ASSOCIATION OF ENGINEERING GEOLOGISTS

San Francisco Section

AEG San Francisco Section
Field Trip
Geology and Tectonics of the San Francisco North Bay Area

Saturday June 14, 2008

Leaders:
James Allen, CSU East Bay, Earth and Environmental Sciences
Peter Holland, Vector Engineering
James Wilen Jr., BACE Geotechnical

Guidebook by:
James Allen
Peter Holland
James Wilen Jr.

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DIRECTIONS

The meeting location is the Caltrans park-and-ride lot in the southwest quadrant of the Highway 101 and Rohnert Park Expressway (Fig. 1). We will consolidate in vehicles because parking will be limited at the fieldtrip stops.

MEETING LOCATION- 0 Mi - CALTRANS PARK & RIDE LOT IN SOUTHWEST QUADRANT OF HIGHWAY 101 AND ROHNERT PARK EXPRESSWAY
Exit the Park & Ride on southbound Highway 101.
0.9 Mi- Take the 1st exit, Gravenstein Highway, turn right (west) onto Gravenstein Highway (Highway 116).
2.1 Mi- The highway cuts through the interbedded WGFand PFs.
2.4 Mi- Turn left (south) at Stony Point Road
3.9 Mi- Turn right (west) onto Roblar Road immediately after the Washoe House.

STOP 1 8.3 Mi - Steinbeck Ranch is to the right. Red House with accessory barns and outbuildings about 100 yards off the road. Leave Steinbeck Ranch the same way we came. Turn left leaving the driveway onto Roblar Road.
12.8 Mi- Turn left onto Stony Point Road. Once onto Stony Point Road, a large berm of waste rock is visible in the distance on the left side of Stony Point Road. This is the edge of STOP 2- Stony Point Rock Quarry.
STOP 2 13.3 Mi- Get into the left turn lane and turn left into the entrance of Stony Point Rock Quarry. Leave Stony Point Rock Quarry and turn left onto Stony Point Road.
14.2 Mi- Gravenstein Highway (Highway 116). Go straight, continue on Stony Point Road through the intersection.
14.4 Mi- Mount St. Helena is straight ahead in the distance.
STOP 3 14.9 Mi- The Pasta King Restaurant is visible on the right. Just past the Pasta King, pull off onto the shoulder. The road-cut we will be looking at is on the opposite side of Stony Point Road, so use caution when crossing the road.
Continue driving north on Stony Point Road as you leave Stop 3-
15.6 Mi- Turn right onto Rohnert Park Expressway.
17.2 Mi- Pass over Highway 101, continuing on Rohnert Park Expressway. Sonoma Mountain is straight ahead. Taylor Mountain is to the left in the distance.
19.7 Mi- Turn left (north) onto Petaluma Hill Road.
21.1 Mi- Turn right (east) onto Crane Canyon Road
22.3 Mi- On left side of road, a road cut has been recently covered with rip-rap. The road-cut is within relatively unstable sandstone and claystone of the PF.
22.9 Mi- The road changes names from Crane Canyon Road to Grange Road.
STOP 4: Taylor Mountain
STOP 5: 23.6 Mi- At the crest of the road there is a curve to the left. Park on the shoulder. Bennett Mountain is to the right at 1:00.
Continue north on Grange Road.
24.7 Mi- Turn Right at the stop sign Bennett Valley Road.
25.4 Mi- Turn right onto Sonoma Mountain Road.
26.7 Mi- Turn left onto Bottasso Court.
STOP 6 26.8 Mi- Park along road. This is a private driveway, or we may be able to get access into the creek.

OVERVIEW OF STOPS

Stop 1 - Steinbeck Ranch

The Steinbeck Ranch stop provides rare outcrops of the WGF and Roblar Tuff. The base of the WGF at Steinbeck Ranch is just west of the ranch house and barns where it overlies Franciscan Complex sandstones along an angular unconformity. Across Roblar Road, SE of the ranch, is an outcrop of ~9 ma Tolay Volcanics which locally underlies the Wilson Grove Formation here. These volcanics also underlie the basal **Petaluma Formation (PF)** at the Stony Point Rock Quarry and between the Tolay and Rodgers Creek faults, providing a ~9 Ma basal age for the two formations. The Wilson Grove Formation exposures at Steinbeck Ranch are fine-grained sandstones typical of this formation and have a gentle dip to the east. The Wilson Grove Formation often appears massive, however the exposures at Steinbeck Ranch show subtle hummocky cross stratification.

The late Miocene (6.26 ma) Roblar Tuff occurs about 105 m above the base of the Wilson Grove, therefore we are seeing the late Miocene to Pliocene transition here. Fossils above the bed are Pliocene in age. Present at the base of the tuff is a 5 to 15 cm-thick angular gravel bed clasts of red to gray mafic volcanics up to 1 cm in diameter.

Fossil beds are common at Steinbeck Ranch with Macoma sp. one of the more dominant bivalves. Fossil shell hash beds are often more resistant due to calcite cementation. A rare primitive Balanopterid whale skull was found here by Allen and Others (1999) and identified by Dr. Lawrence Barnes of the Los Angeles County Museum of Natural History. The skull was found in outcrop, just below the 6.26 Ma Roblar Tuff. Thus far, this is the only whale skull fossil found in the **Wilson Grove Formation (WGF)**.

Stop 2- Stony Point Rock Quarry

Now we have moved east and into the fluvial-marine transition zone. Here we'll see abundant mafic volcanics and the shoreline of the Wilson Grove/distal reach of the fluvial PF. The Stony Point Rock Quarry exposes late Miocene (9.3 ma)

Figure 1: Road map of stops.

Tolay Volcanics and overlying PF. The quarry is actively mining the mafic rocks for various aggregate products. The quarry pit exposes numerous volcanic flows located along the hinge and north limb of a faulted antiform.

Stratigraphically below the volcanics in the open pit is the lower shale member of the PF. Via faulting, the lower shale crops out just outside the pit and about 3,000 feet to the west. We have found marine and nonmarine ostracode fauna from the lower Petaluma shale, indicating the lower shale, although largely deposited in a large lake environment, was at time inundated by marine waters of the WGF during this time (8-9 Ma). The Lower PF is in turn overlain by the conglomeratic Middle Member of the PF. Note the clast composition of the Middle Member is predominantly lithologies from the Franciscan Complex.

Stop 3- Stony Point Road

The base of the PF section exposed in the Stony Point Rock Quarry dips to the north. Overlying sandstone and conglomerate dip to the north as we travel northward on Stony Point Road, until we get to the Upper Member of the PF. Therefore, when we start at the base of the section at the quarry and head north, we walk through time and young to the north. Note the similar dip to the north, but the composition of the conglomerate has changed from Franciscan Complex derived gravels in the Middle Petaluma to pre-dominantly laminated chert in the Upper Petaluma derived from the middle Miocene Monterey Group! The environment of deposition here is fluvial meets marine, therefore the fluvial gravels of the PF are highly polished and very well rounded in this facies. The sandstone interbeds here contain Pliocene marine pelecypod fossils and trace fossils. Meacham Hill and Pepper Road contain the best fossils for this section. This unit, where the Petaluma interfingers with Wilson Grove, has been referred to as the Pliocene-Pleistocene "Cotati Member of the Wilson Grove" by Davies (1986) or "sand and gravel of Cotati" by Fox (1983). Since the age is actually late Miocene to Pliocene and these lithologies crop out throughout Sonoma County, the misleading name and incorrect age of Plio-Pleisto are dropped herein. Unfortunetaly, a small study in Cotati will not adequately do justice for a unit so far reaching (Sears Point to Santa Rosa, Trenton, Cotati to Lakeville and through Taylor and Sonoma mountains).

Stop 4: Taylor Mountain

Here we will examine the conglomerates of the middle Petaluma Formation in the headscarp of a major landlside.

Stop 5- Overview of Bennett Mountain

From this vantage point we can see geomorphic features associated with the WNW trending, northeast verging Bennett Valley fault at the base of Bennett Mountain. This is a major thrust fault. Sonoma Volcanics rocks dated atop Bennett Mountain are approximately 7 Ma and these are thrust over 4 to 5 Ma sediments of the PF in Bennett Valley. East of the Bennett Mountain thrust are a series of parallel WNW trending thrusts in Maacama Mountains indicating major shortening in this area.

Stop 6- Botasso Court & Matanzas Creek

Here we have crossed the Rodgers Creek Fault and now are east of the famous fault. We find the Upper Member of the PF lithologies throughout Bennett Valley. Due to the timing of the field trip, excellent creek exposures mayt be seen due to the flooded, fast moving water and private property mishaps! Fossils from Bennett Valley are Pliocene in age and are Blancan horse teeth & elephant. Fossils I've found here from the Upper PF are marine and include a large crab body minus the claws, razor clams and other pelecypods. This implies there was a marine transgression this far east and into the largely fluvial regime. The Upper Petaluma contains laminated chert pebbles from the Monterey Group, just as we saw in Cotati at **Stop 3**. Do not be confused by the overlying Quaternary Terrace which is flatlying and contains cobbles of volcanics. Bennett Valley contains a great record of Quaternary fluvial terraces, especially well exposed atop steeply dipping PF along creek traverses. A future study on Quaternary uplift in Bennett Valley could be done using these terraces. Gravels in the terraces are volcanic derived and record uplift of Sonoma Volcanics. Note how in the PF we lack abundant volcanic detritus…..

INTRODUCTION

This study focuses on the late Miocene to late Pliocene sedimentary rocks of the northern San Francisco Bay Area (Bay Area). Key stratigraphic units are the marine WGF and nonmarine-transitional marine PF of Sonoma and Marin counties. Field trip stops are shown on Figure 1.

Faults east of the San Andreas fault in the northern Bay Area generally are inferred to have hosted significant dextral slip since the passage of the Mendocino triple junction at about 12 Ma. However, the amount and distribution of dextral slip are poorly constrained because of a paucity of piercing points. Most previous reports have used volcanic rocks to correlate stratigraphic sections in different areas (Fox et al., 1983; Graham et al., 1984; Graymer et al., 2002), but the accuracy of such correlations is unknown given the uncertain or incomplete dating of such rocks in the Bay Area, and the uncertain original (pre-erosion) extent of such rocks.

The goal of this study is to determine whether late Miocene to late Pliocene sedimentary rocks of the WGF and PFs can be used to learn more about the late Cenozoic dextral slip history in the Bay Area. During this study, I collected lithologic, paleontologic, and paleocurrent data and mapped key areas in order to refine the stratigraphic nomenclature, determine sediment provenance, and evaluate possible correlations of late Tertiary units.

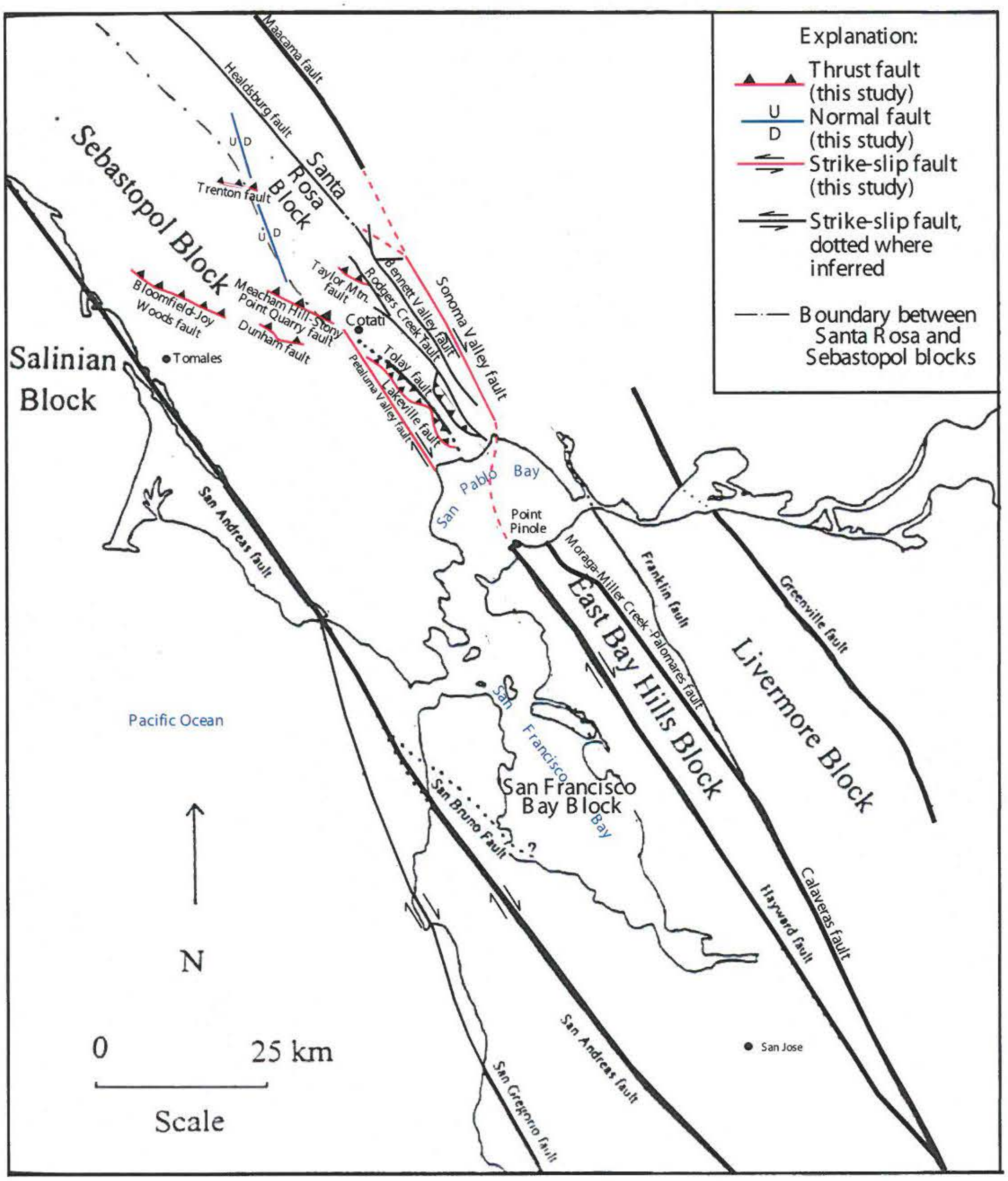


Figure 2. Map of structural blocks (modified from Fox, 1983; Graham et al., 1984; Buising and Walker, 1995; Wentworth et al., 1999, Dickerman, 1999; McLaughlin et al., 2000; Graymer et al., 2002).

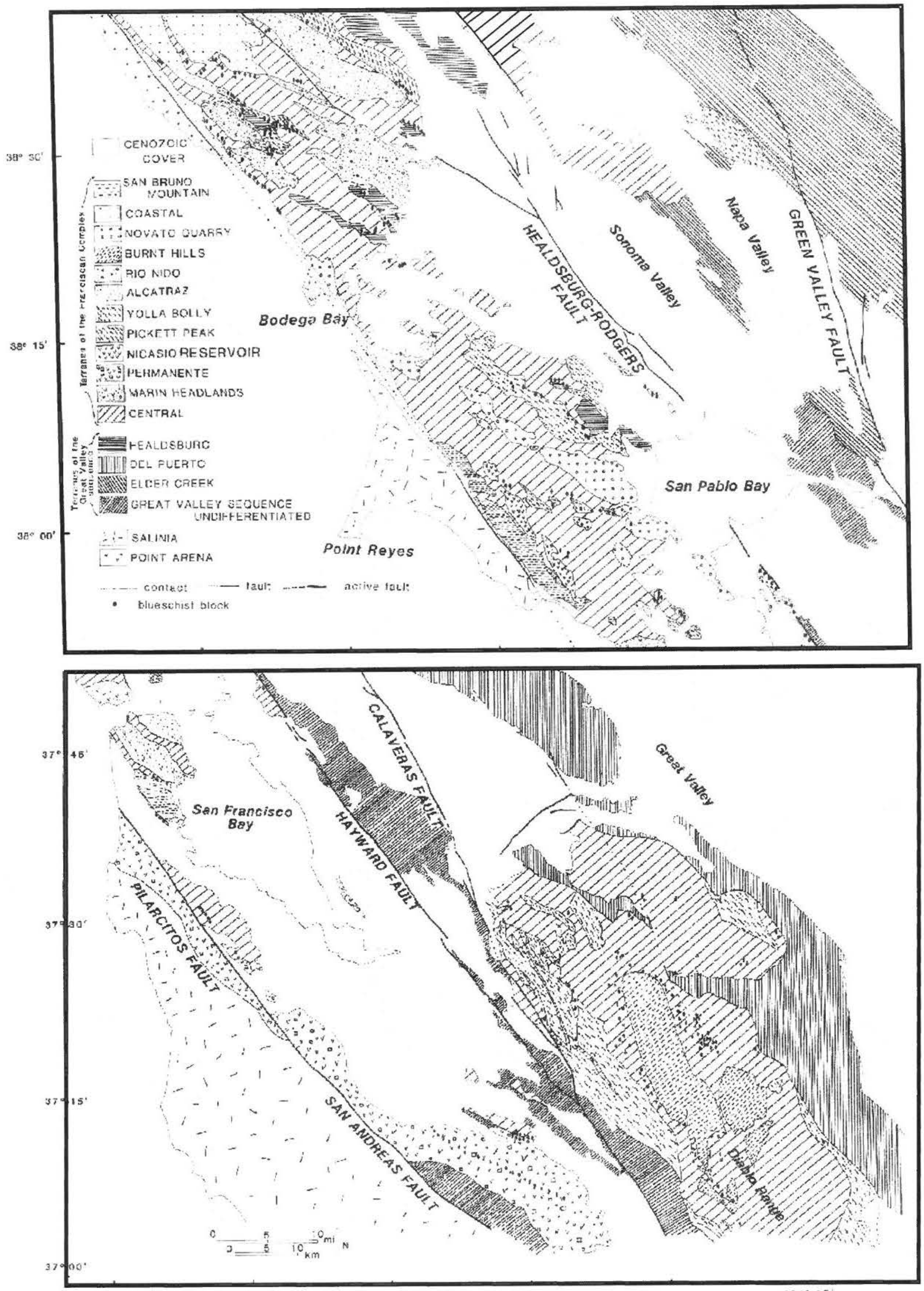


Figure 3. Terrane maps of Mesozoic rocks. A. Northern Bay Area (Blake et al., 1984)
B. Southern Bay Area (Blake et al., 1984). Patterns as in legend of Figure 3A.

REGIONAL GEOLOGY

The central and northern Bay Area are divided into at least four structural blocks (Fig. 2) bounded by active strike-slip faults (Buising and Walker, 1995; Wentworth et al., 1999). The Salinian block is located west of the San Andreas fault. The San Francisco Bay block is bounded by the San Andreas fault to the west and the southern Calaveras, Hayward, and Maacama faults to the east (McLaughlin et al., 1996, 2000). The northern portion of the San Francisco Bay block is divided into the Sebastopol block to the west and the Santa Rosa block to the east (Fox, 1983). The fault dividing these blocks may be located in the Petaluma River area (Collins, 1992; Wright and Smith, 1992) and has been named the Petaluma Valley fault (Graymer et al., 2002). The East Bay Hills block is bounded by the Hayward fault to the west and the Calaveras fault and Moraga-Miller Creek-Palomares fault system to the east (Buising and Walker, 1995). The Livermore block is bounded by the Calaveras fault and Moraga-Miller-Creek-Palomares to the west and the Greenville fault to the east (Buising and Walker, 1995).

Lithologic characteristics of geologic units in each structural block are briefly summarized below to provide data for discussion of provenance. Geologic units in the Diablo Range are included here because the late Miocene-early Pliocene units studied in this report probably were closer to the Diablo Range at the time of deposition.

Franciscan Complex

The Franciscan Complex crops out as mélange blocks and as coherent tracts in the area of this study and throughout the Coast Ranges (Wagner and Bortugno, 1982; Blake et al., 1984, 2000). The Franciscan Complex is subdivided into many terranes (Figs. 3A, 3B) (Blake et al., 1984, 2000). The geology of some of these terranes is reviewed here briefly because Franciscan detritus is an important component of the Tertiary formations that are the focus of this study.

The Marin Headlands terrane is composed of Early Jurassic pillow basalt overlain by radiolarian chert and graywacke (Blake et al., 1984, 2000).

The Yolla Bolly terrane consists of foliated metagraywacke, metachert, and metabasalt. These rocks contain abundant blueschist-facies minerals such as lawsonite, jadeite, pyroxene, and metamorphic aragonite (Blake et al., 1984, 2000). The southern portions of the WGFand PFs unconformably overlie a small part of this terrane. This terrane also crops out in a large area east of, and adjacent to, the Calaveras fault in the northwestern Diablo Range.

The Alcatraz terrane consists chiefly of greywacke sandstone. It lacks blueschist-facies index minerals, and instead contains metamorphic prehnite and pumpellyite (Blake et al., 2000). Fossils include Early and mid-Cretaceous *Inoceramus ellioti* and an Early Cretaceous species of *Buchia* (Blake et al., 1984, 2000).

The Novato Quarry terrane consists of Late Cretaceous thin-bedded turbidites with local channel deposits of massive sandstone. Metamorphic minerals include prehnite and pumpellyite, and fossils include *Inoceramus* sp. (Blake et al., 1984, 2000).

The San Bruno Mountain terrane consists of well-bedded graywacke turbidites containing abundant K-spar plus widespread veins of hydrothermal quartz adularia dated at 13-12 Ma (Blake et al., 1984, 2000; McLaughlin et al., 1996).

The Nicasio Reservoir terrane consists of Late Jurassic-Early Cretaceous pillow basalt, gabbro, and minor radiolarian chert (Blake et al., 1984, 2000). The WGF unconformably overlies this terrane at Tomales and Dillon Beach.

The Burnt Hills terrane in the northern Diablo Range consists of radiolarian chert, mudstone, sandstone, and conglomerate (Blake et al., 1984). Metamorphic mineral assemblages in the sandstone range from quartz-albite-pumpellyite through quartz-albite-lawsonite to quartz-lawsonite-jadeitic pyroxene ± glaucophane (Cowan, 1974; Morrell, 1978 *in* Blake et al., 1984). Abundant blueschist blocks crop out near the margins of the Burnt Hills terrane (Fig. 3B).

The Permanente terrane consists largely of mélange with blocks of interbedded limestone and alkalic pillow basalt (Sliter, 1984 *in* Blake et al., 1984, 2000; McLaughlin et al., 1996).

The Central terrane consists of blocks and slabs of greenstone, chert, metamorphic rocks, and serpentinite that are enclosed in a matrix of sheared mudstone (argillite) and lithic sandstone (Blake et al., 2000). This terrane makes up a large part of the northern Diablo Range. West of the Tolay fault, Central terrane mélange blocks include graywacke, metagraywacke, gabbro, metachert, radiolarian chert, actinolite, serpentinite, medium- to high-grade blueschist, eclogite, and amphibolite.

Great Valley Group

The Great Valley Group, which consists of Late Jurassic to Late Cretaceous conglomerate, sandstone, and shale that overlies the Jurassic Coast Range ophiolite, has been divided into several fault-bounded tectonostratigraphic terranes (Blake et al., 1984, 2000).

The Coast Range ophiolite (Middle Jurassic) consists of keratophyre and quartz keratophyre, serpentinite, pillow basalt, sheeted diabase, static gabbro, cumulate gabbro, and peridotite (Hopson et al., 1981; Blake et al., 1984, 2000). The keratophyre and quartz keratophyre are arc-related intermediate and silicic volcanic and hypabyssal rocks with feldspars replaced by albite, exposed locally at the top of the Coast Range ophiolite, and notably along the Hayward fault zone (Graymer et al., 1995).

The Healdsburg terrane is composed of 3,000 m of conglomerate that overlies peridotite of the Coast Range ophiolite north of Healdsburg. Strata that rest directly on the peridotite contain Early Cretaceous *Buchia* sp. along Atherton Avenue in Novato (Blake et al., 2000). Portions of this terrane are mapped north of the WGF in the Healdsburg area, south of the WGFat Burdell Mountain, and at Alum Rock Park in the east San José area (R. Graymer, personal communication, 2002).

The Del Puerto terrane is mapped along the Hayward fault zone in the Oakland area (Graymer, 2000). The terrane consists of large bodies of dismembered keratophyre, peridotite, and silicic tuff (Blake et al., 1984; Graymer, 2000).

The undifferentiated Great Valley Group of Blake et al. (1984) crops out in the southeastern Bay Area on either side of the Calaveras and Hayward faults (Blake et al., 1984) (Fig. 3B). These strata include the Berryessa Formation (east of San José) and Oakland Conglomerate of Crittenden (1951) (Graymer et al., 1995). Clasts in the conglomerate are black and red chert, black quartzite, coarse-grained recrystallized sandstone, plutonic, vein quartz, metavolcanic, and silicic porphyritic volcanic. These clasts are similar to those in the Healdsburg terrane (Crittenden, 1951; Gealey, 1951).

Salinian Block at Point Reyes Peninsula

According to Weaver (1949), the metamorphic rocks at Point Reyes (Fig. 4) are similar to the metamorphic rocks of the Sur Series in Monterey and San Luis Obispo counties, about 120 km to the south. These metamorphic rocks are older than early Late Cretaceous and possibly are Paleozoic in age (Galloway, 1977). The metamorphic rocks at Point Reyes consist of mica schist, quartzite, and crystalline limestone (Galloway, 1977).

Plutonic rocks that intrude the metamorphic rocks are early Late Cretaceous in age (Curtis et al., 1958). Compositions range from quartz diorite through granodiorite and adamellite (Galloway, 1977). Plutonic rocks of the Salinian block are lithologically similar to plutonic rocks of the Sierra Nevada (Ross, 1972; James et al., 1993).

Tertiary rocks that nonconformably overlie the metamorphic and plutonic rocks at Point Reyes include the Paleocene Point Reyes Conglomerate, the lower(?) to middle(?) Miocene Laird Sandstone, the middle to upper Miocene (Luisian to Delmontian)

Monterey Formation, the Pliocene Drakes Bay Formation (Purisima Fm.), the Pliocene Merced Formation, and Quaternary deposits (Galloway, 1977).

Late Tertiary strata are widespread in the Bay Area. The WGF and PFs (Fig. 4) are discussed at length in the body of this thesis. The following section briefly summarizes important aspects of other mid-Miocene to Pliocene units because they may have a bearing on regional correlations.

Monterey Group

The Miocene Monterey Group is mapped east of the Hayward fault as far south as Santa Clara County and to the north in Carneros Valley, near the Sonoma-Napa county line (Fig.4B) (Wagner and Bortugno, 1982; Wagner et al., 1990). The Briones Formation was included in the Monterey Group by Lawson (1914) but since has been shown to be the lowermost formation of the San Pablo Group (Weaver, 1949; Cebull, 1955; Hill, 1979). A field survey for this study determined that the Monterey Group in Carneros Valley consists of white, tuffaceous, friable, coarse- to fine-grained, thick-bedded sandstone and siltstone. The sliver of Monterey in Carneros Valley does not contain sufficient lithologies or diagnostic fossils to assign it to a specific part of the group (Weaver, 1949).

San Pablo Group

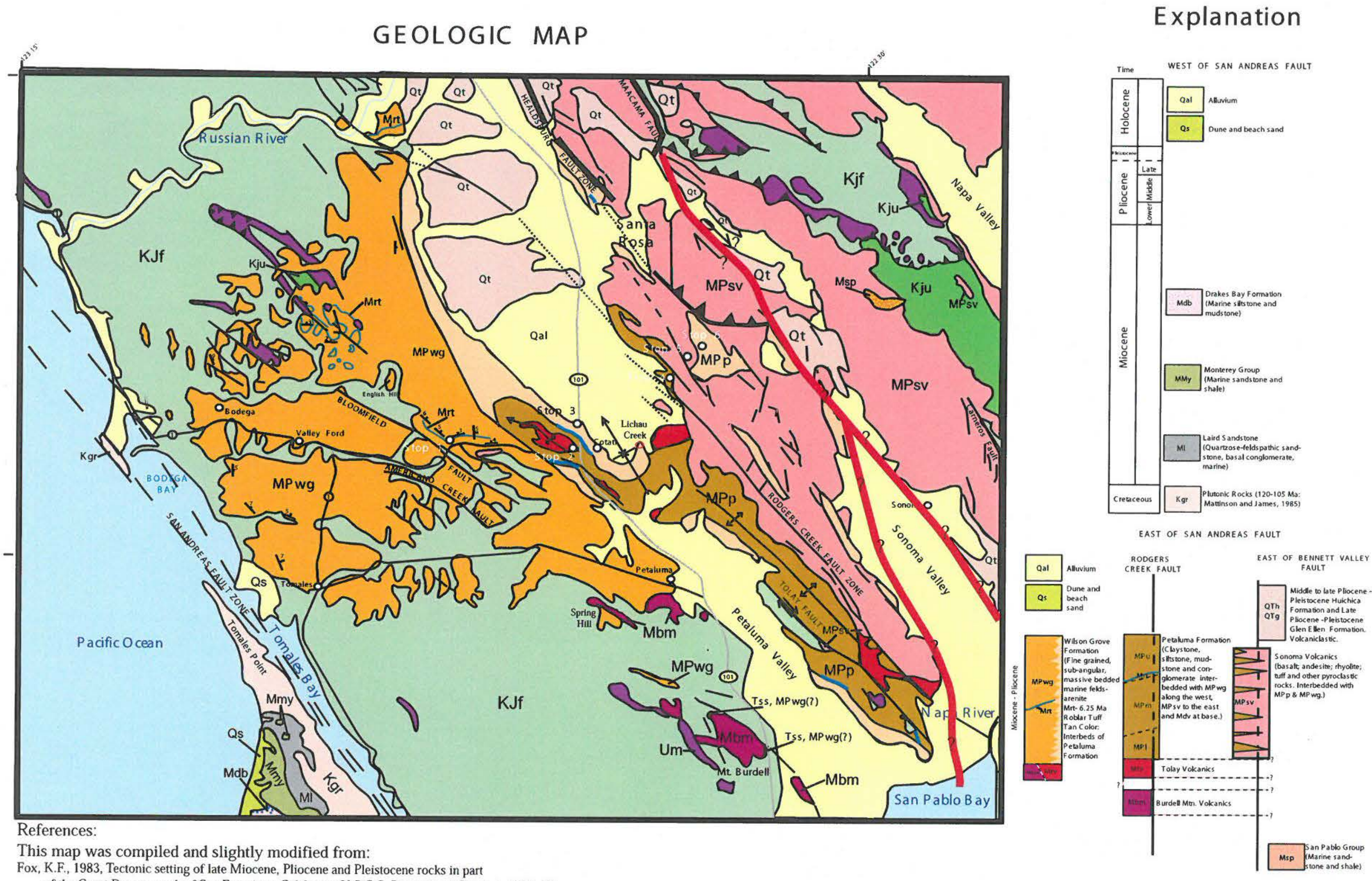
The San Pablo Group is composed of the marine Briones Formation, marine Cierbo Formation, and marine to nonmarine Neroly Formation (Weaver, 1949). The San Pablo Group is mapped throughout the eastern Bay Area from east of San José to the Livermore area, and as far north as Carneros Valley and Nunns Canyon in Sonoma County (Wagner and Bortugno, 1982; Wagner et al., 1990). The Briones Formation overlies the Monterey Group conformably and unconformably at different localities (Wagner, 1978; Hill, 1979). Veins in San Pablo Group strata contain higher-temperature zeolites (e.g., laumontite) in the hills east of San José than in the hills east of Oakland (Fig. 5). These distinctive higher-temperature veins are found in San Pablo outcrops from Niles Canyon to southeastern San José.

Orinda Formation

The Orinda Formation, which crops out from east of San José to the Berkeley Hills, is interpreted to be the product of alluvial fan deposition and derived from a source of Franciscan and Great Valley rocks to the west (Wagner, 1978; Graham et al., 1984; Wakabayashi, 1999). The Orinda Formation has been reported to overlie the Monterey Group, but this contact is everywhere faulted (Wagner, 1978). Marine invertebrate fossils about 305 m above the base of the Orinda Formation indicate time-equivalence with the Miocene Neroly Formation (Wagner, 1978). The Orinda in the Berkeley Hills is upper Barstovian (~11.5 Ma) at its base and is conformably overlain by volcanic rocks dated at 10.2 ± 0.5 Ma (Clarendonian) (Curtis, 1989). The Orinda is overlain by about 230 m of undated volcanic rocks in the Niles Canyon area (Graymer, 1995). East of San José (Mission Peak area), the Orinda contains an undated volcanic interbed (Coyle, 1984).

Moraga Formation

In the Berkeley Hills, the Orinda Formation is conformably overlain by the upper Miocene Moraga Formation, which consists of about 610 m of basalt and andesite flows, minor rhyolite tuff, and interflow sedimentary rocks. Ar/Ar ages obtained from rocks in this unit range from 9.0 ± 0.3 to 10.2 ± 0.5 Ma (Curtis, 1989). Youngman (1989) analyzed 8 samples from the Berkeley Hills by XRF method. According to Youngman (1989), seven samples are basalt and one basaltic andesite.



References:
This map was compiled and slightly modified from:
Fox, K.F., 1983, Tectonic setting of late Miocene, Pliocene and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S.G.S. Professional Paper, p. 1239, 33.
Dickerson, R.E., 1922, Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Academy of Sciences Proceedings, ser. 5, v. 11, no. 19, p. 527-601.
Wagner, D.L. and Bortugno, D.L., 1982, Geologic Map of the Santa Rosa Quadrangle, California, 1:250,000, Regional Geologic Map Series, Santa Rosa Quadrangle-Map No. 2A.

