Geologic and Geophysical Framework of the Santa Rosa 7.5' Quadrangle, Sonoma County, California

By R.J. McLaughlin, V.E. Langenheim, A.M. Sarna-Wojcicki, R.J. Fleck, D.K. McPhee, C.W. Roberts, C.A. McCabe, and Elmira Wan

Open-File Report 2008-1009

U.S. Department of the Interior
U.S. Geological Survey

Front cover photograph: View northward from Taylor Mountain toward Mount St. Helena and across the urbanized part of Santa Rosa 7.5' quadrangle. Low lying area to the north is of the Santa Rosa pull-apart basin, that includes parts of Rincon Valley, northwestern Sonoma Valley and Bennett Valley. A steep fault-related escarpment is evident along the northeast side of Rincon Valley and the Santa Rosa pull-apart structure. The grass and oak-covered foothills in the foreground are traversed from left to right (NW to SE), by active traces of the Rodgers Creek Fault Zone.

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U.S. Geological Survey, Reston, Virginia 2008
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Suggested citation:
McLaughlin, R.J., Langenheim, V.E., Sarna-Wojcicki, A.M., Fleck, R.J., McPhee, D.K., Roberts, C.W., McCabe, C.A., and Wan, Elmira, 2008, Geologic and Geophysical Framework of the Santa Rosa 7.5' Quadrangle, Sonoma County, California: U.S. Geological Survey Open-File Report 2008-1009, 51 p., 3 map sheets.

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By R.J. McLaughlin[1], V.E. Langenheim[1], A.M. Sarna-Wojcicki[1], R.J. Fleck[1], D.K. McPhee[1], C.W. Roberts[1], C.A. McCabe[1], and Elmira Wan[1]

INTRODUCTION

The geologic and geophysical maps of Santa Rosa 7.5' quadrangle and accompanying structure sections portray the sedimentary and volcanic stratigraphy and crustal structure of the Santa Rosa 7.5’ quadrangle and provide a context for interpreting the evolution of volcanism and active faulting in this region. The quadrangle is located in the California Coast Ranges north of San Francisco Bay and adjoins the south side of the Mark West Springs 7.5’ quadrangle, which is bisected by the Maacama Fault Zone (fig. 1, on sheet 1). The Santa Rosa map, together with that of the Mark West Springs 7.5’ quadrangle (McLaughlin and others, 2004) extends detailed geologic coverage by the U.S. Geological Survey (USGS) southwestward from the Maacama Fault to include the Southern Rodgers Creek and Healdsburg segments of the Rodgers Creek Fault Zone and the Bennett Valley Fault Zone. These are the principal active faults in northern California east of the San Andreas Fault, west of the Bartlett Springs Fault, and south of Cape Mendocino. Recent mapping to the southeast of the Santa Rosa quadrangle by the California Geological Survey, extends 7.5’ scale geologic coverage of the Rodgers Creek Fault Zone to the northern edge of San Pablo Bay.

Chapter A of this report, the geologic framework of the Santa Rosa 7.5' quadrangle, and Chapter B, the geophysical map database, are substantial improvements over previous geologic and geophysical maps of the Santa Rosa area, allowing us to address important geologic issues. First, the geologic mapping is integrated with gravity and magnetic data, allowing us to depict the thicknesses of Cenozoic deposits, the depth and configuration of the Mesozoic basement surface, and the geometry of fault structures beneath this region to depths of several kilometers. This information has important implications for constraining the geometries of major active faults and for understanding and predicting the distribution and intensity of damage from ground shaking during earthquakes.

Secondly, the geologic map and the accompanying description of the area describe in detail the distribution, geometry and complexity of faulting associated with the Rodgers Creek, Healdsburg and Bennett Valley Fault Zones and associated faults in the Santa Rosa quadrangle. The timing of fault movements is constrained by new $^{40}Ar/^{39}Ar$ ages and tephrochronologic

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correlations. These new data provide a better understanding of the stratigraphy of the extensive sedimentary and volcanic cover in the area and, in particular, clarify the formational affinities of Pliocene and Pleistocene nonmarine sedimentary units in the map area.

Thirdly, the geophysics, particularly gravity data, indicate the locations of thick sections of sedimentary and volcanic fill within ground water basins of the Santa Rosa plain and Rincon, Bennett, and northwestern Sonoma Valleys, providing geohydrologists a more realistic framework for groundwater flow models.

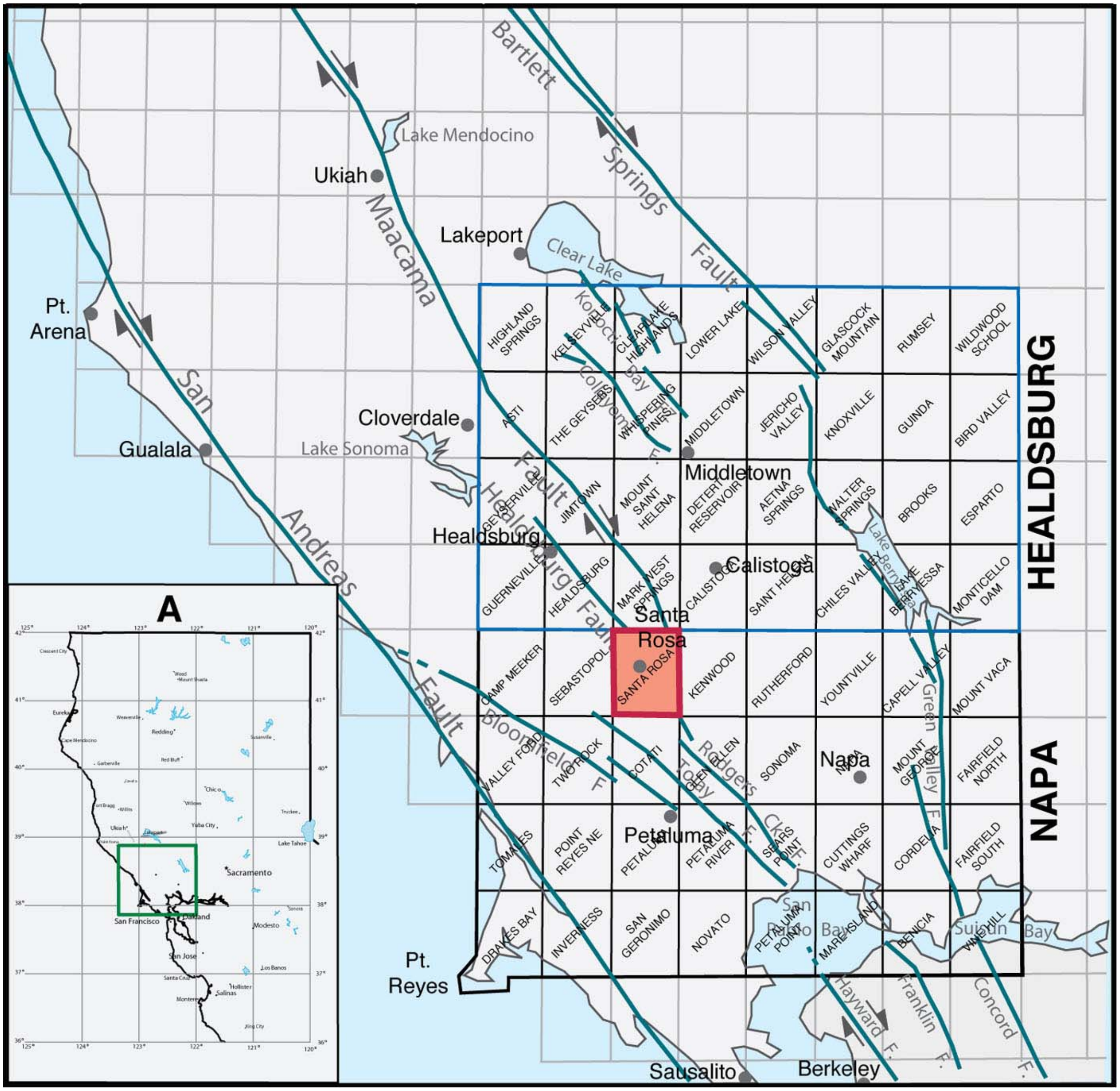


Figure 1. Index map, showing location of Santa Rosa 7.5' quadrangle (red box) within the grids of Napa and Healdsburg 30' x 60' quadrangles, northern California. Green box on inset map shows location of index map.

CHAPTER A. GEOLOGIC FRAMEWORK OF THE SANTA ROSA 7.5' QUADRANGLE

By R.J. McLaughlin, A.M. Sarna-Wojcicki, R.J. Fleck, V.E. Langenheim, C.A. McCabe, and Elmira Wan

Mapping of the Santa Rosa quadrangle by McLaughlin began in 1997 and was completed in September, 2005. This mapping and the sources of other geologic mapping data used here are shown on figure 2. The map area is underlain by Mesozoic to early Tertiary rocks of the Franciscan Complex, the Coast Range Ophiolite, and the Great Valley sequence, considered here to be the pre-Miocene basement of the northern Coast Ranges. More than 85 percent of the quadrangle is, however, covered by younger Tertiary and Quaternary deposits. The configuration of the Mesozoic basement is consequently known mainly from its expression in the gravity and magnetic data (Chapter B) and from limited exposures along the Rodgers Creek fault zone and in the northeast corner of the quadrangle.

The Mesozoic basement rocks are overlain by complexly interstratified and mildly to severely deformed Pleistocene to late Miocene marine and nonmarine sedimentary rocks and subaerial Tertiary volcanic rocks. These strata, and unconformably overlying, less-deformed Holocene and Pleistocene deposits containing one tephra horizon erupted from a volcanic center in southeastern California, are cut by the active right-lateral Rodgers Creek, Healdsburg, Maacama and Bennett Valley Fault Zones.

The extensive volcanic deposits and their intercalation with coeval sedimentary units in the map area provide the primary context for determining the ages of deposition of the Miocene and younger sedimentary section and in understanding the timing of faulting and related deformation in this area. Radiometric dating and tephrochronology are thus an essential component of the geologic mapping. For this reason the sections on stratigraphy and structure in Chapter A are preceeded by a section on chronostratigraphy, including discussions of the $^{40}Ar/^{39}Ar$ dating and tephrochonologic methodology and of the ages based on these datasets. This section is followed by detailed descriptions of the map units and stratigraphic relations, followed in turn, by the section on structure.

