Biostratigraphic and lithologic correlations of two Sonoma County Water Agency pilot wells with the type Wilson Grove Formation, Sonoma County, central California

By Charles L. Powell, II[1] Robert J. McLaughlin[1] and Elmira Wan[1]

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Abstract

Small mollusk faunas characteristic of the uppermost part of the Wilson Grove Formation at Wilson Grove and along River Road at Trenton (Pliocene) were encountered in Sonoma County Water Agency pilot wells at Occidental Road well field between 320-500 ft (98-152 m), depth, and in the Sebastopol Road pilot well field between 560-570 ft (171-174 m), depth. These mollusks support correlations between the two wells made on lithologic grounds.

A benthic foraminifer was recovered from between 380-390 ft (116-119 m), depth, in the Sonoma County Water Agency Occidental Road pilot well. Though an isolated specimen, the presence of this well-preserved foraminifer supports the environmental interpretation of less than 100 m on the continental shelf indicated by the molluscan assemblages at this site.

For this marine stratigraphic interval of the Wilson Grove Formation, we suggest a relatively narrow age range of 5.3 (Miocene-Pliocene boundary) to ~ 4.5 Ma based on the stratigraphic relations of correlative marine strata around the upland margin of Santa Rosa plain and correlative strata in the Santa Cruz area, although an age between 5.3 and ~ 2.8 Ma cannot be discounted.

Introduction

The Occidental Road and Sebastopol Road pilot well sites are situated along the west side of the Santa Rosa plain which overlies the moderately deep (~2.5 km) Cotati sedimentary basin filled with Miocene to Quaternary marine, estuarine and fluvial-lacustrine deposits (Figure 1). These strata are, in turn, intercalated with the Tolay Volcanics (~10.6 to 8.5 Ma; Wagner and others, 2005) and the Sonoma Volcanics (~8.5 to 2.5 Ma; Wagner and others, 2005). A system of Pliocene and younger normal faults bound the Santa Rosa plain on the southwest, and in the subsurface, the plain is partitioned by west-northwest-trending thrust faults, into the Cotati basin (to the south) and Windsor basin (to the north – not figured). The Cotati basin is bounded on the northeast by the active northwest-trending Rodgers Creek-Healdsburg fault zone. Detailed stratigraphy in these buried basins is important to our understanding of local groundwater supplies and the structural configuration of the basins has important earthquake hazards implications (McPhee and others, 2005). The complexity in stratigraphic and structural relations across faults bounding the Santa Rosa plain make it difficult to tie the geology of the surrounding uplands directly to the basin stratigraphy. However, previous work on the exposed basin margin

[1] U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025

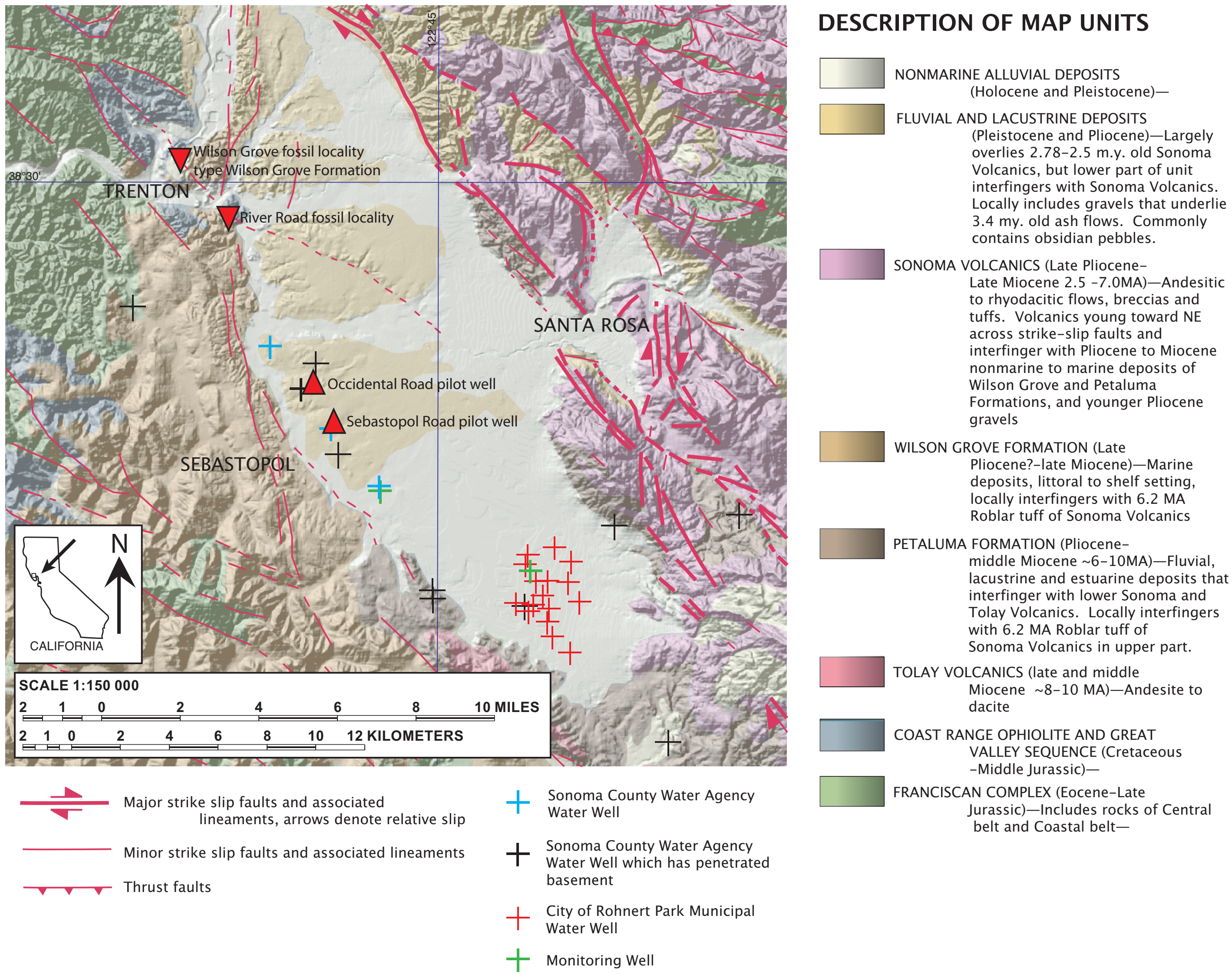

Figure 1. Geologic map of the of the Cotati Basin part of the Santa Rosa plain area showing the location of surface outcrops of the Wilson Grove Formation (upside down triangles) at its type section at Wilson Grove and along River Road at Trenton and of Sonoma County Water Agency Occidental Road and Sebastopol Road pilot wells (triangles), Sonoma County, central California.

stratigraphy (Fox, 1983; Allen, 2003) work on the stratigraphy in oil and gas wells (Wright and Smith, 1992; Zieglar, Wright, and Smith, 2005), and the compilation of water well data by Cardwell (1958) has provided a modern context (*i.e.* Valin and McLaughlin, 2005) for detailed biostratigraphic and chronostratigraphic analysis of the subsurface of Santa Rosa plain.

This report expands the above framework by documenting, for the first time, an invertebrate fauna in the subsurface of Santa Rosa plain that allows correlation to a paleontologically well-studied Pliocene section along the western margin of Santa Rosa plain and to other correlative Pliocene sections elsewhere in central California. Based on the stratigraphic relations of correlative marine strata around the upland margin of Santa Rosa plain and the chronostratigraphic relations of correlative strata in the Santa Cruz area, an age younger than 5.3 Ma is indicated for the fossiliferous horizons in the pilot wells. Although some of the presently available stratigraphic evidence also permits an age as young as late Pliocene for the upper part of the fossiliferous section (Powell, Allen and Holland, 2004), other stratigraphic relations around the margins of the Santa Rosa Plain outlined here, suggest that the marine mollusk-bearing strata could have been deposited over a narrower time interval between 5.3 and ~4.5 Ma. In addition, this correlation, furthermore, identifies a stratigraphic interval in the subsurface that will be useful in constraining displacements and deformation rates across basin bounding faults and on intra-basin fault partitions.

Fossil occurrences in pilot wells

Washed ditch samples from the two pilot wells have produced residues containing mollusks, mollusk fragments, and a microfossil. The Sonoma County Water Agency Occidental Road pilot well is located at 38.4229°N, 122.8088°W (NAD27), on the north side of Occidental Road about 1.7 km northwest of Llano, Sebastopol 7.5' quadrangle (Figure 1). This well contains fossiliferous samples in two shell beds that appear to be continuous, or nearly continuous. One shell bed is located between 320-690 ft (97-210 m) and the other is between 800-840 ft (244- 256 m), total drilled depth.

The Sonoma County Water Agency Sebastopol Road pilot well is located at 38.4085°N, 122.7995°W (NAD27), along the Petaluma and Santa Rosa railroad line about midway between Llano and the Sebastopol Grange (north of Gravenstein), Sebastopol 7.5' quadrangle (Figure 1). This well contains several shell beds based on continuous, or nearly continuous, fossil occurrences between 470-600 ft (143-183 m), 620-640 ft (189-195 m), 780-910 ft (238-277 m), 940-950 ft (287-290 m), and 1000-1070 ft (305-326 m).

