porphyritic Granodiorite of Point Reyes (82-87 Ma). Cretaceous quartz diorite crops out on Bodega Head (Blake and others, 2002).

Three sequences of Tertiary marine formations separated by unconformities overlie the crystalline basement. The oldest is the early Eocene Point Reyes Conglomerate of Galloway (1977) that overlies the granodiorite at the promontory of Point Reyes. It is composed of thick arkosic sandstone and channel conglomerate which contains purple and black siliceous volcanic clasts. A middle to upper Miocene sequence that consists of the Laird Sandstone and the Monterey Formation rests on the granodiorite and granite of Inverness Ridge. The Laird Sandstone is biotitic arkosic sandstone with calcareous concretions and a local boulder conglomerate at its base. The Monterey Formation is thin-bedded, laminated, light-colored siliceous shale. An upper Miocene to Pliocene sequence is the Drakes Bay Formation of Galloway (1977) but similarities in stratigraphy, lithology, and fossils to formations in the Santa Cruz Mountains led Clarke and others (1984) to rename these strata the Santa Margarita Sandstone, the Santa Cruz Mudstone, and the Purisima Formation. The Santa Margarita Sandstone is massive, glauconitic, arkosic sandstone. The Santa Cruz Mudstone is gray to brown siliceous mudstone with carbonate concretions. The Purisima Formation is massive gray siltstone with carbonate concretions. Surficial deposits on the Point Reyes peninsula include terrace deposits, landslides, dunes, and beach sand.

Geologic mapping for the offshore region was compiled from the USGS Seafloor Mapping Program (Hartwell et al., 2015; Johnson et al., 2015a; Johnson et al., 2015b; Watt et al., 2015a; Watt et al., 2015b). Cretaceous and Tertiary basement rocks are a continuation of the onshore rocks described above. Late Holocene marine deposits consist of fine to coarse grained sediments deposited in the nearshore and shelf environments, and Tomales Bay. Due to the limitation of the map scale, the data representing the offshore geology has been simplified.

**Geologic Setting within the San Andreas Fault Zone**

Erosion of weak, sheared rock along the San Andreas Fault has created a linear depression or “rift valley”, as it is referred to on USGS topographic maps. Most of the valley on the Napa quadrangle is flooded by Tomales Bay, but there are alluvial deposits, estuarine deposits, and sand along the bay margins and south of the bay. Interbedded alluvial gravel and estuarine siltstone and mudstone of the Millerton Formation are exposed at Millerton Point on the east side of Tomales Bay. Coeval alluvial gravel estuarine deposits of the Olema Creek Formation are exposed along Olema Creek south of Tomales Bay. Both of these formations record a complex record of sea level fluctuations and tectonism (Grove and others, 1995). Surficial deposits include bay mud, beach sand and dune sand. There are exposures of Franciscan Rocks at Hog Island in Tomales Bay and at Toms Point suggesting that bedrock beneath the bay is mostly Franciscan.

**Geologic Setting East of the San Andreas Fault**

Basement rocks of the east of the San Andreas Fault consist of the Mesozoic rocks of the Franciscan Complex, the Great Valley Sequence and the Jurassic Coast Range ophiolite. The Franciscan rocks constitute a Jurassic to Tertiary subduction complex composed of highly deformed, accreted oceanic sediments and volcanic rocks interspersed with fragments of mafic oceanic crust. Blake and others (1984) subdivided the Franciscan Complex into tectonostratigraphic terranes, regionally extensive, fault-bounded, geologic entities with geologic histories distinct from adjacent terranes. Juxtaposition of
Figure 2. Map modified from Langenheim et al. (2010) showing the study area, faults of the East Bay fault system and their possible extensions north of San Pablo Bay. Also shown are northward younging Cenozoic volcanic fields, some of which, have been correlated across dextral faults of the East Bay fault system. Fault abbreviations: BF Bloomfield; BMF Burdell Mountain; FC Franklin Canyon; CF Carneros; M Moraga; MC Miller Creek; P Palomares; PVF Petaluma Valley; Pin Pinole: Su Sunol; TF Tolay; WNF West Napa.
the Franciscan terranes is the result of accretionary tectonics since the Cretaceous (Dumitru and others, 2010) and later transform tectonics of the San Andreas System during the Neogene (McLaughlin and others, 2012). Franciscan rocks are exposed in the mountainous area in the west-central part of the map area and are also known to extend beneath the Santa Rosa plain (McLaughlin and others, 2008) and the Petaluma Valley (Langenheim and others, 2010). The Great Valley Sequence is largely coeval with the Franciscan Complex and consists of forearc basin deposits that form basement on the eastern part of the map area. Great Valley Sequence strata rest on the Coast Range ophiolite in the western Sacramento Valley. In the central and western part of the quadrangle to the west however, Great Valley strata and ophiolite tectonically overlie, or are imbricated with, the Franciscan Complex. An example of the complicated structure of the Franciscan-Great Valley Sequence interface is in the north central part of the map where Franciscan rocks are thrust over Great Valley rocks along the St. Johns thrust.

In the southeastern part of the map area, the Mesozoic basement is overlain by Paleogene and Eocene marine formations. Neogene marine Formations are well exposed south of San Pablo Bay but only sparsely exposed north of the bay.

Late Cenozoic volcanic rocks on the map area are part of a linear belt of volcanic fields (Figure 2) that are progressively younger to the northwest (Fox and others, 1985a). The oldest field is represented by ~11 Ma lava flows that cap Burdell Mountain in the north west of San Pablo Bay. Two lithologically similar but younger volcanic sequences are exposed in the southern Sonoma Mountains, the Tolay Volcanics and the Sonoma Volcanics. The Tolay Volcanics originally thought to be restricted to the subsurface in the Petaluma oilfield, are now known be exposed around the margins of the Petaluma Valley (Wagner and others, 2011). The younger Sonoma Volcanics are the most widespread volcanic field, exposed throughout much of the central and eastern part of the map.

Late Cenozoic sedimentary rocks of northern California were deposited in basins that formed in response to transform tectonics associated northward migration of the Mendocino triple junction and development of the San Andreas Fault System (Nilsen and Clarke, 1989). The Santa Rosa basin north of San Pablo Bay consists of three subbasins, the Petaluma basin, the Cotati basin and the Windsor basin (McLaughlin, and others, 2008; Langenheim and others, 2010). Mio-Pliocene sedimentary formations in the Santa Rosa basin include the marine Wilson Grove Formation, the fluvial, estuarine, and lacustrine Petaluma Formation, and the littoral sand and gravel of Cotati. Unconformably overlying these units are the Plio-Pleistocene terrestrial deposits of the Huichica Formation, and the Glen Ellen Formation (Weaver, 1949; Fox, 1983). The Livermore basin (Nilsen and Clarke, 1989), also referred as the Contra Costa basin (Creeley and others, 1982), includes the Miocene Contra Costa Group (Wagner, 1978; Creeley and others, 1982; Graham and others, 1984), parts of which are correlative with the Petaluma Formation on the Napa quadrangle.

Major Neogene right-lateral faults are part north of San Pablo Bay are extensions of the East Bay fault zone (Figure 2), including the Rodgers Creek, the Petaluma Valley Fault, Burdell Mountain, the Carneros, the West Napa, and the Green Valley faults (Figure 3), have laterally translated the late Cenozoic rocks in the North Bay region.

**Rock Units East of the San Andreas Fault**

**Franciscan Complex**

Diverse rocks of the Franciscan subduction complex are exposed in the coastal ranges in the western part of the map and in the northernmost part of the map on either side of the Napa Valley. The
Figure 3. Simplified geologic map of the northern San Francisco Bay region modified from Langenheim et al. (2010). Locations of wells discussed in the text are: Bethlehem #1 near Pt. Pinole; Murphy # 1 east of Petaluma; Texaco Nobel#1 near Sears Point. Faults in San Pablo Bay are from Wright and Smith, (1992) and Parsons et al. (2003). Abbreviations: BM, Bennett Mountain; BV, Bennett Valley; CB, Cotati basin; CC Carriger Creek; CV Carneros Valley; DR Donnell Ranch; JL Jack London State Park; L Lakeville; LV Lovall Valley; MP Mt. Pisgah; NV Nunns Valley; PB Petaluma basin; SR Steinbeck Ranch; WB, Windsor basin.
Franciscan Complex is primarily composed of greywacke sandstone and argillite that accumulated on deep sea fans and in oceanic trenches. The sedimentary sequences were tectonically disrupted and now occur as blocks and slabs, which range from boulder-size to slabs measured in tens of kilometers that are set in a sheared, shaley matrix. There are lesser amounts of submarine basalt, called greenstone, which is often associated with radiolarian chert. Metamorphic rocks, including schist, semischist, blueschist, eclogite, metachert, amphibolite, and various more rare types, occur sporadically in the shaley matrix. This sheared mixture has been collectively referred to mélange. Sparse fossils indicate the most of the Franciscan Complex is late Jurassic to late Cretaceous. A younger part of the Franciscan, termed the Coastal Belt, is late Cretaceous to Eocene and has been mapped in the northwest corner of the map. It is composed of sandstone and shale which are less deformed and were subjected to lower grade metamorphism than the older parts of the Franciscan Complex.

Prior to the development of plate tectonic theory, the origin of the Franciscan was enigmatic (Bailey and others, 1964). Based on its outcrop width and general northeast dip, it must be 15 to 20 km or more thick but the intense deformation precludes conventional stratigraphic analysis. Its base has never been observed and all the contacts with coeval rocks are faults as are nearly all the mapped contacts between the rock bodies within the Franciscan on the Napa quadrangle and elsewhere. According to classic plate tectonic models (Hamilton, 1969; Ernst, 1970), the Franciscan pelagic chert, sandstone, and shale were deposited on basaltic oceanic crust that was formed at the Pacific mid-oceanic ridge and scraped off as the oceanic crust was subducted beneath the North American plate. In the northern Coast Ranges the Franciscan Complex has been divided into the Eastern Belt, the Central Belt and the Coastal Belt (Bailey and others, 1964; Blake and others, 1998) composed of oceanic clastic and pelagic sediments, submarine volcanic rocks, as well as metamorphic rocks. The Eastern belt is mostly quartzofeldspathic sandstone deposited during the middle Cretaceous which is overprinted by high pressure/low temperature metamorphism (Ernst, 2011) indicating deep subduction (i.e. ≥ 20km). The Central belt is a mélange containing fragments of greywacke, greenstone, chert, limestone, ultramafic rock, and high grade metamorphic rock set in a sheared argillaceous matrix which also is overprinted with high pressure/low temperature metamorphism (Blake and others, 1988; Ernst, 2011) indicating subduction.

On the Napa quadrangle, the Eastern and Central belts are divided into five lithologic units, sandstone and shale (KJfss), sandstone (Kfs), schist and semischist (KJfsch), greenstone (KJgs), and mélange (KJfm). The first three units are slabs whose dimensions measured in kilometers to tens of kilometers. KJfss and Kfs are sandstone and shale that are terrigenous sediments that were deposited as deep sea fans or in trenches. KJfsch is metagraywacke or schist that varies in metamorphic grade that in general increases from west to east (Blake and others, 1967). KJgs is metabasalt that has been subjected to greenschist facies metamorphism that produces abundant chlorite and pumpellylite giving the rock its characteristic green color. Most greenstone in the Franciscan is presumed to be remnants of the basaltic layer of the oceanic crust, most of which was subducted beneath North America (Wahrhaftig and Wakabyashi, 1989). These slabs are set in mélange (KJfm), often described as a sheared, shaley matrix. Also set in the sheared, shaley matrix are fragments ranging from sub-boulder-size to slabs, of all the rock types described above plus, chert, exotic metamorphic rocks (e.g. blueschist, eclogite), serpentinite, silica carbonate rock.

The Coastal belt is the westernmost, structurally the lowest, and youngest Franciscan belt. It is composed mainly of feldspatholithic sandstone, tuff, and greenstone that are Paleocene to Eocene (Blake
and others, 1988) though Cretaceous age rocks are found. It has a low temperature, mostly zeolite facies metamorphic overprint indicating little of any subduction (Ernst, 2011).

**Serpentinite**

Serpentinite is altered peridotite, presumably derived from oceanic mantle (Coleman, 1989). Serpentinite is quite plastic making it capable of moving along faults and shears so it is commonly found in the more disturbed parts of the Coast Ranges. Serpentinite is usually greenish and forms subdued topography conducive to landsliding. Most outcrops are along stream or in road cuts where it is intensely sheared with fragments up to a meter or more across set in a scaly matrix that commonly displays a shear foliation. Most serpentinite in the Bay area has a low temperature mineral assemblage but in some places the presence of antigorite indicates it was subjected to greenschist facies metamorphism (Coleman, 1989). Weathering of serpentinite produces poor soil that most vegetation cannot tolerate so contacts can often be traced by abrupt vegetation changes.

Travis (1952) mapped an intrusive “serpentine sill” near Camp Meeker in the northwest part of the Napa quadrangle associated with high grade metamorphic rocks. Travis did note however, that metamorphism was confined to “… rounded masses 20 to 30 feet in diameter.” Many serpentinite masses are clearly intrusive but they lack metamorphic aureoles that would be expected if they were emplaced as an ultramafic magma. Bailey and others (1964) concluded that metamorphic rocks associated with serpentinites are not aureoles and that ultramafic rocks were emplaced as cold serpentinite. Though they are intrusive, serpentinite has traditionally been included with the Franciscan rocks (Bailey and others, 1964; Page, 1966). More recently, serpentinite in the Coast Ranges has been interpreted to be from the ultramafic layer of the Coast Range ophiolite (Blake and others, 2000; 2002). A contrasting view is that there are masses of “intra-Franciscan serpentinite” that were scraped off the down-going plate during subduction and tectonically mixed with serpentinite derived from the Coast Range ophiolite in Franciscan mélange (Wakabyashi, 2004). According to Coleman (2000) the difference between the two is that serpentinite in the Franciscan Complex contains high temperature minerals and high grade metamorphic blocks while the serpentinite from the Coast Range ophiolite has low temperature minerals and lacks high grade metamorphic blocks. However, there are blocks of high grade metamorphic rock in the serpentine-matrix mélange that is considered to be part of the Coast Range ophiolite (Phipps, 1984). The large expanses of serpentinite in the eastern Coast Ranges that extend from the Paskenta area south to the northeastern part of the Napa quadrangle is serpentine-matrix mélange (Hopson, and others, 2008) that contains blocks of gabbro, mafic volcanics rocks, chert, and relatively intact masses of partially serpinetized peridotite. Much of this serpentinite-matrix mélange was emplaced as olistostromes (submarine landslides) (Phipps, 1984). On the Napa quadrangle, serpentinite is shown simply as sp and is included in both the Franciscan mélange and the Coast Range ophiolite. It can be inferred however, that serpentinite associated with Great Valley Sequence rocks is part of the Coast Range ophiolite.

Silica carbonate rock is an alteration of serpentinite so it is often included with the Franciscan but it actually is much younger, forming during hydrothermal activity associated with Cenozoic volcanism (Rytuba and Enderling, 1999). One of the most extensive exposures of silica carbonate rock in the Coast Ranges occurs in the hills east of Vallejo. Here the silica carbonate is an alteration of serpentinite that is part of the Coast Range ophiolite.
Coast Range Ophiolite

The Coast Range ophiolite is composed of sheared, serpentinized ultramafic rocks, gabbro, diabase dikes and sills, mafic volcanic rocks, and local andesitic tuff. Most often it occurs as serpentinite-matrix mélangé containing blocks of mafic plutonic and volcanic rocks in selvages between Franciscan rocks and the Great Valley Sequence. According to Hopson and others (1981) the composite Coast Range ophiolite sequence is: basal partially to completely serpentinized peridotite, mafic plutonic rock, usually gabbro, a mafic dike and sill complex, and mafic lava, often pillowled and locally associated with breccia. Anything approaching a complete sequences are only known in a few places in California and on the Napa quadrangle only parts of the sequence occur. East of Napa Valley, there are large bodies of gabbro and serpentinized ultramafic rock and in the hills east of Vallejo there bodies of gabbro and mafic volcanic rock that are mapped as ophiolite fragments. The ophiolitic nature of these rocks was first recognized by Bezore (1969) and later was demonstrated that they are exposures of on-land oceanic crust on which the Great Valley Sequence was deposited (Bailey and others, 1970).

Great Valley Sequence

The Great Valley Sequence, also called the Great Valley group (Ingersoll, 1990), is composed clastic of sediment deposited in a forearc basin between the Mesozoic magmatic arc that is now exposed in the Sierra Nevada and the Klamath Mountains, and the Franciscan subduction complex to the west. It is essentially coeval with the Franciscan, Late Jurassic to Late Cretaceous, and the contact between them is complexly faulted (Bailey and others, 1964).

At the base of the Great Valley Sequence there is mélange (KJgvm) containing blocks of chert, greenstone, and high-grade metamorphic rocks set in a matrix of sheared mudrock or serpentinite. For the most part this mélange is olistostromal (submarine landslides) (Phipps, 1984). The lower part of the Great Valley is dominated by mudrock with thin sandstone interbeds and locally thick channel conglomerate. Locally there are interbeds of sedimentary serpentine most likely derived from the serpentinous olistostromes of Phipps (1984).

Sand-rich strata of the upper Cretaceous part of the Great Valley Sequence unconformably overlie the highly deformed lower Great Valley Sequence. The upper Cretaceous part of the Great Valley Sequence on the Napa quadrangle is over 3.5 km thick and forms a monocline dipping eastward toward the Sacramento Valley. This homoclinal section is divided into six formations based on Kirby (1943). Elsewhere on the Napa quadrangle the Great Valley Sequence is divided into regional chronostratigraphic units. Ingersoll (1990) recommended that the term Great Valley Sequence, previously applied to the forearc basin strata on the west side of the Sacramento Valley (Bailey and others, 1964) be abandoned in favor of Great Valley Group which he divided into petrofacies based on sandstone petrology. The California Geological Survey has historically used chronostratigraphic units on regional maps and has, with the exception of the formal formations of Kirby (1943), used that nomenclature on the Napa quadrangle for subdividing the Great Valley Sequence.

Upper Cretaceous Great Valley Sequence rocks are also exposed in a northwest trending belt in the Mayacmas Mountains in the central part of the map and on both sides of Carquinez Strait in southeastern part of the map. Small bodies of Cretaceous Great Valley Sequence occur in the northwest part of the map as tectonic outliers overlying Franciscan rocks.

A notable occurrence of Great Valley Sequence rock is the Novato Conglomerate, immediately northwest of San Pablo Bay. Its age is poorly constrained within the Cretaceous and it is unusually rich in felsic volcanic clasts and quartzite (Ford, 2007). A similar conglomerate is mapped as an outlier overlying
Franciscan mélange near Camp Meeker and Jenner, in the northwest corner of the Napa quadrangle. Conglomerate in both areas are correlative with a large body of similar conglomerate near Healdsburg which are collectively part of the Healdsburg terrane of Blake and others (1984).

**Paleogene sedimentary rocks**

By the end of the Cretaceous, the forearc basin lying between the Sierran magmatic arc and the Franciscan subduction complex had been filled and Paleogene sediment was transported by rivers draining the Sierra Nevada and the Klamath Mountains to an open marine shelf in the Sacramento Valley (Dickinson and others, 1979). During the early Paleocene marine regression, deep canyons (termed gorges, Redwine, 1972) were incised into the continental shelf delivering sediment to a deep-water depocenter in what is now the Sacramento River delta (Dickinson and others, 1979). During subsequent transgressions, sediments filled the gorges and were deposited as thin sheets across the shelf so both deep and shallow marine formations are now exposed on the southeastern part of the Napa quadrangle.