CHRONOSTRATIGRAPHY

$^{40}Ar/^{39}Ar$ Age Dating

Volcanic rocks exposed in the Santa Rosa 7.5' quadrangle are assigned to the Sonoma Volcanics (Morse and Bailey, 1935) on the basis of their stratigraphic relations and numerous radiometric ages (fig. 3). Ages were determined in this study (table 1) using the $^{40}Ar/^{39}Ar$ dating technique, first utilized by Merrihue and Turner (1966), which increases the precision of K-Ar dating. Samples were selected for dating based on the least altered materials available from the units of interest. These were crushed and sized to ranges appropriate for concentrating the components desired from each. Mineral separates, primarily plagioclase or sanidine, were prepared by standard mineral separation techniques: sonic disaggregation, magnetic separation, heavy-liquid flotation, and acid cleaning with hydrochloric and hydrofluoric acids. Where grain sizes were too small to separate mineral species, partial separation of some undesirable phenocryst phases was performed to yield concentrates of unaltered groundmass (matrix) aggregates, similar to whole-rock concentrates used for dating in earlier studies (for example, Fleck and others, 1996). Presence of olivine and plagioclase phenocrysts are the primary concerns in mafic volcanic rocks because they are known to contain contaminating (or "excess") ^{40}Ar in some circumstances, incorporated during crystallization and not from decay after cooling.

Following preparation, samples are irradiated in a nuclear reactor with fast neutrons, converting ^{39}K to ^{39}Ar in all potassium-bearing phases. Subsequently, heating of the sample in a specially constructed evacuated system then releases the ^{39}Ar together with the radiogenic ^{40}Ar, permitting simultaneous measurement of potassium and argon by mass spectrometry. Ar was released from groundmass and mineral separates of volcanic rocks by the incremental-heating (or "age spectrum") method, involving step-wise heating of the material, evolving the ^{39}Ar gas together with the radiogenic ^{40}Ar, atmospheric ^{40}Ar, and any extraneous ^{40}Ar in sequential steps or increments. $^{40}Ar/^{39}Ar$ ages are calculated by analyzing carefully spaced samples of a monitor mineral of well-determined age to construct a calibration curve of the neutron flux (for example, Dalrymple and Duffield, 1988).

Incremental-heating analyses utilized a low-blank, tantalum and molybdenum, resistance-heated furnace, commonly releasing all Ar from each sample in 8 to 15 heating increments. Samples used in this study were irradiated for 2 to16 hours in the USGS TRIGA Reactor Facility in Denver, Colorado. The neutron flux standard (monitor mineral) used in this study for all irradiations was Taylor Creek Rhyolite sanidine, TCR-2, with an age of 27.87 Ma. This age is standardized to an average age of 513.9 Ma for inter-laboratory standard hornblende, MMhb1 (Samson and Alexander, 1987) and the USGS Menlo Park laboratory biotite standard, SB-3. Decay and abundance constants used in all calculations are those recommended by Steiger and Jager (1977). Ages reported in table 1 are reported in several ways. The integrated age calculated by mathematically combining the ^{40}Ar and ^{39}Ar from all increments is referred to as the "total-gas age". Where individual heating steps define a statistically uniform value or "plateau" for a majority of the gas released, a plateau age is calculated as the weighted mean and uncertainty (Taylor, 1982) of the ages included in that plateau. Plateau ages of Ar-Ar age spectra are defined as the weighted mean ages of contiguous gas fractions representing more than 50% of the ^{39}Ar released for which no difference can be detected between the ages of any two fractions at the 95% level of confidence (Fleck and others, 1977). By regressing $^{40}Ar/^{36}Ar$ against the $^{39}Ar/^{36}Ar$ corrected for reactor-generated interferences for all increments that define an age plateau, an Ar-Ar isochron is determined, the age of which represents the "isochron" age of the rock. This additional means of determining the most representative age defined by the data does not require assumption of the $^{40}Ar/^{36}Ar$ of contaminating atmospheric Ar as required for the total-gas and plateau ages and is a semi-independent check on the age. In samples where no plateau is defined by the ages of contiguous gas steps, an isochron age may still be calculated as a means of checking the total-gas age. The confidence that may attach to the isochron age is evaluated by a "goodness-of-fit" statistic, called the Mean Square of Weighted Deviates or MSWD (McIntyre and others, 1966). Where this parameter is greater than 1.0, the scatter in the isochron data exceeds that expected from analytical errors. This additional error may be incorporated in the isochron age as a more realistic estimate of the error in the age.

Three samples reported in table 1, map numbers 7, 11, and 22 did not yield plateau ages. The plagioclase sample from location 7 yielded very erratic data by incremental heating and the total-gas age is inconsistent with other units in the area. The isochron age, which also represents an integration of data from all increments, appears to better reflect the age of the sample. Two separate $^{40}Ar/^{39}Ar$ experiments on the sample from location 11 yield discordant results. The discordant results are probably due to an experimental artifact of irradiation of materials with rocks that are too fine grained, and recoil redistribution of ^{39}Ar. The integrated ages of both analyses fall in the 4.6 to 5.1 Ma range and a value of about 4.7 Ma is considered a best estimate (table 1). Results of analysis of a groundmass sample from location 22 yields both an age spectrum and integrated ages similar to location 11. An age of about 4.7 Ma is also the best estimate of these results.

The remaining Ar-Ar age determinations yield plateau-type age spectra, which are generally taken as the best estimates of the ages of these samples. In almost all cases the plateau and isochron ages of these samples agree. Two samples, from locations 21 and 35, were run in duplicate with nearly identical results in each case. As with the discordant results from location 11, the experimental results were reproduced regardless of the quality of the actual Ar release. This lends confidence to the validity of all results, although the actual ages of samples with discordant age spectra cannot be as highly regarded.

Tephrochronology

Tephrochronologic analysis of vitric volcanic units in the map area was undertaken to facilitate correlations and dating of intercalated Tertiary sedimentary and volcanic sequences and to assist in structural interpretations. Tephra units that were sampled included ash-falls, pumice-falls, ash flows, and water-reworked tephra layers. We also sampled obsidian and near-source pyroclastic breccias.

Tephra-bearing volcanic rocks in the study area were sampled and analyzed and selected samples were isotopically dated (fig. 4 and tables 2 and 3, sheet 2) to provide a chronostratigraphic framework for geologic units. Tephra units were identified by means of their characteristic geochemical signatures (chemical “fingerprinting”) and then compared to each other and to tephra units dated previously at localities elsewhere in the region. Several localities are assigned to specific regionally correlated and dated tephra units, such as the Lawlor Tuff and Roblar tuff of Sarna-Wojcicki (1992). Other tephras are not correlative with previously known units but have distinctive geochemical signatures that allow their use as marker horizons where their positions in the section are established. Some tephra units were dated directly by the laser-fusion or incremental $^{40}Ar/^{39}Ar$ technique (tables 2 and 3).

Samples were disaggregated or crushed and sieved using plastic sieves with nylon screen (to prevent contamination with metals) to obtain the ~80 to 150 µm fraction. Components of the tephra samples were separated and chemically cleaned to facilitate petrographic description and to prepare the materials for chemical analysis (Sarna-Wojcicki and others, 1984). In addition to isotropic volcanic glass, we separated plagioclase feldspar from some of the samples for radiometric dating. Samples of near-source obsidian were analyzed to provide a means by which the sources and ages of obsidian clasts found in alluvial deposits in the study area could be determined. The geochemically fingerprinted obsidian clasts allow us to trace their distribution away from their sources and across active faults in the study area and constrain the amounts and rates of displacement (McLaughlin and others, 2005b).

Separates of glass shards were mounted in holes on copper-styrofoam wafer slides, cemented with epoxy, and polished with progressively finer grades of diamond paste to provide a microscopically uniform, smooth, flat surface for analysis. The shards were then analyzed by means of a 5-channel JEOL 8900 Superprobe[2] (electron microprobe) for major and minor elements: SiO_2, Al_2O_3, FeO*, MgO, MnO, CaO, TiO_2, Na_2O, and K_2O. Analytical settings were a beam diameter of 10 μm, a beam current of 10.05 νAmps, and 15 kV excitation potential. Element peak intensities were acquired for 20 seconds except for sodium, which was acquired for 10 seconds only, to minimize migration of the ions away from the beam impact area and consequent reduction of counts with time. Standards used in analysis were GSC glass, An^{40}, and other USGS analytical standards, as well as RLS-132, a homogenous obsidian that we use as an internal standard to test for reproducibility and for instrument drift. About 20 shards were analyzed for each sample. Additional shards were analyzed where multiple modes were found to be present.

Data were reduced with the ZAF (Z, atomic number-A, absorption-F, fluorescence) effects data-reduction package. Data reduction involved elimination of outliers or identification of multiple compositional modes, averaging of the major mode(s), and normalization of the average(s) to a 100% fluid free base, to reduce compositional scatter in the samples. FeO* was converted to Fe_2O_3*, for compatibility with our reference database of previously analyzed samples. The database of the Tephrochronology Laboratory, USGS, Menlo Park, Calif., which contains ~5000 analyzed samples, mostly from the western conterminous U.S., was used for comparison. Many of the units in the database are dated and their chemical compositions are well determined. New analyses and $^{40}Ar/^{39}Ar$ ages where determined, were compared with the database using the similarity coefficient method (Borchardt and others, 1972; Sarna-Wojcicki and others, 1984). Several combinations of oxides were used in the comparisons to maximize the statistical advantage of the more abundant oxides; elements present in concentrations lower than ~0.15 weight percent were generally not used. Comparisons were run with and without the alkalies, Na_2O and K_2O, to evaluate the possible effects of post-depositional alkali mobility of the volcanic glass. The alkalies tend to become depleted or enriched in natural glasses with time for tephra layers older then a few thousand years, and alkali concentrations may vary with depositional and natural storage environment. Names, locations and ages of tephra and other pyroclastic units analyzed in this study are given in table 2. Chemical analyses of the pyroclastic units sampled within the Santa Rosa 7.5' quadrangle and analyzed in the present study are presented in table 3.

