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STRATIGRAPHY AND TECTONICS OF NEOGENE STRATA,
NORTHERN SAN FRANCISCO BAY AREA

A Thesis

Presented to

The Faculty of the Department of Geology

San José State University

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science

By

James Rollin Allen

May 2003

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ABSTRACT

STRATIGRAPHY AND TECTONICS OF NEOGENE STRATA, NORTHERN SAN FRANCISCO BAY AREA

By James R. Allen

The coeval upper Miocene-lower Pliocene Wilson Grove and Petaluma formations in the northern San Francisco Bay Area represent fluvial flood-plain to open-ocean deposition. Sediment was derived from the Franciscan Complex during the late Miocene, but by Pliocene time, detritus also was derived from Tertiary sedimentary sources in the eastern Bay Area.

The Wilson Grove and Petaluma formations are correlated to other Tertiary units in the eastern Bay Area based on similar clasts, stratigraphy, tephra units, and paleocurrent and paleontologic data. Unique veined sandstone clasts in the upper part of the Petaluma were derived from a source east of San José.

These data suggest that the Wilson Grove and Petaluma formations were displaced 67 km from similar units and source rocks of the eastern Bay Area along the Silver Creek-Hayward-Sonoma Valley-Healdsburg-Maacama fault system at 18 mm/yr from 5 to 2.5 Ma and 8 mm/yr from 2.5 Ma to the present.

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Robert J. McLaughlin of the U.S. Geological Survey (USGS) walked U.S. 101 and visited many other areas with me. He was very understanding when I would spontaneously stop by his office without an appointment to unload all my questions on

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Ronald Lue (Sonoma State University) and James Walker (USGS) conducted X-ray diffraction and microprobe work on sandstone clasts and the veins within them. Dr. Kenneth Finger of the University of California Museum of Paleontology provided a micropaleontological report of Monterey clasts in thin section. Kris McDougall (USGS) also worked on thin-sectioned Monterey clasts for micropaleontology.

Charles Powell, II (USGS) conducted a comprehensive paleontological study on the marine invertebrate fossils of the Wilson Grove Formation. Dawn Peterson of the California Academy of Sciences (CAS) conducted a full study of ostracodes in the basal Petaluma Formation. Elizabeth Ruck (CAS) and Louis Marincovich (CAS) identified key marine fossils from the middle Petaluma Formation. Dr. Charles Repenning (USGS retired) identified vertebrate fossils.

I thank Dr. Rick Stanley (USGS), Dr. Russell Graymer (USGS), Dr. John Wakabayashi (independent geologist), and Dr. Anna Buising (independent geologist) for discussions about various aspects of this project.

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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 Wilson Grove Formation and nonmarine-transitional marine Petaluma Formation of Sonoma and Marin counties, and the nonmarine “Garrity Member” of the Contra Costa Group in Contra Costa County. Study areas are shown as shaded rectangles in 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 Wilson Grove Formation, Petaluma Formation, and “Garrity Member” of the Contra Costa Group 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 1. General location map. Shaded rectangles show locations of plates 1-4. Dashed line is boundary of Sonoma County.

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.

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).

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 Yolly 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 Wilson Grove and Petaluma formations 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 graywacke. 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).

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.

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 Wilson Grove Formation 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 $\pm$ 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 Wilson Grove Formation in the Healdsburg area, south of the Wilson Grove at 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. 1) 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, the Pliocene Merced Formation, and Quaternary deposits (Galloway, 1977).

Tertiary Rocks

Late Tertiary strata are widespread in the Bay Area. The Wilson Grove Formation, Petaluma Formation, and “Garrity Member” of the Contra Costa Group (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.

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. 1) (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).

The San Pablo Group is composed of the marine Briones Formation, marine Cierbo Formation, and marine to nonmarine Neroly Formation (Weaver, 1949). The San

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

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.

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).

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).

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).

The Moraga Formation is conformably overlain by the Siesta Formation, which 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).

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 Petaluma Formation of Sonoma County.

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).

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.

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.

The Huichica Formation north of San Pablo Bay (Fig. 4) 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 Huichica Tuff (Fox, 1983).

The Glen Ellen Formation in the Santa Rosa area (Fig. 4) 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

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 (in pocket). Figure 1 shows the area covered by each plate.

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 A.

Sandstone samples (locations shown on Plates 1, 2, 3, and 4) 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 Wilson Grove Formation, the Petaluma Formation, and the “Garrity Member” of the Contra Costa Group (Appendix B; Plates 2, 3, and 4). At each sample locality (shown on Plates 2, 3, and 4), at least 300 clasts were collected from an area about 1 m². 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.

Clast imbrication was observed at many conglomerate sample locations, and paleocurrent measurements were recorded at 13 stations (Appendix D). 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 Wilson Grove Formation, Petaluma Formation, and Garrity Member of the Contra Costa Group. 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 Wilson Grove Formation 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 Wilson Grove Formation by Davies (1986). Fox (1983) reported that this interbedded sequence unconformably overlies the Wilson Grove and Petaluma formations, whereas Davies (1986) correlated this sequence with the uppermost Petaluma Formation.

The upper Miocene-Pliocene Petaluma Formation (Dickerson, 1922; Youngman, 1989) was divided by Morse and Bailey (1935) into the Lower Petaluma Formation, consisting predominantly of mudstone, and the Upper Petaluma Formation, consisting of sandstone and conglomerate. Morse and Bailey (1935) did not further subdivide the Upper Petaluma Formation, 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 Petaluma formations into the Petaluma Formation. I consider Morse and Bailey's "Lower Petaluma Formation" to be an informal lower member of the Petaluma Formation. I assign rocks of Morse and Bailey's "Upper Petaluma Formation" to informal middle and upper members of the Petaluma Formation 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 Wilson Grove Formation and conglomerate of the western Petaluma Formation to an informal map unit referred to as the "Interbedded Wilson Grove and Petaluma formations" (Plate 2). 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) 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. Borchardt et al. (1988) described volcanic clasts as derived from the Berkeley Hills and noted the abundance of Monterey clasts.

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. 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.

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).

DESCRIPTION OF SEDIMENTARY UNITS

Late Cenozoic units on which this study focuses are the Wilson Grove Formation, the Petaluma Formation, an informal map unit called “Interbedded Wilson Grove and Petaluma formations,” and the Garrity Member of the Contra Costa Group.

Wilson Grove Formation

The Wilson Grove Formation 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 Wilson Grove sandstone is interbedded with Petaluma conglomerate from its base to its top; this interbedded zone will be discussed in a section following the Petaluma Formation.

Basal Contact and Thickness

The Wilson Grove Formation 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 Wilson Grove Formation at Spring Hill, an erosional disconformable contact is indicated.

Thickness varies throughout the Wilson Grove Formation due to the irregular basin it filled (Johnson, 1934). The restored minimum thickness of the Wilson Grove Formation 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., 2003).

Physical Stratigraphy

The lithology of the Wilson Grove changes 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 Wilson Grove Formation is especially well-exposed at Estero San Antonio (Figs. 1, 8; Plate 1). A 5-m-thick, clast-supported basal conglomerate consists of poorly sorted, angular clasts of 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. 9). 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. 10) and unconformably overlies the Franciscan Complex elsewhere. Burrows in the underlying sandstone are in-filled by

Figure 7. Thickness of Wilson Grove Formation from cross-section analysis (Powell et al.)

Figure 7. Thickness of Wilson Grove Formation from cross-section analysis (Powell et al., 2003). See Powell et al. (2003) for locations of cross-section lines.

Thickness sections

Wilson Grove Formation From Cross Sections

field fault

ion

ummocky cross-stratified marine sandstone.
n the southwest near Dillon Beach, Tomales,
nerate along the hills that border the Santa
an Complex clasts at the base and Monterey
ion, above tuffaceous sandstone. Contains the
n blue; dashed where inferred) northwest of

┆ Borehole data
(Cardwell, 1958)

┆ Borehole data
(Eugene Boudreau,
consulting geologist,
pers. comm., 2002)

ection analysis (Powell et al., 2003). See Powell et al. (2003) for locations of cross-section lines.

Figure 8. Measured sections of lowermost Wilson Grove west of Valley Ford-Franklin School Road along Estero San Antonio.

A.

B.

Figure 9. 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 10. 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.

overlying coarse-grained sandstone (Fig. 11). 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 A; Plate 1).

The central outcrops of the Wilson Grove Formation between the towns of Bloomfield, Bodega, and Sebastopol and west of the Santa Rosa Valley (Fig. 1) 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. 12, 13, and 14). 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; Fig. 15). 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) (Fig. 7). The tuff contains dish structures. The Roblar is overlain by fine- to medium-grained sandstone (Fig. 15) that contains fossiliferous lenses that are approximately 15 m long and 25 cm thick. Invertebrate fossils in these lenses consist of disarticulated, broken

A.

B.

Figure 11. A. Erosional contact between coarse-grained and fine-grained sandstone in the Wilson Grove Formation. Burrows in lower, fine-grained sandstone are in-filled by overlying coarse-grained sandstone. B. In-filled burrows in lower fine-grained sandstone. One burrow is outlined.

Figure 12. Composition of sandstones from the Wilson Grove Formation. Sample numbers are on Plates 1 and 2.

Figure 13. Photomicrographs of Wilson Grove Formation sandstone. Grains are predominantly monocrystalline quartz, polycrystalline quartz, plagioclase, chert and minor volcanic and metamorphic rock fragments. Cement is calcite. G: Glauconite; O: Olivine

Figure 14. Photograph and sketch of hummocky cross-stratified (HCS) sandstone in the Wilson Grove Formation. Arrows show base of hummock.

Figure 15. Photograph and sketch of Roblar Tuff outcrop at Steinbeck Ranch.

pelecypods and gastropods that are typically packed tightly.

Age

The Wilson Grove ranges 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., 2003). The ~6-Ma Roblar Tuff has been identified in this formation (Sarna-Wojcicki, 1992).

Sand dollars (*Scutellaster oregonensis*) from the base of the Wilson Grove Formation at Spring Hill (Fig. 1) 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 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 Wilson Grove (Bedrossian, 1971).

Late Pliocene marine fossils occur at the top of the Wilson Grove near Trenton (Fig. 1) (Powell and Allen, 2001; Powell et al., 2003).

Petaluma Formation

The Petaluma Formation 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 (Figs. 1, 4). The formation is covered by Quaternary alluvium in the Santa Rosa-Cotati plain and is exposed from the Cotati area south to Sears Point (Cardwell, 1958) (Figs. 1, 4). 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. 16). The basis of this revision is the composition of conglomerate clasts, with Franciscan-derived clasts predominant in the middle Petaluma Formation and Monterey-derived clasts predominant in the upper Petaluma Formation. These compositional differences were noted by Morse and Bailey (1935) and are confirmed in this report.

Conglomerates of the Petaluma Formation interfinger with sandstone of the Wilson Grove Formation 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 (Plates 2, 3).

Basal Contact and Thickness

The Petaluma Formation locally overlies undated volcanic rocks and the Jurassic-Cretaceous Franciscan Complex along an angular unconformity (Youngman, 1989). Borehole data show that the Petaluma Formation overlies Tertiary volcanic rocks in the

Figure 16. 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).

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 Petaluma Formation unconformably overlies the Franciscan Complex west of the Tolay fault in the Sears Point-Lakeville area and east of the Dunham fault (Plates 2, 3).

At the Petaluma Oil Field, the Petaluma Formation 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 (Fig. 16). The lower Petaluma Formation thins to 91 m at the Stony Point Rock Quarry (Phil Frame, personal communication, 2002; Plate 2). The equal thicknesses of the middle and upper parts of the Petaluma Formation shown in Figure 16 are approximate; the precise boundary between them cannot be pinpointed because of poor exposure. 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 (Plate 2, A-A', E-E').

Physical Stratigraphy

Complete 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 (Plate 2, A-A', E-E'). 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 (Fig.

16). The following section describes the stratigraphy and lithology of the Petaluma Formation based chiefly on the outcrops in these two key areas.

The lower Petaluma Formation 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. 17). Laminae are 0.5 to 1.0 mm thick and have fissile parting (Fig. 18). Cross strata, if present, must exceed 120 cm in thickness (McKee and Weir, 1953). The thick-bedded, structureless lower Petaluma Formation contains microfossils and has flaggy to slabby parting (McKee and Weir, 1953).

In the southern Tolay Valley area, the lower Petaluma Formation includes chert, dolomite, and limestone (Fig. 19). 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 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

Figure 17. Lower Petaluma Formation ostracodal shale west of Stage Gulch Road.

Figure 18. Laminated lower Petaluma Formation.

A.

B.

Figure 19. Shale, chert, and dolomite of the lower Petaluma Formation. A. Interbedded shale (sh) and dolomite (dlm) in tributary north of Tolay Creek. B. Interbedded shale (sh), dolomite (dlm), and chert (ch) in a tributary north of Tolay Creek.

trough-cross-stratified sandstone or coarse conglomerate. Conglomerate is channelized into the uppermost portion of the lower Petaluma Formation. 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. 20). Clasts are subangular and poorly to moderately sorted.

Conglomerate clasts in the middle Petaluma Formation are dominated by Franciscan Complex material; those in the upper Petaluma Formation are dominated by Monterey sources (Fig. 6; Plates 2 and 3; Appendix B). 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. 21; Appendix D).

Sandstone is thin- to thick-bedded (a few centimeters to about 20 m thick), planar- and trough-cross-stratified (Fig. 22), low-angle cross-bedded, and plane-parallel-bedded. Sand grains are well-sorted, medium- to coarse-grained, angular to subangular, and lithic-

Figure 20. Planar-stratified, medium-grained sandstone underlain by poorly sorted conglomerate of the Petaluma Formation between Lakeville Highway and the Tolay fault.

Figure 21. 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.

A.

B.

Figure 22. 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 from the same locality. View in both photographs is east; paleocurrents from outcrops in this area indicate flow to the west.

rich. According to petrologic data (Appendix A), sandstone in both the middle and upper Petaluma is litharenite (Fig. 23-25) 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 (Figs. 23-25; Appendix A).

Age

The Petaluma Formation is late Miocene to Pliocene according to radiometric and paleontological data. Vertebrate, invertebrate, and plant fossils from the Petaluma Formation 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. All fossil descriptions, ages, and localities, as well as descriptions of their host rocks, are presented in Appendix E.

The lower Petaluma contains an interbedded mafic flow dated at about 8.5 Ma (Plate 3) (Youngman, 1989), and overlies ~9.3-Ma volcanic rocks of Graymer et al. (2002) (Plate 2). A late Miocene (Hemphillian) horse tooth was collected at the top of this unit at the Stony Point Rock Quarry (Charles Repenning, written communication, 2002).

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 (Plates 2, 3; Appendix E).

Figure 23. Composition of sandstones from the Petaluma Formation. Sample numbers are on Plate 3.

Figure 24. Photomicrographs of sandstone from the middle Petaluma Formation.

Figure 25. Photomicrographs of sandstone from the middle Petaluma Formation showing abundant volcanic lithic grains.

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 (Plate 3; Appendix E).

Interbedded Wilson Grove and Petaluma Formations

Rocks in the easternmost outcrop area of the Wilson Grove Formation are interbedded with the westernmost outcrops of the Petaluma Formation (Figs. 26, 27; Powell et al., 2003). This distinctive interbedded sequence, herein called “Interbedded Wilson Grove and Petaluma formations,” is used as an informal map unit and locally unconformably overlies the Franciscan Complex and late Miocene volcanic rocks of Fox et al. (1985) (Plate 2).

Physical Stratigraphy

The most complete sequence of these rocks crops out near the Stony Point Rock Quarry (Plate 2). At the base of the Stony Point section, about 91 m of lower Petaluma Formation shale rests on a volcanic flow (Travis, 1952; Phil Frame, personal communication, 2002). The shale is overlain by up to 30 m of Franciscan-derived Petaluma conglomerate that contains some Tertiary volcanic clasts (Plate 2; Appendix B). A thin olivine basalt overlies the conglomerate and is overlain by about 1,100 m of interbedded Wilson Grove sandstone and Petaluma conglomerate. The sandstone contains

Figure 26. Interbedded Wilson Grove and Petaluma formations. A. Photograph between the towns of Petaluma and Cotati on northbound U.S. 101. B. Close-up of marine sandstone interbedded with pelecypod casts.

Figure 27. 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.

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 (Fig. 27; Plate 2; Appendix B). 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 Petaluma Formation (Fig. 16).

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. 28), 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.

A

B Figure 28. Conglomerate bed in Wilson Grove Formation. A. Thin conglomerate beds pinch out to the west. View is to the northwest. B. Photograph of well-rounded, polished clasts.

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; Plate 2).

Garrity Member of the Contra Costa Group

Basal Contact and Thickness

The Garrity Member of the Contra Costa Group was studied at Point Pinole and San Pablo Avenue (Fig. 1; Plate 4). Between these two outcrop areas the formation is covered by Quaternary deposits and developments (Wagner, 1978; Borchardt et al., 1988). The outcrops at Point Pinole are projected to underlie the outcrops at San Pablo Avenue (Plate 4). The formation is about 1,300 m thick (Fig. 29) and overlies the San Pablo Group (Wright and Smith, 1992; Plate 4). The lower submember of the Garrity Member is bounded by the Hayward fault on the west side of Point Pinole, and the upper submember of the Garrity Member is bounded by the Moraga fault to the east (Plate 4).

Figure 29. Composite columnar section of the Garrity Member of the Contra Costa Group at Pinole, Contra Costa County. Stratigraphic section from geologic mapping at San Pablo Avenue and Point Pinole Regional Shoreline. Section thickness from Plate 4, cross section B-B'. Bounding faults from Graymer (2000).

Physical Stratigraphy

The formation is divided into two units on the basis of clast composition: the lower submember of the Garrity contains conglomerate dominated by clasts derived from Franciscan Complex sources, and the upper submember of the Garrity contains conglomerate dominated by clasts derived from the Monterey Group (Fig. 29; Plate 4; Appendix B). The upper and lower submembers of the Garrity have identical sandstone composition (Appendix A). The equal thicknesses of the lower and upper submembers of the Garrity shown in Figure 29 are approximate; the boundary between them cannot be pinpointed because of poor exposure.

Conglomerate crops out as small (up to 25 cm across) channels or as very thick (15 m) beds that may be parts of large channels or long, tabular sheets. Conglomerate beds erode into underlying units, typically as channels cut into underlying sandstone. Some erosive conglomerate beds contain load structures at their base (Fig. 30). Planar, non-erosive bases of normal-graded conglomerate beds also are present but uncommon. Conglomerate is trough- and planar-cross-stratified, poorly sorted, and clast-supported. Clasts are angular to subrounded. Paleocurrent indicators suggest westward transport (Appendix D).

Sandstone is fine- to medium-grained, angular litharenite and feldspathic litharenite (Fig. 31; Appendix A). Sandstone beds are 1 m to 20 m thick and trough- and planar-cross-stratified. Thinner sandstone beds form lenses within conglomerate units. Some sandstone intervals contain abundant charcoal fragments up to 2 cm across. The charcoal fragments highlight planar (Fig. 32) and trough cross-stratification in these

Figure 30. Poorly sorted, clast-supported conglomerate of lower submember of the Garrity channelized into underlying sandstone at Point Pinole. Tertiary mafic volcanic clast (Tv) and Franciscan Complex eclogite schist clasts (Ec) are present.

Figure 31. Composition of sandstones from the Garrity Member of the Contra Costa Group. Sample numbers are on Plate 4.

Figure 32. Sandstone and conglomerate in the lower submember of the Garrity. Planar stratification in the sandstone indicated by alignment of charcoal. The overlying conglomerate is a debris-flow deposit with a fining-upward sequence. Clasts are dominantly Franciscan Complex-derived with minor Tertiary volcanic fragments. Photograph taken along the shoreline at Point Pinole.

beds. Sandstone petrology for both members (Appendix A) indicates the sand was derived from metamorphic sources such as the Franciscan Complex (Johnson, 1934).

Age

The age of the Garrity is late Miocene to Pliocene (about 9 to 5 Ma). The Garrity Member unconformably overlies the San Pablo Group, which was deposited until late Clarendonian time (~9 to 10 Ma). The lower Garrity contains a late Miocene horse locality (Wagner, 1978), and the upper Garrity contains the ~6- Ma Roblar Tuff (Plate 4). The Garrity is conformably overlain by the ~5-Ma Pinole Tuff, which also contains late Miocene and Pliocene fauna (Wagner, 1978).

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) (Figs. 8-10), 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 from this unit 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., 2003). 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 Wilson Grove is dominantly thick-bedded and hummocky cross-stratified. Marine fossils from this area suggest water depths of 50 m, which is typical of water depths on modern continental shelves.

The eastern part of the formation ("Interbedded Wilson Grove and Petaluma formations") 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 Petaluma Formation coarsens upward from mudstone of the lower Petaluma to the sandstone and conglomerate of the middle and upper Petaluma. The lower Petaluma Formation contains transitional marine and lacustrine ostracodes, a barnacle plate (marine), marine foraminifera, and marine diatoms (Appendix E). Some of the ostracodes required fresh-water environments (Dawn Peterson, personal communication, 2002), so the lower Petaluma Formation represents interfingering of fresh-water environments with a marine system. The lower Petaluma Formation 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 Petaluma Formation 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 (Plate 3; Appendix E). 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 Petaluma Formation was covered by a westward-advancing fluvial system of the middle and upper Petaluma Formation. Because marine interbeds of the Wilson Grove Formation are present in all three members of the Petaluma Formation, one or both of the following must have occurred: the Petaluma basin was continuously subsiding during deposition of the Petaluma Formation, and/or sea level was continuously rising during deposition of the Petaluma Formation.

Garrity Member of the Contra Costa Group

I concur with the interpretations of Wagner (1978) and Borchardt et al. (1988) that the Garrity Member was deposited in a fluvial environment (Wagner, 1978; Borchardt et al., 1988). The Garrity Member contains interbedded normal-graded conglomerate and sandstone sequences. Conglomerate is massive, poorly sorted, and

channelized into lower units. Conglomerate of this nature and its associated horizontally stratified sand and gravel units are indicative of longitudinal bars and in-channel braided stream deposits (Miall, 1977, 1978; Rust, 1978). Plane- to cross-bedded, fine-grained sandstone may represent point-bar deposits in a meandering stream system (Cant and Walker, 1978). A fossil horse from this formation (Appendix E) is consistent with a fluvial environment of deposition.

PALEOCURRENTS

Paleocurrent measurements from imbricated clasts in the Petaluma Formation and Garrity Member show that paleoflow was to the west-northwest (Fig. 33; Appendix D). Thus, interbedding of the fluvial-deltaic Petaluma and marine Wilson Grove indicates 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).

Figure 33 . 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.

PROVENANCE

The compositions of sandstones and conglomerate clasts in the “interbedded Wilson Grove and Petaluma Formations,” Petaluma Formation, and Garrity Member provide clues about their provenance.

Sandstone in all units was derived chiefly from the Franciscan Complex (Appendix A), as had been deduced by previous studies (Johnson, 1934; Travis, 1952). However, the middle Petaluma Formation 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 sandstone (Appendix G). 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 Wilson Grove and Petaluma formations 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 (Wakabayashi, 1999; Graymer et al., 2002). 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. 34), are cemented by silica or clay, and contain accessory biotite and glauconite (Appendix G).

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.

A.

B.

C.

Figure 34. 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).

Field examination of the Briones in the eastern Bay Area shows that quartz veins are present near Clayton Road east of San José (Fig. 35), 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, 35). 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 Wilson Grove and Petaluma Formations,” Petaluma Formation, and Garrity Member in the northern Bay Area.

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

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

0 10 20 km

EXPLANATION

Miocene		PMcc	Contra Costa Group
			Grizzly Peak Volcanics
Bald Peak Volcanics
			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

Figure 35. Map showing geothermal peak temperatures inferred from
Temperatures north of Niles are 40° to 59° C . Temperatures south of Niles :

Nakata, 1993) (southeast of San Jose)
 Graymer, 1995) (near Niles)

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

Quartz vein in Briones sandstone

Quartz vein in clast from Petaluma

Quartz vein in clast from "Interbedded Wilson Grove and Petaluma" formations. Quartz is orange because the thin section was stained with iron.

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 Briones sandstone collected at Clayton Road, San Jose.

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

Quartz vein in clast from "Interbedded Wilson Grove and Petaluma formations." Quartz is orange because the thin section is cut thick.