Figure 4A: Geologic map from Wagner and Bortugno (1982). Petaluma Formation modified to show aerial extent of Upper Petaluma Formation. Faults shown in red bounding Sonoma Valley are inferred herein.

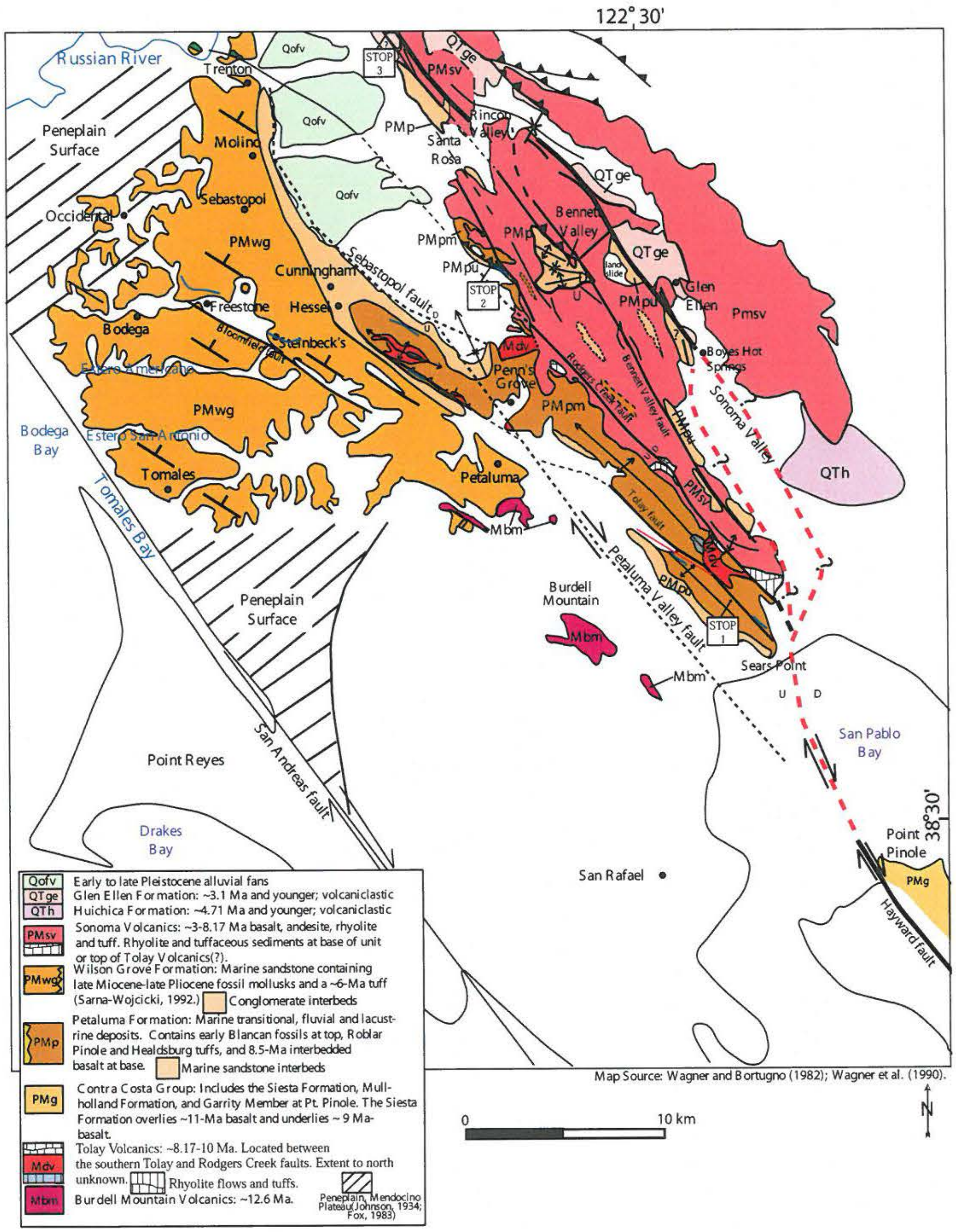


Figure 4B. Map of late Tertiary units in the northern Bay Area.

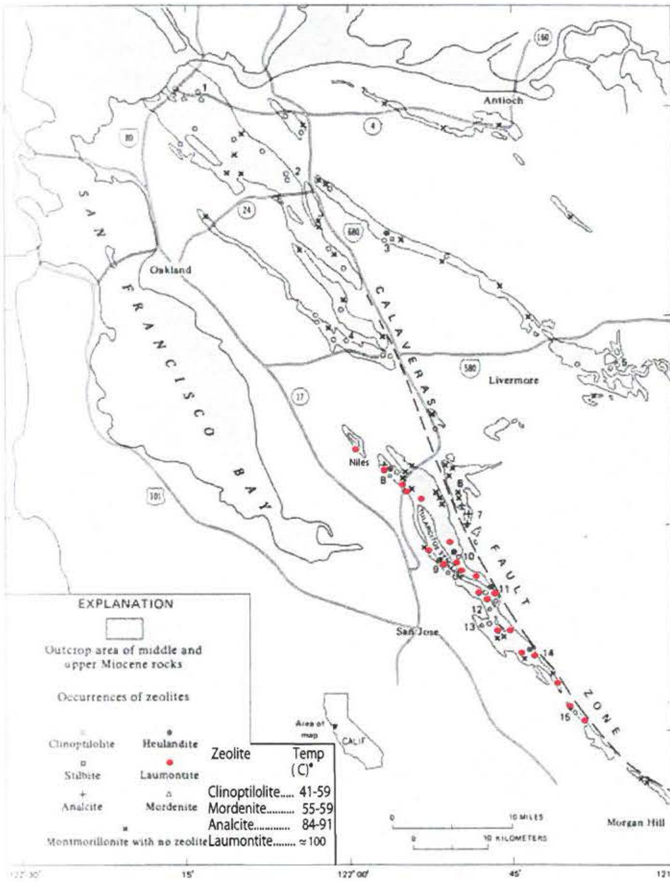


Figure 5. Map showing outcrop areas of middle and upper Miocene formations in the Coast Ranges east of San Francisco Bay and localities of studied zeolites (modified from Murata and Whiteley, 1973).

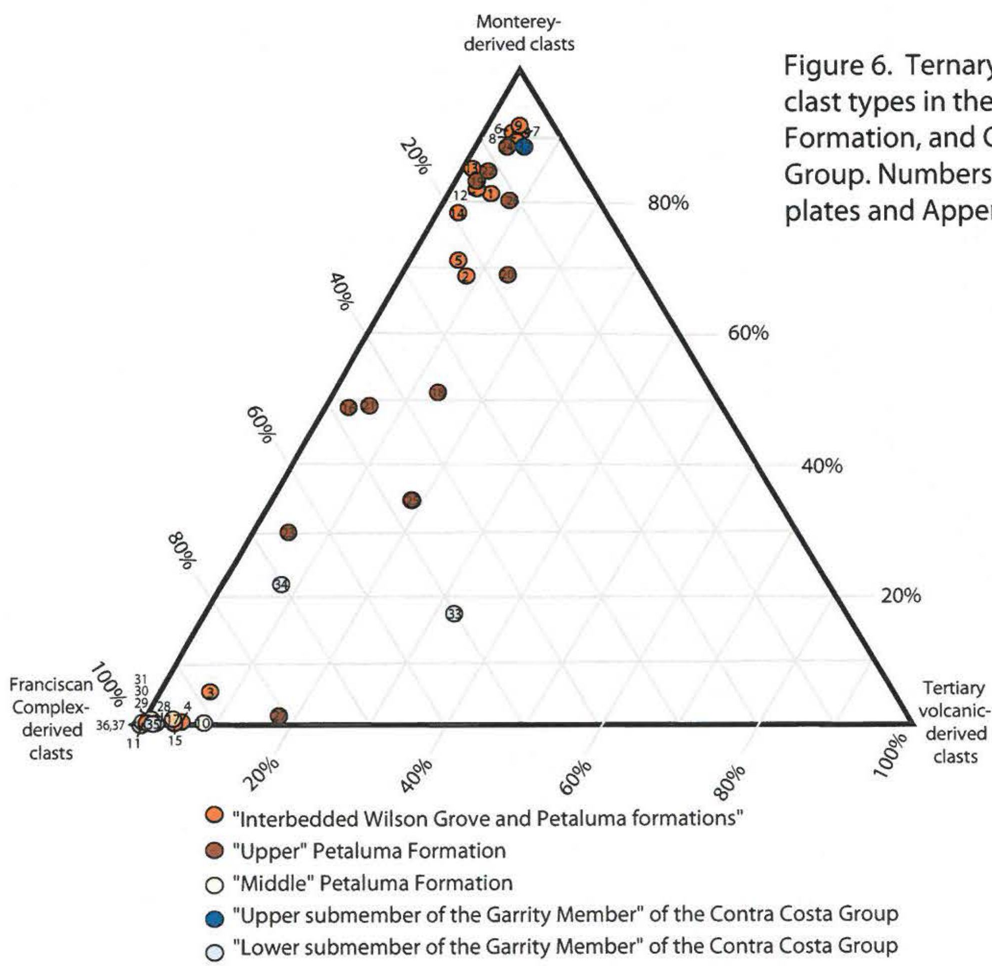


Figure 6. Ternary diagram showing composition of clast types in the Wilson Grove Formation, Petaluma Formation, and Garrity Member of the Contra Costa Group. Numbers refer to specific samples (see plates and Appendix B).

Siesta Formation

The Siesta Formation consists of at least 395 m of nonmarine siltstone, claystone, sandstone, and minor limestone (Wagner, 1978). Firby (1967) reported freshwater ostracodes and gastropods. The Siesta Formation is conformably overlain by the upper Miocene Bald Peak Basalt, which consists of about 100 m of massive basalt flows with Ar/Ar ages of 8.37 ± 0.2 and 8.46 ± 0.2 Ma (Wagner, 1978; Curtis, 1989).

Volcanic Rocks of the Northern San Francisco Bay Area

James Wilen conducted a petrographic analysis of the Tolay/Donnell Ranch Volcanics and Sonoma volcanics. Samples were collected and locations and data are shown in Appendix 1 of this guidebook.

Late Cenozoic volcanic rocks that crop out in the northern San Francisco Bay area consist of northwest trending volcanic fields that are a complex, heterogeneous blend of mafic to felsic flows, pyroclastics, and volcaniclastic rocks (Fox and others, 1985a,b; Fox, 1983). Osmont (1905) subdivided, or "split" these volcanic rocks into three distinct units, whereas Dickerson utilized the term Sonoma Group to effectively "lump" them together. In 1935, Morse and Bailey drilled through a thick sequence of volcanic flows underlying the Petaluma Formation and named them the Tolay Volcanics, and subsequently utilized that designation for all of the volcanics west of the Rogers Creek Fault (RCF). Morse and Bailey also formally named the volcanics east of the RCF the Sonoma Volcanics, a name that has persisted to this day. Despite Morse and Bailey's interpretations, Weaver (1949) mapped all of the volcanic rocks of the Northern San Francisco Bay area as Sonoma Volcanics, which remained the general consensus until the advent of radiometric dating.

Initial K-Ar dating indicated that the lithologically similar volcanic rocks in the region are actually different ages, with a distinct northerly-younging pattern, and are primarily fault-bounded segments that have been displaced on one or more portions of the San Andreas Fault System (SAFS) (Mankinen, 1972, Fox, 1983; Fox and others, 1985a,b; Davies, 1986; Youngman, 1989; Wakabayasi, 1999; Graymer, et. al., 2002). An 11.8 K-Ar date obtained by Mankinen (1972) indicated that the volcanic rocks of Burdell Mountain were older than the rocks to the northeast and grouped them with the Tolay Volcanics, as did subsequent researchers (Wagner and Bortugno, 1982; Fox and others, 1985a). Youngman (1989) proposed a further subdivision of the volcanic units in the southern Sonoma Mountains and called the 10.64 to 9.28 Ma unit west of the RCF the Donnell Ranch Volcanics and the younger rocks east of the RCF the Sonoma Volcanics. Current Ar-Ar radiometric dating and subsequent reinterpretations (Wagner, and others, 2002; Randolph-Loar, 2002; McLaughlin, and others, 2005), as well as a recent petrographic analysis of mafic rocks separated by the RCF and/or Tolay Faults (this report) are leading to a better understanding of the volcanic units of the Northern San Francisco Bay Area and are discussed in detail in the following sections.

Burdell Mountain Volcanics

The 11.6-12.2 Ma Burdell Mountain Volcanics crop out west of the Tolay Fault near Novato at Burdell Mountain and in isolated outcrops west of Petaluma. The unit consists of flow-banded porphyritic andesite, minor flow-banded dacite, lahar deposits, and volcanic breccia (Fox and others, 1985a; Ford, et al, 2003; McLaughlin and others, 2005). Field mapping and petrographic analysis (Appendix 1) of a 12.6 Ma unit west of Petaluma indicate that, at that location, the volcanic rocks range from basaltic andesite to dacite with minor interbedded tuff (this study; John Wakabayashi, pers. comm.. 2008). The average age of the Burdell Mountain Volcanics is similar to that of the Quien Sabe Volcanics near Hollister, and the rocks are lithologically similar, thus indicating a significant amount of separation of the units due to dextral displacement on one or more of the faults in the SAFS (Wakabayashi, 1999).

Tolay Volcanics

The 8.5 to 10.6 Ma Tolay Volcanics crop out northeast of the Burdell Mountain Volcanics in scattered outcrops from the southern Sonoma Mountains to locations near Petaluma and Cotati. According to Morse and Bailey (1935), the unit consists of basalt, andesite, dacite, volcanic breccia, and agglomerates. Mafic flows, tuff, volcanc breccia, and rhyolite in the southern Sonoma Mountains were coined the Donnell Ranch Volcanics by Youngman (1989), but are considered now to be Tolay Volcanics (Wakabayashi, 1999; McLaughlin and others, 2005; this study). Petrographic analysis of mafic volcanic rocks from several different locations indicates that, at the sampling locations, the rocks range from andesite to basaltic andesite (Appendix 1). The Tolay Volcanics are similar in age and lithology to the Berkeley Hills Volcanics in the East Bay Region and have been correlated as such by researchers (Youngman, 1989; Wakabayashi, 1999; Randolph-Loar, 2002). This indicates a significant amount of separation of the units due to right-lateral displacement on one or more of the faults in the SAFS.

Sonoma Volcanics

The 2.5 to 8.5 Ma Sonoma Volcanics crop out northeast of the Tolay Volcanics in an expansive area of about 3100 sq km (Mankinen, 1972). The rocks are predominately basalt, basaltic andesite, rhyolite, dacite, and interbedded tuff, but in some localities the volcanic rocks are interbedded with, or are in complex structural relationships with, similar aged sedimentary rocks of the Wilson Grove and Petaluma Formations. Petrographic analysis of mafic volcanic rocks from several different locations indicates that, at the sampling locations, the rocks range from andesite to basaltic andesite (Appendix 1). This unfortunately complicates petrographic differentiation between the Tolay and Sonoma Volcanics in that they are very similar lithologically.

Mullholland Formation

The Mullholland Formation crops out between the Hayward and Calaveras faults in the central East Bay Hills and is conformable with the Roblar Tuff-bearing undifferentiated Contra Costa Group in this area (Graymer, 2000). The Mullholland contains late Miocene vertebrate fossils (Liniecki, 1983), and its base is time-equivalent with the Bald Peak Basalt (Graham et al., 1984; Liniecki-Laporte and Andersen, 1988). Total thickness of the Mullholland is about 1,349 m (Wagner, 1978). Liniecki-Laporte and Andersen (1988) suggested a correlation with the upper Miocene-Pliocene PF of Sonoma County.

Sycamore Formation

East of the Calaveras fault, the upper Miocene to Pliocene (8.5- to 2.5-Ma) Sycamore Formation consists of fluvial conglomerate, sandstone, and mudstone (Issacson, 1990). Older parts of the Sycamore received Franciscan clasts from the Diablo Range to the south, whereas younger parts received Tertiary clasts from an eastern source (Issacson, 1990). The Sycamore overlies the Neroly Formation, contains the ~8.5-Ma Blackhawk Ranch fauna at its base, and contains several tuff horizons dated at ~6 Ma to 3.35 Ma (Issacson, 1990).

Undifferentiated Contra Costa Group

The undifferentiated Contra Costa Group in the southern East Bay Hills (east of San José) may consist partly of Orinda and younger deposits (Coyle, 1984). An undated volcanic flow crops out in this unit at Clayton Road east of San José.

Silver Creek Gravels

The Miocene to Pliocene Silver Creek Gravels southeast of San José overlie 13- to 10-Ma volcanics and contain the 4.71-Ma Huichica Tuff (Nakata et al., 1993; Graymer and DeVito, 1993; Wills, 1995). The formation is composed of fluvial siltstone, sandstone, and Franciscan- and Monterey-derived conglomerate (Wills, 1995). Franciscan-derived gravels are typical below the Huichica Tuff, whereas Monterey-derived gravels are more abundant above the tuff (Wills, 1995). The formation is bounded by the Silver Creek fault to the west and the Calaveras fault to the east.

Huichica Formation

The Huichica Formation north of San Pablo Bay (Fig. 4B) is a local alluvial fan deposit consisting of volcanic and Franciscan gravels derived from the nearby Sonoma Volcanics and Franciscan Complex (Weaver, 1949); the formation also contains the ~4.71 Ma Huichica Tuff (Fox, 1983; Wagner et al., 2005). The Eastside Fault mapped west of the Huichica Formation may bound the formation on that side. This fault may account for some right-lateral displacement of the Huichica Formation, translating the western portions of the formation northward towards Glen Ellen. The fault may juxtapose Petaluma and Huichica formations at depth in eastern Sonoma Valley. The materials of both units are very similar (diatomite, "soft" sands and gravels, intervening mafics and tuffs). The units differ in age. Modeling the materials of these units differently in geophysical would require an exceptional over-active imagination.

Glen Ellen Formation

The Glen Ellen Formation in the Santa Rosa area (Fig. 4B) is a fluvial deposit consisting of volcanic and Franciscan gravels derived from the nearby Sonoma Volcanics and Franciscan Complex. The Glen Ellen Formation overlies Sonoma Volcanics that are as young as 3.1 Ma (McLaughlin et al., 2000).

METHODS

Radiometric Data

Dr. Alan Deino of the Berkeley Geochronology Center generously analyzes tuff samples for me. At the time of this trip, two dates from Upper Petaluma localities east of the Rodgers Creek Fault have been analyzed and ages of ~4.8 Ma and ~5.2 Ma have been furnished. A tuff from Lichau Creek (Figure 4A) in NE Penngrove is currently being analyzed. The age of tuff with respect to the diatomite and Monterey-derived gravels it is interbedded with is absolutely crucial with respect to the other dated units with these lithologies found on either side of the Rodgers Creek Fault.

Paleontology

Charles Powell, II of the U.S.G.S. identified and worked worth some fairly challenging fossils suites from the WGFand PFs. Either I brought him samples with locality or he joined me in collecting. Stratigraphy was noted per sample so as to approach the sampling in a biostratigraphic fashion.

Dawn Peterson of the California Academy of Sciences provided microfossils analysis. Dr. Sam Van Landingham provided microfossil analysis of diatoms from diatomite exposed east of the Rodgers Creek fault and west of the fault in Lichau Creek, northern Penngrove, California.

Mapping and Measuring of Sections

Geologic mapping was conducted in portions of the Valley Ford, Two Rock, Sebastopol, Santa Rosa, Kenwood, Glen Ellen, Cotati, Petaluma, Petaluma River, Richmond, Mare Island, Tomales, and Sears Point USGS 7.5' topographic quadrangles. This new mapping, plus mapping compiled from previous research, was drafted into Plates 1, 2, 3, and 4 of Allen, 2003).

Stratigraphic thickness was measured in the field by Jacob staff and Brunton™ compass where outcrops were sufficient. In areas of sparse outcrop, stratigraphic thickness was calculated using strike and dip, and elevation differences.

Sandstone Petrography

This project did not entail a comprehensive sampling of sandstone for petrographic analysis. I collected 15 sandstone samples from areas where changes in lithology might be encountered. Thus, the results and interpretations reported here are not based on a thorough petrographic analysis of any of these formations. Petrographic data are given in Appendix 1 of Allen, 2003.

Sandstone samples (locations shown on Plates 1, 2, 3, and 4 of Allen, 2003) were transported back to the lab, washed, sawed by hack-saw, impregnated with epoxy, dried slowly in an oven, polished using 600 and 400 grit until smooth, covered in epoxy with a glass slide, and cut into thin sections for microscopic analysis. The classification scheme of Folk (1974) was used to describe these rocks.

Conglomerate Clasts

Conglomerate clasts were studied from the eastern outcrops of the WGF and the PF (Appendix B; Plates 2, 3, and 4 in Allen, 2003). At each sample locality, at least 300 clasts were collected from an area about 1 m^2. The samples were transported to the laboratory where they were washed, sieved, and counted using a binocular microscope. Some clasts were thin-sectioned for foraminiferal studies by paleontologist Dr. Kenneth Finger, whose report is included as Appendix C of Allen (2003).

Clast imbrication was observed at many conglomerate sample locations, and paleocurrent measurements were recorded at 13 stations (Appendix D of Allen, 2003). Paleocurrent station numbers correspond to the clast count localities. The imbrication direction of each clast was determined relative to the strike of the bedding. The beds were mentally restored to the horizontal while holding the angle between the imbrication and the strike constant. A compass was then placed parallel to the azimuth of the restored imbrication.

TERTIARY STRATA OF THE NORTHERN SAN FRANCISCO BAY AREA

Key upper Cenozoic units analyzed in this study are the WGF, PF, and Garrity Member of the Contra Costa Group. The Garrity Member was determined to be a portion of the PF-Contra Costa Group which occurs now as an isolated fault block between the Hayward and Pinole-related faults. The Garrity will not be addressed in detail in the fieldtrip guidebook, but stratigraphic, mapping and lithologic data is in Allen (2003). This study modifies the stratigraphic nomenclature of these units chiefly on the basis of variations in the composition of conglomerate clasts.

The upper Miocene-upper Pliocene WGF consists chiefly of marine sandstone. Conglomerate is interbedded with the sandstone along the eastern margin of the formation (Powell and Allen, 2001). This interbedded zone was called the Fresh Water Merced by Johnson (1934), the "sand and gravel of Cotati" by Fox (1983), and the "Cotati Member" of the WGF by Davies (1986). Fox (1983) reported that this interbedded sequence unconformably overlies the WGFand PFs, whereas Davies (1986) correlated this sequence with the uppermost PF.

The upper Miocene-Pliocene PF (Dickerson, 1922; Youngman, 1989) was divided by Morse and Bailey (1935) into the Lower PF, consisting predominantly of mudstone, and the Upper PF, consisting of sandstone and conglomerate. Morse and Bailey (1935) did not further subdivide the Upper PF, but they did note that the main source of the clasts in the lower portion of the section was the Franciscan Complex, and the main source of the clasts in the upper part of the section was the Monterey.

In this study, I modify the stratigraphic nomenclature of Morse and Bailey (1935) as follows. I follow the usage of later workers (e.g., Weaver, 1949; Travis, 1952; Youngman, 1989) in grouping Morse and Bailey's Lower and Upper PFs into the PF. I consider Morse and Bailey's "Lower PF" to be an informal lower member of the PF. I assign rocks of Morse and Bailey's "Upper PF" to informal middle and upper members of the PF based on the differences in composition of conglomerate clasts that Morse and Bailey noted and that I quantified in this study. Throughout this paper, I refer to these new informal subdivisions as the lower Petaluma, middle Petaluma, and upper Petaluma.

In this study, I assign the interbedded marine sandstone of the eastern WGF and conglomerate of the western PF to an informal map unit referred to as the "Interbedded WGFand PFs". The western limit of this zone is placed where conglomerate disappears. The eastern limit of this unit was placed where marine sandstone disappears.

Outcrops of late Tertiary strata at Point Pinole and in the Pinole area (Plate 4 in Allen, 2003) were first mapped as Orinda Formation by Weaver (1949), following the work of Lawson (1914). This unit differs from the "type" Orinda in the Berkeley Hills in fossil age and lithology (Wagner, 1978). Savage (1951) introduced the term "Contra Costa Group" to alleviate the problem of broadly using the name Orinda Formation. Wagner (1978) assigned these rocks to the Garrity Member of the Contra Costa Group because clast compositions differ from those in other parts of the Contra Costa Group and Orinda Formation. The Garrity Member contains the 6.25 Ma Roblar Tuff in mid section, at the base of the Pliocene section where clast provenance changes to Monterey-derived materials. Borchardt et al. (1988) described volcanic clasts as derived from the Berkeley Hills and noted the abundance of Monterey clasts which suggests that the Garrity Member of the Contra is younger than the Berkeley Hills Volcanics and underlying Orinda Formation.

In this study, the stratigraphic position of conglomerate clasts of different composition was used to informally subdivide the late Cenozoic units, as described in detail in later sections. The most diagnostic clast types are Franciscan Complex graywacke; white and gray, laminated, foraminiferal, Monterey-derived chert; and Tertiary volcanic rocks.

Distinguishing characteristics used for clast identifications, and photographs of diagnostic clasts, are presented in Appendix B in Allen (2003). The results of clast counts are plotted on a ternary diagram to graphically distinguish the conglomerate units (Fig. 6). Sample locations are shown on the geologic map plates, and clast descriptions and clast counts are tabulated in Appendix B of Allen (2003).

DESCRIPTION OF SEDIMENTARY UNITS

STOP 1

Late Cenozoic units on which this study focuses are the WGF, the PF, an informal map unit called "Interbedded WGFand PFs," and the Garrity Member of the Contra Costa Group.

Wilson Grove Formation

The WGF consists predominantly of fine- to medium-grained marine sandstone, but exhibits significant lateral (west to east) differences. The east-dipping formation includes a basal conglomerate in the west that is overlain by sandstone. Along its eastern margin, the WGFsandstone is interbedded with Petaluma conglomerate from its base to its top; this interbedded zone will be discussed in a section following the PF.

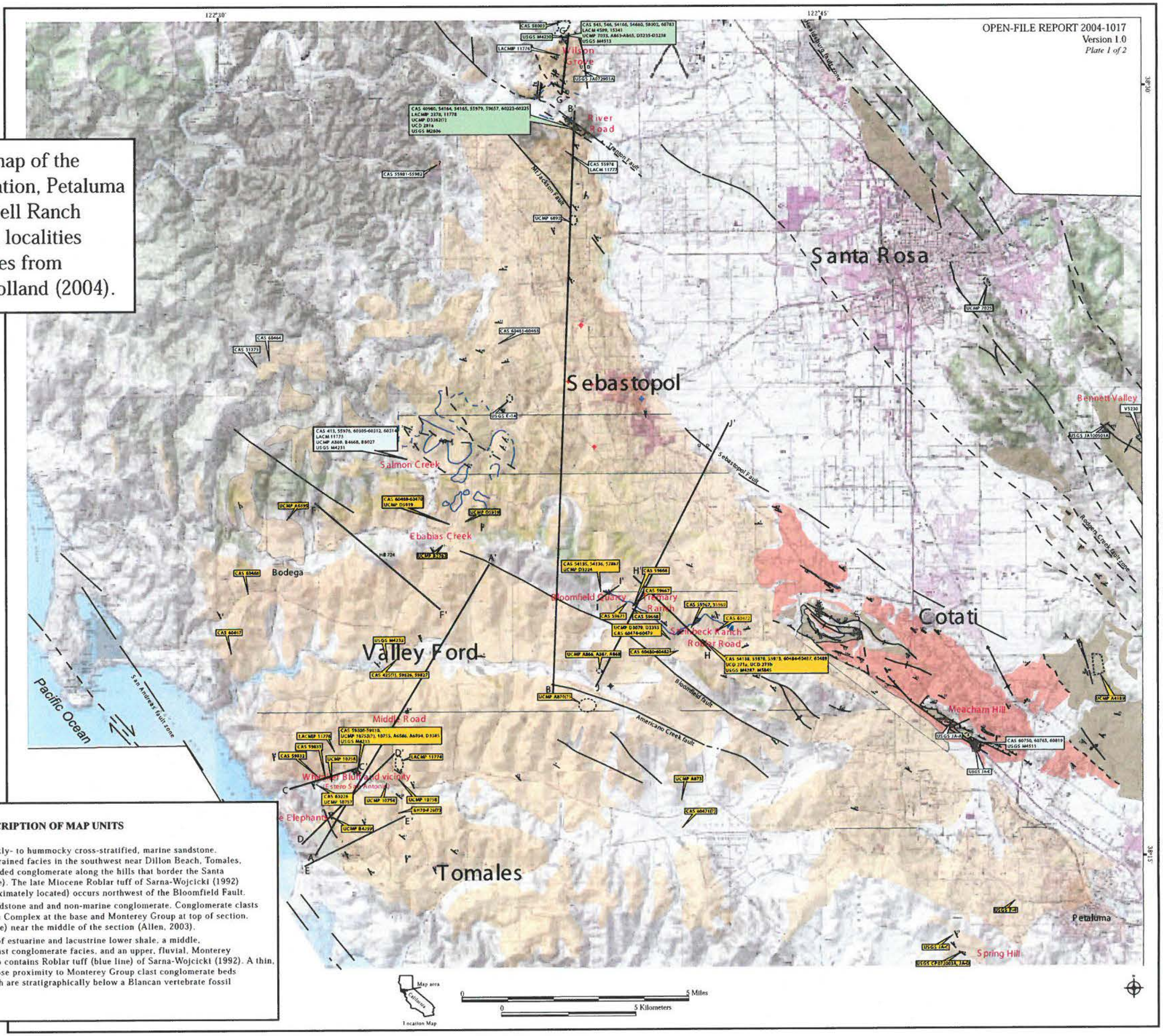
Basal Contact and Thickness

The WGF generally overlies rocks of the Franciscan Complex along an angular unconformity, but it disconformably overlies Tertiary volcanic rocks at Spring Hill and adjacent to the Dunham fault (Travis, 1950; Fig. 1; Plates 1, 2). Fox et al. (1985) reported a K-Ar age of 11.76 ± 0.44 Ma for the volcanic rocks at Spring Hill. Because clasts of the volcanic rock are present in the WGF at Spring Hill, an erosional disconformable contact is indicated. Volcanics at Meacham Hill, Stony Point Rock Quarry, along the Dunham Fault and immediately east of Penngrove are 8 to 9 Ma in age and are referred to herein as Donnell Ranch Volcanics. Age data from Wagner et. al (2005); Allen and Repenning (2005) and Van Landingham and Allen (2007).

Thickness varies throughout the WGF due to the irregular basin it filled (Johnson, 1934). The restored minimum thickness of the WGF is approximately 2,110 m in the deepest parts of the basin to the west and 610 m to 1,219 m in shallower parts of the basin to the east (Fig. 7) (Powell et al., 2004).

A maximum thickness of about 820 m (2,700 ft) has been reported in the literature for the WGF (Bedrossian, 1974), and other reported thickness are less (Osmont, 1905; Dickerson, 1922; Johnson, 1934; Travis, 1952; Bedrossian, 1970; Fox, 1983). The WGF shows a small but pervasive dip to the northeast. The Bloomfield fault is the only major stratigraphic interruption. Therefore, we assumed a nearly continuous section, from southwest to northeast, and calculated a thickness for the WGF on both sides of the Bloomfield fault. We determined a stratigraphic thickness of at least 1,500 m in the block south of the Bloomfield fault and about 295 m north of Bloomfield fault (Figure 8). This results in a maximum original

Figure 7: Geologic map of the Wilson Grove Formation, Petaluma Formation and Donnell Ranch Volcanics with fossil localities and cross-section lines from Powell, Allen and Holland (2004).