Paleocene formations include the Martinez Formation, several unnamed units (Prothero and Brabb, 2001), the Las Juntas Formation of Weaver (1953), the Vine Hill Sandstone of Weaver (1953). The Martinez Formation, which was deposited in and overflowed the Menganos gorge, as well as unnamed units are exposed along the eastern border of the map near Fairfield. They are mostly sandstone that locally contains glauconite, and are often fossiliferous. The Vine Hill Sandstone of Weaver (1953) is exposed at Martinez, across the Carquinez Strait near Benicia, and in a thin belt on the east side of the Franklin Fault. The Las Juntas Shale of Weaver (1953) is also exposed sparingly at Martinez and along the Franklin Fault.

Eocene formations are far more extensive, including the Capay Shale, Domengine Sandstone, Nortonville Shale, and Markley Sandstone, north of the San Pablo and Suisun bays and the Muir Sandstone of Weaver (1953), Escobar Sandstone of Weaver (1953) and the Markley Sandstone south of the bays. Outcrops of Capay Shale in the Fairfield-Vacaville area are the southermost exposures of fill of the Princeton gorge (Dickinson and others, 1979). During the early to middle Eocene shallow marine littoral and paralic sediments of the Domengine Sandstone were deposited (Sullivan and Sullivan, 2007). Along Interstate 80 between Vallejo and Cordelia there are exposures of lignite-bearing Domengine Sandstone overlying Cretaceous mudstone along low angle attenuation faults. In the hills west of Napa, Domengine Sandstone is also in fault contact Cretaceous rocks of the Great Valley Sequence. During the middle Eocene deeper marine conditions prevailed and the Nortonville Shale and Markley Sandstone were deposited. Outcrops of Nortonville Shale are virtually nonexistent and the formation is marked by nearly continuous landsliding. Markley Sandstone is well-bedded to massive and contains abundant muscovite. Tectonic uplift and marine regression at the end of the Paleogene mark a shift from dominantly marine deposition in the eastern part of the Napa quadrangle to dominantly nonmarine deposition during the Neogene.

**Overview of Neogene rocks**

Early Neogene was characterized by uplift and exhumation throughout northern California marked by a hiatus in the geologic record that lasted into the mid to late Miocene. At about 17 Ma, initiation of the San Andreas Fault System began and at about 10-12 Ma the Mendocino triple junction had approached the latitude of the San Francisco Bay region (Atwater, 1970). Neogene basins of northern Coast Ranges of California formed in response to transform tectonics associated northward migration of the Mendocino triple junction (Nilsen and Clarke, 1989; Fox, and others, 1985a) within the San Andreas
System or its effects far to the east (Dickinson, 1997). Volcanic and sedimentary rocks deposited in these basins are interbedded in some areas while in other areas they are not, but the sequences are all essentially coeval.

With the exception of the Lovejoy Basalt exposed in the northeast corner of the map area, Neogene volcanic rocks of the Napa Quadrangle are part of a linear belt of volcanic fields (Figure 2) that are progressively younger to the northwest (Fox and others, 1985a). Several investigators (Fox, 1983, McLaughlin and others, 1996; Wakabayashi, 1999; Graymer and others, 2002) recognized that parts of these volcanic fields are fault-bounded and have been displaced from their original depositional positions by dextral faults of the East Bay Fault System (Figure 2). The oldest field is represented by ~11 Ma lava flows that cap Burdell Mountain in northern Marin and southern Sonoma counties (Ford, 2007; Figure 2). The Tolay Volcanics were described by Morse and Bailey (1935) from cores obtained from the Murphy No. 1 well in the Petaluma Oil Field. Two lithologically similar but younger volcanic sequences are exposed in the southern Sonoma Mountains, the Donnell Ranch volcanics of Youngman (1989) and the Sonoma Volcanics (Figure 3). Both younger sequences consist of rhyolite overlain by and interbedded with mafic breccia, lava flows, and, in contrast to the Burdell Mountain volcanics, contain abundant tuff. The Donnell Ranch volcanics of Youngman (1989) are the older of the two and lie west of the Rodgers Creek Fault. Rocks of the Sonoma Volcanics are found on both sides of the Rodgers Creek Fault.

Neogene sedimentary rocks were also disrupted by the dextral faults of East Bay Fault System so they are now found in fault-bounded blocks. The oldest Neogene sedimentary unit on the map is unnamed shallow marine sediment underlying the Burdell Mountain Volcanics on Burdell Mountain and the Monterey Group, the San Ramon, and Neroly formations underlying the Sonoma Volcanics east of the Carneros Fault in Carneros Valley and the Mayacmas Mountains. Though they are now at about the same latitude and similar in age, they were deposited in separate basins over a 100 km apart. The most extensive Neogene sedimentary units on the map are the late Miocene fluvial, estuarine, and lacustrine, Petaluma Formation and the coeval, marine Wilson Grove Formation. A littoral facies, the sand and gravel of Cotati, marks the marine-nonmarine transition between them. Plio-Pleistocene terrestrial gravel, the Glen Ellen and Huichica formations as well as unnamed gravel overlie the Miocene unit throughout the map area.

Quaternary surficial deposits and valley fill are mapped in much greater detail than on earlier maps, largely due to the mapping of these deposits throughout the San Francisco Bay region by Knudsen and others (2002), Witter and others (2006), and new mapping done in preparation of this map.

Neogene Volcanic rocks

Lovejoy Basalt

A small part of the regionally extensive Lovejoy Basalt is exposed in the northeast corner of the map area. It was originally named the Putnam Peak Basalt by Weaver (1949) for exposures at Putnam Peak near Vacaville. Durrell (1959) correlated it with basalt flows in the northern Sierra which he considered to be Eocene and applied the name Lovejoy Formation to the basalt in both areas. Durrell (1959) also considered basalt that is widespread in the subsurface in the Sacramento Valley to be Lovejoy Basalt. Ar/Ar dating later showed the Lovejoy Basalt is mid-Miocene (Roberts, 1985; Page and others,
1995; Garrison and others, 2008). Chemical and lithological similarities suggested the Lovejoy could be related to the Columbia River Basalt Group (Durrell, 1959; Doukas, 1983; Seigel, 1988). Wagner and others, (2000) suggested the Lovejoy Basalt was generated from the same plume material as the Columbia River basalts which was later corroborated by more extensive investigations (Coe and others, 2005; Garrison and others, 2008).

**Burdell Mountain Volcanics**

The Burdell Mountain Volcanics include flow-banded, porphyritic andesite, volcanic breccia, volcanic mudflow deposits, and minor flow banded dacite that occur on Burdell Mountain west of the Petaluma Valley (Figure 3). Together with the underlying unnamed Tertiary marine strata, the volcanics generally form a moderately, northeast-dipping (~30˚) homocline (Ford, 2007). Although Weaver (1949) mapped the Burdell Mountain Volcanics as Sonoma Volcanics, Mankinen (1972) obtained a K/Ar date of 11.8 Ma on a flow near the base of Burdell Mountain and suggested a correlation with the Tolay Volcanics of Morse and Bailey (1935). Four $^{40}\text{Ar}/^{39}\text{Ar}$ dates on the Burdell Mountain Volcanics (Ford 2007; Wagner and others, 2011, Table 1) range from 11.18 to 10.59 Ma. The average of these dates matches the average age of the basal flows of the Quien Sabe volcanics near Hollister, 175 km south of the map area (Drinkwater and others, 1992). This correlation is strengthened by similarities in Tertiary marine strata and Mesozoic basement beneath both the Quien Sabe and the Burdell Mountain volcanics (Ford, 2007). Volcanic rocks north of Burdell Mountain along the west margin of Petaluma Valley have been assigned to the Burdell Mountain Volcanics by Graymer, and others, (2002) based on K/Ar dates from Fox and others, (1985b). However, these are K/Ar dates that are considerably older than the more recently available $^{40}\text{Ar}/^{39}\text{Ar}$ dates for the Burdell Mountain Volcanics. Three $^{40}\text{Ar}/^{39}\text{Ar}$ dates (Wagner and others, 2011) from mafic volcanics southwest of Cotati, range in age from 8.96 to 8.39 Ma and now show that these rocks fall within the age range of the Tolay Volcanics. More recent dating now shows volcanic rocks in Petaluma, previously considered to be Burdell Mountain Volcanics are, shown on the Napa Quadrangle as Tolay volcanics. The largest exposure of volcanics previously assigned to the Burdell Mountain Volcanics is at Spring Hill, south of Petaluma. Here the volcanics are overlain by Petaluma Formation (Bezore and others, 2002) similar to the basal Petaluma Formation/Tolay Volcanics section on the Donnell Ranch suggesting these are Tolay Volcanics rather than Burdell Mountain Volcanics. Based on dates of 9.32 and 9.64 Ma (R. Fleck, personal communication, 2011) on localities dated by Fox and others, (1985b), the volcanic rocks in this area assigned to the Tolay Volcanics on the Napa Quadrangle.

**Tolay Volcanics including the Donnell Ranch Volcanics**

Morse and Bailey (1935) applied the name Tolay Volcanics to a sequence of rhyolite, andesite and basalt at least 1220 m thick that was penetrated by the Murphy #1 well in the Petaluma Oil field (Figure 3). They also applied the name to a small patch of mafic volcanics along the Tolay Fault, near Lakeville. As discussed in the previous section, volcanic rocks in the Meacham Hill area and along the west margin of the Petaluma Valley are here considered to be part of the Tolay Volcanics. A silicic body west of Cotati, termed the “Cotati rhyolite plug” by Graymer and others, (2002) was also dated in the age range of the Tolay Volcanics.

The Donnell Ranch volcanics were informally named by Youngman (1989) for surface exposures of mafic flows, tuff, breccia and rhyolite that occur between the Rodgers Creek and Tolay faults from Sears Point northward to Lakeville (see Figure 3 for location of Donnell Ranch). The Donnell Ranch volcanics of Youngman (1989) rest unconformably on rocks of the Franciscan Complex and are
conformably overlain by the Petaluma Formation (Wagner and others, 2002a). Youngman (1989) interpreted the Donnell Ranch volcanics to be emplaced as thrust sheets or "flower structures" that extend outward for hundreds of meters on both sides of the Rodgers Creek Fault. Mapping by Randolph-Loar (2002) and Wagner and others, (2002a) confirms that on the west side of the Rodgers Creek Fault the Donnell Ranch volcanics of Youngman (1989) are locally expressed as klippen thrust over younger Petaluma Formation strata. The thrusts are west-dipping, away from the Rodgers Creek Fault, but verge to the east toward the fault as indicated by overturning of Petaluma strata to the east beneath the thrust klippen of the older Tolay volcanics (Randolph-Loar, 2002). Youngman (1989) interpreted silicic volcanic rocks east of the Rodgers Creek Fault to be thrust klippen of Donnell Ranch volcanics of Youngman (1989) emplaced over Sonoma Volcanics. Randolph-Loar (2002) and Wagner and others, (2002a) interpreted all the rocks east of the Rodgers Creek Fault as the Sonoma Volcanics with no localized thrust sheets of Donnell Ranch volcanics as mapped by Youngman (1989).

Basalt, basaltic andesite lava flows and breccia, as well as rhyolitic to dacitic lava flows and tuff, are the predominant lithologies in the Donnell Ranch volcanics of Youngman (1989). Basalt and basaltic andesite have yielded ages of 10.64 to 8.49 Ma (Youngman, 1989; Fox and others, 1985b). An Ar/Ar date of 8.52 Ma (Youngman, 1989) was obtained from an andesite lava flow that is interbedded with the lowermost part of the overlying Petaluma Formation northeast of Tolay Creek (Fox and others, 1985b). A depositional contact between basalt and overlying chert in the Petaluma Formation is exposed in the same area. These relationships provide evidence that the Donnell Ranch volcanics of Youngman (1989) both underlie and are interbedded with the lower Petaluma Formation.

Cebull (1958) was the first to suggest the interbedded Petaluma Formation and volcanic rocks along Tolay Creek are correlative to the "Transition zone" between the Petaluma Formation and the Tolay Volcanics in the Murphy #1 well (Morse and Bailey, 1935). Two $^{40}$Ar/$^{39}$Ar dates (Wagner and others, 2011, Table 1) from andesite samples from the Murphy #1 core are 8.99 ± 0.06 Ma (2492 ft/759.6 m depth) and 9.13 ± 0.06 Ma (3787 feet/1154 m depth). These dates indicate the Tolay Volcanics in the Murphy well are the same age as the Donnell Ranch Volcanics of Youngman (1989). Surface mapping (Wagner and others, 2002a) together with the Ar/Ar dates confirm that the "Transition zone" (Cebull, 1958) is indeed exposed along Tolay Creek and that the Donnell Ranch volcanics of Youngman (1989) are a surface exposure of the Tolay Volcanics of Morse and Bailey (1935). Silicic lava flows and tuff southwest of Tolay Creek, previously mapped as the Pliocene St. Helena Rhyolite (Weaver, 1949; Cebull, 1958), are here also considered as part of the Tolay (Donnell Ranch) Volcanics because of a K-Ar date on plagioclase of 9.56 ± 0.15 Ma (Fox and others, 1985b).

Silicic lava flows and tuff assigned here to be Tolay Volcanics range in age from 9.86 to 9.56 Ma, while silicic rocks assigned to the Sonoma Volcanics range in age from 8.17 to 7.37 Ma. Volcanic rocks lying between the Petaluma Valley and Burdell Mountain faults are assigned to the Tolay Volcanics (Figure 3).

The Tolay Volcanics are truncated by the Rodgers Creek Fault in the southern Sonoma Mountains and extend southward beneath San Pablo Bay. A magnetic anomaly interpreted to be due to volcanic rocks (Wright and Smith, 1992; Parsons and others, 2003) extends across San Pablo Bay nearly to Pt. Pinole.

Louderback (1951) and Taliaferro (1951) were the first geologists to suggest the Tolay Volcanics beneath and interbedded with the Petaluma Formation in the Murphy #1 well are equivalent to the Berkeley Hills volcanics. Youngman (1989) later demonstrated that the trace element chemistry of the
Tolay Volcanics (her Donnell volcanics) is identical with that of the Berkeley Hills volcanics and distinct from the Sonoma Volcanics (Figure 3).

**Sonoma Volcanics**

Basalt, basaltic andesite, rhyolite, rhyodacite and dacite, and interbedded tuff of the Sonoma Volcanics crop out over much of the central part of the Napa Quadrangle and extends beyond the northern boundary of the map. Osmont (1905) was the first to describe the volcanic field and divided these rocks into three units: the Mark West Andesite overlain by the Sonoma Tuff, and the uppermost St. Helena Rhyolite. Dickerson (1922) applied the name Sonoma Group but later, Morse and Bailey (1935) informally applied the name in use today, the Sonoma volcanics. Weaver (1949) formalized the name Sonoma Volcanics, designating the lava flows, breccia and tuffs on Sonoma Mountain as the type area. Fox (1983) divided the Sonoma Volcanics into a lower member that occupies most of the southwestern part of the field, and an upper member that occupies the eastern and northern parts of the field. Fox and others, (1985b) informally divided the lower member into five units: the andesite of Rodgers Creek, the rhyolite of Arrowhead Mountain, the rhyolite of Bismarck Knob, the andesite of Atlas Peak, and the soda rhyolite of Sugarloaf Ridge. They also divided the upper member of the Sonoma Volcanics into five informal units: the rhyolite of Mount George, the tuff breccia of Napa, the andesite of Tulucay Creek, the tuff of Petrified Forest, and the rhyolite of Calistoga. All of these informal units except the rhyolite of Calistoga which is not exposed in the map area, and the andesite of Rodgers Creek are shown on the Napa Quadrangle. The andesite of Rodgers Creek was abandoned by Wagner and others, (2011) because it is not a mappable unit.

Based on radiometric dates from Mankinen (1972), Fox and others, (1985b), Youngman (1989), and Wagner and others, (2011), the Sonoma volcanic field can be separated spatially and temporally into three age groups (McLaughlin and others, 1996; Wakabyashi, 1999; Figure 4). The Western Sonoma Volcanics is oldest (WSV on Figure 3) and ranges in age from 8.17 Ma to 4 Ma. It generally occurs in the southern and western part of the field, and for the most part, conforms to the lower member of Fox and others, (1985b). The Eastern Sonoma volcanics make up the middle age group of about 5.4 to 3.4 Ma, includes parts of both the upper and lower members of Fox and others, (1985b) and generally occupies the east-central part of the field (ESV on Figure 3). The youngest part of the Sonoma Volcanics (NSV on Figure 3) is in the north part of the field where dates range from 2.5 to about 3.4 Ma and is entirely in the upper member of Fox and others, (1985b). Only the Western and Eastern Sonoma Volcanics will be described here because the youngest, northern group is not significantly represented in the map area.

**Western Sonoma Volcanics**

The western age group is the most extensive and has the widest age range (8.17 to 4 Ma) of the three groups shown on Figure 3. These rocks extend from Sears Point near San Pablo Bay north beyond the Santa Rosa area at the north edge of the map. They are also exposed in the Mayacmas Mountains in the central part of the map. The oldest unit (Msvrb) is a distinctive deposit of rhyolite to rhyodacite breccia is exposed on the east side of the Rodgers Creek Fault a few km north of Sears Point and again west of the fault near the north edge of the map at Taylor Mountain. Boulders and blocks a meter or more across are set in a tuffaceous matrix and are interbedded with sediments that are almost entirely rhyodacite detritus deposited by debris flow and fluvial processes. Pebbly sand identical to the Petaluma Formation is intercalated with the silicic detritus at both localities. McLaughlin and others, (2008; 2011) include the breccia in the Petaluma Formation but on the Napa quadrangle it is shown as part of the
Sonoma Volcanics. Radiometric dates ($^{40}\text{Ar}/^{39}\text{Ar}$) on breccia clasts range from 8.17 to 7.3 Ma (Youngman, 1989; McLaughlin and others, 2008; Wagner and others, 2011; McLaughlin and others, 2012) providing maximum ages of the deposit. Tuffaceous matrix from the breccia is chemically similar to several tuffs erupted from the Zamaroni Quarry volcanic center near Santa Rosa, providing a loosely
constrained depositional age of 7.26 to 6.26 Ma (Wagner and others, 2011). Breccia exposed near Sears Point and at Taylor Mountain, have identical ages and similar chemistry (Wagner and others, 2011; McLaughlin and others, 2012). McLaughlin and others, (2005, 2008, 2012) interpreted the breccia at both localities to have been derived from the Cooks Peak rhyodacite exposed on Taylor Mountain during initiation of the Rodgers Creek Fault and the breccia now near Sears Point was subsequently displaced 28 km to the southeast.

The silicic breccia interfingers with and is overlain by a sequence of 7.36 to 5.08 Ma andesitic flows, breccia, and tuff (map unit Tsvm) along with minor rhyolite and basalt that comprise the middle part of the section. These rocks underlie Sonoma Mountain, Taylor Mountain, Cooks Peak, and in the hills north of Santa Rosa. On the southern part of the map, the Rodgers Creek Fault separates Sonoma Volcanics from the Tolay Volcanics and the Petaluma Formation. To the north, along the east margin of Petaluma Valley, the situation is more complex, where Sonoma volcanics occur on both sides of the fault. West of the fault, Sonoma Volcanics overlie moderate-to-steep, east-dipping strata of the Petaluma Formation along a nearly flat contact. Youngman (1989) obtained an 40Ar/39Ar date of 7.37 Ma on a andesite outlier which she considered to be a klippen resting on Petaluma Formation. The Petaluma Formation in this area contains the 6.26 Ma Roblar tuff indicating it is younger than the overlying Sonoma Volcanics. This older over younger relationship shows that the Sonoma Volcanics west of the Rodgers Creek Fault are out of place due to landsliding, thrusting or both. This relationship seems to extend north to the vicinity east of Cotati. Northeast of Cotati, the Sonoma Volcanics west of the RCF have dips similar to the Petaluma Formation and appear to be in place.