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

teolite composition in the Briones Formation of the San Pablo Group.
80° to > 100° C (Murata and Whiteley, 1973).

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 Wilson Grove and Petaluma formations in detail.

The Wilson Grove Formation and Petaluma Formation are interbedded from the base to the top of the section (Figs. 27, 36), indicating not only temporal correlation but also physical contiguity of the two formations.

The Garrity Member of the Contra Costa Group is correlated herein with the Petaluma Formation based on strongly similar clast composition, age, and depositional environment (Fig. 36).

The distribution of the ~6-Ma Roblar Tuff has been used to correlate the Wilson Grove and Petaluma formations 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 Wilson Grove Formation 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 Petaluma Formation to the 8.5-Ma to 2.5-Ma Sycamore Formation in the eastern Bay Area (Fig. 36) (Sarna-Wojcicki,

Explanation

- Tertiary-derived clasts
- Franciscan-derived clasts

Pwg: Pliocene marine Wilson Grove
 MWg: Miocene marine Wilson Grove
 UP: Upper Petaluma
 MP: Middle Petaluma
 LP: Lower Petaluma
 Ppt: Push Tuff
 Pnt: Healdsburg Tuff
 Phc: Huichica Tuff
 Mpt: Pinole Tuff
 Mrt: Roblar Tuff
 Psv: Pliocene Sonoma Volcanics
 Msv: Miocene Sonoma Volcanics
 Mspn: Miocene Neroly Formation
 Mdr: Donnell Ranch Volcanics
 KJf: Franciscan Complex

Map Explanation

Pwg: Pliocene Wilson Grove
 MWg: Miocene Wilson Grove
 PMp: Miocene and Pliocene
 Petaluma Formation
 PMsv: Miocene and Pliocene
 Sonoma Volcanics
 PMcc: Miocene and Pliocene
 undifferentiated Contra
 Costa Group: includes
 Sycamore Formation
 PMsc: Miocene and Pliocene
 Silver Creek Gravels
 HSF: Healdsburg fault
 MAF: Maacama fault
 SVF: Sonoma Valley fault
 SAF: San Andreas fault
 PVF: Petaluma Valley fault
 HF: Hayward fault
 MF: Moraga fault
 CF: Calaveras fault
 SCF: Silver Creek fault
 SGF: San Gregorio fault
 --- Outline of major basins
 --- Major strike-slip faults
 --- Fault from Wagner and
 Bortugno (1982)

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 Petaluma Formation also may be correlative with the Silver Creek Gravels southeast of San José (Fig. 36). 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

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. It is inferred to be kinematically linked to the Healdsburg fault and the Bennett Valley-Maacama fault zone (Fig. 37), 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 (Fig. 37). For example, McLaughlin et al. (2000) reported that the Glen Ellen

Figure 37. 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).

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 (Plates 2, 3) 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 Petaluma Formation 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 (Fig. 37), 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 (Fig. 37).

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 (Fig. 37). First, the Petaluma Formation crops out east of the Rodgers Creek fault zone (Fig. 37; Plate 3), 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 Petaluma Formation on the Rodgers Creek fault. Thus, northward transport of the Petaluma Formation (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 (Fig. 38A). 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 (Fig. 38A). 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 (Fig. 38A). 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

Figure 38. Late Cenozoic basins in the Bay Area interpreted to have formed at right bends in right-late. A. San Pablo basin (figure from Ponce, 2000). B. Evergreen basin (Jachens et al., 2002) (figure from Roberts et al., 2002).

38°15'

milligals

A.

121°45'

Evergreen Basin

San Jose

37°15'

0 5 10 15 20 25 KM

B.

San Francisco Bay Area interpreted to have formed at right bends in right-lateral strike-slip faults.
 Evergreen basin (Jachens et al., 2002) (figure from Roberts and Jachens, 1993).

Silver Creek–Hayward bend and Evergreen basin east of San José (Fig. 38B). I speculate that partitioning of dextral slip onto faults even farther east than the Sonoma Valley, such as the Carneros fault (Fig. 1), 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 (Fig. 39). 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

Figure 39. Deflection of streams possibly caused by dextral slip on the Sonoma Valley fault.

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 (McLaughlin et al., 2000) and the Petaluma Formation (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 Wilson Grove Formation with respect to the southernmost Petaluma Formation, and displacement of a ~9.3-Ma “rhyolite plug” near Cotati (Fig. 37) from volcanic rocks of similar lithology and age in the Berkeley Hills (southeast of the area shown in Fig. 37).

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 Wilson Grove Formation and the southern margin of the Petaluma Formation (Fig. 37). 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. 37) and near Sears Point north of San Pablo Bay (Fig. 37). 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 Wilson Grove and Petaluma formations.

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. 40).

Figure 40. Proposed distribution of dextral slip on faults in the Bay Area since inception of transform plate boundary about 12 Ma.

Figure 41. Palinspastic reconstruction restoring the southernmost Petaluma Formation to an area near its source rocks east of San José. A. Cuaternario and Miocene and Jurassic-Cretaceous rocks of the northern and eastern Bay Area used in correlation and as source rocks. B. Palinspastic reconstruction of the southernmost Petaluma Formation to an area near its source rocks east of San José.

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. 41). 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.

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. 40). 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 Petaluma Formation, 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. 40). 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. 40), 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 Wilson Grove and Petaluma Formations. Alternatively, the southern margins may have formed in their current positions, i.e., their southern margins may not have been originally collinear. In this case, negligible dextral slip is required on the Petaluma Valley fault.

Restoring the Petaluma Formation 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. 40, 41). 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. 36, 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 Petaluma Formation 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. 37, 41), 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. 41). 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. 41). 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. 40). An additional 25 km has accumulated on the San Andreas fault since its reactivation in the late Pliocene or earliest Quaternary (Fig. 40) (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 Wilson Grove Formation 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 Wilson Grove deposition.

The faults mapped in the Wilson Grove Formation are reverse faults that were active before, during, and after Wilson Grove deposition (Weaver, 1949; Travis, 1950). Activity since about 3 Ma is indicated by strong folding of the upper Pliocene part of the Wilson Grove and 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 Wilson Grove Formation 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) (Plate 3). 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 Petaluma Formation. 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 (Plate 3). The Lakeville fault system has an insignificant strike-slip component.

The Taylor Mountain thrust fault, introduced here, places olivine basalt thrust over the Petaluma Formation (Fig. 42; Plate 2). Several fault planes and shear zones are

A.

W

B.

Figure 42. Photograph and explanation of Tertiary olivine basalt (PMsv (?)) over middle fault surface towards the Rodgers Creek fault.

B.

Figure 42. Photograph and explanatory sketch of Taylor Mountain thrust fault that places Tertiary olivine basalt (PMsv (?)) over middle Petaluma Formation (Mpm). Striations plunge east on N20E, 45SE fault surface towards the Rodgers Creek fault zone 300 m to the east.

3.

anatory sketch of Taylor Mountain thrust fault that places
iddle Petaluma Formation (Mpm). Striations plunge east on N20E, 45SE
fault zone 300 m to the east.

located at the base of the volcanic rocks and within the middle Petaluma Formation.

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 (Plate 2), 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 (Plate 2). 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 (Plate 2).

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 Petaluma Formation 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 (Plate 2) (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, Plate

2). 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; Fig. 1). 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 Petaluma Formation along the Roche-Cardoza fault (Fig. 43) 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.

Figure 43. The lowermost Petaluma Formation in a symmetrical fold. The hinge trends N90W. There may be slight vergence to the north. Photograph taken just south of the Roche-Cardoza fault identified by Youngman (1989). dlm = dolomite; sh = shale.

SUMMARY

The coeval and interbedded upper Miocene-lower Pliocene Wilson Grove and Petaluma formations in the northern San Francisco Bay Area represent fluvial flood-plain to open-ocean deposition. The Wilson Grove and 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 Wilson Grove and Petaluma formations.

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 Healdsburg and Maacama faults, is newly proposed in this study on the basis of stratigraphic, geophysical, and geomorphologic observations.

REFERENCES

- 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 Wilson Grove Formation, 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 Wilson Grove Formation, 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 Wilson Grove Formation and the nonmarine Cotati Member of the Wilson Grove Formation, Sonoma County, California: *Geological Society of America, Abstracts with Programs*, v. 32, no. 6, p. A-1.
- 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 Petaluma formation, 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 Mineralogists, 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 diagenesis 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., 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 $^{40}\text{Ar}/^{39}\text{Ar}$ 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 Wilson Grove Formation 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.

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., 2003, Geology and Paleontology of the Wilson Grove Formation, Sonoma County, California: U.S. Geological Survey Open-File Report 03-135, p. 112.

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 sedimentary 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* Bokermann, 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.
- Topozada, 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.
- 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 1:250,000.

- 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 earthquake 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 $^{40}\text{Ar}/^{39}\text{Ar}$ 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 A: SANDSTONE PETROLOGIC DATA

Sample numbers correspond to numbers
on plates (in pocket)

Wilson Grove Formation Sandstone Petrography

Raw Data

Sample #	Quartz Undulatory	Quartz Non-Undulatory	Quartz Polycrystalline few	Quartz Polycrystalline many	Feldspar Lithic	Volcanic Lithic	Sedimentary Lithic	Metamorphic 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

Percent Q,F,L

Sample #	Q	F	L	Total
1	0.7027027	0.1351351	0.162162162	70%
2	0.631111111	0.1644444	0.204444444	63%
3	0.74576271	0.1779661	0.076271186	74%
4	0.82954545	0.1136364	0.056818182	83%

Notes on Wilson Grove sandstone:

Non-undulatory and polycrystalline quartz, minor prismatic grains of basaltic hornblende with a large 2V negative angle, fresh and slightly altered plagioclase, augite, volcanic glass, potassium feldspar, glauconite with a 2V at about 35°(-), garnet, abundant amphiboles which are actinolite-nemolite, epidote, lawsonite as inclusions in feldspars, reddish brown biotite, muscovite, ilmenite, magnetite, and accessory glauconite. Lithic fragments are minor and represent volcanic, siltstone, chert, metagraywacke, and schist sources. The plagioclase is predominantly oligoclase. In the plagioclase population, albite ranges from 15 to 50% with small amounts of andesine (Travis, 1950). The values given for orthoclase include small amounts (less than 1/2%) of sanidine and microcline (Johnson, 1934). Most of the plagioclase and alkali feldspars are fresh. Some of the feldspars are slightly altered where albite twinning is sometimes vague and appears as OghosisUpon rotation of the stage. Most quartz grains are monocrystalline and lack undulatory extinction. Polycrystalline and undulatory quartz grains are present, but not common.

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
5	33	31	10	46	27	14	30
6	19	26	10	38	24	15	18
7	12	24	22	42	31	12	9
8	17	41	12	16	22	12	6
9	45	0	3	15	24	42	3
10	57	3	6	39	33	63	0
11	35	12	15	29	25	57	6
12	51	6	2	18	18	40	2

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

Percent Q,F,L

Sample #	Q	F	L	Q	F	L	Total
5	0.49382716	0.11111111	0.395061728	49%	11%	40%	100%
6	0.364705882	0.0941176	0.541176471	37%	9%	54%	100%
7	0.381679389	0.1183206	0.5	38%	12%	50%	100%
8	0.377192982	0.0964912	0.526315789	37%	10%	53%	100%
9	0.338709677	0.1290323	0.532258065	21%	15%	64%	100%
10	0.393258427	0.1235955	0.483146067	39%	13%	48%	100%
11	0.400881057	0.1101322	0.488986784	40%	11%	49%	100%
12	0.394871795	0.0923077	0.512820513	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 Mantanzas Creek (See Map).

Sample 8 is from the upper Petaluma Formation in southwestern Sonoma Valley on the Chateau St. Jean vineyard.

Samples 9,10,11, and 12 are from the middle Petaluma Formation exposed between Stage Gulch Road and the Tc Rodgers Creek faults.

Geology of the Middle and Upper Petaluma Formation

Quartz	Feldspar	Volcanic	Sedimentary	Metamorphic	Matrix	Total
alline	Polycrystalline	Lithic	Lithic	Lithic	Cement	
many						
46	27	14	30	52	57	300
38	24	15	18	105	45	300
42	31	12	9	110	38	300
16	22	12	6	102	72	300
15	24	42	3	54	114	300
39	33	63	0	66	33	300
29	25	57	6	48	73	300
18	18	40	2	58	105	300

Total
243
255
262
228
186
267
227
195

	Q	F	L	Total
1728	49%	11%	40%	100%
3471	37%	9%	54%	100%
	38%	12%	50%	100%
5789	37%	10%	53%	100%
58065	21%	15%	64%	100%
46067	39%	13%	48%	100%
86784	40%	11%	49%	100%
20513	40%	9%	51%	100%

Petaluma Formation sandstone collected at the Marcucci Ranch in the hinge of the anticline contains pencil structures.
 on in Bennett Valley in Mantazas Creek (See Map).
 ion in southwestern Sonoma Valley on the Chateau St. Jean vineyard property.
 Petaluma Formation exposed between Stage Gulch Road and the Tolay and

Notes on Petaluma sandstone:

Sandstone samples 9-12 were collected from the Petaluma Formation in this study. Sandstone samples 5 and 6 are from the Petaluma Formation sandstone which is an informal unit derived conglomerate and the Roblar Tuff.

The samples from the middle Petaluma Formation are cemented with hematite. The samples from the upper Petaluma Formation these had to be impregnated with epoxy.

Glauconite occurs in the Petaluma Formation.

Petrographic work classifies Petaluma sandstone as litharenite (Folk, 1984). The thin sections were made to determine the composition of the middle Petaluma Formation. The samples are: Q: 35%, F: 12%, L: 53%. Average for the Petaluma Formation is: Q: 40%, F: 11%, L: 49%.

Quartz is usually non-undulatory and is albite with minor sanidine and some feldspar. In mineral separation studies, Davies (1986) reported that potassium feldspar is 12.9% of the total feldspar counts presented herein, but a few grains that

The lithic fragments are volcanic and are from the Dominant Franciscan Complex metamorphic and sandstone lithics are found in the upper Petaluma Formation. Some are volcanic at times in the middle Petaluma. The counted portions of the slides are basaltic hornblende grains that have been plucked from unstable volcanic lithics. Other amphiboles present are Epidote, garnet, lawsonite, biotite, muscovite, and chlorite in thin sections.

The lithologic differences between the middle and upper sandstones appears to lie within the lithic grains. The middle sandstone to contain an abundance of Tertiary volcanic derived lithics. The upper Petaluma Formation contains more lithics.

Metamorphic Lithic	Matrix- Cement	Total
52	57	300
105	45	300
110	38	300
102	72	300
54	114	300
66	33	300
48	73	300
58	105	300

Notes on Petaluma sandstone:

Sandstone samples 9-12 were collected from areas mapped as middle Petaluma Formation in this study. Sandstone samples 5-8 were collected in the upper Petaluma Formation sandstone which is an informal unit closely associated with Monterey Group derived conglomerate and the Roblar Tuff.

The samples from the middle Petaluma Formation are calcite cemented, but most of the cement or matrix in the Petaluma Formation sandstones are argillaceous and hematite. The samples from the upper Petaluma Formation were poorly cemented, so these had to be impregnated with epoxy.

Glaucinite occurs in the Petaluma Formation.

Petrographic work classifies Petaluma Formation medium-grained sandstone as litharenite (Folk, 1984). The thin sections were stained for potassium feldspar. Average composition of the middle Petaluma Formation medium- to coarse-grained sandstone samples are: Q: 35%, F: 12%, L: 53%. Average composition of sandstone from the upper Petaluma Formation is: Q: 40%, F: 11%, L: 49.

Quartz is usually non-undulatory and to a lesser extent is polycrystalline. Feldspar is albite with minor sanidine and some feldspars are zoned with melt inclusions. From mineral separation studies, Davies (1986) reports that calcium feldspar is 87.2% and potassium feldspar is 12.9% of the total feldspars. K-spar was not reported in the point counts presented herein, but a few grains that were not counted are K-spar.

The lithic fragments are volcanic and metamorphic in the middle Petaluma. Dominant Franciscan Complex metamorphic lithics, rare Tertiary volcanic, Tertiary chert and sandstone lithics are found in the upper Petaluma. Over 50% of the lithic fragments are volcanic at times in the middle Petaluma. Amphiboles counted and also present in uncounted portions of the slides are basaltic hornblende, which occurs as prismatic, isolated grains that have been plucked from unstable volcanic lithic fragments and are included as volcanic lithics. Other amphiboles present are common hornblende and glaucophane. Epidote, garnet, lawsonite, biotite, muscovite, augite and hypersthene are also present in thin sections.

The lithologic differences between the middle and upper Petaluma Formation sandstones appears to lie within the lithic grains. The middle Petaluma Formation appears to contain an abundance of Tertiary volcanic lithics along with Franciscan Complex-derived lithics. The upper Petaluma Formation appears to contain abundant metamorphic lithics.

Garrity Member of the Contra Costa Group Sandstone Petrography

Raw Data

Sample #	Quartz Non- undulatory	Quartz Undulatory	Quartz Polycrystalline few	Quartz Polycrystalline many	Feldspar	Volcanic Lithic	Sedimentary Lithic	Metamorphic Lithic	Matrix Cement	Total
13	69	24	6	24	9	39	0	63	66	300
14	93	42	21	30	27	24	0	33	30	300
15	58	25	52	24	17	28	2	47	47	300

Normalized without cement or matrix

Sample #	Q	F	L	Total
13	123	9	102	234
14	186	27	57	270
15	159	17	77	253

Percent Q,F,L

Sample #	Q	F	L	Q	F	L	Total
13	0.525641026	0.0384615	0.435897436	52%	4%	44%	100%
14	0.688888889	0.1	0.211111111	69%	10%	21%	100%
15	0.628458498	0.0671937	0.304347826	63%	7%	30%	100%

Samples numbers correspond to petrographic data and labels on maps.

Notes of Garrity sandstone:

Sandstone samples were collected along the shore of San Pablo Bay at Point Pinole (Samples 13 and 15; Appendix 6) where Franciscan Complex-derived conglomerate dominate. Sandstone petrography is presented in Appendix 6. Petrographic work on potassium feldspar stained sandstone from the fine-to medium-grained sandstone of the Garrity Member classify the rock as predominantly litharenite with one sample classified as feldspathic litharenite. Average QFL composition of sandstone from the Garrity Member of the Contra Costa Group is: Q: 61%, F: 7%, L: 31% (Appendix 6).

Quartz is usually non-undulatory and to a lesser extent is polycrystalline. Feldspar is albite with minor sanidine and some feldspars are zoned with melt inclusions. K-spar was not reported in the point counts presented herein, but a few grains that were not counted are K-spar.

The lithic fragments are volcanic and metamorphic with rare Tertiary chert and sandstone. Over 50% of the lithic fragments are volcanic at times. Amphiboles counted and also present in un-counted portions of the slides are basaltic hornblende, which occurs as prismatic, isolated grains that have been plucked from unstable volcanic lithic fragments and are included as volcanic lithics. Other amphiboles present are common hornblende and glaucophane. Epidote, garnet, lawsonite, biotite, muscovite, augite and hypersthene are also present in thin sections.

APPENDIX B: CLAST-COUNT DATA

Sample numbers correspond to numbers
on plates (in pocket)

XPL

PPL

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

Fossiliferous clasts. A. Clast of coquina. B. 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.

A. 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. B. 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.

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.

A. Monterey-derived conglomerate of the "Interbedded Wilson Grove and Petaluma formations." 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.

A.

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

A. Stratified Roblar Tuff interbedded in the upper Garrity Member of the Contra Costa Group along San Pablo Avenue. Roblar Tuff is below thick, Monterey-derived conglomerate. B. Thick, Monterey-derived conglomerate above Roblar Tuff at San Pablo Avenue, Pinole. C. Close up of Monterey-derived clasts.

Clast Count 1: Llano Road, N of 116

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			9
graywacke w/quartz veins			2
vein quartz			11
eclogite			
blueschist			
argillite			1
red chert + varicolored chert			3
green chert			2
brown chert			11
black chert			3
metachert (black with lighter siliceous swirls)		1	
metavolcanic			24
Great Valley Group			
white and pale porphyries			2
dark porphyries			6
Great Valley sandstone			2
Monterey Group			
Monterey siliceous laminated chert		2	357
porcellinite			4
Tertiary sedimentary (most with quartz veinlets)		1	7
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			1
dark basalt, aphanitic and phaneritic		1	7
banded and non-banded rhyolite			1
tuff, rhyolitic tuff			2
Coast Range Ophiolite keratophyre(?)			6
Total:	0	4	460

Total Counted Clasts:

464

Total Franciscan Complex (KJf):	67
	Total Monterey Group (Mmy):	371
	Total Tertiary volcanic (Tv):	12
	Total:	450
	% Franciscan Complex	14.889%
	% Tertiary Sandstone & Monterey Group	82.4%
	% Tertiary Volcanics	2.7%
		100.000%

Clast Count 25: Mantazas Creek 2

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		6	21
graywacke w/quartz veins		3	12
vein quartz		1	6
eclogite			
blueschist			
quartzite			4
red chert			12
green chert			16
brown chert			8
black chert		2	15
metachert			
metavolcanic			51
Great Valley Group			
white and pale porphyries		4	25
dark porphyries			22
Great Valley sandstone			8
Monterey Group			
Monterey siliceous laminated chert		14	96
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			8
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		12	15
banded and non-banded rhyolite		9	28
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	51	347
			Total Counted Clasts: 398

Clast Count 26: Mantazas Creek 1

	63 mm	63-16.0 mm	16 - 8.0 mm
Franciscan Complex			
graywacke			3
graywacke w/quartz veins			8
vein quartz		2	
eclogite			
blueschist			
quartzite			
red chert			5
green chert		2	7
brown chert		3	
black chert		1	3
metachert			
metavolcanic			
Great Valley Group			
white and pale porphyries		1	
dark porphyries		2	5
Great Valley sandstone		1	3
Monterey Group			
Monterey siliceous laminated chert		4	212
porcellinite			
Tertiary sedimentary (most with quartz veinlets)		4	2
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		8	6
banded and non-banded rhyolite		1	4
tuff, rhyolitic tuff			2
Coast Range Ophiolite keratophyre(?)			
Total:	0	25	260

Total Counted Clasts: 285

Total Franciscan Complex (KJf):	34
	Total Monterey Group: (Mmy)	222
	Total Tertiary volcanic (Tv):	21
	Total:	277
	% Franciscan Complex	12.274%
	% Tertiary Sandstone & Monterey Group	80.1%
	% Tertiary Volcanics	7.6%
		100.000%

Clast Count 2: Pepper and Stony Point Road intersection

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			
graywacke w/quartz veins			
vein quartz			14
eclogite			
blueschist			1
quartzite			
red chert			2
green chert			4
brown chert			7
black chert			9
metachert			11
metavolcanic			5
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		4	147
porcellinite			
Tertiary sedimentary (most with quartz veinlets)		2	5
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite		3	9
tuff, rhyolitic tuff		1	4
Coast Range Ophiolite keratophyre(?)			
Total:	0	8	218
			Total Counted Clasts: 226
			Total Franciscan Complex (KJl): 53
			Total Monterey Group (Mmy): 158
			Total Tertiary volcanic (Tv): 17
			Total: 228
			% Franciscan Complex 23.246%
			% Tertiary Sandstone & Monterey Group 69.3%
			% Tertiary Volcanics 7.5%
			100.000%

Notes: Probably a well-worked near-beach deposit. Sand is clean=quartz rich.