Regionally widespread tephra layers that are present in the Santa Rosa quadrangle include the 6.26 Ma Roblar tuff of Sarna-Wojcicki (1992), hereafter referred to as the Roblar tuff; the 5.2-5.4 Ma Pinole Tuff; the 4.83 Ma Lawlor Tuff; and the 3.34 Ma Putah Tuff Member of the Tehama Formation. These tuffs have been found at numerous localities throughout California and in western Nevada (Sarna-Wojcicki, 1976; Sarna-Wojcicki and others, 1984; Reheis and others, 1991; Reheis and others, 2002). Other tuffs, such as the 7.26 Ma tuff of Zamaroni Quarry of this report, the 4.71 Ma Huichica tuff of McLaughlin and others (2005b), the ~ 4.65 Ma tuff of Napa and Healdsburg and the 3.12 Ma tuff of Riebli Road, are important markers within the Sonoma Volcanics and the north San Francisco Bay area (McLaughlin and others, 2004; McLaughlin and others, 2005b). The ages of other tephra layers within the Santa Rosa 7.5' quadrangle are inferred from their stratigraphic relationships to these dated layers and to dated lava flows above and below the tuffs in the map area or elsewhere in the region.

DESCRIPTION OF MAP UNITS

Surficial Deposits

Surficial deposits of the Santa Rosa quadrangle incorporate units from recent maps of the Quaternary geology of the San Francisco Bay area (Witter and others, 2006; Knudsen and others, 2000). For this report some of the units delineated in Witter and others (2006) and Knudsen and others (2000), were combined or modified, particularly in upland areas.

Some of the units incorporated from the earlier Quaternary mapping (Witter and others, 2006; Knudsen and others, 2000) are erosional features defined on the basis of degree of incision (for example, Holocene channels, unit Qhc) and do not necessarilly include preserved deposits. Other units, such as Holocene basin deposits (Qhb) or Holocene natural levee deposits (Qhl), are defined on the basis of their geomorphic form rather than by lithologic criteria. Similarly, landslide deposits are mapped largely on the basis of topographic form rather than by lithology and texture.

Other surficial deposits in the Santa Rosa quadrangle, such as colluvium (Qc) and alluvial fan and terrace deposits (units Qhf and Qpf), are defined and described on the basis of their geomorphic form and distribution as well as their compositions, textures and sedimentologic character. Where topographic incision has clearly produced different levels of terraces or superposed episodes of alluvial fan deposition, subsidiary alluvial fan and terrace units are delineated (for example, Qhf_1 and Qhf_2).

In upland areas, Quaternary alluvial deposits commonly have no connection to more extensive deposits of the larger valleys and depositional basins and consequently are not well dated. Relative ages of these units are in places inferred on the basis of their degree of dissection (for example, unit Qoa) or deposition above other strata of known or inferred age (for example, unit Qha). The relationship of such Quaternary units to those subdivided in greater detail is not established. Some upland Quaternary units are delineated with no specific age designation (examples of this type of unit are landslides, Qls; Quaternary alluvium, Qal; Quaternary terraces, Qt and Quaternary colluvium, Qc).

af **Artificial fill**—Sedimentary materials of a variety of compositions and textures used in road and land fills, dam construction and for other anthropogenic purposes.

Qha **Alluvium, undivided (Holocene)**

Qhb **Basin deposits (Holocene)**—Mapped locally. Generally includes local silty to muddy alluvial and lacustrine deposits accumulated in low areas where water has ponded. This unit is mapped locally in Bennett Valley, but it may be a component of the younger fill of larger scale depositional basins beneath the Santa Rosa plain and in Bennett, Rincon and Northwestern Sonoma Valleys, discussed later in this chapter and in Chapter B.

Qhc **Channels (Holocene)**—Incised into older deposits. Map unit represents the most recent channels that incise Holocene alluvial deposits. This erosional unit is mapped on the basis of channel incision into older alluvial deposits and is not defined here by the character of the sediments in the channels.

Qhf **Alluvial fan and fluvial terrace deposits, undivided (Holocene)**—Gravel, sand and silt of this unit are derived from Pleistocene and older sedimentary and igneous units, including Pleistocene to older Tertiary non-marine gravel, late Tertiary volcanic rocks, and Mesozoic bedrock units of the Franciscan Complex, Coast Range Ophiolite and Great Valley

Sequence. The unit may be further subdivided locally based on inset of Holocene fans into older Holocene and Pleistocene alluvial fan and terrace deposits. Where mapped, these subsidiary units include the following units.

Qhf_1 **Young Holocene alluvial fan and fluvial terrace deposits**—Inset into old Holocene alluvial fans and fluvial terraces and pre-Holocene deposits

Qhf_2 **Old Holocene alluvial fan and fluvial terrace deposits**—Inset into older Holocene and pre-Holocene deposits

Qhl **Natural levee deposits (Holocene)**—Mapped locally on Santa Rosa plain, near the northwestern boundary of Santa Rosa quadrangle. This unit represents the geomorphic expression of overbank deposits accumulated along active stream channels as the result of repeated flooding events.

Qal **Alluvial deposits, undivided (Holocene and/or Pleistocene)**—Mapped locally, where age relations based on superposition with younger and older Quaternary deposits are unknown.

Qc **Colluvium (Holocene and/or Pleistocene)**—Unconsolidated soil and rock debris, generally transported down-slope by gravitational processes.

Qhp **Alluvial deposits, undivided (Holocene and Pleistocene)**—Mapped locally west of Rincon Valley, between Parker Hill Road and Healdsburg Fault Zones

Qhpf **Alluvial fan and terrace deposits (Holocene? and/or Pleistocene)**—Gravel, sand and silt that commonly includes cobble to boulder gravel reworked from Tertiary to Pleistocene non-marine gravel, from late Tertiary volcanic rocks and from Mesozoic bedrock. In Bennett Valley, unit is subdivided into the following deposits.

$Qhpf_1$ **Younger alluvial fan and terrace deposits (Holocene? and /or Pleistocene)**—Deposits on surfaces inset into older undeformed Pleistocene fans and terraces ($Qhpf_2$) and pre-Pleistocene units

$Qhpf_2$ **Older alluvial fan and terrace deposits (Holocene? and /or Pleistocene)**—Deposits on surfaces inset into deformed older Pleistocene and pre-Quaternary rocks

Qls **Landslide deposits (Holocene and Pleistocene)**—Deposits varying from intact slabs of rock to unconsolidated mixtures of rock, soil, and colluvium that are displaced down-slope by gravitational processes. Landslides may vary in area from less than 100 m^2 to greater than 1 km^2.

Qoa **Older alluvium, undivided (Pleistocene)**—Generally uplifted and dissected, this unit is delineated locally along the Healdsburg Fault and west of Rincon Valley, as isolated surfaces and as alluvial fills to small basins with sag ponds or marshes.

Qpf **Alluvial fans and fluvial terrace deposits, undivided (Pleistocene)**—Gravel, sand and silt that are distinguished from younger alluvial fan deposits by characteristically dissected irregular surface morphology and incision by younger Pleistocene and Holocene alluvial deposits. This unit is mapped in the southeastern part of the Santa Rosa 7.5' quadrangle and southwestern part of adjacent Kenwood 7.5'quadrangle, along the sides of Bennett Valley, and locally along the northeast side of the Santa Rosa plain. These deposits are characterized by their unsorted alluvial character, relict fan-like morphology, and their presence on elevated surfaces. The unit unconformably overlies the Petaluma Formation (Tp) and is either inset into or interfingers with an isolated remnant of the gravel of Cloverleaf Ranch (Tcg) that overlies the Petaluma Formation on the southwest side of Bennett Valley.

Qpb **Volcanic talus breccia (Pleistocene ?)**—Coarse volcanic talus composed of debris from silicic ash and andesitic breccia of the Sonoma Volcanics is present along the northeastern side of Rincon Valley. This talus breccia may be derived from normal fault scarps along the margin of Santa Rosa pull-apart basin (fig. 5). On the basis of map relations, the unit is older than or coeval with basal Holocene to Pleistocene alluvial fan and terrace deposits (Qhpf). The breccia unconformably overlies the fluvial and lacustrine gravel of Humbug Creek (Tgp).

Qt **Alluvial deposits, undivided (Holocene and Pleistocene)**—This unit includes undivided Holocene and Pleistocene terrace deposits whose ages are not clearly Holocene or Pleistocene. Terraces of this unit probably are equivalent either to unit Qhf or Qhpf.

Early Quaternary and Tertiary Units

QTg **Fluvial and lacustrine deposits (early Pleistocene and Pliocene)**—Gravel, sandstone, siltstone, mudstone, and non-marine diatomite, locally with minor siliceous ash dispersed in the uppermost part. This unit forms a westwardly propagated alluvial fan system that includes gravels previously assigned to the Glen Ellen and Huichica Formations. These names are not used here because the lithologic and age criteria for separating the Glen Ellen and Huichica Formations are unreliable and inconsistent with newer stratigraphic data presented here and elsewhere (McLaughlin and others, 2004; Wagner and others, 2005; also discussions in McLaughlin and others, 2005b).

Gravel of this unit is pebbly to bouldery and derived predominantly from Tertiary volcanic terranes and pre-Tertiary basement to the east and southeast, very different source areas than those for gravels deposited in the type areas of the Glen Ellen and Huichica Formations. Locally, the gravels have a dominant pre-Tertiary basement provenance and display a paleoflow pattern suggesting derivation from the paleodrainage of Dry Creek and the Mayacmas Mountains (McLaughlin and others, 2005b). In the Mark West Springs quadrangle to the north, a thin marine diatomite bed is intercalated near the base of the formation. The diatomite overlies 5.0-3.1 Ma basaltic andesites and siliceous tuffs and was tentatively assigned to the marine Wilson Grove Formation by McLaughlin and others (2004). McLaughlin and others (2004) considered the diatomite as evidence that the fluvial and lacustrine deposits are coeval and interfinger with the uppermost Wilson Grove Formation. This interpretation suggests that the stratigraphically lowest gravels of unit QTg interfinger with the upper part of the late Pliocene marine Wilson Grove Formation beneath Santa Rosa plain.

Fine-grained glass shards dispersed in a silt bed stratigraphically high in this unit correlate with the Bishop Glass Mountain tephra section in the Long Valley area of the southeastern Sierra Nevada, dated at between 0.8 and 1.2 Ma (Metz and Mahood, 1991; Sarna-Wojcicki and others, 2004). In the Santa Rosa 7.5' quadrangle, the early Pleistocene and Pliocene fluvial gravels of this unit typically include very rare to common clasts of rounded to subrounded obsidian from less than 1 cm to more than 10 cm diameter. The geochemical signature of the obsidian (McLaughlin and others, 2005) indicates that it comes from two different sources: one in the Napa Valley (Napa-Glass Mountain area), dated radiometrically at 2.8 Ma, and another source associated with 2.8-3.2 Ma ash flows in the Franz Valley area west of the Napa Valley. Obsidian clasts having these geochemical signatures are found in gravels and silts of unit QTg southwest and northeast of the Maacama and Healdsburg Faults (McLaughlin and others, 2004; McLaughlin and others, 2005b). Significantly, obsidian clasts in gravels of Pliocene and Pleistocene age near the town of Glen Ellen (type area of the Glen Ellen Formation) do not have Napa-Glass Mountain or Franz Valley geochemical signatures, nor do obsidian clasts in gravels of the Huichica Formation in its type area.