The youngest rocks in this part of the western Sonoma Volcanics are 4 Ma andesite lava flows around Lake Ralphine in Santa Rosa (McLaughlin et al., 2008) and a tuffaceous volcanic sequence on the north slope of Sonoma Mountain. This sequence is up to 120 m thick and thins southward to less 100m in the Carriger Creek area. It is composed of silicic and andesitic tuffs overlain by basalt on the crest of Sonoma Mountain. These intermediate and silicic pyroclastic strata include the Huichica Tuff (4.76 Ma) and the Tuff of Napa (4.71 Ma). The basalt flows that cap the section yielded an 40Ar/39Ar date of 4.1 Ma (Wagner and others, 2011).

The part of the Mayacamas Mountains covered by the Napa quadrangle is composed almost entirely of rocks of the western Sonoma Volcanics. Arrowhead Mountain, the dominant peak of the southern end of the range, is a rhyolite dome with lava flows and locally-welded tuffs extending from it. Although the age of the rhyolite dome and the flows is similar to the age of the rhyodacite breccia in the Sears Point area, the lithology and mode of occurrence are quite different making it unlikely the two are the same unit. The andesite of Schocken Hill and the rhyolite of Arrowhead Mountain extend northward along the western slope of the Mayacamas Mountains to the Kenwood Valley and dip 20° to 40° toward the west. Just north of Schocken Hill, an intrusive andesite body appears to be a volcanic neck marking a stratovolcano that could be the source of the andesite of Schocken Hill. Flows of gray, plagioclase-phyric, platy, andesite, informally named the andesite of Mission Highlands, overlie the Rhyolite of Arrowhead Mountain along the western flank of the Mayacamas Mountains and it also dips southwest toward Sonoma Valley.

The Rhyolite of Arrowhead Mountain extends northward to at least Sugar Loaf Ridge. It is interbedded with and overlain by andesitic flows and tuff. Andesitic tuff interbedded with the rhyolite yielded fission track date of 7.9 ± 0.8 Ma, near the town of Sonoma (Fox and others, 1985b). The andesite of Schocken Hill (map unit Msvas) is a sequence of at least four flows of gray, aphyric andesite that are well exposed in the hills immediately north of the town of Sonoma. The other fission track date, 7.5 ± 1.8
Figure 5. Schematic stratigraphic columns of the Mayacmas Mountains showing sequences of the Sonoma Volcanics.
Ma, is from the rhyolite that interfingers with the andesite of Schocken Hill. Another sequence of west-facing andesite lava flows and tuff overlying the Neroly Formation makes up the ridge east of Lovall Valley and appears to dip beneath the rhyolite of Arrowhead Mountain but it is not known if these flows are correlative with the andesite of Schocken Hill. A lithic tuff breccia is exposed in Lovall Valley is a well-bedded tuff containing cobble to boulder-sized lithics. Lithic clasts are often cracked and have red oxidation rinds indicating they were hot when emplaced. This tuff breccia and similar ones farther north have been interpreted as proximal, “throat-clearing breccias” (J. Rytuba, personal communication, 2007). In the Huichica Creek drainage in the southeastern corner of the Mayacamas Mountains, olivine-phyric mafic flows underlie dacite and trachydacite flows dated at 6.673 ± 0.35 Ma by Wagner and others, (2011) who informally named it the dacite flows of Huichica Creek. These flows are dark, glassy lava with a variable phenocryst assemblage of plagioclase, pale olivine, amphibole and/or pyroxene.

Diatomaceous sediment and volcanic rocks are exposed on the west slope of Bismarck Knob, about 8 km north of Arrowhead Mountain (Figure 4). These rocks overlie the more steeply dipping rhyolite of Arrowhead Mountain, the andesite of Shocken Hill, and the andesite of Mission Highlgrounds and extend about 6 km north to Sugar Loaf Ridge (Figure 5). The basal part of the assemblage rests on the andesite of Mission Highlgrounds and a lithic tuff breccia informally named the lithic tuff breccia of Mt. Pisgah which is a “throat clearing” breccia that is similar to and likely correlative with the lithic tuff breccia in the Lovall Valley. Diatomaceous lacustrine sediments are interbedded with the lithic tuff breccia. A tuff interbedded with the diatomite contains tephra that is chemically similar to and possibly correlative with tuffs in the Tassajara area near Mt. Diablo suggesting an age of about 6.2 Ma (Wagner and others, 2011). Dacitic lava erupted into a lake or wetlands environment where it interacted with water to form hyaloclastite. This dacitic volcanism is similar in age though slightly younger than the dacitic lava flows in the Huichica Creek area in the Arrowhead Mountain sequence to the south. Another tuff along strike farther north in lithic tuff breccia correlates with the 6.26 Ma Roblar tuff (Wagner and others, 2011).

At Bismarck Knob on the crest of the range there is a succession of basalt, andesite and rhyolite. The lower unit, informally named the basalt of Bismarck Knob, is a plagioclase, pyroxene-olivine-phyric flow basalt. It is the only true basalt known in the western Mayacmas range section based on chemical data (Wagner and others, 2011). Overlying the basalt is a massive andesite flow. At the top of the sequence is the informally named rhyolite of Bismarck Knob of Fox, (1983) which is a dome with associated flows, tuffs, boulder breccia, and minor water-laid sediments. Sanidine from a single block of vitrophyre yielded Ar40/Ar39 age 6.143 ± 0.061 Ma (Wagner and others, 2011). Lobes of the rhyolite of Bismarck Knob extend as far south as Lovall Valley where it overlies the rhyolite of Arrowhead Mountain. In places it is a welded and lithoidal tuff. East of Bismarck Knob, this rhyolite is truncated by the Carneros Fault and possibly displaced to the southeast at least four km where it laps onto the Great Valley Sequence. Immediately east of Bismarck Knob, across the Carneros Fault there is ash flow tuff that rests on the Great Valley Sequence in juxtaposition with the rhyolite. Pumice fragments collected near the base of the tuff correlate with the Lawlor Tuff (Wagner and others, 2011). Basalt flows overlie both the rhyolite of Bismarck Knob and the ash-flow tuff. The basalt is in the same stratigraphic position as the basalt flows that cap Sonoma Mountain which were dated at 4.1 Ma (Wagner and others, 2011).

A sequence western Sonoma Volcanics, mostly composed of tuff, extends northwestward from the town of Glen Ellen to the south slope of Bennett Mountain. The sequence is also found along the southwest margin of the Kenwood Valley. It is interbedded with the upper part of the Petaluma Formation. The sequence consists of the tuff of Mark West Springs, the 4.88 Ma Carriger tuff, the
4.70-4.71 Ma tuff of Napa (Healdsburg), and the 3.27 to 3.35 Ma Putah Tuff (Wagner and others, 2011). A K/Ar date of 5.66 Ma by Mankinen (1972) on a tuff from the south slope of Bennett Mountain, is the oldest reported age for the section. The tuff of Mark West Springs (4.83-5.2 Ma) has been identified at two places along the southwest margin of Kenwood Valley (Wagner and others, 2011). The “Carriger Creek tuff” was identified at one locality southwest of Kenwood. The Tuff of Napa (Healdsburg) is the most extensive tuff in the sequence. Originally identified near and named for Healdsburg, this tuff was later renamed Tuff of Napa because it erupted from the Napa Valley center (Sarna-Wojcicki and others, 2011). In many outcrops it is a distinctive brown color and contains dark pumice fragments up to 2-3 cm in diameter, while in other outcrops the tuff is white and cannot be identified in hand specimen. Areas underlain by the tuff have a distinctive rolling topography easily mistaken for landslides.

White, pumiceous ash flow tuff and reworked tuff exposed in the hills around and north of Glen Ellen were included in the Glen Ellen Formation by Weaver (1949). Recently, this tuff has been correlated with the Putah Tuff (Wagner and others, 2011) so it is here assigned to the Sonoma Volcanics. Fox and others, (1973) had considered it as part of the undivided Huichica and Glen Ellen Formation. Fox and others, (1985b) later included the tuff in the Huichica Formation because they believed it to be the same age as a tuff in the type locality of the Huichica Formation. The tuff in the type locality of the Huichica Formation, now known as the Huichica Tuff, is 4.71 Ma (Sarna-Wojcicki and others, 2011), significantly older than the Putah Tuff (3.27 to 3.33 Ma).

At Sugarloaf Ridge, about 6 km north of Bismarck Knob, there is a sequence of silicic and mafic tuff, lava flows and agglomerate (Figure 4). The sequence is in fault contact with Mesozoic rocks on the east and to the west it dips into the Kenwood Valley. Its northern extent is uncertain but rocks mapped by McLaughlin and others, (2008) in the northeastern corner of the Santa Rosa quadrangle appear to be correlative. The sequence rests on rocks that are equivalent to the Ryolite of Arrowhead Mountain, which in turn, rest on the Neroly Formation (Figure 5). A lithic tuff breccia exposed in Nunn’s Valley contains the 6.26 Ma Roblar tuff (Wagner and others, 2011). This is the northeastern-most occurrence yet known for the Roblar and shows the tuff breccia in Nunn’s Valley is equivalent to the lithic tuff breccia at Mt. Pisgah in the Bismarck Knob assemblage and possibly to the tuff breccia in Lovall Valley as well. Near the top of the lithic breccia there are interbeds of aphyric andesite that yielded $^{40}\text{Ar}/^{39}\text{Ar}$ dates of ~5.6 and ~5.7 Ma (Wagner, and others, 2011, Table 1). A welded rhyolite tuff interbedded with the lithic breccia and the aphyric andesite yielded a date of 5.65 Ma (Wagner and others, 2011, Table 1). These 5 to 6+ Ma flows and tuffs appear to be a continuation of the Bismarck Knob assemblage.

Sugarloaf Ridge is a volcanic edifice of rhyolite and andesite possibly as old as 5.3 Ma but mostly around 4.8 Ma and younger that was built on the older substrate. The oldest exposed unit at Sugarloaf Ridge is the Rhyolite of Adobe Canyon, which has a K/Ar date of 5.3 ± 0.2 Ma (Mankinen, 1972). A tuff containing tephrta that correlates with the Tuff of Mark West Springs (5.2 to 4.84 Ma) overlies the Rhyolite of Adobe Canyon. A body of sodic amphibole-bearing rhyolite, called the soda rhyolite of Sugarloaf Ridge by Fox et al (1985b) overlies the tuff. An $^{40}\text{Ar}/^{39}\text{Ar}$ date of 4.83 Ma (Wagner, and others, 2011, Table 1) was obtained for the soda rhyolite. Fox and others, (1985b) believed it to be extrusive and interbedded with andesite flows that overlie the Rhyolite of Adobe Canyon. The soda rhyolite is nearly the same age as the Lawlor Tuff though their chemistry and petrography are different (Sarna-Wojcicki, and others, 2011). Above the soda rhyolite is a thick, mafic, coarsely lithic tuff breccia interpreted to be a “throat clearing” breccia proximal to a vent (J.Rytuba, personal communication, 2007). At least two andesite flows are interbedded with the breccia. Intrusive basaltic andesite forms the arcuate Sugarloaf Ridge and in places basaltic andesite ring dikes intruded and locally overturned well-bedded lithic tuff.
breccia. Two associated basaltic andesite near-vent breccia deposits contain volcanic bombs, twisted spindles, and agglomerate and are separated by an unconformity. Wagner and others, (2011) interpreted the vent facies mafic rocks as intracaldera fill. A partially welded, crystal-vitric tuff exposed within the arcuate structure yielded an 40Ar/39Ar date of 4.806 Ma (Wagner and others, 2011, Table 1) and may also be an intracaldera tuff. Langenheim and others, (2010) interpret the arcuate topography, as well as local gravity and magnetic anomalies as a possible caldera.

Across the Kenwood Valley, northwest of Kenwood, basaltic andesite apparently flowed westward from the caldera down a paleochannel that contained ash-flow tuff as well as reworked tuffaceous channel deposits. The ash flow tuff contains a tephra that correlates with the tuff of Mark West Springs (4.83-5.0 Ma.) (Wagner, and others, 2011) and reworked tephra that have chemical similarities to the Putah and/or Roblar tuffs (Wagner and others, 2011). This suggests these flows emanated from the Sugarloaf Ridge caldera and flowed westward, prior to the opening of the Kenwood Valley.

**Eastern Sonoma Volcanics**

The Eastern Sonoma Volcanics (ESV on Figure 4) consists of Miocene to Pliocene andesite lava flows and flow breccia, some basalt lava flows, and intrusions overlain by Pliocene silicic pyroclastic rocks and lava flows. These rocks make up the bulk of the Howell Mountains east of the Napa Valley but are also found along the western side of Napa Valley near Rutherford and around the Suisun marshes and lowlands in the southeastern part of the map. The lower extrusive andesitic part of the ESV is divided into three units, andesite flows of Stags Leap, andesite flow breccia of Stags Leap, and andesite ash flow tuff and tuff breccia of Stags Leap all of which Sweetkind and others, (2011) consider to be flanks of the Stags Leap stratovolcano (to be discussed in the next section). Two 40Ar/39 dates, one from base of the 350 m thick andesitic section and the other from the top (4.35-4.3 Ma) are analytically identical indicating very rapid deposition (Sweetkind, and others, 2011). A granitic body, the only one known in the Sonoma Volcanics, shown on the map as the Stags Leap Stock, is also part of the stratovolcano.

**Volcanic Centers**

Volcanic centers recognized within the Sonoma Volcanics in the map area include the Zamaroni Quarry-San Pablo Bay center (McLaughlin and others, 2005,2012; Sarna Wojcicki, and others, 2011; Wagner and others, 2011), the Napa Valley center ( Sweetkind and others, 2005, 2011; Andrei Sarna-Wojcicki and others, 2011 ), the andesitic stratovolcano at Stags Leap (Sweetkind and others, 2005a; 2011), a silicic volcanic center at Mt. George (Sweetkind and others, 2011), a rhyolite dome at Arrowhead Mountain (Fox and others, 1985b), a possible andesitic stratovolcano in the highlands near Sonoma (Wagner and others, 2011), a rhyolite dome near Bismarck Knob (Wagner and others, 2011), and a possible caldera and ring dike at Sugar Loaf Ridge (Langenheim and others, 2010; Wagner and others, 2011). In addition there are small, mostly mafic intrusions, cinder cones, fissure eruptions, dikes, sills and plugs throughout the Mayacamas Mountains and on Sonoma Mountain that are too numerous to describe individually. At Annadel State Park on Bennett Mountain, there are intrusive rhyolite, massive rhyolite flows and breccia some of which contain obsidian, and ash flow tuff (Higgins, 1983).

**Zamaroni Quarry-San Pablo Bay volcanic center**

Rhyodacitic intrusives, flows, tuff, and breccia exposed west of the Rodgers Creek Fault at the Zamaroni Quarry on the west margin of the Santa Rosa plain, just south of Santa Rosa have an 40Ar/39Ar age of 7.26 Ma (McLaughlin, and others, 2005; in press). A southeast extension of the rhyodacite at
nearby Cook Peak has an $^{40}$Ar/$^{39}$Ar age of 7.94 Ma (McLaughlin and others, 2008). A sedimentary breccia exposed in the same area was interpreted by McLaughlin and others, (2005; 2012) to be a basin margin fault scarp breccia or a debris avalanche deposit. McLaughlin and others, (2012) and Wagner and others (2011) interpret these rhyodacitic rocks to be part of a volcanic center that was truncated by the Rodgers Creek Fault. Rhyodacite of the same age (7.84- 7.96 Ma, Table 2) and identical sedimentary breccia are exposed east of the Rodgers Creek Fault 28 km to the southeast. This suggests that the volcanic center at Zamaroni Quarry was displaced along the Rodgers Creek Fault from the San Pablo Bay volcanic center that is now concealed beneath San Pablo Bay and/or Sonoma Valley. Wells drilled around the margin of San Pablo Bay penetrated agglomerate (Wright and Smith, 1992) which may reflect the presence of the volcanic center. Wright and Smith’s cross sections (A-A’ and B-B’ on p. 416) show the volcanics extending beneath San Pablo Bay. Older Sonoma Volcanics (~8 to 5 Ma) of the Sonoma Mountain assemblage and the volcanic section in the Cooks Peak-Taylor Mountain area on the Santa Rosa quadrangle (McLaughlin and others, 2008) were likely erupted from this center before the initiation of the Rodgers Creek Fault. The tuff of Zamaroni Quarry, the Roblar tuff, and probably the tuff of Lichau Creek were erupted from the Zamaroni-San Pablo Quarry volcanic center (Wagner and others, 2011).

**Napa Valley volcanic center**

The Napa Valley eruptive center of Sarna-Wojcicki and others, (2001), called the Cup and Saucer volcanic center by Sweetkind and others, (2005a; 2011), is in and east of the city of Napa (Figure 4). An arcuate escarpment marks the eastern wall of a caldera and an apron of near-vent facies of pyroclastics and lava flows extend eastward into the Howell Mountains (Sweetkind and others, 2011). Aeromagnetic and gravity data (Langenheim and others, 2010) suggest the caldera complex extends from the Cup and Saucer westward beneath Napa Valley to the West Napa Fault. Several intracaldera volcanic units are shown on the Napa quadrangle including the andesitic tuff and tuffaceous agglomerate of Tulucay Creek, the basalt of Tulucay Creek, the rhyolitic breccia of Napa, and rhyolite. Parts of these units were correlated with pyroclastic outflow facies by Sweetkind and others, (2011). They correlated the andesitic tuff and tuffaceous agglomerate of Tulucay Creek with the 5.4 to 5.2 Ma Pinole Tuff. There has been some question as to whether the Pinole Tuff was erupted from the Napa Valley center or another volcanic center in the vicinity of San Pablo Bay (Louderback, 1951; Sarna-Wojcicki, 1976). Its chemistry is similar to intracaldera andesitic rocks of Tulucay Creek (Sweetkind, 2011) suggesting the Napa Valley eruptive center is the source of the Pinole Tuff. Three younger tuffs also erupted from the Napa Valley volcanic center, the Lawlor Tuff (4.84 Ma), the Huichica Tuff (4.76 Ma), and the Tuff of Napa (Healdsburg) ($\leq$4.70-4.71 Ma) are of regional significance (Sarna-Wojcicki and others, 2011). All of the aforementioned tuffs have been found in the Mt. George area east of Napa where they are associated with aprons of proximal vent facies flows and domes (Sweetkind and others, 2011). To the west the caldera has been truncated by faulting and the western proximal vent (Langenheim and others, 2010; Sarna-Wojcicki and others, 2011; Sweetkind and others, 2011, Wagner and others, 2011).