Molluscan taxa identifiable at order level or below are present in the Occidental Road pilot well between 320-330 ft (98-101 m), 340-360 ft (104-110 m), 370-380 ft (113-116 m), 390-440 ft (119-134 m), 460-480 ft (140-146 m), and 500-510 ft (152-155 m) (Appendix 1). Identifiable taxa are present in the Sebastopol Road pilot well between 510-520 ft (155-158 m) and 560-570 ft (171-174 m) (Appendix 1).

The microfossil taxon is identifiable to the species level and the specimen was recovered from the 380–390 ft (116-119 m) interval in the Occidental Road pilot well.

Mollusks

In the Occidental Road pilot well, the 320-500 ft (98-152 m) cutting depth interval contains a fauna similar to that found in the type Wilson Grove Formation at Wilson Grove, and along River Road at Trenton, both localities in northern Sonoma County (Figure 1). The small fauna reported here consists of eight identifiable taxa (one bivalve, seven gastropods; see Table 1). This fauna is too small for detailed age and environmental assessment. However, the occurrence of specimens questionably attributed to *Nassarius grammatus* (Dall) and *Ophiodermella graciosana* Arnold indicate a Pliocene age. *Nassarius grammatus* (Dall) has been reported in Pliocene formations from Humboldt County, northern California, to San Diego and possibly Baja California Norte, Mexico (Addicott, 1965). *Ophiodermella graciosana* (Arnold) occurs in the Careaga Sandstone in northern Santa Barbara County (Woodring and Bramlette, 1950), the Merced Formation (Yancey, 1978) on the San Francisco Peninsula, and the Purisima Formation (references in Powell, 1998) between Año Nuevo, San Mateo County and the Sargent oil field area in southern Santa Cruz County. All outcrops containing *Ophiodermella graciosana* Arnold are considered Pliocene. Moreover, environmentally, all of the taxa are marine and modern representatives of these genera mainly represent shelf water depths (≤100 m).

The Sebastopol Road pilot well contains only two specifically identified taxa, *Nassarius* sp., cf. *N. grammatus* (Dall) and *Ophiodermella graciosana* Arnold(?) both found between 560-570 ft (171-174 m). Other collections from this well contained only unidentifiable mollusk, bivalve, and gastropod fragments. The two species recovered from between 560-570 ft (171-174 m) are both present from the type Wilson Grove Formation at Wilson Grove and along River Road (Trenton), both in northern Sonoma County (Figure 1). Other occurrences are discussed above, but both species are restricted to the Pliocene. There is again too few taxa in the cuttings from this well for detailed age or environmental assessment. But, both taxa are restricted to the Pliocene and are marine forms with modern representatives of the genera most often encountered at shelf water depths (~100 m or less).

Mollusca
Bivalvia
Arcoida, indeterminate
Gastropoda
Nassarius sp., cf. *N. grammatus* (Dall)
Nassarius sp.
Naticidae, indeterminate
Olivella pycna Berry
Olivella sp.
Ophiodermella graciosana (Arnold)?
Ophiodermella? sp.

Table 1. Faunal list of mollusks identified at Order level or below, in the Sonoma County Water Agency Occidental Road pilot well, Sonoma County, central California.

Samples between 320-690 ft (98-210 m), depth in the Occidental Road pilot well and between 560-570 ft (171-174 m), depth (and likely above) in the Sebastopol Road pilot well contain the same species. These species are common in the type Wilson Grove and the River Road at Trenton fossil localities of the Wilson Grove Formation in northern Sonoma County (Powell, Allen and Holland, 2004) where these and associated species indicate a Pliocene age. The Pliocene age is supported by a biocorrelation of the River Road (Trenton) locality with the Pliocene part of the Purisima Formation section in the sea-cliffs at and south of Capitola in Santa Cruz County, central California (Powell, Allen, and Holland, 2004).

Microfossils

Samples were examined for microfossils while logging the Occidental Road and Sebastopol Road pilot wells. Elsewhere in this region, in cores from oil and gas wells in the Petaluma basin, and in surface exposures surrounding the Santa Rosa plain and Petaluma basin, fresh to brackish water diatoms and ostracodes and rare benthic foraminifers are preserved in fluvial, lacustrine and estuarine lithofacies of the Petaluma Formation (Starratt and others, 2005). Only a single benthic foraminifer was encountered during the course of this study.

A well-preserved benthic foraminifer, *Nonionella basispinata* (Cushman and Moyer) (Figure 2), was recovered from between 380-390 ft (116-119 m) core interval in the Occidental Road pilot well. *N. basispinata* is a long-ranging (Tertiary) taxon typically observed as a dominant species in inner shelf (0-50 m) benthic foraminiferal assemblages. However, it has been found in deeper, generally nutrient-rich, middle shelf (50-90 m) water depths off of San Francisco (Bandy, 1953, Quinterno and Gardner, 1987, McGann, personal communication). Off southern California, *N. basispinata* is characteristic of outer shelf (50-200 m) assemblages (Douglas and Heitman , 1979, K. McDougall, 2006, personal communication). Though an isolated specimen, the presence of *N. basispinata* supports the marine environmental interpretation indicated by the molluscan assemblage in this well.

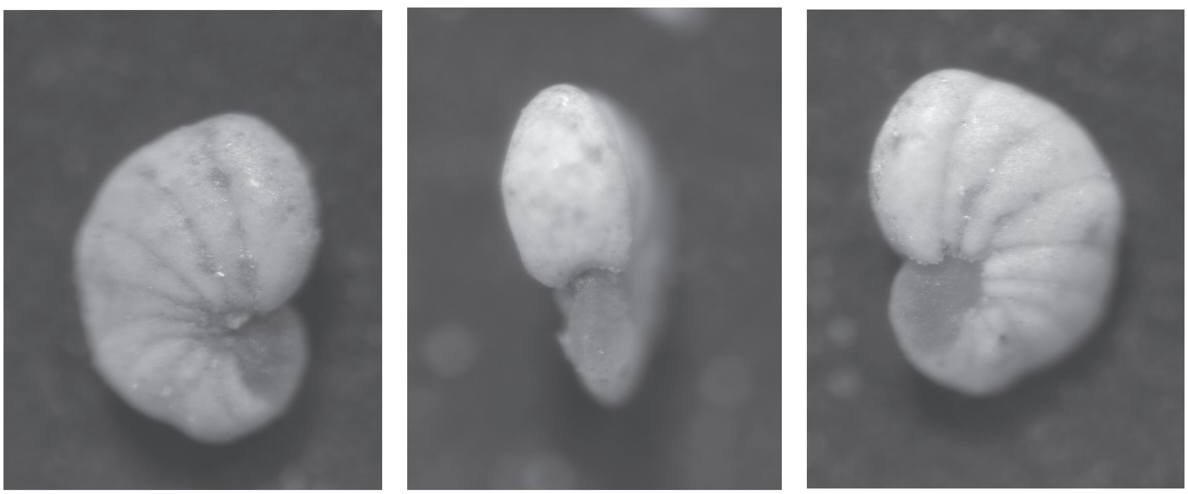

Figure 2. *Nonionella basispinata* (Cushman and Moyer). Digital photomicrograph of benthic foraminiferal specimen from Sonoma County Water Agency Occidental Road pilot well, Sonoma County, California, 380-390 feet, depth. Left: ventral view, center: profile, right: dorsal view. Magnification 160X.

Tephrochronology

Tephra or volcanic ash layers can be extremely useful for dating sedimentary sequences. Tephrochronology includes the use of established geochemical "fingerprinting" (usually by Electron Microprobe) and correlation techniques to identify and indirectly date sediment intervals containing isotropic glass shards from known volcanic eruptions or source areas (Sarna-Wojcicki, 1976; 1979).

The search for tephra-containing sediment layers from the Sonoma County pilot wells yielded largely negative results. Although some of the clay-rich horizons probably included fine-grained tephra, inspection with binocular and petrographic microscopes failed to identify any recoverable unaltered glass shards. All of the examined intervals showed only quartz, feldspar, lithic grains, and altered or clayey composite grains that may have been vitreous or glassy prior to devitrification. In several stratigraphic intervals, very fine, globule-like grains resembling minute obsidian clasts were noted in the lithologic log (Appendix 2). Upon detailed examination, most of these grains turned out to be very fine sand-sized, rounded, and polished particles of chromite, ilmenite, chert or cherty argillite.

Well stratigraphy and regional stratigraphic relationships

Detailed lithologic descriptions of the washed cuttings from the Occidental Road and Sebastopol Road pilot wells (Appendix 2; summary - Figure 3) indicate the southwestern side of Santa Rosa plain southwest of Santa Rosa is underlain by 50-150 ft (15-46 m) of Pleistocene and Holocene floodplain and basin deposits. In turn, the deposits are underlain by 250-300 ft (76-90 m) of Pliocene and Pleistocene fluvial to deltaic silt, sand, and gravel. Moreover, these sediments are underlain by at least 650 feet of dominantly shoreline to shelfal marine strata with minor non-marine intercalations. These marine strata correlate with parts of the Petaluma and Wilson Grove Formations, which overlap in age and interfinger, transitioning from southeast to northwest, from a fluvial-lacustrine to a deltaic-estuarine, then to a marine littoral, and finally, to a shelfal depositional system (Allen, 2003; Powell, Allen, and Holland, 2004; Staratt and others, 2005). In addition, textural and sorting characteristics of the sediments suggest that one or more shoreline fluctuations are preserved in the lithologic records of these wells. Here we describe and stratigraphically correlate between the Occidental Road and Sebastopol Road pilot wells and to outcrops of the Wilson Grove Formation on the southwest side of Santa Rosa plain. These correlations are based on sedimentologic interpretation of textural and sorting characteristics of the cuttings in the wells, together with the paleontologic data and age constraints implied by stratigraphic and sedimentologic relations of the exposed surface deposits.