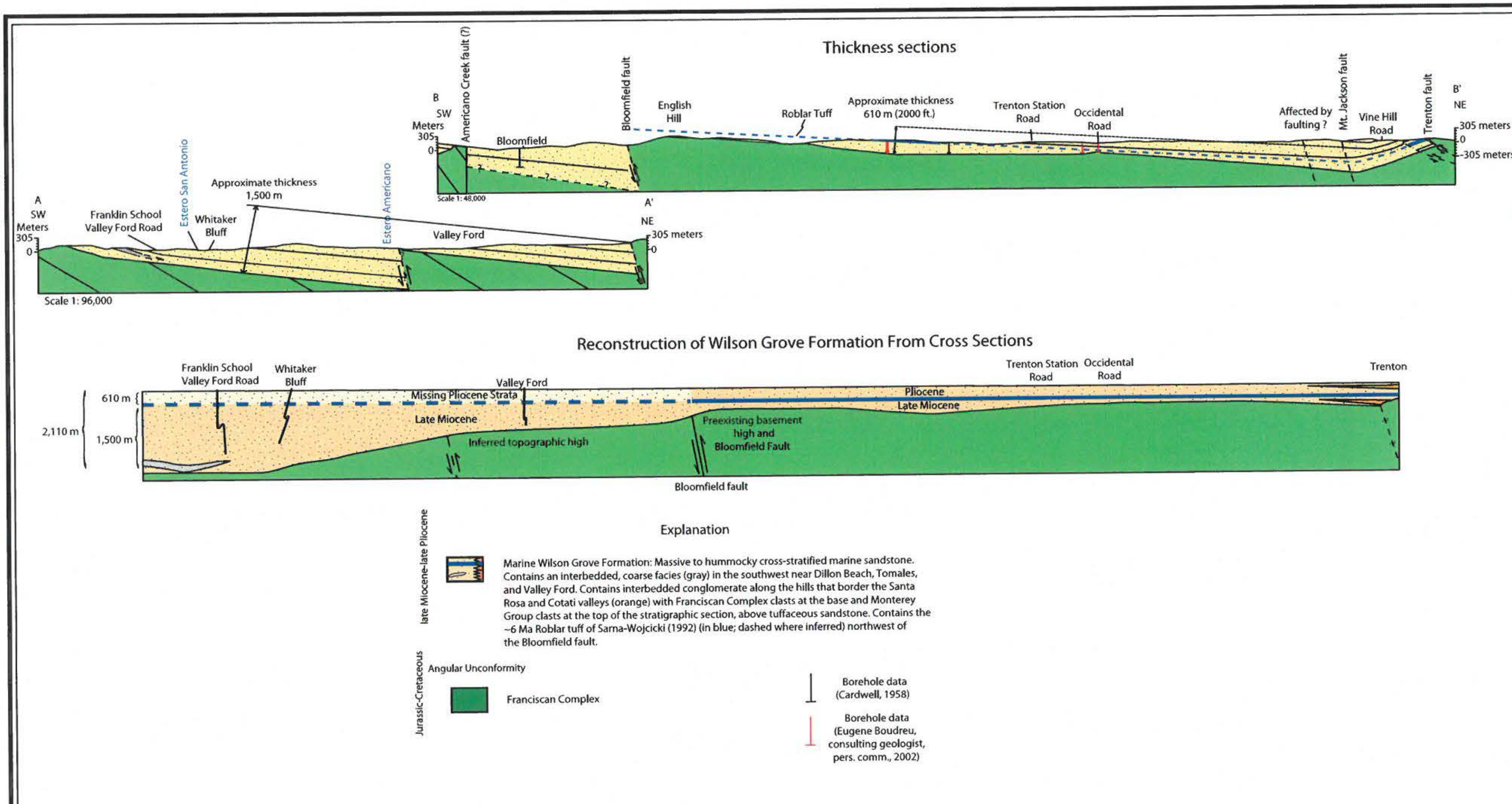


Figure 8: Thickness of Wilson Grove Formation from cross-section analysis (Powell et al., 2004). See Powell et al. (2004) & Figure 7 for locations of cross-section lines.

stratigraphic thickness of about 1,795 m for the WGF (Figure 7), although at any site the preserved thickness will be considerably less. The Roblar tuff of Sarna-Wojcicki (1992), the only significant marker bed in the formation, occurs near the base of the WGF in the block northeast of the Bloomfield fault and is absent southwest of the fault (Travis, 1952; Blake and others, 2002; Allen, 2003). Therefore, we suggest that the Roblar tuff of Sarna-Wojcicki (1992) and overlying section were originally on the block southwest of the Bloomfield fault, but have been removed by differential uplift and erosion. This shows the WGF southwest of the Bloomfield fault older than 6.25 Ma, the age of the Roblar tuff of Sarna- Wojcicki (1992), and most of the section northeast of the Bloomfield fault younger than 6.25 Ma.

These thickness calculations assume the basement close to the surface along Estero Americano and near Valley Ford are topographic highs, and the WGF was deposited around and eventually, over these basement islands (Figure 9, cross section A-A' and F-F'). However, if uplift in this area is the result of faulting and the WGF is repeated here, then a restored thickness of only about 880 m (2,900 ft) is present south of the Bloomfield fault. We can find no evidence for faulting or that the WGF is repeated in the southern block, so we favor the 1,500 m thickness for the formation in this area.

Basement structure

The top of the Franciscan Complex on which the WGF was deposited has been interpreted both as a highly irregular contact by Dickerson (1922) and as a peneplain or plateau by Johnson (1934) and Fox (1983) (Figure 10). We suggest that the surface is a combination of both. In many areas the surface is apparently flat lying, in some areas substantial relief in the basement is evident. Dickerson (1922) reported relief of 120 to 150 m (400 to 500 ft) on the top of the underlying Franciscan Complex basement, although our thickness and structural sections suggest a much greater relief (i.e., up to 670 m near Estero Americano; Figures 8 and 9, cross sections A-A' and F-F'). Topographic high areas (i.e., Hill 724 east of Bodega) cannot be explained by known faults and folds, so we interpret the basement relief as pre-existing highs which have since been exhumed by erosion of the overlying WGF Figure 9, cross section F-F ; Johnson, 1934).

Structurally, outcrops of the WGF are cut by a series of northwest-trending reverse faults of relatively small displacement, including the Bloomfield fault (Travis, 1952; Hitchcock and Kelson, 1998, Plate 1). These faults strike approximately N 60 ° W, dip to the east, and typically the northeast block is up-thrown (Travis, 1952; Hitchcock and Kelson, 1998). Hitchcock and Kelson (1998) suggest that the Bloomfield fault has a minimum of 183 m of vertical offset based on restoration of throw using depth to Franciscan Complex basement rocks across the fault. This determination was based on cross section data that depicts a small outcrop of Wilson Grove Formation capping English Hill, north of the Bloomfield fault, and assumes a thin, flat-lying veneer of WGF south of the fault. Unfortunately, the WGF outcrops on English Hill do not represent the lowermost part of the formation in that area. Outcrops on English Hill that occur along strike are found at a lower elevations than the base of the formation on English Hill. This indicates that the base of the WGF is lower than their model shows and supports our contention that English Hill was a pre-existing high, or island , similar to that of Hill 724 east of Bodega (Figure 8).

Using our model, there is at least 1,500 m of WGF south of the Bloomfield fault with a consistent 6 degree dip to the northeast (Travis 1952) (Figure 11, cross section K-K). Hitchcock and Kelson (1998) did not evaluate the implications that the 6 degree dip has on basement restoration and overall thickness of the formation. Furthermore, the WGF is at least 300 m (1,000 ft) thick immediately south of English Hill based on borehole data, along their cross section line (Cardwell, 1958), while Hitchcock and Kelson (1998) estimated the WGF was 75 m (250 ft) thick in this area. By taking into account dip, varying depths to basement, and stratigraphy within the WGF, we suggest the section south of the Bloomfield fault cannot be duplicated by a basement-to-basement throw restoration across the fault.

Physical Stratigraphy

The lithology of the WGFchanges from the base of the section, in the west near Tomales, to the top of the section, in the east near Steinbeck Ranch (Fig. 1).

The base of the WGF is especially well-exposed at Estero San Antonio (Fig. 12). A 5-m-thick, clast-supported basal conglomerate consists of poorly sorted, angular clasts of

F-F' Hill 724 (between Ebabias Creek and Bodega)

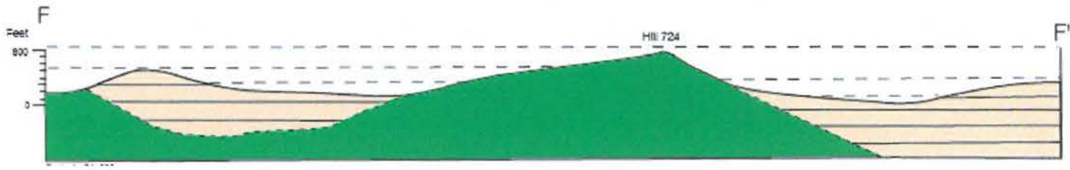


Figure 9: Cross sectional analysis from Powell, Allen and Holland, 2004).

Figure 10: Peneplain of Johnson (1934), south of Wilson Grove Formation.

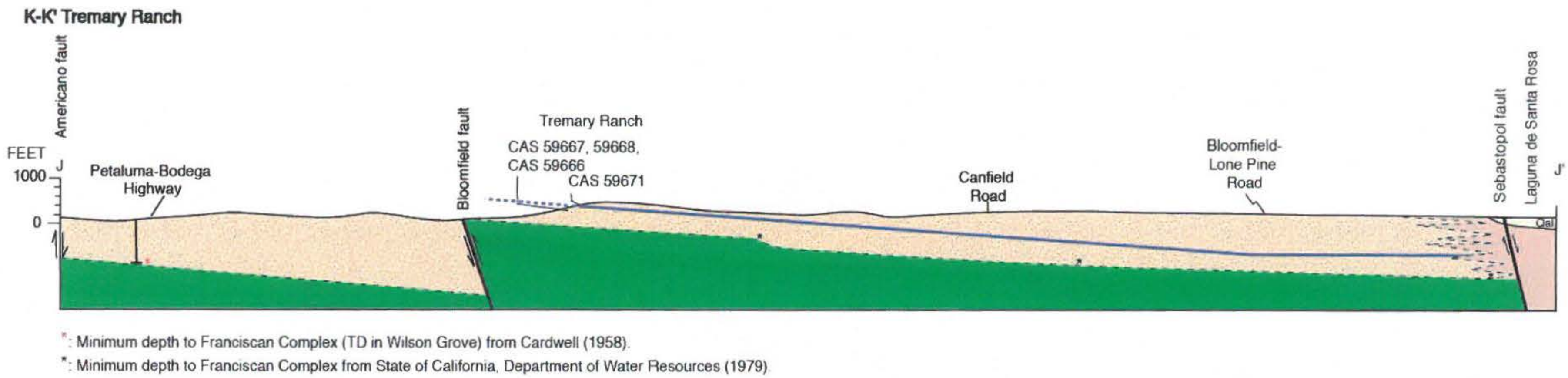
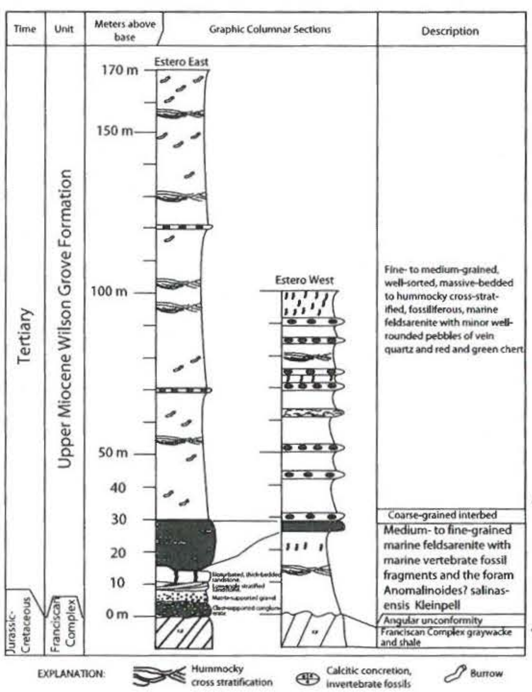


Figure 11: Cross section K-K' from Powell, Allen and Holland (2004).



Foraminifera from coarse, basal unit:
Buccella frigida group (transitional and inner shelf),
Neoconorbina sp. (inner shelf),
Cibicides sp. (shelf-bathyal; 0-2,000 m),
Cibicidina sp. (shelf, bathyal?), and
Cibicidoides sp. (shelf-bathyal).

Figure 12. Measured sections of lowermost Wilson Grove west of Valley Ford-Franklin School Road along Estero San Antonio.

Composite faunal list from outcrops at and near Whittaker Bluff, Sonoma County from Powell, Allen and Holland (2004).

Mollusca
Bivalvia
Acila? sp.
Clinocardium sp.
Lituyapecten turneri (Arnold)
Mactridae, indeterminate
Modiolus sp.
Mytilidae?, indeterminate
Panomya sp.
Patinopecten? sp. ?
Pectinidae, indeterminate
Solen sp.
Teredo sp.
Tresus sp., cf. T. pajaroanus (Conrad)
Indeterminate bivalve
Gastropoda
Crepidula princeps (Conrad)
Fusitriton? sp.
Lirabuccinum?
Nassarius? sp.
Naticidae, indeterminate
Neogastropoda, indeterminate
Scaphopoda
Dentalium? sp.

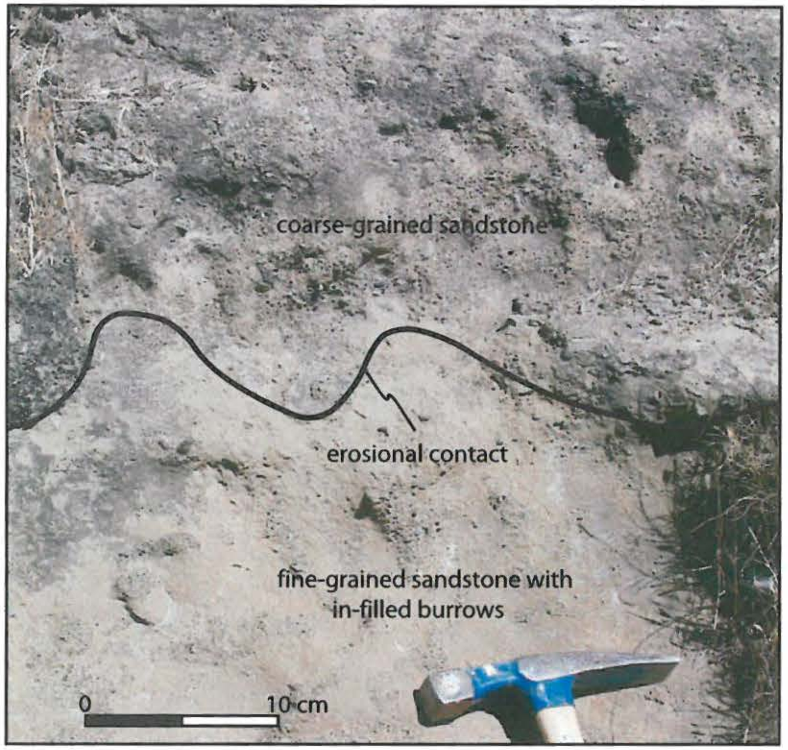
Scaphopoda
Dentalium? sp. Arthropoda
Crustacea
Indeterminate crab parts (two taxa)
Echinodermata
Echinoidea
Brisaster? sp.
Indeterminate echinoid

A.

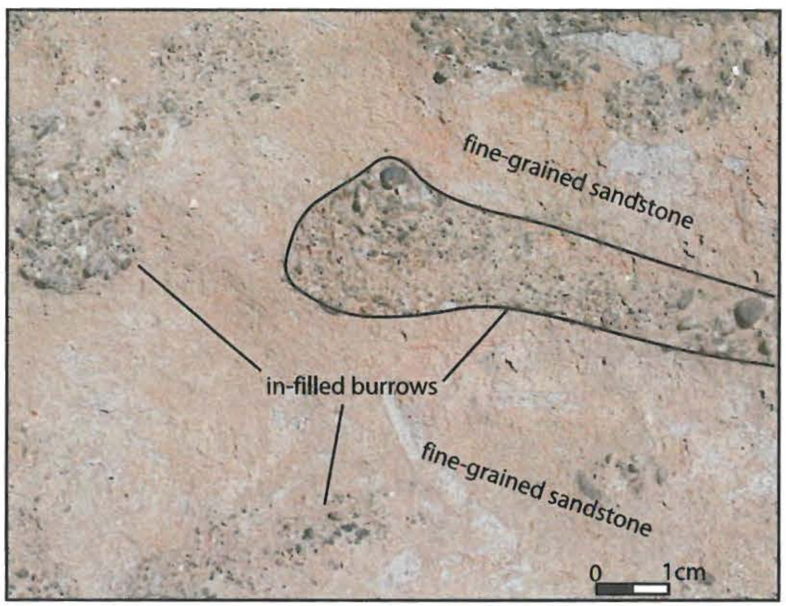
B.

Figure 13. Photographs of basal conglomerate in the Wilson Grove Formation near Estero San Antonio. A. Basal conglomerate in angular unconformity atop Franciscan Complex. B. Large clast in poorly sorted basal conglomerate.

Figure 14. Bold outcrops of coarse-grained sandstone near the base of the Wilson Grove Formation. Photograph taken east of Dillon Beach-Franklin School road. View is northwest.



A.



B.

Figure 15.
A. Erosional contact between coarse-grained and fine-grained sandstone in the WilsonGrove Formation. Burrows in lower, fine-grained sandstone are in filled by overlying coarse-grained s andstone. B. In-filled burrows in lower fine-grained sandstone. One burrow is outlined.

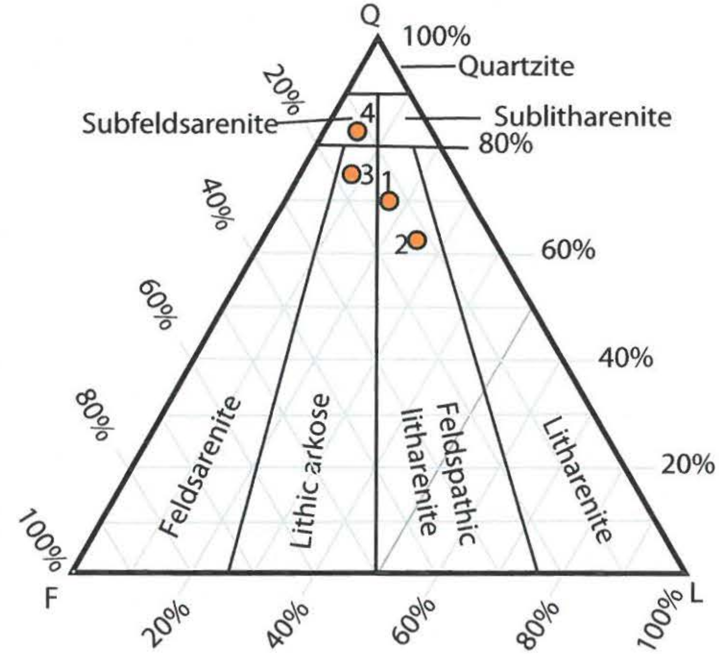


Figure 16. Composition of sandstones from the Wilson Grove Formation. Sample numbers are on Plates 1 and 2 in Allen (2003).

Wilson Grove Formation Sandstone Petrography

Raw Data

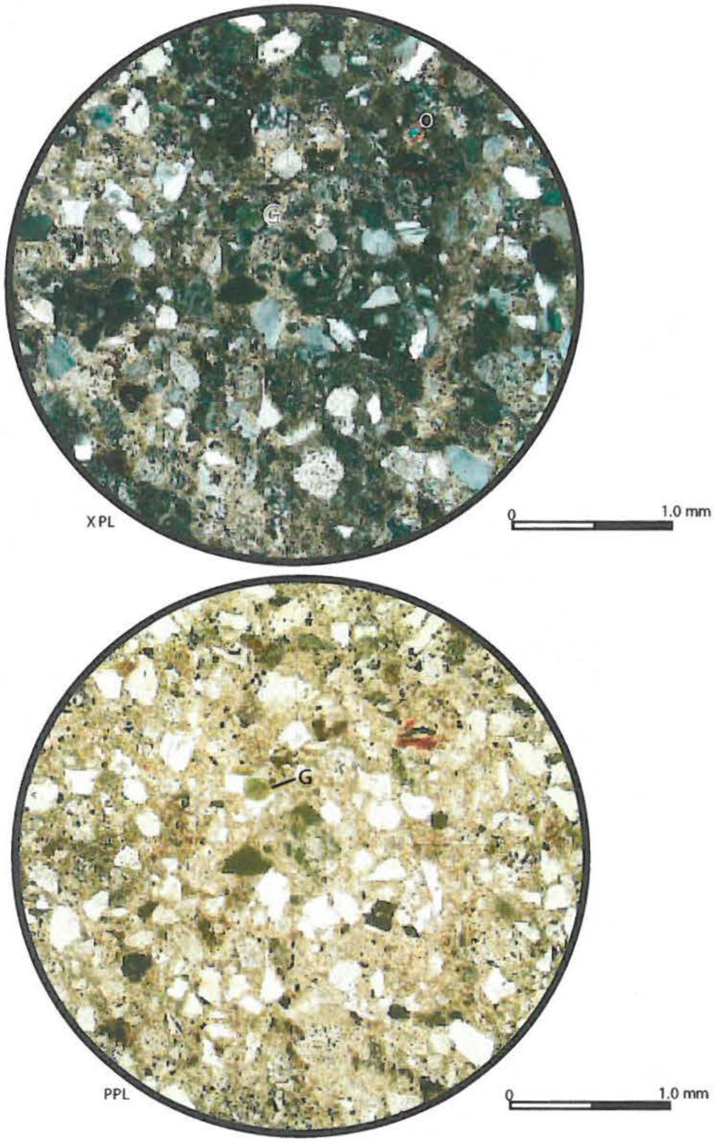
Sample #	Quartz Non-undulatory	Quartz Undulatory	Quartz Polycrystalline few	Quartz Polycrystalline many	Feldspar	Volcanic Lithic	Sedimentary Lithic	Metamorph Lithic	Matrix-Cement	Total
1	87	27	18	24	30	9	3	24	78	300
2	53	35	21	33	37	10	5	31	75	300
3	83	39	35	19	42	3	1	14	64	300
4	96	66	27	30	30	3	0	12	36	300

Normalized without cement or matrix

Sample #	Q	F	L	Total
1	156	30	36	222
2	142	37	46	225
3	176	42	18	236
4	219	30	15	264

Precent Q,F,L

Sample #	Q	F	L	Q	F	L	Total
1	0.7027027	0.13514	0.16216216	70%	14%	16%	100%
2	0.6311111	0.16444	0.20444444	63%	16%	21%	100%
3	0.7457627	0.17797	0.07627119	74%	18%	8%	100%
4	0.8295455	0.11364	0.05681818	83%	11%	6%	100%



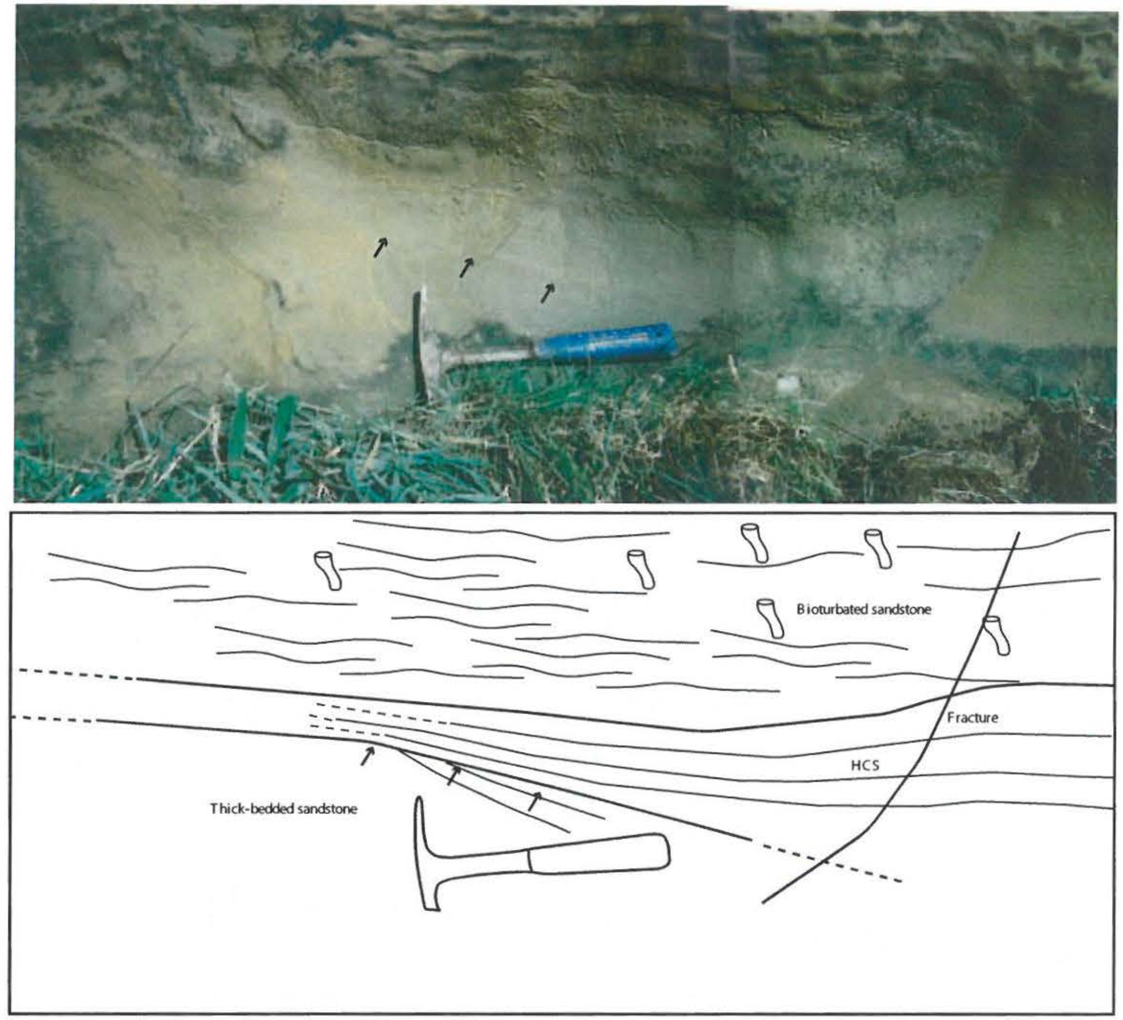


Figure 18. Photograph and sketch of hummocky cross-stratified (HCS) sandstone in the Wilson Grove Formation. Arrows show base of hummock.

Figure 17. Photomicrographs of Wilson Grove Formation sandstone. Grains are predominantly mono-crystalline quartz, polycrystalline quartz, plagioclase, chert and minor volcanic and metamorphic rock fragments. Cement is calcite. G: Glauconite; O: Olivine

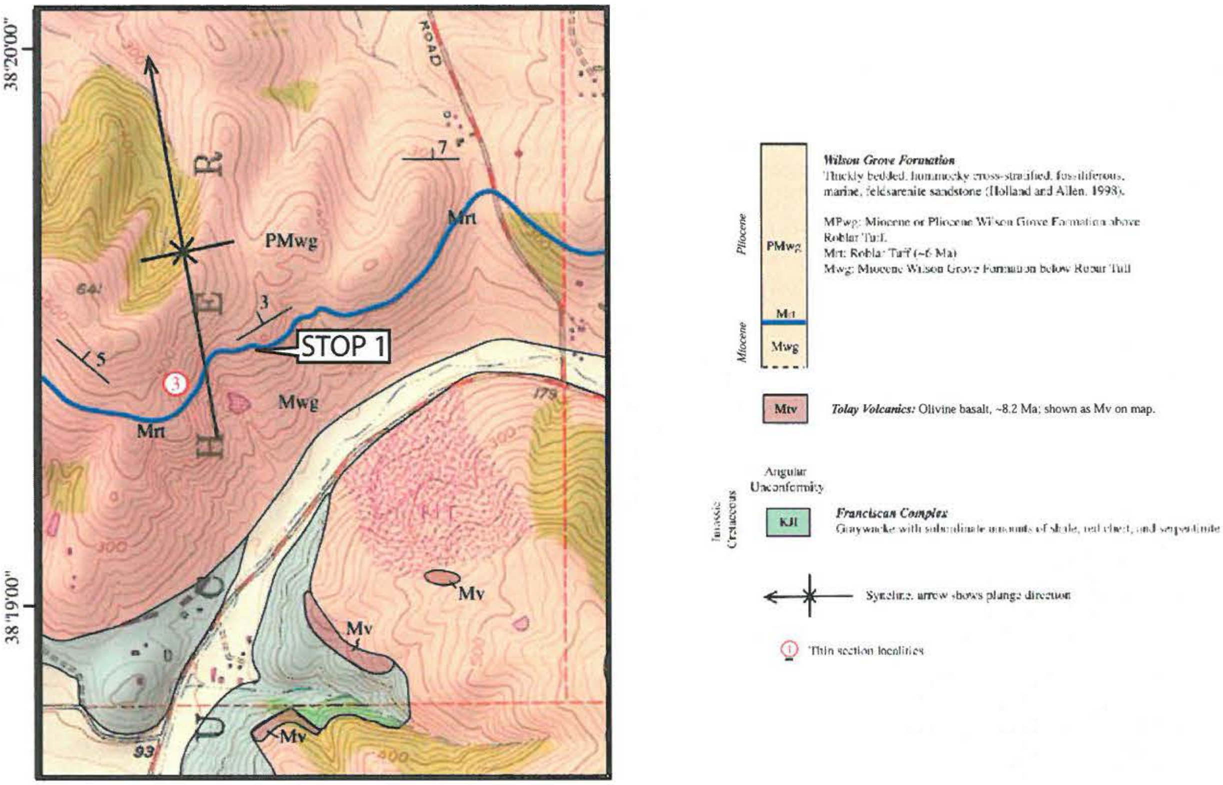


Figure 19. Geologic Map of Stop 1. Numbered sample corresponds to thin section in Figure 17.

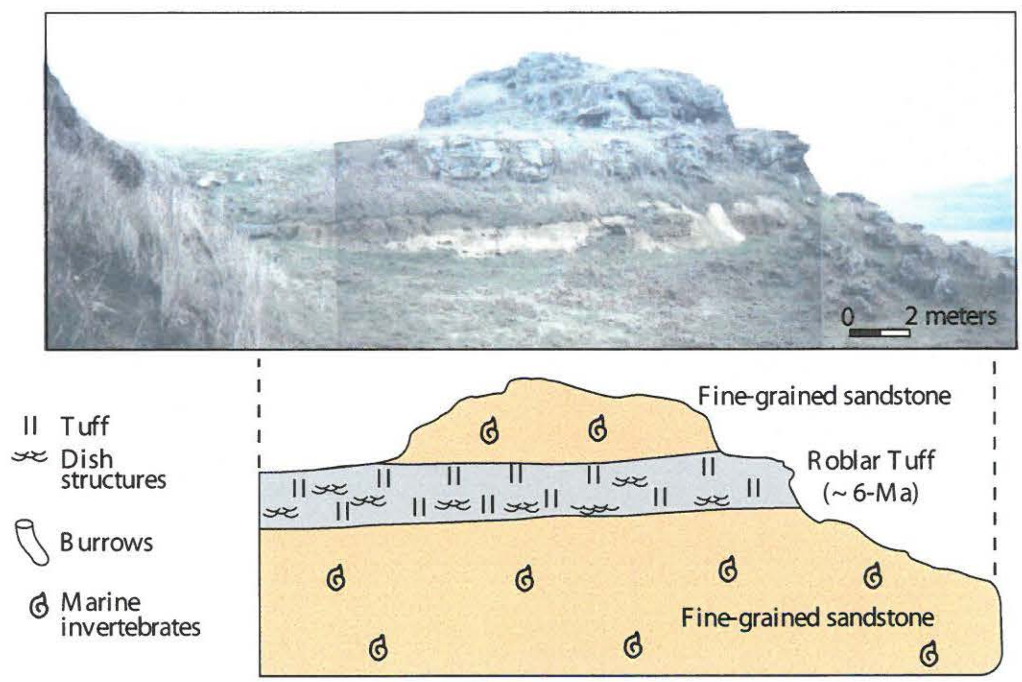


Figure 20. Photograph and sketch of Roblar Tuff outcrop at Steinbeck Ranch.

graywacke, shale, and greenstone that are 5 to 50 cm in diameter encased in a carbonate-cemented, coarse-grained sandstone matrix that contains marine foraminifera, bryozoans, and cetacean bones (Fig. 13). The basal conglomerate fines upward into a 3-m-thick bed of matrix-supported, pebbly sandstone followed by a 3-m-thick bed of thick-bedded, low-angle-stratified, fine- to medium-grained sandstone. A 5-m-thick, thick-bedded, bioturbated, fine-grained sandstone unit overlies the low-angle-stratified sediment. The top of this unit is locally channelized.

A resistant, 15- to 17-m-thick, carbonate-cemented, coarse-grained sandstone unit overlies the bioturbated unit at Estero San Antonio (Fig. 14) and unconformably overlies the Franciscan Complex elsewhere. Burrows in the underlying sandstone are in-filled by overlying coarse-grained sandstone (Fig. 15). The coarse-grained sandstone is locally thick-bedded to vaguely planar-cross-stratified and contains minor plane-parallel sets of cross strata. This unit is a litharenite (Folk, 1970). The sand grains are about 2 mm in diameter and are composed of Franciscan Complex metamorphic lithic fragments and minor Tertiary volcanic (red cinder) lithic fragments. The sandstone contains uncommon 20- to 30-cm-thick pebble layers. Imbricated pebbles show transport to the northwest.

The remainder of the section (2,080 m) above this basal sequence consists of thick-bedded to hummocky cross-stratified, marine subfeldsarenite and lithic arkose (Folk, 1970; Appendix 1; Plate 1 both in Allen, 2003).

The central outcrops of the WGF between the towns of Bloomfield, Bodega, and Sebastopol and west of the Santa Rosa Valley (Fig. 4A & 4B) consist of thick-bedded to hummocky cross-stratified (Harms et al., 1975), fine- to medium-grained, subangular feldsarenite (Holland and Allen, 1998), feldspathic litharenite, and lithic arkose (Figs. 16 and 17). The thick-bedded sandstone contains numerous burrows.

At Steinbeck Ranch, the ~ 6-Ma Roblar Tuff (Sarna-Wojcicki, 1992) crops out approximately 105 m above the basal contact with the Franciscan Complex (Holland and Allen, 1998; Figs. 18, 19 and 20). The Roblar is absent from the section south of the Bloomfield fault, apparently due to uplift and erosion (Holland and Allen, 1998; Powell et al., 2003). The tuff contains dish structures. The Roblar is overlain by fine- to medium- grained sandstone that contains fossiliferous lenses that are approximately 15 m long and 25 cm thick. Invertebrate fossils in these lenses consist of disarticulated, broken pelecypods and gastropods that are typically packed tightly.

Age

The WGFranges in age from late Miocene to late Pliocene (Powell and Allen, 2001). Newly collected fossils are late Miocene at the base of the formation and late Pliocene at the top (Powell et al., 2004). The ~6-Ma Roblar Tuff has been identified in this formation (Sarna-Wojcicki, 1992).