Clast Count 3: Weekend at Ernie's 11

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			12
graywacke w/quartz veins			15
vein quartz		5	12
eclogite			
blueschist			2
quartzite			
red chert		2	13
green chert			4
brown chert		1	2
black chert			8
metachert		6	12
metavolcanic		3	46
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone		2	9
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			10
Jurassic and/ or Cretaceous Plutonic			
plutonic			3
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite		3	8
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	22	156

Total Counted Clasts: 178

Total Franciscan Complex (KJf):	143
	Total Monterey Group (Mmy):	10
	Total Tertiary volcanic (Tv):	11
	Total:	164
	% Franciscan Complex	87.195%
	% Tertiary Sandstone & Monterey Group	6.1%
	% Tertiary Volcanics	6.7%
		100.000%

Clast Count 4: Weekend at Ernie's 2.5

Franciscan Complex	63 mm	31.5-16.0 mm	16 - 8.0 mm
graywacke		22	135
graywacke w/quartz veins		3	54
vein quartz		18	12
eclogite			
blueschist			
quartzite			2
red chert			5
green chert			1
brown chert			
black chert			3
metachert			18
metavolcanic		8	58
Great Valley Group			
white and pale porphyries			
dark porphyries		2	2
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			18
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	53	308
		Total Counted Clasts:	361
		Total Franciscan Complex (KJf):	339
		Total Monterey Group: (Mmy)	0
		Total Tertiary volcanic (Tv):	18
		Total:	357
		% Franciscan Complex	94.958%
		% Tertiary Sandstone & Monterey Group	0.0%
		% Tertiary Volcanics	5.0%
			100.000%

Clast Count 5: Lichau Creek 2

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			
graywacke w/quartz veins			
vein quartz			7
eclogite			
blueschist			1
quartzite			
red chert			3
green chert			6
brown chert			4
black chert			7
metachert			9
metavolcanic			6
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		2	130
porcellinite			
Tertiary sedimentary (most with quartz veinlets)		1	3
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			7
banded and non-banded rhyolite			5
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	2	188

Total Counted Clasts: 190

Total Franciscan Complex (KJf):	43
	Total Monterey Group (Mmy):	136
	Total Tertiary volcanic (Tv):	12
	Total:	191
	% Franciscan Complex	22.513%
	% Tertiary Sandstone & Monterey Group	71.2%
	% Tertiary Volcanics	6.3%
		100.000%

Clast Count 6: Lichau Creek 1

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			
graywacke w/quartz veins			
vein quartz			
eclogite			
blueschist			
quartzite			
red chert			4
green chert			3
brown chert			
black chert			3
metachert			2
metavolcanic			3
Great Valley Group			
white and pale porphyries			
dark porphyries		2	2
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		4	15
porcellinite			
Tertiary sedimentary (most with quartz veinlets)		8	245
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			2
banded and non-banded rhyolite			3
tuff, rhyolitic tuff		2	
Coast Range Ophiolite keratophyre(?)			
Total:	0	8	282
			Total Counted Clasts: 290

Clast Count 7: Pepper and Stony Point intersection

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			1
graywacke w/quartz veins			2
vein quartz			
eclogite			
blueschist			1
quartzite			
red chert		1	3
green chert		2	4
brown chert			2
black chert			4
metachert			
metavolcanic			3
Great Valley Group			
white and pale porphyries			
dark porphyries			2
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		4	15
porcellinite			
Tertiary sedimentary (most with quartz veinlets)		6	298
Jurassic and/ or Cretaceous Plutonic			
plutonic			1
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			1
banded and non-banded rhyolite		1	1
tuff, rhyolitic tuff		2	3
Coast Range Ophiolite keratophyre(?)			
Total:	0	10	341

Total Counted Clasts: 351

Total Franciscan Complex (KJf):	23
	Total Monterey Group (Mmy):	323
	Total Tertiary volcanic (Tv):	8
	Total:	354
	% Franciscan Complex	6.497%
	% Tertiary Sandstone & Monterey Group	91.2%
	% Tertiary Volcanics	2.3%
		100.000%

Clast Count 8: west of Meacham Hill, shoulder of northbound 101

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		1	3
graywacke w/quartz veins			
vein quartz			2
eclogite			
blueschist			
quartzite			
red chert		2	5
green chert			1
brown chert			
black chert		3	4
metachert			
metavolcanic		1	2
Great Valley Group			
white and pale porphyries			5
dark porphyries			2
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		1	3
porcellinite			
Tertiary sedimentary (most with quartz veinlets)		3	329
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		3	12
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	11	368

Total Counted Clasts: 379

	Total Franciscan Complex (KJf):	24
	Total Monterey Group (Mmy):	336
	Total Tertiary volcanic (Tv):	15
	Total:	375
	% Franciscan Complex	6.400%
	% Tertiary Sandstone & Monterey Group	89.6%
	% Tertiary Volcanics	4.0%
		100.000%

Tertiary sandstone petrofacies. Appears to be in marine transtion zone where clasts are extremely well-rounded, polished, well-sorted. Overlain by KJf-derived gravel which is poorly sorted, angular, oxidized coarse ss matrix i.e. typical near-fluvial match with Petaluma Formation. Marine fossil molds are present below and above this cgl bed. One clam was found within the bed. Stratigraphy is wipped out from bioturbation.

Clast Count Locality 9: Highway 116 and Stony Point Road

Franciscan Complex	>31.5 mm	>16.0 mm	16 to 8.0 mm
graywacke			
graywacke w/quartz veins			
vein quartz		1	7
garnet blueschist/eclogite			
blueschist			1
red chert		1	2
green chert			
brown chert			
black chert			3
metachert			8
metavolcanic			
Great Valley Group			
white and pale porphyries		1	4
dark porphyries			
quartzite			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert	1	68	378
porcellinite			
mudstone			
Tertiary sedimentary			
Jurassic and/ or Cretaceous Plutonic			
plutonic			1
Tertiary volcanic			
red, friable, scoria-like			1
rhyolite tuff		1	1
dark basalt			
gray basalt			
banded and non-banded rhyolite			
tuff			5
Total count per sed size:	1	72	411

Total Counted Clasts: 484

**Clast Count 10: Near truck stop entrance to 101 S., Cotati
Cgl over marine sandstone**

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		5	16
graywacke w/quartz veins			
vein quartz		4	
eclogite			
blueschist		2	8
quartzite			
red chert (one clast is mixed red & green)			1
green chert		2	1
brown chert			
black chert			
metachert		2	5
metavolcanic		11	19
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone		52	204
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (carbonate cemented)			
Jurassic and/ or Cretaceous Plutonic			
plutonic		2	
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		2	8
banded and non-banded rhyolite			4
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	80	266

Total Counted Clasts:		346
Total Franciscan Complex (KJf):		332
Total Monterey Group (Mmy):		0
Total Tertiary volcanic (Tv):		14
Total:		346
% Franciscan Complex		95.954%
% Tertiary Sandstone & Monterey Group		0.0%
% Tertiary Volcanics		4.0%
		100.000%

Clast Count 11: Between Truck stop and RR Avenue, 101 Southbound
Cgl over marine sandstone

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		49	62
graywacke w/quartz veins		15	24
vein quartz		6	4
eclogite			
blueschist		2	3
quartzite			
red chert (one clast is mixed red & green)			
green chert		2	1
brown chert			
black chert			
metachert		5	18
plagiogranite		18	21
metavolcanic		36	53
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (carbonate cemented)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	115	186
		Total Counted Clasts:	319

A ternary diagram with vertices labeled Mmy (top), KJf (bottom left), and Tv (bottom right). A single data point is plotted near the KJf vertex.

Total Franciscan Complex (KJf):	319
Total Monterey Group (Mmy):	0
Total Tertiary volcanic (Tv):	0
Total:	319
% Franciscan Complex	100.000%
% Tertiary Sandstone & Monterey Group	0.0%
% Tertiary Volcanics	0.0%
	100.000%

Clast Count 12: Monterey-rich along 101 Northbound, west of Meacham's Hill

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			9
graywacke w/quartz veins			2
vein quartz			14
eclogite			
blueschist			
Argillite			
red chert + varicolored chert			2
green chert			
brown chert		2	4
black chert			1
metachert (black with lighter siliceous swirls)		1	
metavolcanic			18
Great Valley Group			
white and pale porphyries			2
dark porphyries			6
Great Valley sandstone			2
Monterey Group			
Monterey siliceous laminated chert		2	270
porcellinite			3
Tertiary sedimentary (most with quartz veinlets)			4
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite		4	8
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	9	345

Total Counted Clasts: 354

Total Franciscan Complex (KJf):	53
	Total Monterey Group (Mmy):	279
	Total Tertiary volcanic (Tv):	12
	Total:	344
	% Franciscan Complex	15.407%
	% Tertiary Sandstone & Monterey Group	81.1%
	% Tertiary Volcanics	3.5%
		100.000%

Clast Count 13: Lichau Creek
Cgl over marine sandstone

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		4	16
graywacke w/quartz veins			
vein quartz			6
eclogite			
blueschist			
quartzite			
red chert (one clast is mixed red & green)			
green chert			
brown chert			
black chert			8
metachert			
plagiogranite			3
metavolcanic			
Great Valley Group			
white and pale porphyries			4
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert			17
porcellinite			
Tertiary sedimentary (carbonate cemented)			254
Jurassic and/ or Cretaceous Plutonic			
plutonic			1
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff			1
Coast Range Ophiolite keratophyre(?)			
Total:	0	4	310
		Total Counted Clasts:	314

Total Franciscan Complex (KJf):			41
Total Monterey Group (Mmy):			271
Total Tertiary volcanic (Tv):			1
Total:			313
% Franciscan Complex			13.099%
% Tertiary Sandstone & Monterey Group			86.6%
% Tertiary Volcanics			0.3%
			100.000%

Clast Count 14: Tertiary sandstone clasts along US 101, Northbound

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		6	25
graywacke w/quartz veins		1	
vein quartz		4	7
eclogite			
blueschist		1	
quartzite			2
red chert (one clast is mixed red & green)			
green chert			
brown chert			
black chert			3
metachert			
plagiogranite			18
metavolcanic			
Great Valley Group			
white and pale porphyries			
dark porphyries			4
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		2	23
porcellinite			
Tertiary sedimentary (carbonate cemented)		8	219
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff			6
Coast Range Ophiolite keratophyre(?)			
Total:	0	14	305
Total Counted Clasts:			329
Total Franciscan Complex (KJf): 63 Total Monterey Group (Mmy): 252 Total Tertiary volcanic (Tv): 6 Total: 321
% Franciscan Complex % Tertiary Sandstone & Monterey Group % Tertiary Volcanics			19.626% 78.5% 1.9% 100.000%

Clast Count 15: KJf cgl at Ernie's Ranch

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke	3	130	98
graywacke w/quartz veins		18	24
vein quartz		15	
eclogite			
blueschist		1	
quartzite			2
red chert (one clast is mixed red & green)		3	8
green chert			5
brown chert			
black chert			
metachert			
plagiogranite			
metavolcanic			28
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone		3	16
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (carbonate cemented)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		8	5
banded and non-banded rhyolite			
tuff, rhyolitic tuff		2	9
Coast Range Ophiolite keratophyre(?)			
Total:	3	180	135
		Total Counted Clasts:	375

Total Franciscan Complex (KJf):	256
Total Monterey Group (Mmy):	0
Total Tertiary volcanic (Tv):	16
Total:	272
% Franciscan Complex	94.118%
% Tertiary Sandstone & Monterey Group	0.0%
% Tertiary Volcanics	5.9%
	100.000%

Clast Count 27: #3 101 Southbound, near W. Sierra Ave., near truck stop

Franciscan Complex	>31.5 mm	>16.0 mm	16 to 8.0 mm
graywacke	1	14	239
graywacke w/quartz veins			
vein quartz		17	10
garnet blueschist/eclogite		1	
blueschist			
red chert		2	2
green chert		1	
brown chert			
black chert			
metachert			
metavolcanic		28	37
Great Valley Group			
white and pale porphyries: Leona? (quartz and plag phenocrysts)			
dark porphyries			
quartzite			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert (Contains foraminifer fossils)			
porcellinite			
mudstone			
Tertiary sedimentary (Blue and quartz-rich, tuffaceous ss)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
red, friable, scoria-like			
rhyolite/rhyolitic tuff			
dark, black basalt		4	16
gray basalt			
banded and non-banded rhyolite			
tuff			
Total count per sed size:	1	67	304

Clast Count Locality 16: Château St. Jean Vineyard, Sonoma County, California

	>31.5 mm	>16.0 mm	16 to 8.0 mm
Franciscan Complex		1	11
graywacke			1
graywacke w/quartz veins			
vein quartz		11	35
garnet blueschist/eclogite			
blueschist			1
red and green mixed chert with quartz veins			
red chert			6
green chert			4
brown chert			4
black chert			11
metachert			30
jade(?)			1
metavolcanic			23
Great Valley Group			
white and pale porphyries: Leona? (quartz and plag phenos)		3	12
dark porphyries		2	12
quartzite			
Great Valley sandstone			10
Shale			1
Monterey Group			
Monterey siliceous laminated chert (Contains foram fossils)		2	145
porcellinite			
mudstone			
Tertiary sedimentary (Blue and quartz-rich, tuffaceous ss)			17
Jurassic and/ or Cretaceous Plutonic			
plutonic			1
Tertiary volcanic			
red, friable, scoria-like			
rhyolite/rhyolitic tuff			
dark, black basalt			2
gray basalt		1	5
banded and non-banded rhyolite			
tuff			2
Total count per sed size:		18	334

Total Counted Clasts:

Total Franciscan Complex (KJf):	139
Total Monterey Group (Mmy):	147
Total Tertiary volcanic (Tv):	10

Total:

Percentage: $x/296 = x\%$

46.95% Franciscan Complex

49.67% Monterey Group

3.38% Tertiary Volcanics

Sears Point Clast Count #17 Locality #2

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke	1	12	21
graywacke w/quartz veins		1	2
vein quartz		2	9
eclogite			
blueschist		1	2
quartzite			2
red chert		1	7
green chert		2	4
brown chert			
black chert			
metachert		5	14
metavolcanic	2	19	22
Great Valley Group			
white and pale porphyries			
dark porphyries	1	11	3
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		2	
porcellinite			
Tertiary sedimentary			
Jurassic and/ or Cretaceous Plutonic			
plutonic		1	
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic	5	11	8
banded and non-banded rhyolite	1		
tuff, rhyolitic tuff	1	2	
Coast Range Ophiolite keratophyre(?)		1	
Total:	11	70	94

Total Counted Clasts: 175

Total Franciscan Complex (KJf):	129
	Total Monterey Group (Mmy):	2
	Total Tertiary volcanic (Tv):	28
	Total:	159
	Percentage: $x/ = x\%$	
	% Franciscan Complex	81.132%
	% Monterey Group	1.3%
	% Tertiary Volcanics	17.6%
		100.000%

Notes:

plutonic clasts, fossiliferous marine sandstone (San Pablo Gp.), scoria volcanic clasts
green metavolcanic clasts present in canyon exposures.

Clast Count Locality 18: Glen Ellen Town, Petaluma Formation in Fault Contact With Glen Ellen Formation

Franciscan Complex	>31.5 mm	>16.0 mm	16 to 8.0 mm
graywacke			19
graywacke w/quartz veins			2
vein quartz		1	28
garnet blueschist/eclogite			
blueschist		1	2
red chert	1		24
green chert			16
brown chert		5	4
black chert		2	12
metachert			35
metavolcanic		8	41
Great Valley Group			
white and pale porphyries: Leona? (quartz and plag phenos)			34
dark porphyries			24
quartzite			17
Great Valley sandstone			3
Monterey Group			
Monterey siliceous laminated chert (contains foram fossils)		19	274
porcellinite			
mudstone			2
Tertiary sedimentary (blue and quartz-rich, tuffaceous ss)			7
Jurassic and/ or Cretaceous Plutonic			
plutonic			2
Tertiary volcanic			
red, friable, scoria-like	1		2
dark basalt	1	1	10
gray basalt		8	7
banded and non-banded rhyolite	2	13	31
tuff			4
Total count per sed size:	5	58	600

Total Counted Clasts: 663

Total Franciscan Complex (KJf):	201
	Total Monterey Group (Mmy):	295
	Total Tertiary volcanic (Tv):	80
	Total:	576
	Percentage: $x/576 = x\%$	
	34.89% Franciscan Complex	
	51.22% Monterey Group	
	13.89% Tertiary Volcanics	

Lakeville Highway, #19, Winery south of Canon Lane, same Gully as #7, different bed

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm	
graywacke	8	3		
graywacke w/quartz veins		1	2	
vein quartz			4	
eclogite				
blueschist			1	
quartzite			2	
red chert		3	10	
green chert		4	7	
brown chert		6	3	
black chert		2	8	
metachert		4	11	
metavolcanic		4	3	
Great Valley Group				
white and pale porphyries			1	
dark porphyries				
Great Valley sandstone				
Monterey Group				
Monterey siliceous laminated chert			164	221
porcellinite			13	8
Tertiary sedimentary			5	4
Jurassic and/ or Cretaceous Plutonic				
plutonic				
Tertiary volcanic				
scoria-like				
dark basalt, aphanitic and phaneritic		3	1	
banded and non-banded rhyolite				
tuff, rhyolitic tuff		4	1	
Coast Range Ophiolite keratophyre(?)		2		
Total:	8	214	286	
Total Counted Clasts: 508

Mmy

KJf

Tv

Total Franciscan Complex (KJf):	78
Total Monterey Group (Mmy):	414
Total Tertiary volcanic (Tv):	9
Total:	501
Percentage: x/ = x%	
% Franciscan Complex	15.569%
% Monterey Group	82.6%
% Tertiary Volcanics	1.8%
	100.000%

Notes:

Monterey petrofacies above Roblar Tuff. This sample from an anticline west of the Tolay Fault, east of Lakeville Highway, 0.2mi south of Winery at Canon Lane

Sears Point Clast Count Locality #20

Franciscan Complex	>16.0 mm	16 to 8.0 mm
graywacke		7
graywacke w/quartz veins		16
vein quartz	1	9
garnet glaucophane eclogite schist		1
blueschist		2
quartzite	1	4
red chert		3
green chert		3
brown chert		7
black chert		3
metachert		1
metavolcanic	3	11
Great Valley Group		
white and pale porphyries		3
dark porphyries		1
Great Valley sandstone		2
Monterey Group		
Monterey siliceous laminated chert	5	274
porcellinite	1	2
Tertiary sedimentary		5
Jurassic and/ or Cretaceous Plutonic		
plutonic		2
Tertiary volcanic		
scoria-like	1	
dark basalt		24
banded and non-banded rhyolite	3	27
tuff	1	1
Coast Range Ophiolite keratophyre(?)		4
Total		428

Count 21: Lakeville, Vineyard south of Canon Lane, Gully 1, north of Gully 2

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke	3	17	30
graywacke w/quartz veins		3	1
vein quartz		3	8
eclogite			
blueschist		3	2
quartzite			3
red chert		4	6
green chert		1	4
brown chert			
black chert			
metachert		10	13
metavolcanic	2	19	22
Great Valley Group			
white and pale porphyries			
dark porphyries	1	9	4
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		17	145
porcellinite			
Tertiary sedimentary			
Jurassic and/ or Cretaceous Plutonic			
plutonic		4	
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		5	7
banded and non-banded rhyolite			
tuff, rhyolitic tuff	1	2	5
Coast Range Ophiolite keratophyre(?)		1	2
Total:	7	94	252

Total Counted Clasts: 353

	Total Franciscan Complex (KJf):	154
	Total Monterey Group (Mmy):	162
	Total Tertiary volcanic (Tv):	20
	Total:	336
	Percentage: $x/ = x\%$	
	% Franciscan Complex	45.833%
	% Monterey Group	48.2%
	% Tertiary Volcanics	6.0%
		100.000%

Notes:

plutonics, fossiliferous marine sandstone (San Pablo Gp.), scoria volcanic clasts
green metavolcanics present in canyon exposures.

Lakeville Highway #22,
Monterey, KJf and White Clay series. Vertebrate fragment.

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		1	10
graywacke w/quartz veins		2	1
vein quartz			10
eclogite			
blueschist			
quartzite			
red chert			10
green chert			7
brown chert			5
black chert			4
metachert			3
metavolcanic			12
Great Valley Group			
white and pale porphyries			2
dark porphyries			4
Great Valley sandstone			2
Monterey Group			
Monterey siliceous laminated chert		12	382
porcellinite		7	6
Tertiary sedimentary		11	4
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			5
banded and non-banded rhyolite		1	
tuff, rhyolitic tuff		3	1
Coast Range Ophiolite keratophyre(?)			
Total:	0	26	468
Total Counted Clasts: 494			

Mmy

KJf

Tv

Total Franciscan Complex (KJf):	65
Total Monterey Group (Mmy):	407
Total Tertiary volcanic (Tv):	10
Total:	482
Percentage: x/ = x%	
% Franciscan Complex	13.485%
% Monterey Group	84.4%
% Tertiary Volcanics	2.1%
	100.000%

Notes:

Monterey petrofacies. This type looks 100% Monterey clasts in the field.

This bed is interbedded with KJf petrofacies. All are above a white, indurated clay (tuff)

Clast Count 23

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke			10
graywacke w/quartz veins			
vein quartz			14
eclogite			
blueschist		3	
quartzite			
red chert (one clast is mixed red & green)			4
green chert			
brown chert			6
black chert			
metachert		18	
metavolcanic		25	80
Great Valley Group			
white and pale porphyries		2	
dark porphyries			
Great Valley sandstone			40
Monterey Group			
Monterey siliceous laminated chert		3	72
porcellinite			
Tertiary sedimentary (carbonate cemented)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			6
Tertiary volcanic			
scoria-like			4
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff		2	8
Coast Range Ophiolite keratophyre(?)			
Total:	0	53	240

Total Counted Clasts:		293
Total Franciscan Complex (KJf):		160
Total Monterey Group (Mmy):		75
Total Tertiary volcanic (Tv):		14
Total:		249
% Franciscan Complex		64.257%
% Tertiary Sandstone & Monterey Group		30.1%
% Tertiary Volcanics		5.6%
		100.000%

Clast Count 24: Lower Marcucci

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		4	8
graywacke w/quartz veins			
vein quartz			
eclogite			
blueschist			
quartzite			
red chert		2	1
green chert			
brown chert			
black chert		3	4
metachert			
metavolcanic			
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		4	238
porcellinite			15
Tertiary sedimentary (most with quartz veinlets)		3	12
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like		1	10
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			4
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)		1	1
Total:	0	18	293
			Total Counted Clasts: 311

Sand interbeds are clean, quartz rich.

Clast Count 28: Petaluma Formation, Gossage Creek

Franciscan Complex	63 mm	31.5-16.0 mm	16 - 8.0 mm
graywacke	2	190	
graywacke w/quartz veins	1	78	
vein quartz		12	
eclogite			
blueschist		1	
quartzite			
red chert		11	
green chert		8	
brown chert			
black chert			
metachert		17	
metavolcanic	1	7	
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		4	
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	4	328	0

Total Counted Clasts:		332
Total Franciscan Complex (KJf):		328
Total Monterey Group (Mmy):		0
Total Tertiary volcanic (Tv):		4
Total:		332
% Franciscan Complex		98.795%
% Tertiary Sandstone & Monterey Group		0.0%
% Tertiary Volcanics		1.2%
		100.000%

Above shale in faulted anticline

Clast Count 29: Stage Gulch Road 1

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke	3	39	76
graywacke w/quartz veins		14	32
vein quartz		17	9
eclogite			
blueschist			
quartzite		2	
red chert		8	4
green chert		5	7
brown chert			
black chert			
metachert		3	
metavolcanic		10	15
Great Valley Group			
white and pale porphyries			
dark porphyries	1	3	8
Great Valley sandstone		8	13
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (carbonate cemented)		5	2
Jurassic and/ or Cretaceous Plutonic			
plutonic			2
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)		3	2
Total:	4	112	168
			Total Counted Clasts: 284

Clast Count 30: Tp at Lynch Creek near volcanics

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke	3	46	98
graywacke w/quartz veins		24	16
vein quartz		12	4
eclogite			
blueschist		3	
quartzite		8	2
red chert		2	
green chert		3	2
brown chert			
black chert			
metachert		25	42
metavolcanic		18	72
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like		4	2
dark basalt, aphanitic and phaneritic		9	7
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	3	154	243

Probably a well-worked near-beach deposit. Sand is clean=quartz rich.