Late Pliocene and Quaternary non-marine deposits

The upper ~50 feet of the Occidental Road drill hole and the upper ~150 feet of the Sebastopol Road drill hole consist of Pleistocene and Holocene clayey to pebbly, dominantly lacustrine and non-marine basinal or distal floodplain deposits. These sediments are underlain in both wells, probably unconformably, by ~265’ (Occidental Road) and ~300’(Sebastopol Road), respectively, of silt, sand and gravel, interpreted on the basis of textural and sorting characteristics, as distal fluvial, lacustrine, deltaic, and dune deposits. These deposits correspond at the surface to mildly to moderately tilted and locally folded fluvial and lacustrine sediments of late Pliocene and Pleistocene age, derived from several different local paleodrainage basins. These deposits include the Glen Ellen Formation, the Huichica Formation, and several other locally named and unnamed gravels.

Pliocene marine and non-marine deposits

Unconformably beneath the late Pliocene and Pleistocene non-marine section in the Occidental Road and Sebastopol Road wells are strata assigned here to the Petaluma and Wilson Grove Formations. The dominantly marine character of these strata and the shelfal affinities of the mollusks lead us to assign most of the beds to the Wilson Grove Formation. Some poorly sorted pebbly strata in the section, which are devoid of fossil or bioclastic debris, could represent minor fluvial or estuarine intertongues of the Petaluma Formation in the dominantly marine shelfal and littoral section. Most of the pebbly to gravelly component of this section is characterized by well-rounded and polished clasts and locally the gravels are clast supported and nearly devoid of fines. These deposits are interpreted here to be indicative of well-winnowed (washed) shoreline deposits (i.e., intertidal depositional setting).

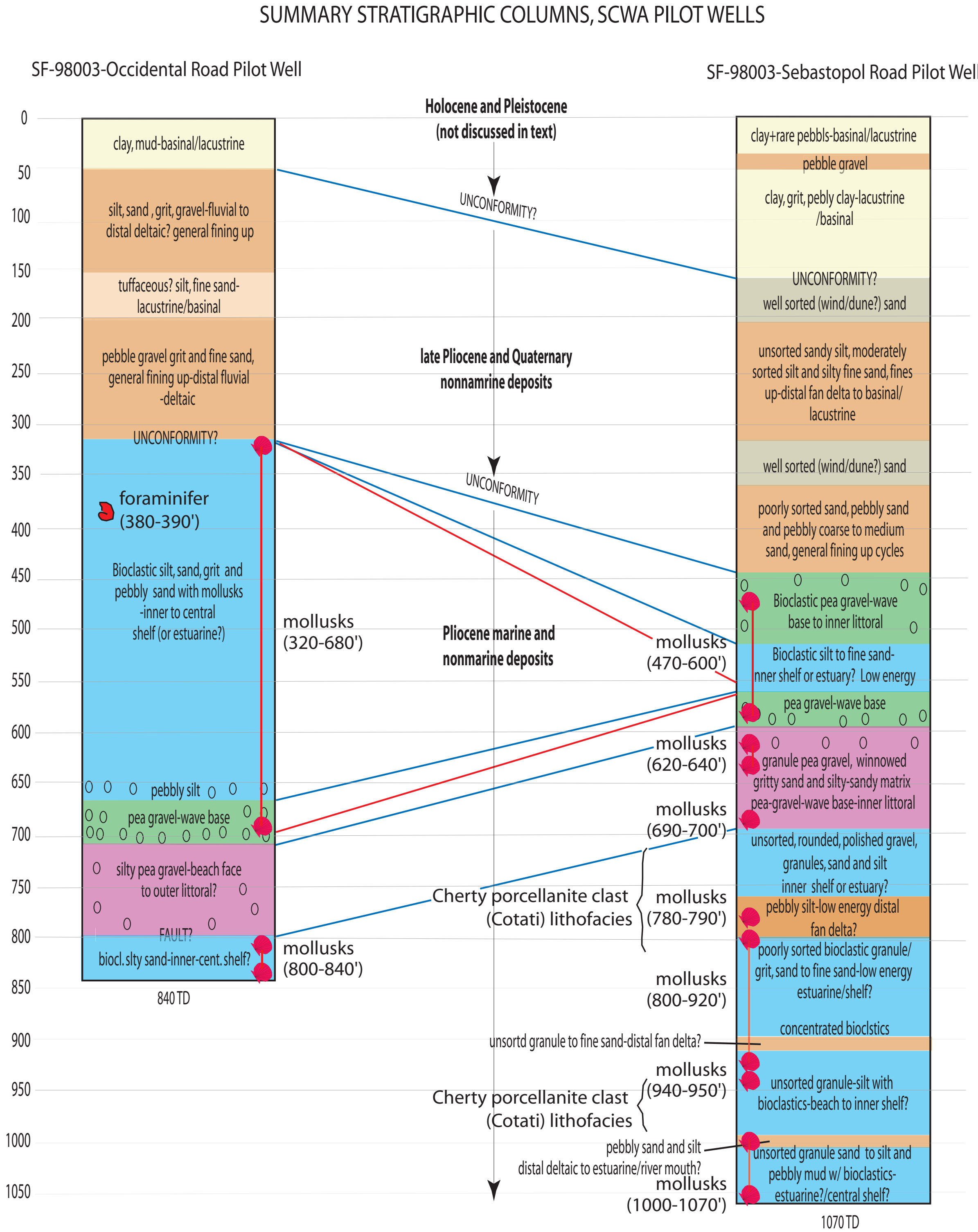

Figure 3. Correlations between Sonoma County Water Agency Occidental Road and Sebastopol Road pilot wells, Sonoma County, central California, based on mollusks (red) and lithology (blue). Also shows stratigraphic occurrence of fossils and the cherty porcellaneous clast (Monterey-like pebble lithofacies) deposits.

A distinctive lithofacies of these marine deposits, noted in the Sebastopol Road pilot well, is characterized by banded porcellanite pebbles. This lithofacies resembles a cherty porcellaneous lithofacies common in middle Miocene part of the Monterey Formation and the equivalent Claremont Shale of the Monterey Group of the eastern San Francisco Bay region (Allen, 2003; Allen and Repenning, 2005). In addition, this lithofacies is a common component of the gravels in the sand and gravel of Cotati (Fox, 1983), exposed at the surface on the southwest side of the Santa Rosa plain near Cotati, as a lithofacies of the Petaluma Formation. In the Sebastopol Road pilot well Monterey-like porcellanite pebbles, some of which appear to contain foraminifers, occur within two depth intervals, between 720-810 ft and 940-990 ft. No pebbles of this lithology were noted in the Occidental Road well, which was drilled to a total depth of only 840 ft. On the basis of the mollusks and lithologic correlations, it appears that the Occidental Road pilot well did not reach the depth of the sand and gravel of Cotati of the Petaluma Formation, providing another important lithologic constraint to our correlation to the Wilson Grove Formation type section.

Fossil occurrences and stratigraphic relations at the River Road at Trenton and Wilson Grove fossil localities of the Wilson Grove Formation permit an age range for these strata of between 5.3 Ma to ≥ 2.8 Ma, based on the extinct (Pliocene) mollusks discussed above and age constraints of an unconformity between the Wilson Grove Formation and an overlying unit of fluvial gravel containing obsidian from a Napa Valley source (McLaughlin and others, 2005). Other regional stratigraphic relations could indicate that sections of Wilson Grove Formation along River Road at Trenton and at Wilson Grove could be significantly older than 2.8 Ma, and are confined to a relatively shorter depositional window between 5.3 to ~4.5 Ma.

The Wilson Grove Formation is overlain unconformably by late Pliocene and(or) Pleistocene fluvial sediments that have been assigned by others to the Glen Ellen Formation (Fox, 1983; Fox and others, 1985) east of Wilson Grove. The Glen Ellen Formation in this area locally includes gravels with minor but conspicuous obsidian pebbles that have been geochemically fingerprinted and correlated to a radiometrically dated source material from the Sonoma Volcanics in the Napa Valley (Napa-Glass Mountain obsidian source area) (McLaughlin and others, 2005). The Napa Valley obsidian source has an $^{40}Ar/^{39}Ar$ age of 2.8 Ma (McLaughlin and others, 2005). This implies that the Glen Ellen Formation overlying the Wilson Grove Formation is younger than 2.8 Ma. Although we assume they are coeval with obsidian-bearing gravels northeast of the Trenton and Wilson Grove localities, non-marine fluvial and lacustrine sediments that overlie Wilson Grove equivalent strata in the Occidental Road and Sebastopol Road Pilot wells lack obsidian pebbles. The lack of obsidian detritus in Pliocene and Pleistocene strata south of Trenton may be related to structural partitioning of the subsurface of Santa Rosa plain into two separate basins by the Trenton thrust fault, but the lack of obsidian cannot be resolved here.