**Mt. George volcanic center**

Silicic flows, domes, and shallow intrusives from the Mt. George eruptive center, located in the Howell Mountains above Napa, overlap rocks of the Napa Valley volcanic center (Sweetkind and others, 2011). Typically these rocks are gray to tan dacite. Flows are usually banded dacite with the margins of perlite vitrophyre. K/Ar ages range from 3.73 to 4.3 Ma (Fox and others, 1985b; Mankinen, 1972).
Rhyolite dome at Arrowhead Mountain

Arrowhead Mountain in the southern Mayacmas Mountains is a dome (Figure 4) and the source of 7.5 Ma (Fox and others, 1985b) rhyolite lava flows and tuff. Arrowhead Mountain is the oldest of several eruptive centers in the Mayacmas Mountains that young to the north. Rhyolitic lava flows and tuff were erupted from the dome at Arrowhead Mountain about the same time the San Pablo Bay center was active but whether or not there is a direct relationship is unknown. Rhyolite flows emanating from the dome near Bismarck Knob to the north overlap rhyolite flows of Arrowhead Mountain.

Stratovolcano near Sonoma

In the hills north of Sonoma there are near vent breccia and at least one conical intrusive that is dacitic to andesitic. In addition to the intrusive, there are exceptionally thick andesite lava flows. It appears the intrusion is a volcanic neck that is a remnant of a stratovolcano (Figure 4) that could be the source for the mafic lava flows that are so prevalent in this area.

Rhyolite dome at Bismarck Knob

On the northwest slope of Bismarck Knob (Figure 4), there are bulbous ridges of vitric rhyolite tuffs and lava flows. A sample of perlitic pitchstone (Wagner and others, 2011) yielded an $^{40}\text{Ar}/^{39}\text{Ar}$ age of $6.143 \pm 0.0061 \text{ Ma}$. In the deep stream canyons cut into the west slope of Bismarck Knob rhyolite with vertical flow banding is exposed.

Sugarloaf Ridge “caldera”

Sugarloaf Ridge is an arcuate topographic high suggesting the presence of a caldera and a localized gravity low (Langenheim and others, 2010) also suggests there may be a small caldera here (Figure 4). Structure and lithology of the rocks of the Sugarloaf Ridge assemblage are similar and the age range is the same as that of the rocks at the Napa Valley eruptive center. West of Sugarloaf Ridge across Kenwood Valley, there are vent breccias, domes, tuffs, including the 4.51 Ma obsidian bearing rhyolite (Higgins, 1983; McLaughlin and others, 2008; Dellattre and others, 2007) at Annadel State Park on the east slope of Bennett Mountain. Its chemistry suggests it is related to the Napa Valley volcanic center (Sweetkind and others, 2011). In as much as it is flow rock, it must have been proximal to a volcanic center, presumably the Sugarloaf Ridge “caldera”. The Lawlor tuff and the tuff of Napa are widespread between Kenwood Valley and Bennett Valley. The tuff of Napa contains pumice fragments larger than 2 cm suggesting it is proximal. Based on new $^{40}\text{Ar}/^{39}\text{Ar}$ dates (Wagner and others, 2011), chemistry (Sweetkind and others, 2011), and tephrochronological correlations Sarna-Wojcicki and others, 2011) the basaltic andesite flows emanating from the Sugarloaf Ridge “caldera”, the Lawlor and Napa tuffs, and obsidian rhyolite flows at Annadel State Park have been interpreted as the near vent apron deposited on the west flank of the Napa Valley volcanic center, some 30 km to the southeast which was subsequently displaced to its present location along the Carneros, West Napa, and related faults (Wagner and others, 2011).

Pliocene basalt flows

Basalt flows that cap Sonoma Mountain and the Mayacmas Mountains near Bismarck Knob, as well as basalt flows near Glen Ellen provide important constraints on the opening of the Sonoma Valley. Basalt flows capping Sonoma Mountain were dated at $4.1 \pm 0.1 \text{ Ma}$ (Wagner and others, 2011) and basalt
flows capping the Mayacmas Mountains between Bismarck Knob and Mount Veeder overlie tuff that contains tephra correlated with the 4.84 Ma Lawlor Tuff (Wagner and others, 2011) suggesting they could be equivalent. An undated basaltic center east of Glen Ellen (Berkland, 2001) produced basalt flows and breccia that that underlie the late Pliocene Glen Ellen Formation. If they were once continuous with the lava flows on Sonoma Mountain and the Mayacmas Mountains, they must have predated opening of the Sonoma Valley basin as discussed by Langenheim and others, (2005; 2010).

Neogene Sedimentary Rocks

Monterey Shale and San Ramon Sandstone

Weaver (1949) mapped narrow belts of Monterey Shale, a formation of the Monterey Group, and the San Ramon Sandstone and reported middle to upper Oligocene fossils in the Carneros Valley. The age of the San Ramon sandstone, based on the fossils, is uncertain (Fox, 1983; Graymer, Jones and Brabb, 2002) and it appears that the presence of the Kirker Tuff is crucial for age control. Although there are poor exposures of tuffaceous sediment where Weaver (1949) mapped San Ramon Sandstone, no tuff bed was found during mapping for this investigation (Wagner and others, 2004; Clahan and others, 2004).

Neroly Formation

Marine sandstone and volcaniclastic sediments of the Neroly Formation underlie the Sonoma Volcanics in the Carneros Valley and in the Nunns Valley area in the Mayacmas Mountains (Weaver, 1949). In Carneros Valley the Neroly Formation dips west beneath the Sonoma Volcanics and can be traced in the subsurface southwest into the southern Sonoma Valley (Wright and Smith, 1992 p. 416; D. Zieglar, unpublished data). A tuff interbedded with the Neroly Formation in Carneros Valley contains tephra that correlates with the Coal Valley tuff in Nevada that is about 11.1 Ma (Wagner and others, 2011, Table 3). These occurrences of the Neroly Formation mark the northernmost part of an open marine basin that received detritus from the east (Buising and Walker, 1995).

Petaluma Formation

Dickerson (1922) applied the name Petaluma Formation to deformed sediments on the west side of Petaluma Valley. Morse and Bailey (1935) provided a detailed description of approximately 1200 m of Petaluma Formation sediments that were penetrated by the Murphy #1 well in the Petaluma Oil Field. They divided this section into a lower unit dominated by estuarine mudstone and an upper unit dominated by fluvial sandstone and conglomerate. Originally the Petaluma Formation was believed to unconformably underlie the Sonoma Volcanics and therefore predate them (Morse and Bailey, 1935; Weaver, 1949) but Fox (1983) showed that the Petaluma Formation is mostly Miocene and is interbedded with the Sonoma Volcanics. Allen (2003) revised the subdivision of the Petaluma Formation of Morse and Bailey (1935), resulting in a three-fold subdivision. Allen’s lower Petaluma is interbedded with the underlying Tolay Volcanics and was called the “Transition Zone” by Morse and Bailey (1935). Allen divided the upper Petaluma of Morse and Bailey (1935) into two units based on clast types in the conglomerate. His middle Petaluma is characterized by a predominance of Franciscan and Sonoma Volcanics clasts, and his upper Petaluma is characterized by clasts of laminated siliceous shale similar to the Claremont Shale of the Monterey Group. Allen’s subdivisions of the Petaluma Formation into a lower and middle part are followed on the Napa Quadrangle in the Petaluma Valley and parts of the Santa Rosa plain west of the Rodgers Creek Fault. However the upper Petaluma Formation is defined on the Napa
Quadrangle as the lignite-bearing, diatomaceous lacustrine and fluvial sediments that overlie the Pinole Tuff and are interbedded with younger tuffs erupted from the Napa Valley volcanic center. Upper Petaluma Formation strata are exposed in the Santa Rosa area, in Bennett Valley, and along the east flank of Sonoma Mountain in the Sonoma Valley. Strata between the Roblar tuff (6.26 Ma) and the Pinole Tuff (5.4-5.2 Ma) considered to be upper Petaluma by Allen (2003) in the Petaluma Valley and in the Cotati area are here considered to be middle Petaluma. West of the Rodgers Creek-Healdsburg Fault, the Petaluma Formation becomes progressively younger to the north. To the east however, the progression is disrupted by the Rodgers Creek, Maacama, and Bennett Valley faults.

Lower Petaluma Formation

Well-bedded to laminated lacustrine and estuarine sediments with some possible marine interbeds (Peterson and Allen, 2005) exposed along Tolay Creek make up the lower Petaluma Formation. Morse and Bailey (1935) described a gradational contact between the lowermost sediments and the underlying Tolay Volcanics in the Murphy #1 well, which they termed the “Transition Zone”. This zone consists of massive to laminated mudstone with ostracode-rich intervals, cream-colored dolomite interbeds (Figure 6), and volcanic interbeds. Cebull (1958) mapped a similar section along Tolay Creek to the south and suggested it is the same “Transitional Zone”. Wagner and others, (2002a) mapped a depositional contact

Figure 6. Folded dolomite in the lower Petaluma Formation in Tolay Valley.
between the Petaluma Formation and the Tolay Volcanics along Tolay Creek that were dated at 9.2 Ma, nearly the same age as the Tolay Volcanics in the Murphy No. 1 well, corroborating Cebull (1958). A date of 8.52 Ma on an interbed of Tolay Volcanics and a date of 9.28 Ma on Tolay Volcanics below the Petaluma Formation (Youngman, 1989) constrains the age of the base of the Petaluma in this area to about 9 Ma.

**Middle Petaluma Formation**

The middle part of the Petaluma Formation consists of mudstone that grades upward into a section dominated by fluvial sandstone and gravel containing abundant Franciscan detritus. Lacustrine and estuarine intervals persist well up into the middle Petaluma but the upper part is mostly fluvial (Starratt and others, 2005). There are abundant megafauna, petrified and carbonized wood, lignite, and a sparse mammalian fauna (Weaver, 1949; Allen 2003). The middle Petaluma Formation is the most widespread of the three subunits, cropping out along the west slope of Sonoma Mountain west to Meacham Hill where it interfingers with the marine Wilson Grove Formation. It has been mapped along the west side of the Rodgers Creek Fault from Sears Point to the Santa Rosa area where it is interbedded with the Sonoma Volcanics (McLaughlin and others, 2008). The middle Petaluma Formation is present in the subsurface (McLaughlin and others, 2008; Sweetkind and others, 2009) and exposed long the western margin of the Santa Rosa plain. East of the Rodgers Creek Fault, on southernmost Sonoma Mountain, interbeds of gravel identical to that of the middle Petaluma of Allen (2003) are found within the Sonoma Volcanics that are from 8 to 5 Ma. A distinctive feature of the middle part of the Petaluma formation is the presence of chips of laminated siliceous shale derived from the Claremont Shale of the Monterey Group (Morse and Bailey, 1935; Allen, 2003). The tuff of Zamaroni Quarry (7.26 Ma), the tuff of Lichau Creek (6.71 Ma, Table 2) and the Roblar tuff (6.26 Ma) are interbedded with this part of the Petaluma Formation.

**Upper Petaluma Formation**

Tuffaceous sandstone and gravel interbedded with diatomite (Figure 7) and lignite belonging to the upper part of the Petaluma Formation interfinger with the Sonoma Volcanics in the Santa Rosa area, Bennett Valley and on the west side of Sonoma Valley. Sandstone and gravel of the upper Petaluma are lithologically indistinguishable from those of the middle Petaluma Formation. Fox (1983) and Fox and others, (1985b) considered these sediments to belong to the Huichica Formation and Graymer and others, (2007) considered them to be part of sand and gravel of Cotati. Based on the presence of sparse marine fossils, Powell and others, (2004 p.10 and 23) considered some of these sediments in Bennett Valley to be part of the Wilson Grove Formation. Apparently the Petaluma Formation sediments in Bennett Valley interfinger with the Pliocene part of the Wilson Grove Formation in Bennett Valley and possibly in the Santa Rosa area as well.

A distinctive tephra assemblage that is younger than tephra found in the older parts of the Petaluma strata in the Petaluma and Cotati area is characteristic of the upper Petaluma Formation. Thick diatomite contains several tephra layers, including Lawlor Tuff and the tuff of Mark West Springs, which together indicate an age of 4.83 Ma for this part of the section (Wagner and others, 2011). The locality of the tuff that is similar to the Mark West Springs is very close to or the same as a locality that yielded a sample dated at 3.95 ±0.32 Ma (BH71-2 of Fox and others, 1985a) using the K/Ar method. Based on this date Fox and others, (1985a) assigned these strata to the Huichica Formation. Given the revised age of 4.76 Ma for the Huichica Tuff in the type locality (Sarna-Wojcicki and others, 20114) and differing
lithologies in the two areas, the correlation of Fox and others, (1985a) does not appear to be correct. Rather, based on the revised age of the tephra this section is considered equivalent to a lithologically similar section at Carriger Creek about 10 km to the south. In the southwest part of Bennett Valley, McLaughlin and others, (2008) mapped a gently folded section of diatomaceous Petaluma Formation that is here considered to be part of the upper Petaluma Formation. McLaughlin and others, (2008) also mapped a folded section of diatomaceous Petaluma Formation west of the Rodgers Creek Fault Santa Rosa that is here suggested to be correlative with the upper Petaluma Formation in Bennett Valley. This indicates there was a connection between Bennett Valley and the Cotati basin during deposition of the upper part of the Petaluma Formation.

Although exposures are poor, upper Petaluma sediments can be traced along the east slope of Sonoma Mountain from its southern end northwest to Carriger Creek area and then northward to Graham Creek at the north boundary of Jack London State Park. Sparse exposures of diatomite-bearing sediments along the west slope of Sonoma Mountain suggest that the sediments of the upper Petaluma Formation extend beneath the mountain. Unfortunately, the stratigraphic relations in this area are obscured by the Bennett Valley Fault Zone and large-scale landsliding. Near Carriger Creek, an exposure of tuff interbedded with diatomite, sand and well-sorted pebble gravel yielded a K/Ar age of 11.83 Ma (Fox and

Figure 7. Well-bedded sandstone, tuff and diatomite in the upper part of the Petaluma Formation exposed along Graham Creek in Jack London State Park.
others, 1985b), which was then considered the maximum age for the Petaluma Formation. However the diatomite contains diatoms with Pliocene affinities (S. Starratt, written communication, 2002). A date of 4.88 ± 0.06 Ma (Wagner and others, 2011) on tuff from the same locality using $^{40}$Ar/$^{39}$Ar indicates these sediments are part of the upper Petaluma Formation and are nearly coeval with the 4.84 Ma Lawlor Tuff. However, the chemistry is incompatible with an eruptive source within the Sonoma Volcanics showing it is not Lawlor tuff. Nevertheless, the tuff is a good marker and has been informally referred to as the tuff of Carriger Creek by Wagner and others (2011). Another tephra collected along Carriger Creek (Wagner and others) is possibly of equivalent to the Pinole Tuff. To the south at the Donnell Ranch, a tuff interbedded with diatomite, appears to be a mixture of more than one tuff based on the trace element chemistry. An $^{40}$Ar/$^{39}$Ar date of 5.37± 0.11 Ma (Wagner and others, 2011) on a sample from this locality indicates an similar age as Pinole Tuff so it may correlate with the Pinole Tuff (5.4-5.2 Ma). These data provide a maximum age of about 5.3 Ma the upper part of the Petaluma Formation in this area.

Although there was a brief marine transgression during the latest Miocene or earliest Pliocene (Powell, and others, 2004), most of the upper Petaluma sediments were deposited in freshwater lakes and or wetlands. Along Carriger Creek, basalt flows interbedded with the upper Petaluma Formation overlie burnt vegetation showing it was a volcanically active setting as well. Although the upper Petaluma Formation contains more freshwater diatomite, lignite, petrified wood characteristic of lacustrine and wetland environments than the dominantly fluvial middle Petaluma Formation, presence of the of the Pinole, and younger tuffs is required to conclusively identify the upper Petaluma Formation.

**Wilson Grove Formation**

The Wilson Grove Formation was named by Fox (1983) for marine sediments formerly considered to be correlative with the Merced Formation on the San Francisco Peninsula (Weaver, 1949). The Wilson Grove Formation extends north from Petaluma to north of Santa Rosa and west to the Sonoma County coast. Powell and others (2004) divided the Wilson Grove Formation into three environments: 1) A deep marine facies along the western margin, 2) a shallow marine facies in the central portion of the formation and 3) a marine and estuarine environments along the eastern margin of the outcrop area where the Wilson Grove Formation is interfingered with the non-marine Petaluma Formation. At Steinbeck Ranch northwest of Meacham Hill, the 6.26 Ma Roblar tuff is interbedded with the Wilson Grove Formation about 105 m above its base (Allen, 2003) indicating the Wilson Grove is late Miocene in its southwestern part. It becomes progressively younger to the northeast to the Santa Rosa area where it is possibly as young as late Pliocene (Powell and others, 2004). It is the marine equivalent of the Petaluma Formation, spanning the same age range.

**Sand and Gravel of Cotati**

Fox (1983) named the sand and gravel of Cotati and considered it to be Plio-Pleistocene and to overlie the Wilson Grove Formation. Davies (1986) described it as a member of the Wilson Grove Formation. Allen (2003) and McLaughlin and others, (2005) consider it to be a transitional lithofacies interbedded with the marine Wilson Grove Formation and the fluvial/estuarine Petaluma Formation. It is rich in laminated chert pebbles derived from the Claremont Shale of the Monterey Group. Many of the pebbles are polished suggesting at least part of the gravel is a beach deposit. In agreement with Allen (2003) and McLaughlin and others, (2005) it is here considered that the sand and gravel of Cotati is a littoral deposit marking the shoreline between the fluvial-estuarine-lacustrine Petaluma Formation and marine Wilson Grove Formation.
Huichica Formation

Weaver (1949) named the Huichica Formation for gravelly deposits at the south end of the
Mayacmas Mountains along Huichica Creek. Pebble- to cobble-sized clasts in the Huichica are derived
from the Franciscan Complex, the Great Valley Sequence, Tertiary marine formations, and the Sonoma
Volcanics. The abundance and size of the Franciscan derived material are curious because there is no
nearby source. Well data (Zieglar and others, 2005) show the Huichica Formation thickens dramatically
to the southwest, suggesting a possible source of Franciscan material in that direction. Fox (1983)
reported a K/Ar date of 3.94 Ma for a tuff interbed along Huichica Creek. Subsequent $^{40}$Ar/$^{39}$Ar analysis
of the same tuff (Sarna-Wojcicki and others, 2011) has yielded what is considered to be a more reliable
age of 4.76 Ma. Sediments and massive tuff along Sonoma Creek near Glen Ellen shown as Huichica
Formation by Fox (1983) and Fox and others, (1985b) has now been assigned to the Glen Ellen
Formation, Tuff of Napa-Healdsburg or the Putah Tuff.

Glen Ellen Formation

Weaver (1949) assigned the name Glen Ellen Formation to tuffaceous sand and gravel around the
towns of Glen Ellen and Kenwood, and north to Rincon Valley and on Santa Rosa plain. The thickness of
the Glen Ellen is variable; it overlies the upper part of the Petaluma Formation in Bennett Valley, and the
Putah Tuff along Sonoma Creek in and around Glen Ellen. A tephra correlation of a tuff from near the
base of the formation along Mill Creek near Glen Ellen indicates an age range between 3.19 Ma and ~3.4
Ma) and the underlying Putah Tuff is 3.27-3.35 Ma, providing a well constrained age for the base of the
Glen Ellen Formation in the type area (Wagner and others, 2011). Some of the sediments along the east
side of Sonoma Mountain, originally mapped as Petaluma Formation (Weaver, 1949; Fox and others,
1973, 1985b), contain tephra similar to a tuff from Kettleman Hills with an age range of 3.33 to ~2.5 Ma
and a second tuff that is similar to a tuff in the upper part of the Tuff of Petrified Forest that is younger
than 3.27-3.35 Ma (Wagner and others, 2011). These data indicate these sediments are the basal part of
the overlying Glen Ellen Formation and not Petaluma Formation as shown on earlier maps (Weaver,
1949; Fox and others, 1973; Huffman and Armstrong, 1980).