**Clast Count 31: Taylor Mountain
Fluvial**

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke		28	140
graywacke w/quartz veins		14	8
vein quartz		4	9
eclogite		1	
blueschist		10	16
quartzite			
red chert (one clast is mixed red & green)		3	
green chert		5	1
brown chert			
black chert			
metachert			
plagiogranite			
metavolcanic		15	9
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone		4	6
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (carbonate cemented)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic			
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	0	84	189

Total Counted Clasts:	263
	Total Franciscan Complex (KJf):	259
	Total Monterey Group (Mmy):	0
	Total Tertiary volcanic (Tv):	0
	Total:	259
% Franciscan Complex		100.000%
% Tertiary Sandstone & Monterey Group		0.0%
% Tertiary Volcanics		0.0%
		100.000%

Clast Count Locality 32: San Pablo Avenue, Pinole, Contra Costa County, California

	>31.5 mm	>16.0 mm	16 to 8.0 mm
Franciscan Complex			
graywacke			
graywacke w/quartz veins			4
vein quartz			
garnet blueschist/eclogite			
blueschist			
red and green mixed chert with quartz veins		2	1
red chert	2		1
green chert		1	
brown chert			
black chert	1		1
metachert			
metavolcanic			
Great Valley Group or other Cretaceous Material			
white and pale porphyries: Leona? (quartz and plag phenocrysts)		4	1
dark porphyries			1
quartzite			
Great Valley sandstone		1	1
Monterey Group			
Monterey siliceous laminated chert (Cont's for porcellanite mudstone)	4	110	125
Tertiary sedimentary (blue and quartz-rich)	2	3	
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
red, friable, scoria-like			
Rhyolite/Rhyolitic tuff			
dark, black basalt			
gray basalt	1	1	
banded and non-banded rhyolite		3	
tuff		7	4
Total count per sed size:	10	132	140

Total Counted Clasts: 282

	Total Franciscan Complex (KJf):	13
	Total Monterey Group (Mmy):	239
	Total Tertiary volcanic (Tv):	14
	Total:	266
	Percentage: $x/276 = x\%$	
	4.89% Franciscan Complex	
	89.85% Monterey Group	
	5.26% Tertiary Volcanics	

Clast Count 33: Garrity Member at Point Pinole

Franciscan Complex	63 mm	31.5-16.0 mm	16 - 8.0 mm
graywacke		16	14
graywacke w/quartz veins		2	1
vein quartz		2	
eclogite			
blueschist		2	
quartzite		2	
red chert		2	
green chert			
brown chert			
black chert		2	
metachert		2	
metavolcanic		18	16
Great Valley Group			
white and pale porphyries			
dark porphyries	1	12	9
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		26	
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			1
Jurassic and/or Cretaceous Plutonic			
plutonic		1	
Tertiary volcanic			
scoria-like			1
dark basalt, aphanitic and phaneritic	7	18	12
banded and non-banded rhyolite	2	9	
tuff, rhyolitic tuff		2	1
Coast Range Ophiolite keratophyre(?)	1		
Total:	11	115	54

Total Counted Clasts:

180

Total Franciscan Complex (KJf):

79

Total Monterey Group (Mmy):

27

Total Tertiary volcanic (Tv):

52

Total:

158

% Franciscan Complex

50.000%

% Tertiary Sandstone & Monterey Group

17.1%

% Tertiary Volcanics

32.9%

100.000%

Clast Count 34: Middle of Point Pinole Section, Garrity Member

Franciscan Complex	31 mm	16.0 mm	
graywacke	3	122	
graywacke w/quartz veins	2		
vein quartz		16	
eclogite			
blueschist			
quartzite		10	
red chert	1	5	
green chert		3	
brown chert		6	
black chert		4	
metachert			
metavolcanic	2	110	
Great Valley Group			
white and pale porphyries			
dark porphyries	2	15	
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert		91	
porcellinite			
Tertiary sedimentary	1		
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like		2	
dark basalt, aphanitic and phaneritic	2	20	
banded and non-banded rhyolite			
tuff, rhyolitic tuff		5	
Coast Range Ophiolite keratophyre(?)		2	
Total:	13	411	0

Total Counted Clasts:		424
Total Franciscan Complex (KJf):		284
Total Monterey Group (Mmy):		91
Total Tertiary volcanic (Tv):		29
Total:		404
% Franciscan Complex		70.297%
% Tertiary Sandstone & Monterey Group		22.5%
% Tertiary Volcanics		7.2%
		100.000%

KJf petrofacies

Clast Count 35: Start of Point Pinole Section, Garrity Member

Franciscan Complex	31 mm	16.0 mm	
graywacke	4	107	
graywacke w/quartz veins	2	24	
vein quartz		9	
eclogite			
blueschist		4	
quartzite		2	
red chert	2	3	
green chert		6	
brown chert			
black chert		4	
metachert		2	
metavolcanic	3	120	
Great Valley Group			
white and pale porphyries		1	
dark porphyries	1	8	
Great Valley sandstone			
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like		1	
dark basalt, aphanitic and phaneritic		1	
banded and non-banded rhyolite		2	
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	12	294	0
		Total Counted Clasts:	306

Total Franciscan Complex (KJf):	292
Total Monterey Group (Mmy):	0
Total Tertiary volcanic (Tv):	4
Total:	296
% Franciscan Complex	98.649%
% Tertiary Sandstone & Monterey Group	0.0%
% Tertiary Volcanics	1.4%
	100.000%

KJf petrofacies

Clast Count 36: Point Pinole

Franciscan Complex	63 mm	63-16.0 mm	16 - 8.0 mm
graywacke	8	142	76
graywacke w/quartz veins	2	16	25
vein quartz		21	11
eclogite			
blueschist		1	
quartzite		3	
red chert		2	6
green chert		1	9
brown chert			
black chert			
metachert		6	2
metavolcanic		135	18
Great Valley Group			
white and pale porphyries			
dark porphyries	2	6	3
Great Valley sandstone		12	10
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (carbonate cemented)			
Jurassic and/ or Cretaceous Plutonic			
plutonic		1	
Tertiary volcanic			
scoria-like			
dark basalt, aphanitic and phaneritic		1	
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)		3	2
Total:	12	349	162

Total Counted Clasts: 523

Total Franciscan Complex (KJf):	484
Total Monterey Group (Mmy):	0
Total Tertiary volcanic (Tv):	1
Total:	485
% Franciscan Complex	99.794%
% Tertiary Sandstone & Monterey Group	0.0%
% Tertiary Volcanics	0.2%
	100.000%

Clast Count 37: Point Pinole 8

Franciscan Complex	63 mm	31.5-16.0 mm	16 - 8.0 mm
graywacke	4	170	56
graywacke w/quartz veins	2	94	16
vein quartz		17	18
eclogite			
blueschist		2	
quartzite			
red chert		8	
green chert		2	
brown chert			
black chert		1	
metachert		12	
metavolcanic	2	14	
Great Valley Group			
white and pale porphyries			
dark porphyries			
Great Valley sandstone		3	1
Monterey Group			
Monterey siliceous laminated chert			
porcellinite			
Tertiary sedimentary (most with quartz veinlets)			
Jurassic and/ or Cretaceous Plutonic			
plutonic			
Tertiary volcanic			
scoria-like		1	
dark basalt, aphanitic and phaneritic		1	
banded and non-banded rhyolite			
tuff, rhyolitic tuff			
Coast Range Ophiolite keratophyre(?)			
Total:	8	325	91

Total Counted Clasts:

424

Total Franciscan Complex (KJf):	418
	Total Monterey Group (Mmy):	0
	Total Tertiary volcanic (Tv):	2
	Total:	420
	% Franciscan Complex	99.524%
	% Tertiary Sandstone & Monterey Group	0.0%
	% Tertiary Volcanics	0.5%
		100.000%

APPENDIX C: FORAMINIFERAL DATA FOR MONTEREY CLASTS

**Foraminiferal analysis of thin sectioned clasts, interbedded gravel with marine
Wilson Grove Formation, Sonoma County, California**

M-1: Sample Locality on Plate 2

Kenneth L. Finger, Ph.D., Consulting Paleontologist, 2/7/01

MICROSCOPIC ANALYSIS

Slide #1N

Recognizable Planktic Taxa: *Globigerina bulloides*, spongodiscid radiolarian

Recognizable Benthic Taxa: none

P:B Ratio = 50:0

% Planktics = 100.0

Slide #1A

Recognizable Planktic Taxa: *Globigerina bulloides*, *Globigerina pseudociperoensis*

Recognizable Benthic Taxa: none

P:B Ratio = 30:2 = 15:1

% Planktics = 93.8

Slide #2

Recognizable Planktic Taxa: spongodiscid radiolarian

Recognizable Benthic Taxa: *Siphonodosaria quadrilatera*?

P:B Ratio = 13:5

% Planktics = 72.2

Slide #3

Recognizable Planktic Taxa: none

Recognizable Benthic Taxa: none

P:B Ratio = 3:5

% Planktics = 37.5

Slide #4

Recognizable Planktic Taxa: *Globigerina bulloides*, *Globigerina pseudociperoensis*,
Tenuitellinata angustiumbilitata

Recognizable Benthic Taxa: *Gyroidina rosaformis*

P:B Ratio = 37:6 = 6:1 (P includes 1 radiolarian)

% Planktics = 86.0

Slide #5

Recognizable Planktic Taxa: none

Recognizable Benthic Taxa: none

P:B Ratio = 2:2 = 1:1
 % Planktics = 50.0

Slide #6

Recognizable Planktic Taxa: *Globigerina bulloides*
 Recognizable Benthic Taxa: *Bolivina* sp., *Siphonodosaria quadrilatera*
 P:B Ratio = 8:1
 % Planktics = 72.0

Slide #7

Recognizable Planktic Taxa: none
 Recognizable Benthic Taxa: none
 P:B Ratio = 4:4 (P includes 1 radiolarian)
 % Planktics = 50.0

Slide #8

Recognizable Planktic Taxa: *Globigerina bulloides*, spongodiscid radiolarian
 Recognizable Benthic Taxa: *Gyroidina rosaformis*, *Protoglobobulima pseudotorta*?,
Siphonodosaria quadrilatera
 P:B Ratio = 1:1
 % Planktics = 50.0
 Comments: Very meager assemblage

Slide #9

Recognizable Planktic Taxa: *Globigerina bulloides*, spongodiscid radiolarian
 Recognizable Benthic Taxa: none
 P:B Ratio = 2:5
 % Planktics = 28.6

Slide #14

Recognizable Planktic Taxa: *Globigerina pseudociperoensis*
 Recognizable Benthic Taxa: none
 P:B Ratio = 22:0
 % Planktics = 100.0

Slide #16

Recognizable Planktic Taxa: *Globigerina pseudociperoensis*
 Recognizable Benthic Taxa: none
 P:B Ratio = 36:0
 % Planktics = 100.0

Slide #18

Recognizable Planktic Taxa: ? *Globigerina pseudociperoensis*, spongodiscid radiolarian
 Recognizable Benthic Taxa: *Nodogenerina sagrinensis*

P:B Ratio = 10:0
 % Planktics = 100.0
 Comments: Most specimens are crushed

Slide #19

Recognizable Specimens: none
 P:B Ratio = none
 % Planktics = none

Slide #20

Recognizable Planktic Taxa: none
 Recognizable Benthic Taxa: *Gyroidina rosaformis*
 P:B Ratio = 0:3
 % Planktics = 0.0

Slide #21

Recognizable Planktics: *Tenuitellinata angustiumbilicata*
 Recognizable Benthics: *Buliminella subfusiformis*, ?*Globobulimina pseudotorta*,
 P:B Ratio = >9:1
 % Planktics = >90%
 Comments: Abundant foram voids; shell material is very scarce

SUMMARY

The taxa recognized on these 16 slides are among the most commonly occurring and abundant in the Monterey Formation. The slides include 262 specimens that were identifiable as either planktic (227 specimens) or benthic (35 specimens) on the basis of their geometries and test wall structures. The planktics, which include a few radiolarians, account for 86.64% of the total. Thus, the overall P:B ratio is nearly 9:1.

CONCLUSIONS

Biostratigraphy

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.

Depositional Paleoenvironment

Several of the benthic foraminifers are bathyal-depth indicators. Of these, *Nodogenerina sagrinensis* (represented by a very nice void in Slide 18) has the deepest upper-depth limit (lower middle-bathyal range (1,500-2,000 m)). This depth range is the one most commonly interpreted for the Monterey Formation throughout its geographic range and biostratigraphic interval. *In situ* middle-bathyal deposits in the coastal basins of

California will have high P:B ratios. However, basin-floor deposits in tectonic basins are commonly turbidites bearing mixed assemblages containing abundant benthics that have been displaced from shallower depths. In contrast, the thin-sectioned Cotati sediments are fine-grained and contain no indication of significant downslope displacement.

**Foraminiferal analysis of thin-sectioned clasts from the Garrity Member of the Contra Costa Group, Contra Costa County, California
(San Pablo Avenue).**

By Kenneth L. Finger, Ph.D., Consulting Paleontologist, 7/5/01

**"UPPER SUBMEMBER" OF THE GARRITY MEMBER OF THE CONTRA
COSTA GROUP**

M-2: Sample locality on Plate 4

Slide G-1

Section parallel to bedding.

Assemblage: *Bolivina advena* (4), *Gavelinopsis* sp. (1), *Globigerina bulloides* (1),
Globigerina pseudociperoensis (2), *Pseudoparrella subperuviana* (1),
?Siphonodosaria quadrulata (1), *Tenuitellinata angustiumbilitata* (19)

P:B Ratio = 22:9 (71% planktics)

Slide G-2

Section parallel to bedding.

Assemblage: About a dozen specimens, mostly voids and mostly planktics (including
Globigerina bulloides)

Slide G-3

Section oblique to bedding.

< 6 planktics; very poor condition, indeterminate

Slide G-4

Section oblique to bedding.

Assemblage: 3 spongodiscid radiolarians (planktics)

Slide G-5

Section parallel to bedding.

Assemblage: *Bolivina advena* (1), *Globigerina bulloides* (1), and a few planktic fragments

Slide G-5 w/ "maybe?" label

Section parallel to bedding.

Assemblage: *Bolivina advena*? (1), *Bolivina brevior* (1), *Globigerina bulloides* (2), and a few foram fragments

Slide G-6

Section oblique to bedding, but too thick!

Assemblage: very few *Bolivina* and *Globigerina*, and spongodiscid radiolarian

P:B Ratio = indeterminate

Slide G-7

Section oblique to bedding, but too thick!

Assemblage: a couple if partial indeterminate forams.

P:B Ratio = indeterminate

Slide G-8

?Section oblique to bedding

Assemblage: *Bolivina advena* (3), *Globigerina bulloides* (14), *Tenuitellinata angustiumbilitata* (11)

P:B Ratio = 25:3 (99%)

Slide G-9

Section oblique to bedding

Assemblage: *Bolivina advena* (2), *Globigerina bulloides* (5), indeterminate planktic forams (6)

P:B Ratio = 11:2 (85%)

Slide G-10

Section oblique to bedding

Assemblage: *Bolivina advena* (4), *Buliminella subfusiformis* (1), *Globigerina bulloides* (3), indeterminate planktic forams (12)

P:B Ratio = 3:1 (75%)

Slide G-11

Section parallel to bedding

Assemblage: *Bolivina advena* (2), *Bolivina brevior* (1), *Globigerina bulloides* (2), *Gyroidina rosaformis* (5), *Protoglobobulimina pseudotorta* (1), indeterminate planktic forams (3)

P:B Ratio = 5:9 (36%)

Slide G-12

Section parallel to bedding

Assemblage: *Bolivina advena* (1), *Bolivina brevior* (3), *Buliminella elegantissima* (1), *Gyroidina rosaformis* (3), *Tenuitellinata angustiumbilitata* (1)

P:B Ratio = 1:8 (11%)

Slide G-13

Section oblique to bedding; mostly too thick

Assemblage: A few forams, but too poor to recognize.

Slide G-14

Section oblique to bedding

Assemblage: A very few indeterminate planktics

Slide G-15

Section oblique to bedding, but too thick!

Assemblage: very few *Bolivina* and *Globigerina*

Slide G-16

Section parallel to bedding

Assemblage: *Globigerina bulloides* (3), spongodiscid radiolarians (3), and numerous voids, many appear to be of *Globigerina bulloides*

P:B Ratio = 100% planktics

Slide G-17

Section oblique to bedding

Assemblage: *Globigerina bulloides* and a spongodiscid radiolarian, and a very few indeterminate forams

Interpretation of the Garrity Pebbles

The 18 thin-sections of pebbles in the Garrity Formation have assemblages that more-or-less typify the Miocene Monterey Formation, but none have index species that would enable assignment to a foraminiferal stage. Most of the species recognized are very common and abundant throughout the Monterey. Although the low numbers of specimens do not make these statistically valid, it is perhaps significant to note that the composite assemblage is dominated by planktic foraminifera in association with radiolarians. This suggests offshore deposition at bathyal depths, which further supports the interpretation that these pebbles have been derived from the Monterey.

BASAL WILSON GROVE FORMATION SANDSTONE MATRIX**Slide WG-1A**

Section consists of unconsolidated material

Assemblage: ?*Anomalinoides salinasensis* (2), bryozoan? sp. A (2), bryozoan? sp. B (1)

Interpretation of forams from the basal Wilson Grove sandstone matrix:

Numerous voids and clasts have shapes and features similar to large benthic foraminifers, but their nature is uncertain. A couple of partial whorls resembling those of the benthic

foraminifer *Anomalinoides salinasensis* are present. This benthic species ranges from Saucesian to Mohnian, but is most common in the Luisian and relatively rare in the Mohnian.

APPENDIX D: PALEOCURRENT DATA

Sample numbers correspond to clast-count station numbers and are located on the plates (in pocket)

Sector Interval Angle = 10°
 Scale spacing = 10% [1 data]
 Maximum = 40% [2 data]
 Mean Resultant direction = 248°
 Circular Mean Dev. = 41°

Resultant length = 3.49
 Mean Resultant length = 0.70
 [Circ. Variance = 0.30]
 Circular Std.Dev. = 0.8
 Circ. Dispersion = 0.92
 Circ.Skewness = -0.32
 Circ.Kurtosis = -1.60

'Mean' Moments: Cbar = -0.26; Sbar = -0.65
 'Full' trig. sums: SumCos = -1.31; Sbar = -3.23
 von Mises concentration param. estimate = 1.99
 Mean resultant of doubled angles = 0.10
 Mean direction of doubled angles = 105°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 50% [1 data]
 Mean Resultant direction = 310°
 Circular Mean Dev. = 40°

Resultant length = 1.53
 Mean Resultant length = 0.77
 [Circ. Variance = 0.23]
 Circular Std.Dev. = 0.7
 Circ. Dispersion = 0.70
 Circ. Skewness = 0.00
 Circ. Kurtosis = -3.12

'Mean' Moments: $\bar{C} = 0.49$; $\bar{S} = -0.59$
 'Full' trig. sums: $\text{SumCos} = 0.98$; $\bar{S} = -1.17$
 von Mises concentration param. estimate = 2.50
 Mean resultant of doubled angles = 0.17
 Mean direction of doubled angles = 260°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 323°
 Circular Mean Dev. = 18°

Resultant length = 2.81
 Mean Resultant length = 0.94
 [Circ. Variance = 0.06]
 Circular Std.Dev. = 0.4
 Circ. Dispersion = 0.14
 Circ. Skewness = -0.68
 Circ. Kurtosis = -2.74

'Mean' Moments: $\bar{C} = 0.75$; $\bar{S} = -0.56$
 'Full' trig. sums: $\text{SumCos} = 2.25$; $\bar{S} = -1.68$
 von Mises concentration param. estimate = 7.90
 Mean resultant of doubled angles = 0.76
 Mean direction of doubled angles = 286°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 235°
 Circular Mean Dev. = 45°

Resultant length = 1.93
 Mean Resultant length = 0.64
 [Circ. Variance = 0.36]
 Circular Std.Dev. = 0.9
 Circ. Dispersion = 0.80
 Circ. Skewness = -1.57
 Circ. Kurtosis = -1.36

'Mean' Moments: Cbar = -0.37; Sbar = -0.53
 'Full' trig. sums: SumCos = -1.11; Sbar = -1.58
 von Mises concentration param. estimate = 1.70
 Mean resultant of doubled angles = 0.33
 Mean direction of doubled angles = 020°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 5% [0 data]
 Maximum = 20% [1 data]
 Mean Resultant direction = 268°
 Circular Mean Dev. = 50°

Resultant length = 2.83
 Mean Resultant length = 0.57
 [Circ. Variance = 0.43]
 Circular Std.Dev. = 1.1
 Circ. Dispersion = 1.18
 Circ.Skewness = 0.02
 Circ.Kurtosis = -1.83

'Mean' Moments: Cbar = -0.02; Sbar = -0.57
 'Full' trig. sums: SumCos = -0.10; Sbar = -2.83
 von Mises concentration param. estimate = 1.38
 Mean resultant of doubled angles = 0.24
 Mean direction of doubled angles = 354°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 5% [0 data]
 Maximum = 25% [1 data]
 Mean Resultant direction = 303°
 Circular Mean Dev. = 43°

Resultant length = 2.39
 Mean Resultant length = 0.60
 [Circ. Variance = 0.40]
 Circular Std.Dev. = 1.0
 Circ. Dispersion = 0.69
 Circ. Skewness = 1.82
 Circ. Kurtosis = 0.48

'Mean' Moments: $\bar{C} = 0.33$; $\bar{S} = -0.50$
 'Full' trig. sums: $\text{SumCos} = 1.32$; $\bar{S} = -1.99$
 von Mises concentration param. estimate = 1.49
 Mean resultant of doubled angles = 0.51
 Mean direction of doubled angles = 313°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 5% [0 data]
 Maximum = 20% [1 data]
 Mean Resultant direction = 273°
 Circular Mean Dev. = 44°

Resultant length = 3.37
 Mean Resultant length = 0.67
 [Circ. Variance = 0.33]
 Circular Std.Dev. = 0.9
 Circ. Dispersion = 1.00
 Circ.Skewness = -0.49
 Circ.Kurtosis = -1.85

'Mean' Moments: Cbar = 0.04; Sbar = -0.67
 'Full' trig. sums: SumCos = 0.19; Sbar = -3.37
 von Mises concentration param. estimate = 1.86
 Mean resultant of doubled angles = 0.09
 Mean direction of doubled angles = 103

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 311°
 Circular Mean Dev. = 43°

Resultant length = 2.05
 Mean Resultant length = 0.68
 [Circ. Variance = 0.32]
 Circular Std.Dev. = 0.9
 Circ. Dispersion = 0.72
 Circ. Skewness = 1.82
 Circ. Kurtosis = -1.44

'Mean' Moments: $\bar{C} = 0.45$; $\bar{S} = -0.51$
 'Full' trig. sums: $\text{SumCos} = 1.35$; $\bar{S} = -1.54$
 von Mises concentration param. estimate = 1.90
 Mean resultant of doubled angles = 0.33
 Mean direction of doubled angles = 340°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 323°
 Circular Mean Dev. = 18°

Resultant length = 2.81
 Mean Resultant length = 0.94
 [Circ. Variance = 0.06]
 Circular Std.Dev. = 0.4
 Circ. Dispersion = 0.14
 Circ.Skewness = -0.68
 Circ.Kurtosis = -2.74

'Mean' Moments: $Cbar = 0.75$; $Sbar = -0.56$
 'Full' trig. sums: $SumCos = 2.25$; $Sbar = -1.68$
 von Mises concentration param. estimate = 7.90
 Mean resultant of doubled angles = 0.76
 Mean direction of doubled angles = 286°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 304°
 Circular Mean Dev. = 44°

Resultant length = 2.02
 Mean Resultant length = 0.67
 [Circ. Variance = 0.33]
 Circular Std.Dev. = 0.9
 Circ. Dispersion = 0.70
 Circ.Skewness = 1.95
 Circ.Kurtosis = -1.33

'Mean' Moments: $\bar{C} = 0.37$; $\bar{S} = -0.56$
 'Full' trig. sums: $\text{SumCos} = 1.12$; $\bar{S} = -1.68$
 von Mises concentration param. estimate = 1.85
 Mean resultant of doubled angles = 0.37
 Mean direction of doubled angles = 327°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 264°
 Circular Mean Dev. = 43°
 Resultant length = 2.07
 Mean Resultant length = 0.69
 [Circ. Variance = 0.31]
 Circular Std.Dev. = 0.9
 Circ. Dispersion = 0.69
 Circ. Skewness = 1.93
 Circ. Kurtosis = -1.43
 'Mean' Moments: Cbar = -0.07;
 Sbar = -0.69; 'Full' trig. sums: SumCos =
 -0.22; Sbar = -2.06; von Mises concentration
 param. estimate = 1.94
 Mean resultant of doubled angles = 0.35
 Mean direction of doubled angles = 243°
 (Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 329°
 Circular Mean Dev. = 60°
 Resultant length = 1.00
 Mean Resultant length = 0.33
 [Circ. Variance = 0.67]
 Circular Std.Dev. = 1.5
 Circ. Dispersion = 2.36
 Circ. Skewness = -0.82
 Circ. Kurtosis = -0.39
 'Mean' Moments: Cbar = 0.29;
 Sbar = -0.17
 'Full' trig. sums: SumCos = 0.86;
 Sbar = -0.52
 von Mises concentration param. estimate
 = 0.71; Mean resultant of doubled angles =
 0.47; Mean direction of doubled angles =
 188° ; (Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 5% [0 data]
 Maximum = 20% [1 data]
 Mean Resultant direction = 232°
 Circular Mean Dev. = 48°