Other fluvial gravels that crop out east of the River Road at Trenton and Wilson Grove fossil localities along the east side of Santa Rosa plain near Santa Rosa, unconformably overlie Petaluma Formation strata containing a Monterey-like pebble lithofacies. The Monterey-like pebble lithofacies is similar to one seen in the lower part of the Sebastopol Road pilot well section. The gravels overlying the Petaluma Formation in this area include obsidian pebbles. However, the source of the obsidian pebbles, based on their geochemical signature (McLaughlin and others, 2005), is directly east of Santa Rosa at Annadel State Park. The obsidian source at Annadel State Park is dated by $^{40}Ar/^{39}Ar$ techniques at ~4.5 Ma (McLaughlin and others, 2005). The stratigraphic position of these gravels unconformably above the Monterey-like pebble lithofacies of the Petaluma Formation, indicates that the overlying gravel is ≤ 4.5 Ma but possibly could be much younger than the age of the obsidian clast source. The Annadel–sourced gravel appears to be underlain by andesitic volcanic rocks and the 4.8 Ma Lawlor Tuff that are intercalated with or overlie the Petaluma Formation in this area. Although exposures are complicated by faulting, this relation suggests that the Monterey-like pebble lithofacies of the Petaluma Formation could be ≥ 4.8 Ma in age.

The notable lack of any obsidian clasts in the Wilson Grove Formation on the west side of Santa Rosa plain and in the pilot well drill holes, could be interpreted to indicate that the Wilson Grove strata at River Road at Trenton, at Wilson Grove, and in the Occidental Road and Sebastopol Road pilot wells are: 1) entirely older than the 2.8 Ma and 4.5 Ma obsidian clast sources for the late Pliocene and Pleistocene gravels overlying the Petaluma and Wilson Grove Formations; 2) that neither of the obsidian clast sources were exposed to erosion until after deposition of the Wilson Grove Formation late in the Pliocene and early Pleistocene; or 3) that depositional systems carrying sediment sourced in the Napa-Franz Valley and Annadel areas never reached the southwestern Santa Rosa plain. Alternative 1) implies that the Wilson Grove Formation is entirely older than 4.5 Ma and a significant unconformity between ~4.5 and ~ 2.8 Ma. Alternative 2) permits relatively uninterrupted Wilson Grove Formation deposition well into the late Pliocene, with major uplift and unroofing of depositional sources in the Sonoma Volcanics after ~2.8 Ma. Alternative 3 explains the lack of obsidian clasts in the Wilson Grove Formation merely by a limit in the westward reaches of the fluvial systems carrying obsidian detritus from their source regions. It is noted, however, that Napa-Franz Valley obsidian pebbles are present in Pliocene and Pleistocene gravels that overlie marine Wilson Grove strata immediately east of Wilson Grove in the Windsor basin, which argues against alternative 3. None of these alternative interpretations uniquely explain the stratigraphic relations presented herein, although alternative 1) is favored as a better fit to the available data and field relations.

The lower part of the River Road section of the Wilson Grove Formation at Trenton includes the 6.3 Ma Roblar tuff of Sarna-Wojcicki (1992) (Sarna-Wojcicki, 1992; McLaughlin and others, 2005). The Roblar tuff of Sarna-Wojcicki (1992) is also present along the east side of the Santa Rosa plain, stratigraphically beneath local Monterey-like pebble lithofacies gravels. The fossiliferous sections described from River Road at Trenton and Wilson Grove are stratigraphically above the Roblar tuff (Allen, 2005; Powell, Allen, and Holland, 2004), consistent with the age based on fossils. The Roblar tuff of Sarna-Wojcicki (1992) is absent in the Occidental Road and Sebastopol Road pilot wells. The well stratigraphy suggests that the tuff is probably present below the drilled depths of the wells.

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Appendix 1: Macrofossil samples

Forty-one washed ditch samples from Sonoma County Water Agency-Occidental Road Pilot Well were found to contain mollusk shells or fragments. The well is located at 38.4229°N, 122.8088°W (NAD27), on the north side of Occidental Road about 1.7 km northwest of Llano, Sebastopol 7.5′ Quadrangle, Sonoma County, California.

Field No.: 320′-330′ (98-101 m).

Mollusca
- Bivalvia
  - Indeterminate fragments
- Gastropoda
  - *Nassarius* sp., cf. *N. grammatus* (Dall)
  - *Olivella pycna* Berry
  - Indeterminate fragments

Field No.: 330′-340′ (101-104 m).

Mollusca
- Bivalvia
  - Indeterminate fragments
- Gastropoda
  - Indeterminate fragments

Field No.: 340′-350′ (104-107 m).

Mollusca
- Bivalvia
  - Indeterminate fragments
- Gastropoda
  - *Nassarius* sp.
  - Indeterminate fragments

Field No.: 350′-360′ (107-110 m).

Mollusca
- Bivalvia
  - Indeterminate fragments
- Gastropoda
  - Naticidae?, indeterminate
  - Indeterminate fragments

Field No.: 360′-370′ (110-113 m).

Mollusca
- Bivalvia
  - Indeterminate fragments

Gastropoda
Indeterminate fragments

Field No.: 370′-380′ (113-116 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Nassarius sp.
Indeterminate fragments

Field No.: 380′-390′ (116-119 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 390′-400′ (119-122 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Olivella pycna Berry
Indeterminate fragments

Field No.: 400′-410′ (122-125 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Olivella pycna Berry
Indeterminate fragments

Field No.: 410′-420′ (125-128 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Nassarius? sp.
Olivella pycna Berry
Indeterminate fragments

Field No.: 420′-430′ (128-131 m).

Mollusca

Bivalvia
Indeterminate fragments
Gastropoda
Nassarius sp., cf. *N. grammatus* (Dall)
Olivella pycna Berry
Indeterminate fragments

Field No.: 430′-440′ (131-134 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Nassarius sp., cf. *N. grammatus* (Dall)
Olivella pycna Berry
Ophiodermella graciosana Arnold(?)
Indeterminate fragments

Field No.: 440′-450′ (134-137 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 450′-460′ (137-140 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Nassarius? sp.
Olivella sp.
Indeterminate fragments

Field No.: 460′-470′ (140-143 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Nassarius? sp.
Olivella sp.
Indeterminate fragments

Field No.: 470′-480′ (143-146 m).

Mollusca
Bivalvia

Indeterminate fragments
Gastropoda
Nassarius? sp.
Olivella sp.
Ophiodermella? sp.
Indeterminate fragments

Field No.: 480′-490′ (146-149 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 490′-500′ (149-152 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 500′-510′ (152-155 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Nassarius sp., cf. *N. grammatus* (Dall)
Indeterminate fragments

Field No.: 510′-520′ (155-158 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 520′-530′ (158-161 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 530′-540′ (161-165 m).

Mollusca

Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 540′-550′ (165-168 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 550′-560′ (168-171 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 560′-570′ (171-174 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 570′-580′ (174-177 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 580′-590′ (177-180 m).

Mollusca
Bivalvia
Arcoida, indeterminate (taxodont hinge fragment)
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 590′-600′ (180-183 m).

Mollusca
Bivalvia
Indeterminate fragments

Gastropoda

Indeterminate fragments

Field No.: 600′-610′ (183-186 m).

Mollusca

Bivalvia

Indeterminate fragments

Gastropoda

Indeterminate fragments

Field No.: 610′-620′ (186-189 m).

Mollusca

Bivalvia

Indeterminate fragments

Gastropoda

Indeterminate fragments

Field No.: 620′-630′ (189-192 m).

Mollusca

Bivalvia

Indeterminate fragments

Gastropoda

Indeterminate fragments

Field No.: 630′-640′ (192-195 m).

Mollusca

Bivalvia

Indeterminate fragments

Gastropoda

Indeterminate fragments

Field No.: 640′-650′ (195-198 m).

Mollusca

Indeterminate fragments

Field No.: 650′-660′ (198-201 m).

Mollusca

Bivalvia

Indeterminate fragments

Field No.: 660′-670′ (201-204 m).

Mollusca

Indeterminate fragments

Field No.: 670′-680′ (204-207 m).

Mollusca

Indeterminate fragments

Field No.: 680′-690′ (207-210 m).

Mollusca

Indeterminate fragments

Field No.: 800′-810′ (244-247 m).

Mollusca

Indeterminate fragments

Field No.: 810′-820′ (247-250 m).

Mollusca

Indeterminate fragments

Field No.: 820′-830′ (250-253 m).

Mollusca

Indeterminate fragments

Field No.: 830′-840′ (253-256 m).

Mollusca

Indeterminate fragments

Thirty-five washed ditch samples from Sonoma County Water Agency- Sebastopol Road pilot well were found to contain mollusk shells or fragments. The well is located at 38.4085°N, 122.7995°W (NAD27), along the Petaluma and Santa Rosa railroad line about midway between Llano and the Sebastopol Grange (just north of Gravenstein), Sebastopol 7.5′ Quadrangle, Sonoma County, California.

Field No.: 470′-480′ (143-146 m).

Mollusca

Indeterminate fragments

Field No.: 480′-490′ (146-149 m).

Mollusca

Bivalvia

Indeterminate fragments

Field No.: 490′-500′ (149-152 m).

Mollusca

Bivalvia

Indeterminate fragments

Field No.: 500′-510′ (152-155 m).

Mollusca
Bivalvia
Indeterminate fragments

Field No.: 510′-520′ (155-158 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Astyris? sp.
Indeterminate fragments

Field No.: 520′-530′ (158-162 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 530′-540′ (162-165 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 540′-550′ (165-168 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 550′-560′ (168-171 m).