Unnamed Plio-Pleistocene sediments

Some tuffaceous, gravelly sediments previously mapped as Huichica or Glen Ellen formations
(Weaver, 1949) are shown on the Napa Quadrangle as unnamed (QPu). It appears that previous mappers
considered any gravelly, and or tuffaceous units containing detritus from the Sonoma Volcanics to be
Huichica or Glen Ellen formations. At first glance the Huichica Formation in its type locality appears to
be a clastic wedge shed of off the south end of the Mayacmas Mountains. However, it contains an
assemblage of well-rounded clasts of Franciscan rocks, Great Valley Sequence sandstones, and Tertiary
marine sandstones that do not crop out on the south end of the Mayacmas Mountains. It appears then, that
the Huichica Formation records a history that has not yet been deciphered. Tuffaceous rock mapped as
Huichica Formation east of the city of Napa appears to be local mafic tuff associated the Napa volcanic
center. Rocks along the northeast margin of Napa Valley near Lake Hennessey mapped by Weaver as
Huichica Formation are local gravels derived from the Sonoma Volcanics. McLaughlin and others (2008)
reached a similar conclusion about gravel mapped as Glen Ellen Formation in the Rincon Valley east of
Santa Rosa.
**Quaternary deposits**

Extensive deposits of valley fill occur in Petaluma, Sonoma, and Napa valleys and estuarine deposits occur along the margins of Suisun, San Pablo and Tomales bays. More restricted and thinner alluvial deposits occur in intermontane valleys. Coalescing alluvial fans along the mountain fronts of the larger valleys form piedmonts while in the valley centers there are basinal deposits. Estuarine deposits are mostly bay mud and intertidal marsh deposits. For the most part the Quaternary deposits shown on the Napa Quadrangle are based on Knudsen and others, (2000) and Witter and others, (2006) who subdivided them by age and environment of deposition. Age of deposits was evaluated based on geomorphology, degree of soil profile development, and erosional dissection of geomorphic surfaces.

**Landslides**

Landslides are conspicuous features on the Napa quadrangle. The largest ones cover several tens of square kilometers and often occur where the Sonoma Volcanics overlie shaley rocks of the Great Valley Sequence. In addition to being inherently weak, the shale has been intensely sheared by faulting. For example, the largest slide on the west slopes west of Green Valley covers 20 square kilometers. Here Sonoma Volcanics overlie the Great Valley Sequence and the headwall of the slide is traversed by the Green Valley Fault. To the north near Lake Hennessy, there is another large landslide in a similar geologic setting that covers 10 square kilometers.

Large-scale, deep-seated landslides are conspicuous on the slopes of Sonoma Mountain, particularly on the north part of the mountain. Both rotational and translational block slides have modified bedrock structure in significant ways so recognition of them is critical. Most of them originate in Sonoma Volcanics, displacing masses of volcanic rock downslope and, in many instances, out into the valleys, where they now rest out of stratigraphic position. One of the largest landslides is on the west slope of Sonoma Mountain about 5 km north of Petaluma. It is about 2.5 km wide and its length is uncertain but on the order of 5 km. There are closed depressions along a well-developed headwall scarp that is 60 to 70 m high. The toe of the slide is not evident in the topography so the full extent of the mega slide is not known. Observations by Michael Dwyer (Personal communication, 2002), using 1:100,000 scale air photos suggest that it could extend beneath the alluvium of Petaluma Valley. Small thrust faults dipping 20° east displacing gravel beds in the Petaluma Formation were observed along Lynch Creek aligned with a topographic break in slope at the bedrock alluvium contact. These small thrusts are consistent with compression near the toe of the mega landslide providing evidence that the toe is beneath the alluvium of the valley. Most of this mega landslide is a relatively old block slide, possibly early Quaternary. It is mantled with active landslides. The Rodgers Creek Fault traverses the mega landslide and topographic features indicative of faulting post-date slide features except in areas where active landslides are present. The amount of downslope movement is unknown, but it is possible that blocks of Sonoma Volcanics moved out into the valley overriding the Petaluma Formation.

Another large landslide covering nearly 4 square km underlies much of Jack London State Park near Glen Ellen and the vineyards of Benzinger Winery. There is a well-defined headwall scarp, and jumbled topography, most notable in the Benzinger Vineyard. The slip surface is exposed in the north wall of the channel of Graham Creek in Jack London State Park. Sonoma Creek flows around the toe of the slide and appears to have been deflected by the landslide. Aside from active landslides around the margin of the landslide, most of the movement seems to be relatively old, probably Pleistocene.

A gravity-driven detachment is mapped on the southeast slope of Sonoma Mountain about 2.5 km north of Sears Point. It was not mapped as a landslide because it lacks physiographic features diagnostic
of landslides. As discussed earlier, the north-facing slope of Sonoma Mountain is a monocline composed
of Sonoma Volcanics that dips beneath the alluvium of Sonoma Valley. Failures occurred along thin beds
of weathered tuff rich in smectite clay, causing kilometer-sized slabs of andesite flow rock and breccia to
move out into Sonoma Valley. If, as suggested by Langenheim and others (2005), Sonoma Valley opened
rapidly along a releasing bend of a fault, then this detachment may well have been a response.

Due to the limitation of the map scale, only landslides larger than 50,000 square meters are shown
to preserve the clarity of the underlying bedrock geology. Exceptions to this rule include small landslides
surrounded by, or adjacent to larger landslides.

Geologic Structure

Physiography and geologic structure of the Coast Ranges of California are nearly parallel to the
San Andreas Fault System, a clear indication that their structural and topographic development is related
to the evolution of the plate margin. In the northern San Francisco Bay region, episodes of extensional,
contractional and dextral faulting ensued rapidly or even overlapped in time as the San Andreas transform
margin developed progressively northward. The San Andreas transform margin in central and northern
California consists of the San Andreas Fault System and the subsidiary the East Bay Fault System
(McLaughlin 1996; Graymer, 2000). The San Andreas Fault is the present plate boundary and the faults
of the East Bay system to the east are part of an evolving inboard transform boundary. Several major
faults were initiated as normal faults in a transtensional regime and later morphed into dextral or high-
angle reverse faults in a subsequent transpressional regime. The Rodgers Creek Fault (McLaughlin and
others, 2012) and the Tolay Fault (Wagner and others, 2011) are excellent examples of this complex fault
evolution.

San Andreas Fault Zone

The 1,100-km-long San Andreas Fault Zone is the principal element of the San Andreas Fault
system, a network of faults with predominantly dextral strike-slip displacement that collectively
accommodates the majority of relative motion between the North American and Pacific plates (Bryant
and Lundberg, 2002; Figure 2 ). For most of its extent on the Napa Quadrangle, it is submerged beneath
Tomales and Bodega bays as well as the Pacific Ocean but there are onland segments in the Olema
Valley, Bodega Head, and near Fort Ross. The zone is about 2,100 m wide in Tomales Bay and narrows
to about 450 m in the Olema Valley (Galloway, 1977). In Olema Valley there are abundant geomorphic
features suggestive of Holocene faulting. Although the San Andreas was recognized as a fault before
1906 (Anderson, 1899), it took the earthquake of that year to demonstrate its activity. The effects of the
event were carefully chronicled by G.K. Gilbert in Lawson (1908). Ground rupture occurred nearly
continuously from Tomales Bay south to Bolinas Lagoon south of the map boundary. Offsets along the
rupture ranged from 3.1 to 6.1 m (Gilbert, 1908, Galloway, 1977). At Bodega Head the 1906 surface
rupture trended through the north side of the harbor and traversed the sand dunes south of Salmon Creek
(Brown and Wolfe, 1972). A small segment of the 1906 rupture is mapped on the Napa quadrangle near
Fort Ross at the northwest corner of the map but here it is obscured by landsliding. Paleoseismic
investigations (Knudsen and others, 2002 and references therein) suggest that previous 1906-type
earthquakes occurred around 1300 AD and again around 1600 AD.
Rodgers Creek Fault and Healdsburg Faults

The Rodgers Creek Fault Zone (RCF) is an active dextral fault that extends from San Pablo Bay to beyond Santa Rosa (Figures 3 and 4). It has been mapped beneath San Pablo Bay (Wright and Smith, 1992; Parsons and others, 2003) but it has not been recognized south of the bay.

Estimates of total displacement range from 45 km (Louderback, 1951; Fox and others, 1985a; Curtis, 1989; Youngman, 1989) to 28 km (Sarna-Wojcicki, 1992) to as little as 5 km or less (Allen, 2003). The RCF displays abundant geomorphic evidence of activity and, along with the Hayward Fault, is considered by the Working Group on California Earthquake Probabilities 2002, as one of the most likely Bay Area faults to produce a major earthquake in the next 30 years. It has been zoned as an Earthquake Hazard Zone pursuant to the Alquist-Priolo Earthquake Fault Zoning Act.

Sarna-Wojcicki’s (1992) palinspastic reconstruction of the Roblar tuff suggests 28 km of displacement on the RCF since 6.26 Ma. As discussed earlier, rhyodacite breccia at Sears Point has been correlated to a similar breccia along Warrington Road on the Santa Rosa quadrangle indicating ~28 km of displacement along the RCF since 6.26 Ma, corroborating the reconstruction of Sarna-Wojcicki (1992). The interpretation of 5 km or less displacement along the RCF (Allen, 2003) is based on radiometric dates of ~7.3 Ma reported by Youngman (1989) on andesite on both sides of the fault. Based on evidence presented earlier herein, the dated andesite west of the RCF is allochthonous, emplaced from the east side of the RCF by thrusting, landsliding, or a combination of the two. Landsliding appears to be more likely since thrust faulting is this area has been shown to be east vergent and mega landslides are common along this segment of the RCF.

Although geomorphic features indicative of Holocene activity abound along the RCF (Hart, 1992; Randolph-Loar, 2002), there have been no large earthquakes documented along the fault for at least 200 years (Wong, 1991; Budding and others, 1991; Hecker and others, 2005). Paleoseismic investigations conducted along the southern RCF (Budding and others, 1991; Schwartz and others, 1992; Randolph-Loar, 2002) indicate late Holocene slip rates of 6.4-10.4 mm/yr, which are consistent with the geologic slip rate of ~6.3 mm/yr for the last 1.2-0.8 Ma (McLaughlin and others, 2005; 2012). An important issue regarding the seismogenic potential of the RCF is whether it connects directly with the Hayward Fault.

Geophysical data suggest there is a connection between the Hayward and Rodgers Creek faults (Langenheim and others, 2010). In contrast, interpretation of geophysical and well data by Wright and Smith (1992) suggested a ~6 km right-stepover between the Hayward and Rodgers Creek faults. Parsons and others, (2003) showed compelling evidence for an extensional basin between the Hayward and Rodgers Creek faults beneath San Pablo Bay and that the closest approach of the faults is 4 km. Geophysical data (Wright and Smith, 1992; Parsons and others, 2003; Langenheim and others, 2010) and cores from the Texas Noble #1 and Bethlehem #1 wells (Figure 3) (Wright and Smith, 1992) indicate the Tolay Volcanics extend beneath San Pablo Bay. It is difficult to explain the distribution of Tolay Volcanics if the Hayward and Rodgers Creek faults are not connected. There must be older faults east of the present Hayward Fault, now obscured by San Pablo Bay, that are responsible for some of the displacement of the Tolay Volcanics from the Berkeley Hills Volcanics. Parsons and others, (2003) recognized a discontinuity they interpreted as an ancestral trace of the Hayward Fault about 1 km to the east of the presently active trace (Figure 3). It is likely that if future geophysical investigations surmount the technical problems presented by San Pablo Bay described by Parsons and others, (2003), a structurally complex step-over will be revealed.
Preliminary Geologic Map of the Napa and Bodega Bay 30'x60' Quadrangles, California

Tolay Fault Zone

The Tolay Fault was named by Morse and Bailey (1935) who described it as a reverse fault extending southward from near Lakeville to Sears Point. They estimated 1,363 m (4,500 ft.) of dip-slip displacement along the fault that dips 60° to the west. Morse and Bailey (1935) mapped the Tolay to about a mile north of Lakeville where they indicated it is truncated by a northeast-trending fault. Weaver (1949) suggested the Tolay Fault could be an extension of the Hayward Fault. However, the Hayward and Tolay faults are not aligned and display different displacement histories so a direct connection between the faults is not well supported. Huffman and Armstrong (1980) depicted the Tolay Fault as potentially active (i.e. Quaternary movement) but a later evaluation of the recency of movement on the Tolay Fault indicates no evidence of Quaternary displacement (Hart, 1982).

Mapping by Wagner and others, (2002 a, b) revealed the Tolay Fault to be a zone of disparate faults with a complex history. Rather than a single fault, the Tolay Fault Zone consists of imbricate thrusts and at least one high angle fault. Observations of extensive excavations at the Infineon Raceway at Sears Point during 2001, revealed a zone of pervasive deformation more than 610 m (2,000 ft.) wide depicted on the Napa Quadrangle as a shear zone. This deformation included intensely sheared clayey siltstone and minor pebble conglomerate of the Petaluma Formation, interleaved with Franciscan rocks and serpentinite. Though complicated by landsliding and folding, the general structure consists of west-dipping, east-vergent imbricate thrust faults (Donn Ristau, personal communication, 2001) that can be described as a schuppen-structure. Along the southwest side of Tolay Creek, Franciscan rocks have been thrust to the northeast over strata of the lower part of the Petaluma Formation. In this area the fault zone is a series of imbricate thrusts though the shear zone is not as wide as, nor is the shearing as pervasive as it is at Sears Point. A near-vertical fault cuts across the thrust plate, with the northeast side down. Huffman and Armstrong (1980) interpreted topographic lineaments along this fault as evidence for Quaternary movement but Hart (1982) later interpreted them as erosional features in bedrock. Field observations (Wagner and others, 2002a) indicate the lineaments are indeed due to differential erosion of hard and soft sediments and do not indicate Quaternary activity.

A few km to the northwest, the Tolay Fault is depicted differently on previous maps. For example, Blake and others (1971) show it as a single fault concealed beneath alluvium along Tolay Creek, while Huffman and Armstrong (1980) show it as a complex fault zone in bedrock west of the alluvium along Tolay Creek. Near Lakeville, the Tolay Fault changes dramatically where it appears to be a single, nearly vertical fault juxtaposing Franciscan rocks to the west with lower Petaluma Formation to the east. Whether this fault is the high-angle fault that cuts the thrusts, a steepened thrust fault, or a high-angle reverse fault (Morse and Bailey, 1935) is unknown at this point.

Weaver (1949) extended the Tolay Fault northwest to the edge of the alluviated Petaluma Valley and beyond. He incorrectly extended the Franciscan wedge to a low hill along South Ely Road in Petaluma. No Franciscan rocks are exposed along South Ely road. Cuttings from a water well drilled just north of the road on the crest of the hill are only Petaluma Formation sediments (Wagner and others, 2011). In addition, Petaluma strata are continuously exposed along a creek north of South Ely Road where Weaver (1949) shows the Tolay Fault juxtaposing Franciscan rocks and Petaluma Formation. This error, depicted on compilations (Fox and others, 1973; Huffman and Armstrong, 1980; Wagner and Bortugno, 1982; Blake and others, 2000) since Weaver (1949), has been corrected on Napa Quadrangle.

Based on the suggestion of Weaver (1949) that the Tolay Fault is a continuation of the Hayward Fault, subsequent workers have generally assumed that the Tolay is a dextral fault that extends northwest beneath the alluvium of the Petaluma Valley and is exposed again northwest of Meacham Hill (Travis,
However, Roblar tuff overlies the Franciscan wedge west of the Tolay Fault Zone (Wagner and others, 2011) and is interbedded in the Petaluma Formation east of the Tolay Fault Zone. The occurrence of the Roblar tuff on both sides of the Tolay Fault Zone at Sears Point precludes major strike-slip displacement since the deposition of the Roblar tuff (6.26 Ma). Morse and Bailey (1935) show the Tolay Fault being truncated by a northeast-trending normal fault, an interpretation that is accepted here. The gravity gradient beneath the Petaluma Valley cited as evidence for extension of the Tolay Fault (Chapman and Bishop, 1988; Langenheim and others, 2010) is probably caused by the Petaluma Valley Fault (Graymer, and others, 2002).

To summarize, the Tolay Fault as defined by Morse and Bailey (1935), is composed of imbricate thrust faults that are part of a fold and thrust belt (Figure 3), which is overprinted by normal faulting.

**Petaluma Valley Fault**

The Petaluma Valley Fault was named by Graymer and others, (2002) for a fault concealed by young deposits in Petaluma Valley but exhibiting geomorphic expression in older deposits west of Cotati (Figures 3). Interpretations by Wright and Smith (1992) suggest the Petaluma Valley Fault is an inactive northern extension of the Hayward Fault. Based on offsets of the Roblar tuff, Graymer and others, (2002) assigned 35 km of displacement on this fault between 6 and 3.5 Ma. At that time, K/Ar dates on volcanic rocks on Meacham Hill indicated them to be the same age as the volcanics on Burdell Mountain. New 40Ar/39Ar dates (Wagner and others, 2011) show these rocks and rocks farther to the west are part of the Tolay Volcanics, constraining displacement along Petaluma Valley Fault to 15 to 26 km. Is likely that the belt of middle Petaluma Formation exposed along the east flank of Meacham Hill was displaced from the Sears Point-Lakeville area along the Petaluma Valley Fault between 6 and 3.5 Ma. Because both the Rodgers Creek and Petaluma Valley faults offset the Roblar tuff, they must have been active after 6.26 Ma, but now the Petaluma Valley Fault is inactive. There was an abrupt increase in the slip rate of the Rodgers Creek Fault in the Late Pliocene (McLaughlin, and others, 2005; 2012) consistent with the conclusion of Graymer and others, (2002) that the Petaluma Valley Fault became inactive at 3.5 Ma with all the displacement then occurring along the Rodgers Creek Fault. If there was only 15 to 26 km of displacement along the Petaluma Valley Fault then about 10 to 20 km of displacement can assigned to faults to the west.

**Burdell Mountain Fault and other northwest trending faults**

The Burdell Mountain Fault is one of several northwest-trending faults that lie to the west of the Petaluma Valley Fault. The Burdell Mountain Fault is a near vertical fault that extends 18 km northwest from San Pablo Bay past the northeast flank of Burdell Mountain into the hills of western Sonoma County (Figure 3). It was investigated by Ford (2007) who demonstrated it has at least 10 km of right-lateral displacement. It has long been recognized as a Quaternary fault (Rice, 1973), and Ford (2007) presented evidence for Holocene ground rupture along the central part of the fault.