Sand dollars (*Scutellaster oregonensis*) from the base of the WGF at Spring Hill (Fig. 4A) are late Miocene (Richard Mooi, California Academy of Sciences, personal communication, 2003; Charles Powell, II, U.S. Geological Survey, personal communication, 2003).

A bird humerus was collected from a fossiliferous bed west of the Meacham Hill fault that has abundant Pliocene marine pelecypods and gastropods. This humerus may be middle Pliocene in age (Thomas Stidman, University of California Museum of Paleontology, personal communication, 2002). Other fossils from this locality indicate a Pliocene age for the WGF(Bedrossian, 1971).

Late Pliocene marine fossils occur at the top of the WGFnear (Powell and Allen, 2001; Powell et al., 2004).

Petaluma Formation

STOP 2: Stony Point Rock Quarry

The PF coarsens upward from claystone and siltstone at its base to sandstone and conglomerate higher in the section. The formation crops out between Petaluma Valley and western Sonoma Valley (east of the Rodgers Creek and Bennett Valley faults), west of Glen Ellen, within Bennett Valley, and north of Santa Rosa (Fig. 4B). The formation is covered by Quaternary alluvium in the Santa Rosa-Cotati plain and is exposed from the Cotati area, to Bennett Valley, outcrops within Taylor and Sonoma mountains, south to Sears Point (Cardwell, 1958). The Petaluma is highly folded and faulted on either side of the Rodgers Creek fault, especially in the Sears Point area.

In this report, I split the Upper Petaluma of Morse and Bailey (1935) into informal "middle" and "upper" parts (Fig. 21). The basis of this revision is the composition of conglomerate clasts, with Franciscan-derived clasts predominant in the middle PF and

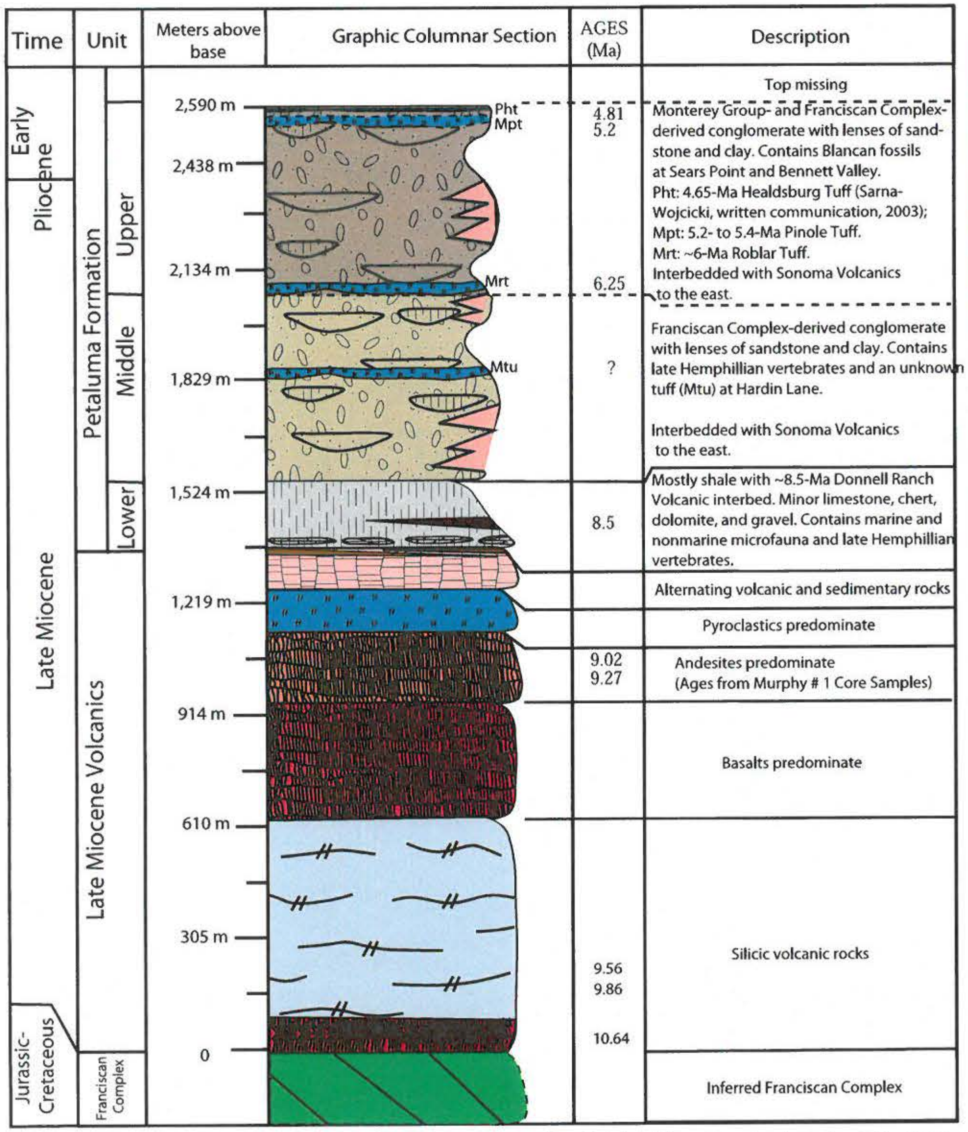


Figure 21. Stratigraphic section of Petaluma Formation and underlying Miocene volcanic rocks at the Petaluma Oil Field Area. Thickness from Morse and Bailey(1935) with lithology data added from this study. Volcanic rocks below Petaluma Formation from Morse and Bailey (1935); ages from Youngman (1989). Lithologic symbols from Compton (1985).

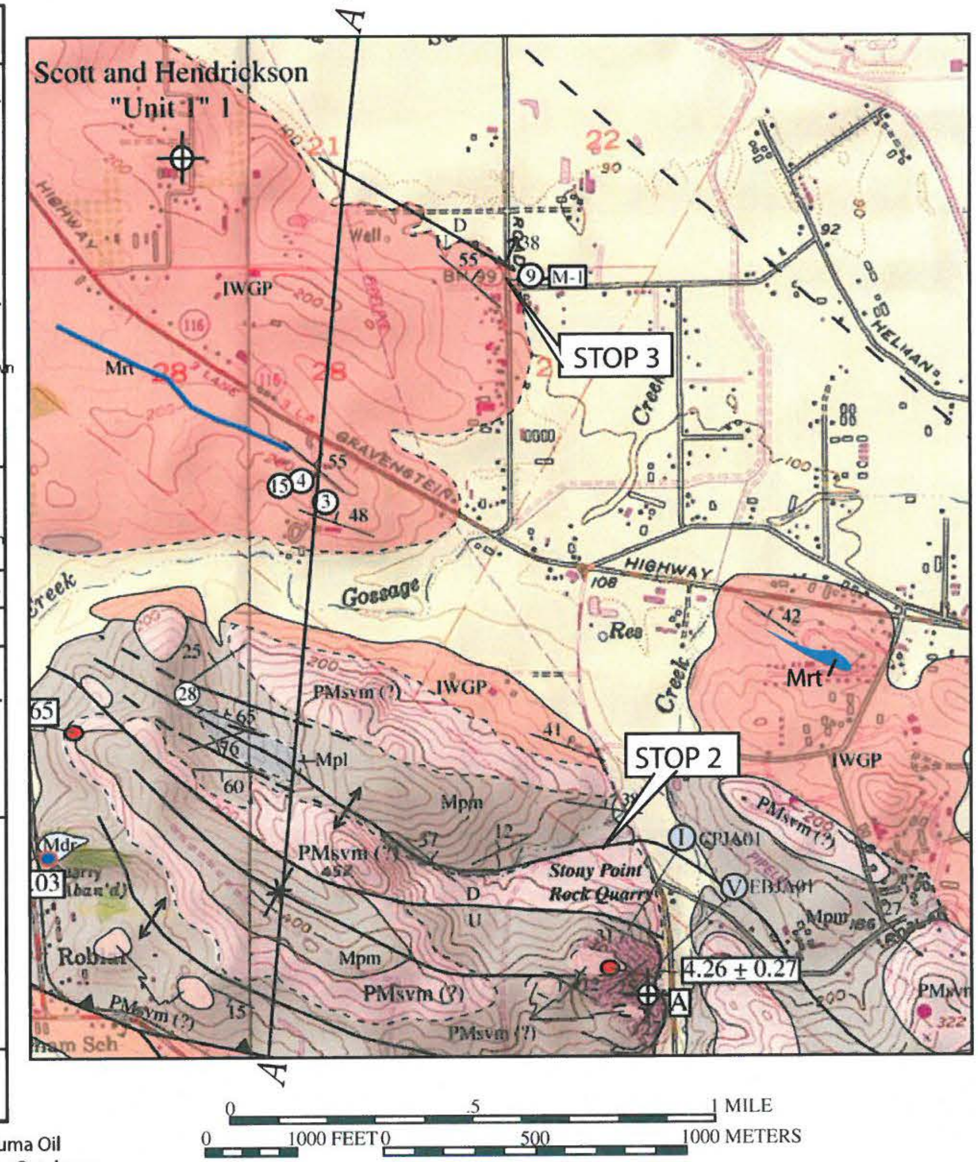


Figure 22. Geologic map of stops 2 and 3, Petaluma Formation and Wilson Grove Formation transition zone from fluvial to marine.

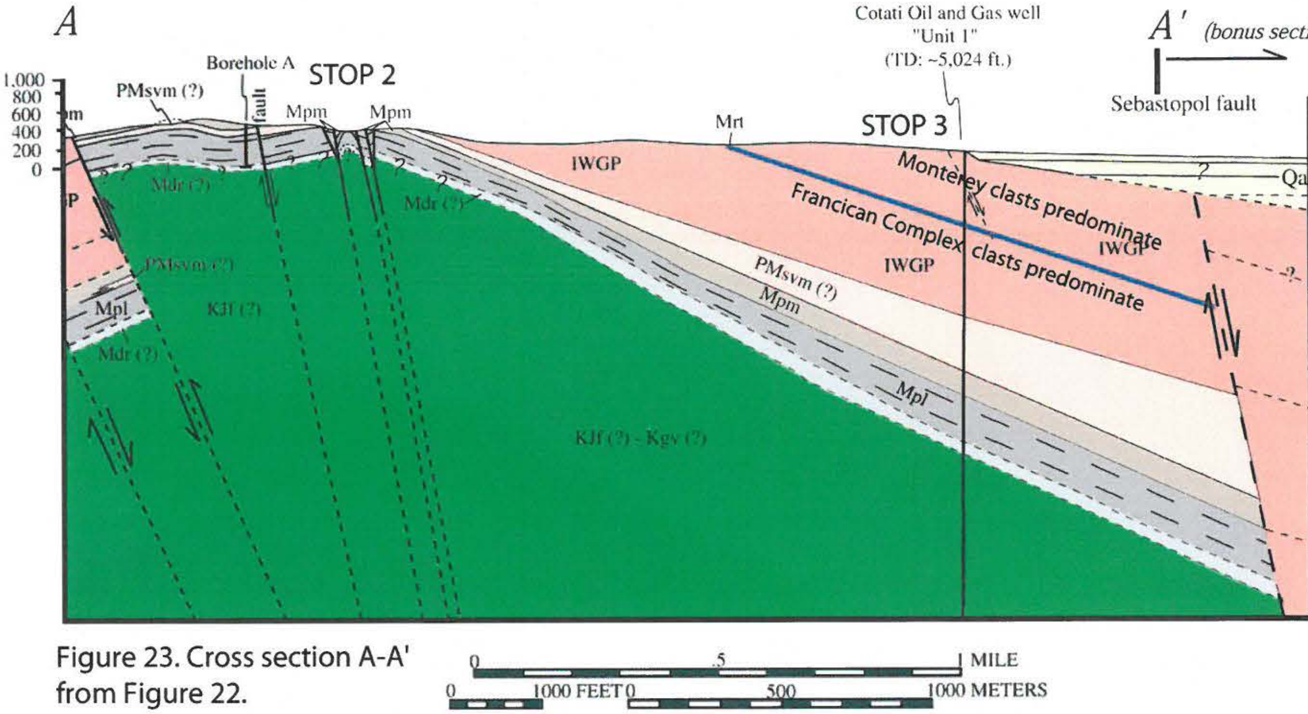


Figure 23. Cross section A-A' from Figure 22.

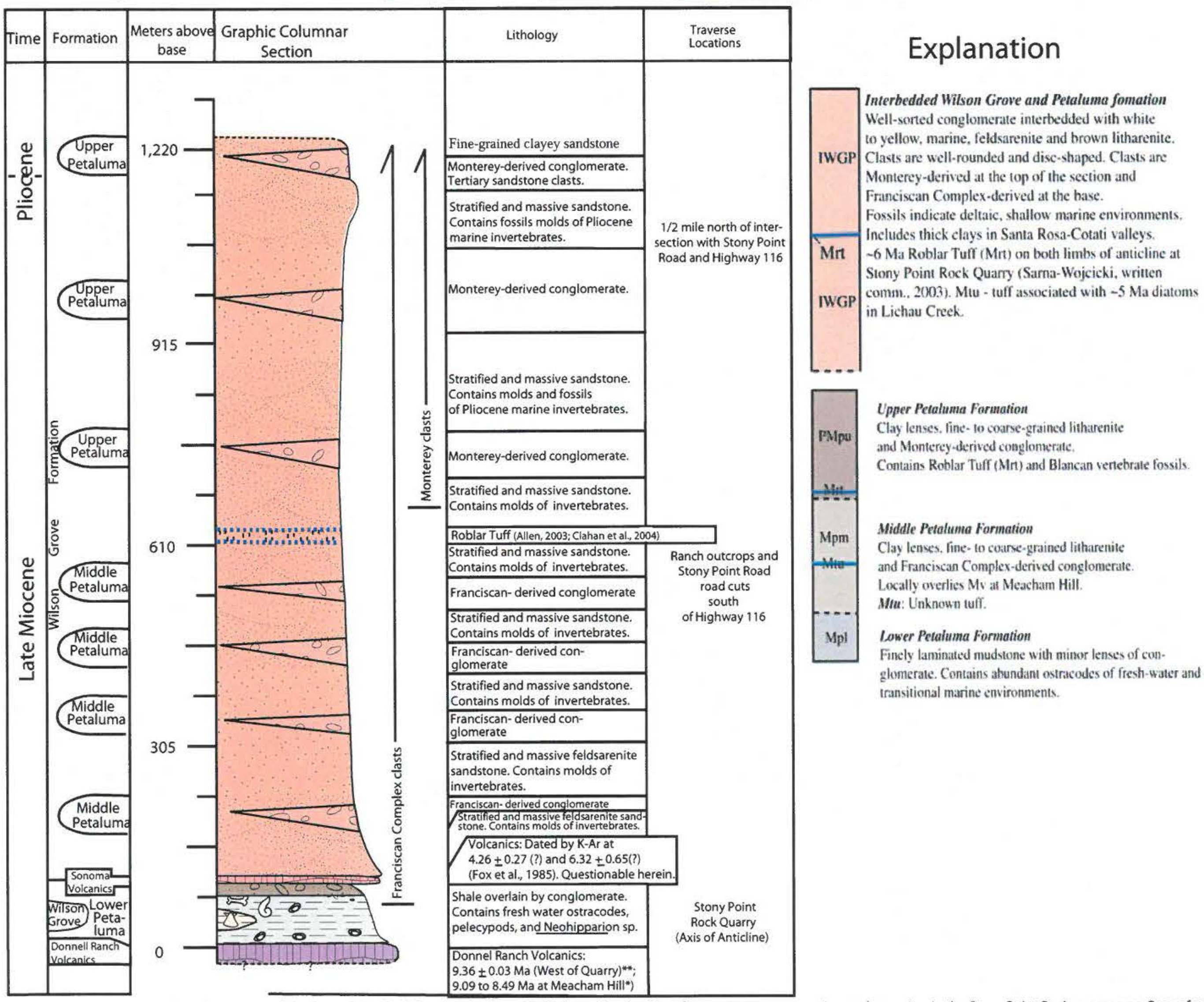


Figure 24. Composite stratigraphic section of the Stony Point Rock Quarry - Gravenstein Highway Section. Data from outcrop, cross section and mapping in the Stony Point Rock quarry area. Base of section measured and mapped at the core of the prominent anticline at the Stony Point Quarry. The remainder of the column is from the north limb of the anticline. Both south and north limbs contain Franciscan Complex-derived conglomerate clasts up-section from the lower Petaluma Formation shale exposed in the core of the anticline. Both limbs contain the 6.25 Ma Roblar Tuff horizon, followed by Monterey-derived conglomerate clast beds further up-section. The south limb was chosen for the column because more abundant outcrops occur along that traverse. (** Graymer et al, 2002; *Wagner et. al, 2005)

Figure 25. Lower Petaluma Formation ostracodal shale west of Stage Gulch Road.

Figure 26. Shale, chert, and dolomite of the lower Petaluma Formation. Interbedded shale sh) and dolomite (dlm) in tributary north of Tolay Creek. B

Figure 27. Planar-stratified, medium-grained sandstone underlain by poorly sorted conglomerate of the Petaluma Formation between Lakeville Highway and the Tolay fault.

Figure 28. Clast imbrication in Petaluma Formation. Bedding in this photograph is horizontal. The camera view is to the north. The conglomerate is underlain and overlain by sandstone. Several clasts are imbricated at least 40 degrees from the horizontal bedding plane. Flow direction is to the west.

Monterey-derived clasts predominant in the upper PF. These compositional differences were noted by Morse and Bailey (1935) and are confirmed in this report.

Conglomerates of the PF interfinger with sandstone of the WGF to the west (Johnson, 1934); this interbedded zone is described in the next section. The Petaluma is interbedded with several mafic flows and tuffs of the Sonoma Volcanics to the east, as indicated by preliminary mapping in the Taylor Mountain and southern Sonoma Mountains areas (Fig. 22; Plates 2, 3 of Allen, 2003).

Diatomite in the PF is an interesting feature. A Pliocene (5.2 to 4.8 Ma and possibly younger) diatomite bloom in this formation occurs coincidently where the Petaluma interfingers with Sonoma Volcanics, therefore, diatomites are largely found interbedded in the Petaluma-Sonoma Volcanic section throughout Sonoma and Taylor Mountains. An important diatomite find is in Lichau Creek, west of the Rodgers Creek fault (Figure 4A). Diatomites, a low-energy accumulation, do not last long in the "Interbedded Wilson Grove-Petaluma" section due to paleo-wave action/high energy. Diatomite blooms exposed well in the Sonoma and Taylor Mountains are probably associated with temporary volcanic dams from the Sonoma Volcanic eruptions in the fluvial Pliocene section of the Petaluma system at that time. Therefore, diatomite is found along the western Sonoma Valley in Petaluma sediments, east of the Rodgers Creek fault, between the Rodgers Creek and Bennett Valley faults in Sonoma Mountain-Taylor Mountain, and west of these faults at Lichau Creek, although Wagner et. al (2005) do not recognize the diatomite in Lichau Creek and it's importance. Diatoms were analyzed at many localities by Dr. Sam Van Landingham (Van Landinham and Allen, 2007).

Basal Contact and Thickness

The PF locally overlies approximately 9 to 10 Ma volcanic rocks and the Jurassic-Cretaceous Franciscan Complex along an angular unconformity (Youngman, 1989). Borehole data show that the PF overlies Tertiary volcanic rocks in the Petaluma Oil Field area and at the Stony Point Rock Quarry (Morse and Bailey, 1935; Youngman, 1989; Phil Frame, personal communication, 2003). New geologic mapping for this project indicates the PF unconformably overlies the Franciscan Complex west of the Tolay fault in the Sears Point-Lakeville area and east of the Dunham fault.

At the Petaluma Oil Field, the PF is at least 1,220 m thick, including 183 m of basal mudstone (lower Petaluma) and at least 1,037 m of conglomerate and sandstone of the middle and upper Petaluma. The lower PF thins to 91 m at the Stony Point Rock Quarry. The equal thicknesses of the middle and upper parts of the PF shown in Figure 21 are approximate; the precise boundary between them cannot be pinpointed because of poor exposure.

The Petaluma Oil Field area and data out of it is truly helpful, but one should know that thickness of the Petaluma varies throughout Sonoma County, for example, the unit is thinner at the Stony Point Rock Quarry area due to the westward-paleodrainage and erosion at the beach/deltaic interface during that time. There are enough outcrops along a ~1,200-m stratigraphic section to visually inspect lithologic changes throughout the stratigraphy, but the contact between the two lithologic units is not exposed.

Physical Stratigraphy

Sections of the lower, middle, and upper Petaluma are exposed in the Stony Point Rock Quarry area and in an unnamed creek between Lynch and Adobe creeks. Stratigraphic columns are constructed by pulling together many outcrops roughly along strike and along a somewhat zig-zag traverse in one direction. Total stratigraphic thickness at each location is about 1,220 m, which is similar to the total thickness for the formation at the Petaluma Oil Field. The following section describes the stratigraphy and lithology of the PF based chiefly on the outcrops in these two key areas.

The lower PF consists of blue-gray, thick- and thin-bedded, structureless to thinly laminated mudstone and very fine-grained sandstone. The predominant rock type is thin-bedded to thinly laminated, planar-cross-stratified clayey siltstone (Fig. 25). Laminae are 0.5 to 1.0 mm thick and have fissile parting. Cross strata, if present, must exceed 120 cm in thickness (McKee and Weir, 1953). The thick-bedded, structureless lower PF contains microfossils and has flaggy to slabby parting (McKee and Weir, 1953).

In the southern Tolay Valley area, the lower PF includes chert, dolomite, and limestone (Fig. 26). The chert is brown and orange-brown with abundant siliceous cement. Petrographic analysis shows that the chert contains 20-30% diatoms. Creamy-white dolomite crops out locally. Petrographic analysis shows this rock

Figure 29. Trough cross-stratification in the Petaluma Formation. A. Trough cross-stratification within a channel in the upper Petaluma west of Sears Point. B. Close-up of trough cross-stratification fromthe same locality. View in both photographs is e ast; paleocurrents from outcrops in this area indicate flow to the west.

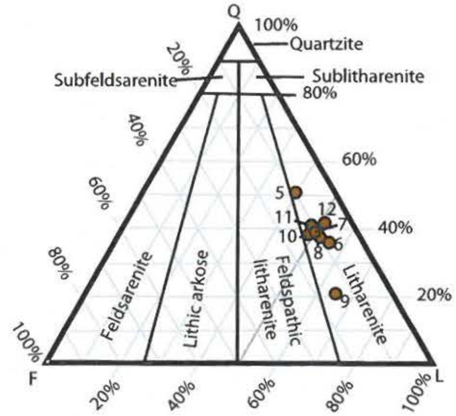


Figure 30. Composition of sandstones from the Petaluma Formation. Sample numbers are on Plate 3. of Allen, 2003.

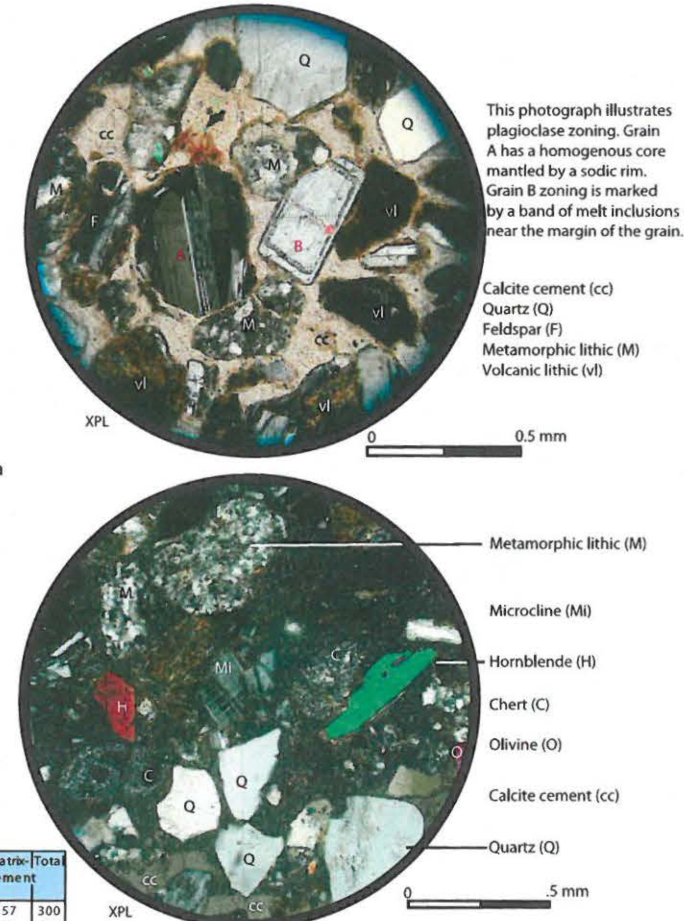


Figure 31. Photomicrographs of sandstone from the middle Petaluma Formation.

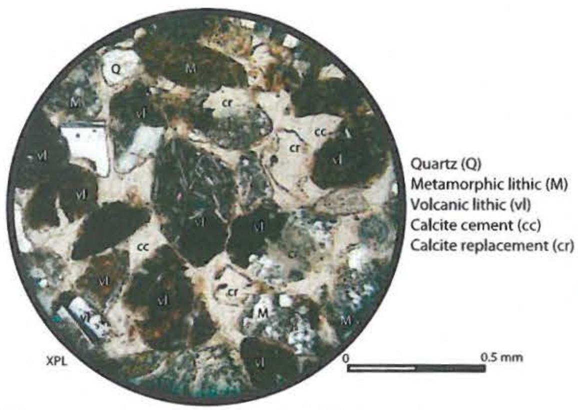


Figure 32 Photomicrographs of sandstone from the middle Petaluma Formation showing abundant volcanic lithic grains.

Sandstone Petrography of the Middle and Upper Petaluma Formation

Raw Data

Sample #	Quartz Non-undulatory	Quartz Undulatory	Quartz Polycrystalline few	Quartz Polycrystalline many	Feldspar	Volcanic Lithic	Sedimentary Lithic	Metamorphic Lithic	Matrix-Cement	Total
5	33	31	10	46	27	14	30	52	57	300
6	19	26	10	38	24	15	18	105	45	300
7	12	24	22	42	31	12	9	110	38	300
8	17	41	12	16	22	12	6	102	72	300
9	45	0	3	15	24	42	3	54	114	300
10	57	3	6	39	33	63	0	66	33	300
11	35	12	15	29	25	57	6	48	73	300
12	51	6	2	18	18	40	2	58	105	300

Normalized without cement or matrix

Sample #	Q	F	L	Total
5	120	27	96	243
6	93	24	138	255
7	100	31	131	262
8	86	22	120	228
9	63	24	99	186
10	105	33	129	267
11	91	25	111	227
12	77	18	100	195

Precent Q,F,L

Sample #	Q	F	L	Q	F	L	Total
5	0.4938272	0.11111	0.39506173	49%	11%	40%	100%
6	0.3647059	0.09412	0.54117647	37%	9%	54%	100%
7	0.3816794	0.11832	0.5	38%	12%	50%	100%
8	0.377193	0.09649	0.52631579	37%	10%	53%	100%
9	0.3387097	0.12903	0.53225806	21%	15%	64%	100%
10	0.3932584	0.1236	0.48314607	39%	13%	48%	100%
11	0.4008811	0.11013	0.48898678	40%	11%	49%	100%
12	0.3948718	0.09231	0.51282051	40%	9%	51%	100%

NOTES: Samples 5 and 6 are from the upper Petaluma Formation sandstone collected at the Marcucci Ranch in the axis of an anticline mapped on Plate 3. The hinge of the anticline contains pencil structures.
Sample 7 is from the upper Petaluma Formation in Bennett Valley in Mantazas Creek (See Map).
Sample 8 is from the upper Petaluma Formation in southwestern Sonoma Valley on the Chateau St. Jean vineyard property.
Samples 9,10,11, and 12 are from the middle Petaluma Formation exposed between Stage Gulch Road and the Toby and Rodgers Creek faults.

contains mostly fine-grained dolomite and a few large dolomite rhombs, with clusters of closely packed ostracode shells. Limestone is grayish-white.

The lower Petaluma also contains minor clastic interbeds of sandstone and conglomerate. Clasts are about 2 cm across and angular, and consist chiefly of metagraywacke and chips of black, angular shale. Sandstone is poorly sorted, medium- to coarse-grained, and planar- to trough-cross-stratified, and forms beds about 5 cm thick.

The contact between the lower and middle Petaluma is placed at the top of the highest laminated shale that is overlain by thick beds of either coarse-grained, planar- to trough-cross-stratified sandstone or coarse conglomerate. Conglomerate is channelized into the uppermost portion of the lower PF. Rip-up clasts of the lower Petaluma up to 10 cm long are present within the lowest 30 cm of the middle Petaluma. These rip-up clasts comprise up to 15% of the clast population.

Most conglomerate beds in the middle and upper Petaluma are lenticular, with a maximum length of 5 m and maximum thickness of 2 m. Conglomerate beds up to 7 m thick have been observed in the field, but their lateral extents are not well-constrained due to poor exposure. Thin, lenticular pebble conglomerate forms interbeds 20 to 25 cm long and 10 cm thick in thick-bedded sandstone outcrops. Conglomerate beds are planar- and trough-cross-stratified and clast-supported, and fine upwards into planar-stratified sandstone (Fig. 27). Clasts are subangular and poorly to moderately sorted.

Conglomerate clasts in the middle PF are dominated by Franciscan Complex material; those in the upper PF are dominated by Monterey sources. Average clast size is about 5 cm, with some clasts up to 25 cm by 15 cm. Outcrops in Bennett Valley and north of Santa Rosa contain clasts 4 to 6 cm across. These outcrops are rare and poorly exposed, so larger clasts may be present. Six paleocurrent measurements show westward flow (Fig. 28).

Sandstone is thin- to thick-bedded (a few centimeters to about 20 m thick), planar- and trough-cross-stratified (Fig. 29), low-angle cross-bedded, and plane-parallel-bedded. Sand grains are well-sorted, medium- to coarse-grained, angular to subangular, and lithic-rich. According to petrologic data (Appendix 1), sandstone in both the middle and upper Petaluma is litharenite (Fig. 30-32) derived from metamorphic rocks (Franciscan Complex), as recognized by Johnson (1934). Sandstone in the middle Petaluma contains a higher percentage of volcanic lithic fragments than sandstone in the upper Petaluma.

Age

The PF is late Miocene to Pliocene according to radiometric and paleontological data. Vertebrate, invertebrate, and plant fossils from the PF were identified by Osmont (1905), Dickerson (1922), Morse and Bailey (1935), Stirton (1952), and Davies (1986). New microfossils and vertebrate and invertebrate fossils were collected during this study. The lower Petaluma contains an interbedded mafic flow dated at about 8.5 Ma (Youngman, 1989), and overlies ~9.3-Ma volcanic rocks of Graymer et al. (2002). A late Miocene (Hemphillian) horse tooth was collected at the top of this unit at the Stony Point Rock Quarry (Allen and Repenning, 2005).

The middle Petaluma contains interbeds of the Sonoma Volcanics that have yielded K-Ar and Ar-Ar dates of about 7.37 to 6 Ma (Plates 2, 3) (Fox et al., 1985;Youngman, 1989). Fossils collected in this unit are Hemphillian in age (Fig. 33).

The ~6-Ma Roblar Tuff crops out near the base of the upper Petaluma. The upper Petaluma contains early Pliocene fossils and the 4.65-Ma Healdsburg Tuff in Bennett Valley.

Diatomite beds are Pliocene in age, spanning early to late Pliocene, and crop out from Lichau Creek west of the Rodgers Creek Fault to the western Sonoma Valley area east of the Rodgers Creek fault, in Taylor Mountain, Bennett Valley and in Fountain Grove of Santa Rosa (Van Landingham and Allen, 2007). Our oldest age calls from extinct diatoms in two localities have been corroborated by Ar/Ar dating. These dates are approximately 4.8 Ma and 5.2 Ma and are shown on Figure 41.

<u>Interbedded Wilson Grove and Petaluma Formations</u>

STOP 3

Rocks in the easternmost outcrop area of the WGF are interbedded with the westernmost outcrops of the PF. This distinctive interbedded sequence, herein called "Interbedded WGFand PFs," is used as an informal map unit and locally unconformably overlies the Franciscan Complex and late Miocene volcanic rocks of Fox et al. (1985). This unit is simply the interbedded zone between the PF and WGF (Figs 4A and 4B).

This unit was previously mapped and described as the Plio-Pleistocene "Cotati Member" of the WGFby Fox (1983) who mapped it only in Cotati. Since it is Pliocene only, stratigraphically above the Roblar Tuff horizon, contains Pliocene tuffs, Pliocene marine and nonmarine fauna and crops out from Sears Point, Lakeville, eastside of Sonoma Mountain, Bennett Valley and Cotati, and is proven to be a continous horizon throughout the PF and where the Pliocene horizon interbeds with the WGFin Cotati, the misleading name "Cotati Member" and Pleistocene age are not used herein.

Physical Stratigraphy

The most complete sequence of these rocks crops out near the Stony Point Rock Quarry to Meacham Hill. This petrofacies is found in the fluvial environment from Sears Point, Lakeville, eastside of Sonoma Mountain, Bennett Valley to Fountain Grove. Here we see the unit in the marine-nonmarine transitional environment. At the base of the Stony Point section, about 91 m of lower PF shale rests on a volcanic flow (Travis, 1952). The shale is overlain by up to 30 m of Franciscan-derived Petaluma conglomerate that contains some Tertiary volcanic clasts. A thin olivine basalt overlies the conglomerate and is overlain by about 1,100 m of interbedded WGFsandstone and Petaluma conglomerate. The sandstone contains invertebrate marine fossils. Conglomerate clasts lower in the section were derived chiefly from the Franciscan Complex, whereas those higher in the section were derived chiefly from the Monterey (Figs. 33A-C). This change in conglomerate clast lithology, plus the presence of the Roblar Tuff in mid-section, correspond to the stratigraphy of the main body of the PF.