Mollusca
Bivalvia
Indeterminate fragments
Gastropoda
Indeterminate fragments

Field No.: 560′-570′ (171-174 m).

Mollusca
  Bivalvia
    Indeterminate fragments
  Gastropoda
    Nassarius sp., cf. *N. grammatus* (Dall)
    Ophiodermella graciosana Arnold?
    Indeterminate fragments

Field No.: 570′-580′ (174-177 m).

Mollusca
  Bivalvia
    Indeterminate fragments
  Gastropoda
    Indeterminate fragments

Field No.: 580′-590′ (177-180 m).

Mollusca
  Bivalvia
    Indeterminate fragments
  Gastropoda
    Indeterminate fragments

Field No.: 590′-600′ (180-183 m).

Mollusca
  Bivalvia
    Indeterminate fragments
  Gastropoda
    Indeterminate fragments

Field No.: 620′-630′ (189-192 m).

Mollusca
  Bivalvia
    Indeterminate fragments

Field No.: 630′-640′ (192-195 m).

Mollusca
  Bivalvia
    Indeterminate fragments

Field No.: 690′-700′ (210-213 m).

Mollusca
  Bivalvia
    Indeterminate fragments

Field No.: 780′-790′ (238-241 m).

Mollusca
Bivalvia
Indeterminate fragments

Field No.: 800′-810′ (244-247 m).

Mollusca
Bivalvia
Indeterminate fragments
Vertebrata
Bone fragment(?)

Field No.: 810′-820′ (247-250 m).

Mollusca
Bivalvia
Indeterminate fragments

Field No.: 820′-830′ (250-253 m).

Mollusca
Bivalvia
Indeterminate fragments

Field No.: 830′-840′ (253-256 m) .

Mollusca
Bivalvia
Indeterminate fragments

Field No.: 840′-850′ (256-259 m)

Mollusca
Bivalvia
Indeterminate fragments

Field No.: 850′-860′ (259-262 m).

Mollusca
Indeterminate fragments

Field No.: 860′-870′ (262-265 m).

Mollusca
Indeterminate fragments

Field No.: 870′-880′ (265-268 m).

Mollusca
Indeterminate fragments

Field No.: 880′-890′ (268-271 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 890′-910′ (271-277 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 910′-920′ (277-280 m).

Mollusca
        Indeterminate fragments

Field No.: 940′-950′ (287-290 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 1000′-1010′ (305-308 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 1020′-1030′ (311-314 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 1030′-1040′ (314-317 m).

Mollusca
    Bivalvia
    Indeterminate fragments

Field No.: 1040′-1050′ (317-320 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 1050′-1060′ (320-323 m).

Mollusca
    Bivalvia
        Indeterminate fragments

Field No.: 1060′-1070′ (323-326 m).

Mollusca

Bivalvia

Indeterminate fragments

Appendix 2: Lithologic logs of ditch samples

Lithologic logs of washed ditch samples from Sonoma County Water Agency-Occidental Road Pilot Well located at 38.4229°N, 122.8088°W (NAD27), on the north side of Occidental Road about 1.7 km northwest of Llano, Sebastopol 7.5′ Quadrangle, Sonoma County, California.

Depth(ft)	Lithology	Notes
20-30 (6-9 m)	Mudstone; clayey grey.	May be tuffaceous.
30-40 (9-12 m)	Mudstone; clayey dark grey.	May be tuffaceous. May have ostracodes or diatoms.
40-50 (12-15 m)	Mudstone; clayey dark grey, with angular white fragments to 5 mm.	May be tuffaceous. May have ostracodes or diatoms.
50-60 (15-18 m)	Sandstone; silty-muddy, with white tephra-like fragments, much fine quartzo-feldspathic matrix, and Tertiary volcanics, abundant Franciscan/Mesozoic lithics.	Probably tuffaceous silt.
60-70 (18-21 m)	Sand; quartzo-feldspathic with hard, white, rhyolitic lithics and lithified sandstone fragments.	Minor white tuff(?) fragments.
70-80 (21-24 m)	Sand; quartzo-feldspathic, lithic, gritty.	Includes rounded to subrounded, black chert and argillite (chalcedonic) pebbles + mostly Mesozoic-derived lithics.
80-90 (24-27 m)	Grit; quartzo-feldspathic.	Clasts include white rounded vein quartz, dark chert, scattered ashy rhyolite, subrounded, hard meta-sandstone.
90-100 (27-30 m)	Same as 80-90'.	Includes a 1-cm diameter, subrounded, fine-grained, tuff pebble.
100-110 (30-34 m)	Sand; fine to medium grained, lithic quartzo-feldspathic.	Includes probable minor tephra component and fine to medium-grained, rounded, black chert clasts.
110-120 (34-37 m)	Sand; pebbly lithic, quartzo-feldspathic. Like 90-100', but no tuff.	Includes prominent 0.5-2.0 cm graywacke clasts.
120-150 (37-46 m)	Gravel; rounded pebble.	Clasts include red chert, andesite-rhyodacite, quartzite, black chert/argillite.
150-160 (46-49 m)	Sand; medium to fine grained.	Includes black rounded "globules" of obsidian glass; doubly terminated, clear, euhedral quartz, what appear to be fine rounded white water-transported tephra. Other detritus include serpentinite + other quartz, argillite, chert (Franciscan Complex and Great Valley sequence-derived) detritus and Tertiary volcanic (andesitic-rhyodacitic) detritus.
160-170 (49-52 m)	Sand; orange-brown stained, silt and silty.	Includes some minor gray pumice grains, clear euhedral to rounded quartz and feldspar, also cloudy clastic-derived rounded quartz + argillite + serpentinite grains, and some minor very fine grained black glass globules.
170-180 (52-55 m)	Sand; locally gritty, orange-brown stained, silty to fine grained.	Includes clear euhedral quartz and feldspar, some very fine black glassy globules + very fine white clumps of possible tephra, and other Tertiary volcanics, Franciscan Complex /Great Valley sequence detritus, as above.
180-190 (55-58 m)	Same as 170-180, orange-brown stained.	Includes some rounded fine sand (0.3-0.5 mm), white, euhedral tephra grains. Clear feldspar and some clear double-terminated quartz, glass globules if present not obvious. Some red/black grains of possible welded(?)

		tuff.
190-200 (58-61 m)	Sand; gray, quartz-rich, angular silty.	Some clear feldspar + quartz; possibly some minor black glass (obsidian?). Significant Franciscan Complex/Great Valley sequence component. No obvious tephra.
200-210 (61-64 m)	Sand; gray silty sand, same 190-200’.	No obvious tephra; includes clear + some minute rounded brown glass(?) "globules."
210-220 (64-67 m)	Silt; gray.	Appears to have very fine tuffaceous(?) matrix and minor very fine glassy globules + abundant clear to milky, subhedral to subrounded feldspar and quartz, mixed with Mesozoic-derived clastics including schist, and serpentinite.
220-230 (67-70 m)	Silty sand.	Mostly quartz-feldspar, angular to subangular grains, with mafic rock fragments (gabbro-diabase).
230-240 (70-73 m)	Sand; gritty, medium to coarse grained; like 220-230'.	Mostly quartz + feldspar, angular to subangular, with rounded, grit to small pebble-sized clasts of bull quartz, veined hard argillite, minor gabro-diabase, granitic quartz-feldspar, and fine-grained rhyolite-dacite (Tertiary volcanic?) and possible chromite/picotite.
240-250 (73-76 m)	Same as 230-240'.	
250-260 (76-79 m)	Pebbly grit ($\leq$ 0.75cm).	Rounded, with clasts largely of bull quartz, veined dark grey black argillite, red chalcedonic, felsite volcanic, and red Franciscan-type radiolarian chert.
260-270 m (79-82 m)	Same as 250-260'.	Rounded clasts up to 1 cm dominate; prominent red chert pebble.
270-280 (82-85 m)	Same as 260-270'.	
280-290 (85-88 m)	Pebbly to gritty gravel ($\leq$ 0.5 cm).	Well rounded, polished clasts, largely of hard, quartz veined argillite, bull quartz; mostly of Franciscan melange derivation.
290-300 (88-91 m)	Pebble gravel ($\leq$ 1 cm).	Well rounded as in 280-290', largely Mesozoic-derived clasts, spilite/metabasilt, but also including greywacke, porphy, diabase, quartz, quartzite, quartz-veined argillite, and red radiolarian chert.
300-310 (91-94 m)	Pebble gravel ($\leq$ 1 cm); same as 290-300'.	Same well rounded Mesozoic-derived clasts and some aggregate clasts of coarse rounded sand/grit cemented by possible altered fine-grained tuff.
310-320 (94-98 m)	Pebble gravel ($\leq$ 1 cm); same as 300-310'.	Rounded clasts include hard silica cemented chert, felsite-clast-gritty sandstone, red radiolarian chert, and composite lumps of quartzose sand with altered tuff matrix (observed one definite pumice shard in matrix/interclast area of one sandstone lump).
320-330 (98-101 m)	Shell fragments ($\geq$ 80%$\pm$) with sporadic pebbles ($\leq$ 0.5 cm).	Includes sporadic pebbles of bull quartz + a few lumps of lithic quartz-rich sand.
330-340 (101-104 m)	Shell fragments $\geq$ 85% $\pm$.	One or two broken pebble fragments.
340-350 (104-107 m)	Mixed thin-shell hash (~70% $\pm$) with sand + grit.	Secondary pyritic coatings locally on shell material.
350-360 (107-110 m)	Shell hash (~60%), + sand grit.	In sand/grit matrix.
360-370 (110-113 m)	Shell hash, in silty sandy grit; ~90%.	Silty, sandy matrix.
370-380 (113-116 m)	Shell hash in gritty, rounded sandstone-clast matrix; ~75%	Gritty, rounded, sandstone matrix.
380-390 (116-	Silty-sand with bivalve/gastropod hash.	Foraminifer picked (slide slot #19).