Several, en echelon, northwest-trending faults, including the Bloomfield Fault, occur northeast of the Burdell Mountain Fault. If, as posited by McLaughlin and others (2005,2008; 2012), the Rodgers Creek Fault was initiated at 6.7 to 7.3 Ma then the northwest-trending faults may be ancestral traces of the Hayward Fault or perhaps even predate the Hayward Fault. McLaughlin et al (2012) consider these faults to comprise the “Proto-Hayward Fault Zone”.
Bennett Valley Fault Zone

The Bennett Valley Fault Zone branches south from the Maacama Fault, trends southeast across Bennett Mountain into the southeast part of Bennett Valley (Figure 3) where it is a range-bounding fault along Bennett Mountain. The northern part of the Bennett Valley Fault is straight and seismicity associated with it suggests it is vertical (Wong, 1991). This northern segment forms the eastern structural boundary of the Santa Rosa pull-apart basin that opened from 1.2 to 0.8 Ma (McLaughlin and others, 2005; 2012). South of Bennett Valley, on Sonoma Mountain, surface mapping (Wagner and others, 2003) and air photo interpretation indicate that the youngest lava flows (4 Ma or less) on Sonoma Mountain are not significantly offset. This segment of the Bennett Valley Fault must be older than the segment in Bennett Valley. At Carriger Creek on the southern slope of Sonoma Mountain, the fault is a well-defined zone of parallel faults and is easily traced south to the Donnell Ranch where it disappears beneath alluvium in Sonoma Valley. Randolph-Loar (2002) considered the southern part of the Bennett Valley Fault to be a thrust fault but more recent mapping (Wagner and others, 2002a, 2003) shows it as a high angle fault. Sediments of the upper Petaluma Formation appear to be offset a few kilometers to the southeast along the southeast slope of Sonoma Mountain. It does not appear that the northern segment in Bennett Valley Fault is the same structure as the fault of the same name south of Bennett Valley. McLaughlin and others, (2005) speculated that the youthful segment of the Bennett Valley Fault formed with the opening of the Santa Rosa pull-apart basin between 1.2 and 0.8 Ma and the older segments south of Bennett Valley are part of an ancestral Maacama Fault that predates the Santa Rosa pull apart basin.

Carneros, Pinole, and Franklin Faults

The Carneros is a major fault that juxtaposes Tertiary marine strata including the Neroly Formation and overlying Sonoma Volcanics on the west, with Great Valley Sequence and overlying Sonoma Volcanics on the east (Figures 2,3). It is exposed in Carneros Valley where it is a vertical fault (Clahan and others, 2005; Weaver, 1949). North of the Carneros Valley, mapping of the Carneros Fault is hampered by dense vegetation, extensive landslides, and restricted access which has resulted in differing interpretations of the extent and nature of the structure. Clahan and others, (2005) extended the fault trace a few km to the north where its strike changes from N25˚W to N50˚W. Clahan and others, (2005) show the change in trend as a truncation of the Carneros Fault by an inferred younger fault. Graymer and others, (2007) however, show the change in trend as a truncation of the Carneros Fault by an inferred younger fault. Graymer and others, (2007) however, show the change in trend as a truncation of the Carneros Fault by an inferred younger fault. Graymer and others, (2007) however, show the change in trend as a truncation of the Carneros Fault by an inferred younger fault. Based on the presence of a steep gravity gradient along the fault, Langenheim and others, (2010) extended the Carneros Fault not only to the northwest consistent with recent workers (Clahan and others, 2005; Dellattre and others, 2007; Graymer and others, 2007), but also south to San Pablo Bay. Fox (1983) considered the Carneros Fault to be an extension of the Franklin-Sunol-Calaveras fault system (Figure 2) and suggested as much as 35 km of right-lateral displacement. Based on the aforementioned gravity gradient, Langenheim and others, (2010) suggested the Carneros Fault could be an extension of the Pinole Fault and could have as much as 20 km of displacement. If there were 20 or more km of displacement along the Carneros and either the Pinole or Franklin-Sunol-Calaveras faults, it probably took place between 10 Ma and about 4 Ma. This follows because the Carneros Fault cuts the Rhyolite of Bismarck Knob (6.143 Ma, Wagner and others, 2011) and a tuff containing tephra correlated with the Lawlor Tuff (4.84 Ma, Wagner and others, 2011), but a basalt lava flow at the top of the section shows very little if any displacement. Though this basalt has not been dated, it is similar to the basalt that caps Sonoma Mountain that was dated at ~4.1 Ma. According to Fox (1983) the Carneros Fault cuts his lower member of the Sonoma Volcanics but is
overlapped by upper member of the Sonoma Volcanics. These constraints appear to limit how much displacement of the Napa Valley eruptive center mentioned in the earlier discussion of the volcanic centers that can be attributed to the Carneros Fault to less than 5 km.

**West Napa Fault**

The West Napa Fault was first mapped by Helley and Herd (1977) from north of Vallejo through west Napa northward to Yountville. The 2000 M 5.2 Yountville earthquake, which severely damaged downtown Napa, occurred along the West Napa Fault (Langenheim, and others, 2006). The 2014 M 6.0 South Napa earthquake also occurred along the West Napa Fault (Hudnut, and others, 2014) and caused considerable damage from Browns Valley to downtown Napa. The southern part of the West Napa Fault, near Vallejo is known to be Holocene active and has been designated as an Earthquake Hazard Zone by the California Geological Survey but its extent north of Napa, has been problematical. Fox (1983) could not find any evidence of the fault mapped by Helley and Herd (1977) through Yountville and cited evidence for its existence along the west side of Napa Valley as far north as St. Helena. He speculated the West Napa Fault could be a major strike-slip fault but noted there is at least 147 m of vertical displacement of the Sonoma Volcanics with the east side (valley side) down. Langenheim and others, (2010) suggested a correlation of a deep magnetic and dense source near St. Helena with a similar source on the other side of the West Napa Fault some 40 km to the south near Vallejo. If this correlation is valid then all of the displacement of the Napa Valley eruptive source can be attributed to the West Napa Fault. Given its significance to the tectonic evolution of this region and its seismogenic potential, the West Napa Fault clearly needs more investigation.

**Green Valley and Concord Faults**

The Green Valley and Concord faults are Holocene active, dextral faults that appear to be connected along a right-stepover beneath Suisun Bay. Both faults are included in Alquist-Priolo earthquake hazards zones by the California Geological Survey. The Concord Fault extends south of the map area and the Green Valley Fault extends from Suisun Bay north to Wooden Valley where its surface trace is obscured by landslides. Extension of the Green Valley Fault north of Wooden Valley is uncertain. Part of the slip along the Green Valley Fault may be transferred westward to the Maacama Fault causing contractional deformation in the Howell Mountains (Baldwin and Unruh, 2004). A more northerly extension is suggested by aligned seismicity (Wong, 1990) and a prominent gravity anomaly that has been mapped west of Lake Berryessa (Langenheim and others, 2010). Both Green Valley and Concord faults are characterized by aseismic creep and geomorphic features indicative of Holocene, strike slip movement (Bryant and Cluett, 1998). Paleoseismic investigations along the Green Valley Fault suggest multiple surface rupture events have occurred in the last 2700 years (Borchardt and Baldwin, 2004). Sarna-Wojcicki and others, (2011) determined the displacement since the late Pliocene to be 21 km. based on displacement of the 4.83 Ma Lawlor tuff for a slip rate of 4.3 mm/yr. Total displacement along the Concord Fault is not known, but it has a slip rate of 3.0 to 3.7 mm/yr (Bryant and Cluett, 1998) suggesting it is similar to, but less than the Green Valley Fault.

**Cordelia Fault**

The Cordelia Fault is a north-trending fault first mapped by Helley and Herd (1977) who considered t to a dextral, stike-slip fault cutting Holocene alluvium near Cordelia in the southeast part of
the map area. It is included in an Alquist-Priolo earthquake hazards zone by the California Geological Survey. It extends northward from the alluvial lowlands at Cordelia into uplands underlain by Sonoma Volcanics where it is a zone of faulting over a 100 m across.

**Fold and thrust belt at Sears Point and Meacham Hill**

Along Tolay Creek between Sears Point and the Petaluma Valley, west-dipping, east-vergent thrust faults were mapped by Morse and Bailey (1935), Youngman, (1989) Randolph-Loar (2002), and Wagner and others, (2002), along with associated back-thrusting (Morse and Bailey, 1935; Wagner and others, 2002a,b). Morse and Bailey (1935) showed a wedge of Franciscan rocks bounded by steeply dipping faults. The middle part of the Petaluma Formation is tightly folded, overturned in places, along the back-thrusts along the southwest side of the Franciscan wedge. The wedge extends southward to Sears Point and has been called the Sears Point anticline (Weaver, 1949; Cebull, 1958; Fox, 1983; Davies, 1986). The wedge appears to be a diapir-like structure with a core of Franciscan Complex that is surrounded and, in places, overlain by the Petaluma Formation. The structure does have aspects of a fold, but more accurately it is a piercement, in many respects similar to the much larger Mount Diablo piercement in the Diablo Range (Pampeyan, 1963). Wagner and others, (2011) interpreted this structure as part of a fold and thrust belt (Figure 3).

In the Petaluma Oil Field east of Petaluma, subsurface structure is a relatively simple, doubly plunging, faulted anticline referred to as the Adobe anticline (Morse and Bailey,1935; Weaver, 1949; Wright, 1992). At the surface, however, bedding attitudes are chaotic and where the axis of the fold should be exposed there is a vertical shear zone and near-vertical and locally overturned bedding (Wagner and others, 2003). Wright (1992) attributed the folding to Late Neogene compression. Wagner and others (2011) suggested that there is a detachment between the complex surface structure and the relatively simple anticlinal structure that traps the hydrocarbons at depth. Whether the detachment in the Petaluma Oil Field is due entirely to thrusting or whether landsliding (see previous discussion of mega landslides) is also involved remains unresolved. In any case, the compression post-dating the Roblar tuff (6.26 Ma) affected along the eastern side of the Petaluma Valley all the way to Sears Point.

At Meacham Hill, west-vergent thrusting has juxtaposed Tolay Volcanics over interbedded Wilson Grove and Petaluma formations. Along strike to the northwest, in the Stony Point area, the Petaluma Formation, the sand and gravel of Cotati, and Sonoma Volcanics with K/Ar ages of 6.32 to 4.26 Ma (Fox and others, 1985b) and the Roblar tuff are folded. However, mapping on the Two Rock quadrangle by Bezore and others, (2003) indicates the folding did not involve the Wilson Grove Formation. Geophysical evidence (Langenheim et. al, 2010) suggests the folded Petaluma Formation extends 7-8 km northwest beneath relatively flat-lying Wilson Grove Formation. As mapped by Bezore and others, (2003) the Wilson Grove appears to overlap the Petaluma Formation. This relationship presents a paradox since both the folded and unfolded strata contain the Roblar tuff (Bezore and others, 2003; Clahan, and others, 2003) indicating they are the same age. If this is true, then there must be a previously unrecognized thrust fault separating the folded strata from the unfolded strata.

It may be that the west-vergent thrust faults on Meacham Hill are back thrust faults above concealed east-vergent thrusts that daylight in the Cooks Peak-Taylor Mountain area about 8 km to the northeast McLaughlin and others (2008). Back thrusting and wedging have been documented in the Lakeville area to the south (Morse and Bailey, 1935). A similar situation may exist to the north in the Cotati basin where there are west-vergent thrusts such as the Trenton Fault (McLaughlin and others, 2005; Langenheim and others, 2010). Thus, it appears that the east-vergent thrusts in the Cook Peak-
Taylor Mountain area on the Santa Rosa quadrangle (McLaughlin and others, 2008) are equivalent to the east-vergent thrusts in the Sears Point-Tolay Creek area to the south.

Taken together, these contractional structures formed in a belt west of and parallel to the Rodgers Creek Fault (Figure 4). Rocks older than the Pinole Tuff (5.2-5.4 Ma) in the Sonoma Mountain area including the Roblar tuff (6.26 Ma), were folded during its compressional episode. The folding propagated northward and persisted to at least 4 Ma or possibly later in the Cotati basin McLaughlin and others, (2005; 2008).

Attenuation Faulting

A long-lived convergent plate margin along western North America during the Mesozoic and early Tertiary resulted in the formation of an accretionary wedge consisting of the Franciscan lithotectonic belts that were thrust beneath a forearc basin consisting to the Coast Range ophiolite and the Great Valley Sequence (Ernst, 1970). The contact between the accretionary wedge forearc basin was considered to be the Coast Range thrust (Bailey and others, 1970), but later, Jayko and others, (1987) pointed out that in places along the Coast Range thrust where deeply subducted, high grade metamorphic rocks are juxtaposed with unmetamorphosed rocks implies that several kilometers of section are missing, which requires attenuation, not contraction (Platt, 1986). Jayko and others (1987) proposed that the fault contact between the accretionary wedge and the forearc basin be called the Coast Range Fault rather than the Coast Range thrust. Unruh and others, (1995) demonstrated that the forearc basin was undergoing active sedimentation and attenuation during exhumation of the Franciscan in the early Tertiary around Mount Diablo. During mapping for the Napa Quadrangle in the Cordelia area, Bezore and others, (1998) recognized detachment faulting between the Eocene Domengine Formation and the late Cretaceous Great Valley Sequence. In the basal part of the Domengine Formation near the horizontal detachment fault, there are cobbles of gabbro and serpentinite derived from nearby exposures of the Coast Range ophiolite. The ophiolitic rocks are juxtaposed with latest Cretaceous and Eocene rocks; the Paleocene section widely exposed elsewhere is missing here, providing unequivocal evidence of attenuation of the forearc basin.

Another example of attenuation faulting occurs in the Duncans Mills area in northwest corner of the Napa Quadrangle where Paleocene to Eocene Coastal Belt Franciscan rocks structurally overlie Cretaceous Central belt Franciscan rocks along a nearly horizontal fault marked by hydrothermal alteration.
Description of Map Units

Units West of the San Andreas Fault Zone

Surficial Deposits

Qhbs  Beach sand (latest Holocene)—Well-sorted fine- to coarse-grained sand with some fine gravel; may locally include dune sand.

Qhds  Dune sand (Holocene)—Very well sorted fine- to medium-grained sand deposits of active dunes.

Qha  Alluvium, undivided (Holocene)—Alluvium deposited on fans, terraces, or in basins; composed of sand, gravel, silt, and clay that are poorly sorted.

Qhe  Estuarine deposits (Holocene)—Heterogenous mixture of coarse and fine estuarine sediments.

Qhed  Estuarine-delta deposits (Holocene)—Sediments deposited at the mouths of tidally influenced coastal streams. Includes silt and clay with interbedded layers of peat and woody debris deposited by slack and tidal and fluvial currents; sand and gravel deposited by more vigorous currents.

Qhf  Alluvial fan deposits (Holocene)—Alluvial fan sediments deposited by streams emanating from the mountains as debris flows, hyper-concentrated mudflows, or braided stream flows. Sediments include sand, gravel, silt, and clay, that are moderately to poorly sorted and moderately to poorly bedded.

Qa  Alluvium (Holocene and Pleistocene)—Unconsolidated, poorly –sorted clay, silt, sand, and gravel.

Qbm  Bay mud (Holocene and Pleistocene)—Water-saturated clay, silt, and sand.

Qls  Landslides (Holocene to Pleistocene)—Large, complex slide complexes in the Double Point area and active slope failures along the sea cliffs in the Bolinas area. Arrows indicate direction of movement. Only landslides larger than 50,000 square meters are shown.

Qobs  Older beach sand (late Pleistocene?)—Reddish-brown, friable, well-sorted sand and fine gravel.

Qmt  Marine terrace deposits (late Pleistocene)—Deposits of unconsolidated sand, silt, and gravel on uplifted wave-cut terraces.

Offshore Deposits

Qms  Marine nearshore and shelf deposits (late Holocene)—Predominantly sand and some mud; ripple marks common; found on seaward-dipping surface between the nearshore and water depths of about 65 m.

Qmsc  Coarse-grained marine nearshore and shelf deposits (late Holocene)—Predominantly coarse sand, gravel, and cobbles; typically found on gently seaward-dipping (less than 2°) surface in water depths up to 65 m. Extensive exposures (as much as 5 km2) are mapped on Bodega Head–Tomales Point shelf and near mouth of Drakes Estero and Estero de Limantour where scour (caused by large waves and strong tidal currents in Drakes Bay) has winnowed away fine-grained sediments. Also found as elongate nearshore bar (water depths of less than 10 m) offshore of Salmon Creek, as elongate east-west-trending bar in northern Bodega Bay (water depths of 10 to 20 m) and along boundaries of bedrock outcrops.
Qmsf  Fine-grained marine shelf deposits (late Holocene)—Predominantly mud, very fine sand, and silt; commonly bioturbated; found on gently seaward-dipping (less than 1°) surface at depths greater than about 25 to 30 m offshore of mouth of Russian River, Drakes Estero, and Estero de Limantour, as well as depths greater than about 45 m in other parts of map area.

Qmsd  Marine shelf scour depressions (late Holocene)—Inferred to be coarse sand and possibly gravel; consists of irregular, arcuate scour depressions that vary from solitary features occupying a few hundred square meters to fields of interconnected depressions covering tens of thousands of square meters. Found as single depressions or in fields of depressions interspersed with elevated shelf sediments (units Qms, Qmc, and Qmsd). Depressions typically are 15 to 50 cm deep, and they have sharp to diffuse boundaries.

Qmsw  Marine sediment wave deposits (late Holocene)—Predominantly sand; locally formed by strong tidal currents that wrap around Point Reyes headland and into Drakes Bay.

Qmsl  Marine sediment lobes (late Holocene)—Fields of elongate, shore-normal pairs of sediment lobes (inferred to consist of mixture of sand and mud) and chutes, at depths of between 40 and 70 m in southern part of map area; individual lobes are as much as 650 m long and 200 m wide, and they have as much as 4 m of relief above surrounding smooth seafloor. Also occurs as an approximately 250-m-wide field of four discrete lobes and paired arcuate, low-relief scours on south flank of east-west-trending bar in northern Bodega Bay. Unit reveals failure of gentle slopes, possibly related to strong ground motion associated with earthquakes on adjacent San Andreas Fault.

Qstb  Sediments of central Tomales Bay (late Holocene)—Mixed fine sand and silt on the mostly flat floor of Tomales Bay.

Qsw  Sand at the mouth of Tomales Bay (late Holocene)—Coarse to medium sand present at the mouth of Tomales bay, forming a large field of sand waves, dunes, and flats.

Sedimentary Units

PMps  Purisima Formation (Pliocene and Miocene)—Olive-gray siltstone with carbonate concretions that is interbedded with lithic arkose. Locally contains diatomite. Formerly mapped as Drakes Bay Formation by Galloway (1977) but now assigned to the Purisima by Clark and Brabb (1997). This unit also occurs offshore in Drakes Bay and west of Drakes Beach.

Msc  Santa Cruz Mudstone (late Miocene)—Gray to brown siliceous mudstone with carbonate concretions. Formerly mapped as Drakes Bay Formation and as Monterey Formation in the Bolinas area by Galloway (1977) but now assigned to the Santa Cruz Mudstone by Clark and Brabb (1997).

Tu  Sedimentary rocks, undivided (Pliocene to middle Miocene)—Sedimentary rocks mapped offshore that may consist of the Santa Cruz Mudstone (unit Tsc), the Monterey Formation (mapped onland as unit Tm), the Santa Margarita Sandstone (mapped onland as unit Tsm), and the Purisima Formation (unit Tp); units decrease in age to the southwest

Msm  Santa Margarita Sandstone (late Miocene)—Massive, glauconite-bearing, arkosic sandstone. Formerly mapped as Drakes Bay Formation by Galloway (1977) but now assigned to the Santa Margarita by Clark and Brabb (1997).

Mmy  Monterey Formation (late and middle Miocene)—Thin-bedded siliceous shale interbedded with arkosic sandstone. The siliceous shale is often intricately contorted.
Laird Sandstone (middle Miocene)—Arkosic sandstone with a granitic boulder conglomerate at the base. This unit also occurs offshore, west of Tomales Point.

Point Reyes Conglomerate of Galloway (1977) (lower Eocene)—Sandy conglomerate interbedded with arkosic sandstone resting on granitic basement at Point Reyes; seafloor outcrops appear massive to well bedded.