Resultant length = 2.76
 Mean Resultant length = 0.55
 [Circ. Variance = 0.45]
 Circular Std.Dev. = 1.1
 Circ. Dispersion = 1.08
 Circ. Skewness = -1.08
 Circ. Kurtosis = 0.10

'Mean' Moments: $\bar{C} = -0.34$; $\bar{S} = -0.44$
 'Full' trig. sums: $\text{SumCos} = -1.69$; $\bar{S} = -2.19$
 von Mises concentration param. estimate = 1.33
 Mean resultant of doubled angles = 0.34
 Mean direction of doubled angles = 034°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 5% [0 data]
 Maximum = 25% [1 data]
 Mean Resultant direction = 283°
 Circular Mean Dev. = 26°

Resultant length = 3.53
 Mean Resultant length = 0.88
 [Circ. Variance = 0.12]
 Circular Std.Dev. = 0.5
 Circ. Dispersion = 0.28
 Circ. Skewness = 0.16
 Circ. Kurtosis = -2.42

'Mean' Moments: $\bar{C} = 0.20$; $\bar{S} = -0.86$
 'Full' trig. sums: $\text{SumCos} = 0.81$; $\bar{S} = -3.43$
 von Mises concentration param. estimate = 4.23
 Mean resultant of doubled angles = 0.57
 Mean direction of doubled angles = 207°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 33.3% [1 data]
 Mean Resultant direction = 254°
 Circular Mean Dev. = 34°

Resultant length = 2.41
 Mean Resultant length = 0.80
 [Circ. Variance = 0.20]
 Circular Std.Dev. = 0.7
 Circ. Dispersion = 0.49
 Circ.Skewness = 1.81
 Circ.Kurtosis = -2.05

'Mean' Moments: $\bar{C} = -0.23$; $\bar{S} = -0.77$
 'Full' trig. sums: $\text{SumCos} = -0.68$; $\bar{S} = -2.31$
 von Mises concentration param. estimate = 2.89
 Mean resultant of doubled angles = 0.37
 Mean direction of doubled angles = 173°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

Sector Interval Angle = 10°
 Scale spacing = 10% [0 data]
 Maximum = 50% [2 data]
 Mean Resultant direction = 356°
 Circular Mean Dev. = 9°

Resultant length = 3.94
 Mean Resultant length = 0.99
 [Circ. Variance = 0.01]
 Circular Std.Dev. = 0.2
 Circ. Dispersion = 0.03
 Circ.Skewness = -0.78
 Circ.Kurtosis = -2.80

'Mean' Moments: $\bar{C} = 0.98$; $\bar{S} = -0.06$
 'Full' trig. sums: $\text{SumCos} = 3.94$; $\bar{S} = -0.26$
 von Mises concentration param. estimate = 35.74
 Mean resultant of doubled angles = 0.94
 Mean direction of doubled angles = 352°

(Usage reference: Mardia & Jupp,
 'Directional Statistics', 1999, Wiley)

APPENDIX E: PALEONTOLOGY AND LOCALITY DATA

Lower and Middle Petaluma Formation Hemphillian vertebrate fossils

to scale

Neohipparion gidleyi (tooth cast)

Hemphillian

C.I.T. Loc. 134 Original # C.I.T. Loc 499
U.C.B.G. vol 29, No. 13, p. 391, Fig. 74-75
(lit. reference), Stirton 1939

Neohipparion gidleyi (lower molar M^3)

Hemphillian

Lawlor Ranch, Locality # 1036, Osmont 1904
Pictured: Same tooth, front and back side shown.

Neohipparion cf. N. gidleyi

Hemphillian

Petaluma Pipeline, Locality V3826
No. 34119, Acc 343, RAS#1283 (Stirton)

Camel (tooth M^2)

Hemphillian

Petaluma Pipeline, Locality V3826, Acc. 657
Stirton and Macdonald, 1946

Equidae (Dist.
tibia).

Hemphillian

No. 33044,
Lakeville Divide,
V3647, Acc
229, 1936
U.C. Party
Stirton 1939

Camelidae

Hemphillian

No. 37042

T.F. Harri

Upp

Upper Hemphillian vertebrate fossils

Neohipparion gidleyi (lower molar M^3)
Hemphillian

Lawlor Ranch, Locality # 1036, Osmont 1904
Pictured: Same tooth, front and back side shown.

Camel (tooth M^2)
Hemphillian

Petaluma Pipeline, Locality V3826, Acc. 657
Stirton and Macdonald, 1946

Equidae (Dist.
tibia).

Hemphillian

No. 33044,
Lakeville Divide,
V3647, Acc
229, 1936
U.C. Party
Stirton 1939

Top view

Camelidae
Hemphillian

No. 37042, locality # V4202, Acc. 566, Adobe Fort
T.F. Harris

Upper Petaluma Formation Blancan (Pliocene) vertebrate fossils

0 1 cm

0 3 cm

Pliohippine
E. Blancan
No. 42
1952, 1
W. Mo
Benne

Occlusal

0
Side views

Pliohippine equus

E. Blancan

Locality V5231, CCC. 1304, R. Stirton
Sears Point
(Collected from Monterey clast conglomerate upon
field check).

0 4 cm

Is

1904
e shown.

57

dae (Dist.

phillian

33044,
ville Divide,
47, Acc
1936
Party
on 1939

Top view

Side view

Camelidae
Hemphillian.

No. 37042, locality # V4202, Acc. 566, Adobe Fort
T.F. Harris

0 6 cm

Upper Petaluma Formation Blanco (Pliocene) vertebrate fossils

0 1 cm

0 3 cm

Pliohippine equus
E. Blanco

No. 42415, V5230
1952, L. Herrera &
W. Moen: Jacob's Ranch,
Bennett Valley, CA.

Occlusal views

0 5 cm

Side views

Pliohippine equus
E. Blanco

Locality V5231, CCC. 1304, R. Stirton
Sears Point
(Collected from Monterey clast conglomerate upon
field check).

0 4 cm

A.

B.

A. Marine invertebrate fossil *Polinices* cf. aff. *draconis* from the Petaluma Formation (Marincovich, pers. comm. 2002). B. Vertebrate fossils from the Stony Point Rock Quarry. The three fossils on the left are *Neohipparion gidleyi* (Repenning, pers. comm. 2002). The two bone fragments are possibly from a camel (Repenning, pers. comm., 2002).

A

B.

Microfauna

The ostracodes and non-marine are exclusively *Surirella striatula* (Repenning, pers. comm., 2002). C. Enlarged *Surirella striatula*

A

XPL

0 1 mm

B.

PPL

C.

XPL

Microfauna of the lower Petaluma Formation. The ostracodes in the lower Petaluma consist of marine and non-marine species. Diatoms in the lower Petaluma are exclusively marine. A. Ostracodal shale; B. Diatom *Surirella striatula* (E. Ruck, California Academy of Sciences, written communication, 2002; Sample D-1 on Plate 3). C. Enlarged *Surirella striatula* (XPL); D. Enlarged *Surirella striatula* (PPL); E. *Surirella striatula* (Jensen, 1985).

f. aff. *draconis* from the Petaluma
Vertebrate fossils from the Stony
are *Neohipparion gidleyi* (Repenning,
possibly from a camel (Repenning,

Microfauna of the lower Petaluma Formation. The ostracodes in the lower Petaluma consist of marine and non-marine species. Diatoms in the lower Petaluma are exclusively marine. A. Ostracodal shale; B. Diatom *Surirella striatula* (E. Ruck, California Academy of Sciences, written communication, 2002; Sample D-1 on plate 3). C. Enlarged *Surirella striatula* (XPL); D. Enlarged *Surirella striatula* (PPL); E. *Surirella striatula* (Jensen, 1985).

Marine fossiliferous outcrop in Bennett Valley where Pliocene vertebrates and the Pliocene Healdsburg tuff occur in the upper Petaluma Formation.

The Fossil of the Petaluma Formation					
Sonoma County, California					
Fossil	Formation	AGE	Lithology	Environment	Locality/Description
Invertebrates					
<i>Planorbis</i>	Upper Petaluma		clay	fresh-water	Lawlor Ranch 38° 17' 19"N, 122° 35' 16"W Glen Ellen 7.5 quad
<i>Lymnaea</i>	Upper Petaluma		clay	fresh-water	Lawlor's Ranch (location same as above)
<i>Gyrena California</i>				brackish	upper Lichau Creek
<i>Corbicula California</i>				fresh-water	upper Lichau Creek
<i>Bitum totocensis</i>					Hagen Creek, one mile southeast of
<i>Sphaerium</i>					Pena's Grove, clay on eridan by conglomerate.
<i>Platidium</i>					38° 17' 14"N, 122° 35' 30"W Coon 7.5 quad
<i>Palaeorthis</i>					
<i>Lymnaea</i>					
<i>Physa</i>					
<i>Psidium</i> sp., cf. <i>P. compressum</i>				fresh-water	CPIA01 on map
<i>Planorbidae</i> , indeterminate				fresh-water	CPIA01 on map
<i>Polinices</i> cf. <i>P. Anconis</i> (This study)	Lower Petaluma	Middle Pliocene-recent	dark green clay	marine	LMIA02 on map
<i>Surirella sinuata</i>	Lower Petaluma	late Miocene	Chert	Marine	D-1 locality. See Plate 3, collected during this study
Vertebrates					
<i>Neohippurion galleyi</i>	middle Petaluma	late Miocene	light gray, sandy clays	fluvial-lacustrine	Petaluma Pipeline V3826; see plates for localities
<i>Neohippurion galleyi</i>	middle Petaluma	late Miocene	light brown, laminated		Ckt 134 V77062
<i>Neohippurion galleyi</i>	middle Petaluma	late Miocene			Lawlor Ranch 1 V1036
<i>Neohippurion galleyi</i>	middle Petaluma	late Miocene			Lawlor Ranch 1 V1036
<i>Neohippurion galleyi</i>	middle Petaluma	late Miocene	upper shale	fluvial-lacustrine	Stony Point Rock Quarry: EBJA01
<i>Equidae Perisodactyla</i>	middle Petaluma	late Miocene		Lakeville Divide	V 3647
<i>Leporidae Lagomorpha</i>	middle Petaluma	late Miocene		Eureka Creek	V 3825
<i>Chelonia</i>	middle Petaluma	late Miocene		Petaluma Pipeline	V 3826
<i>Camelidae Artiodactyla</i>	middle Petaluma	late Miocene		Adobe Fort	V 4202
<i>Camelidae Artiodactyla</i>	middle Petaluma	late Miocene		Petaluma Pipeline	V 3526
<i>Rhinocerotidae Perissodactyla</i>	middle Petaluma	late Miocene		Bozeman	V 74088
Blanca (Pliocene) Vertebrates from the Petaluma Formation: See plates for localities					
<i>Equus</i> sp.	Pliocene	Early Blaskan		fluvial-lacustrine	Seam Point 1 V 5231
<i>Equus</i> sp.	Pliocene	Early Blaskan		fluvial	Jacobs Ranch (Berrant Valley) V 5230
<i>Proboscidea fragment</i>	Upper Petaluma		claystone		BJA02190

Microfaleontology of the Petaluma Formation

SAMPLE #	Locality Data	Formation	Well Depth	Age	Genus	Species	Author & Date	Faunal Notes
	LOCALITY DATA							FAUNAL NOTES
MW-1 Plate 3	Moss Well #1 - Sonoma County	Petaluma	255-271'	U. Mioc. - L. Plioc.	BARREN			
MW1A-01	Moss Well #1 - Sonoma County	Petaluma	255-271'	U. Mioc. - L. Plioc.	BARREN			
MW1A-02	Moss Well #1 - Sonoma County	Petaluma	958-968'	U. Mioc. - L. Plioc.	<i>Heterospyris</i> <i>Camdonia</i> <i>Lamnosyllis</i> <i>Foraminifera</i> <i>Chama</i>	<i>glauca</i> aff. <i>C. caudata</i> <i>marginata</i> sp. indet. sp.	Furtos, 1933 Kaufmann, 1900 (Band, 1843)	lacustrine, but also found in trans. marine - TDS 30ppm+ primarily lacustrine, but ponds, streams also - TDS 30ppm+ lacustrine, TDS 30ppm+
MW1A-03	Moss Well #1 - Sonoma County	Petaluma	1321 - 1331'	U. Mioc. - L. Plioc.	<i>Heterospyris</i> <i>Camdonia</i> <i>Camdonia</i> <i>Lamnosyllis</i>	<i>glauca</i> aff. <i>C. caudata</i> aff. <i>C. caudata</i> sp.	Furtos, 1933 Kaufmann, 1900	lacustrine, but also found in trans. marine - TDS 30ppm+ primarily lacustrine, but ponds, streams also - TDS 30ppm+ lacustrine, ponds, streams, TDS 30ppm+ lacustrine, TDS 30ppm+
MW1A-04	Moss Well #1 - Sonoma County	Petaluma	1510 - 1522'	U. Mioc. - L. Plioc.	<i>Cyprina</i> <i>Camdonia</i> <i>Heterospyris</i> <i>Lamnosyllis</i> <i>Darwinula</i> <i>Foraminifera</i>	sp. sp. (juv. s.) <i>glauca</i> <i>marginata</i> <i>stevensoni</i>	Furtos, 1933 (Band, 1843) Brady & Robertson, 1890	lacustrine, but also found in trans. marine - TDS 30ppm+ lacustrine, TDS 30ppm+ lacustrine, ponds, streams, TDS 30ppm+, higher tolerance in the CF
MW1A-05	Moss Well #1 - Sonoma County	Petaluma	1658 - 1671'	U. Mioc. - L. Plioc.	<i>Cyprina</i> <i>Heterospyris</i> <i>Lamnosyllis</i> <i>Foraminifera</i> <i>Darwinula</i>	sp. <i>glauca</i> <i>marginata</i> <i>gabba</i> <i>stevensoni</i>	Furtos, 1933 (Band, 1843) (Ramsdell, 1908) Brady & Robertson, 1890	lacustrine, but also found in trans. marine - TDS 30ppm+ lacustrine, TDS 30ppm+ stream pond rare lacustrine - but elevated TDS lacustrine, ponds, streams, TDS 30ppm+, higher tolerance in the CF
MW1A-06	Moss Well #1 - Sonoma County	Petaluma	1719 - 1751'	U. Mioc. - L. Plioc.	<i>Cyprina?</i> <i>Heterospyris</i>	sp. <i>glauca</i>	Furtos, 1933	lacustrine, but also found in trans. marine - TDS 30ppm+
MW1A-07	Moss Well #1 - Sonoma County	Petaluma	1768 - 1775'	U. Mioc. - L. Plioc.	<i>Heterospyris</i>	<i>glauca</i>	Furtos, 1933	lacustrine, but also found in trans. marine - TDS 30ppm+
MW1A-08	Moss Well #1 - Sonoma County	Petaluma	1784-1790'	U. Mioc. - L. Plioc.	<i>Heterospyris</i>	<i>glauca</i>	Furtos, 1933	lacustrine, but also found in trans. marine - TDS 30ppm+
MW-2 Plate 3								
MW2B-01	Murphy Well #1 - Sonoma County	Petaluma	1856'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-02	Murphy Well #1 - Sonoma County	Petaluma	1957'	U. Mioc.-L. Plioc.	BARREN			fluvial?
MW2B-03	Murphy Well #1 - Sonoma County	Petaluma	1984'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-04	Murphy Well #1 - Sonoma County	Petaluma	1903'	U. Mioc.-L. Plioc.	BARREN			
MW2B-05	Murphy Well #1 - Sonoma County	Petaluma	1999'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-06	Murphy Well #1 - Sonoma County	Petaluma	2002'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-07	Murphy Well #1 - Sonoma County	Petaluma	2003'	U. Mioc.-L. Plioc.	BARREN			fluvial
MW2B-08	Murphy Well #1 - Sonoma County	Petaluma	2011' (from label)	U. Mioc.-L. Plioc.	<i>Heterospyris</i> <i>Cyprinocypris</i>	sp. aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, pond, stream, also trans. marine - TDS 30+ lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-09	Murphy Well #1 - Sonoma County	Petaluma	2030'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-10	Murphy Well #1 - Sonoma County	Petaluma	2047'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-11	Murphy Well #1 - Sonoma County	Petaluma	2208'	U. Mioc.-L. Plioc.	<i>Cyprinocypris</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
MW2B-12	Murphy Well #1 - Sonoma County	Petaluma	2320-21'	U. Mioc.-L. Plioc.	BARREN			

Micropaleontology of the Petaluma Formation

	Genus GENUS	Species SPECIES	Author & Date AUTHOR & DATE	Faunal Notes FAUNAL NOTES	PH Ranges PH RANGES	Sed type SED. TYPE	Paleohydrochem. PALEOHYDROCHEMISTRY	Coll COLL
	BARREN					Greenish gray, finely laminated, compact, micaceous siltstone - lacustrine?	undetermined	L. B
	<i>Heterospyris</i> <i>Candida</i> <i>Lamnosythere</i> <i>Foraminifer</i> <i>Chara</i>	<i>glauvus</i> aff. <i>C. caudata</i> <i>inopinata</i> sp. indet. sp.	Furtos, 1933 Kaufmann, 1900 (Baird, 1843)	lacustrine, but also found in trans. marine - TDS 30ppm+ primarily lacustrine, but ponds, streams also - TDS 30ppm lacustrine, TDS 30ppm+	7.7-11 5-9.5 no data	bioturbated, silty to sandy mudstone; light greenish gray - DIATOMS?	oligohaline	
	<i>Heterospyris</i> <i>Candida</i> <i>Lamnosythere</i>	<i>glauvus</i> aff. <i>C. caudata</i> <i>C. caudata</i> <i>Lamnosythere</i> sp.	Furtos, 1933 Kaufmann, 1900	lacustrine, but also found in trans. marine - TDS 30ppm+ primarily lacustrine, but ponds, streams also - TDS 30ppm+ lacustrine, ponds, streams, TDS 30ppm lacustrine, TDS 30ppm+	7.7-11 5-9.5 6.5-10	gray claystone, minute pyrite nodules abundant	oligohaline	L. B
	<i>Cyprina</i> <i>Candida</i> <i>Heterospyris</i> <i>Lamnosythere</i> <i>Darwinula</i> <i>Foraminifera</i>	sp. sp. (juvs.) <i>inopinata</i> <i>stevensoni</i>	Furtos, 1933 (Baird, 1843) Brady & Robertson, 1890	lacustrine, but also found in trans. marine - TDS 30ppm+ lacustrine, TDS 30ppm+ lacustrine, ponds, streams, TDS 30ppm+, higher tolerance in the CL	7.7-11 no data 6-9.5	greenish gray compact mudstone, silty	oligohaline, transitional marine influenced, in part determined by presence of very rare forams - secondary artifacts?	L. B
	<i>Cyprina</i> <i>Heterospyris</i> <i>Lamnosythere</i> <i>Heterospyris</i> <i>Darwinula</i>	sp. <i>glauvus</i> <i>inopinata</i> <i>stevensoni</i> <i>glauvus</i>	Furtos, 1933 (Baird, 1843) (Ramakrish, 1908) Brady & Robertson, 1890	lacustrine, but also found in trans. marine - TDS 30ppm lacustrine, TDS 30ppm+ stream pond rate lacustrine - but elevated TDS lacustrine, ponds, streams, TDS 30ppm+, higher tolerance in the CL	7.7-11 no data 6.5-9 6-9.5	compact interbedded gray mudstone and arkosic sandstone (lacustrine)	oligohaline, elevated TDS	L. B
	<i>Cyprina?</i> <i>Heterospyris</i>	sp. <i>glauvus</i>	Furtos, 1933	lacustrine, but also found in trans. marine - TDS 30ppm	7.7-11	compact, dark gray mudstone	oligohaline, elevated TDS	L. B
	<i>Heterospyris</i>	<i>glauvus</i>	Furtos, 1933	lacustrine, but also found in trans. marine - TDS 30ppm	7.7-11	dark, flaggy mudstone w. silty layers	oligohaline, NaCl dominated	L. B
	<i>Heterospyris</i>	<i>glauvus</i>	Furtos, 1933	lacustrine, but also found in trans. marine - TDS 30ppm	7.7-11	gray compact medium-grained, biotitic micaceous arkosic w. mudstone interbed	probably oligohaline	L. B
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray arkosic claystone	oligohaline, Alk. dominated	Shell O
	BARREN			fluvial?		coarse to fine-grained sandstone	oligohaline, Alk. dominated	Shell O
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray claystone w. reddish light gray interformational clasts	oligohaline, Alk. dominated	Shell O
	BARREN					medium-grained brown-gray mudstone w. marcastite(?) granules	oligohaline, Alk. dominated	Shell O
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray claystone w. reddish light gray interformational clasts	oligohaline, Alk. dominated	Shell O
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray claystone w. reddish light gray interformational clasts	oligohaline, Alk. dominated	Shell O
	BARREN			fluvial		dark gray & reddish cherty stone with weathered granite clasts	oligohaline, Alk. dominated	Shell O
	<i>Heterospyris</i> <i>Cyprineus</i>	sp. aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, pond, stream, also trans. marine - TDS 30+ lacustrine, more often pond & stream - TDS 30-1000ppm	7.7-11 5.3-8.75	light gray, arkosic claystone	oligohaline, Alk. dominated	Shell O
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray claystone	oligohaline, Alk. dominated	Shell O
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray claystone and well indurated ostracode coquina	oligohaline, Alk. dominated	Shell O
	<i>Cyprineus</i>	aff. <i>reticulatus</i>	(Zaddach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm	5.3-8.75	dark gray claystone and well indurated ostracode and fishbone coquina	oligohaline, Alk. dominated	Shell O
	BARREN					light gray claystone	oligohaline, Alk. dominated	Shell O

ataluma Formation

S	PH Ranges PH RANGES	Sed type SED. TYPE	Paleohydrochem, PALEOHYDROCHEMISTRY	Collector COLLECTOR	Date DATE	Comments COMMENTS
		Greenish gray, finely laminated, compact, micaceous siltstone - lacustrine?	undetermined	L. Beyer	36671	minor plant fibers
ppm+ 30ppm	7.7-11 5.9-5 no data	botuliferal, silty to sandy mudstone; light greenish gray - DIATOMS?	oligohaline			gastropod shell fragments, plant matter, fish teeth and bone
ppm+ 30ppm+	7.7-11 5.9-5 6.5-10	gray claystone, minute pyrite nodules abundant	oligohaline	L. Beyer	36671	juveniles abundant
ppm+	7.7-11 no data 6-9.5	greenish gray compact mudstone, silty	oligohaline, transitional marine influenced, in part determined by presence of very rare forams - secondary artifacts?	L. Beyer	36671	root plant fibers
ppm+	7.7-11 no data 6-9.5	compact interbedded gray mudstone and arkosic sandstone (lacustrine)	oligohaline, elevated TDS	L. Beyer	36671	<i>Trinonema hexarticulatum</i> good worm burrows, woody vitrinite, thin-shelled bivalves
ppm+	7.7-11	compact, dark gray mudstone	oligohaline, elevated TDS	L. Beyer	36671	
ppm+	7.7-11	dark, fluggy mudstone w/ silty layers	oligohaline, NaCl dominated	L. Beyer	36671	hydrocarbon source potential?
ppm+	7.7-11	gray compact medium-grained, biotite micaceous arkosic w/ mudstone interbed	probably oligohaline	L. Beyer		ostracodes rare, other bioclasts absent
ppm	5.3-8.75	dark gray arkosic claystone	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes rare, in general, poorly preserved, other bioclasts absent
ppm	5.3-8.75	coarse to fine-grained sandstone	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	
ppm	5.3-8.75	dark gray claystone w/ rolled light gray interformational clasts	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes rare, in general, poorly preserved, other unidentified bioclasts
ppm	5.3-8.75	medium-grained brown-gray mudstone w/ marcasite(?) granules	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	marcasite? granules abundant, well crystallized
ppm	5.3-8.75	dark gray claystone w/ rolled light gray interformational clasts	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes abundant, fairly well preserved, mostly inv. single valves
ppm	5.3-8.75	dark gray claystone w/ rolled light gray interformational clasts	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes not common, fairly well preserved, mostly single valves
ppm	5.3-8.75	dark gray & reddish claystone with weathered granitic clasts	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	
ppm	7.7-11 5.3-8.75	light gray arkosic claystone	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes abundant, well preserved whole adults predominate
ppm	5.3-8.75	dark gray claystone	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes very abundant moderately well preserved, fish bones and scales common
ppm	5.3-8.75	dark gray claystone and well indurated ostracode coquina	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes abundant, well preserved, fish bones and scales, vegetable matter
ppm	5.3-8.75	dark gray claystone and well indurated ostracode and fishbone coquina	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	ostracodes very abundant, variously preserved, fish bones and scales, sparse vegetable matter
		light gray claystone	oligohaline, Alk. dominated	Shell Oil - CAL	1935?	some vegetable matter, seeds