119 m)		
390-400 (119-122 m)	Pebbly (≤ 1.3 cm) silt with admixed shell hash.	Matrix is silty with pebbles.
400-410 (122-125 m)	Same as 390-400'	One possible green glauconite pellet(?) observed.
410-420 (125-128 m)	Same as 400-410'	Includes some lumps of what look like altered grey ash.
420-430 (128-131 m)	Silty-sand; fine-grained with ~75% fossil shell material.	Silty fine-grained-sand matrix.
430-440 (131-134 m)	Sand; pebbly (≤ 0.66 cm), fine-grained, with shell fragments and minor fragments of carbonate-cemented, quartzo-feldspathic clasts.	
440-450 (134-137 m)	Shell fragments (~50%), in silty matrix (~30%) and pebbles (~20%).	Few round cherty veined argillite pebbles (≤ 1 cm) make up ~20%.
450-460 (137-140 m)	Shell hash with silt matrix; ~same as 440-450', cements.	
460-470 (140-143 m)	~similar to 450-460'	
470-480 (143-146 m)	~similar to 460-470'; matrix slighly coarser (i.e., silty fine sand).	
480-490 (146-149 m)	Sand; bioclastic, fine to coarse, with rounded polished grit-sized clasts.	Milky quartz prominent grit clast component.
490-500 (149-152 m)	Sand; bioclastic (~50%), same as 480-490', with rounded polished grit to small pebble sized clasts (≤ 0.5 cm).	Pebble and grit clasts include quartz and bull quartz.
500-510 (152-155 m)	Sand; bioclastic (~40%), pebbly to gritty. Similar to 490-500'.	A few rounded green pellet-like (glauconite?) grains.
510-520 (155-158 m)	Sand; bioclastic, pebbly to gritty; same as 500-510'.	
520-530 (158-162 m)	Silty fine sand; quartzo-feldspathic with ~ 20% shell fragments.	
530-540 (162-165 m)	Silt to fine sand; ~ same as 520-530'.	Silt to fine sand with a few scattered polished rounded grit to ≤ 0.5 cm pebbles, including red chert.
540-550 (165-168 m)	Silty sand; fine to medium grained, bioclastic,; ~same as 520-530'.	
550-560 (168-171 m)	~same as 540-550'.	
560-570 (171-174 m)	~same as 550-560'.	
570-580 (174-177 m)	~same as 560-570'.	A few clear, euhedral, feldspar grains + altered yellowish brown composite tuff grains; any glass gone to clay.
580-590 (177-180 m)	Silty sand; bioclastic; ~same as 560-570'.	
590-600 (180-183 m)	Silty sand; cemented bioclastic.	
600-610 (183-186 m)	Silty bioclastic bed.	Agglutinated foraminifers?
610-620 (186-189 m)	Bioclastic bed with minor silt matrix and a few, ≤ 0.3 cm, hard, rounded, milky-bull quartz, and cherty argillite clasts.	
620-630 (189-192 m)	Silt; bioclastic with angular quartzo-feldspathic matrix.	Matrix silt locally with clumps of CO_3 cemented sandstone and shell.
630-640 (192-195 m)	Silt; with ~ 20% shell fragments.	Silty sediment, angular, quartzo-feldspathic, with sand-sized rounded polished, hard black grains, and milky

		bull quartz.
640-650 (195-198 m)	Silt; with minor (~15%) shell fragments.	Silt, possibly has ash component?
650-660 (198-201 m)	Silt; with slight oxidation to orange-grey.	Possible ashy component to silt(?) with a few black ($\leq$ 0.5%) scoria-like grains.
660-670 (201-204 m)	Pebbly silt; like 650-660'.	Possible ashy, pebbly, silt, not as oxidized as above. Includes rounded quartz $\pm$ cherty veined argillite pebbles $\leq$ 1 cm diameter.
670-680 (204-207 m)	Grit; well sorted (clast supported?) rounded/polished.	Includes clasts of spilitic metabasalt, hard recrystallized quartose-meta-sandstone, bull quartz, and cherty veined argillite.
680-690 (207-210 m)	"Pea gravel;" well sorted with pebbles $\leq$ ~0.6 cm; clast supported.	Clasts rounded and polished, including red metachert, black cherty argillite; same suite as 670-680'.
690-700 (210-213 nm	~same as 680-690'.	
700-710 (213-216 m)	~same as 690-700'.	Clasts include metaquartzite and vein quartz.
710-720 (216-219 m)	Pebbly-gravel; ~same as 700-710'; includes fine silty sand matrix.	
720-730 (219-223 m)	Pea gravel; pebbly to gritty, rounded, and polished clasts ~0.25 to 0.75 cm; ~ same suite as 680-690'.	
730-740 (223-226 m)	Pea gravel; coarse, rounded, 0.6-1.0 cm, with minor fine silt as interclast matrix; otherwise same as 720-730'.	Silt locally with pyrite clusters; pebble grit clasts locally with common CO_3 (calcite?) cement.
740-750 (226-229 m)	Pea gravel; ~ $\leq$ 1 cm rounded clasts.	No silt observed, possibly washed out(?).
750-760 (229-232 m)	Pea gravel; coarse, rounded, ~ 0.3 - 1.2 cm clasts; otherwise ~ same as 740-750'.	
760-770 (232-235 m)	Silty gravel; clasts ~ 0.3 to 1.0 cm, in silty matrix (matrix supported?).	Pebble clasts include chert + quartzite and ~ same clast suite as 750-760'.
770-780 (235-238 m)	~ same as at 760-770.	
780-790 (238-241 m)	Pea gravel; silty. ~ same as 770-780.	
790-800 (241-244 m)	~ same as 780-790'.	
800-810 (244-247 m)	Sand; silt to fine grained with minor sporadic rounded pebbles (0.3-1.0 cm). Possibly drifted down-hole(?).	
810-820 (247-250 m)	Sand; bioclastic, silt to fine sand, with sporadic broken pebbles.	Includes questionable tuff component in fine grained silt.
820-830 (250-253 m)	Sand; silty, fine sand, with abundant to common bioclastics; ~same as 810-820', but no pebbles and fewer shell fragments.	
830-840TD (253-256 m)	Silt; fine sandy silt; ~same as 820-830', but with slightly greater silt content and fewer shell fragments.	

Lithologic logs of washed ditch samples from Sonoma County Water Agency- Sebastopol Road pilot well located at 38.4085°N, 122.7995°W (NAD27), along the Petaluma and Santa Rosa railroad line about midway between Llano and the Sebastopol Grange (just north of Gravenstein), Sebastopol 7.5' Quadrangle, Sonoma County, California.

Depth (ft)	Lithology	Notes
20-30 (6-9 m)	Clay; with rare subrounded 0.5 cm pebbles, compact, gray.	Non-calcareous; possibly derived from ash/bentonite; appears to include areas of white chunks of fine grained, undevitrified, tephra, some with feldspar microphenocrysts. Includes rare subrounded 0.5 cm pebbles of meta-sandstone and altered mafic rock (silica carbonate?).
30-40 (9-12 m)	Pebble-gravel; rounded, 0.5-2.0 cm.	Multi-lithologic, with abundant clasts of rounded, banded to non-banded, porphyritic, white rhyolite-dacite, rare red (baked?) siliceous volcanic clasts (derived from Miocene andPliocene volcanics rocks), lithic metasandstone (Franciscan Complex/Great Valley sequence), + minor chunks of clayey matrix like at 20-30'.
40-50 (12-15 m)	Pebble gravel; rounded to subrounded, like at 30-40', but coarser (< 2.5 cm), and with more clayey matrix.	Large subrounded clasts up to 2.5 cm of hard porphyritic, gray to white rhyolite/rhyodacite (probably from Tertiary volcanic section). Also includes hard welded rhyodacite, (also from Tertiary volcanic section - affinity to Zammaroni-Warrington Road section?); hard, rounded, medium grained, lithic arkosic wacke; fine grained cherty, dark grey, argillite; one tan rounded clast of possible porcellanite (no foraminifers), or fine-grained banded rhyolite; includes chunks of possibly tuffaceous matrix clay. Like 20-30' (down hole sluff or in place(?).
50-60 (15-18 m)	Clay; brownish gray, compact; similar to clay at 20-30' but more brown.	May be derived from devitrified ash??
60-70 (18-21 m)	Grit; rounded to subrounded.	Composed of mixed Mesozoic- igneous rocks, argillite, and rounded white rhyolite/dacite.
70-80 (21-34 m)	Grit; rounded ~same as 60-70'.	Includes rounded white rhyodacite clasts.
80-90 (24-27 m)	Grit; rounded to subangular, otherwise ~same as 70-80'.	Includes much subrounded white rhyodacite clasts + flaggy rhyolitc (or diatomitic?) shale.
90-100 (27-30 m)	Pebbly clay; brownish grey.	Pebbles (~1.0 cm) of banded chalcedony, veined rhyodacite, green spilite and milky quartz grit; clay may be very fine grained (devitrified?) ash.
100-110 (30-34 m)	Pebbly clay; ~same as 90-100'.	Pebbles < 1.3cm; clay may be fine grained devitrified ash. Pebbles of rounded, white rhyodacite, hard lithic meta-sandstone, vein quartz, meta-graywacke, and argillite.
110-120 (34-37 m)	Pebbly clay; ~same as 100-110'.	Subrounded to subangular pebbles up to ~1.2 cm include greenstone, meta-gabbro, quartzite, and argillite; clay somewhat sandy to gritty, may be ashy, like above(?). Fine, euhedral, clear feldspar and clear, angular, quartz in matrix clay.
120-130 (37-40 m)	Pebbly clay; ~same as 110-120', but with only 1 large pebble ~2.0 cm.	Pebble subangular, hard, grey, recrystalized felsite porphyry (probably old, reworked); possibly sluff down-hole. Clay with locally prominent(?) white, ash "chunk." Clay matrix with fine, angular to subrounded, aggregates to single grains of clear, fresh quartz or feldspar? Clay is probably devitrified fine grained ash, though can't see shards?
130-140 (40-43 m)	Pebbly clay; ~same as at 120-130 .	Clay appears ashy as above, with clear euhedral -subhedral quartz-feldspar grains.