Tertiary Rocks

sc **Silica carbonate rock (Pliocene-Miocene?)**—Hydrothermally altered ultramafic rocks, composed of quartz and magnesium carbonate mineral assemblages that commonly host mercury mineralization. Silica carbonate rock locally may be associated with other epithermal base-metal-bearing (Pb, Zn, Cu) or precious- metal-bearing (Ag, Au) mineralization. Regionally, hydrothermal mineralization ages are close to but somewhat younger than Tertiary to Quaternary volcanic rocks that provided hydrothermal heat sources (McLaughlin and others, 1996; Rytuba, 1993; Peabody and Einaudi, 1992). In the map area these heat sources are largely of Pliocene and Miocene age. However, later stage, lower- temperature hydrothermal carbonate assemblages may also be present in silica carbonate rock along some faults.

Tgc **Gravel of the Cloverleaf Ranch (Pliocene?)**—Fluvial, pebbly to cobbly gravel, pebbly, lithic to quartzose sand, and tuffaceous white clayey mudstone and siltstone. Unit locally contains an undated waterlain ash layer containing glass shards with a geochemical signature suggesting it is younger than ~ 3.12 Ma (tables 2 and 3, loc. 8). The unit also contains common rounded pebbles of obsidian, derived from a source at Annadel State Park, dated here at 4.5 Ma (table 1, map loc. 21; fig. 4) and assigned by others to the Andesite of Rodgers Creek (Fox and others, 1985, Higgins, 1983). This gravel unit occurs on the Cloverleaf Ranch in the northwest part of the Santa Rosa 7.5’ quadrangle, along the southwest side of the Healdsburg segment of the Rodgers Creek Fault Zone. Here, the gravel is highly faulted and deformed but is considered to unconformably overlie the Petaluma Formation, the Lawlor tuff (4.83 Ma) and associated 4.5 Ma and older andesitic volcanic rocks (tables 1 and 2, map locs. 9, 10)**.** The gravel of Cloverleaf Ranch is also recognized in one small outcrop area near the southeast corner of the Santa Rosa 7.5’ quadrangle, ~14 km southeast of the Cloverleaf Ranch; in this area, the gravel is subhorizontal or slightly tilted and overlies the Petaluma Formation unconformably. A Pliocene (< 2.8 to ≤ 3.12 Ma) or younger age is indicated for the gravel of the Cloverleaf Ranch and is based on presence of the ≤ 3.12-Ma ash bed intercalated in the lower part of the gravel section and of obsidian pebbles eroded from a 2.8-Ma source in Franz Valley. The unit is partly coeval with Pleistocene and Pliocene fluvial and lacustrine deposits (unit QTg; < 2.8 Ma), but the older age of the contained obsidian-clast suite and of underlying volcanic and sedimentary strata preclude direct correlation; contrasts in obsidian-clast provenance suggest that these units were deposited in separate drainage basins.

Tgp **Fluvial and lacustrine deposits of Humbug Creek (Pliocene)**—This unit consists of pebble to boulder gravel, sandstone, siltstone, mudstone and nonmarine diatomite. Intercalated siliceous tuff (Tst) was locally mapped in this unit in the Mark West Springs quadrangle to the north, but no such tuffs are recognized in the Santa Rosa quadrangle. In the map area this unit consists largely of clastic debris derived from underlying Mesozoic rocks (largely Franciscan Complex mélange and rocks of the Coast Range Ophiolite) and from Tertiary volcanic rocks. Near the northeast corner of the quadrangle unit caps basaltic andesite flows and breccias and siliceous ash of the Sonoma Volcanics, which includes tephra units correlated with the 3.3 Ma Putah tuff Member of the Tehama Formation and the 4.65 Ma tuff of Napa-Healdsburg (tables 2 and 3; fig. 4; cross sections B and C; map locs. 6 and 15). Southwest of Melita (fig. 3), in the Annadel State Park and Lake Ralphine areas, the gravel overlies andesitic flows, flow breccia, tuff breccia and glassy rhyodacitic tuff as young as 4.4 Ma. In the Mark West Springs quadrangle, gravels assigned to this unit interfinger with 3.3-3.4-Ma ash-flow tuffs in the Sonoma Volcanics of the Petrified Forest and Franz Valley (McLaughlin and others, 2004). On the basis of this interfingering we interpret the age of the fluvial and lacustrine deposits of Humbug Creek to be largely between 3.3 and 4.4 Ma, although it is permissive that some of the unit is younger.

In Rincon Valley the fluvial and lacustrine deposits of Humbug Creek (Tgp) may be unconformably overlain by unnamed Pleistocene and Pliocene fluvial and lacustrine deposits (QTg). At the surface, however, unit Tgp is separated from the younger gravels (QTg) by faults or the contact is covered by Holocene or Pleistocene deposits. Clast imbrication data and crossbedding in the gravels of Humbug Creek east of Rincon Valley indicate that paleoflow was primarily toward the west-northwest.

Tw **Wilson Grove Formation (Pliocene and Miocene)**—The Wilson Grove Formation is not exposed at the surface in the Santa Rosa 7.5' quadrangle but underlies much of the Santa Rosa Plain (cross sections B, C), based on drillhole data and stratigraphic relations of exposures in adjacent quadrangles (Powell and others, 2006). In the Cotati, Sebastopol and Healdsburg 7.5' quadrangles west of the Santa Rosa Plain, the Wilson Grove Formation includes marine pebbly sandstone, siltstone and friable, matrix- and clast-supported pebbly gravel. The gravels locally consist of well-rounded and polished quartz, dark chert and porcellanitic shale clasts in a sandy to silty matrix. These distinctive gravels were named the gravels of Cotati by Fox (1983) and appear to be a marine nearshore lithofacies of the Wilson Grove Formation. Elsewhere, the gravels of Cotati are intercalated in the Petaluma Formation, indicating that parts of the Wilson Grove and Petaluma Formations are coeval. Speculatively, the upper part of the Wilson Grove Formation could also be locally coeval with early Pleistocene to Pliocene fluvial and lacustrine non-marine gravel (QTg), determined by the presence of a thin marine diatomite in the lower part of unit QTg (see earlier discussion).

In structure sections across the Santa Rosa Plain (cross sections B and C), strata shown as Petaluma Formation locally include marine strata, on the basis of lithologic data from water and oil and gas well logs (Valin and McLaughlin, 2005; Powell and others, 2006). These marine strata probably represent interfingering of the Wilson Grove Formation with the Petaluma Formation but occur beneath a thicker marine section shown as Wilson Grove Formation on the cross sections. Because the distribution of interfingered marine and nonmarine strata is poorly defined in the subsurface, the lower interfingered marine and nonmarine beds are undifferentiated and included in the Petaluma Formation in cross sections B and C.

In the Santa Rosa quadrangle, the Wilson Grove and Petaluma Formations locally include the pumiceous, rhyodacitic Roblar tuff, radiometrically dated at 6.26 ± 0.4 Ma (McLaughlin and others, 2005b; and table 2).

Beneath Santa Rosa Plain southwest of Santa Rosa, invertebrate marine fossils occur in two water wells drilled by the Sonoma County Water Agency (SCWA): in the Occidental Road well (fig. 5, sheet 2) fossils occurred below a depth of 320 ft (98 m); in the Sebastopol Road well (fig. 5) the fossiliferous horizons were below 450 ft (137 m). The fossil assemblages in these wells are considered to be Pliocene or younger (≤ 5.3 Ma) and are the same as present in the Wilson Grove Formation at Trenton and in the type section of the Wilson Grove Formation southwest of Healdsburg (Powell and others, 2006). The Cotati lithofacies of the Wilson Grove and Petaluma Formations occurs in the Sebastopol Road well and the Roblar tuff is absent from both of the wells (fig. 5), indicating an age younger than 6.3 Ma for the upper 1070 ft (326 m) of subsurface section.

Tp **Petaluma Formation (Pliocene and Miocene)—**The Petaluma Formation is predominantly sandy to silty gravel, silty sandstone, siltstone, and mudstone. The formation contains diatomite and clayey diatomaceous shale, local lenses of lignite and lignitic mudstone, silicified wood, and fresh- water limestone. It also locally contains the 6.26 ± 0.4-Ma Roblar tuff, which also occurs in the Wilson Grove Formation, in addition to younger volcanic units.

Petaluma Formation strata were deposited in fluvial, lacustrine, and brackish to estuarine settings, as indicated by invertebrate fossils, diatoms, ostracodes, rare foraminifers, and rare land mammal fossils (geologic map, fossil localities 1 to 4). Southwest of the Rodgers Creek-Healdsburg Fault Zone, the Petaluma Formation underlies Pliocene and Quaternary sediments and Tertiary volcanic rocks. Beneath the Santa Rosa Plain, the Petaluma Formation interfingers to the west and northwest with the marine Wilson Grove Formation and is overlain by Pliocene to early Pleistocene fluvial gravel (QTg). Where it is exposed on the southwest side of the Healdsburg segment of the Rodgers Creek Fault Zone in northwestern Santa Rosa, the formation includes fluvial and estuarine deposits of pebbly sandstone and siltstone that are bioturbated and burrowed. The Petaluma Formation is intercalated with ~4.5 Ma and older andesitic flows and breccias in this area and the 4.83 Ma Lawlor Tuff. The formation is overlain by the gravel of the Cloverleaf Ranch (unit Tgc, Tables 2.1 and 2.2; cross section A). A gomphothere tooth was found by one of the authors (McLaughlin) in alluvium that overlies the Petaluma Formation and Pliocene gravel of the Cloverleaf Ranch (Tgc) southwest of the Healdsburg Segment of the Rodgers Creek Fault Zone (geologic map, fossil locality 3). The Petaluma strata in this area also overlie the Roblar tuff. The tooth was identified by C.A. Repenning (written commun. 2002), as from a juvenile *Gomphotherium taoensis?* (Frick) [=*Gomphotherium obscurum* (Leidy); Alroy, 2002]. Repenning assigned the fossil tooth to the late Barstovian to early Clarendonian vertebrate stage (about 12 to 10 m.y. ago). The stratigraphic position of the Gomphothere-bearing strata indicates reworking and the age assigned to the tooth suggests derivation from an older part of the Petaluma Formation (known to be present only to the south and east of the Rodgers Creek Fault Zone. Alternatively, the fossil is derived from 12-10 Ma Petaluma Formation strata that has been squeezed-up vertically or translated by strike-slip along the Healdsburg Segment of the

Rodgers Creek Fault Zone. A web search of The Paleobiology Database (ie. Alroy, 2002), by the first author of this report (McLaughlin), furthermore, indicates that *Gomphotherium obscurum* (Leidy) is found in deposits estimated to range from ~10.3- 4.9 Ma in the state of Hidalgo, Mexico (Alroy, 2002). This suggests a possibly younger (~ 5 to 6 Ma) age for the *Gomphotherium* tooth in the Santa Rosa area that is more compatible with the local stratigraphy.