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PLATE 2		Borehole D - Stony Point Quarry	Petaluma	62.2 - 62.5	U. Mioc. - L. Plioc.	BARREN			
JA2002.1		Borehole C - Stony Point Quarry	Petaluma	124.8 - 125.1	U. Mioc. - L. Plioc.	<i>Stenospirax</i> <i>Darwinula</i>	<i>arc. hupites</i> <i>stevensoni</i>	Ferguson, 1964 Brady & Robertson, 1890	lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher tolerance in the CL
JA2002.3		Borehole A - Stony Point Quarry	Petaluma	199.5' - 199.8'	U. Mioc. - L. Plioc.	<i>Candona</i> <i>Stenospirax</i> <i>Limonocythere</i>	sp. <i>arc. hupites</i> <i>veronaberosa</i>	Ferguson, 1964 DeLorme, 1967	primarily lacustrine, but ponds, streams also - TDS 300ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher CL-tolerance
JA2002.4		Borehole A - Stony Point Quarry	Petaluma	200.9' - 201'	U. Mioc. - L. Plioc.	<i>Candona</i> <i>Stenospirax</i> <i>Limonocythere</i>	aff. <i>C. candida</i> <i>arc. hupites</i> <i>veronaberosa</i>	Kaufmann, 1960 Ferguson, 1964 DeLorme, 1967	primarily lacustrine, but ponds, streams also - TDS 300ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher CL-tolerance
JA2002.5		Borehole A - Stony Point Quarry	Petaluma	211.25'	U. Mioc. - L. Plioc.	<i>Candona</i> <i>Stenospirax</i> <i>Limonocythere</i> <i>Chara</i>	aff. <i>C. candida</i> <i>arc. hupites</i> <i>veronaberosa</i> sp. indet.	Kaufmann, 1960 Ferguson, 1964 DeLorme, 1967	primarily lacustrine, but ponds, streams also - TDS 300ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher CL-tolerance
JA2002.6		Borehole A - Stony Point Quarry	Petaluma	222.25'	U. Mioc. - L. Plioc.	<i>Stenospirax</i> <i>Limonocythere</i> <i>Darwinula</i>	<i>arc. hupites</i> <i>veronaberosa</i> <i>stevensoni</i>	Ferguson, 1964 DeLorme, 1967 Brady & Robertson, 1890	lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher CL-tolerance lacustrine, ponds, streams; TDS 300ppm ⁺ , higher tolerance in the CL
JA2002.7		Borehole A - Stony Point Quarry	Petaluma	226.08' - 226.5'	U. Mioc. - L. Plioc.	<i>Heterospirax</i> <i>Candona</i> <i>Stenospirax</i> <i>Limonocythere</i> <i>Hyospirax</i> <i>Darwinula</i> <i>Chara</i>	<i>glaucois</i> aff. <i>C. candida</i> <i>arc. hupites</i> <i>veronaberosa</i> <i>gibba</i> <i>stevensoni</i> sp.	Furios, 1933 Kaufmann, 1960 Ferguson, 1964 DeLorme, 1967 (Ramdohr, 1908) Brady & Robertson, 1890	lacustrine, but also found in trans. marine - TDS 300ppm ⁺ primarily lacustrine, but ponds, streams also - TDS 300ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher CL-tolerance stream pond rare lacustrine - but elevated TDS lacustrine, ponds, streams; TDS 300ppm ⁺ , higher tolerance in the CL
JA2002.8		Borehole A - Stony Point Quarry	Petaluma	228.4'	U. Mioc. - L. Plioc.	<i>Heterospirax</i> <i>Candona</i> <i>Stenospirax</i> <i>Chara</i>	<i>glaucois</i> aff. <i>C. candida</i> <i>arc. hupites</i> sp.	Furios, 1933 Kaufmann, 1960 Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 300ppm ⁺ primarily lacustrine, but ponds, streams also - TDS 300ppm ⁺ lacustrine
JA2002.9		Creek on Ernest Maffia Farm	Petaluma	anticlinal flank	U. Mioc. - L. Plioc.	<i>Stenospirax</i> <i>Limonocythere</i>	<i>arc. hupites</i> sp.	Ferguson, 1964	lacustrine lacustrine, ponds, streams; TDS 300ppm ⁺ , higher CL-tolerance
JA2002.10		Creek on Ernest Maffia Farm	Petaluma	anticlinal flank	U. Mioc. - L. Plioc.	<i>Heterospirax</i> <i>Stenospirax</i>	sp. <i>arc. hupites</i>	Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 300ppm ⁺ lacustrine
JA2002.11		Creek on Ernest Maffia Farm	Petaluma	anticlinal nose	U. Mioc. - L. Plioc.	<i>Heterospirax</i> <i>Stenospirax</i>	sp. <i>arc. hupites</i>	Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 300ppm ⁺ lacustrine
JA2002.12		Creek on Ernest Maffia Farm	Petaluma	anticlinal flank	U. Mioc. - L. Plioc.	BARREN			fluvial
PLATE 3		Roadcut nr. Tolay Fault	Petaluma	surface	U. Mioc. - L. Plioc.	<i>Heterospirax</i> <i>Stenospirax</i>	sp. <i>arc. hupites</i> [?]	Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 300ppm ⁺ lacustrine
PLATE 2		Matanzas Creek, Bennett Rd	Petaluma	surface	U. Mioc. - L. Plioc.	BARREN			fluvial
PLATE 3		Matanzas Creek, Bennett Rd	Petaluma	surface	U. Mioc. - L. Plioc.	BARREN			fluvial
JA2002.18		Nr. basal Sears Point	Petaluma	surface	U. Mioc.-L. Plioc.	<i>Cyprioceras</i>	aff. <i>reticulatus</i>	(Zadach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
JA2002.19		Nr. basal Sears Point	Petaluma	surface	U. Mioc.-L. Plioc.	<i>Cyprioceras</i>	aff. <i>reticulatus</i>	(Zadach, 1844)	lacustrine, more often pond & stream - TDS 30-1000ppm
JA2002.20		Basal Sears Point	Petaluma	surface	U. Mioc.-L. Plioc.	<i>Heterospirax</i> <i>Candona</i> <i>Cyprioceras</i> <i>Cytheromorpha</i> <i>Palanus</i>	sp. aff. <i>C. candida</i> aff. <i>C. beaumontensis</i> sp. sp.	Kaufmann, 1960 (i.e. Rev., 1943)	lacustrine, but also found in trans. marine - TDS 300ppm ⁺ primarily lacustrine, but ponds & streams also - TDS 300ppm ⁺ - fragments transitional marine transitional marine, elevated TDS lacustrine barnacle opercular plate - marine to very low salinity transitional marine
Some Recent Ostracoda from Sonoma Co., CA		Lichau Creek, at intersect with Petaluma Hill Rd.			Recent	<i>Cyprioceras</i> <i>Heterospirax</i> <i>Hyospirax</i> <i>Petalospirax</i> <i>Hyospirax</i>	sp. <i>incongruens</i> <i>reptans</i> <i>sonomaensis</i> <i>gibba</i> <i>brachy</i>	(Ramdohr, 1808) (Baird, 1835) (Vavra, 1891) (Ramdohr, 1908) Sars, 1903	dead shells dead shells H. reptans recovered from within worm egg masses single live specimen dominant taxon, dead shells common, dead shells only
JA2002.17		Gossage Creek at intersection of Peterson Rd. and Peterson Rd.			Recent	<i>Candona</i> <i>Cyprioceras</i>	sp. <i>cutha</i>	(Muller, 1776)	single broken valve abundant, juveniles predominate

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U.Misc. - L.Phoc.	BARREN						dense greenish-gray claystone with large CaCO ₃ nodule	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Stenocypris</i> <i>Darwinula</i>	<i>arc. hoplitex</i> <i>strevensoni</i>	Ferguson, 1964 Brady & Robertson, 1890	lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher tolerance in the Cl-	6-9.5		dark gray, flaggy claystone - no gypsum	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Candona</i> <i>Stenocypris</i> <i>Limnocythere</i>	sp. <i>arc. hoplitex</i> <i>ceratoluberosa</i>	Ferguson, 1964 DeLorme, 1967	primarily lacustrine, but ponds, streams also - TDS 30ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher Cl- tolerance	5-9.5	11-Jul	dark gray, flaggy claystone - no gypsum	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Candona</i> <i>Stenocypris</i> <i>Limnocythere</i>	aff. <i>C. caudata</i> <i>arc. hoplitex</i> <i>ceratoluberosa</i>	Kaufmann, 1900 Ferguson, 1964 DeLorme, 1967	primarily lacustrine, but ponds, streams also - TDS 30ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher Cl- tolerance	5-9.5	11-Jul	dark gray, laminated claystone, occasional minute gypsum crystals	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Candona</i> <i>Stenocypris</i> <i>Limnocythere</i> <i>Chara</i>	aff. <i>C. caudata</i> <i>arc. hoplitex</i> <i>ceratoluberosa</i> sp. indet.	Kaufmann, 1900 Ferguson, 1964 DeLorme, 1967	primarily lacustrine, but ponds, streams also - TDS 30ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher Cl- tolerance	5-9.5	11-Jul	dark gray, laminated claystone, minute gypsum crystals, crevasse fillings	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Stenocypris</i> <i>Limnocythere</i> <i>Darwinula</i>	<i>arc. hoplitex</i> <i>ceratoluberosa</i> <i>strevensoni</i>	Ferguson, 1964 DeLorme, 1967 Brady & Robertson, 1890	lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher Cl- tolerance lacustrine, ponds, streams; TDS 30ppm ⁺ , higher tolerance in the Cl-	6-9.5	11-Jul	dark gray, laminated claystone, common minute gypsum crystals	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Heterocypris</i> <i>Candona</i> <i>Stenocypris</i> <i>Limnocythere</i> <i>Hyocypris</i> <i>Darwinula</i> <i>Chara</i>	<i>glauca</i> aff. <i>caudata</i> <i>arc. hoplitex</i> <i>ceratoluberosa</i> <i>gibba</i> <i>strevensoni</i> sp.	Furtos, 1933 Kaufmann, 1900 Ferguson, 1964 DeLorme, 1967 (Ramdohr, 1908) Brady & Robertson, 1890	lacustrine, but also found in trans. marine - TDS 30ppm ⁺ primarily lacustrine, but ponds, streams also - TDS 30ppm ⁺ - fragments lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher Cl- tolerance stream pond rare lacustrine - but elevated TDS lacustrine, ponds, streams; TDS 30ppm ⁺ , higher tolerance in the Cl-	7.7-11 5-9.5 6-9.5 6-9.5	11-Jul	fine sandy mudstone with high organic content, minute gypsum crystals common	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Heterocypris</i> <i>Candona</i> <i>Stenocypris</i> <i>Chara</i>	<i>glauca</i> aff. <i>caudata</i> <i>arc. hoplitex</i> sp.	Furtos, 1933 Kaufmann, 1900 Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 30ppm ⁺ primarily lacustrine, but ponds, streams also - TDS 30ppm ⁺ lacustrine	7.7-11 5-9.5		organic mudstone, common minute gypsum crystals	oligohaline, Alk. dominated
U.Misc. - L.Phoc.	<i>Stenocypris</i> <i>Limnocythere</i>	<i>arc. hoplitex</i> sp.	Ferguson, 1964	lacustrine lacustrine, ponds, streams; TDS 30ppm ⁺ , higher Cl- tolerance			well laminated gray claystone	oligohaline
U.Misc. - L.Phoc.	<i>Heterocypris</i> <i>Stenocypris</i>	sp. <i>arc. hoplitex</i>	Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 30ppm ⁺ lacustrine	7.7-11		well laminated gray claystone, abundant gypsum crystals, Fe concretions	oligohaline
U.Misc. - L.Phoc.	<i>Heterocypris</i> <i>Stenocypris</i>	sp. <i>arc. hoplitex</i>	Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 30ppm ⁺ lacustrine	7.7-11		conglomerate claystone contact	oligohaline, Alk. dominated, high carbonate
U.Misc. - L.Phoc.	BARREN			fluvial			contact claystone overlying conglomerate, sand & green clay	
U.Misc. - L.Phoc.	<i>Heterocypris</i> <i>Stenocypris</i>	sp. <i>arc. hoplitex</i>	Ferguson, 1964	lacustrine, but also found in trans. marine - TDS 30ppm ⁺ lacustrine	7.7-11		well laminated gray claystone	oligohaline
U.Misc. - L.Phoc.	BARREN			fluvial			fine to medium reddish sandstone - gray claystone contact	
U.Misc. - L.Phoc.	BARREN			fluvial			fine to medium reddish sandstone - gray claystone contact	
U.Misc.-L.Phoc.	<i>Cypricercus</i>	aff. <i>reticulatus</i>	(Zaidach, 1844)	lacustrine, more often pond & stream - TDS 30-100ppm	5.3-8.75		tan, poorly indurated, laminated limestone ostracode columns	oligohaline, Alk. dominated, high carbonate
U.Misc.-L.Phoc.	<i>Cypricercus</i>	aff. <i>reticulatus</i>	(Zaidach, 1844)	lacustrine, more often pond & stream - TDS 30-100ppm	5.3-8.75		tan, well indurated dolomitic ostracode column	oligohaline, Alk. dominated, high carbonate
U.Misc.-L.Phoc.	<i>Heterocypris</i> <i>Candona</i> <i>Cypricercus</i> <i>Cytheromorphus</i> <i>Balanus</i>	sp. aff. <i>C. caudata</i> aff. <i>C. beaumonti</i> sp. sp.	Kaufmann, 1900 (Helfer, 1943)	lacustrine, but also found in trans. marine - TDS 30ppm ⁺ primarily lacustrine, but ponds, streams also - TDS 30ppm ⁺ - fragments transitional marine transitional marine, elevated TDS lacustrine barnacle opercular plate - marine to very low salinity transitional marine	7.7-11 5-9.5	8	w. many pyrite rosettes	transitional marine w. freshwater influence
Recent	<i>Cypricercus</i> <i>Heterocypris</i> <i>Patamonocypris</i> <i>Hyocypris</i>	sp. <i>incongruus</i> <i>reptans</i> <i>ovata</i> <i>gibba</i> <i>bradyi</i>	(Ramdohr, 1808) (Blair, 1835) (Vavra, 1891) (Ramdohr, 1908) Sars, 1903	dead shells dead shells H. reptans recovered from within worm egg masses single live specimen dominant taxon, dead shells common, dead shells only				
Recent	<i>Candona</i> <i>Cypricercus</i>	sp. <i>exilis</i>	(Muller, 1776)	single broken valve abundant, juveniles medullate				

		dense greenish-gray claystone with large CaCO ₃ nodules	oligohaline, Alk. dominated	Jim Allen	2-26-02	
ance in the Cl-	6-9.5	dark gray, flaggy claystone - no gypsum	oligohaline, Alk. dominated	Jim Allen	2-25-26-02	uncommon plant or bioclastic material
ym + fragments	5-9.5	dark gray, flaggy claystone - no gypsum	oligohaline, Alk. dominated	Jim Allen	2-21-02	uncommon plant or bioclastic material <i>Linnæothere</i> females only
ference	11-Jul					
ym + fragments	5-9.5	dark gray, laminated claystone, occasional minute gypsum crystals	oligohaline, Alk. dominated	Jim Allen	2-21-02	fish bone fragments, uncommon plant or bioclastic material; <i>Linnæothere</i> females only
ference	11-Jul					slightly elevated T. <i>verumbona</i> n.s suggest elevated IDS
ym + fragments	5-9.5	dark gray, laminated claystone, minute gypsum crystals, crevasse fillings	oligohaline, Alk. dominated	Jim Allen	2-21-02	fish bone fragments common, uncommon plant or bioclastic material; <i>Linnæothere</i> females only
ference	11-Jul					
ference	11-Jul	dark gray, laminated claystone, common minute gypsum crystals	oligohaline, Alk. dominated	Jim Allen	2-21-02	fish bone fragments abundant, uncommon plant or bioclastic material; <i>Linnæothere</i> females only
nice in the Cl-	6-9.5					
+ fragments	7.7-11 5-9.5	fine sandy mudstone with high organic content, minute gypsum crystals common	oligohaline, Alk. dominated	Jim Allen	2-21-02	ostracodes abundant in sandy layers, muddy layers entirely vegetation mats, woody fibers, seeds and ostracodes
ference	11-Jul					
nice in the Cl-	6-9.5 6-9.5					<i>H. glaucus</i> dominant (screen for SEM candidates) FW gastropod, "Giantus" sp., SIMILAR TO MOSSI #1 FAUNA
+ pm+	7.7-11 5-9.5	organic mudstone, common minute gypsum crystals	oligohaline, Alk. dominated	Jim Allen	2-21-02	fish, mollusca, ostracoda not abundant SIMILAR TO MOSSI #1 FAUNA
ference		well laminated gray claystone	oligohaline	Dawn Peterson	3-31-02	ostracodes abundant, <i>Sternaspis</i> preserved as casts and molds, <i>Linnæothere</i> as films on the bedding plane (very abundant)
+	7.7-11	well laminated gray claystone, abundant gypsum crystals, Fe concretions	oligohaline	Dawn Peterson	3-31-02	ostracodes moderately abundant, plant matter not abundant, fish remains common, leaf fossil
+	7.7-11	conglomerate claystone contact	oligohaline, Alk. dominated, high carbonate	Dawn Peterson	3-31-02	ostracodes abundant, recrystallized, general poor preservation, plant matter scarce, (compare to JA2002.13), fish remains present
+		contact claystone overlying conglomerate, sand & green clay		Dawn Peterson	3-31-02	no bioclastics - plant matter present
+	7.7-11	well laminated gray claystone	oligohaline	Dawn Peterson	3-31-02	ostracodes abundant, recrystallized, badly compressed and distorted, limonite filled burrows or root structures, scattered woody stumps
		fine to medium reddish sandstone - gray claystone contact		Dawn Peterson	3-31-02	Upper Petaluma - no bioclastics - plant matter present
		fine to medium reddish sandstone - gray claystone contact		Dawn Peterson	3-31-02	Upper Petaluma - leaf fragments, plant matter present
m	5.3-8.75	tan, poorly indurated, laminated limestone ostracone column	oligohaline, Alk. dominated, high carbonate	Jim Allen	2-Jun	ostracodes variously preserved, many perfect specimens
m	5.3-8.75	tan, well indurated dolomitic ostracone column	oligohaline, Alk. dominated, high carbonate	Jim Allen	2-Jun	ostracodes variously preserved, many perfect specimens
+ fragments	7.7-11 5-9.5	w. many pyrite rosettes	transitional marine w. freshwater influence	Jim Allen	2-Jun	many pyritized ostracodes, barnacle tergum well-preserved, coated in brown hydrocarbon (?)
ustional marine	b					
				Dawn Peterson	5-15-02	
				Dawn Peterson	5-15-02	

APPENDIX F: TEPHRA DATA

SAMPLE: JA080402A T491-3

~100' E of N-S paved private (?) road, ~600' N of int. w/ Roblar Rd., 1 mi. W of int. w/ Stony Pt. Rd., about 1/4 mi. SE of Roblar, on Cotati 7.5' Quad. Coarse pumice lapilli and ash tuff with abundant clastic materials, including well-rounded pebbles; lower part coarse, grades up to fine-grained, hard tuff at top. Described by J. Allen. Good match to the Roblar Tuff. Given the grading, tuff is more likely to be water-deposited, rather than ash flow.

SAMPLE: JA080402B T491-4

~100' E of N-S paved private (?) road, ~600' N of int. w/ Roblar Rd., 1 mi. W of int. w/ Stony Pt. Rd., about 1/4 mi. SE of Roblar, on Cotati 7.5' Quad. Same location. as sample above. Finer-grained, upper part of tuff, overlying JA080402A. Good match to the Roblar Tuff, but with somewhat greater scatter, probably due to hydration, leaching, and incipient alteration of glass, or presence of shards from other tephra units. The latter interpretation seems less likely, because the scatter is towards lower values of FeO and CaO, consistent with hydration and leaching.

SAMPLE: JA2002-A T490-3

Tuff exposed in S. bank of South fork Mantanzas Creek, ~1/4 mi. S. of Sonoma Mountain Rd., and ~1/4 mi. SE. of BM 872, south edge of Bennett Valley, in sediments mapped as Petaluma Fm. This tephra layer is a good match to the tuff of Napa (Healdsburg tuff), dated 4.64-4.65 Ma. Presence of this tuff suggests that the sediments here are equivalent in part to the Silver Creek Gravels of Wills (1995), Sycamore Formation of Issacson (1990), Huichica Formation of Weaver (1949), and the Los Medanos gravels of Weaver (1949) overlying the Lawlor Tuff S. of Suisun Bay, N. of Mount Diablo.