140-150 (43-46 m)	Clay; muddy, grey; same unit as 130-140', but no pebbles and very fine silt component.	Some clay pieces look graded from mud to clay; chunks of questionable fine-white ash present.
150-160 (46-49 m)	Mud; clayey to silty, ~same as at 140-150'; higher component of silt and fine sand than above.	Approximate base of clay unit; includes definite higher component of silt to fine sand than above; observed one 0.5 cm round pebble of milky bull quartz in clayey (ashy?) mud.
160-170 (49-52 m)	Sand; fine-grained, well-sorted, dominantly round-subrounded quartz-rich sand (dune?).	Sand dominantly well sorted, rounded to subrounded; quartz rich; with bull quartz, black argillite, chert lithics.
170-180 (52-55 m)	~same as 160-170'.	
180-190 (55-58 m)	~same as 170-180'.	
190-200 (58-61 m)	~same as 180-190.	Base of well sorted unit.
200-210 (61-64 m)	Silt; ~same composition as 190-200', but less sorted and with mud component.	Distinctly different hydrodynamic unit from above unit.
210-220 (64-67 m)	Silt; ~same as 200-210'.	Matrix with clayey component, possibly tuffaceous, but if so ash is completely altered to clay.
220-230 (67-70 m)	Sand; medium to fine grained, moderately sorted, rounded to subrounded, quartz-rich, multimodal.	Multimodal sand, with lithics from Franciscan Complex/Great Valley sequence/ophiolite sources (black chert/argillite,serpentinite, greenstone, mafic igneous, bull quartz, etc.). Euhedral quartz + feldspar relatively clear, probably from Tertiary volcanics.
230-240 (70-73 m)	~same as at 220-230'.	
240-250 (73-76 m)	Sand; Poorly sorted, silty to medium-grained; same unit as at 230-240', but poorer sorting.	Picotite (or ilmenite?) grains noted in fine-grained population.
250-260 (76-79 m)	Sandy-silt; greenish orange, probable top of new sedimentation unit; unsorted, with weathered, altered clayey matrix component.	Coloration change due to groundwater/fluids?
260-270 (79-82 m)	Silt; quartz-rich; subangular-subround, moderately sorted; ~same as at 250-260'.	
270-280 (82-85 m)	~same as at 260-270'.	
280-290 (85-88 m)	Sand; silty, fine grained, moderately sorted, subangular-subround; ~same as 280-290'.	
290-320 (88-98 m)	~ 280-290'.	
320-330 (98-101 m)	Sand; silty fine grained; ~same as 290-320'.	
330-340 (101-104 m)	Sand; fine grained, moderately well sorted, subangular-subrounded, quartz-rich, lithic; ~ 320-330'.	(dune or beach?).
340-350 (104-107 m)	Sand; fine to medium grain, well sorted; same as 330-340'.	Sporadic subhedral grains of clear feldspar.
350-360 (107-110 m)	Sand; fine-medium grain, well sorted; ~same as 340-350'.	No fines (dune sand?).
360-370 (110-113 m)	Sand; medium grain, lithic, quartzo-feldspathic, poorly sorted, subangular.	New sedimentation unit?
370-380 (113-1`16 m)	Sand; poorly sorted, lithic, subangular, medium grained.	

380-390 (116-119 m)	Sand with grit; lithic, bimodal, with medium grained, subrounded to subangular, quartzofeldspathic sand matrix with rounded grit, 0.25-0.3 cm.	Grit clasts include bull quartz and dark veined argillite
390-400 (119-122 m)	Sand with grit; ~same as 380-390', with small pebbles, < 0.5 cm.	
400-410 (122-125 m)	Sand with pebbles and grit; fine to coarse grained, poorly sorted, angular to subrounded, sand, with sporadic, rounded, pebbles and grit.	Pebbles and grit Franciscan-derived, with cherty-veined argillite, bull quartz.
410-420 (125-128 m)	Sand with pebbles and grit; ~same as at 400-410.	
420-430 (128-131 m)	Sand with grit to pebbles; medium grained, moderately sorted, rounded to angular; ~same as 410-420', but slightly coarser.	
430-440 (131-134 m)	Sand with grit and pebbles; rounded to subangular, coarse to medium, sand, with subrounded grit to fine pebble (< .5 cm) clasts; ~same as 420-430'.	
440-450 (134-137 m)	Pea-gravel; rounded, sandy, clasts < 0.6 cm); ~same as at 430-440', but significantly more pebbles (~50%).	Beach?
450-460 (137-140 m)	Pea-gravel; ~same as 440-450', but pebbles < 0.3 cm.	Probable beach.
460-470 (140-143 m)	Sandy gravel; ~ same as 440-450'.	
470-480 (143-146 m)	Pea gravel; rounded to subrounded, ~0.5 to 1 cm, with minor fine sand matrix and minor abraded angular shell fragments.	Clasts include veined argillite, bull quartz, red chert, other Franciscan-derived clasts.
480-490 (146-149 m)	Shell fragments; ~80% with ~ 20% pea to grit-sized rounded clasts of same clast suite as seen in 470-480'.	Top of new bioclastic unit
490-500 (149-152 m)	Pea gravel; Bioclastic, ~50% bivalves and pebbles, < 1 cm; ~50% rounded ~0.3-1.0 cm.	
500-510 (152-155 m)	Gravel; sandy, bioclastic, ~50% angular shell fragments, ~30% fine-medium sand; ~20% rounded pebbles; as in 490-500'.	
510-520 (155-158 m)	Gravel; ~same as 500-510'; somewhat less sand.	
520-530 (158-162 m)	Sand; bioclastic, fine grained, subrounded to subangular, shell fragments up to ~0.5 cm, with < 1% rounded grit to ~0.3 cm.	Rounded grit to 0.3 cm largely includes black argillite/vein quartz, (Franciscan Complex/Great Valley sequence-derived); note pyritic /sulfide coatings on many shell fragments.
530-540 (162-165 m)	Sand; bioclastic, same as 520-530', but somewhat more sand matrix.	Some black spherule-shaped < 1 mm-size grains?
540-550 (165-168 m)	Sand; bioclastic; ~ same as 530-540'.	Includeds well rounded, 1 cm, chert (green-gray), also 1 grain of rare black (~.25-.3mm) glass (obsidian?).
550-560 (158-161 m)	Sand; bioclastic, fine grained, same as at 540-550', but sand is coarser and includes clasts to ~1 cm of subrounded, fine grained, banded chert (with probable diatoms/foraminifers), resembles Monterey Formation chert.	Sand matrix is fine grained (silty), coarser than above, moderately well sorted, quartz-rich, subangular to subrounded.
560-570 (171-	Sand; abundant granule-sized rounded	