Sandstone beds in the interbedded zone are 1 to 3 m thick and locally show high-angle to planar stratification and herringbone cross-stratification. Burrows and disarticulated marine invertebrate fossils occur in structureless sandstone. Three-dimensional views of cross strata and cosets have not been observed due to poor outcrop, so current-direction indicators have not been obtained.

Conglomerate beds in the interbedded zone range in thickness from 25 cm to at least 5 m, and thin and pinch out to the west (Fig. 34), as indicated by the absence of conglomerate in outcrops of thick to hummocky cross-stratified sandstone west of this area. The conglomerate is well-sorted, and clasts are very well-rounded. Clast size is approximately 2 cm to 10 cm. Some beds contain clasts that are uniformly 1 to 2 cm in diameter, whereas other conglomeratic beds contain clasts that are uniformly 10 cm in diameter. Conglomerate is typically thick-bedded, although it locally exhibits trough cross-stratification.

Age

Volcanic rocks below the interbedded unit have been dated at ~9 Ma (Graymer et al., 2002). The late Miocene *Scutelaster oregonensis* was collected at the base of this unit at Spring Hill (Richard Mooi, California Academy of Sciences, personal communication, 2003; Charles Powell, II, U.S. Geological Survey, personal communication, 2003). The ~6-Ma Roblar Tuff crops out mid-way through the interbedded zone. Invertebrate marine fossils collected at the top of the interbedded zone at Stony Point and Pepper roads are Pliocene (Bedrossian, 1971; Powell et. al, 2004).

DEPOSITIONAL ENVIRONMENT

Wilson Grove Formation

In the Estero San Antonio area, the ~16-m-thick, coarse-grained unit at the base of the section is thick-bedded, has a concave-up morphology, and contains grains of uniform size. It is interpreted as a channel deposit at the shelf-slope break (Allen and Holland, 1998), but here I interpret it as a sediment-gravity-flow deposit that accumulated in a channel near the head of a submarine canyon. Sandy channel-fill deposits at canyon heads along the outer shelf are commonly thick-bedded (up to 350 m thick), have a concave-up outcrop pattern, and show uniform grain sizes (Stanley and Urug, 1972; Stanley et al., 1978). Foraminifera collected from this unit during this project and analyzed by Dawn Peterson of CAS/UCMP, include *Buccella frigida* group (transitional and inner shelf), *Neoconorbina* sp. (inner shelf), *Cibicides* sp. (shelf-bathyal; 0-2,000 m), *Cibicidina* sp. (shelf, bathyal?), and *Cibicidoides* sp. (shelf-bathyal). The mixture of shallow-water and deeper-water benthic foraminifera in the same outcrop probably indicates downslope transport of the shallow-water fauna. Rapid deposition of this unit is suggested by the burrows in the fine-grained sandstone below this unit that are in-filled with coarse-grained sediment.

Hummocky cross-stratified, fine-grained sandstone in this area is a key indicator of deposition on the continental shelf (Boggs, 1992; Miall, 1995; Powell and Allen, 2001; Powell et al., 2004). Invertebrate fossils from these outcrops suggest water depths of at least 100 m, which is similar to the modern water depths on the outer continental shelf.

In the Steinbeck Ranch area, the WGF is dominantly thick-bedded and hummocky cross-stratified. Marine fossils from this area suggest water depths of 50m to 100m, which is typical of water depths on modern continental shelves (Powell, et. al 2004).

The eastern part of the formation ("Interbedded WGFand PFs") was deposited in coastal environments, as indicated by interbedding of marine sandstone and fluvial conglomerate. This interpretation is supported by marine invertebrate fossils that were deposited in very shallow-water deltaic environments (Powell and Allen, 2001; Powell et al., 2003).

Petaluma Formation

The PF coarsens upward from mudstone of the lower Petaluma to the sandstone and conglomerate of the middle and upper Petaluma. The lower PF contains transitional marine and lacustrine ostracodes, a barnacle plate (marine), marine foraminifera, and marine diatoms (Fig. 39). Some of the ostracodes required fresh-water environments (Dawn Peterson, personal communication, 2002), so the lower PF represents interfingering of fresh-water environments with a marine system. The lower PF has been described as a fine-grained unit that was deposited in a low-energy lacustrine and estuarine environment (Morse and Bailey, 1935). The results of this study support that interpretation. The environment of deposition of the lower PF must have been low-energy and near sea level . The lower Petaluma is interpreted to have been deposited as a distal, fine-grained unit in a delta (Davies, 1986). Distal facies of deltas typically consist of thinner and finer-grained sediment that are coeval with thicker, coarser proximal units (Coleman and Wright, 1975; Heward, 1978; Miall, 1995).

The middle and upper Petaluma contain terrestrial vertebrates and sparse marine invertebrates. The sandstone beds that contain marine fossils exhibit herringbone cross-stratification, which is evidence of a tidal-flat environment (Miall, 1995).

Within the middle and upper Petaluma, abundant normal-graded conglomerate to plane-stratified sandstone are interpreted as gravels and sand deposited within a braided stream environment (Miall, 1977; Boggs, 1992; Reading, 1996).

From about 7 Ma to at least 4.65 Ma, the lower PF was covered by a westward-advancing fluvial system of the middle and upper PF. Because marine interbeds of the WGF are present in all three members of the PF, one or both of the following must have occurred: the Petaluma basin was continuously subsiding during deposition of the PF, and/or sea level was continuously rising during deposition of the PF.

PALEOCURRENTS

Paleocurrent measurements from imbricated clasts in the Petaluma show that paleoflow was to the west-northwest (Fig. 35; Appendix D *in* Allen, 2003). Thus, interbedding of the fluvial-deltaic Petaluma and marine WGFindicates a generally west-flowing continental drainage that emptied into a marine basin (open ocean) to the west. This corroborates the paleogeography suggested by Sarna-Wojcicki (1992). The simple fact that the conglomeratic units are east of the WGFand interfinger with the easternmost WGFindicate alone that paleofolow was to the west (Johnson, 1934).

PROVENANCE

The compositions of sandstones and conglomerate clasts in the "interbedded WGFand PFs," PF, and Garrity Member provide clues about their provenance.

Sandstone in all units was derived chiefly from the Franciscan Complex, as had been deduced by previous studies (Johnson, 1934; Travis, 1952). However, the middle PF also contains abundant Tertiary volcanic sediment that could have been derived locally from the upper Miocene Donnell Ranch Volcanics and upper Miocene-Pliocene Sonoma Volcanics or from reworking of more distal sources.

Conglomerate in all units was derived chiefly from the Franciscan Complex, the Great Valley Group, the Monterey Group, Tertiary volcanic rocks, and Tertiary quartz-veined

A

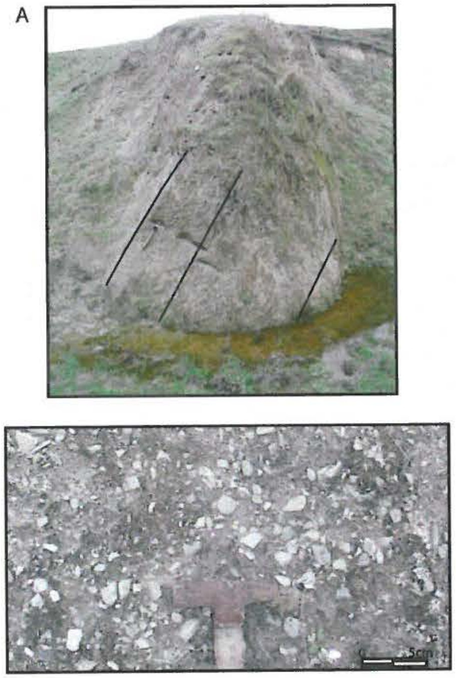


Figure 33A: Photographs of upper Petaluma Formation Monterey-derived fluvial conglomerate. This outcrop overlies the Roblar Tuff nearby at CannonLane. A. Lines depict bedding in outcrop. B. Close-up of Monterey-derived clasts.

B

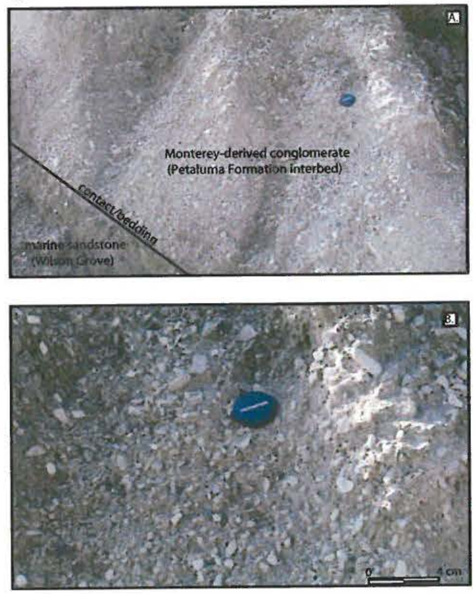


Figure 33B: A. Monterey-derived conglomerate of the "Interbedded Wilson Grove and Petalumaformations." The sandstone contains marine trace fossils that include molds of pelecypods as well as burrows. B. Close-up of photograph A. Photographs taken at an outcrop located approximately 610 m north of the intersection of Gravenstein Highway and Stony Point Road, Sonoma County. This outcrop is on the north limb of the anticline at the Stony Point Rock Quarry, above a tuff identified as Roblar on the south limb of the anticline.

C

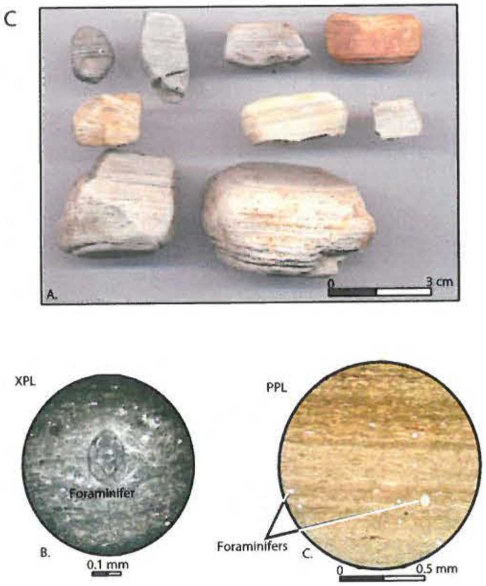


Figure 33C: Clasts of Monterey-derived laminated chert from the Petaluma Formation. B & C. Photomicrographs of thin sections of Monterey-derived clasts showing forams.

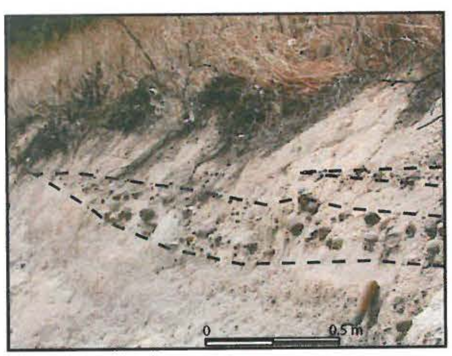


Figure 34. Conglomerate bed in Wilson Grove Formation. A. Thin conglomerate beds pinch out to the west. View is to the northwest.

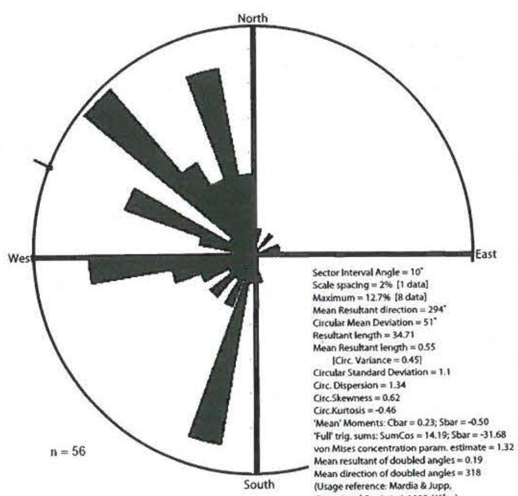


Figure 35. Rose diagram of paleocurrent indicators for the "Interbedded Wilson Grove and Petaluma formations," Petaluma Formation, and Garrity Member of the Contra Costa Group. Individual rose diagrams for each station are in Appendix D of Allen, 2003.

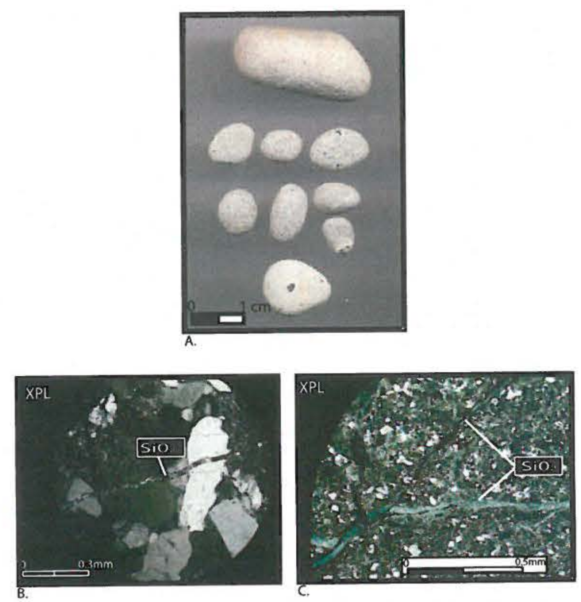


Figure 36. Tertiary quartzo-feldspathic sandstone clasts and photomicrographs. A. Tertiary quartzo-feldspathic sandstone clasts from the "Interbedded Wilson Grove and Petaluma formations" and Petaluma Formation. The fine- to coarse-grained sandstone contains polycrystalline veins (B) or microcrystalline quartz veins (C).

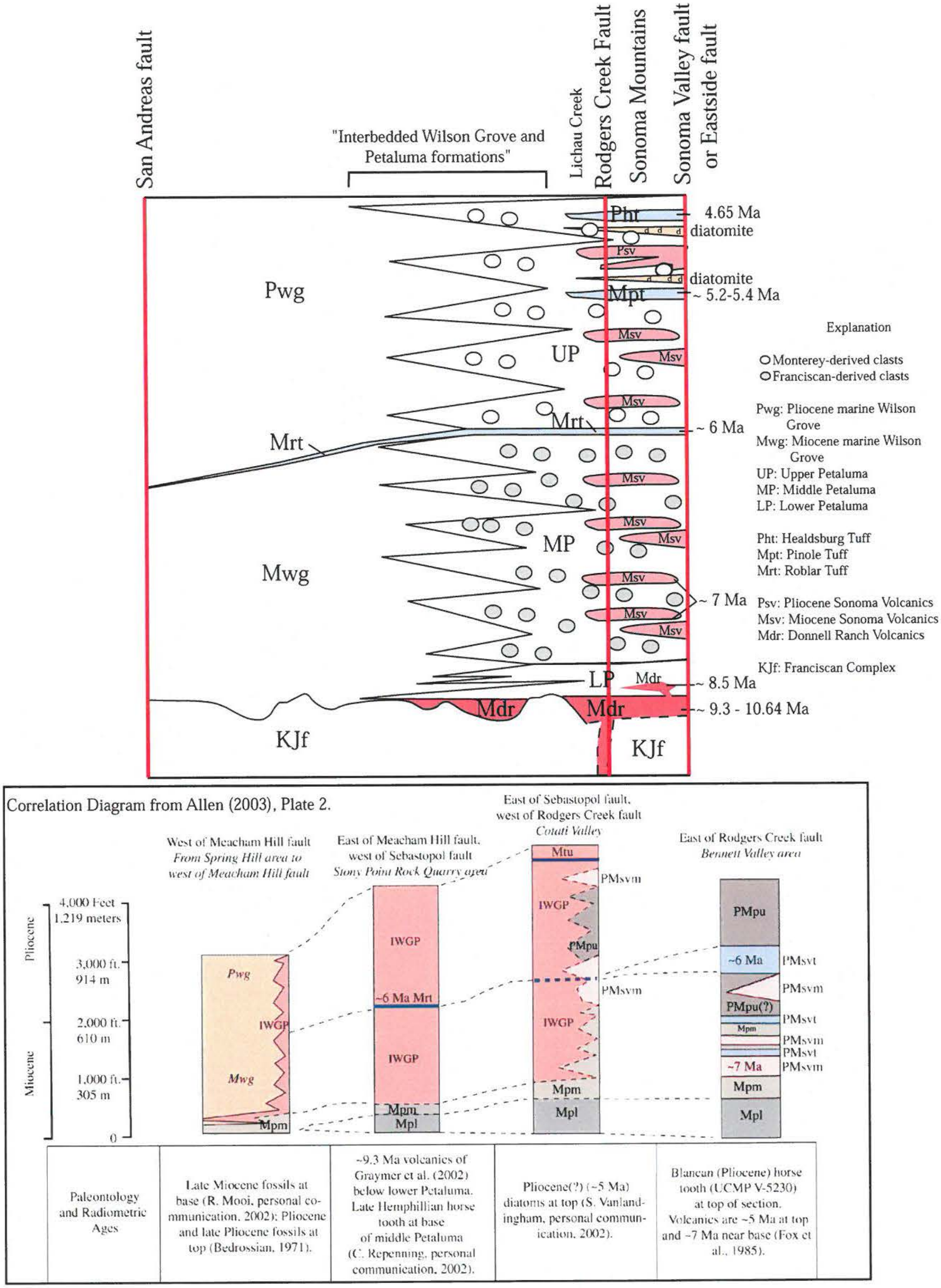
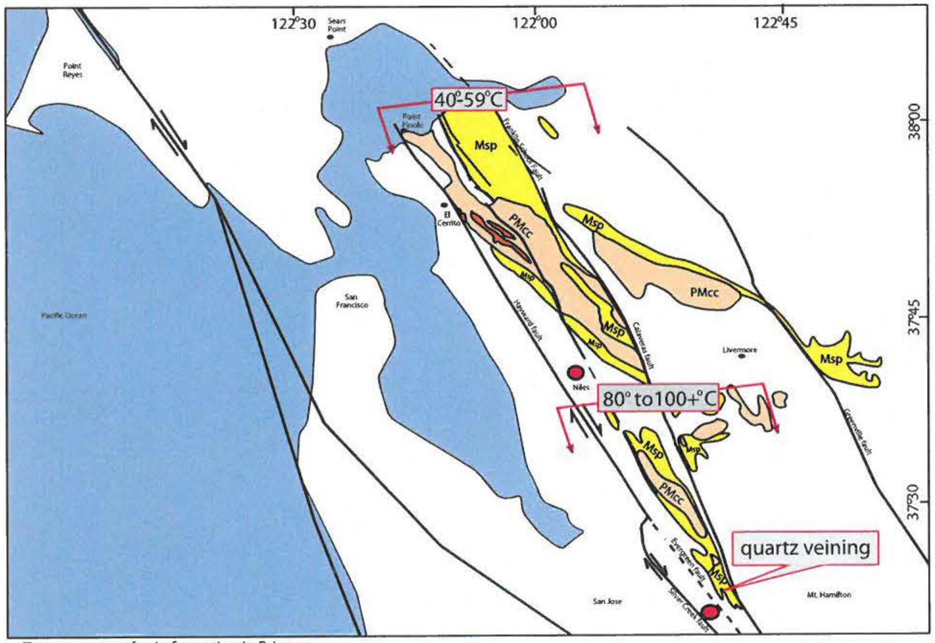


Figure 37. Schematic portrayal of relation of Wilson Grove Formation, Petaluma Formation, and zone of interbedding of rocks of these formations. Thickness of formations, interbeds of Sonoma Volcanics, and distribution of conglomerate clasts in Petaluma Formation are shown schematically.



Temperatures of vein formation in Briones Formation from (Murata and Whiteley, 1973)
Geology from Wagner et al. (1991)

0 10 20 km

N

EXPLANATION

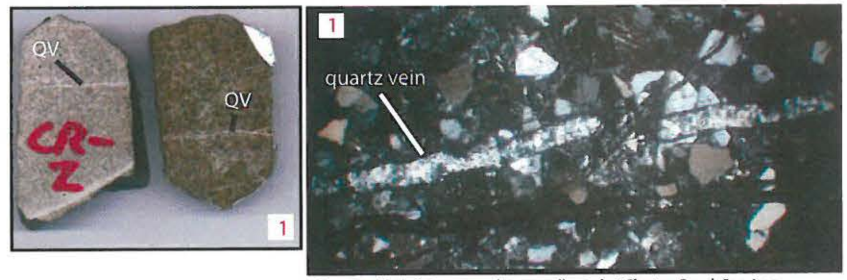
PMcc Contra Costa Group

Grizzly Peak Volcanics
Bald Peak Volcanics

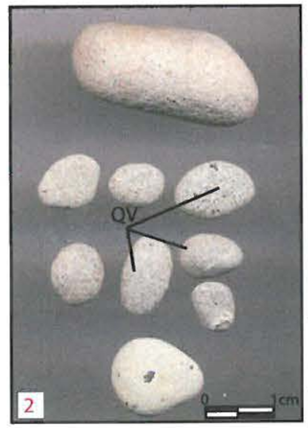
Miocene

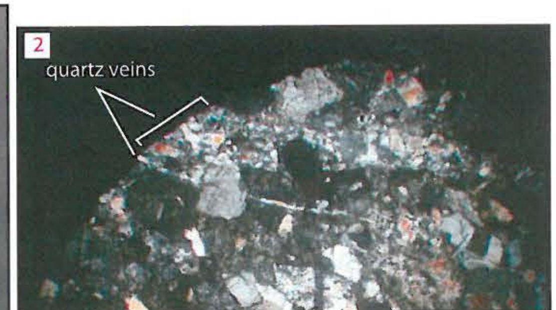
Silver Creek volcanics (~13-10 Ma; Nakata, 1993) (southeast of San Jose)
Union City volcanics (Pliocene(?); Graymer, 1995) (near Niles)

Msp Briones Formation of the San Pablo Group



Quartz vein in Briones sandstone collected at Clayton Road, San Jose.





Quartz vein in clast from Petaluma Formation collected west of Meacham Hill.

Explanation

1 Sandstone of Briones Formation near Clayton Road, San Jose. Hand specimen B is darker because it has been impregnated with epoxy for thin section work. QV: Quartz veinlets

2 Tertiary sandstone clasts from the "Interbedded Wilson Grove and Petaluma formations" and Petaluma Formation.
QV: quartz veinlets

Quartz vein in clast from "Interbedded Wilson Grove and Petaluma formations." Quartz is orange because the thin section is cut thick by the useless thin section guy (Jim Allen).

Figure 38. Map showing geothermal peak temperatures inferred from zeolite composition in the Briones Formation of the San Pablo Group. Temperatures north of Niles are 40 to 59 C. Temperatures south of Niles are 80° to > 100° C (Murata and Whiteley, 1973).

Micropaleontology of the Lower Petaluma Formation shale

Collected by James Allen and Dawn Peterson. Identifications by Dawn Peterson (UCMP)

Locality Data LOCALITY DATA	Genus GENUS	Species SPECIES	Faunal Notes FAUNAL NOTES
Mossi Well #1 - Sonoma County	*Heterocypris*	*glaucus*	lacustrine, but also found in trans. marine - TDS 30ppm+
	Candona	aff. *C. caudata*	primarily lacustrine, but ponds, streams also ;TDS 30ppm
	Foraminifer	sp. indet.	marine?
	Chara	sp.	
	Candona	aff. *C. caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+
	Candona	aff. *C. acutula*	lacustrine, ponds, streams;TDS 30ppm
	Limnocythere	sp.	lacustrine, TDS 30ppm+
	Cypria	sp.	
	Candona	sp. (juvs.)	
	Limnocythere	*inopinata*	lacustrine, TDS 30ppm+
	Darwinula	*stevensoni*	lacustrine, ponds, streams; TDS 30PPm+, higher tolerance in the Cl-
	Foraminifera		marine?
	Cypria	sp.	
	Heterocypris	*glaucus*	lacustrine, but also found in trans. marine - TDS 30ppm+
	Ilyocypris	*gibba*	stream/pond/rare lacustrine - but elevated TDS
Murphy Well #1 - Sonoma County	*Cypricercus*	aff. *reticulatus*	lacustrine, more often pond & stream - TDS 30-1000ppm
	Heterocypris	sp.	lacustrine, pond, stream, also trans. marine - TDS 30+
Borehole C - Stony Point Quarry	*Stenocypris*	*archoplites*	lacustrine
	Darwinula	*stevensoni*	lacustrine, ponds, streams; TDS 30PPm+, higher tolerance in the Cl-
Borehole A - Stony Point Quarry	*Candona*	sp.	primarily lacustrine, but ponds, streams also - TDS 30ppm+ - fragments
	Stenocypris	*archoplites*	lacustrine
	Limnocythere	*ceriotuberosa*	lacustrine, ponds, streams; TDS 30ppm+, higher Cl- tolerance
Borehole A - Stony Point Quarry	*Candona*	aff. *C. caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+ - fragments
	Stenocypris	*archoplites*	lacustrine
	Limnocythere	*ceriotuberosa*	lacustrine, ponds, streams; TDS 30ppm+, higher Cl- tolerance
Borehole A - Stony Point Quarry	*Candona*	aff. *C. caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+ - fragments
	Stenocypris	*archoplites*	lacustrine
Borehole A - Stony Point Quarry	*Candona*	aff. *C. caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+ - fragments
	Stenocypris	*archoplites*	lacustrine
	Limnocythere	*ceriotuberosa*	lacustrine, ponds, streams; TDS 30ppm+, higher Cl- tolerance
	Chara	sp. indet.	
Borehole A - Stony Point Quarry	*Stenocypris*	*archoplites*	lacustrine
	Limnocythere	*ceriotuberosa*	lacustrine, ponds, streams; TDS 30ppm+, higher Cl- tolerance
	Darwinula	*stevensoni*	lacustrine, ponds, streams; TDS 30PPm+, higher tolerance in the Cl-
Borehole A - Stony Point Quarry	*Heterocypris*	*glaucus*	lacustrine, but also found in trans. marine - TDS 30ppm+
	Candona	aff. *caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+ - fragments
	Stenocypris	*archoplites*	lacustrine
	Limnocythere	*ceriotuberosa*	lacustrine, ponds, streams; TDS 30ppm+, higher Cl- tolerance
	Ilyocypris	*gibba*	stream/pond/rare lacustrine - but elevated TDS
	Darwinula	*stevensoni*	lacustrine, ponds, streams; TDS 30PPm+, higher tolerance in the Cl-
	Chara	sp.	
Borehole A - Stony Point Quarry	*Heterocypris*	*glaucus*	lacustrine, but also found in trans. marine - TDS 30ppm+
	Candona	aff. *caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+
	Stenocypris	*archoplites*	lacustrine
	Chara	sp.	
Roadcut nr. Tolay Fault	*Heterocypris?*	sp.	lacustrine, but also found in trans. marine - TDS 30ppm+
	Stenocypris	*archoplites?*	lacustrine
Basal Petaluma-Tolay Valley, E. Sears Point	*Cypricercus*	aff. *reticulatus*	lacustrine, more often pond & stream - TDS 30-1000ppm
	Heterocypris	sp.	lacustrine, but also found in trans. marine - TDS 30ppm+
	Candona	aff. *C. caudata*	primarily lacustrine, but ponds, streams also - TDS 30ppm+ - fragments
	Cyprideis	aff. *C beaconensis*	transitional marine
	Cytheromorpha	sp.	transitional marine, elevated TDS lacustrine
	Balanus	sp.	barnacle opercular plate - marine to very low salinity
			transitional marine

Micropaleontology of the Petaluma Formation

Foraminifers	Formation	Environment	Locality
Ammonia beccari	Lower Petaluma	marine	Shell Oil Co. well Mossi #1, 38° 15' 30"N, 122° 33' 32"W (Glen
Buccella sp.	Lower Petaluma	marine	Shell Oil Co. well Mossi #1, 38° 15' 30"N, 122° 33' 32"W (Glen
Rosalina sp.	Lower Petaluma	marine	Shell Oil Co. well Mossi #1, 38° 15' 30"N, 122° 33' 32"W (Glen
Elphidiella hannai	Lower Petaluma	marine	Stony Point Rock Quarry-38° 19' 16"N, 122° 44' 05"W (Cotati 7.5'

Vertebrates			
Neohipparion sp.	Upper Petaluma		38° 15' 19"N, 122° 33' 12"W Glen Ellen 7.5' quad.
Neohipparion sp.	Lower Petaluma	Hemphillian	Stony Point Rock Quarry
scapula fragment	Upper Petaluma	Blancan-Pliocene	38° 10' 03"N, 122° 29' 39"W
UCMP V4102		no records	38° 22' 29"N, 122° 37' 24"W
UCMP V3825		Hemphillian(?)	38° 14' 56"N, 122° 32' 52"W
UCMP 3647		Hemphillian	38° 13' 20"N, 122° 32' 22"W
UCMP V74088		Hemphillian	38° 18' 04"N, 122° 37' 51"
UCMP V4202		Hemphillian	38° 16' 42"N, 122° 35' 40"W
Neohipparion gidleyi	Upper Petaluma		Lawlor's Ranch 38° 17' 19"N, 122° 35' 16"W
Pliohippus cf. tantalus	Upper Petaluma	mid Clarendonian-early Blancan	UCMP V5231
or probably Equus (?)		early Blancan(?)	38° 10' 02"N, 122° 28' 07"W
unknown, probably Equus (?)		Blancan-Pliocene	UCMP 5230

Microfossils From Monterey Pebbles in Upper Petaluma Formation, Cotati, CA
Thin sectioned by James Allen
Thin Section Identification by Dr. Kenneth Finger (UCMP)

Basal Wilson Grove coarse sandstone:
?Anomalinoides salinasensis?

This benthic species ranges from Saucesian to Mohnian, but is most common in the Luisian and relatively rare in the Mohnian. (from Ken Finger's report *in* Allen, 2003).

Clasts in Upper Petaluma where it's interbedded with Wilson Grove sandstone:

Globigerina bulloides, spongodiscid radiolarian
Globigerina pseudociperoensis
Siphonodosaria quadrilatera?
Tenuitellinata angustiumbilicata
Gyroidina rosaformis
Bolivina sp., *Siphonodosaria quadrilatera*
Gyroidina rosaformis, Protoglobobulima pseudotorta?,
Siphonodosaria quadrilatera
Nodogenerina sagrinensis
Gyroidina rosaformis
Tenuitellinata angustiumbilicata
Buliminella subfusiformis, ?Globobulimina pseudotorta

The taxa recognized on these 16 slides are among the most commonly occurring and abundant in the Monterey Formation. The fauna is typical Luisian-Mohnian, but the predominance of planktics (86.64%), which includes some radiolarians, is generally more characteristic of the Mohnian Stage (from Ken Finger's report *in* Allen, 2003).

Microfossils from the base of the Wilson Grove Formation
Collected by James Allen and Dawn Peterson (CAS).
Identifications by Dawn Peterson (CAS-UCMP)

Foraminifera:

Buccella *frigida* **group** (transitional and inner shelf),
Neoconorbina sp. (inner shelf),
Cibicides sp. (shelf-bathyal; 0-2,000 m),
Cibicidina sp. (shelf, bathyal?),
and **Cibicidoides sp.** (shelf-bathyal)

The mixture of shallow-water and deeper-water benthic foraminifera in the same outcrop probably indicates downslope transport of the shallow-water fauna. Rapid deposition of this unit is suggested by the burrows in the fine-grained sandstone below this unit that are in-filled with coarse-grained sediment.
Locality: Along cliff outcrops north of Estero San Antonio and west of Valley Ford - Franklin School Road. Collected from coarse basal unit atop KJf. These are the bold, resistant outcrops that stand alone overlooking Dillon Beach and around the western Tomales area. Locals refer to them as the "Elephant Rocks". They also look like Easter Island statues and are strange!

Diatomites of Sonoma Mountain East of the Rodgers Creek Fault and Lichau Creek West of the Rodgers Creek Fault
Collected by James Allen
and Dr. Sam VanLandingham
Identified by Dr. VanLandingham

Locality	Diatoms	Age
Lichau Creek West of RCF (VL 2296)	*Hantzschia amphioxys v densistriata*	4-2 Ma (tuff in progress)
	Melosira areolata	
	Melosira praeislandica	
	Melosira praegranulata f. curvata	
	Stephanodiscus excentricus	
	Epithemia turgida v. capitata	
	Epithemia turgida v. capitata	
	Eunotia formica	
Carriger Creek East of RCF (VL 2023)	*Cyclostephanos undatus*	5.2-4 Ma (4.88 Ma by Ar/Ar)
	Cyclotella jonesi	
	Cyclotella ovata	
	Cyclotella transsylvanica v. elliptica	
	Melosira praeislandica	
	Navicula suglobosa	
	Stephanodiscus excentricus	
Bennett Valley East of RCF Sonoma Mtn Road (VL-1921)	*Melosira ambigua v. robusta*	5.2-2.3 Ma (4.1 Ma tuff)
	Melosira canalifera	
	Melosira praeislandica	
	Melosira praegranulata f. curvata	
	Navicula subglobosa	
	Stephanodiscus excentricus	
	Achnanthes exigua v. heterovalvata	
	Pinnularia ruttneri	
SW Sonoma Valley-Southern Sonoma Mtns. (VL 2306)	*Cyclostephanos fenestratus*	5.2-4 Ma (5.2 Ma tuff)
	Cyclotella kansasensis	
	C. subatomus	
	Cymbella cymbiformis v. producta	
	C. hagermanensis	
	Epithemia cistula v. lunaris	
	Eunotia hungarica v. gracilior	

Figure 39: Paleontology

sandstone. Strata dominated by Franciscan clasts contain ~7-Ma volcanic rocks and late Miocene (Hemphillian) fossils. Strata dominated by Monterey and Tertiary sandstone clasts contain the ~6-Ma Roblar Tuff, early Pliocene (early Blancan) vertebrate fossils, and the 4.65-Ma Healdsburg Tuff.