APPENDIX G: QUARTZ-VEIN MICROPROBE DATA

Quartz Vein Microprobe Data by Jim Walker (USGS)											
MgO	Al2O3	SiO2	K2O	CaO	TiO2	MnO	FeO	Total	Briones ss at Clayton Rd, San Jose		
0.000	0.124	97.781	0.034	0.042	0.000	0.028	0.056	98.114	JIM_ALLEN'S	M1	1
0.005	0.074	98.542	0.024	0.006	0.000	0.000	0.000	98.651	JIM_ALLEN'S	M1	2
1.129	2.453	90.954	0.739	0.070	0.000	0.033	2.734	98.127	JIM_ALLEN'S	M1	3
0.008	0.016	98.334	0.023	0.004	0.000	0.028	0.053	98.468	JIM_ALLEN'S	M1	4
0.009	1.999	92.275	0.119	0.446	0.000	0.030	0.031	95.319	JIM_ALLEN'S	M1	5
0.123	0.812	96.569	0.204	0.036	0.052	0.000	0.511	98.390	JIM_ALLEN'S	M1	6
0.000	2.334	94.781	2.005	0.007	0.334	0.000	0.230	99.727	JIM_ALLEN'S	M1	7
0.007	19.938	67.142	1.590	0.404	0.012	0.025	0.097	100.124	JIM_ALLEN'S	M1	8
0.000	0.782	97.410	0.035	0.000	0.028	0.000	0.085	98.366	JIM_ALLEN'S	M1	9
SS: Pebbles from T.01, North-Cotati											
0.000	0.352	98.448	0.025	0.000	0.004	0.000	0.000	98.835	JIM_ALLEN'S	COTATI	1
0.000	0.384	98.357	0.022	0.000	0.000	0.000	0.000	98.775	JIM_ALLEN'S	COTATI	2
0.000	0.264	97.820	0.041	0.007	0.018	0.000	0.054	98.236	JIM_ALLEN'S	COTATI	3
0.000	0.400	98.075	0.038	0.020	0.000	0.026	0.008	98.589	JIM_ALLEN'S	COTATI	4
0.001	0.367	98.427	0.014	0.038	0.000	0.000	0.000	98.854	JIM_ALLEN'S	COTATI	5
0.000	0.226	97.003	0.034	0.006	0.058	0.000	0.063	97.412	JIM_ALLEN'S	COTATI	6
0.007	0.221	97.869	0.019	0.000	0.000	0.000	0.043	98.159	JIM_ALLEN'S	COTATI	7
0.024	0.897	96.956	0.218	0.039	0.030	0.000	0.148	98.459	JIM_ALLEN'S	COTATI	8
0.021	0.413	97.882	0.033	0.034	0.000	0.005	0.056	98.444	JIM_ALLEN'S	COTATI	9
0.004	0.380	98.125	0.019	0.000	0.000	0.000	0.003	98.541	JIM_ALLEN'S	COTATI	10
0.000	0.349	96.387	0.037	0.016	0.006	0.008	0.019	96.854	JIM_ALLEN'S	COTATI	11
0.000	0.440	95.875	0.022	0.016	0.018	0.000	0.057	96.494	JIM_ALLEN'S	COTATI	12
0.026	0.526	0.193	0.073	0.099	61.098	4.262	26.880	93.169	JIM_ALLEN'S	COTATI(GRAIN)	13
0.041	0.660	0.284	0.096	0.179	61.048	4.298	25.000	91.606	JIM_ALLEN'S	COTATI(GRAIN)	14
0.016	1.136	96.146	0.085	0.088	0.030	0.016	0.000	97.684	JIM_ALLEN'S	COTATI	15
0.026	2.194	94.234	0.796	0.098	0.042	0.000	0.218	97.903	JIM_ALLEN'S	COTATI	16
0.070	0.901	96.853	0.047	0.078	0.038	0.003	0.227	98.330	JIM_ALLEN'S	COTATI	17
0.000	0.320	98.022	0.017	0.012	0.002	0.000	0.045	98.479	JIM_ALLEN'S	COTATI	18
0.000	0.561	97.988	0.017	0.006	0.034	0.000	0.039	98.657	JIM_ALLEN'S	COTATI	19
0.013	0.462	98.136	0.015	0.011	0.026	0.013	0.005	98.708	JIM_ALLEN'S	COTATI	20
8.499	17.882	40.167	6.340	0.181	4.080	0.177	13.803	91.225	JIM_ALLEN'S	COTATI	21
8.881	16.631	39.552	6.798	0.103	3.894	0.112	13.532	89.635	JIM_ALLEN'S	COTATI	22
8.740	16.801	39.575	6.833	0.106	4.334	0.124	13.968	90.628	JIM_ALLEN'S	COTATI	23
0.000	0.275	97.913	0.000	0.000	0.000	0.000	0.015	98.219	JIM_ALLEN'S	COTATI	24
0.000	0.544	98.358	0.152	0.000	0.004	0.000	0.000	99.067	JIM_ALLEN'S	COTATI	25
0.000	0.704	97.103	0.365	0.000	0.000	0.000	0.000	98.247	JIM_ALLEN'S	COTATI	26
0.015	0.279	97.955	0.022	0.002	0.020	0.009	0.002	98.317	JIM_ALLEN'S	COTATI	27
0.005	0.427	97.844	0.011	0.011	0.004	0.067	0.000	98.402	JIM_ALLEN'S	COTATI	28
Matrix of ss pebbles-Cotati											
0.008	21.608	65.625	0.176	1.894	0.048	0.030	0.054	100.629	JIM_ALLEN'S	COTATI(MAATRIX?)	29
0.015	18.684	64.198	16.088	0.035	0.060	0.014	0.102	99.516	JIM_ALLEN'S	COTATI(MAATRIX?)	30
0.005	19.265	64.885	13.102	0.072	0.024	0.046	0.106	100.172	JIM_ALLEN'S	COTATI(MAATRIX?)	31
0.019	1.386	93.081	0.320	0.169	0.062	0.016	0.091	95.474	JIM_ALLEN'S	COTATI(MAATRIX?)	32
0.012	11.762	79.589	3.006	1.209	0.018	0.044	0.140	100.089	JIM_ALLEN'S	COTATI(MAATRIX?)	33
0.022	18.427	65.774	15.625	0.018	0.047	0.008	0.181	100.438	JIM_ALLEN'S	COTATI(MAATRIX?)	34
0.000	0.661	97.064	0.395	0.000	0.018	0.052	0.020	98.241	JIM_ALLEN'S	COTATI(MAATRIX?)	35
0.024	5.796	90.425	1.420	0.526	0.087	0.040	0.129	100.126	JIM_ALLEN'S	COTATI(MAATRIX?)	36
0.013	16.160	56.034	0.541	6.327	0.056	0.005	0.293	84.998	JIM_ALLEN'S	COTATI(MAATRIX?)	37
0.023	0.562	97.274	0.090	0.015	0.012	0.018	0.125	98.124	JIM_ALLEN'S	COTATI(MAATRIX?)	38
0.013	0.681	97.058	0.055	0.036	0.000	0.000	0.048	97.977	JIM_ALLEN'S	COTATI(MAATRIX?)	39
0.008	0.577	97.256	0.021	0.016	0.008	0.010	0.048	98.010	JIM_ALLEN'S	COTATI(MAATRIX?)	40
0.355	2.345	21.628	0.104	1.150	0.086	0.156	43.157	69.191	JIM_ALLEN'S	COTATI(MAATRIX?)	41
0.287	1.616	3.094	0.049	0.667	0.012	0.000	35.571	41.403	JIM_ALLEN'S	COTATI(MAATRIX?)	42
0.057	8.538	70.928	3.642	0.867	0.038	0.031	5.719	91.742			
0.113	8.552	29.207	6.205	1.679	0.029	0.040	14.332	16.846			
0.355	21.046	94.18	16.067	6.327	0.087	0.156	43.137	59.226			
0	0.562	3.094	0.021	0	0	0	0.02	41.403			
0.355	21.608	97.274	16.088	6.327	0.087	0.156	43.157	100.629			
14	14	14	14	14	14	14	14	14			
0.065	4.938	16.863	3.583	0.969	0.017	0.023	8.275	9.726			
Pebbles from T.01N, Cotati											
0.000	7.829	87.144	0.000	0.000	0.000	0.000	0.000	99.698	JIM_ALLEN'S	COTATI	43
0.000	0.614	97.660	0.009	0.000	0.000	0.000	0.000	98.430	JIM_ALLEN'S	COTATI	44
0.022	3.908	86.948	0.422	0.119	0.000	0.000	0.073	93.652	JIM_ALLEN'S	COTATI	45
0.000	0.238	97.172	0.000	0.000	0.000	0.000	0.000	97.415	JIM_ALLEN'S	COTATI	46
0.001	0.401	97.300	0.034	0.027	0.026	0.011	0.043	97.843	JIM_ALLEN'S	COTATI	47
0.000	0.093	96.983	0.034	0.000	0.000	0.024	0.006	97.165	JIM_ALLEN'S	COTATI	48
0.011	0.548	97.777	0.026	0.013	0.010	0.018	0.034	98.454	JIM_ALLEN'S	COTATI	49
0.011	0.363	97.370	0.034	0.000	0.000	0.068	0.003	97.854	JIM_ALLEN'S	COTATI	50
0.000	0.324	96.994	0.028	0.002	0.000	0.000	0.000	97.355	JIM_ALLEN'S	COTATI	51
0.285	0.904	94.971	0.047	0.031	0.000	0.000	0.850	97.126	JIM_ALLEN'S	COTATI	52

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI

122°59.000' W

122°58.000' W

122°57.000' W

122°56.000' W

38°17.000' N

38°16.000' N

38°15.000' N

122°57.000' W

122°56.000' W

Explanation

Pleistocene-
Holocene

Qd

Qd: Dunes

Qal

Qal: Quaternary alluviumRancholabrean fauna in
Pleistocene stream terraces
(Weaver, 1949; Travis, 1954)

Disconformity

Late Miocene

Mwg

Wilson Grove FormationPredominantly fine- to medium-grained, cross-stratified, marine facies
to pebbly sandstone interbedded with siltstone

Jurassic-Cretaceous

Angular
Unconformity

Franciscan Complex

Predominantly graywacke and sandstone

Early
CretaceousWest of San
Andreas fault

Salinian Block: Plutonic rocks

Feet
1,000
0

A

Estero San Antonio

basal conglomerate

Feet
1,000
0

B

Tonales
BaySan Andreas
fault

Dillon Beach

Feet
1,000
0

C

Qd

Notes: Kd inferred from Weaver (1949).

6,000' W

Explanation

Pleistocene-Holocene

Qd: Dunes

Qal: Quaternary alluvium

Rancholabrean fauna in some older Pleistocene stream terrace deposits (Weaver, 1949; Travis, 1952).

Qls: Quaternary landslide

Disconformity

Late Miocene

Wilson Grove Formation

Predominantly fine- to medium-grained, thickly bedded to hummocky-cross-stratified, marine feldsarenite with one or two coarse-grained to pebbly sandstone interbeds (shown in gray).

Jurassic-Cretaceous

Angular Unconformity

Franciscan Complex

Predominantly graywacke and shale with some red chert.

Early Cretaceous

West of San Andreas fault

Salinian Block: Plutonic rocks

Notes: Kd inferred from Weaver (1949).

tion

vium

n fauna in some older
ream terrace deposits
; Travis, 1952).

nation

e- to medium-grained, thickly bedded to hummocky-
rine feldsarenite with one or two coarse-grained
e interbeds (shown in gray).

vaccke and shale with some red chert.

onic rocks

Qls: Quaternary landslide

Strike and dip of beds

A—A' Cross section lines

Fault; arrows show direction of movement.

Thin section sample locality

WG-1A. Foraminifer locality discussed in report

Measured sections

Map sources: Compilations from Weaver (1949) and Travis (1950).
Additional mapping by James Allen (1999-2002)

Qls: Quaternary landslide

to hummocky-
fine-grained

Strike and dip of beds

A—A' Cross section lines

Fault; arrows show direction of movement.

④ Thin section sample locality

WG-1A. Foraminifer locality discussed in report

Measured sections

Map sources: Compilations from Weaver (1949) and Travis (1950).
Additional mapping by James Allen (1999-2002)

122°59.000' W

122°58.00

122°57.00

Scale 1 : 24 000

Map Location

200 miles

Scale 1 : 24 000

1 MILE

0

500

1000 METERS

Scale 1 : 24 000
 1 MILE
 500 1000 METERS

Angular Unconformity

Jurassic-Cretaceous

Early Cretaceous

Franciscan Complex
 Predominantly graywacke and sandstone

West of San Andreas fault

Salinian Block: Plutonic rocks

Notes: Kd inferred from Weaver (1949).

Notes: Wilson Grove Formation dips 20 to 13 degrees inland. The Franciscan Complex dips 45-60 degrees inland.

38° 17.000' N
38° 16.000' N
38° 15.000' N

Jurassic-Cretaceous
Early Cretaceous

Angular Unconformity

Franciscan Complex

Predominantly graywacke and shale with some red chert.

West of San Andreas fault

Salinian Block: Plutonic rocks

Map sou

Notes: Kd inferred from Weaver (1949).

Notes: Wilson Grove Formation dips 20 to 13 degrees to the east near contact with Franciscan Complex and shallows to 7 degrees inland. The Franciscan Complex dips 45-60 degrees to the east.

Angular
Unconformity

Franciscan Complex
Predominantly graywacke and shale with some red chert.

Map sources: Compilations from Weaver (1949)
Additional mapping by James

West of San
Andreas fault

Salinian Block: Plutonic rocks

s: Kd inferred from Weaver (1949).

Wilson Grove Formation dips 20 to 13 degrees to the east near contact with Franciscan Complex and shallows to
degrees inland. The Franciscan Complex dips 45-60 degrees to the east.

Geology
and

Measured sections

Map sources: Compilations from Weaver (1949) and Travis (1950).
Additional mapping by James Allen (1999-2002)

can Complex and shallows to

Geologic Map of Portions of the Point Reyes
and Tomales U.S.G.S. 7.5' Quadrangles

Plate 1

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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UMI

1000000

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122°48' 00"

122°47' 00"

38°23' 00"

38°22' 00"

38°21' 00"

38°20' 00"

122°47' 00" 122°46'00" 122°45'00" G' 122°44'00"

G' 122°44'00"

122°43'00"

122°42'00"

122°42'00"

122°41'00"

122°40'00"

EXPLANATION

Quaternary alluvium
Includes undifferentiated Pleistocene and Holocene alluvial and fluvial deposits (see Helley et al., 1979).

Recent landslide

Quaternary landslide

Wilson Grove Formation
Thickly bedded, hummocky cross-stratified, fossiliferous, marine, feldsarenite sandstone (Holland and Allen, 1998).

MPwg: Miocene or Pliocene Wilson Grove Formation above Roblar Tuff.
Mrt: Roblar Tuff (~6 Ma)
Mwg: Miocene Wilson Grove Formation below Roblar Tuff

Interbedded Wilson Grove and Petaluma formation
Well-sorted conglomerate interbedded with white to yellow, marine, feldsarenite and brown litharenite. Clasts are well-rounded and disc-shaped. Clasts are Monterey-derived at the top of the section and Franciscan Complex-derived at the base. Fossils indicate deltaic, shallow marine environments. ~6 Ma Roblar Tuff (Mrt) on both limbs of anticline at Stony Point Rock Quarry.

Upper Petaluma Formation
Clay lenses, fine- to coarse-grained sandstone and Monterey-derived conglomerate. Contains Roblar Tuff (Mrt).

Middle Petaluma Formation
Clay lenses, fine- to coarse-grained sandstone and Franciscan Complex-derived sandstone. Locally overlies Mv at Meigs Peak.
Mtu: Unknown tuff.

Lower Petaluma Formation
Finely laminated mudstone and siltstone with glomerate. Contains abundant transitional marine environments.

Mafic volcanics of unknown age
Tertiary volcanics below Wilson Grove Formation and Petaluma Formation. Tolay or Donnell Ranch volcanics (Morse and Bailey, 1935; Youngman, 1989; Fox et al., 1985).

Unconformity

Eocene sandstone (?)

Angular Unconformity

Franciscan Complex
Graywacke with subordinate amounts of shale, red chert, and serpentinite.

Map Symbols

Strike and dip of bedding

- Strike and dip of beds. Ball on dip bar indicates direction of top of beds inferred from sedimentary structures.
- Contact (dotted where covered or inferred)
 - Fault: Arrow shows direction and amount of dip where inclined. Dashed where approximately located.
 - Fault (DWR, 1979)
 - Fault, arrows show direction of movement
 - Rodgers Creek fault (inferred from this study)
 - Fault (Fox et al., 1973)
 - Normal fault; D, down-dropped block, U, upthrown block. Tick marks show dip direction of fault plane and point toward down-dropped block.
 - Thrust or reverse fault, teeth point toward upper plate.

...ve and *Petaluma formation*
 ...te interbedded with white
 ...arenite and brown litharenite.
 ...and disc-shaped. Clasts are
 ...top of the section and
 ...rived at the base.
 ...shallow marine environments.
 ...) on both limbs of anticline at
 ...y.

Upper Petaluma Formation

Clay lenses, fine- to coarse-grained litharenite and Monterey-derived conglomerate. Contains Roblar Tuff (Mrt) and Blancan vertebrate fossils.

Middle Petaluma Formation

Clay lenses, fine- to coarse-grained litharenite and Franciscan Complex-derived conglomerate. Locally overlies Mv at Meacham Hill.
Mtu: Unknown tuff.

Lower Petaluma Formation

Finely laminated mudstone with minor lenses of conglomerate. Contains abundant ostracodes of fresh-water and transitional marine environments

Sonoma Volcanics

Age: ~7.28 to 4.65 Ma (Youngman, 1989)
 PMsvm: Mafic flows.
 PMsvt: Tuff beds; some have been dated (Fox et al., 1985)

Donnell Ranch Volcanics (*Mdr*: rhyolitic flows; *Mdm*: mafic flows)
 Age: 10.64 ± 0.27 to 8.24 ± 0.22 Ma (Youngman, 1989).
 Lower flow at Stony Point Rock Quarry inferred to be ~9.3 Ma (Youngman et al., 2002). Donnell Ranch Volcanics crop out along Lichau Road immediately west of the Rodgers Creek fault zone (~9.3 age from

PMsvm
PMsvt
PMsvm
PMsvt
PMsvm
PMsvt
PMsvm

Sonoma Volcanics

Age: ~7.28 to 4.65 Ma (Youngman, 1989)

PMsvm: Mafic flows.

PMsvt: Tuff beds; some have been dated (Fox et al., 1985)

Mdr
Mdm

Donnell Ranch Volcanics (Mdr: rhyolitic flows; Mdm: mafic flows)

Age: 10.64 ± 0.27 to 8.24 ± 0.22 Ma (Youngman, 1989).

Lower flow at Stony Point Rock Quarry inferred to be ~9.3 Ma (Graymer et al., 2002). Donnell Ranch Volcanics crop out along Lichau Road, immediately west of the Rodgers Creek fault zone (~9.3 age from Davies, 1986).

Areas mapped by author shown in gray. White and gray areas Armstrong (1974)

1. Mapped with R. McLaughlin (2002)
2. Mapped with D. Wagner (2002)

Schematic Correlation Chart of Map

Areas mapped by author shown in gray. White and gray areas also compiled from: Johnson (1934), Weaver (1949), Fox et al (1973), and Bishop and Armstrong (1974)

1. Mapped with R. McLaughlin (2002)
2. Mapped with D. Wagner (2002)

Schematic Correlation Chart of Map Units

from: Johnson (1934), Weaver (1949), Fox et al (1973), and Bishop and

East of Rodgers Creek fault
Bennett Valley area

16

Cadwell
IWGP

19

20

Hesset

Eucalyptus
School

Turner

Scott and Hendrickson
Unit 1

21

Laguna de Santa Rosa

22

9 M-1

27

Mr. 28

28

ROSA

Gosage
Creek

Gosage

6.32 ± 0.65

9.36 ± 0.03

Dunham Sch

Stony Point
Rock Quarry

4.26

Stony Point

Dunham fault

38°21'00"

38°20'00"

38°19'00"

Eocene (?)

Jurassic-Cretaceous

20

65

65

D

U

←

←

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Mafic volcanics of unknown age

Tertiary volcanics below Wilson Grove Formation and Petaluma Formation. Tolay or Donnell Ranch volcanics (Morse and Bailey, 1935; Youngman, 1989; Fox et al., 1985).

Eocene (?)

Unconformity

Eocene sandstone (?)

Jurassic-Cretaceous

Angular Unconformity

Franciscan Complex

Graywacke with subordinate amounts of shale, red chert, and serpentinite.

Map Symbols

Strike and dip of bedding

Strike and dip of beds. Ball on dip bar indicates direction of top of beds inferred from sedimentary structures.

Contact (dotted where covered or inferred)

Fault: Arrow shows direction and amount of dip where inclined. Dashed where approximately located.

Fault (DWR, 1979)

Fault, arrows show direction of movement

Rogers Creek fault (inferred from this study)

Fault (Fox et al., 1973)

Normal fault; D, down-dropped block, U, upthrown block. Tick marks show dip direction of fault plane and point toward down-dropped block.

Thrust or reverse fault, teeth point toward upper plate.

Syncline, arrow shows plunge direction

Anticline, arrow shows plunge direction

Oil and gas well, Calif. Div. of Oil and Gas

Borehole at Stony Point Rock Quarry (P. Frame, personal communication, 2002)

Volcanic Rock Ages

K-Ar age with reasonable error (Fox et al., 1973; Davies, 1986).

Ar-Ar age from Graymer et al. (2002)

Fossil Localities and Ages

Pliocene vertebrate locality

Miocene vertebrate locality

Miocene invertebrate locality

Pliocene marine invertebrate fossil locality

USGS JA-A: (Powell et al., 2003)

CAS: California Academy of Sciences

USGS M: United States Geological Survey collection

JA2002 9-12: Ostracode locality: Stony Point Rock Quarry area; in Mpl exposed in Gossage Creek

JA2002 3-7: Ostracode locality: Stony Point Rock Quarry area; in Mpl from borehole A

Sample Localities

Thin section localities

Clast count localities

M-1 Monterey clast foraminifera study locality

Quaternary volcanics of unknown age
 Quaternary volcanics below Wilson Grove Formation and Petaluma Formation. Tolay or Donnell
 and volcanics (Morse and Bailey, 1935; Youngman, 1989; Fox et al., 1985).

Pliocene sandstone (?)

Franciscan Complex

Graywacke with subordinate amounts of shale, red chert, and serpentinite.

Map Symbols

Bedding

Ball on dip bar indicates direction of top of beds
 Sedimentary structures.

Dotted where covered or inferred)

Arrow shows direction and amount of dip where inclined. Dashed
 approximately located.

(R, 1979)

Arrows show direction of movement

Creek fault (inferred from this study)

— Fault (Fox et al., 1973)

— Normal fault; D, down-dropped block, U, upthrown block.
 Tick marks show dip direction of fault plane and point toward
 down-dropped block.

— Thrust or reverse fault, teeth point toward upper plate.

— Arrow shows plunge direction

— Arrow shows plunge direction

Well, Calif. Div. of Oil and Gas

at Stony Point Rock Quarry
 personal communication, 2002)

Volcanic Rock Ages

with reasonable error (Fox et al, 1973; Davies, 1986).
 from Graymer et al. (2002)

Fossil Localities and Ages

Invertebrate locality Pliocene marine invertebrate fossil locality
 USGS JA-A: (Powell et al., 2003)
 Invertebrate locality CAS: California Academy of Sciences
 Invertebrate locality USGS M: United States Geological Survey collection

bed locality: Stony Point Rock
 area; in Mpl exposed in Gossage

bed locality: Stony Point Rock
 area; in Mpl from borehole A

Sample Localities

localities
 localities

last foraminifera study locality

et al., 2002). Donnell Ranch Volcanics crop out along Lichau Road,
immediately west of the Rodgers Creek fault zone (~9.3 age from Davies, 1986).

Areas mapped by author shown in gray. White and gray areas also compiled
Armstrong (1974)
1. Mapped with R. McLaughlin (2002)
2. Mapped with D. Wagner (2002)

Schematic Correlation Chart of Map Units

Meacham Hill fault

Meacham Hill

Old Redwood Hwy.

Sebastopol fault

Areas mapped by author shown in gray. White and gray areas also compiled from: Johnson (1934), Weaver (1949), Fox et al (1973), and Bishop and Armstrong (1974)

1. Mapped with R. McLaughlin (2002)
2. Mapped with D. Wagner (2002)

Schematic Correlation Chart of Map Units

Fossils at personal collection (2); Pliocene fossils at (n, 1971).	~9.3 Ma volcanics of Graymer et al. (2002) below lower Petaluma. Late Hemphillian horse tooth at base of middle Petaluma (C. Repenning, personal communication, 2002).	Pliocene(?) (~5 Ma) diatoms at top (S. Vanlandingham, personal communication, 2002).	Blancan (Pliocene) horse tooth (UCMP V-5230) at top of section. Volcanics are ~5 Ma at top and ~7 Ma near base (Fox et al., 1985).
--	--	--	--

1973), and Bishop and

Lower and middle Petaluma projected from Taylor Mountain thrust fault area.
 Petaluma Formation of 4,000 feet (~1219 m) inferred from Morse and Bailey (1935) and this report.

Mountain thrust fault area.
and Bailey (1935) and this report.

38°18'00"

38°17'00"

122°48'00"

122°47'00"

122°47'00"

122°46'00"

122°45'00"

122°44'00"

Map Location

122°43'00"

122°42'00"

122°41'00"

122°40'00"

Scale 1 : 24 000

0 500 1000 METERS

MILE

00" 122 40'00" 122 39'00" 122 38'00"

JA2002 9-12: Ostracode locality: Stony Point Rock
Quarry area; in Mpl exposed in Gossage
Creek

JA2002 3-7: Ostracode locality: Stony Point Rock
Quarry area; in Mpl from borehole A

Sample Localities

- ① Thin section localities
- ① Clast count localities

M-1 Monterey clast foraminifera study locality

122°39'00"

122°38'00"

JA2002 9-12: Ostracode locality: Stony Point Rock
Quarry area; in Mpl exposed in Gossage
Creek

JA2002 3-7: Ostracode locality: Stony Point Rock
Quarry area; in Mpl from borehole A

Sample Localities

- ① Thin section localities
- ① Clast count localities

M-1 Monterey clast foraminifera study locality

PMsvm

38°18'00"

E

A

FEET
1,000
800
600
400
200
0

Thickness from strike and dip data.