In the western part of Santa Rosa quadrangle, the Petaluma Formation is penetrated by numerous water wells that indicate it underlies the Quaternary cover of much of Santa Rosa Plain. The nearest deep well on Santa Rosa Plain for which detailed lithologic and geophysical data are available is the Stephens-Rohnert #1 exploratory oil and gas well, drilled to a total depth of 5790 feet (1765 m), in the adjacent Cotati 7.5' quadrangle (fig. 5, cross section C). This well indicates that the Petaluma Formation unconformably overlies a Mesozoic basement of Franciscan Complex or Great Valley Sequence rocks and interfingers with mafic to intermediate volcanic rocks that also occur to the southwest in a drill hole at Stonypoint quarry (fig. 5), at a depth of 256 feet (78m). These volcanics, dated at ~8.5 Ma are assigned to the Tolay Volcanics and are displaced a minimum of 40 km across the Hayward and Rodgers Creek Fault Zones from equivalent rocks in the Oakland and Berkeley Hills east of the Hayward Fault (Fox and others, 1985; McLaughlin and others, 1996; Graymer and others, 2002).

Near the Sonoma County Fairgrounds and on Taylor Mountain, fluvial strata mapped as Petaluma Formation are interbedded with ~5.2 to 7.9-Ma rhyodacitic (Tsr, Tst) to basaltic (Tsb) rocks in the lower part of the Sonoma Volcanics. These Petaluma Formation strata are highly disrupted by folding and faulting and include fresh water diatomite with local lenses of lignite. The diatom flora (geologic map, fossil locality 4) suggest a shallow, eutrophic, neutral to slightly alkaline, stagnant lacustrine setting (S. Staratt, written commun. 2006).

The locally high organic content of the diatomite and its common association with lignite make these nonmarine strata potential source rocks for minor gas occurrences in the Cotati basin southwest of Santa Rosa. Gas collected in 2001 by McLaughlin, T. D. Lorenson and L. B. Magoon from the Cotati gas field (fig. 5) is more than 90 percent methane, with a carbon isotope content (-37.2) and organic composition favoring generation from type III kerogen. The data suggest gas generation at shallow depths (2-3 km), at temperatures less than ~100° C (T. D. Lorenson, written commun, 2006), consistent with an interpretation that the methane was generated from woody source beds.

Petaluma Formation deposition between ~6.3 and 7.3 Ma is here considered to have occurred contemporaneously with transtensional faulting along the eastern margin of the Bellevue basin low of Cotati structural basin (now concealed beneath the Santa Rosa plain).

In the Bennett Valley area the Petaluma Formation includes sandy gravels that contain marine fossils (geologic map, fossil locality 2; Powell and others, 2004) as well as nonmarine vertebrate fossils and intercalated fresh water diatomite, lignite and Sonoma Volcanics. The non-marine strata are similar to the disrupted section of Petaluma Formation and intercalated Sonoma Volcanics near the Sonoma County Fairgrounds. Sonoma Volcanics dated at between 5.0 and 4.4 Ma (tables 1 and 2 and fig. 4, Sheet 2), overlie and are intercalated with the upper part of the Petaluma Formation in this area.

In summary the stratigraphic and radiometric data indicate that the Petaluma Formation along the east side of Santa Rosa Plain is older than ~5.0 Ma and younger than ~8.0 Ma.

Beneath Santa Rosa Plain, the lower Petaluma Formation is significantly older since it is intercalated with the ~8.5-10 Ma Tolay Volcanics. The following distinctive lithologic units in the Petaluma Formation are mapped separately.

Tpd **Diatomite and diatomaceous mudstone--** White to light-brown, fissile to blocky, diatomite and diatomaceous mudstone, commonly associated with air fall volcanic ash or lenses of lignite. Probably deposited in ponded water and lacustrine settings associated with volcanism and fluvial delta environments.

Tplg **Lignite and lignitic mudstone—**Black to dark-brown low-grade coal, peat and carbonaceous mudstone, composed of carbonized wood and plant debris. Deposited in lacustrine or ponded water settings, commonly with diatomite and air fall tuffs of the Sonoma Volcanics.

Tpwd **Silicified (petrified) wood—**Local horizons of wood debris that has undergone replacement by chalcedonic to opalitic silica, possibly due to past local reaction with thermal waters. Unit is locally associated with ash deposits and fresh water diatomite.

Tplm **Limestone—**Brackish or fresh-water depositional setting, locally fossiliferous and present as minor lenses in the upper parts of basaltic andesite flows and breccias interbedded in the Petaluma Formation along the east side of Santa Rosa Plain. Limestone deposition is apparently related to reaction of the volcanic rocks with brackish and fresh water (estuarine to deltaic) into which the volcanics erupted or flowed.

Tprb **Breccia—**Composed predominantly of angular, tectonically slickened clasts of rhyodacitic rocks with variable textures, that occurs beneath, or intercalated in the lower part of the Petaluma Formation along the western slope of Taylor Mountain, west of the Rodgers Creek Fault Zone and the east side of the Santa Rosa Plain. On the basis of the stratigraphic and age relations, this breccia and interbedded gravel were deposited between ~7.3 and 6.3 Ma. Correlative breccia occurs ~28 km southeast of Taylor Mountain along the eastern side of the Rodgers Creek Fault Zone, in the Sears Point quadrangle (D. Wagner, personal commun., 2005; McLaughlin and others, 2006). The breccia is unsorted, with clasts ranging in size to ≥ 3 m in a comminuted rhyodacitic matrix. It is here interpreted to represent a fault scarp-derived breccia, that locally includes gravel lenses.

Tprg **Gravel lenses—**Up to ~5 m thick; unsorted and unorganized to poorly sorted and weakly segregated and cross-bedded. The gravel in this unit is composed of rounded to subangular pebbles and cobbles derived from Franciscan Complex and related Mesozoic sources and from Tertiary volcanic sources. In contrast to the coarse, unsorted monolithologic talus shed from actively forming fault scarps (unit Tprb), unit Tprg represents sediment that underwent transport in alluvial fans, debris flows and talus deposits that interfingered with unit Tprb along the eastern margin of a probable strike-slip basin.

Late Tertiary Volcanic Rocks

Sonoma Volcanics (Pliocene and Miocene)—The Sonoma Volcanics are comprised of rhyolitic to dacitic ash-flow and air-fall tuff, andesitic water-lain tuff, and rhyolitic to basaltic flows and flow breccia. Regionally, the volcanic section becomes increasingly silicic up-section, and youngs from southwest to northeast, across the Rodgers Creek-Healdsburg and Maacama Faults (McLaughlin and others, 2005b; Fox and others, 1985). In the Santa Rosa quadrangle, abrupt alternation from mafic to silicic volcanism (as indicated on the geologic map and structure sections) occurs in several parts of the volcanic section and is superposed on the overall up-section trend toward more silicic compositions in the Sonoma Volcanics. The oldest volcanics (7.3-8.0 Ma) exposed in the Santa Rosa quadrangle are rhyolitic to dacitic (rhyodacitic) in composition. These silicic flows, intrusives and pyroclastic deposits are exposed along the southwest side of Taylor Mountain along the Taylor Mountain and Cooks Peak Fault Zones. Northeast of these faults the Sonoma Volcanics include ~5.0 - 4.4 Ma basaltic to andesitic flows, flow breccia, tuff and tuff breccia, which alternate with dacitic to rhyodacitic ash-flow, air-fall and waterlain deposits, with ages ranging from ~5.4 to 4.5 Ma. In the Mark West Springs quadrangle to the north, ages of the volcanic rocks substantially overlap across major structural blocks; McLaughlin and others (2004) noted that, northeast of the Maacama Fault, ~3.4 Ma and younger silicic volcanics are volumetrically more abundant than andesitic rocks of that age and that basaltic andesite flows are less abundant high in the volcanic section than lower in the sequence. The Sonoma Volcanics consist of the following units.

Tsd **Dacitic flows**—Mapped near the northeast corner of the Santa Rosa quadrangle and east of the Mark West Fault Zone, and along the Rodgers Creek Fault Zone in the southeast half of the quadrangle. The dacite generally lacks macroscopic quartz or K-feldspar but commonly contains plagioclase phenocrysts and rarely, microphenocrysts of hornblende. The dacite may be gray, pink or brown and vesicular, with local amygdules filled by quartz or chalcedony. Matrix of the dacite is aphanitic to microgranular.

Tsr **Rhyolitic and rhyodacitic flows and intrusive rocks**—Porphyritic to aphanitic, with phenocrysts of quartz and plagioclase. The rhyodacitic rocks may be white, pink or gray. The unit includes the rhyodacitic rocks of Zamaroni Quarry, dated radiometrically at 7.26±0.04 Ma (table 1, loc. 25), the rhyodacitic rocks of Cooks Peak dated at 7.94±0.02Ma (table 1, loc. 35), an undated hydrothermally altered and mineralized rhyodacitic dike intruded along the southwest side of the Rodgers Creek Fault Zone northeast of Taylor Mountain, and perlitic to banded rhyolitic to rhyodacitic flow rocks and obsidian in Annadel State Park, dated at 4.5 ± 0.01 Ma (table 1, loc.21).