Granitic rocks of the Point Reyes Peninsula

Granitic rocks (Cretaceous)—Seafloor outcrops of granitic rocks. Offshore equivalent of the tonalite of Tomales Point and quartz diorite of Bodega Head (unit Kgd) and the Granodiorite and granite of Inverness Ridge (unit Kgr).

Porphyritic granodiorite of Point Reyes (Late Cretaceous)—Contains K-feldspar phenocrysts that average 2 to 3 cm and up to 5 cm long; seafloor outcrops appear massive, highly fractured, and bulbous.

Granodiorite and granite of Inverness Ridge (Late Cretaceous)—Exposed along Inverness Ridge, where dikes and masses of aplite and alaskite are common.

Tonalite of Tomales Point and quartz diorite of Bodega Head (Late Cretaceous)—Hornblende-biotite tonalite that contains dark diorite inclusions.

Metamorphic rocks of uncertain age (Mesozoic, Paleozoic)—Patches and small roof pendants of mica schist, quartzite, and marble scattered through the granitic rocks of Inverness Ridge. Slivers of PzMz marble occur in the San Andreas Fault Zone.

Units within the San Andreas Fault Zone

Surficial Deposits

Beach sand (latest Holocene)—Well-sorted fine- to coarse-grained sand with some fine gravel; may locally include dune sand.

Dune sand (Holocene)—Very well sorted fine- to medium-grained sand deposits of active dunes.

Estuarine deposits (Holocene)—Sediments deposited at the mouths of tidally influenced coastal streams. Includes silt and clay with interbedded layers of peat and woody debris deposited by slack and tidal and fluvial currents; sand and gravel deposited by more vigorous currents.

Alluvium, undivided (Holocene)—Alluvium deposited on fans, terraces, or in basins; composed of sand, gravel, silt, and clay that are poorly sorted.

Bay mud (Holocene and Pleistocene)—Water-saturated clay, silt, and sand.

Older alluvium (late Pleistocene)—Pebbles, cobbles, and boulders with varying amounts of sand matrix.

Offshore Deposits

Marine nearshore and shelf deposits (late Holocene)—Predominantly sand and some mud; ripple marks common.

Coarse-grained marine nearshore and shelf deposits (late Holocene)—Predominantly coarse sand, gravel, and cobbles.
Qmsd  Marine shelf scour depressions (late Holocene)—Inferred to be coarse sand and possibly gravel.

Qstb  Sediments of central Tomales Bay (late Holocene)—Mixed fine sand and silt on the mostly flat floor of Tomales Bay.

Qsw  Sand at the mouth of Tomales Bay (late Holocene)—Coarse to medium sand present at the mouth of Tomales bay, forming a large field of sand waves, dunes, and flats.

Sedimentary Units

Qoc  Olema Creek Formation (late Pleistocene)—Alluvial and estuarine sediments including granitic sand interbedded with organic mud and peat. Deposited on a plain at the head of Tomales Bay about the same time as the deposition of the Millerton Formation (Grove and others, 1995).

Qml  Millerton Formation (late Pleistocene)—Alluvial and estuarine clay, silt, sand, and gravel deposited on terraces along the eastern margin of Tomales Bay.

Franciscan Complex, Central Belt

KJfss  Franciscan Complex sandstone and shale (Late Cretaceous to Late Jurassic)—Thick-bedded greywacke and arkosic sandstone with interbedded shale and minor conglomerate. This unit is moderately to intensely sheared but lacks tectonic blocks characteristic of mélangé.

Units East of the San Andreas Fault Zone

af  Artificial fill (historic, Holocene)—May be engineered and/or non-engineered. Locally includes artificial dam fill.

afbm  Artificial fill placed over bay mud (historic, Holocene)—May be engineered and/or non-engineered.

adf  Artificial dam fill (historic, Holocene)—Earth dams, rock-fill dams and embankments constructed to impound water.

alf  Artificial levee fill (historic, Holocene)—May be engineered and/or non-engineered.

ac  Artificial stream channel (historic, Holocene)—Modified stream channels including straightened or realigned channels and flood control channels. Deposits within artificial channels consist of minimal to significant thicknesses of loose sand, silt and gravel.

Qhbs  Modern beach sand (Holocene < 150 years)—Well-sorted fine to coarse sand with some gravel deposited on active beaches.

Qhc  Stream channel deposits (modern <150 years to late Holocene)—Deposits in active, natural stream channels. Consists of loose alluvial sand, gravel, and silt.

Qhbm  Bay mud (modern to latest Holocene)—Estuarine silt, clay, peat, and fine sand deposited in San Pablo Bay, Suisun Bay, and Grizzly Bay; post 1849.

Qhly  Alluvial fan levee deposits (latest Holocene <=1,000 years)—Natural levee deposits of latest Holocene alluvial fans.

Qhty  Stream terrace deposits (latest Holocene)—Stream terraces are deposited as point bar and overbank deposits. Composed of moderately sorted clayey sand and sandy clay with gravel.
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Qhay</td>
<td><strong>Alluvial deposits, undivided</strong> <em>(latest Holocene)</em>—Fluvial sediments deposited on the modern flood plain.</td>
</tr>
<tr>
<td>Qhfy</td>
<td><strong>Alluvial fan deposits</strong> <em>(latest Holocene)</em>—Alluvial fan sediments deposited by streams emanating from the Dry Creek drainage on the Napa quadrangle.</td>
</tr>
<tr>
<td>Qms</td>
<td><strong>Marine nearshore and shelf deposits</strong> <em>(late Holocene)</em>—Predominantly sand and some mud; ripple marks common; found on seaward-dipping surface between the nearshore and water depths of about 65 m.</td>
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<td><strong>Coarse-grained marine nearshore and shelf deposits</strong> <em>(late Holocene)</em>—Predominantly coarse sand, gravel, and cobbles; typically found on gently seaward-dipping (less than 2°) surface in water depths up to 65 m. Extensive exposures (as much as 5 km²) are mapped on Bodega Head–Tomales Point shelf and near mouth of Drakes Estero and Estero de Limantour where scour (caused by large waves and strong tidal currents in Drakes Bay) has winnowed away fine-grained sediments. Also found as elongate nearshore bar (water depths of less than 10 m) offshore of Salmon Creek, as elongate east-west-trending bar in northern Bodega Bay (water depths of 10 to 20 m) and along boundaries of bedrock outcrops.</td>
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<tr>
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<td><strong>Sediments of central Tomales Bay</strong> <em>(late Holocene)</em>—Mixed fine sand and silt on the mostly flat floor of Tomales Bay.</td>
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<td><strong>Sand at the mouth of Tomales Bay</strong> <em>(late Holocene)</em>—Coarse to medium sand present at the mouth of Tomales bay, forming a large field of sand waves, dunes, and flats.</td>
</tr>
<tr>
<td>Qkdtb</td>
<td><strong>Subaqueous delta at the mouth of Walker Creek</strong> <em>(late Holocene)</em>—Semicircular subaqueous delta extending into Tomales Bay from the mouth of Walker Creek.</td>
</tr>
<tr>
<td>Qha</td>
<td><strong>Alluvium, undivided</strong> <em>(Holocene)</em>—Alluvium deposited on fans, terraces, or in basins; composed of sand, gravel, silt, and clay that are poorly sorted.</td>
</tr>
<tr>
<td>Qhb</td>
<td><strong>Basin deposits</strong> <em>(Holocene)</em>—Fine-grained, clay-rich alluvium with horizontal stratification. May contain peat and interbedded coarser alluvium.</td>
</tr>
<tr>
<td>Qhe</td>
<td><strong>Estuarine deposits</strong> <em>(Holocene)</em>—Heterogenous mixture of coarse and fine estuarine sediments.</td>
</tr>
<tr>
<td>Qhed</td>
<td><strong>Estuarine-delta deposits</strong> <em>(Holocene)</em>—Sediments deposited at the mouths of tidally influenced coastal streams. Includes silt and clay with interbedded layers of peat and woody debris deposited by slack and tidal and fluvial currents; sand and gravel deposited by more vigorous currents.</td>
</tr>
<tr>
<td>Qhbm</td>
<td><strong>Bay mud</strong> <em>(Holocene &lt;10,000 years)</em>—Estuarine silt, clay, peat, and fine sand deposited at or near sea level in San Pablo Bay. Includes latest Holocene beach sand in the Petaluma Point quadrangle.</td>
</tr>
</tbody>
</table>
Qht Stream terrace deposits (Holocene, 10,000 years)—Stream terraces deposited as point bar and overbank deposits, composed of moderately to well-sorted and bedded gravel, sand, silt and clay.

Qhf Alluvial fan deposits (Holocene)—Alluvial fan sediments deposited by streams emanating from the mountains as debris flows, hyper-concentrated mudflows, or braided stream flows. Sediments include sand, gravel, silt, and clay, that are moderately to poorly sorted, and moderately to poorly bedded

Qhff Fine-grained facies

In Chileno Valley on the Petaluma quadrangle, Holocene fan deposits are subdivided into:

Qhf1 Younger

Qhf2 Older

Qhl Fan levee deposits (Holocene)—Sediments of late Holocene age deposited in topographic lows. Fine-grained alluvium with horizontal stratification. May have interbedded peat.

Qhds Dune sand (Holocene)—Very well sorted fine- to medium-grained sand deposits of active dunes.

Qa Alluvium, undivided (Holocene to latest Pleistocene)—Flat, relatively undissected fan, terrace, and basin deposits.

Qf Alluvial fan deposits (Holocene to latest Pleistocene <=30,000 years)—Sand, gravel, silt, and clay mapped on gently sloping, fan-shaped, relatively undissected alluvial surfaces.

Qfe Fan of Carriger Creek on Glen Ellen and Sonoma quadrangles. Composed of well-rounded cobbles of Sonoma Volcanics.

Qt Stream terrace deposits (Holocene to late Pleistocene)—Deposited in point bar and overbank settings. Composed of unconsolidated, poorly sorted clayey sand with gravel.

Qc Colluvium (Holocene to latest Pleistocene)—Unconsolidated and unsorted weathered rock fragments accumulated on or at the base of slopes.

Qtv Travertine (Holocene to Pleistocene)—Surficial deposits of fine- to coarse-grained travertine deposited by saline springs.

Qls Landslides (Holocene to Pleistocene)—Includes debris flow and block slump landslides. Only landslides larger than 50,000 square meters are shown.

Qlsv—landslides dominantly composed of volcanic material.

Qpa Alluvium, undivided (latest Pleistocene)—Alluvial fan, stream terrace, basin, and channel deposits composed of poorly to moderately sorted sand, silt, clay, and gravel.

Qpf Alluvial fan deposits (latest Pleistocene)—Sand, gravel, silt, and clay that is moderately to poorly sorted and bedded. Similar to Holocene fans (Qhf), but they are more dissected.

Qg Fluvial gravel (Pleistocene)—Boulder gravel west of Kenwood composed primarily of clasts from the Sonoma Volcanics though large clasts of Franciscan rocks do occur. Previously mapped as Glen Ellen Formation by Weaver (1949).

Qoa Alluvial deposits, undivided (late to early Pleistocene)—Alluvial fan, stream terrace, basin, and channel deposits. Topography is gently rolling with little or no original alluvial surfaces preserved; moderately to deeply dissected.
Qot  Stream terrace deposits (late to early Pleistocene)—Composed of moderately to well-sorted and bedded sand, gravel, silt, and minor clay. Deposited on slightly dissected terraces above flood level.

Qmt  Marine terrace deposits (Pleistocene)—Deposits on uplifted marine abrasion platforms. Deposits consist of well-sorted, moderately to well-bedded sand and gravel.

Qbmt  Bay and marine terrace deposits (Pleistocene)—Sand, gravel, and silty clay deposited on wave-cut platforms above present sea level along San Pablo Bay.

Qof  Alluvial fan deposits (late to early Pleistocene)—Sand, gravel, silt, and clay, deeply dissected. Topography is moderately rolling with little or no original alluvial surfaces preserved.

Qofv  Predominantly volcanic gravel with clasts up to 0.5 m in diameter.

Qml  Millerton Formation (late Pleistocene)—Alluvial and estuarine clay, silt, sand, and gravel deposited on terraces along the eastern margin of Tomales Bay.

Qop  Fan or terrace deposits (middle or early Pleistocene)—Moderately to deeply dissected alluvial deposits capped by alfisols, ultisols, or soils containing silica or calcic hardpan. Deposits are thin (<3 m thick) and form a veneer over bedrock.

Qols  Older, deeply dissected landslides (early Pleistocene to Pliocene?)

QPge  Glen Ellen Formation (Pleistocene-Pliocene)—Tuffaceous gravel, sand and silt. Sediments are mostly derived from the Sonoma Volcanics though pebbles of Franciscan rock types are common. Obsidian pebbles are characteristic of this unit. Tephra from the type area of the Glen Ellen Formation range from about 3.3 Ma to slightly older than 2.5 Ma (Wagner and others, 2011). Elsewhere deposits mapped as Glenn Ellen Formation are Pleistocene.

QPu  Gravel, conglomerate, sand, reworked tuff (early Pleistocene, late Pliocene)—Fluvial and lacustrine sediments and volcaniclastics derived mostly from Sonoma Volcanics; significant amount detritus was also derived from the Franciscan Complex, the Great Valley Sequence, Tertiary marine formations, as well as other local sources. Includes some deposits mapped as the Glen Ellen Formation, and several Plio-Pleistocene deposits mapped by McLaughlin and others (2008) on the Santa Rosa quadrangle. Includes some deposits mapped as Huichica Formation outside of its type area in the Huichica Creek area.

Pth  Tehama Formation (Pliocene)—Continental siltstone and conglomerate.

Ppt  Putah Tuff member

Tgd  Sandstone, gravel, and diatomite (Pliocene-Miocene?)—Limited exposures along Adobe road on the Kenwood quadrangle.

Tsu  Sedimentary deposits of uncertain age—Friable deposits of sandy gravel derived from volcanics with interbedded tuffaceous sand, clay and diatomite.

Tss  Sandstone and volcanic gravel (Pliocene)—Poorly consolidated tan sandstone and tuffaceous sandstone with lenses of volcanic conglomerate. The sandstone contains sparse flakes of white mica, probably derived from the Markley Sandstone.

Ph  Huichica Formation (Pliocene)—Fluvial gravel, sand, silt, and clay. Sediments derived mostly from Sonoma Volcanics but coarse sand is rich in Franciscan pebbles and cobbles.

Tdi  Diatomite
Sonoma Volcanics, undivided (Pliocene to late Miocene)—Basalt, andesite, rhyolite, dacite, and tuff that are divided into the Western Sonoma Volcanics and the Eastern Sonoma Volcanics. A few units, TsVm for example, are common to both areas.

Western Sonoma Volcanics

Sonoma Volcanics, mafic flows and breccia (Pliocene, Miocene)—Includes basalt, basaltic andesite and andesite. Includes some andesitic tuff.

Sonoma Volcanics, tuff and sediments (Pliocene, Miocene)—Light-colored tuff locally interbedded with sediments similar to the Petaluma Formation. Locally subdivided into:

Putah Tuff (Pliocene)—Ash flow tuff and reworked tuff dated at 3.3 Ma (A. Sarna-Wojcicki, written communications, 2003-2006).

Tuff of Napa (formerly tuff of Healdsburg) (Pliocene)—Pumiceous ash flow tuff dated at ~4.70 Ma (A. Sarna-Wojcicki, written communication, 2009).

Lawlor Tuff (Pliocene)—Pumiceous, andesitic ash-flow tuff. $^{40}\text{Ar}/^{39}\text{Ar}$ age of 4.84 Ma (Andrei Sarna-Wojcicki, written communication, 2005).

Pinole Tuff (Miocene)—White ash-flow tuff and pumiceous to tuffaceous sandstone.

Roblar Tuff (Miocene)—Ash-flow tuff and reworked water-lain tuff dated a 6.26 Ma (Robert Fleck, written communication, 2002).

Tuff interbedded with Wilson Grove Formation—White water-laid tuff and yellow to gray pumice breccia on the Camp Meeker quadrangle. Portions appear similar to the Roblar tuff but correlations remain to be established.

Air fall tuff—Fine-grained interbedded with water-laid, diatomaceous tuff in the Sugarloaf Ridge area on the Kenwood quadrangle.

White pumiceous tuff (Pliocene)—Locally contains mudstone clasts from the underlying Great Valley Sequence. Contains tephra similar or equivalent to the 4.84 Ma Lawlor Tuff (Andrei Sarna-Wojcicki and Elmira Wan, written communication, 2005).

Tuff breccia—Tuff breccia and agglomerate in the Sugarloaf Ridge area on the Kenwood quadrangle.

Tuff—Interbedded with the middle Petaluma Formation - Cotati quadrangle.

Rhyolite of Bennett Mountain—Massive flows and flow breccia of rhyolite and rhyodacite. Typically flow banded with perlitic zones and local obsidian. In Annadel State Park Ar/Ar dating of flow rock yielded an age of 4.51 to 4.54 ± 0.01 Ma (McLaughlin and others, 2008)

Soda rhyolite of Sugarloaf Ridge—Light-gray, fine-grained, with phenocrysts of Sanidine and anorthoclase. Appears to be in part intrusive. Dated at 4.83 Ma (Ar/Ar) R. Fleck written communication 2009).

Rhyolite of Abode Canyon—Glassy, gray to white lava flows with well-developed, contorted and folded flow banding. Dated (K/Ar) at 5.3 ± 0.2 Ma (Mankinen, 1972).

Rhyolite of Bismarck Knob (Miocene)—Plagioclase phyric, bluish-gray to white rhyolite tuff and flows. Domes and proximal breccia with reworked tuff, sand and gravel near Bismarck Knob on the Sonoma quadrangle. Dated by $^{40}\text{Ar}/^{39}\text{Ar}$ at 6.07 ± 0.06 Ma (Wagner and others, 2011)

Dacitic lava flows of Huichica Creek (late Miocene)—Dark, glassy flow rock with a $^{40}\text{Ar}/^{39}\text{Ar}$ age of 6.143 ± 0.061 Ma (Wagner and others, 2011).
Tvb  Unnamed basalt along the Rodgers Creek Fault Zone

Tsvft  Tuff and flows—Ash flow tuff, tuff breccia, water-lain tuff, and agglomerate thinly interbedded with mafic lava flows in the Sugarloaf Ridge area on the Kenwood quadrangle.

Msvtl  Tuff of Lovall Valley—Well-bedded tuff, rich in cobble to boulder-sized lithics.

Msvtp  Tuff of Mt. Pisgah—Well-bedded lithic tuff interbedded with tuffaceous, diatomaceous lacustrine sediments.

Tsvwt  Welded ash flow tuff—Sugarloaf Ridge area on the Kenwood quadrangle.

Psvmb  Mafic flows of Bennett Mountain (Pliocene)—Andesite, basaltic andesite, and basalt in massive flows and breccia with intercalated tuff and silicic deposits locally. Ar/Ar dating of flow rock in Annadel State Park yielded an age of 4.7 ± 0.03 Ma (McLaughlin and others, 2008).

Tsva  Andesite lava flows of Mt. Veeder

Tsvg  Fluvial gravel, sand and silt—Occurs beneath Tsva.

Psvb  Basalt flows

Psvbp  Basalt of Bouverie Preserve

Msvbb  Basalt of Bismarck Knob—Plagioclase, pyroxene, olivine phryic flow basalt. Pyroxene phenocrysts have a distinctive yellow alteration.