Paleocurrent data from this study indicate that the source rocks for the WGFand PFs must have lain to the east, but modern outcrops probably were not sources. Tertiary strata east of the study area consist of friable clastic rocks that lack sources of the clasts of laminated Monterey chert and well-indurated, quartz-veined Tertiary sandstone that are abundant in the study area. Thus, appropriate source rocks either have been eroded away or exist elsewhere. I concur with previous studies (Sarna-Wojcicki, 1992; Dickerman, 1999) that favor the latter option. Furthermore, the

Franciscan, Great Valley, and Monterey rocks along the Hayward fault lay beneath the Contra Costa Group in the late Miocene to Pliocene and were not exhumed until after deposition of late Tertiary rocks of the northern Bay Area. Thus, Franciscan, Great Valley, and Monterey clasts probably were derived from an indeterminate part of the northern Diablo Range, as was suggested by Dickerman (1999).

Tertiary volcanic clasts in the middle Petaluma probably were derived from the interbeds of Donnell Ranch Volcanics and Sonoma Volcanics.

Tertiary sandstone clasts with quartz veins provide the strongest tie to a specific source area to the east. These distinctive clasts contain veins of microcrystalline to polycrystalline quartz (Fig. 36), are cemented by silica or clay, and contain accessory biotite and glauconite (Appendix G *in* Allen, 2003).

My field checks corroborate dozens of field studies that find widespread veins in sandstones of the Franciscan Complex and Briones Formation, but few to no veins in sandstones of the Great Valley Group and Monterey Group. The clasts of veined sandstone were not derived from the Franciscan because they lack high-pressure minerals typical of the Franciscan and contain accessory biotite and glauconite that do not persist at Franciscan metamorphic conditions. Thus, I conclude that the sandstones with veined quartz probably were derived from the Briones Formation.

Field examination of the Briones in the eastern Bay Area shows that quartz veins are present near Clayton Road east of San José (Fig. 37), but not farther to the north. Veined Briones sandstone crops out within the higher-temperature zeolite zone (peak temperatures 85 °C to at least 100 °C) identified by Murata and Whiteley (1973) (Figs. 5, 37, 38). The Briones in the higher-temperature zone is cemented by silica and clay, whereas the Briones in the lower-temperature (40–59 °C) zeolite zone north of Niles is cemented by carbonate. Veined Briones clasts in the Petaluma are cemented by silica and clay, further supporting derivation from the Clayton Road region. Conglomerates of the Contra Costa Group that overlie the Briones near Clayton Road also contain Briones sandstone clasts riddled with quartz veins. The combination of quartz veins and high-temperature zeolites is extraordinarily uncommon in rocks younger than about 12 Ma in the Bay Area (Murata and Whiteley, 1973). I consider the Briones near Clayton Road to be the source of the quartz-veined clasts in the "interbedded WGFand PFs," and PF in the northern Bay Area.

In light of this evidence, I conclude that the late Miocene – Pliocene Wilson Grove-Petaluma basin lay much further south than it is today. After deposition of these formations, the basin was extremely fragmented.

REGIONAL CORRELATION

Several researchers have noted a possible correlation of rocks in and offshore the northern Bay Area and in the eastern Bay Area (Louderback, 1951; Taliaferro, 1951; Savage in Cebull, 1958; Fox et al., 1985; Liniecki-Laporte and Andersen, 1988; Youngman, 1989, Sarna-Wojcicki, 1992; Dickerman, 1999), but none of them studied the WGFand PFs in detail.

The WGF and PF are interbedded from the base to the top of the section, indicating not only temporal correlation but also physical contiguity of the two formations (Fig. 37).

The distribution of the ~6-Ma Roblar Tuff has been used to correlate the WGFand PFs and Contra Costa Group with the Delgada submarine fan, which currently lies southeast of Cape Mendocino, about 150 km northwest of Healdsburg (Sarna-Wojcicki, 1992; McLaughlin et al., 1996, 2000; Graymer et al., 2002). Channelized coarse-grained rocks of the western WGF were deposited in an outer shelf environment, possibly near the head of a submarine canyon that fed a fan such as the Delgada (Allen and Holland, 1999).

The Roblar Tuff also has been used to correlate the PF to the 8.5-Ma to 2.5-Ma

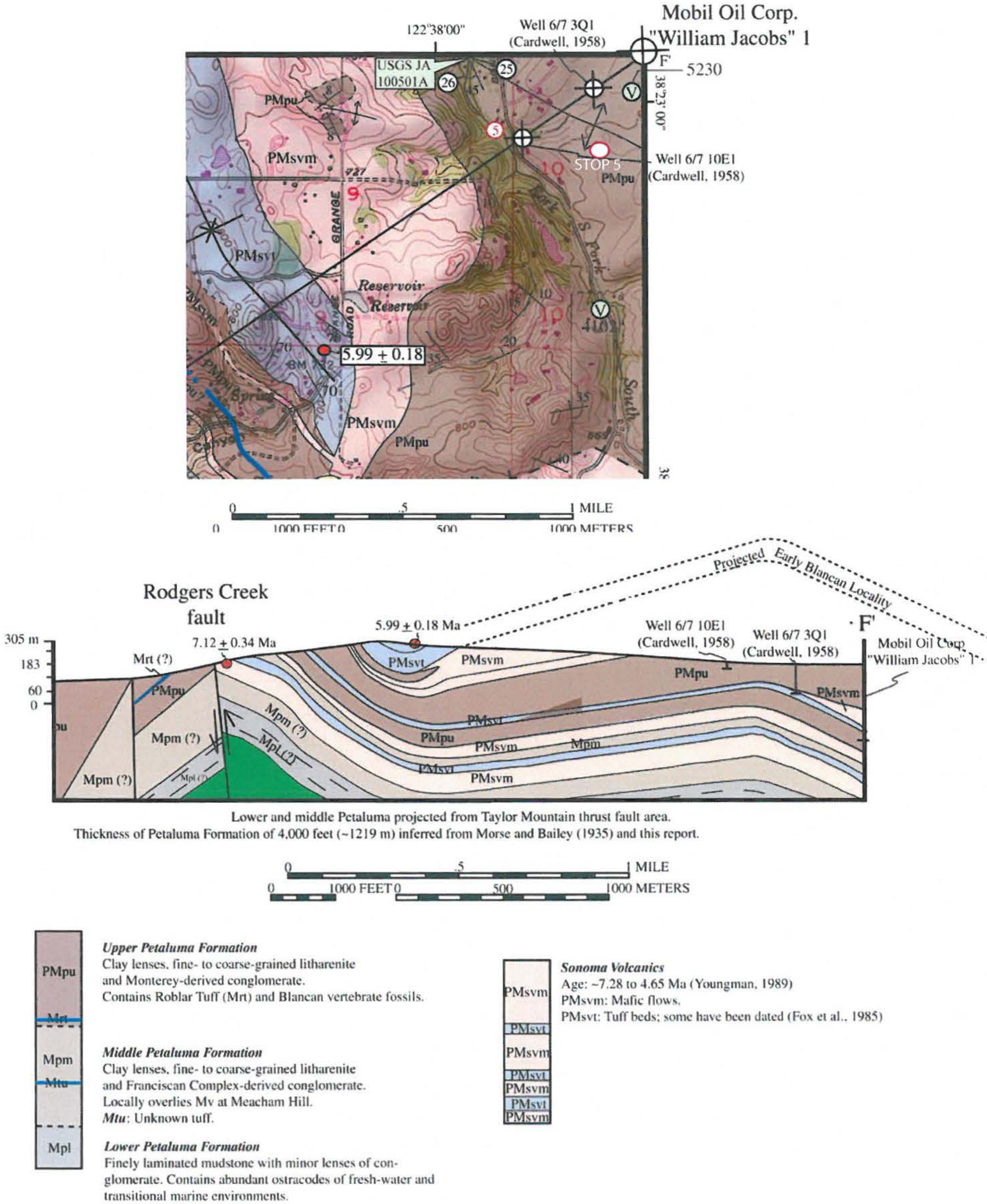


Figure 40: Geologic Map of the Bennet Valley area and Stop 5.

Sycamore Formation in the eastern Bay Area (Fig. 41) (Sarna-Wojcicki, 1992). Like the Petaluma, the Sycamore contains Franciscan-derived and volcanic-derived material in strata below the Roblar Tuff. Both formations also exhibit a marked change in source rocks at about the Roblar Tuff horizon: the Petaluma received Monterey and Briones detritus, and the Sycamore received detritus from the Neroly Formation in the Altamont Hills (Issacson, 1990).

The PF also may be correlative with the Silver Creek Gravels southeast of San José (Fig. 38). These rocks overlie 13- to 10-Ma volcanic rocks, contain Franciscan-derived clasts lower in the section and Monterey-derived clasts higher in the section, and contain the 4.75-Ma Huichica Tuff high in the section (Wills, 1995). Paleocurrents in the Silver Creek Gravels indicate flow to the north (Wills, 1995).

TECTONIC SIGNIFICANCE

STOPS 4, 5 and 6

Tectonic reconstructions of the Pacific–North America transform plate boundary typically assign significant dextral slip to faults in the northern and eastern Bay Area, such as the Hayward, Calaveras, and Rodgers Creek. My studies of late Miocene and Pliocene strata provide constraints on (1) the recognition and significance of major dextral-slip faults in the northern Bay Area east of the San Andreas fault, (2) a tectonic model of late Cenozoic dextral slip on these and other faults in the northern and eastern Bay Area, and (3) late Cenozoic thrust and normal faulting in the northern Bay Area.

Dextral-Slip Faults in the Northern Bay Area

Rodgers Creek Fault

The Rodgers Creek fault is widely interpreted to accommodate the fastest rate of modern dextral slip in the northern Bay Area east of the San Andreas fault (Figures 40-48). It is inferred to be kinematically linked to the Healdsburg fault and the Bennett Valley-Maacama fault zone, each of which have accommodated late Cenozoic dextral slip (McLaughlin et al., 2000). The Rodgers Creek fault exhibits a strong geomorphic expression, befitting its Holocene activity, but the following discussion shows that longer-term dextral-slip may be much less than generally thought.

Pre-Holocene dextral slip on the Rodgers Creek fault generally is inferred to be kinematically linked to dextral slip on the Healdsburg fault and Bennett Valley-Maacama fault zones. For example, McLaughlin et al. (2000) reported that the Glen Ellen Formation west of the Healdsburg fault has been offset about 20 km from its source rocks along the Rodgers Creek–Healdsburg fault zone since 2.5 Ma. McLaughlin et al. (2000) assigned about 7 km of slip to the Bennett Valley–Maacama fault zone, which is inferred to be kinematically linked to the Rodgers Creek–Healdsburg fault zone via a right stepover in the Santa Rosa area.

Mapping south of Santa Rosa is difficult to reconcile with ≥20 km of late Cenozoic dextral slip inferred on the Rodgers Creek fault by McLaughlin et al. (2000). My study indicates that the strata east of the Rodgers Creek fault have strong lithologic and chronologic links to the upper PF west of the Rodgers Creek fault; in fact, these rocks were mapped as Petaluma by Wagner and Bortugno (1982) and considered Petaluma by Weaver (1949) and Youngman (1989). Conglomerate in the strata east of the fault is dominated by Monterey clasts, suggesting correlation with the upper Petaluma west of the fault. East of the Rodgers Creek fault, upper Petaluma strata contain marine interbeds with poorly preserved crabs and razor clams, early Pliocene vertebrates, the 5.2-Ma Pinole Tuff, and the 4.65-Ma Healdsburg Tuff. West of the Rodgers Creek fault, upper Petaluma strata overlie the ~6-Ma Roblar Tuff and contain tuffs that are too altered to date (Sarna-Wojcicki, written communication, 2002), Pliocene marine fossils where interbedded with the Wilson Grove, and early Pliocene vertebrates where wholly fluvial.

Several other lines of evidence also suggest that cumulative dextral slip on the Rodgers Creek fault has been minor. (1) Outcrops of the Sonoma Volcanics that have yielded K-Ar and Ar-Ar ages of ~7 to 6 Ma crop out west of, within, and east of the Rodgers Creek fault, suggesting a maximum of about 5 km of dextral offset (Fox et al., 1985; Youngman, 1989). (2) Strata near the base of the Sonoma Volcanics yield similar K-Ar ages (about 7-8 Ma) on opposite sides of the Rodgers Creek fault just south of Santa Rosa, consistent with about 3-4 km of dextral slip. (3) The apparent truncation of the ~10- to 8-Ma Donnell Ranch Volcanics just north of San Pablo Bay is consistent with ≤5 km of dextral slip on the Rodgers Creek fault, assuming the offset rocks underlie the northern edge of northern San Pablo Bay.

I concur with Youngman (1989) and Wright and Smith (1992) that stratigraphic and radiometric data preclude more than about 5 km of dextral slip on the Rodgers Creek fault, and are consistent with little or no dextral slip and vertical separation of about 1 km. Assuming a modern slip rate of about 10 mm/yr, the Rodgers Creek would have started accumulating this ≤5 km of dextral slip no earlier than about 0.5 Ma.

Sonoma Valley fault

Four lines of reasoning indicate significant late Cenozoic dextral slip on a newly proposed fault in Sonoma Valley that I term the Sonoma Valley fault . First, the PF crops out east of the Rodgers Creek fault zone, requiring that northward translation of the Petaluma from sources east of San Jose, including quartz-veined Briones Formation, occurred on a fault east of the Rodgers Creek fault. Reconstructions of late Cenozoic dextral slip in the Bay Area that link the Hayward and Rodgers Creek faults, such as those by Sarna-Wojcicki (1992), McLaughlin et al. (1996), Wakabayashi (1999), and Graymer et al. (2002), do not address the Wilson Grove, Petaluma, and possible sources and correlatives, and thus tacitly ignore these key outcrops of the Petaluma.

The evidence for stratigraphic similarity on both sides of the Rodgers Creek fault preclude large dextral offset of the PF on the Rodgers Creek fault. Thus, northward transport of the PF (Sarna-Wojcicki, 1992; Graymer et al., 2002) must have been accommodated on a fault east of all the Petaluma outcrops and east of the Rodgers Creek. This fault, for which I propose the name Sonoma Valley fault, is covered by Quaternary alluvium in Sonoma Valley.

A second indicator of the existence of, and significant dextral slip on, the Sonoma Valley fault is the major gravity low near San Pablo Bay . The San Pablo gravity low probably results from down-dropped Franciscan and Great Valley basement in a pull-apart basin that formed at a releasing bend or step in a dextral fault system. The linear gravity gradient west and south of the San Pablo pull-apart basin coincides with the mapped trace of the Hayward fault. Northwest of the basin, the same gravity gradient lies several kilometers east of the Rodgers Creek fault, and lies along the proposed Sonoma Valley fault. The Rodgers Creek fault is unlikely to have constituted the northward continuation of the Hayward fault during formation of the San Pablo basin (cf. Graymer et al., 2002) because it does not seem to lie sufficiently far east to produce the width of the basin or gravity anomaly of San Pablo Bay.

Linkage of the Hayward with the proposed Sonoma Valley fault produces a geometry that is much more likely to have produced a pull-apart of this size. The inferred geometry and scale of the Hayward–Sonoma Valley bend and San Pablo basin are nearly identical to that of the Silver Creek–Hayward bend and Evergreen basin east of San José. I speculate that partitioning of dextral slip onto faults even farther east than the Sonoma Valley, such as the Carneros fault, would have assisted in opening the San Pablo basin to its full extent.

A third line of evidence is historical seismicity in the northern Bay Area. Relevant earthquakes include the 1898 M6.2-6.7 "Mare Island," the 1969 M5.6 and M5.7 "Santa Rosa," and two ~M3 events in 1999 in Bennett Valley. The epicenter of the 1898 Mare Island earthquake was originally considered to lie in Sonoma Valley, but later was moved to the southern Rodgers Creek fault because a fault had not been identified in Sonoma Valley (Toppozada et al., 1992). The two epicenters of the 1969 Santa Rosa earthquakes occurred on the southern Maacama fault and an unnamed fault 5 km northwest of Santa Rosa. The ~M3 earthquakes in 1999 occurred east of the Rodgers Creek fault in Bennett Valley. I infer that all these earthquakes indicate an active fault or faults in the western Sonoma Valley area that may connect northward to the Healdsburg and Maacama faults in the Santa Rosa area and southward to the Hayward fault.

Finally, several drainages that flow east into Sonoma Valley show right deflections at or near the point where they cross the inferred Sonoma Valley fault. Such deflections could be due to human development in the region, but the northwest-southwest alignment of deflections of numerous drainages over a large distance suggests that dextral slip on the Sonoma Valley fault may be at least partially responsible. Drainages are incised into undivided Quaternary units that have not been mapped or dated, so incision rates, slip rates, and the timing of dextral slip cannot be calculated at this time.

I infer that the Sonoma Valley fault accommodated the bulk of the ~27 km of late Cenozoic dextral slip traditionally assigned to the Rodgers Creek-Healdsburg-Maacama fault system. Northward partitioning of dextral slip from the Sonoma Valley to the Healdsburg and Maacama faults would account for the displacement of both the Glen Ellen Formation

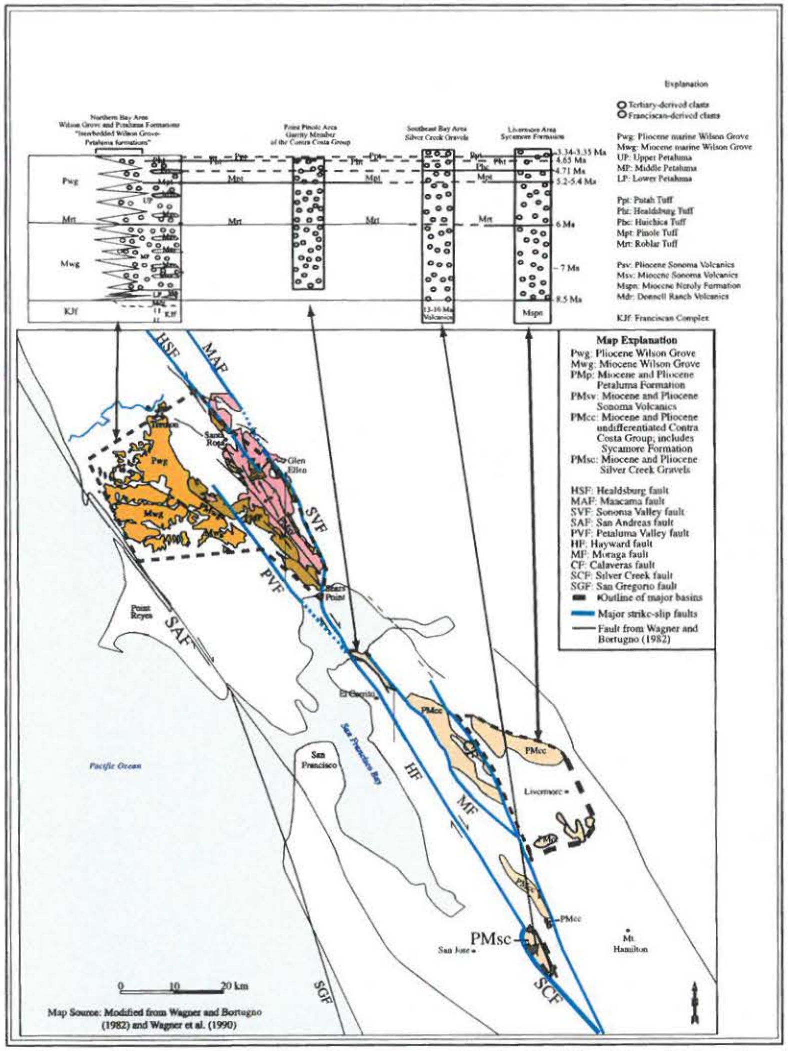


Figure 41. Correlation diagram for the Wilson Grove Formation, "Interbedded Wilson Grove-Petaluma formations," Petaluma Formation, Garrity Member of the Contra Costa Group, Silver Creek Gravels, and Sycamore Formation. Schematic stratigraphic columns not shown to scale. Silver Creek stratigraphy modified from Wills (1995); Sycamore stratigraphy modified from Issacson (1990). Contra Costa Group strata between Moraga and Calaveras faults are too disrupted to show with stratigraphic columns.

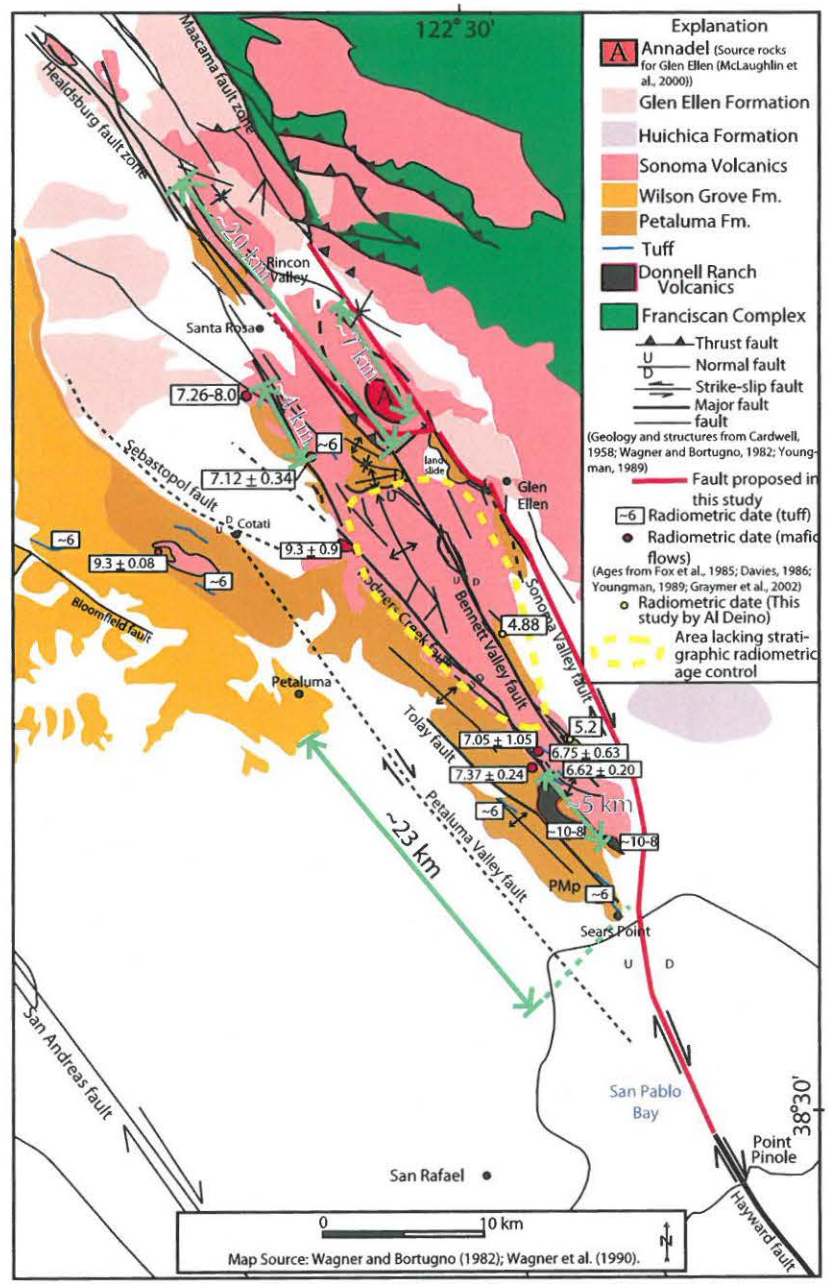


Figure 42 . Map of late Cenozoic Tertiary strata and volcanic rocks in the northern Bay Area, faults discussed in text, and possible offset features. Radiometric dates from Davies (1986), Youngman (1989), Fox et al. (1985), Sarna-Wojcicki (written communication, 2003), and D. Wagner (personal communication, 2003). Petaluma Formation mapped from this study. Sonoma Volcanics, Glen Ellen Formation, Franciscan Complex, and faults and structures from Wagner and Bortugno (1982).

(McLaughlin et al., 2000) and the PF (this study).

Petaluma Valley fault

A fault in Petaluma Valley was previously identified by Wright and Smith (1992) and Collins (1992) and named the "Petaluma Valley fault" by Graymer et al. (2002). The fault is inferred from geophysical data, deflection of the Petaluma River, displacement of the southernmost WGF with respect to the southernmost PF, and displacement of a ~9.3-Ma "rhyolite plug" near Cotati from volcanic rocks of similar lithology and age in the Berkeley Hills.

The results of my study are consistent with a maximum of about 23 km of dextral slip, based on the apparent misalignment of the southern margin of the WGF and the southern margin of the PF. However, this interpretation assumes that the southern margins of the two formations originally were collinear and roughly perpendicular to the strike of the future Petaluma Valley fault. If the original southern margin of the Wilson Grove–Petaluma depositional system had another orientation, this interpretation would be invalid.

Rhyolite near Cotati resembles similar rocks in the Berkeley Hills, but inferred dextral offset is difficult to defend because similar rocks crop out elsewhere in the northern Bay Area. For example, 10- to 9-Ma rhyolite crops out east of Cotati (near the Rodgers Creek fault; Fig. 42) and near Sears Point north of San Pablo Bay. The strong similarities among the rhyolites in these four outcrop areas indicate that a unique piercing point across the Petaluma Valley fault cannot be obtained. Instead, these rocks may be the remnants of widely dispersed volcanoes of similar composition that erupted about 10 Ma to 9 Ma.

I conclude that the maximum late Cenozoic dextral slip on the Petaluma Valley fault is the 23 km permitted, but not required, by the possible offset of the southern margins of the outcrop areas of the WGFand PFs.

Model of Late Cenozoic Dextral Slip

Graham et al. (1984) estimated that 315 km of slip has been accommodated by the San Andreas fault system in central California since early Miocene time, with 260–270 km of this slip occurring since about 10 Ma at the latitude of the northern Bay Area. The results of my study, combined with the results of Stanley and Lillis (2000) and McLaughlin et al. (2000), indicate 269-292 km of dextral slip in the northern Bay Area since about 12 Ma (Fig. 48).

From about 12 Ma to 10 Ma, Great Valley Group rocks and Miocene volcanic rocks at Burdell Mountain were displaced a maximum of about 40 km northward on the Calaveras and central San Andreas faults from similar rocks at Quien Sabe (Fig. 48). Slip in excess of 40 km is unlikely because it would have placed the future Wilson Grove–Petaluma basin too far north of its Franciscan Complex, Monterey, and Briones source rocks east of San José. The maximum average slip rate for the period 12–10 Ma is about 20 mm/yr.

Stanley and Lillis (2000) report oil bearing rocks of the Davenport-Point Reyes areas were at one time adjacent to each other prior to ~115 km of right-lateral separation along the San Gregorio-Northern San Andreas fault system separated them. They report oil migration and sandstone intrusion in these rocks occurred between approximately 9-7 Ma and the rocks were displaced subsequently. Based on my study, I suggest the rocks were separated starting at about 10-9 Ma. From about 10 to 3 Ma, 115 ± 10 km of displacement accumulated on the San Gregorio-northern San Andreas fault system, based on similar hydrocarbons at Point Reyes and La Honda (Stanley and Lillis, 2000) (Fig. 48). Average dextral slip rates are estimated at 40 mm/yr from 10 to 9 Ma and 16 mm/yr from 9 to 3 Ma (Stanley and Lillis, 2000).

From about 10 to 5 Ma, little or no dextral slip probably accumulated on faults in the eastern Bay Area; significant dextral slip in this time interval would have placed the southernmost PF, which was deposited from about 9 Ma to 4 Ma, too far north of its source rocks.

At about 5 Ma, dextral slip initiated or resumed on faults in the eastern Bay Area (Fig. 48). I used 5 Ma in order to calculate slip rates conservatively, but the actual onset or resumption may have occurred as late as about 3 Ma. This more recent date would result in correspondingly faster average slip rates.

The Petaluma Valley fault may have accommodated up to 23 km of dextral slip since 5 Ma (Fig. 45), corresponding to an average slip rate of 4.6 mm/yr over this time interval. This interpretation assumes initially collinear southern margins of the outcrop areas of the WGFand PFs. Alternatively, the southern margins may have formed in their current positions, i.e., their southern margins may not have been originally

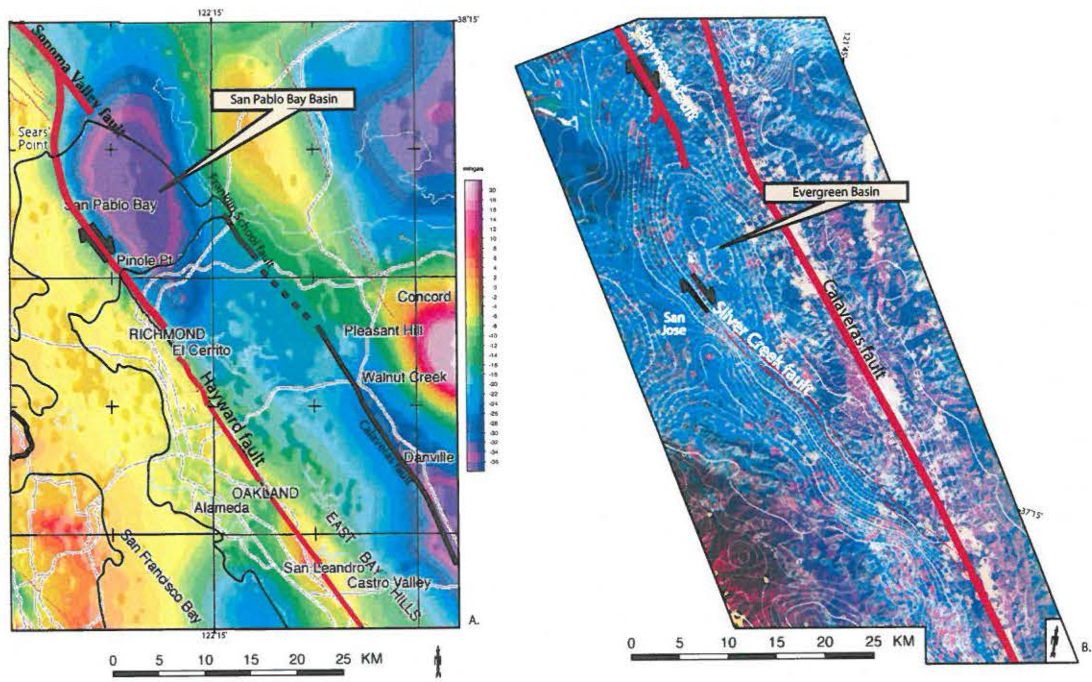


Figure 43. Late Cenozoic basins in the Bay Area interpreted to have formed at right-bends in right-lateral strike-slip faults. A. San Pablo basin (figure from Ponce, 2000). B. Evergreen basin (Jachens et al., 2002) (figure from Roberts and Jachens, 1993).

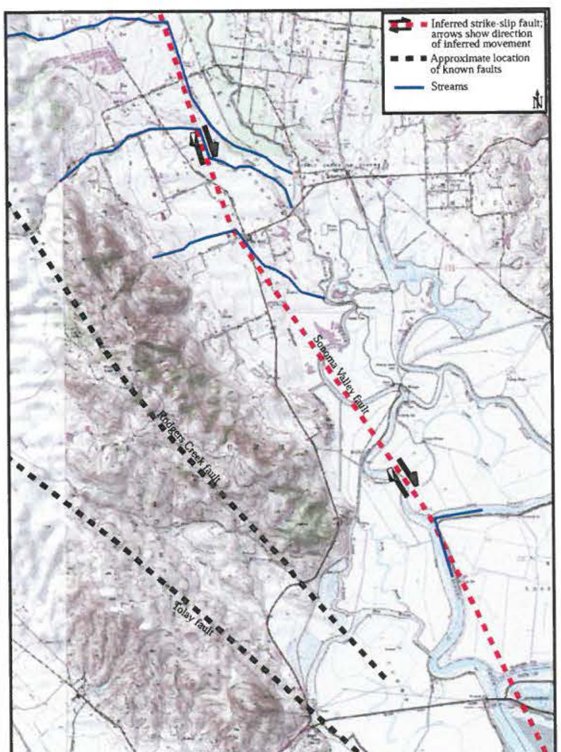


Figure 44. Deflection of streams possibly caused by dextral slip on the Sonoma Valley fault.

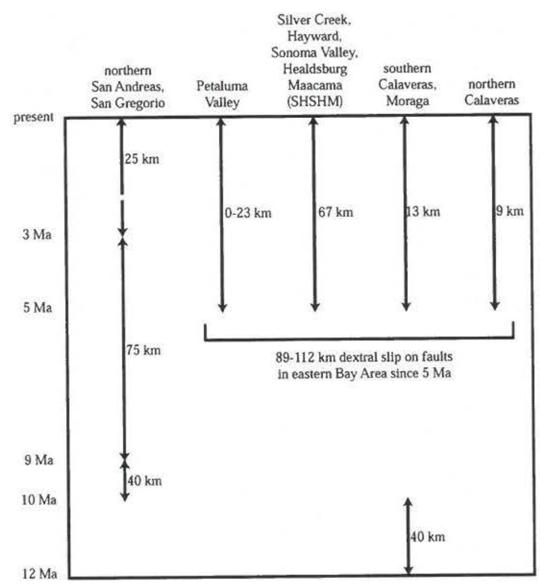


Figure 45. Proposed distribution of dextral slip on faults in the Bay Area since inception of transform plate boundary about 12 Ma.

collinear. In this case, negligible dextral slip is required on the Petaluma Valley fault.