Tst **Rhyolitic to dacitic and minor andesitic pumiceous tuff**—Mostly ash flows and minor air fall. This unit includes named and unnamed tephra layers of different ages in the Sonoma Volcanics (figs. 3 and 4). Tuffs in the Sonoma Volcanics are white to gray where fresh and weather to a buff to pink color. Texturally the tuffs vary from lithic and coarsely pumiceous, with angular fragments of partly re-constituted mafic to silicic igneous or sedimentary wallrock material, perlitic glass globules, or subround obsidian clasts; to crystal rich, with fine to coarse phenocrysts of plagioclase, to uniformly fine-grained and non-lithic, to vitric, with podiform obsidian enclosed in a glassy pumiceous matrix. The tuffs locally include lapilli tuffs (lapilli ≤ 3 cm). Tops of tuff layers may be welded by overlying mafic flow units.

Southwest of the Rodgers Creek-Healdsburg Fault Zone, the Roblar tuff (6.26 Ma) and Lawlor Tuff (4.83 Ma) are interbedded with the Petaluma Formation (localities 16 and 9, tables 2 and 3; fig. 4). An unnamed tephra unit with a geochemical fingerprint suggesting an age < 3.12 Ma occurs stratigraphically higher in this area (locality 8, tables 2 and 3; fig. 4) in the overlying gravels of Cloverleaf Ranch (Tgc).

South of the mouth of Santa Rosa Creek, a different suite of tuffs occur with the Roblar tuff in the Taylor Mountain area (localities 23-24, 25, 27, 29-34, 36-38, 40-42; tables 2 and 3; fig. 4). These tuffs include the tuff of Zamaroni Quarry (7.26 Ma), a tuff in rhyodacitic breccia of the Petaluma Formation (Tprb, ~6.26-7.3 Ma), the Pinole Tuff (5.2-5.4 Ma), and the tuff of Mark West Springs (4.83-5.0 Ma). An unnamed tuff similar to unnamed tuff in the gravels of Cloverleaf Ranch, that is questionably correlated with a < 3.12 Ma unnamed tuff in the Mark West Springs quadrangle, occurs in a small structural depression along the Rodgers Creek Fault north of Guenza Road (locality 36, tables 2 and 3; fig. 4).

Tephra units along the southwest side of Bennett Valley include the tuff of Mark West Springs (4.83 - 5.0 Ma) and the tuff of Napa-Healdsburg (4.65 Ma). An undated tuff mapped east of the Bennett Valley Fault in Annadel State Park (Higgins, 1983), underlies andesitic flows and breccias. One of the overlying andesitic flows is dated at 4.7± 0.03 Ma (^{40}Ar/^{39}Ar) (locality 22, table 1, and fig. 4). Vitric rhyolitic flows (obsidian of Annadel State Park) in the adjacent Kenwood quadrangle, dated at 4.5± 0.01 Ma, are also stratigraphically higher than the undated tuff (Map A, Sheet 1, and locality 21, table 1 and fig. 4). The unnamed tuff is therefore > 4.7 Ma. About 0.5 km northeast of the Bennett Valley Fault along Bennett Valley Road, tephra from near the top of the unnamed tuff (locality 39, table 2, fig. 4) correlates with the tuff of Mark West Springs (4.83-5.02 Ma). We therefore infer the stratigraphically low tuff-bearing section beneath the andesitic and rhyolitic rocks of Annadel State Park to be ≥ 4.83-5.02 Ma. The stratigraphic relations suggest that tephra horizons between 4.7 and 4.83 Ma (including the Huichica tuff and the Lawlor Tuff) could be present above the tuff of Mark West Springs along the contact with overlying andesitic rocks (fig. 3).

In the northeastern part of the Santa Rosa quadrangle and northwesternmost Kenwood quadrangle, tuffs interbedded with andesitic flows and flow breccias occur along the northeast side of Rincon Valley. In stratigraphically ascending order, named tuffs include the Lawlor Tuff (4.83 Ma), tuff of Goodyear Station (4.67-4.83 Ma), tuff of Napa-Healdsburg (4.65 Ma), and the Putah Tuff (3.22 ± 0.02 Ma). These tuffs are overlain by unnamed tephra layers with geochemical affinities to some of the youngest tephra units in the Sonoma Volcanics (possibly as young as ~3.22-2.78 Ma).

Tstw **Crystal-rich rhyolitic to rhyodacitic welded tuff**—These rocks are mapped locally in the quadrangle as welded zones at the tops of tuff layers (Tst) that are overlain by flows of andesite or basalt.

Tstb **Andesitic to rhyodacitic breccia (Pliocene)**—This unit is mapped locally in the northeast part of Santa Rosa 7.5'quadrangle, along the contact between the Lawlor Tuff and overlying basaltic andesite. The breccia consists of angular boulders and blocks, greater than 1 m in diameter, of basalt, andesite, and vitric, porphyritic rhyodacite, in a lithic rhyodacitic pumiceous tuff matrix. The breccia may be associated with syn-volcanic faulting and /or proximal pyroclastic venting.

Tsb **Andesite, basaltic andesite and basalt**—Subaerial andesitic to basaltic flows, flow breccia and tuff-breccia, local waterlain andesitic tuff and minor dacitic ash-flow tuff are areally extensive between the Healdsburg and Southern Rodgers Creek segments of the Rodgers Creek Fault Zone, and the Mark West Fault Zone. Gravity data (Chapter B; Langenheim and others, 2006a) suggest that these andesitic rocks together with tuffs in the Sonoma Volcanics compose a relatively thin cover to the pre-Miocene basement over much of this area (cross sections A-C). Geologic map relations consistent with a thin Tertiary volcanic cover are provided by local exposures of Franciscan Complex and ophiolitic rocks along the Rodgers Creek Fault and in the bottoms of a few drainages that deeply incise the volcanic section. Andesitic to basaltic rocks are intercalated with and underlain by estuarine, lacustrine and fluvial strata of the Petaluma Formation in the Bennett Valley area, along the Rodgers Creek and Healdsburg faults, on Taylor Mountain, and along the east side of Santa Rosa plain. Andesitic rocks are also intercalated with the numerous tuffs (Tst), and local rhyodacitic flows and intrusive rocks (Tsr).

Dated andesitic rocks in the Santa Rosa 7.5'quadrangle (tables 1 and 2 and fig. 4) span a significantly narrower age range than the tephra units (Tst). In northern Santa Rosa quadrangle, andesite along Fountain Grove Parkway northeast of the Healdsburg Fault Zone, is dated at 5.0 ± 0.4 m.y. (table 1, map loc. 7). Basaltic andesite from the Cloverleaf Ranch area along the southwest side of the Healdsburg Fault Zone yielded a plateau age of 4.53 ± 0.04 Ma and an isochron age of 4.46 ± 0.12 Ma (table 1, map loc. 10). The total fusion age of 4.75 ± 0.04 suggests that excess Ar is present, and the plateau age of 4.53 ± 0.04 is taken to be the best age for this flow unit. The basaltic andesite is in contact with a poorly exposed small outcrop area of tuff, geochemically correlative with the 4.83 Ma Lawlor Tuff, that was mapped as capping the dated andesite. The age determined for the andesite, however, suggests that the tuff is either stratigraphically interbedded beneath the dated andesite or structurally interleaved along a fault of the Healdsburg Fault Zone.

In the Taylor Mountain area, andesitic rocks are complexly intercalated with numerous tephra layers and the Petaluma Formation and are juxtaposed with 7.9 Ma and younger rhyodacitic rocks across the Cooks Peak Fault Zone. Basaltic andesite on Taylor Mountain summit was too chloritized to date, but tephra layers intercalated with basaltic andesite flows and flow breccias stratigraphically beneath the Taylor Mountain summit andesite are correlated with the the Pinole Tuff (5.2 to 5.4 Ma), the Roblar tuff (6.26 Ma) and the tuff of Zamaroni Quarry (7.3 Ma). This suggests an age ≤ 5.4 Ma for the basaltic andesite on Taylor Mountain summit.

Andesite flows of unit Tsb exposed in an area of abandoned cobblestone quarries east of Lake Ralphine, are dated at 4.4 ± 0.03 Ma**.** East of Lake Ralphine in the adjacent Kenwood 7.5’ quadrangle (Higgins, 1983), a lithologically and texturally similar plagioclase-rich, olivine-bearing andesite is dated at 4.7 ± 0.03 Ma (table 1, map loc. 22). The age of unit Tsb east of Lake Ralphine is further constrained by an Ar/Ar age of 4.5 ± 0.01 Ma on previously discussed, stratigraphically higher rhyolitic rocks (unit Tsr) and by the presence of the previously discussed tuff of Mark West Springs (< ~5.02 >4.83 Ma) in the Annadel State Park section (unit Tst; loc. 21, table 1; locs. 26 and 39, table 2, fig. 4). Near the northeast corner of the map area, porphyritic basaltic andesite of unit Tsb overlies the 4.83 Ma Lawlor Tuff (unit Tst). The basaltic andesite, in turn, is overlain by the ~ 4.65 Ma tuff of Napa-Healdsburg (also of unit Tst). This basaltic andesite is dated at 4.63 ± 0.02 Ma (table 1, map loc. 11), within the one-sigma error range of the estimated age of the overlying tuff. Collectively, andesitic rocks between the Rodgers Creek-Healdsburg Fault Zone and the Maacama Fault range in age from ~5.4 to 4.4 Ma.

Tsbt **Andesitic to dacitic tuff, breccia and minor flows—**This unit includes air-fall and ash-flow tuffs and some possibly reworked, waterlain tuff (Higgins, 1983). The unit underlies basaltic andesite flows of unit Tsb, dated at 4.7 ± 0.03 Ma. Younger andesitic tuff breccia overlies andesitic flows and breccias (Tsb) and rhyolitic rocks (Tsr) on the northeast side of Bennett Mountain that are probably correlative with the obsidian of Annadel State Park, dated at 4.5 ± 0.01 Ma **(**loc. 21, table 1 and fig. 4).

Tvt **Tolay Volcanics (Miocene)—**Rhyolite, andesite and basalt interbedded with sedimentary rocks of the Petaluma Formation and assigned to the Tolay Volcanics are not present at the surface in the Santa Rosa 7.5' quadrangle. These volcanics are, however, mapped at the surface in the adjacent Cotati 7.5' quadrangle (Clahan and others, 2003) and beneath Santa Rosa Plain, on the basis of oil and gas well data (cross section C, and fig. 5, Sheet 2). These volcanics are greater than 1220 m thick in oil and gas exploration wells in Petaluma Valley basin, southeast of the map area (Morse and Bailey, 1935; Youngman, 1989; Wagner and others, 2005). The Tolay Volcanics are mapped southwest of the Rodgers Creek Fault (Wagner and others, 2005) where they are considered to range in age from ~8.5 - 10.6 Ma, based on ^{40}Ar/ ^{39}Ar dates (Wagner and others, 2005). The distribution of the volcanics southwest of the Rodgers Creek Fault and their age, suggests they are displaced ~45- 49 km along the right-lateral Hayward-Rodgers Creek Fault Zone, apparently from coeval volcanic rocks of the Berkeley Hills (Fox and others, 1985; Graymer and others, 2002).