Msvb  Basalt—Flows and breccia in the Meacham Hill area. Includes olivine basalt flows dated from 6.83 to 7.83 (Fox and others, 1985).

Tsvdt  Andesitic to dacitic ash flow tuff—tuff breccia, and some water-laid tuff, agglomerate and minor lava flows on the Kenwood quadrangle.

Msvh  Hyaloclastite—Well-bedded deposit of angular, vesicular, mafic glass lapilli with abundant lithic clasts of basalt, andesite, and diatomite.

Tsvib  Basalt pugs and dikes.

Tsvms  Mafic lava flows and intrusions of Sugarloaf Ridge—Basaltic andesite and basalt erupted from vents along Sugarloaf Ridge. Includes interbeds of red- and brown-stained tuff, scoriaceous breccia and volcanic bombs.

Msvam  Andesite of Mission Highlands (Miocene)—Gray, plagioclase phryic andesite interbedded with tuff. Locally has platy foliation.

Msvas  Andesite of Shocken Hill—Gray, aphyric andesite lava flows interbedded with tuff. A fission track age of 7.9 ± 0.8 Ma was reported by Fox and others (1985).

Tsvr  Rhyolite and dacite undivided—An 40Ar/39Ar age of 5.79 ± 0.03 Ma from a sample collected on the west side of Sonoma Valley near Carriger Creek was reported by Wagner and others (2011).

Msvbr  Silicic breccia (Miocene)—Blocks of silicic (rhyolite to dacite) flow rock in a tuffaceous, sandy-gravelly matrix. Blocks are mostly angular though some are rounded, some a meter or more across with color ranging from pink, white, to brown. Many clasts have slickensides suggesting the breccia is in part a fault scarp breccia (McLaughlin and others (2005). Blocks and fragments of perlite are common. Fluvial and debris flow deposits are present. There are occasional interbeds of Franciscan derived gravel similar to the Petaluma Formation. Dates on the blocks range from 7.36 to 8.11 Ma (Youngman, 1989; Fox and others, 1985). However, chemistry of trace elements of the tuffaceous matrix suggest affinities to
approximately 6 Ma tuffs of the Zamaroni Quarry area near Santa Rosa suggesting the tuff deposit formed a little over six million years ago (Andrei Sarna-Wojcicki and Elmira Wan, personal communication, 2005) Mapped on the Sears Point quadrangle by Wagner and others, (2002) and in the Cooks Peak/Taylor Mountain area on the Santa Rosa quadrangle by McLaughlin and others (2008).

Msvrah  **Rhyolite of Arrowhead Mountain**—Rhyolite flows, domes and tuff south of the town of Sonoma. A fission track age of 7.9 ± 1.8 Ma was reported by Fox and others, (1985b) in this area. Msvrah is also mapped long the east side of Sonoma and Kenwood valleys.

Msvr  **Rhyodacite to dacite flows (Miocene)**—Includes the rhyodacitic rocks at Zamaroni quarry 7.26 ± 0.04 Ma, and Cooks Peak 7.94 ± 0.02 Ma (McLaughlin and others, 2008) and rhyolitic to rhyodacitic rocks in the Sears Point area, 7.36 to 8.11 Ma (Youngman, 1989; Fox and others, 1985)

### Eastern Sonoma Volcanics

Tsvm  **Sonoma Volcanics, mafic flows and breccia (Miocene, Pliocene)**—Includes basalt, basaltic andesite and andesite. Includes some andesitic tuff.

**Andesite of Stags Leap Volcanic Center** (4.3 - 4.35 Ma, Sweetkind and others, 2011). Includes:

- **Psvasl**  Andesite lava flows of Stags Leap (Pliocene).
- **Psvbsl**  Andesite flow breccia of Stags Leap (Pliocene).
- **Psvatsl**  Andesite ash flow tuff and tuff breccia of Stags Leap (Pliocene)
- **Pgisl**  Stags Leap Stock - Coarse to fine-grained granitic intrusive with abundant quartz veins and alteration.

**Psvtt**  Andesitic tuff and tuffaceous agglomerate of Tulucay Creek

**Psvbt**  Basalt of Tulucay Creek

Tsvt  **Sonoma Volcanics, tuff and sediments (Pliocene, Miocene)**—Light-colored tuff locally interbedded with sediments similar to the Petaluma Formation. Locally subdivided into:

- **Psvrt**  Rhyolite ashflow tuff and flows (Pliocene)—Black to light-gray vitrophyre with partially welded tuff at the base with one or more rhyolite flows at some locations. This unit overlies older volcanic units above an angular unconformity and has yielded a K/Ar date of 3.89 Ma (Fox and others, 1985)

- **Psvtr**  Tuff of Rockville—Light-gray to white pumice lapilli tuff and welded pumice lapilli tuff overlain by lithic tuff breccia. The tuff is exposed in the southeast corner of the Mt. George quadrangle along Monticello Road. K/Ar ages for this tuff are 4.8 ± 0.2 Ma and 4.2 ± 0.4 Ma (Fox and others, 1985).

- **Psvpff**  Ash flow tuff and welded ash flow tuff

- **Tsvmt**  Ash flow tuff of Milliken Dam

- **Tsvat**  White pumiceous tuff of Atlas Peak

**Tsvr**  **Rhyolite to dacite flows and tuff (Pliocene, Miocene).** Locally subdivided as follows:

- **Psvdg**  Dacite of Mt. George (Pliocene)—Flows, domes and shallow intrusions of gray to tan porphyritic dacite. The dacite is typically strongly flow banded. The upper surfaces of the flows and the margins of the domes and intrusions are commonly perlitic. At the bases of the
flow there is porphyritic pitchstone and pitchstone breccia. K/Ar ages for the dacite are 4.3 ±
0.2 Ma and 3.73 ± 1.23 Ma (Fox and others, 1985). Includes:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Psvdgp</td>
<td>Pumice breccia, pumice lapilli tuff, with lithic fragments and perlitic glass fragments that mantle and or occur between flows.</td>
</tr>
<tr>
<td>Psvdni</td>
<td>Gray porphyritic intrusion in Milliken Canyon.</td>
</tr>
<tr>
<td>Psvbn</td>
<td>Breccia of Napa - Dacite breccia underlying the low hill east of Napa. This breccia is likely a resurgence volcano within the caldera.</td>
</tr>
<tr>
<td>Tsvri</td>
<td>Intrusive rhyolite plugs and breccia</td>
</tr>
<tr>
<td>Mwg</td>
<td>Wilson Grove Formation (late Miocene to Pliocene)—Marine sandstone and conglomerate. Roblar tuff (Mrt) is interbedded with the upper part of the Wilson Grove.</td>
</tr>
<tr>
<td>PMp</td>
<td>Petaluma Formation (Pliocene to late Miocene)—Fluvial and estuarine sandstone, siltstone, and conglomerate.</td>
</tr>
<tr>
<td>PMpu</td>
<td>Upper Petaluma Formation (Pliocene to late Miocene)—Fluvial, estuarine, lacustrine conglomerate, sandstone, and diatomite. Some marine strata in Bennett Valley (Powell and others, 2004).</td>
</tr>
<tr>
<td>Mpm</td>
<td>Middle Petaluma (Miocene)—Fluvial and estuarine sandstone, siltstone, and conglomerate.</td>
</tr>
<tr>
<td>Mco</td>
<td>Sand and gravel of Cotati (Miocene)—Pebbly sand and gravel, locally rich if siliceous shale chips.</td>
</tr>
<tr>
<td>Mtvm</td>
<td>Tolay Volcanics, mafic volcanics (Miocene)—Basalt and basaltic andesite flows and breccia. Includes the Donnell Ranch volcanics of Youngman (1989).</td>
</tr>
<tr>
<td>Mtvt</td>
<td>Tolay Volcanics, tuff (Miocene)—Rhyolitic to dacitic tuff.</td>
</tr>
<tr>
<td>Mtvr</td>
<td>Tolay Volcanics, rhyolite to dacite flows and tuff (Miocene)—Rhyolitic to dacitic lava flows, tuff, and breccia.</td>
</tr>
<tr>
<td>sc</td>
<td>Silica carbonate rocks (age unknown, variable)—Hydrothermal alteration of serpentinite.</td>
</tr>
<tr>
<td>Mor</td>
<td>Orinda Formation (late Miocene)—Greenish-gray lithic sandstone, conglomeratic sandstone, and conglomerate and green and maroon siltstone and claystone.</td>
</tr>
<tr>
<td>Msp</td>
<td>San Pablo Group, undivided (late Miocene)—Brown, gray, and white marine sandstone, shale and conglomerate. Includes Briones Sandstone, Cierbo Sandstone, and Neroly Sandstone:</td>
</tr>
<tr>
<td>Mnr</td>
<td>Neroly Sandstone (late Miocene)—Light-colored to bluish-gray, medium-grained, volcanic rich, marine sandstone.</td>
</tr>
<tr>
<td>Mc</td>
<td>Cierbo Sandstone (late Miocene)—Brown, gray, and white quartz and quartz-lithic marine sandstone, with minor tuffaceous sandstone, shale and conglomerate.</td>
</tr>
<tr>
<td>Mbr</td>
<td>Briones Sandstone, undivided (late and middle Miocene)—Orange- to tan-weathering, white to gray quartz-lithic sandstone, conglomerate, siltstone, and shale.</td>
</tr>
<tr>
<td>Tms</td>
<td>Marine sandstone and tuffaceous mudstone (Miocene?)—Light-colored sandstone, coarse-grained, pumice-rich sandstone, chocolate brown mudstone. Mapped as Monterey Formation and San Ramon Sandstone by Weaver (1949).</td>
</tr>
</tbody>
</table>
Monterey Group, undivided (middle and late Miocene)—Thin-bedded siliceous shale interbedded with arkosic sandstone. The siliceous shale is often intricately contorted.

Mmyd Diatomite

Mmys Sandstone and tuffaceous sandstone

Rodeo Shale (middle Miocene)—Light-brown siltstone, silty shale, shale, siliceous shale, and chert.

Hambre Sandstone (middle Miocene)—Light-brown to gray, massive, medium- to fine-grained sandstone and siltstone.

Tice Shale (middle Miocene)—Brown to light-gray siliceous shale, argillaceous chert, and yellow-orange dolomitic lenses and concretions.

Sobrante Sandstone (early Miocene)—Massive, white, medium-grained, calcareous quartz sandstone.

Burdell Mountain volcanics (middle Miocene)—Andesite flows, breccia, and mudflow deposits, and dacite flows. Includes rhyolite on the south slope of Burdell Mountain. Age range is 11.8 to 10.59 Ma (Ford, 2007).

Putnam Peak Basalt (Miocene)—Olivine-bearing basalt flow. Columnar jointing weakly developed locally. Correlated with the Lovejoy Basalt of the Sierra Nevada (Durrell, 1959; Seigel, 1988) indicating it is a distal part of flood basalt that extended from the Sierra to the Coast Ranges. Radiometric ages (Ar/Ar) indicates the basalt is 16 Ma (Page and others, 1995; Wagner and others, 2000).

San Ramon Sandstone (early Miocene?)—Bluish-gray to brown, medium-grained sandstone with local conglomerate near the base.

Unnamed sediments (Miocene?)—Tuffaceous sediments beneath the volcanic rocks on Burdell Mountain on the Novato and Petaluma quadrangles.

Escobar Sandstone of Weaver (1953) (Eocene)—Massive, medium- to coarse-grained brown sandstone and silty shale; includes basal shale member.

Markley Sandstone (Eocene)—Buff-weathering, white to light-gray quartz-mica sandstone.

Jameson Shale member—Laminated and siliceous brown mudstone.

Nortonville Shale (Eocene)—Gray-weathering, brown shale. Also contains thin beds of fine-grained, quartz-lithic, glauconitic sandstone.

Upper member

Middle member

Lower member

Muir Sandstone of Weaver (1953) (Eocene)—Massive, yellow-weathering, brownish-gray, fine- to medium-grained silty arkose and silty shale

Domengine Sandstone (Eocene)—Light-colored, fine- to coarse-grained quartzose sandstone.

Unnamed mudstone sandstone and siltstone (Eocene)—Foram-bearing; contains early Eocene nannofossils (Ristau, unpublished data, 2006).

Shale (Eocene)—Brown to dark-gray mudstone containing micaceous shale, sandy shale, and glauconite horizons. Previously mapped as Capay Formation (Weaver, 1949). Contains
middle and early Eocene age foraminifera and calcareous nanofossils (Almgren and others, 1988; Prothero and Brabb, 2001; Ristau, unpublished data, 2007).

Ec  Capay Shale (Eocene)—Brown, thin-bedded mudstone and gray micaceous shale.

Rlj  Las Juntas Shale of Weaver (1953) (Eocene and Paleocene)—Gray shale with minor siltstone and sandstone.

Rlu  Unnamed sandstone, shale (Paleocene)—Sandstone, siltstone, and foram-bearing mudstone and shale. In the Cement Hill area this unit contains Paleocene nanofossils and a glauconite-rich basal zone in contact with Upper Cretaceous rocks (Ristau, unpublished data, 2006). On the Mt. Vaca quadrangle, this unit contains brownish shale with thin beds of friable glauconite-bearing biotite wacke. This unit contains Paleocene foraminifera (Graymer and others, 2002).

Rlus Basal sandstone member present in the Vaca Valley area.

Rvh  Vine Hill Sandstone of Weaver (1953) (Paleocene)—Medium- to coarse-grained brown, glauconitic sandstone and silty shale.

Rmz  Martinez Formation (Paleocene)—Light-brown and light-gray fine-grained micaceous sandstone and mudstone.

Kgv  Great Valley Sequence, undivided (Cretaceous)—Includes:

Ku  Great Valley Sequence (Late Cretaceous)—Sandstone, siltstone, shale and minor conglomerate. Includes:

Kus  Massive sandstone.

Kush  Unnamed sandstone and shale (Late Cretaceous)—Sandstone, siliceous shale, and mudstone.

Kfo  Forbes Formation (Late Cretaceous)—Thick beds of fine- to coarse-grained sandstone with shell fragments grading into interbedded siltstone and shale.

Kg  Guinda Formation (Late Cretaceous)—Thick-bedded to massive sandstone grading upward into siltstone and shale.

Kf  Funks Formation (Late Cretaceous)—Siltstone and mudstone with thin interbeds of sandstone.

Ks  Sites Formation (Late Cretaceous)—Thick-bedded fine-to medium-grained sandstone with moderately thick beds of siltstone.

Ky  Yolo Formation (Late Cretaceous)—Moderately thick bedded, fine- to medium-grained sandstone, mudstone and micaceous siltstone.

Kv  Venado Sandstone (Late Cretaceous)—Massive- to thick-bedded, shale chip-bearing sandstone with minor siltstone.

Kl  Great Valley Sequence (Early Cretaceous)—Marine mudstone, sandstone, and conglomerate.

Kgvc  Great Valley Sequence conglomerate (Early Cretaceous)—Pebble to boulder conglomerate. Correlative with the Healdsburg terrane of Blake and others (1984).

Kn  Novato Conglomerate (Early Cretaceous)—Pebble to boulder conglomerate with minor coarse sandstone interbeds. Correlative with the Healdsburg terrane of Blake and others (1984).
**KJgv**  Great Valley Sequence, undivided (Late Cretaceous to Late Jurassic)—Marine shale, sandstone, and conglomerate; coeval with and structurally overlying the Franciscan Complex. Includes:

**KJss**  Ridge-forming sandstone beds on the Capell Valley, Fairfield North and Mt. Vaca quadrangles.

**KJgvm**  Melange in the lower Great Valley Sequence—Structurally disrupted mudstone and sandstone that is lithologically similar to Kgv. Includes:

**KJv**  Greenstone blocks.

**KJssp**  Detrital serpentinite. Includes serpentinite matrix mélange on the Camp Meeker quadrangle.

**Jk**  Knoxville Formation (Late Jurassic)—Well-bedded mudstone with thin sandstone interbeds; local channel pebble conglomerate.

**Coast Range Ophiolite (Jurassic)**—Includes:

**Jv**  Volcanic rocks—Mainly altered, massive and pillow basalt (greenstone); includes keratophyre on the Cordelia and Camp Meeker quadrangles.

**Jgb**  Gabbro and diabase

**sp**  Ultramafic rocks—Partially to completely serpentinized periodtite.

**Franciscan Complex (Eocene and Late Cretaceous to Late Jurassic)**—A subduction complex consisting of sandstone, shale, chert, limestone, volcanic rocks, metamorphic rocks, and minor plutonic rocks. Includes:

**TKfs**  Coastal Belt or Central Belt sandstone (Eocene to Late Cretaceous)—Chiefly massive, white to greenish-gray, brown and orange-weathering sandstone. Also includes some argillite and shale with disrupted bedding. Sandstone is mostly feldspathic-lithic wacke with detrital biotite and muscovite (Blake and others, 2002). This unit also occurs offshore, north of Jenner.

**Kfs**  Franciscan Complex sandstone—Massive to distinctly bedded feldspathic and feldspathic-lithic wacke. This unit also occurs offshore, north of Bodega Head.

**KJfss**  Franciscan Complex sandstone and shale—Thick-bedded greywacke and arkosic sandstone with interbedded shale and minor conglomerate. This unit is moderately to intensely sheared but lacks tectonic blocks characteristic of mélange.

**KJfgs**  Franciscan Complex greenstone—Altered volcanic rocks, chiefly pillow lava and less abundant tuff, breccia, and intrusive basalt and diabase. Locally includes metagreenstone and chert.

**KJfsch**  Franciscan Complex metamorphic rocks—Tectonic mixture of metamorphic rocks containing blueschist and variably sheared. The unit is predominantly metagreywacke with weak to moderate foliation, meta-shale, and metagreenstone. Tectonic inclusions of coarse-grained metamorphic rocks and metachert are common.

**KJfm**  Franciscan Complex mélange—Parts of the Franciscan are a chaotic mixture of fragmented rock masses in a sheared shaly matrix. This unit also occurs offshore. Coherent rocks masses large enough to be shown on this map are as follows:

**ss**  Sandstone, shale, and conglomerate
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ch</td>
<td>Chert and metachert</td>
</tr>
<tr>
<td>gs</td>
<td>Greenstone (altered mafic volcanic rocks) and metagreenstone</td>
</tr>
<tr>
<td>mg</td>
<td>Metagraywacke and graywacke</td>
</tr>
<tr>
<td>mv</td>
<td>Metavolcanic rocks</td>
</tr>
<tr>
<td>sch</td>
<td>Schist and semischist</td>
</tr>
<tr>
<td>um</td>
<td>Serpentinitized ultramafic rocks</td>
</tr>
<tr>
<td>♦</td>
<td>Blueschist blocks</td>
</tr>
</tbody>
</table>
Sources of mapping for the Napa and Bodega Bay 30’ x 60’ quadrangles

For complete citations see the References Cited section following this list

Arched Rock

Benicia

Bodega Head
Wagner, D.L., 2012

Camp Meeker

Capell Valley

Cordelia
Cotati

Cuttings Wharf

Duncans Mills
Wagner, D.L., 2012

Drakes Bay

Fairfield South

Fairfield North

Glen Ellen

Inverness

Kenwood

Mare Island

Mt. George

M. Vaca

Napa

Novato

Petaluma

Petaluma Point

Petaluma River

Point Reyes NE

Rutherford
San Geronimo

Santa Rosa

Sears Point

Sebastopol

Sonoma

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USGS Seafloor Mapping Program Block 29
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USGS Seafloor Mapping Program Block 30
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Tomales

Two Rock

Valley Ford
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Vine Hill

Yountville
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