Restoring the PF to an area near its Franciscan, Monterey, and Briones source rocks east of San José requires about 67 km of displacement along the Silver Creek–Hayward–Sonoma Valley–Healdsburg–Maacama (SHSHM) fault system (Figs. 42). This restoration places the southernmost Petaluma opposite the northernmost Silver Creek Gravels, suggesting that the Petaluma and Silver Creek may have been contiguous prior to offset on the SHSHM fault system. This restoration also places the northernmost Petaluma near correlative strata of the Sycamore Formation (Figs. 41). The Garrity Member of the Contra Costa Group probably has been offset from the Petaluma along the SHSHM, but no piercing point has been identified. The modern Hayward fault bounds the Garrity on the west, but the early Pliocene Hayward fault bounded it to the east (Wakabayashi, 1999).

The southernmost PF was faulted about 45 km to the north along the SHSHM fault system from 5 to 2.5 Ma, yielding an average dextral slip rate of about 18 mm/yr. Latest Pliocene strata in the Glen Ellen Formation received obsidian sediment from a source to the east at Annadel (McLaughlin et al., 2000) (Figs. 42), so since 2.5 Ma the southernmost Petaluma and Glen Ellen formations have been faulted about 22 km to their present-day positions along the SHSHM fault system. This model accepts the post-2.5 Ma offset along the Healdsburg–Maacama fault system presented by McLaughlin et al. (2002) (Fig. 42). The average slip rate on the SHSHM since 2.5 Ma has been about 8.5 mm/yr.

Restoration of the northern margins of outcrop areas of the Contra Costa Group requires about 22 km of dextral slip along the southern Calaveras-Moraga (~13 km) and northern Calaveras (~9 km) faults (Fig. 42). Since 5 Ma, the average cumulative slip rate on these faults has been about 4.4 mm/yr.

Thus, faults in the eastern Bay Area have accommodated a maximum of about 89 km and perhaps as much as 112 km of dextral slip since 5 Ma (Fig. 48). An additional 25 km has accumulated on the San Andreas fault since its reactivation in the late Pliocene or earliest Quaternary (Fig. 48) (Wakabayashi, 1999). Thus, cumulative dextral slip at the latitude of the northern Bay Area since 12 Ma is at least 269 km and perhaps as much as 292 km, depending on the interpretation of the Petaluma Valley fault.

Thrust and Normal Faulting

The study area is cut by significant thrust and reverse faults such as the Bloomfield-Joy Woods and Mt. Jackson-Trenton; many unnamed faults also have thrust or reverse slip (Hitchcock and Kelson, 1998). There is no evidence for significant dextral offset of the WGF on any of these faults. Instead, these northeast-dipping faults show reverse or thrust slip with significant vertical offset; for example, the Trenton fault places Franciscan Complex atop Wilson Grove. Based on these observations, any strike-slip faulting must have occurred prior to the late Miocene onset of WGFdeposition.

The faults mapped in the WGF are reverse faults that were active before, during, and after WGFdeposition (Weaver, 1949; Travis, 1950). Activity since about 3 Ma is indicated by strong folding of the upper Pliocene part of the WGFand the Pliocene-Pleistocene Glen Ellen Formation (Fox, 1983). Thrust faults are probably reactivated thrusts rooted in the Jurassic and Cretaceous basement rocks. The irregularity of the basement on which the WGF was deposited may reflect older topographic highs in the Franciscan Complex attributed to Cretaceous or Paleogene slip on these faults.

The Tolay fault has been mapped from the Sears Point area north to the Cotati area. The southern portion of the Tolay fault from Sears Point to Stage Gulch Road dips 60° to the southwest (Morse and Bailey, 1935). At Sears Point Raceway, the Tolay fault is a complex zone of multiple northwest-trending, east-vergent faults (D. Wagner, personal communication, 2001). The Tolay fault zone places the Franciscan Complex mélange and capping volcanic rocks (possibly Donnell Ranch Volcanics) atop the PF. But this is a moot point since the PF overlies the Donnell Ranch Volcanics! Wright and Smith (1992) show the Tolay fault as vertical at depth.

The Lakeville fault of Morse and Bailey (1935) lies west of the Tolay fault and east of Lakeville Highway (Plate 3). The Lakeville fault system is interpreted as an east-dipping back-thrust possibly rooted in the Tolay fault. The Lakeville fault system has an insignificant strike-slip component.

The Taylor Mountain thrust fault, introduced here, places olivine basalt thrust over the PF. Several fault planes and shear zones are located at the base of the volcanic rocks and

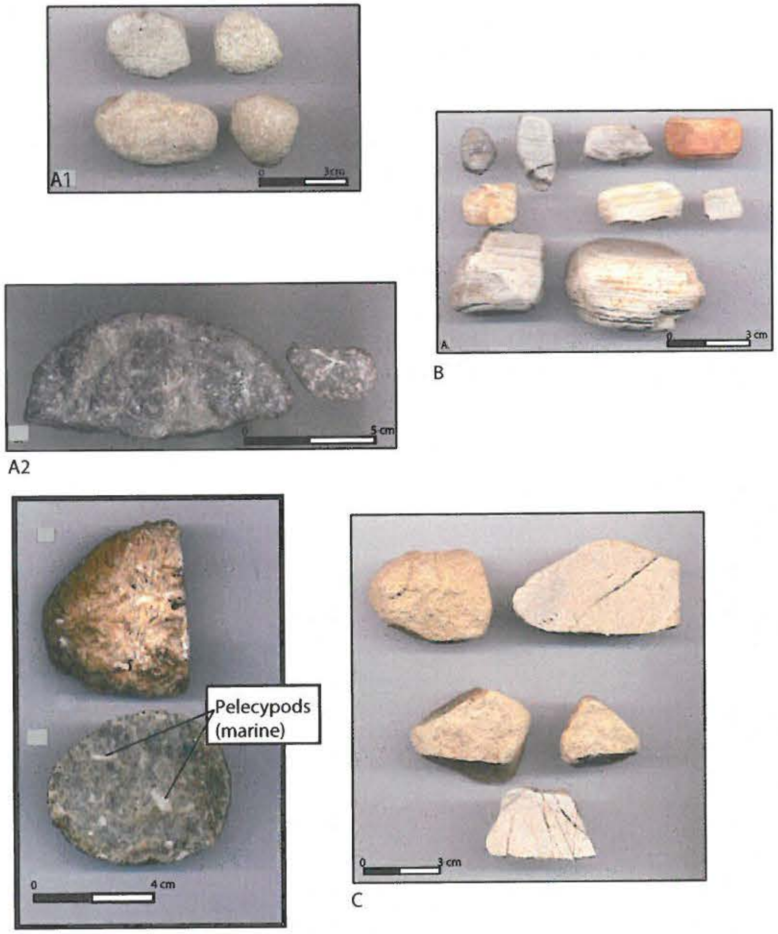


Figure 46:
A1. Franciscan Complex-derived graywacke clasts from the Petaluma Formation. These clasts are foliated, contain muscovite and an altered matrix. Other clasts contain >1 cm quartz veins. A2. Silicic, porphyritic volcanic clasts. The large clast at left is a broken round (Vanderhurst et al., 1982). Rare plutonic clasts occur as broken rounds. The "broken round" is strongly suggestive of reworking from older conglomerates. B. Clasts of Monterey-derived laminated chert from the Petaluma Formation.
-C. Great Valley Group sandstone clasts collected from the Petaluma Formation along Freeway 101, southbound, opposite West Sierra Avenue exit to Cotati. This clast type is present in the eastern portion of the Wilson Grove Formation, Petaluma Formation, and the "Garrity Member" of the Contra Group at Point Pinole. These clasts contain several grains of biotite, lack quartz veins, lack an altered matrix, lack foliation, and are moderately cemented.
-Fossilferous clasts. D. Clast of coquina & Fossiliferous sandstone.
These are most likely from the Briones Formation in the East Bay area because the Briones has many known coquina beds and fossiliferous zones.

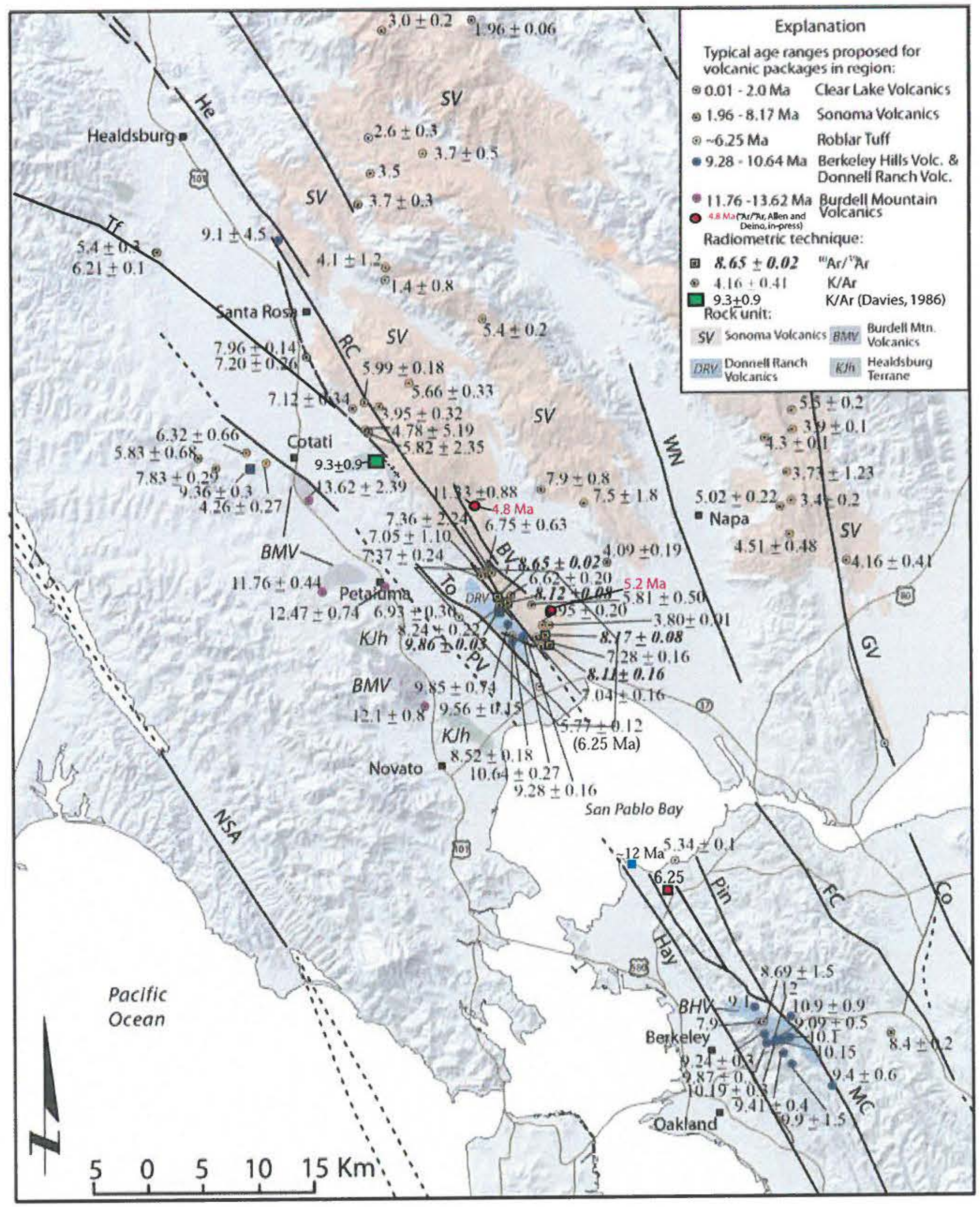


Figure 47: Radiometric dates and distribution of volcanic rocks near study area (Randolph-Loar, 2002).Figure is slightly modified to show new age dates from Davies (1986) and Allen and Deino,(in press). NSA: Northern San Andreas Fault, Hay: Hayward Fault; Pin: Pinole Fault; FC: Franklin Fault; Co: Concord Fault; GV: Green Valley Fault; WN: West Napa Fault; BV: Bennett Valley Fault;To: Tolay Fault; RC: Rodgers Creek Fault; PV: Petaluma Valley Fault; Tf: Trenton Fault; He: HealdsburgFault; Ma: Maacama Fault.

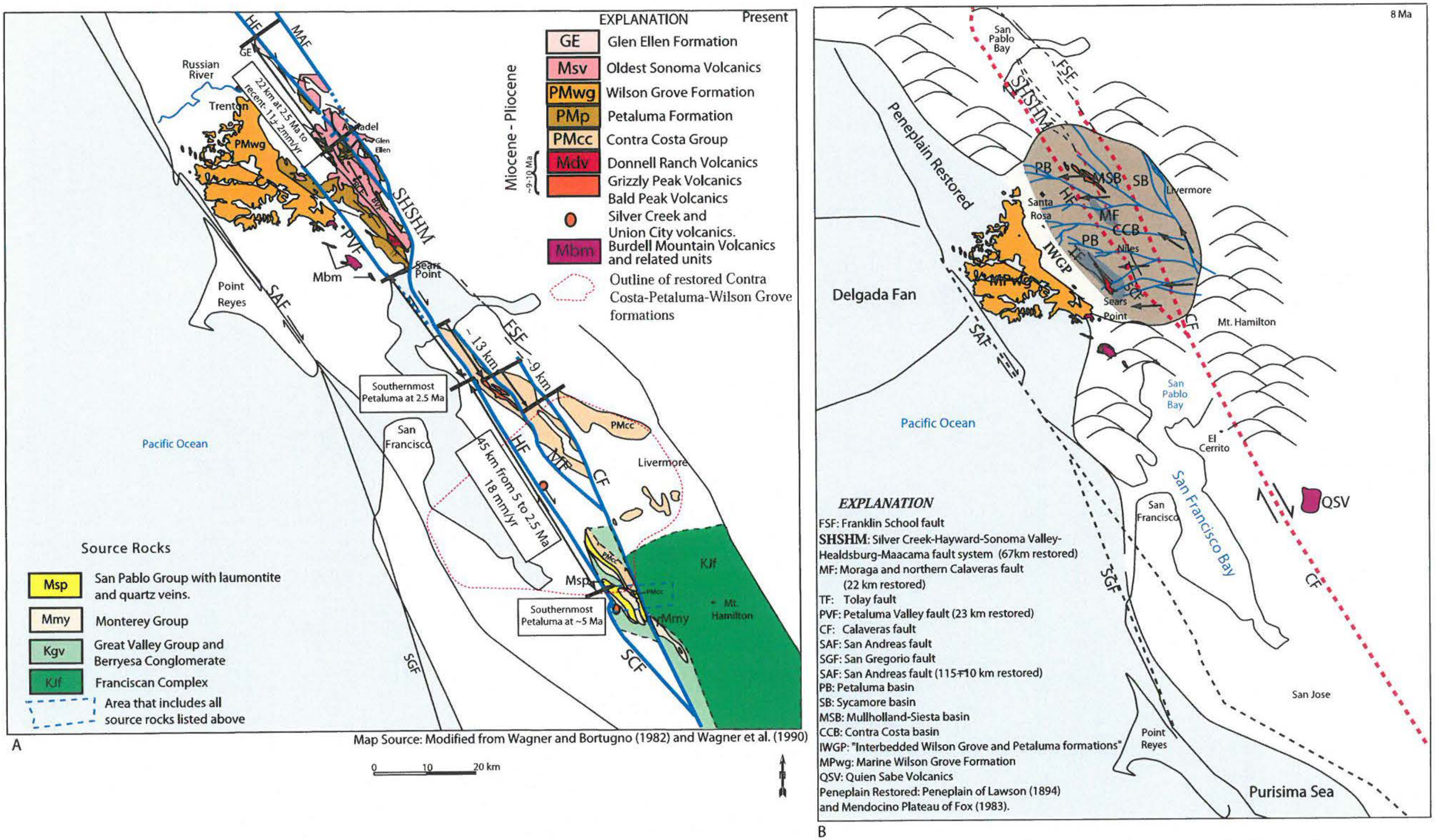


Figure 48. Palinspastic reconstruction restoring the southernmost Petaluma Formation to an area near its source rocks east of San Jose A. Current distribution of late Miocene-Pliocene and Jurassic-Cretaceous rocks of the northern and eastern Bay Area used in correlation and as source rocks. B. Palinspastic reconstruction at about 8 Ma.

within the middle PF. Striations plunge east towards the Rodgers Creek fault. I interpret this structure as a thrust splaying from the Rodgers Creek fault zone, as has been documented elsewhere in the study area (Youngman, 1989).

The Meacham Hill fault, which bounds Miocene volcanic rocks similar to the Burdell Mountain volcanics (Fox et al., 1985), is probably the northward continuation of the Tolay fault. Dip separation on this fault is unknown, but has been sufficient to juxtapose ~13-Ma volcanic rocks and overlying late Miocene sedimentary rocks with Pliocene sedimentary rocks. The Meacham Hill fault is concealed or completely disappears northwest of the Stony Point Rock Quarry, but an anticline and minor faults along the projected Meacham Hill fault suggest that it continues northwest as a blind thrust.

Thrust faults associated with the Rodgers Creek fault are inferred between the Tolay and Rodgers Creek faults at Sears Point, based on the placement of older volcanic rock atop the PF along sheared contacts (Youngman, 1989; Randolph Loar, 2002). Thrust faults exposed north of Sears Point and at Taylor Mountain support Youngman's inferences in the Sears Point area.

East of Cotati and Penngrove, volcanic rocks dated at 9.3 ± 0.3 Ma (similar to the Donnell Ranch Volcanics) crop out west of the Rodgers Creek fault (Fig. 42) (Davies, 1986). This outcrop is east of the inferred Petaluma Valley fault and is less than 3 km east of ~9.3-Ma volcanic rocks at the Stony Point Rock Quarry (Graymer et al., 2002). The emplacement of this ~9-Ma volcanic unit may be associated with a flower structure rooted to the Rodgers Creek fault, as interpreted in the Sears Point area.

Normal faults, such as the fault bounding the western portion of the Cotati and Santa Rosa valleys and the Roche Cardoza fault of Youngman (1989), appear to cut older thrust faults (Youngman, 1989). A wide zone of normal faulting along the western portions of the Cotati and Santa Rosa valleys appears to have down-dropped the valley floors (Department of Water Resources, 1979; R. McLaughlin, personal communication, 2001). This fault zone appears to cut the Trenton reverse fault.

The Roche-Cardoza fault truncates the Wildcat Mountain thrust fault (Youngman, 1989) with apparent normal separation. However, the recent normal fault probably overprints an earlier thrust fault. Folding of the PF along the Roche-Cardoza fault is typical of deformation in the lower plate of a thrust fault, rather than along a normal fault. Youngman (1989) interpreted the Roche-Cardoza fault as a thrust splaying from the Rodgers Creek fault.

SUMMARY

The coeval and interbedded upper Miocene-lower Pliocene WGFand PFs in the northern San Francisco Bay Area represent fluvial flood-plain to open-ocean deposition. The WGFand Petaluma are correlative to the Silver Creek Gravels in east San José and Sycamore Formation near Livermore, and possibly to tectonically disrupted coeval strata in the East Bay Hills. In all these units, sediment in the late Miocene part of the section was derived from the Franciscan Complex, whereas sediment from the Pliocene part of the section also was derived from Tertiary sedimentary sources in the eastern Bay Area.

Distinctive clasts of veined sandstone in the Wilson Grove-Petaluma rocks probably were derived from the Briones Formation east of San José. This source region also probably delivered the Franciscan, Great Valley, and other Tertiary detritus that makes up the bulk of the WGFand PFs.

Restoration of the Wilson Grove-Petaluma rocks to an area near their source rocks east of San José requires about 67 km of displacement along a fault system consisting of the Silver Creek, Hayward, Sonoma Valley, Healdsburg, and Maacama faults. About 45 km of this slip accumulated from 5 Ma to 2.5 Ma, for an average slip rate of 18 mm/yr, and about 22 km has accumulated since 2.5 Ma, for an average slip rate of 9 mm/yr. The Sonoma Valley fault, which interpreted to connect the Hayward fault with the Healds-burg and Maacama faults, is newly proposed in this study on the basis of stratigraphic, geophysical, and geomorphologic observations.

REFERENCES

Allen, J.R., 2003, Stratigraphy and Tectonics of Neogene Strata, Northern San Francisco Bay Area, California [Master Thesis], San Jose State University, 183 pgs.

Allen, J.R., and Repenning, C.A., 2005, Lithology and Vertebrate Fossils of the PF, Sonoma County, California, Geological Society of America, Cordilleran Section abstracts with programs, Paper No. 25-12.

Allen, J.R., Barnes, L.G., and Holland, P.J., 1999, A small species of mysticete whale (Cetacea: Balaenopteridae) from the late Miocene - early Pliocene WGF, Sonoma County, California: Paleobios, Abstracts, v. 19, p.1.

Allen, J.R., and Holland, P.J., 1999, Description and interpretation of the pebbly sandstone facies of the WGF, Marin County, California: A possible sediment for the Delgada Fan during late Miocene-early Pliocene time: Geological Society of America, Abstracts with Programs, v. 31, no. 6, p. A-33.

Allen, J.R., Holland, P.J., and Yip, G.Y., 2000, Geology and significance of the contact between the marine WGF and the nonmarine Cotati Member of the WGF, Sonoma County, California: Geological Society of America, Abstracts with Programs, v. 32, no. 6, p. A-1.

Armstong, C.F., 1980, Geologic Map Exclusive of Landslides - Southern Sonoma County *in* Geology for Planning in Sonoma County, CDMG Special Report 120, Plate 3B.

Barnes, L.G., 1976, Outline of eastern North Pacific fossil cetacean assemblages: Systematic Zoology, v. 25, no. 1, p. 334.

Barnes, L. G., 1978, A review of *Lophocetus* and *Liolithax* and their relationships to the Delphinoid family Kentriodontidae (Cetacea: Odontoceti): Science Bulletin, v. 20, 35 p.

Bedrossian, T.L., 1971, Paleoecology of the Pliocene "Merced" formation, Sebastopol region, *in* Lipps, J.H., and Moores, E.M., eds., Geologic Guide to the northern Coast Ranges, Point Reyes Region, California: Annual Field Trip Guidebook of the Geological Society of Sacramento: Sacramento, Geological Society of Sacramento, p. 87-95.

Bedrossian, T.L., 1982, Geology and slope stability, West Sebastopol area: California Geology, v. 35, no. 4, p. 71-79.

Berkland, J.O., 1971, Geology of the Napa Valley area with new data on the age of the Sonoma volcanics and the underlying PF, *in* Lipps, J.H., and Moores, E.M., eds., Geologic Guide to the northern Coast Ranges, Point Reyes Region, California: Annual Field Trip Guidebook of the Geological Society of Sacramento: Sacramento, Geological Society of Sacramento p. 11-22.

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

Blake, M.C., Jr., Graymer, R.W., and Jones, D.L., 2000, Geologic map and map database of parts of Marin, San Francisco, Alameda, Contra Costa, and Sonoma Counties, California: U.S. Geological Survey Miscellaneous Field Studies MF-2337, p. 1-29.

Boggs, S., Jr., 1992. Petrology of Sedimentary Rocks: MacMillan Pub. Co., 707 p.

Borchardt, G., Seelig, K.A., and Wagner, D.L., 1988, Geology, paleosols, and crustal stability of Point Pinole Regional Shoreline, Contra Costa County, California, *in* Borchardt, G., ed., 1988, Soil development and displacement along the Hayward Fault: California Division of Mines and Geology Open-File Report 88-13, v. 2, p. 3-94.

Buising, A.V., and Walker, J.P., 1995, Preliminary palinspastic paleogeographic reconstructions for the greater San Francisco Bay Area, 15 Ma-5 Ma, *in* Sangines, E.M., Andersen, D.W., and Buising, A.B., eds., Recent geologic studies in the San Francisco Bay Area: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 76, p. 141-160.

Cant, D.J.,and Walker, R.G., 1978, Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada: Sedimentology, v. 26, p. 625-848.

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

Cebull, S.E., 1958, The structure and stratigraphy of portions of the Mare Island, Sears Point, and Richmond quadrangles, California [M.S. thesis]: Berkeley, University of California, 79 p.

Clark, J.C., Brabb, E.E., Greene, H.G., and Ross, D.C., 1984, Geology of Point Reyes Peninsula and implications for San Gregorio fault history, *in* Crouch, J.K., and Bachman, S.B., eds., Tectonics and sedimentation along the California margin: Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineral-ogists, v. 45, p. 67-86.

Coleman, J.M., and Wright, L.D., 1975, Modern river deltas: variability of processes and sand bodies, *in* Broussard, M.L., ed., Deltas, Models for Exploration: Houston, Houston Geological Society, v. 21, p. 99-149.

Collins, L.M., 1992, Possible evidence for faulting at the Petaluma marsh, *in* Wright, T.L. ed., Field Trip Guide to Late Cenozoic Geology in the North Bay Area Region, Northern California Geological Society, p. 107-113.

Compton, R.R., 1985. Geology in the Field: New York, John Wiley & Sons, 398 p.

Cowan, D.S., 1974, Deformation and metamorphism of the Franciscan subduction zone complex northwest of Pacheco Pass, California: Geological Society of America Bulletin, v. 85, p. 1623-1634.

Coyle, J.M., 1984, Bedrock and surficial geology of the San José, Milpitas foothills area, Santa Clara County, California [M.S. thesis]: San José State University, 234 p.

Creely, S., Savage, D.E., and Ogle, B.A., 1982, Stratigraphy of upper Tertiary non-marine rocks of central Contra Costa basin, California, *in* Ingersoll, R.V., and Woodburne, M.O., eds., Cenozoic nonmarine deposits of California and Arizona: Society for Economic Paleontologists and Mineralogists, Pacific Section, v. 38, 122 p.

Crittenden, M.D., 1951, Geology of the San José-Mount Hamilton area, California: California Division of Mines and Geology Bulletin 157, 74 p.

Curtis, G.H., Evernden, J.F., and Lipson, J., 1958, Age determinations of some granitic rocks in California by the potassium-argon method: California Division of Mines Special Report 54, 16 p.

Curtis, G.H., 1989, Berkeley Hills *in* Warhaftig C., ed., Geology of San Francisco and vicinity, 28th International Geological Congress Field Trip Guidebook T105: Washington D.C., American Geophysical Union, p. 47-52.

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

Department of Water Resources, 1979, Meeting groundwater demands in the City of Rohnert Park: State of California, the Resources Agency, Department of Water Resources, Central District, 127 p., 7 plates.

Dickerman, S.I., 1999, Coarse clasts of the upper Miocene Contra Costa Group, west-central California [M.S. thesis]: California State University, Hayward, 226 p.

Dickerson, R.E., 1922, Tertiary and Quaternary history of the Petaluma, Point Reyes, and Santa Rosa quadrangles: California Academy of Sciences Proceedings, ser. 5, v. 11, no. 19, p. 527-601.

Drake, D. E., Cacchione, D. A., Gardner, J. V., and McCulloch, D.S., 1989, Morphology and growth history of Delgada fan: Implications for the Neogene evolution of Point Arena Basin and the Mendocino Triple Junction: Journal of Geophysical Research, v. 94, no. B3, p. 3139-3158.

Eichhubl, P., and Boles, J.R., 1998, Vein formation in relation to burial diagensis in the Miocene Monterey Formation, Arroyo Burro Beach, Santa Barbara, California, *in* Eichhubl, P., ed., 1998, Diagenesis, deformation, and fluid flow in the Miocene Monterey Formation: Society for Economic Paleontologists and Mineralogists, Pacific Section, Book 83, p. 1-96.

Evernden, J.F., Savage, D.E., Curtis, G.H., and James, G.T.,1964, Potassium-argon dates and the Cenozoic mammalian chronology of North America: American Journal of Science, v. 262, no. 8, p. 145-198.

Firby, J.R., 1967, Pliocene nonmarine mollusks from Contra Costa County, California: Proceedings of California Academy of Sciences, 4th Series, v. 34, no. 14.

Folk, R.L., 1974, Petrology of Sedimentary Rocks: Austin, Texas, Hemphills, 218 p.

Fox, K.F., Jr., Sims, J.D., Bartow, J.A., and Helley, E.J., 1973, Geologic Map of Eastern Sonoma County and Western Napa County, California, Miscellaneous Field Studies Map MF-483, Sheet 2 of 4.

Fox, K.F., Jr., 1983, Tectonic setting of late Miocene, Pliocene, and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S. Geological Survey Professional Paper 1239, p. 1-33.

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

Gabb, W.M., 1866, Tertiary invertebrate fossils California Geological Survey, Paleontology, v. 2, sec. 1, pt. 1, p. 1-38.

Gabb, W.M., 1869, Paleontology of California: California Geological Survey, v. 2, 125 p.

Galloway, A.J., 1977, Geology of the Point Reyes Peninsula, Marin County, California: California Division of Mines and Geology Bulletin, v. 202, 72 p.

Gealey, W.K., 1951, Geology of the Healdsburg quadrangle, California: California Division of Mines Bulletin 161, 76 p.

Graham, S.A., McCloy, C., Hitzman, M., Ward, R., and Turner, R., 1984, Basin evolution during change from convergent to transform continental margin in central California: American Association of Petroleum Geologists Bulletin, v. 68, no. 3, p. 233-249.

Graymer, R.W. and DeVito, L., 1993, Geology of the southeastern Bay Area Hills: A field trip for the Peninsula Geological Society, 20 p.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1995, Geology of the Hayward fault zone: A digital map database: U.S. Geological Survey Open-File Report 95-597, 16 p.

Graymer, R.W, Jones, D.L., and Brabb, E.E., 1996, Preliminary geologic map emphasizing bedrock formations in Alameda County, California: A digital database: U.S. Geological Survey Open-File Report 96-252.

Graymer, R.W., 2000, Geologic map and map database of the Oakland Metropolitan area, Alameda, Contra Costa, and San Francisco Counties, California: U.S. Geological Survey Miscellaneous Field Studies MF-2342.

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

Grimsich, J.L., Scott, G.R., Swisher, C.C., III, and Curtis, G.H., 1996, Paleomagnetism and 40Ar/39Ar dating of the Miocene Contra Costa Group, Berkeley Hills, California: Eos, Transactions, American Geophysical Union, v. 77, no. 46, p. 165.

Ham, C.K., 1951, Geology of Las Trampas Ridge and Vicinity, California [M.A. thesis], Berkeley, University of California, 90 p.

Harms, J.C., Southard, J.B., Spearing, D.R., and Walker, R.G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists, Short Course 2, 161 p.

Hein, James R., 1973, Increasing rate of movement with time between California and the Pacific Plate from Delgada submarine fan source areas: Journal of Geology, v. 78, no. 32, p. 7752-7762.

Helley, E.J., Lajoie, K.R., Spangle, W.E., and Blair, M.L., 1979, Flatland deposits of the San Francisco Bay Region, California - Their geology and engineering properties, and their importance to comprehensive planning: U.S. Geological Survey Professional Paper 943, 88 p.

Heward, A.P., 1978, Alluvial fan sequence and megasequence models: with examples from Westphalian D-Stephanian B coalfields, Northern Spain, *in* Miall A.D., ed., Fluvial Sedimentology: Calgary, Memoir of the Canadian Society of Petroleum Geologists, pp. 669-702.

Higgins, C.G., 1960, Ohlson Ranch formation, Pliocene, northwestern Sonoma County, California: University of California Publications on Geological Sciences, v. 36, no. 3, p. 199-231.

Hill, J.M., 1978, Stratigraphy and Paleoenvironment of the Miocene Monterey Group in the East San Francisco Bay Region, California [M.S. thesis]: San José State University, 113 p.

Hill, J.M., 1979, Stratigraphy and paleoenvironment of Miocene phosphatic rocks in the East San Francisco Bay Region, California: U.S. Geological Survey Open-File Report 79-1570, p. 1-69.

Hitchcock, C.S., and Kelson, K.I., 1998, Assessment of seismogenic sources between the Rodgers Creek and San Andreas faults, northwestern San Francisco Bay Region, Sonoma County, California: U.S. Geological Survey National Earthquake Hazards Reduction Program Award 1434-HQ-97-GR-03153, p. 1-55.

Holland, P.J., and Allen, J.R., 1998, Description and interpretation of the late Miocene –early Pliocene WGF at Steinbeck Ranch, Sonoma County, California: Geological Society of America Abstracts with Programs, v. 30, n. 7, p. A339.

Hopson, C.A., Mattison, J.M., and Pessago, E.A., Jr., 1981, Coast Range ophiolite, western California, *in* Ernst, W.G., ed., The Geotectonic Development of California: New Jersey, Prentice Hall, Rubey, vol. 1, p. 307-328.

Huffman, M.E., and Armstrong, C.F., 1980, Geology for planning in Sonoma County: California Division of Mines and Geology Special Report 120, 31 p.

Issacson, K.A., 1990, Late Tertiary synorogenic sedimentation in the northern Livermore basin, California [M.S. thesis]: San José State University, 104 p.

James, E.W., Kimbrough, D.L., and Mattinson, J.M., 1993, Evaluation of displacements of pre-Tertiary rocks on the northern San Andreas fault using U-Pb zircon dating, initial Sr, and common Pb isotopic ratios, *in* Powell, R.E., Weldon, R J., II, and Matti, J.C., eds., The San Andreas fault system; displacement, palinspastic reconstructions, and geologic evolution: Geological Society of America Memoir 178, p. 257-271.