Pre-Tertiary Rocks

KJso **Great Valley Sequence and Coast Range Ophiolite, undivided (Cretaceous and Jurassic)—**Marine sedimentary rocks of the Cretaceous and Jurassic Great Valley Sequence and /or igneous and pelagic sedimentary rocks of the Jurassic Coast Range

Ophiolite are inferred to be locally present beneath the Santa Rosa Plain and beneath Miocene and younger units between the Rodgers Creek-Healdsburg and Maacama Fault Zones. Regionally, strata of the Great Valley Sequence include thinly interbedded black to dark-greenish-gray shale and minor arkosic wacke with local concretionary calcareous horizons; rhythmically interbedded arkosic wacke and shale turbidites; and local thick bedded to massive, lenticular channels of conglomeratic arkosic wacke. The conglomerates typically include distinctive well rounded clasts of hard porphyritic hypabyssal rocks of rhyolitic to dioritic compositions and dark chert and felsite. The arkosic sandstones contain up to several percent detrital K-feldspar.

No exposures of Great Valley Sequence strata are recognized at the surface in the Santa Rosa 7.5'quadrangle. The inferred presence of these rocks is based on along-strike and down-plunge projection from their exposure in synforms and antiforms in the adjacent Healdsburg, Kenwood and Calistoga 7.5' quadrangles, and locally, on aeromagnetic data (see Chapter B). Where exposed in adjacent areas the Great Valley Sequence overlies or is imbricated with the Coast Range Ophiolite (Gealey, 1951; Blake and others, 1971; Fox and others, 1973; McLaughlin and Ohlin, 1984; McLaughlin, 1978; Graymer and others, 2002).

Coast Range Ophiolite (Jurassic)—Rocks presumably derived from the Coast Range Ophiolite in the map area include the following.

Jos **Serpentinized ultramafic rocks**—These rocks are predominantly serpentinized non-cumulate tectonitic harzburgite and dunite. The serpentine mineral assemblage is typically a mixture of lizardite and chrysotile. The unit locally includes minor cumulate ultramafic to gabbroic rocks. Small areas of serpentinized ultramafic rock and minor gabbro cumulates occur along the Rodgers Creek Fault on Taylor Mountain and in the northeast corner of the map area. Pods and lenses of serpentinized ultramafic rock also occur within melange of the Franciscan Complex, presumably as the result of structural imbrication with the Coast Range Ophiolite and Great Valley Sequence (McLaughlin and Ohlin, 1984; McLaughlin, 1978).

Central Belt of the Franciscan Complex (Upper Cretaceous to Lower Jurassic)—The Franciscan Complex is exposed in the northeastern part of the Santa Rosa 7.5' quadrangle as well as along the Rodgers Creek Fault zone on Taylor Mountain and along the Healdsburg Fault zone in northwestern Santa Rosa east of Highway 101. The rocks in the map area are assigned to the Central Belt of the Franciscan Complex (McLaughlin and Ohlin, 1984; Blake and others, 2002; McLaughlin and others, 2004).

fcm **Undifferentiated melange**—The melange consists largely of penetratively sheared sandstone and argillite containing blocks of varying lithology. Where blocks are large enough to map, the melange includes the following units.

bls **Blueschist blocks**—Mafic to felsic igneous and pelitic rocks, metamorphosed to high blueschist grade. Includes eclogite and amphibolite-grade blocks partially retrograded to blueschist and locally, tuffaceous pelitic rocks that contain chrome mica (fuchsite), white mica, lawsonite and sodic amphibole.

fcc **Radiolarian chert of Marin Headlands-Geysers terrane**—Red to green, locally tuffaceous, and in places depositional on, or interlayered with, basaltic volcanic rocks. In the nearby Geysers 7.5' quadrangle, where the chert section overlies pillow basalt, the radiolarian assemblage is early Late Cretaceous (Cenomanian) to Early Jurassic (Pliensbachian) age (McLaughlin and Pessagno, 1978; Murchey, 1984; Hagstrum and Murchey, 1993) and is depositionally overlain by terrigenous metasandstone and shale.

fcv **Basaltic volcanic rocks**—These rocks consist of massive to pillowed basalt, pillow breccia, aquagene tuff, local pelagic tuff, and diabase that generally is metamorphosed to low-greenschist grade, containing epidote and pumpellyite. The unit includes basaltic rocks of the Marin Headlands-Geysers terrane.

STRUCTURE

Faults

The Santa Rosa 7.5' quadrangle is traversed by several major right-lateral strike-slip faults as well as thrust faults and extensional faults (fig. 5). All these faults have contributed to regional deformation over the past 10 million years, during development of the San Andreas transform margin from an earlier subduction margin setting. Several of these faults are seismically active and pose significant earthquake hazards. We discuss the faulting by fault type: strike-slip, thrust and extensional and in the context of their distribution in the map area.

Rodgers Creek-Maacama Strike-slip Fault Corridor

The Rodgers Creek and Maacama Fault Zones are considered to be the northern extension of the active right-lateral Hayward-Calaveras Fault System and represent the most significant earthquake hazard east of the San Andreas Fault in the northern San Francisco Bay region.

Rodgers Creek Fault Zone

Significant complexity exists in the Holocene and older traces of the Rodgers Creek Fault Zone in the map area. The complexity is related to partitioning of slip among the Rodgers Creek, Healdsburg and Maacama Fault Zones and in how fault zone geometries have evolved. We view the Rodgers Creek Fault Zone as consisting of two segments: the southern segment, defined as that part of the fault zone south of the Santa Rosa Creek floodplain; and the segment north of the Santa Rosa Creek floodplain, which we call the Healdsburg Fault segment, recognizing the usage of previous workers (Fox, 1983; Gealey, 1951). Each segment of the Rodgers Creek Fault Zone consists of multiple traces and strands (figs. 5 and 6).

Early geologic maps of this region interpreted the Healdsburg Fault as distinctly separate from the Rodgers Creek Fault Zone (Gealey, 1951). More recent mapping, however, shows that the southern part of the Healdsburg Fault Zone of Gealey exhibits Holocene movement and includes these southern fault traces as part of the Rodgers Creek Fault Zone (Herd and Helley, 1977; California Division of Mines and Geology, 1983; Schwartz and others, 1992; Hecker and others, 2005).

This geologic map (Map A, sheet 1; fig. 6) recognizes both Holocene and older faulting and consequently reveals more complexity in the Rodgers Creek Fault Zone northwest and southeast of the floodplain of Santa Rosa Creek than is shown on maps delineating only Holocene fault traces (fig. 6). The mapping shows that the southern segment of the Rodgers Creek Fault Zone is not along a straight line projection of the Healdsburg Fault segment of the fault zone beneath the Quaternary deposits of Santa Rosa Creek floodplain. The misalignment is interpreted to indicate a possible northeastward step of the southern Rodgers Creek Fault segment across the Santa Rosa Creek floodplain to the Healdsburg Fault segment, in contrast to previous geologic maps that infer the fault zone to be continuous (Fox and others, 1973; Fox, 1983; California Division of Mines and Geology, 1983). We prefer the interpretation of a small right-step, on the basis of the observed right-stepping regional geometry of the most recent segments of the fault zone. In this same area, prominent gravity and magnetic gradients along the southwest side of magnetic and gravity anomalies suggest a through-going connection between the southern Rodgers Creek and the Healdsburg Fault segments of the Rodgers Creek Fault Zone at depth (Chapter B; also Youngs and others, 1985); however the gravity and magnetic data do not preclude a right step in the fault zone at the surface. West-northwest- oriented air-photo lineaments mapped in Quaternary fan deposits of Santa Rosa Creek floodplain are not expressed in the gravity and magnetic data and if related to faulting, probably do not offset the bedrock by more than a few meters (Chapter B). The reader is referred to the above referenced publications and to numerous geotechnical studies of the Rodgers Creek Fault Zone for information on zoned active traces and site-specific studies in the Santa Rosa area (for example, Cooper, Clark and Associates, 1970; Cooper, Clark and Associates, 1976).

Southern Rodgers Creek Fault Segment-- The Southern Rodgers Creek Fault Segment of the Rodgers Creek Fault Zone enters the Santa Rosa quadrangle about 1.5 km west of the southeast corner of the quadrangle, where it consists of several fault strands that trend about N 15˚ W, and splay northward away from the ~N 50˚ W-trending Taylor Mountain Fault Zone. The Southern Rodgers Creek Fault Segment again changes trend to ~ N 43˚ W about 2 km north of the quadrangle boundary. This latter orientation is maintained by the fault zone segment to the northwest, where it projects beneath Holocene and Pleistocene alluvium northeast of the Sonoma County Fairgrounds. Directly south of the Santa Rosa quadrangle, the Southern Rodgers Creek Fault Segment bends into an ~ N 40˚ W trend (Clahan and others, 2003). The northward inflection in the trend of the Southern Rodgers Creek Fault Segment is aligned with a similar northward bend in the Bennett Valley Fault Zone north of Bennett Valley. This alignment is associated with the southeast side of a releasing bend pull-apart basin beneath Rincon and Bennett Valleys (fig. 6).

Northeast of Taylor Mountain, the Southern Rodgers Creek Fault Segment offsets basaltic to rhyodacitic rocks of the Sonoma Volcanics and gravel and diatomite of the Petaluma Formation, which are present along both sides of the fault zone. A thin sliver of serpentinite and gabbro (Jos) is locally exposed along the southwest side of the fault zone in this area. Approximately 900 m to the southeast, a small outcrop of Franciscan Complex metasandstone and mélange crops out beneath the Tertiary cover along a tributary of Matanzas Creek.