174 m)	and polished clasts; sandy matrix < 50%; included are uncommon but distinct banded porcellaneous chert (Monterey Formation-like) clasts. Base of bioclastic zone?	
570-580 (174-177 m)	"Pea gravel"; granule-sized, polished, well rounded, well sorted, with matrix largely lacking (winnowed).	Polished, rounded granule clasts include quartzite, bull quartz, black argillite/chert.
580-590 (177-180 m)	"Pea gravel"; some fine sand matrix (< 10%); largely clast supported. Base of same unit as 570-580'.	
590-600 (180-183 m)	Granule to grit gravel; without matrix (winnowed); granules rounded, well sorted finer grained (3-5mm).	Grains largely dark chert/argillite, bull quartz, quartzite, derived from Mesozoic source? Good aquifer?
600-610 (183-186 m)	Granule to grit gravel; but average clast size somewhat coarser (~4-6 mm), winnowed, matrix lacking, well rounded and polished. ~ same unit as at 590-600',.	Same Mesozoic source for clasts as above; probably good aquifer?
610-620 (186-189 m)	Granule to grit gravel; ~ same unit as 600-610'.	Well rounded and polished granule gravel. Aquifer?
620-630 (189-192 m)	Granule to grit gravel; same as 610-620'. Base of unit?	Granule size range ~3-6 mm; one angular clast of banded travertine; either shell fragment or vein material? Aquifer base?
630-640 (192-195 m)	Granule to grit; less well sorted than above, no fines (winnowed), well rounded and polished grains. Separate unit?	A few composite grains of cemented coarse sand grit. Matrix of these composite grains is fine grained and white, possibly ash? Unit is otherwise like 620-630'
640-650 (195-198 m)	Pea gravel; with clasts ~4-10mm; lithologies ~same as above. Top of unit.	Includes 1 clast (rounded) of fine-grained soft, grey probable ash (picked, in vial)
650-670 (198-207 m)	Pea gravel; same unit as at 640-650'.	
670-680 (204-207 m)	Pea gravel; same unit as 650-670', with < 2% fine sand matrix (largely clast supported), and same subrounded quartz-veined, red radiolarian chert.	
680-690 (207-210 m)	Pea gravel; same unit as 670-680'.	
690-700 (210-213 m)	Sand/silt with granule to pebble-size clasts, same lithology as 680-690'; with ~20-30% unsorted fine grained sand/silt matrix. Rounded, polished ~3-12 mm granules to pebbles. New unit?	Clasts derived from Franciscan Complex/Great Valley sequence/Mesozoic sources.
700-710 (213-216 m)	Silt/sand with granule to pebble size clasts; same as 690-700'	
710-720 (216-219 m)	Pebbly gravel; polished clasts to ~3-11 mm, with less silty sand than in 700-710'. Base of unit?	
720-730 (219-223 m)	Gravel; silty (matrix supported), rounded; includes subangular to subrounded, hard, banded fine-grained welded tuff and (or) porcellaneous (diatomaceous?) mudstones (Monterey Formation?) + some fine grained tephra-like aggregates with fresh, clear feldspars and quartz.	Fine grained tephra like aggregates with clear fresh euhedral feldspar and quartz.
730-740 (223-226 m)	Pebble gravel; rounded, polished, silty pebble from 0.8-1.0 cm, with matrix of	Pebbles of black chert, argillite, and bull quartz.

	angular to subangular, fine silt and sand, and clear equant, euhedral feldspar and quartz grains. ~Same unit as at 720-730'.	
740-750 (226-229 m)	Pebble gravel; same as 730-740'.	includes angular fine, euhedral, clear quartz, feldspar sand with possible fine tephra ? Component
750-760 (229-232 m)	Silty gravel; same as at 740-750', but probably more silty (~20% silt matrix of subrounded to angular, quartzo-feldspathic, fine sand).	Pebble and granule clasts include rounded bull quartz, hard aphanitic rhyolite, porcellanite (Monterey Formation or freshwater diatomite?).
760-770 (232-235 m)	Silty granule-pebble gravel; more silty than at 750-760'; definite bimodality. Pebbles/granules ~0.5-1.0 cm; well rounded, polished. Base of unit.	Pebbles and granules include prominent black argillite, chert.
770-780 (235-238 m)	Pebbly silt; clast suite same as above unit.	Clast suite includes milky vein quartz, banded porcellanite/chert (Monterey Formation-like); silt matrix with much fine, clear, quartz and feldspar, commonly subhedral to euhedral and equant.
780-790 (238-241 m)	Pebbly silt and silty mudstone; same as at 770-780', but more silt and mud and clasts to 1cm as above.	Clasts include some angular fragments (disrupted thin fissile layer?) of thin-bedded fissile diatomite.
790-800 (241-244 m)	Pebbly silt; same as at 780-790'. Base of unit.	Silt includes clear, equant subangular euhedral feldspar. Pebbles include prominent banded porcellanite/chert (Monterey Formation-like).
800-810 (244-247 m)	Granule sand; poorly sorted to unsorted bioclastic, with fine silty to muddy matrix.	Granules include Monterey Formation-like buff banded porcellanite, Franciscan-derived fine-grained schist, bull quartz, serpentinite.
810-820 (247-250 m)	Granule sand; poorly sorted, silty, same as 800-810'.	Same clast suite as above
820-830 (250-253 m)	Gritty silt and fine sand, with ~1-2% shell fragments; grit sized sand clasts are rounded to subrounded, and polished. Silt and fine sand is angular to subrounded, with common clear quartz and feldspar.	Unit probably is nearshore marine.
830-840 (253-256 m)	Gritty silt and fine sand, with < 1% shell fragments; granule/grit sized clasts. Same as 820-830'	Granule/grit sized sediment clasts largely Mesozoic derived + gray andesite/dacite porphyry (Tertiary), that are generally rounded but not highly polished.
840-850 (256-259 m)	Gritty silt and fine sand, with < 1% shell fragments; fine silt matrix with questionable ash component. Same as 830-840'.	
850-860 (259-262 m)	Gritty silt and fine sand, with < 1% shell fragments. Same as at 840-850'.	Rounded andesitic/dacitic granule clasts common.
860-870 (262-265 m)	Gritty silt and fine sand, with < 1% shell fragments; with some chips of muddy siltstone up to ~ 1 cm. Granules, largely of rounded hard dark argillite; black chert, are up to ~ 4 mm diameter. Same as 850-860'.	Unit probably marine shelf or estuarine, based on shell fragments and texture.
870-880 (265-268 m)	Gritty silt and fine sand, with < 1% shell fragments; with an ~ 1 cm diameter subrounded clast of banded dolomitic sandstone. Same as at 860-870'.	
880-890 (268-271 m)	Gritty silt and fine sand; but with 5-10% bioclastic angular, abraded and concentrated shell fragments; top of new	Well rounded bull quartz, black chert/argillite clasts < 5 mm; and fine-medium-grained angular to subangular quartz-feldspar sand matrix; estuarine or shelf?

	unit. Same as at 870-880'.	
890-900 (271-274 m)	Gritty silt and fine sand; base of concentrated bioclastics. Same as at 880-890'.	
900-910 (274-277 m)	Granule-grit-rich silty fine sand; unsorted, with rare (< 0.5%) abraded shell material.	Local clots of fine silt and sand with questionable ashy? cement.
910-920 (277-280 m)	Granule-grit-rich silty fine sand; with clots/aggregates of fine silty sand; base of unit. Same as at 900-910'.	Aggregates of fine silty sand with white ashy cementing or intergranular material?
920-930 (280-283 m)	Sand; fine grained, moderately sorted quartzo-feldspathic subangular to subrounded.	Probably marine?
930-940 (283-287 m)	Sand; but with rare, grit-sized, rounded black chert/argillite. Same as at 920-930'.	
940-950 (287-290 m)	Sand; with rare, rounded to subrounded, white pordcellanite grains (Monterey Formation-like). Same as at 930-940'.	
950-960 (290-293 m)	Sand; same as 940-950'.	
960-970 (293-296 m)	Sand; with sporadic (< 2%) granule and grit-sized subrounded to round grains. Also includes sporadic "chunks" (< 0.7 cm) of mud with probable tephra component. Same as 950-960'.	
970-980 (296-299 m)	Sand; same as at 960-970'.	
980-990 (299-302 m)	Sand; but includes 1.5 cm long hard Franciscan-like meta-graywacke clast fragment; common fine "clumps" of ashy(?) cemented fine sand/silt. Includes rare angular fragments of light brown porcellanite with probable planktic foraminifers. Same as at 970-980'.	
990-1000 (302-305 m)	Sand; except includes large pebble fragments (> 1.2-2.0 cm) of rounded, dark gray, dacite porphyry, and the same clumps of ashy, grey, cemented sand/silt; also includes thin fragments of silicified wood with cellular texture (i.e., palm-like?) or possibly same as foraminiferal porcellanite fragments as at 980-990'(?). Same as 980-990'.	
1000-1010 (305-308 m)	Sand; with large pebble fragments, large angular fragments of very fine-grained ashy silty sand, and fragments of silicified petrified wood 2-3 cm in length. Same as at 990-1000'.	Angular pebble fragments include porpyritic, white to grey, rhyolite (Tertiary source?), and angular fragments of very fine-grained, ashy(?), silty sand
1010-1020 (308-311 m)	Sand; with prominent angular chunks of vitric, dacite porphyry (probably Tertiary), and a rounded piece of a bull quartz pebble (~8 mm); sililcified wood fragments largely absent. ~same unit as 1000-1010'.	
1020-1030 (311-314 m)	Granule-silt; unsorted, with subangular to angular quartzo-feldspathic-rich matrix.	Quartz-feldspar includes much relatively "fresh"-looking grains (i.e., first-cycle, probably from siliceous volcanic

		source); granule-size (< 5 mm) clasts of round to subrounded bull quartz, dark chert and argillite derived from Franciscan Complex/Great Valley sequence/ophiolite sources; and fragments of white rhyodacitic rock in silt to fine sand range.
1030-1040 (314-317 m)	Pebbly granule-silt; with rounded - subrounded pebble/granule clasts up to ~0.7 cm. Approximate base of unit. Same as 1020-1030'.	
1040-1050 (317-320 m)	Pebbly to granule-bearing mud; similar to above unit, but dominantly mud matrix.	Mud may be ashy or bentonitic(?). Includes rounded pebble of quartzite and some white aggregates/clumps of coarser, probable siliceous ash/tuff.
1050-1060 (320-323 m)	Mud; with rounded granules of same lithologies as above.	
1060-1070 TD (323-326 m)	Bentonitic?/ashy? mud; same as above.	Estuarine?