Johnson, F.A., 1934, Geology of the Merced, Pliocene, Formation north of San Francisco Bay, California [Ph.D. thesis]: Berkeley, University of California, 148 p. and atlas of plates.

Lawson, A.C., 1894, The geomorphology of the coast of Northern California: University of California Publications in Geography, v. 1, no. 8, p. 241-271.

Lawson, A.C., 1914, Description of the San Francisco District; Tamalpais, San Francisco, Concord, San Mateo, and Hayward quadrangles: U.S. Geological Survey Geological Atlas Folio 193, 24 p., scale 1:65,500.

Lillis, P.G., Magoon, L.B., Stanley, R.G., McLaughlin, and Warden, A., 1999, Characterization of northern California petroleum by stable carbon isotopes: U.S. Geological Survey Open-File Report 99-164, 19 p.

Liniecki, M., 1983, Lacustrine facies of the Mulholland Fm. (upper Miocene, upper Contra Costa Group), Moraga, Central California, *in* Cherven, V.B., and Graham, S.A., eds., Geology and sedimentology of the southwestern Sacramento Basin and East Bay Hills: Los Angeles, Society of Economic Paleontologists and Mineralogists, Pacific Section, Field Trip Guidebook, p. 93-99.

Liniecki-Laporte, M., and Andersen, D.W., 1988, Possible new constraints on late Miocene depositional patterns in west-central California: Geology, v. 16, p. 216-220.

Louderback, G.D., 1951, Geologic history of San Francisco bay: California Division of Mines and Geology Bulletin 154, p. 75-94.

McKee, E.D., and Weir, G.W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geological Society of America Bulletin: v. 64, p. 381-389.

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

McLaughlin, R.J., Sarna-Wojcicki, A.M., Fleck, R.J., Jachens, R.C., Graymer, R.W., Walker, J.P., and Valin, Z.C., 2000, Evolution of the San Francisco Bay structural block and northeastward migration of the San Andreas fault system, *in* Bokelmann, G, and Kovach, R.L, eds., Proceedings of the 3rd Conference on Tectonic Problems of the San Andreas Fault System: Stanford University Publications, v. 21, p. 370.

Miall, A.D., 1977, A review of the braided river depositional environment: Earth Science Review, v. 13, p. 1-62.

Miall, A.D., 1978, Fluvial sedimentology: an historical review, *in* Miall, A.D., ed., Fluvial sedimentology: Toronto, Canadian Society of Petroleum Geologists Memoir, v. 5, p. 1-47.

Miall, A.D., 1995, Description and interpretation of fluvial deposits: a critical perspective: Sedimentology, v. 42, p. 379-384.

Morrell, R.P., 1978, Geology and mineral paragenesis of Franciscan metagraywacke near Paradise Flat, northwest of Pacheco Pass, California [MS thesis]: Stanford University, 73 p.

Morse, R.R., and Bailey, T.L., 1935, Geological observations in the Petaluma district, California: Geological Society of America Bulletin, v. 46, p. 1437-1456.

Murata, K.J., and Whiteley, K.R., 1973, Zeolites in the Miocene Briones sandstone and related formations of the central Coast-Ranges, California: Journal of Research of the U.S. Geological Survey, v. 1, no. 3, p. 225-254.

Nakata, J.K., Sorg, D.H., Russell, P.C., Meyer, C.E., Wooden, J., Lamphere, M.A., McLaughlin, R.J, Sarna-Wojcicki, A.M., Saburomaru, J.Y., Pringle, M.S., and Drinkwater, J., 1993, New radiometric ages and tephra correlations from the San José and the northeastern part of the Monterey 1:100,000 map quadrangles, California: Isochron/West, v. 60, p. 19-32.

Osmont, V.C., 1905, A geological section of the Coast Ranges north of the Bay of San Francisco: California University Department of Geological Sciences Bulletin, v. 4, p. 39-87.

Pease, M.R., 1954, Geology of the Sobrante anticline and vicinity [M.S. thesis]: Berkeley, University of California, 98 p.

Peterson, D. E., and Allen, J.R., 2005, Transitional Marine, Oligohaline, Limnic Ostracode Assemblages of the Lower PF, Sonoma County, California, Geological Society of America, Cordilleran Section – 101st Annual Meeting, Paper Number 25-11.

Ponce, D. A., 2000, Principal facts for gravity data along the Hayward Fault and vicinity, San Francisco Bay Area, Northern California: U.S. Geological Survey Open-File Report 01-124, p. 1-10.

Powell, C.L., II, and Allen, J.R., 2001, Invertebrate fossils of the Wilson Grove Formation (Late Miocene - Late Pliocene), Sonoma County, Northern California: Paleobios, Abstracts, v. 21, supp. to no. 2, p. 105.

Powell, C.L., II, Allen, J.R., and Holland, P.J., 2004, Invertebrate Paleontology of the WGF (Late Miocene to Late Pliocene), Sonoma and Marin Counties, California, with some Observations on Its Stratigraphy, Thickness, and Structure: U.S. Geological Survey Open-File Report 2004-1017, 105 pgs.

Randolph Loar, C. E., 2002, Neotectonics of the southern Rodgers Creek fault, Sonoma County, California [M.S. thesis]: San Francisco State University, 54 p.

Reading, H.G., ed., 1996, Sedimentary environments: Oxford, England, Blackwell Science, Ltd., 688 p.

Roberts, C.W., and Jachens, R.C., 1993, Aeromagnetic map of the San José 1:100,000-scale quadrangle, California: U.S. Geological Survey Open-File Report 93-277.

Ross, D.C., 1972, Petrographic and chemical reconnaissance study of some granitic and gneissic rocks near the San Andreas fault from Bodega Head to Cajon Pass, California: U.S. Geological Survey Professional Paper 698, 92 p.

Rust, B.R., 1978, A classification of alluvial channel systems, *in* Miall, A.D., ed. Fluvial Sedimentology: Memoir of the Canadian Society of Petroleum Geologists, v. 5, p. 175-184.

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

Sarna-Wojcicki, A.M., Bowman, H.W., and Russell, P.C., 1979, Chemical correlation of some late Cenozoic tuffs of northern California by neutron activation analysis of glass and comparison with X-ray fluorescence analysis: U.S. Geological Survey Professional Paper 1147, 15 p.

Sarna-Wojcicki, A.M., Meyer, C.E., Slate, J.L., 1986, Displacement of a ca. 6 Ma tuff across the San Andreas fault system, Northern California: Eos Transactions, American Geophysical Union, v. 67, n. 44, p.1224.

Sarna-Wojcicki, A.M., S.D. Morrison, C.E. Meyer, and J.W. Hillhouse, 1987, Correlation of upper Cenozoic tephra layers between sediments of the western United States and eastern Pacific Ocean and comparison with biostratigraphic and magnetostratigraphic age data: Geological Society of America Bulletin, v. 98, p. 207-223.

Sarna-Wojcicki, A.M., 1992, Long-term displacement rates of the San Andreas Fault system in northern California from the 6-Ma Roblar Tuff, *in* Borchardt, G. et al., eds., Earthquake hazards in the eastern Bay Area, Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Report 113, p. 29-30.

Savage, D.E., 1951, Late Cenozoic vertebrates of the San Francisco Bay region: University of California Publications, Bulletin of the Department of Geological Sciences, v. 28, p. 215-314.

Stanley, D.J., Palmer, H.D., and Dill, R.F., 1978, Coarse sediments transport by mass flow and turbidity current processes and downslope transformations in Annot Sandstone canyon-fan valley systems, *in* Stanley, D.J., and Kelling, G., eds., Sedimentation in submarine canyons, fans and trenches: Dowdon, Hutchinson and Ross, Inc., p. 85-115.

Stanley, D.J., and Unrug, R., 1972, Submarine channel deposits, fluxoturbidites and other indicators of slope and base-of-slope environments in modern and ancient marine basins, *in* Rigby, J.K., and Hamblin, W.K., eds., Recognition of ancient sed-imentary environments: Society of Economic Paleontologists and Mineralogists, Special Publication 16, p. 287-340.

Stanley, R.G., and Lillis, P.G., 2000, Oil-bearing rocks of the Davenport and Point Reyes areas and their implications for offset along the San Gregorio and northern San Andreas faults, *in* Bokelmann, G., and Kovach, R.L., eds., Proceedings of the 3rd Conference on Tectonic Problems of the San Andreas Fault System: Stanford University Publications, v. 21, p. 371-384.

Stirton, R.A., 1952, Are Petaluma horse teeth reliable in correlation? American Association of Petroleum Geologists Bulletin, v. 36, no. 10, p. 2011-2025.

Suppe, J., 1985, Principles of structural geology: New Jersey, Prentice Hall, 537 p.

Taliferro, N.L., 1951, Geology of the San Francisco Bay counties, California: California Division of Mines and Geology Bulletin 154, p. 142-149.

Toppozada, T.R., Bennett, J.H., Hallstrom, C.L., and Youngs, L.G., 1992, 1898 "Mare Island" earthquake at the southern end of the Rodgers Creek fault, *in* Borchardt, G., et al., eds., Earthquake hazards in the eastern Bay Area, Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 385-392.

Travis, R.B., 1950, The geology of the Sebastopol Quadrangle, California [PhD Thesis]: Berkeley, University of California, 145 p., 2 plates.

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

Van Landingham, S. and Allen, J.R., 2007, Late Miocene – Pliocene Diatomites of the PF, Sonoma County, California, Geological Society of America abstracts with programs, Paper Number 235-13.

Wagner, J.R., 1978, Late Cenozoic history of the Coast Ranges east of San Francisco Bay [Ph.D. Thesis]: Berkeley, University of California, 161 p.

Wagner, D.L., and Bortugno, 1982, Santa Rosa Quadrangle: California Division of Mines and Geology, Regional Geologic Map Series, Map 2A (Geology), scale 1:250,0000.

Wagner, D.L., Bortugno, E.J. and McJunkin, R.D., 1990, Geologic Map of the San Francisco - San José Quadrangle: California Division of Mines and Geology, scale 1:250,000.

Wahrhaftig, Clyde, and J.H. Birman, 1965, The Quaternary of the Pacific mountain system in California, *in* Wright, Jr., H.E. and Frey, D.G., eds., The Quaternary of the United States: Princeton, Princeton University Press, p. 299-340.

Wakabayashi, J., 1999, Distribution of displacement on and evolution of a young transform fault system: the northern San Andreas fault system, California: Tectonics, v. 18, no. 6, p. 1245-1274.

Weaver, C.E., 1949, Geology of the Coast Ranges immediately north of the San Francisco Bay Region, California: Geological Society of America Memoir 35, 242 p.

Wentworth, C.M., Blake, M.C., Jr., McLaughlin, R.J., and Graymer, R.W., 1999, Preliminary geologic description of the San José 30' X 60' quadrangle, California: U.S. Geological Survey Open-File Report 98-795, 52 p.

Whitney, J.D., 1865, Geology of California: California Geological Survey, v. 1, p. 83-85.

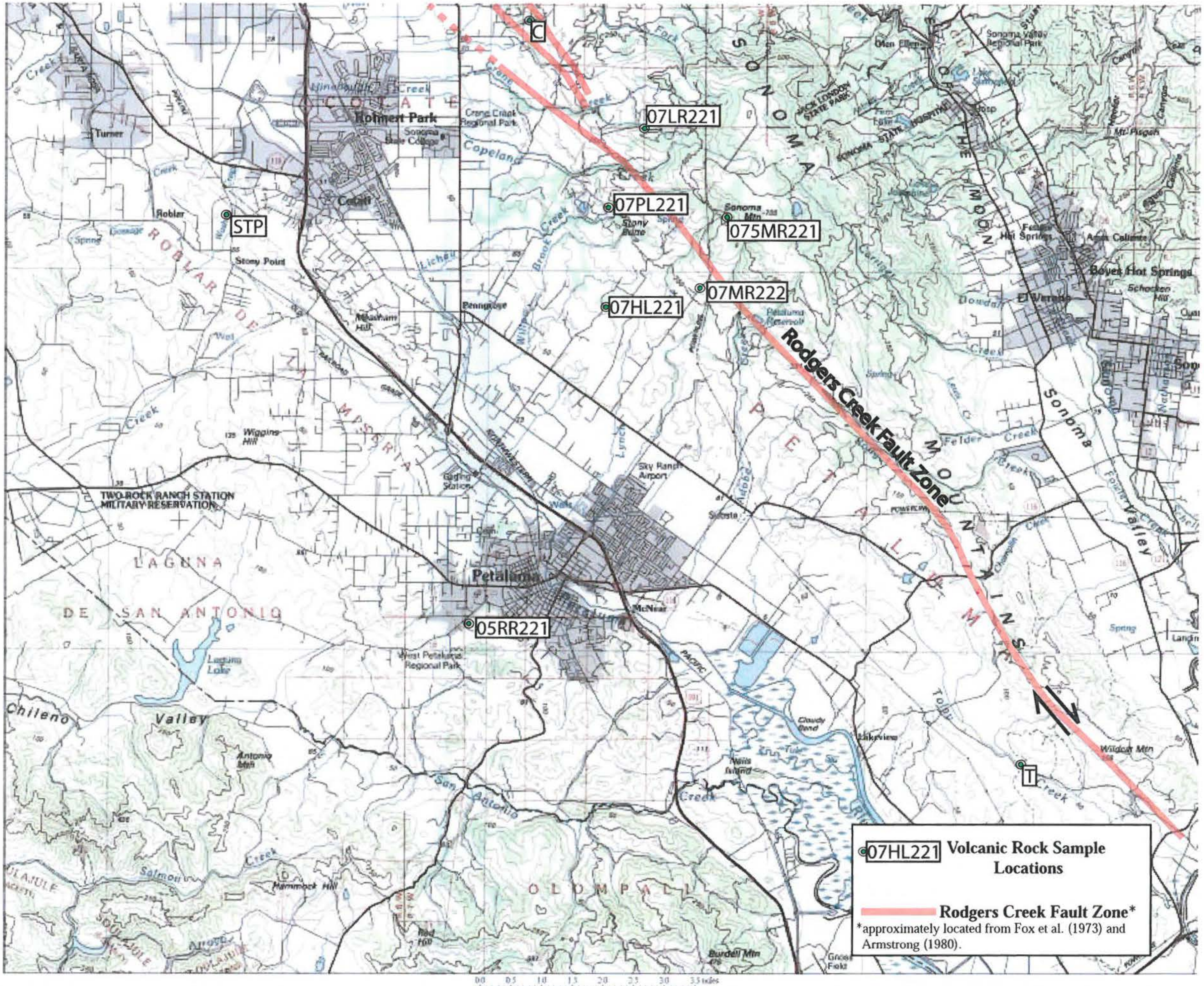
Wills, M.A., 1995, The Pliocene alluvial gravels in the southeastern Santa Clara Valley, California, [M.S. thesis]: San José State University, 92 p.

Working Group on California Earthquakes Probabilities, 1999, Earthquake Probabilities in the San Francisco Bay Region: 2000 to 2030- A Summary of Findings: United States Geological Survey Open File Report 99-517, Online Version 1.0.

Wright, T.L., and Smith, N., 1992, Right step from the Hayward fault to the Rodgers Creek fault beneath San Pablo Bay, *in*: Borchardt, G., et al., eds., Earthquake hazards in the eastern Bay Area, Proceedings of the second conference on earth-quake hazards in the eastern Bay Area: California Division of Mines and Geology Special Report 113, p. 407-417.

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

Appendix 1


C
07LR221
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07HL221
Rodgers Creek Fault Zone
05RR221
T
07HL221 Volcanic Rock Sample Locations
Rodgers Creek Fault Zone*
*approximately located from Fox et al. (1973) and Armstrong (1980).

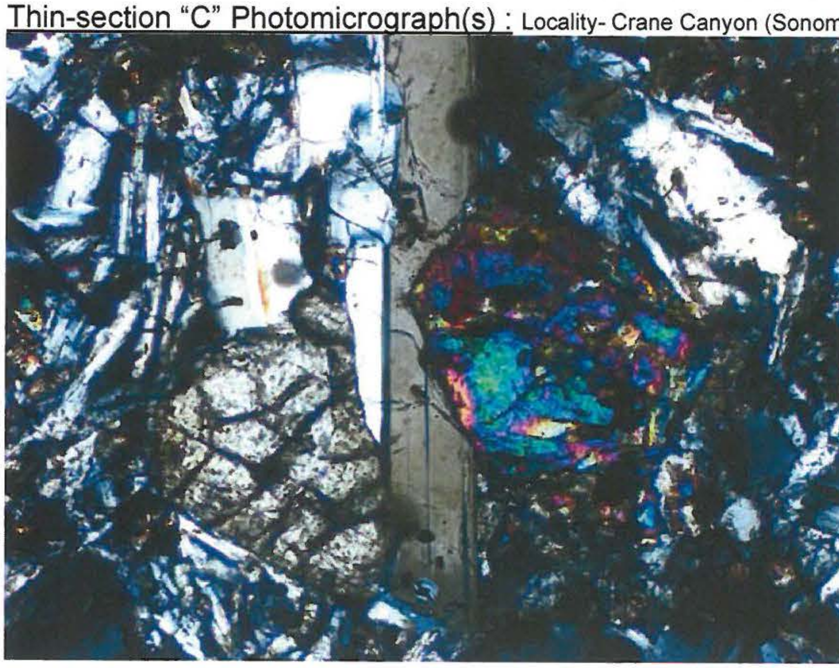
Petrographic Analysis of Volcanic Rocks From the Burdell, Tolay and Sonoma Volcanics

By

James Wilen Jr.
February-June, 2008

Thin-Section "C" IUGS Nomenclature:	Calcic Clinopyroxene Plagioclase Phyric Basaltic Andesite	
Thin-Section "C" Mineral % List:	Groundmass	79%
	-plagioclase microlites	
	-unidentified opaque mineral	
	-brown glass	
	-calcic clinopyroxene (augite?)	
	Plagioclase Feldspar	11%
	-An40 Andesine	
	Calcic Clinopyroxene (Augite?)	5%
	Glomerophyric aggregate	3%
	Amphibole (Hornblende?)	1%
	Olivine?	1%

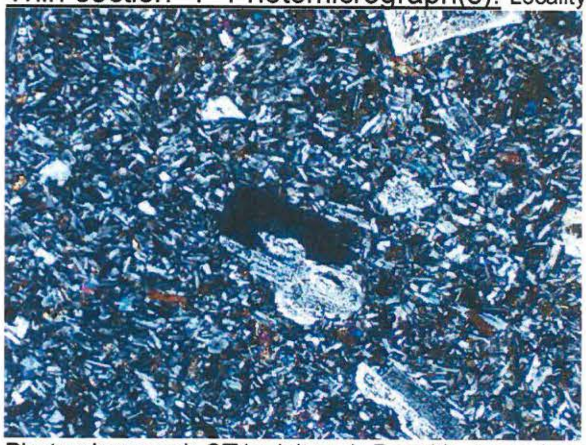
Thin-section "C" Photomicrograph(s) : Locality- Crane Canyon (Sonoma Volcanics)



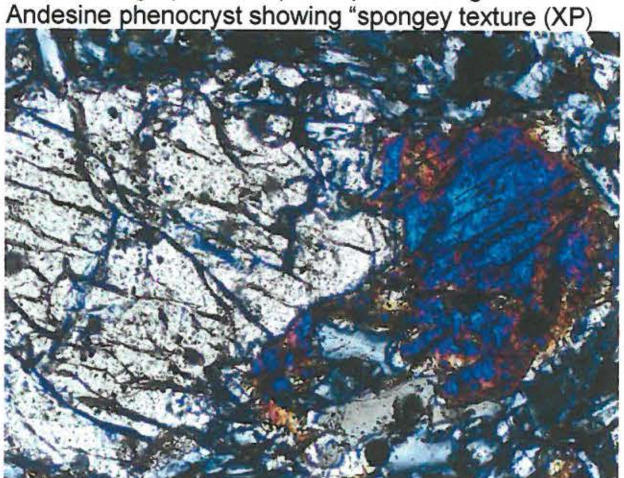
Photomicrograph C6a: Plagioclase Feldspar – An40 Andesine phenocryst + hi-birefringence ferro-magnesian minerals (olivine? Calcic-clinopyroxene?) (XP)

Thin-Section "T" IUGS Nomenclature:	Plagioclase Phyric Basaltic Andesite	
Thin-Section "T" Mineral % List:	Groundmass	78%
	-plagioclase microlites	
	-calcic clinopyroxene (augite?)	
	-brown glass	
	Plagioclase Feldspar	13%
	-An38 Andesine	
	Unknown Fe-ox material (altered olivine?)	4%
	Calcic Clinopyroxene (Augite?)	3%
	Glomerophyric aggregate	2%
	Amphibole (Hornblende?)	<1%

Thin-section "T" Photomicrograph(s): Locality-Tolay Volcanics; Mangel Ranch Road



Photomicrograph CT1a (above): Basaltic groundmass with Plagioclase Feldspar – An38 Andesine phenocryst showing "spongey texture (XP)



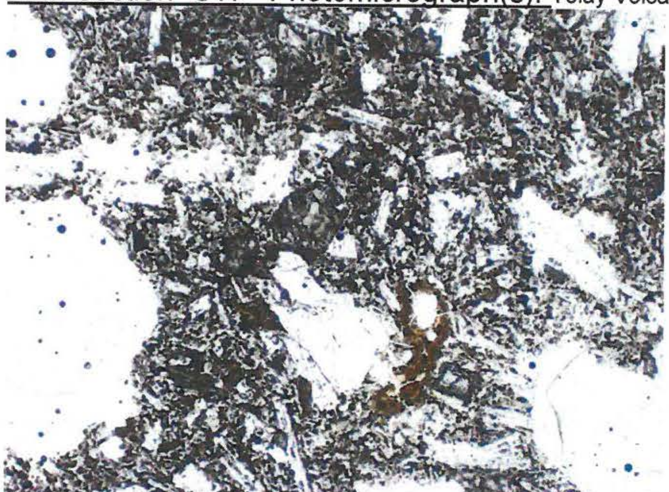
Photomicrograph CT4a (above): Calcic-clinopyroxene (Augite?) phenocryst (XP)

Thin-Section "STP" IUGS Nomenclature: Vesicular Plagioclase Phyric Basalt

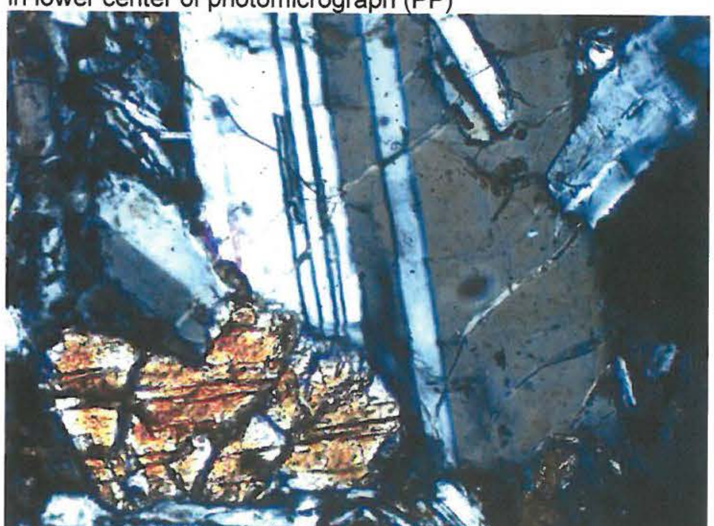
Thin-Section "STP" Mineral % List:

Groundmass	72%
-plagioclase microlites	
-brown glass	
-unidentified opaque mineral	
Plagioclase Feldspar	18%
-An35 Andesine	
Calcic Clinopyroxene (Augite?)	4%
Vesicle filling Fe-ox or clay	3%
Glomerophyric aggregate	2%
Amphibole (Hornblende?)	<1%
Olivine?	<1%

Thin-section "STP" Photomicrograph(s): Tolay Volcanics, Stony Point Rock Quarry



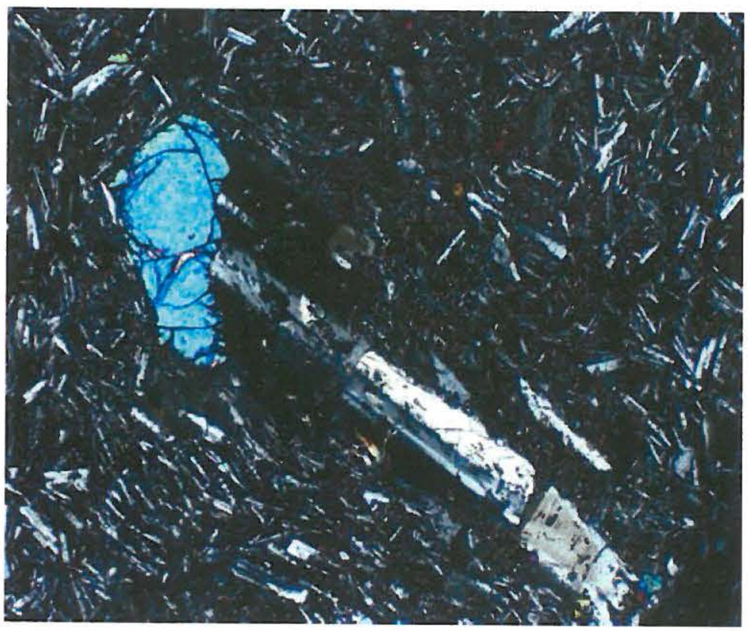
Photomicrograph CTS2a:Basaltic groundmass showing vesicles and clay mineral in-fill of vesicle in lower center of photomicrograph (PP)



Photomicrograph CTS5b:Plagioclase Feldspar-An35 Andesine phenocryst + calcic-clinopyroxene phenocryst (XP)

Thin-Section "07LR221" IUGS Nomenclature:	Plagioclase Phyric Basaltic Andesite	
Thin-Section "07LR221" Mineral % List:	Groundmass	74%
	-plagioclase microlites	
	-green glass	
	-unidentified black opaque mineral	
	-calcic clinopyroxene (augite?)	
	-various iron oxides	
	Plagioclase Feldspar	23%
	-An33 Andesine	
	Calcic Clinopyroxene (Augite?)	<1%
	Glomerophyric aggregate	2%

Thin-section "07LR221" Photomicrograph(s)

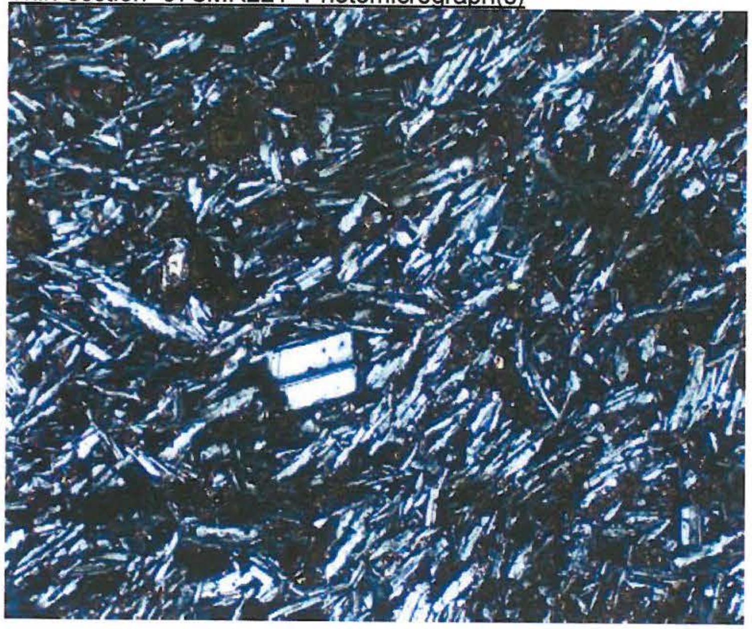


Thin-Section "07SMR221" IUGS Nomenclature: Aphanitic Basaltic Andesite

Thin-Section "07SMR221" Mineral % List:

Groundmass	93%
-plagioclase microlites	
-calcic clinopyroxene (augite?)	
-unidentified black opaque mineral	
-brown glass	
-various iron oxides (altered olivine?)	
Plagioclase Feldspar	3%
-An33 Andesine	
Glomerophyric aggregate	4%

Thin-section "07SMR221" Photomicrograph(s)

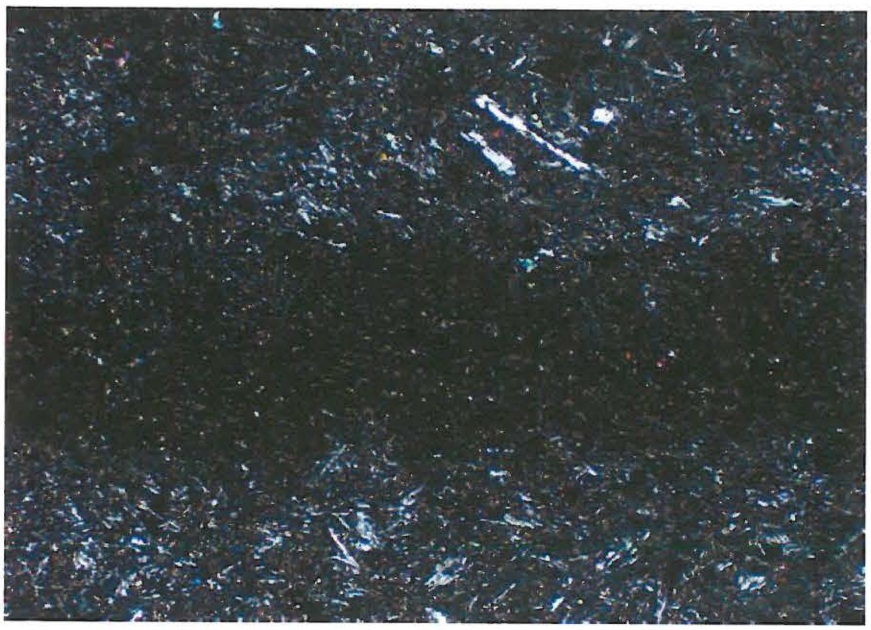


Thin-Section "07HL221" IUGS Nomenclature: Flow-banded Aphanitic Basaltic Andesite

Thin-Section "07HL221" Mineral % List:

Groundmass	98%
-plagioclase microlites	
-calcic clinopyroxene (augite?)	
-green glass	
-unidentified black opaque mineral	
-various iron oxides (altered olivine?)	
Plagioclase Feldspar	2%
-An40 Andesine	

Thin-section "07HL221" Photomicrograph

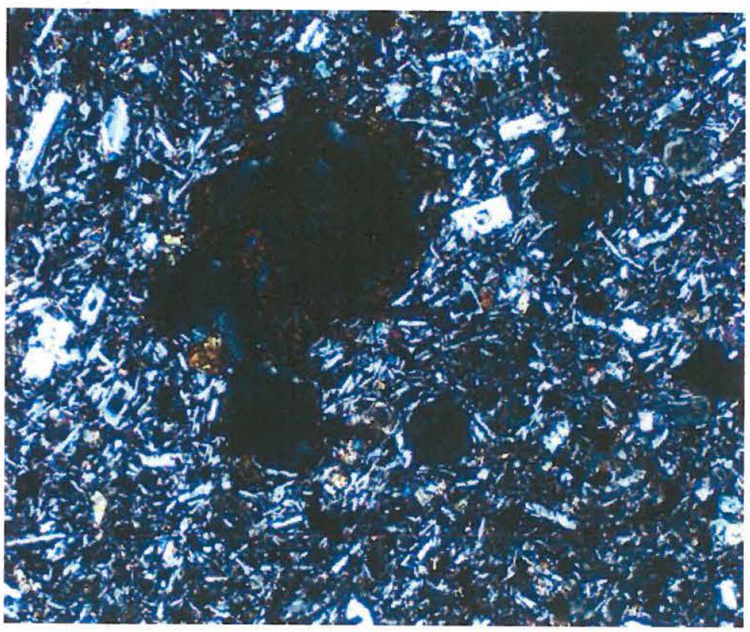


Thin-Section "07SMR222" IUGS Nomenclature: Vesicular Calcic Clinopyroxene Plagioclase Phyric Andesite

Thin-Section "07SMR222" Mineral % List:

Groundmass	55%
-plagioclase microlites	
-unidentified black opaque mineral	
-reddish brown glass	
-calcic clinopyroxene (augite?)	
-various iron oxides	
Plagioclase Feldspar	20%
-An39 Andesine	
Calcic Clinopyroxene (Augite?)	5%
Amphibole (Hornblende)	4%
Reddish brown glass/iron oxides	11%
Unidentified black opaque mineral	5%

Thin-section "07SMR222" Photomicrograph



Thin-Section “07PL221” IUGS Nomenclature: Calcic Clinopyroxene Plagioclase Phyric Andesite

Thin-Section “07PL221” Mineral % List:

Groundmass	71%	
-plagioclase microlites		
-calcic clinopyroxene (augite?)		
-brown glass/green glass		
-unidentified black opaque mineral		
-various iron oxides		
Plagioclase Feldspar		19%
-An38 Andesine		
Calcic Clinopyroxene (Augite?)		9%
Glomerophyric aggregates		<1%

Thin-section “07PL221” Photomicrograph:

Thin-Section "05RR221" IUGS Nomenclature: Plagioclase Phyric Andesite

Thin-Section "05RR221" Mineral % List:

Groundmass	80%
-plagioclase microlites	
-ortho-clinopyroxene?	
-brown glass	
Plagioclase Feldspar	10%
-An32 Andesine	
Ortho-Clinopyroxene?	3%
Amphibole (Hbl/Oxyhbl?)	3%
Glomerophyric aggregates	4%

Thin-section "05RR221" Photomicrograph: Benjamin Avenue, Petaluma, Burdell Mountain Volcanics