Thickness from strike and dip data. Basement high from D. Ponce (personal communication, 2002)

Folded Hanging Wall

Thickness of lower Petaluma Formation bedded Wilson Grove and Petaluma on north limb of anticline at Stony Point from "Unit 1" well, located about 510 line A-A'. Total depth is about 6,000 feet suggest 1- to 2-km-deep basin in block (Wagner and Bortugno, 1982; D. Ponce McLaughlin, personal communication,

lip data. Basement high from D. Ponce (personal communication, 2002)

Thickness of interbedded Wilson Grove and Petaluma formations from Stephens-Rohnert 1 well strike, at same elevation and within same fault block. Gravity data suggest 1- to 2-km-deep basin, Sebastopol and North College faults (Wagner and Bortugno, 1982; D. Ponce, personal communication, 2002). Eocene (?) at base of well (Ess?); basement not reached (Oil and Gas, Stephens-Rohnert 1 well log report). Franciscan Complex inferred as basement below.

hanging Wall

Thickness of lower Petaluma Formation, volcanic flows, and the interbedded Wilson Grove and Petaluma formations is from mapping data on north limb of anticline at Stony Point Rock Quarry. Thickness also from "Unit 1" well, located about 510 meters to the west of cross section line A-A'. Total depth is about 6,000 feet (1,828 meters). Gravity data suggest 1- to 2-km-deep basin in block north of the Sebastopol fault (Wagner and Bortugno, 1982; D. Ponce, personal communication, 2002; McLaughlin, personal communication, 2002).

Thickness of interbedded Wilson Grove and Petaluma formations from Stephens-Rohnert 1 well inferred along strike, at same elevation and within same fault block. Gravity data suggest 1- to 2-km-deep basin in block between Sebastopol and North College faults (Wagner and Bortugno, 1982; D. Ponce, personal communication, 2002; R. McLaughlin, personal communication, 2002). Eocene (?) at base of well (Ess?); basement not reached (Calif. Div. of Oil and Gas, Stephens-Rohnert 1 well log report). Franciscan Complex inferred as basement below Eocene sandstone.

Basement high from D. Ponce (written communication, 2002)

formation, volcanic flows, and the interbedded formations is from mapping data by Point Rock Quarry. Thickness also at 510 meters to the west of cross section at 1,000 feet (1,828 meters). Gravity data block north of the Sebastopol fault (Ponce, personal communication, 2002; McLaughlin, personal communication, 2002).

Basement high from D. Ponce (written communication, 2002)

ong
between
; R.
f. Div. of
sandstone.

Intersection With
Cross-Section D-D'

East Cotati Ave

Lower and middle Petaluma projected from Taylor
Thickness of Petaluma Formation of 4,000 feet (~1219 m) inferred from Morse

Lower and middle Petaluma projected from Taylor Mountain thrust fault area.
Thickness of Petaluma Formation of 4,000 feet (~1219 m) inferred from Morse and Bailey (1935) and this report.

U.S. 101

Qal

IWGP

Geologic Map of Portions of the Two Rock, Co
and Glen Ellen U.S.G.S.

By James Allen (200

Mountain thrust fault area.
and Bailey (1935) and this report.

Geologic Map of Portions of the Two Rock, Cotati, Sebastopol, Santa Rosa, Kenwood,
and Glen Ellen U.S.G.S. 7.5' Quadrangles

By James Allen (2001-2002).

Plate 2

NOTE TO USERS

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UMI[®]

122°33' 00"

122°32' 00"

38°16' 00"

38°15' 00"

38°14' 00"

122°30' 00"

122°28' 00"

00"

122°28' 00"

122°27' 00"

38°16' 00"

38°15' 00"

38°14' 00"

EXPLANATION

Map Symbols

EXPLANATION

Quaternary alluvium
Includes Pleistocene and Holocene alluvial and fluvial deposits.

Quaternary landslide, arrows show slide direction.

Quaternary

Age in millions of years

4.65 Ma

5.2-5.4 Ma

6.25 Ma

~7 Ma

8.5 Ma

~10 - 8.2 Ma

Pliocene

Miocene

Jurassic-Cretaceous

Upper Petaluma Formation

Clay lenses, fine- to coarse-grained sandstone and Monterey-derived conglomerate. Contains ~6 Ma Roblar Tuff (*Mrt*) (Sarna-Wojcicki, 1992), 5.2-5.4 Ma Pinole Tuff (*Mpt*), 4.65 Ma Healdsburg Tuff (*Phl*), and Blacan vertebrate fossils.

Middle Petaluma Formation

Clay lenses, fine- to coarse-grained sandstone and Franciscan Complex-derived conglomerate. Contains Hemphillian vertebrate fossils. Contains ~7 Ma Sonoma Volcanic flows. Mtu: Unknown tuff

Lower Petaluma Formation

Finely laminated to thick-bedded mudstone with minor lenses of conglomerate, sandstone, dolomite, chert, and limestone. Contains abundant lacustrine and transitional marine ostracodes. Contains marine diatoms in thin chert bed near base, and marine gastropod near contact with middle Petaluma. Contains ~8.52 Ma mafic interbed at base (Youngman, 1989).

Mafic volcanics

Tertiary volcanics below Petaluma Formation. Either Tolay or Donnell Ranch volcanics (Morse and Bailey, 1935; Youngman, 1989).

Angular

Unconformity

Franciscan Complex

KJfm: mélangé undivided; KJfgw: graywacke with minor foliation; KJfs: schist; KJmv: metavolcanic; KJbs: blueschist; KJmg: m; KJc: red chert; KJgs: greenstone; KJact: actinolite; KJsc: silica-carbonate rock, KJgb: gabbro; KJmc: metachert; KJas: amphibolite schist; KJes: eclogite schist

Sonoma Volcanics

PMsvm: Mafic flows. Ages range from ~7 to 7.3 Ma (Youngman, 1989).

PMsvt: Tuff. Ages range from ~6.75 to 6.62 Ma in this area (Fox et al., 1985). Sonoma Volcanics are interbedded with middle and upper Petaluma Formation in Sonoma Mountain area.

Donnell Ranch Volcanics

Mdr: Flow-banded white rhyolite. Age: 10.64 ± 0.27 to 8.24 ± 0.22 Ma. (Youngman, 1989)
Mdm: Mafic flows, Gray or dark gray-black oliv and basaltic andesite. Age: 10.64 ± 0.27 to 8.24 ± 0.22 Ma (Youngman, 1989)

Map Symbols

Strike and dip of bedding

Strike and dip of overturned beds

Strike and dip of beds. Ball on dip bar indicates direction of top beds inferred from sedimentary structures.

Contact; dashed where covered or inferred)

Sample Localities

- ① Clast count locality (numbers correspond to stations in report appendix).
- ① Thin section locality (numbers correspond to stations in report appendix).

Quaternary and Holocene
sedimental deposits.

Quaternary landslide, arrows
show slide direction.

Formation

to coarse-grained sandstone
derived conglomerate.

Roblar Tuff (*Mrt*) (Sarna-Wojcicki, 1992),
Tuff (*Mpt*), 4.65 Ma Healdsburg Tuff (*Pht*),
vertebrate fossils.

Formation

to coarse-grained sandstone
complex-derived conglomerate.
Miocene vertebrate fossils. Contains
volcanic flows. Mtu: Unknown tuff

Formation

to thick-bedded mudstone with minor
conglomerate, sandstone, dolomite, chert, and
contains abundant lacustrine and transitional
fossils. Contains marine diatoms in thin chert
and marine gastropod near contact with
volcanics. Contains ~8.52 Ma mafic interbed at
(1989).

below Petaluma Formation. Either Tolay or Donnell
(Morse and Bailey, 1935; Youngman, 1989).

Complex

undivided; KJfgw: graywacke with minor foliation; KJfs: schist; KJmv: metavolcanic; KJbs: blueschist; KJmg: metagraywacke;
KJgs: greenstone; KJact: actinolite; KJsc: silica-carbonate rock, KJgb: gabbro; KJmc: metachert;
KJsch: schist; KJes: eclogite schist

Sonoma Volcanics

PMsvm: Mafic flows. Ages range from
~7 to 7.3 Ma (Youngman, 1989).

PMsvt: Tuff. Ages range from ~6.75 to
6.62 Ma in this area (Fox et al., 1985).
Sonoma Volcanics are interbedded with
middle and upper Petaluma Formation
in Sonoma Mountain area.

Undivided
Quaternary or Tertiary
sediments of
Wright and Smith
(1992)

Donnell Ranch Volcanics

Mdr: Flow-banded white rhyolite. Age:
10.64±0.27 to 8.24±0.22 Ma. (Youngman, 1989)

Mdm: Mafic flows, Gray or dark gray-black olivine basalt
and basaltic andesite. Age: 10.64±0.27
to 8.24±0.22 Ma (Youngman, 1989)

Sample Localities

- ① Clast count locality (numbers correspond
to stations in report appendix).
- ① Thin section locality (numbers correspond
to stations in report appendix).

Volcanics

Mafic flows. Ages range from ~7 to 7.3 Ma (Youngman, 1989).
Tuff. Ages range from ~6.75 to in this area (Fox et al., 1985).
Volcanics are interbedded with and upper Petaluma Formation
na Mountain area.

QTu

Undivided
Quaternary or Tertiary
sediments of
Wright and Smith
(1992)

uch Volcanics

banded white rhyolite. Age:
to 8.24 ± 0.22 Ma. (Youngman, 1989)
flows, Gray or dark gray-black olivine basalt
andesite. Age: 10.64 ± 0.27
2 Ma (Youngman, 1989)

volcanic; KJbs: blueschist; KJmg: metagraywacke;
; KJmc: metachert;

Sample Localities

count locality (numbers correspond
ions in report appendix).
ection locality (numbers correspond
ions in report appendix).

8.5 Ma
~10 - 8.2 Ma

8.5 Ma
~10 - 8.2 Ma

Jurassic-
Cretaceous

Mtu

Mpl

Mv

Angular

Unconformity

KJfm

Contains Hesperian vertebrate fossils. Contains ~7 Ma Sonoma Volcanic flows. Mtu: Unknown tuff

Lower Petaluma Formation

Finely laminated to thick-bedded mudstone with minor lenses of conglomerate, sandstone, dolomite, chert, and limestone. Contains abundant lacustrine and transitional marine ostracodes. Contains marine diatoms in thin chert bed near base, and marine gastropod near contact with middle Petaluma. Contains ~8.52 Ma mafic interbed at base (Youngman, 1989).

Mafic volcanics

Tertiary volcanics below Petaluma Formation. Either T Ranch volcanics (Morse and Bailey, 1935; Youngman,

Franciscan Complex

KJfm: mélange undivided; KJfgw: graywacke with mica; KJc: red chert; KJgs: greenstone; KJact: actinolite; KJas: amphibolite schist; KJes: eclogite schist

Map Symbols

- Strike and dip of bedding
- Strike and dip of overturned beds
- Strike and dip of beds. Ball on dip bar indicates direction of top beds inferred from sedimentary structures.
- Contact; dashed where covered or inferred)
- Fault: Arrow shows direction and amount of dip where inclined. 1 where approximately located.
- Fault, arrows show direction of movement
- Fault (Fox et al., 1973)
- Thrust fault (Youngman, 1989)
- Thrust or reverse fault, teeth point toward upper plate
- Syncline, arrow shows plunge direction
- Anticline, arrow shows plunge direction

Texaco TD: 7,167 ft.
Noble 1 (2,185 meters)
(Wright and Smith, 1992)

Contains Hemphillian vertebrate fossils. Contains
~7 Ma Sonoma Volcanic flows. Mtu: Unknown tuff

Lower Petaluma Formation

Finely laminated to thick-bedded mudstone with minor lenses of conglomerate, sandstone, dolomite, chert, and limestone. Contains abundant lacustrine and transitional marine ostracodes. Contains marine diatoms in thin chert bed near base, and marine gastropod near contact with middle Petaluma. Contains ~8.52 Ma mafic interbed at base (Youngman, 1989).

Mafic volcanics

Tertiary volcanics below Petaluma Formation. Either Tolay or Donnell Ranch volcanics (Morse and Bailey, 1935; Youngman, 1989).

Angular
unconformity

Franciscan Complex

KJfm: mélange undivided; KJfgw: graywacke with minor foliation; KJfs: schist; KJmv: metavolcanic; KJbs: blueschist; KJmg: metagraywacke; KJc: red chert; KJgs: greenstone; KJact: actinolite; KJsc: silica-carbonate rock, KJgb: gabbro; KJmc: metachert; KJas: amphibolite schist; KJes: eclogite schist

Donnell Ranch Volcanics

Mdr: Flow-banded white rhyolite. Age: 10.64±0.27 to 8.24±0.22 Ma. (Youngman, 1989)
Mdm: Mafic flows, Gray or dark gray-black olivine basalt and basaltic andesite. Age: 10.64±0.27 to 8.24±0.22 Ma (Youngman, 1989)

Map Symbols

- Strike and dip of bedding
- Strike and dip of overturned beds
- Strike and dip of beds. Ball on dip bar indicates direction of top beds inferred from sedimentary structures.
- Contact; dashed where covered or inferred)
- Fault: Arrow shows direction and amount of dip where inclined. Dashed where approximately located.
- Fault, arrows show direction of movement
- Fault (Fox et al., 1973)
- Thrust fault (Youngman, 1989)
- Thrust or reverse fault, teeth point toward upper plate.
- Syncline, arrow shows plunge direction
- Anticline, arrow shows plunge direction

Sample Localities

- ① Clast count locality (numbers correspond to stations in report appendix).
- ① Thin section locality (numbers correspond to stations in report appendix).

Fossil Localities

- ① 3647: UCMP Miocene (late Hemphillian) vertebrate fossil locality (numbers correspond to stations in report appendix).
- ① 4908: UCMP Pliocene (early Blancan) vertebrate fossil locality (numbers correspond to stations in report appendix).

Volcanic Rock Ages

- Radiometric ages from Youngman (1989)

CO TD: 7,167 ft.
e 1 (2,185 meters)
(Wright and Smith, 1992)

onnell Ranch Volcanics

dr: Flow-banded white rhyolite. Age:

0.64 ± 0.27 to 8.24 ± 0.22 Ma. (Youngman, 1989)

dm: Mafic flows, Gray or dark gray-black olivine basalt

and basaltic andesite. Age: 10.64 ± 0.27

8.24 ± 0.22 Ma (Youngman, 1989)

Jmv: metavolcanic; KJbs: blueschist; KJmg: metagraywacke;
gb: gabbro; KJmc: metachert;

Sample Localities

- ① Clast count locality (numbers correspond to stations in report appendix).
- ① Thin section locality (numbers correspond to stations in report appendix).

Fossil Localities

- ① 3647: UCMP Miocene (late Hemphillian) vertebrate fossil locality (numbers correspond to stations in report appendix).
- ① 4908: UCMP Pliocene (early Blancan) vertebrate fossil locality (numbers correspond to stations in report appendix).

Volcanic Rock Ages

- Radiometric ages from Youngman (1989)

- 1. Mapped by James Allen (San José State University); shown in gray.
- 2. Mapped by Dave Wagner (California Geological Survey); shown in gray.
- 3. Mapped by Don Ristau (Geologist); shown in gray.
- 4. Mapped by Youngman (1989)
- 5. Mapped by Fox et al. (1973)

1. Mapped by James Allen (San José State University); shown in gray.
2. Mapped by Dave Wagner (California Geological Survey); shown in gray.
3. Mapped by Don Ristau (Geologist); shown in gray.
4. Mapped by Youngman (1989)
5. Mapped by Fox et al. (1973)

University); shown in gray.
ological Survey); shown in gray.
wn in gray.

38°13'00"

38°12'00"

38°11'30"

● Radiometric ages from Youngman (

Texaco TD: 7,167 ft.
Noble 1 (2,185 meters)
(Wright and Smith, 1992)

Thickness and formations from Youngman (1989)

● Radiometric ages from Youngman (1989)

Petaluma River Valley

1. Mapped by James Allen (San Jose)
2. Mapped by Dave Wagner (Califor)
3. Mapped by Don Ristau (Geologis
4. Mapped by Youngman (1989)
5. Mapped by Fox et al. (1973)

s from Youngman (1989)

1. Mapped by James Allen (San José State University); shown in gray.
2. Mapped by Dave Wagner (California Geological Survey); shown in gray.
3. Mapped by Don Ristau (Geologist); shown in gray.
4. Mapped by Youngman (1989)
5. Mapped by Fox et al. (1973)

interbeds

University); shown in gray.
 Geological Survey); shown in gray.
 own in gray.

38°11'00"

38°10'00"

38°09'00"

JA2002-18, 19, 20

JRA021501

22

20

BDY

38°11'00"

38°10'00"

C

38°09'00"

Thickness from Wright and Smith (1992).
Tolay fault dips west near surface and vertical at depth (Wright and Smith, 1992).
Basement KI of Wright and Smith (1992) changed to Mv in this study.

Youngman (1989)

Thickness and formations from Youngman (1989)

Section

38°10' 00"

38°09' 00"

122°33' 00"

122°32' 00"

122°32' 00"

122°31' 00"

122°30' 00"

Scale 1 : 24 000

122°30' 00"

122°29' 00"

MILE

Thickness from Wright and Smith (1992)
 Tolay fault dips west near surface and vertical at depth (Wright and Smith, 1992)
 Basement KI of Wright and Smith (1992) changed to

122°27' 00"

Thickness from Wright and Smith (1992).
 Tolay fault dips west near surface and vertical at depth (Wright and Smith, 1992).
 Basement KI of Wright and Smith (1992) changed to Mv in this study.

Thickness and formations from Youngman (1989)

Thickness and formations from Youngman (1989)

Thickness and formations from Youngman (1989)

h, 1992).
udy.

Compile

Addition

Thickness and formations from Youngman (1989)

Section inferred along strike from cross-section

Geologic Map of Portions of the Petaluma River, Sears Point and Sonoma U.S.G.S. 7.5' Quadrangles

Compiled from: Morse and Bailey (1935), Weaver (1949), Fox et al (1977),
Bishop and Armstrong (1974), Youngman (1989).

Additional, unpublished mapping by Dave Wagner (2001-2002) and James A.

Youngman (1989)

Section inferred along strike from cross-section B-B'.

Geologic Map of Portions of the Petaluma River, Sears Point, Glen Ellen, and Sonoma U.S.G.S. 7.5' Quadrangles

Compiled from: Morse and Bailey (1935), Weaver (1949), Fox et al (1973), Bishop and Armstrong (1974), Youngman (1989).

Additional, unpublished mapping by Dave Wagner (2001-2002) and James Allen (2001-2002).

Plate 3

NOTE TO USERS

Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

This reproduction is the best copy available.

UMI[®]

122°20'00"

122°21'00"

122°20'00"

122°19'00"

San Pablo Bay

Wilson Point

0"

122°20'00"

122°19'00"

San Pablo Bay

38°01'00"

38°00'00"

37°59'00"

Map Location

0 1000 FEET

Pleistocene--
Holocene
Pliocene
Late Miocene

Qal

Quaternary alluvium

Extensive Pleistocene deposits conceal most of the Garrity between Point Pinole and San Pablo Avenue (see Helley et al., 1979 and Knudson et al., 2000 for Quaternary geology in this area). Geology inferred between these two areas.

Mrt
PMgu
Mgl

Garrity Member of the Contra Costa Group

Fluvial conglomerate with sandstone and minor mudstone interbeds. Monterey-derived clasts from middle to top (PMgu: upper submember) and Franciscan Complex-derived clasts at base to mid-point of formation (Mgl: lower submember). Mrt: ~6 Ma Roblar Tuff (Sarna-Wojcicki, 1992).

Unconformity

Mor

Orinda Formation

Fluvial sandstone and conglomerate (Weaver, 1949; Graham et al., 1984; Grauer (2002).

fault

San Pablo Group

Marine, estuarine and fluvial sandstone with conglomerate interbeds; coeval with Orinda Formation in Berkeley Hills area

Eocene

Eocene strata from Wright and Smith (19

Cretaceous

Upper Cretaceous Great Valley Group (Y

Classic-Cretaceous

Hayward fault

Franciscan Complex with serpentinite w

along the Hayward fault (Borchardt et al

122°23'00"

122°22'00"

122°21'00"

122°20'00"

Compiled from
(1988), and
2002) with a

t of the Garrity between
lley et al., 1979 and
y in this area).

up
minor mudstone interbeds,
(PMgu: upper submember)
base to mid-point of formation
lar Tuff (Sarna-Wojcicki,

San Pablo Group
Marine, estuarine and fluvial

Eocene
Cretaceous
Cretaceous

- Eocene strata from Wright and Smith (1992).
- Upper Cretaceous Great Valley Group (Wright and Smith, 1992).
- Hayward fault
- Franciscan Complex with serpentinite west of the Garrity Member

Map Symbols

- 54 Strike and dip
- Vertical beds
- Geologic contact
- Anticline; dashed line indicates direction
- Syncline, dashed line indicates direction
- Strike-slip fault; direction of movement indicated by arrows
- Thrust or reverse fault; direction of movement indicated by arrows

Scale 1 : 24 000

Compiled from Weaver (1949), Cebull (1958), Wagner (1979), Borchardt et al. (1988), and Graymer (2000). Additional mapping by James R. Allen (1999-2002) with assistance from Peter J. Holland (SJSU).

Map Symbols

	Strike and dip of beds		Thin section locality
	Vertical beds		Clast count locality
	Geologic contact, dashed where inferred		Monterey Clast-Study Locality
	Anticline; dashed where inferred; arrow at tip indicates plunge direction.		UCMP vertebrate fossil (Hemphillian; Late M)
	Syncline, dashed where inferred.		
	Strike-slip fault, arrows show direction of movement		

and Smith (1992).

ey Group (Wright and Smith, 1992).

Compiled from Weaver (1949), Cebull (1958), Wagner (1979), Borchardt et al. (1988), and Graymer (2000). Additional mapping by James R. Allen (1999-2002) with assistance from Peter J. Holland (SJSU).

1 MILE
1000 METERS

Map Symbols

	Strike and dip of beds		Thin section locality
	Vertical beds		Clast count locality
	Geologic contact, dashed where inferred		Monterey Clast-Study Locality
	Anticline; dashed where inferred; arrow at tip indicates plunge direction.		UCMP vertebrate fossil locality (Hemphillian; Late Miocene)
	Syncline, dashed where inferred.		
	Strike-slip fault, arrows show direction of movement		
	Thrust or reverse fault of Graymer (2000).		

Map Location

122°21'00"

122°20'00"

122°19'00"

Compiled from Weaver (1949), Cebull (1958), Wagner (1979), Borchardt et al. (1988), and Graymer (2000). Additional mapping by James R. Allen (1999-2002) with assistance from Peter J. Holland (SJSU).

Scale 1 : 24 000

Map Symbols

54

Strike and dip of beds

Vertical beds

Geologic contact, dashed where inferred

Anticline; dashed where inferred; arrow at tip indicates plunge direction.

Syncline, dashed where inferred.

Strike-slip fault, arrows show direction of movement

Thrust or reverse fault of Graymer (2000). Dashed where inferred.

A—A'

Cross-section line

⑮ Thin section locality

③③ Clast count locality

M-2 Monterey Clast-Study Locality

⑤5508 UCMP vertebrate fossil locality (Hemphillian; Late Miocene)

Smith (1992).

Group (Wright and Smith, 1992).

limestone west of the Garry Member (Borchardt et al., 1988).

Stratigraphy of the Garry Member of the Contra Costa Group

Geologic Map of Portions of the Mare Island
Richmond USGS 7.5'
Quadrangles

Plate 4

from Graymer (2000).

122° 20' 00"

122° 19' 00"

Compiled from Weaver (1949), Cebull (1958), Wagner (1979), Borchardt et al. (1988), and Graymer (2000). Additional mapping by James R. Allen (1999-2002) with assistance from Peter J. Holland (SJSU).

1 MILE
1000 METERS

Map Symbols

	Strike and dip of beds		Thin section locality
	Vertical beds		Clast count locality
	Geologic contact, dashed where inferred		Monterey Clast-Study Locality
	Anticline; dashed where inferred; arrow at tip indicates plunge direction.		UCMP vertebrate fossil locality (Hemphillian; Late Miocene)
	Syncline, dashed where inferred.		
	Strike-slip fault, arrows show direction of movement		
	Thrust or reverse fault of Graymer (2000). Dashed where inferred.		
	Cross-section line		

Geologic Map of Portions of the Mare Island and Richmond USGS 7.5' Quadrangles

Plate 4