Although obscured by massive landslides along the east side of Taylor Mountain, the Southern Rodgers Creek Fault segment in that area is characterized by linear topography, spring lines and several small closed or elongate depressions parallel to strands of the fault zone. These features include a prominent 250 x 150 m elliptical basin along the fault about 200 m north of the southern boundary of the Santa Rosa quadrangle (locality 1, fig. 6) and another prominent elongate alluviated depression (loc. 2, fig. 6) ~ 0.5 km to the northwest, along a different strand of the fault. About 0.8 km east of Taylor Mountain, two small alluvial flats of probable Holocene age exhibit 250 to 430 meters of right-lateral separation along the southwesternmost strand of the fault zone (localities 3a and 3b, fig. 6). Northwest of the offset alluvial flats, the Southern Rodgers Creek Fault segment forms a prominent linear rift that extends to the alluviated floodplains of Matanzas and Santa Rosa Creeks. Northeast of the Sonoma County Fairgrounds, a prominent west-facing escarpment marks the contact of alluvial fan deposits with an upland underlain by the Petaluma Formation and Sonoma Volcanics (loc. 4, fig. 6). Closely spaced homes along the base of this escarpment obscure the trace of the Southern Rodgers Creek Fault segment in this area. Northwest of this escarpment, the fault segment projects beneath the floodplain and either steps or bends northeastward to emerge north of Santa Rosa Creek floodplain as the Healdsburg Fault segment of the Rodgers Creek Fault Zone.

Healdsburg Fault Segment-- The Healdsburg Fault segment of the Rodgers Creek Fault Zone extends northwestward from Santa Rosa and the confluence of Matanzas and Santa Rosa Creeks. The Healdsburg Fault segment is a zone about 1 km wide, of right-stepping fault strands that juxtapose Pliocene and Quaternary fluvial deposits, 5 Ma and younger Sonoma Volcanics, and older than 5 Ma strata of the Petaluma Formation. Mainshocks of the October, 1969 Santa Rosa earthquake sequence (fig. 6) are located along the southern part of the Healdsburg Fault Segment (Wong and Bott, 1998). Much of this fault segment is covered by residential development, and geomorphic features associated with the youthful faulting are modified considerably. However, aerial photos flown between the 1940's and 1980's show linear topography and closed and alluviated elongate basins with associated wetlands and ponds along the fault zone in the area of Santa Rosa Memorial Park and southeast of the Sonoma County Hospital complex (loc. 5, fig. 6). Southeast of the north edge of Santa Rosa quadrangle, over a distance of about 2 km, right-stepped strands of the fault zone are delineated by springs (loc. 6, fig. 6), a linear alluviated drainage (loc. 7, fig. 6), a small patch of ponded alluvium (loc. 8, fig. 6), a prominent right-lateral jog in a minor west-flowing drainage (loc. 9, fig. 6), and at least one sag pond (loc. 10, fig. 6). In this area several faults with components of oblique normal strike-slip splay north-northeast from the Healdsburg Fault segment, and parallel the west side of a structural basin beneath Rincon and Bennett Valleys.

Two lineaments, oriented about N 60˚W are defined by subtle alignment of minor tributaries in the alluvial fans of the Santa Rosa Creek drainage basin near Montgomery Village (sheet 1). These lineaments, if fault related, may be splays from the Matanzas Creek or Bennett Valley Fault Zones that connect with the Healdsburg Fault segment.

Southernmost Maacama Fault Zone and Mark West Fault

The Maacama Fault Zone is a major active right-lateral strike-slip fault that extends northwestward from the northeastern corner of the Santa Rosa 7.5' quadrangle for about 170 km to the vicinity of Laytonville, California (figs. 1 and 5). Parts of the Maacama Fault Zone in the Ukiah and Willits areas, north of the map area, exhibit fault creep (Harsh and others, 1978; Galehouse, 2002). North of Laytonville, the Maacama Fault Zone is more or less colinear and on-strike with steeply northeast-dipping strands of the Garberville Fault Zone and other faults having components of strike-slip and oblique reverse-slip, that extend offshore into the southern Cascadia Subduction Zone (McLaughlin and others, 2000; Castillo and Ellsworth, 1993).

The Maacama Fault Zone extends for less than a kilometer into the northeast part of the Santa Rosa 7.5' quadrangle, where it appears to merge with the Mark West Fault. The dominantly transtensional Mark West Fault projects along the base of the steep escarpment at the northeast side of Rincon Valley, toward the northern end of the Spring Valley strand of the Bennett Valley Fault Zone and the Melita-Los Guilicos and Northeast Kenwood Valley fault zones (fig. 6). These transtensional faults may collectively accommodate most of the dextral strike-slip partitioned from the Maacama Fault Zone.

Bennett Valley Fault Zone and Associated Faults

The Bennett Valley Fault Zone has been shown on previous geologic maps (Fox and others, 1973) as a sinuous fault zone comprised of a network of braided faults that extends for approximately 30 km southeastward from the Spring Valley Reservoir area east of Santa Rosa to Sonoma Valley (Fox, 1983). The fault zone exhibits evidence of latest Pleistocene displacement but was not considered to exhibit evidence of Holocene surface displacement (Fox, 1983; Herd and Helley, 1977). Surface expression of the fault zone, however, is obscured by landslides in many places. Seismicity occurs along the fault zone in Santa Rosa 7.5' quadrangle (Waldhauser and Ellsworth, 2000), indicating that the fault zone is active at depth along the east side of the Santa Rosa pull-apart basin, where the fault has strong geomorphic expression and offsets terrace and alluvial fan deposits of latest Pleistocene age. On the basis of its different orientation and geomorphic expression, the Spring Valley strand of the Bennett Valley Fault Zone is here described separately from the less well exposed Bennett Valley Fault Zone in the Bennett Valley and Bennett Mountain areas. The Spring Valley strand is considered to accommodate extensional right slip associated with formation of the Santa Rosa pull-apart basin. The regional distribution of seismicity (Waldhauser and Ellsworth, 2000) further suggests that the Bennett Valley Fault Zone and associated unnamed faults southeast of the map area are associated with northeastward partitioning of slip between the Rodgers Creek and the Maacama Fault Zones. For details of the geology of the Bennett Valley Fault Zone and associated faults in adjacent areas, see Wagner and others (2003).

Spring Valley Strand-- The Spring Valley strand is exposed east of the parking lot for Spring Valley County Park (locality 12, fig. 6), where an artificial diversion canal drains into Santa Rosa Creek Reservoir. Here, the fault zone is about 3 m wide, east side up, with a dip that varies from 70º E to vertical. In this canal, the fault zone cuts reddish-orange-stained clayey gravels considered to be of latest Pleistocene age (Herd and Helley, 1977; Knudsen and others, 2000; Witter and others, 2006). The gravels exhibit a conspicuous paleosol and carbonate-lined shears and fractures. The apparent reverse sense of fault slip is inconsistent with the overall extensional aspect of the faults bounding the Santa Rosa pull-apart basin. This kinematic inconsistency, however, may simply reflect near-surface fault-zone complexity or along-strike variation in fault dip. Alternatively, young (Holocene) contraction may overprint the pull-apart basin.

North of the reservoir the fault zone is covered by Holocene-Pleistocene (Qhpf) and latest Pliocene (Tgp) alluvial fan deposits of Rincon Valley and northwest Kenwood Valley. Extensive urbanization of these valleys has largely obliterated any geomorphic evidence of surface faulting. Inspection of 1942 vintage aerial photographs shows a few subtle north- to northwest-oriented topographic lineaments that extend toward the Maacama and Mark West Fault Zones, but none of these lineaments are through-going or connect to the mapped Spring Valley Fault strand of the Bennett Valley Fault Zone.

The 1954 U.S.G.S. topographic map shows a linear marsh and springs that are aligned with the Spring Valley strand of the Bennett Valley Fault Zone along the east side of Spring Valley (locality 13, fig. 6). The marsh is now covered by the reservoir. Consulting reports (Woodward, Clyde, Sherard and Associates, 1959), memoranda and photographs in files of the California Division of Safety of Dams (J. Howard, written and oral commun., 2006) provide further documentation of features consistent with latest Pleistocene or younger surface faulting along the east side of Spring Valley. North of Spring Valley this fault strand either has not ruptured to the surface in the Holocene or steps northeastward to the Mark West Fault Zone. A prominent aeromagnetic gradient that is coincident with the Spring Valley segment of the Bennett Valley

Fault Zone (Chapter B) at the north dam of Santa Rosa Creek Reservoir deviates westward in the alluviated area north of the dam, away from the mapped photo lineaments. This deviation would be consistent with a 1 km wide northeast step to the Mark West Fault (Chapter B, Figure 2) although other interpretations are possible.

Bennett Valley and Bennett Mountain area-- Along the southwest flank of Bennett Mountain and in the Kenwood 7.5' quadrangle, the Bennett Valley Fault Zone has a N 35º-40º W trend that differentiates this segment of the fault from the more northerly-striking Spring Valley strand (fig. 6, sheet 2). In the upland area of Annadel State Park, the fault zone cuts Sonoma Volcanics and is marked by aligned springs and the linear entrenched topography of the north fork of Matanzas Creek. Further to the southeast the fault zone trends into eastern Bennett Valley about 2 km east of the boundary of Kenwood quadrangle and aligns with the upper reaches (middle fork) of Matanzas Creek.

Matanzas Creek Fault Zone

The Matanzas Creek Fault Zone is inferred from a series of N 50º W to N 60º W-trending en-echelon topographic lineaments that bound the southwest side of Bennett Valley and local steep dips in juxtaposed Sonoma Volcanics and Petaluma Formation strata in Matanzas Creek (particularly at the southeast end of Matanzas Creek Reservoir and in the creek further to the southeast). In the adjacent Kenwood quadrangle, lineaments associated with the fault zone nearly merge with lineaments southwest of the main trace of the Bennett Valley Fault Zone. Along the northeast side of Bennett Valley Road and southeast of Bennett Valley School, the fault zone exhibits a prominent east-side-down scarp that is associated with seeps, suggesting that Holocene fan deposits of Bennett Valley may be faulted. However, the scarp and seeps are also close to the toe of a large landslide complex and thus may have origins more closely associated with the landsliding. A more detailed investigation of the scarp area will be necessary to determine the relative significance of faulting and landsliding.

Northeast Kenwood Valley Fault Zone and Related Faults

The Northeast Kenwood Valley, Mount Hood, and Plum Ranch Road Fault Zones extend along the northeastern side of Rincon and Kenwood Valleys (fig. 6). The Northeast Kenwood Valley Fault Zone dips steeply at the surface (cross sections B, C), where it places Pliocene fluvial gravels (Tgp), underlying basaltic andesite (Tsb) and the 4.65 Ma tuff of Napa-Healdsburg (Tst) on the southwest against the same down-dropped section on the northeast side of the fault zone. At depth, a structural low delineated by gravity data (the Northern Sonoma Valley Low) is present northeast of the surface trace of the fault (see cross section C and Chapter B). The Mount Hood and Plum Ranch Road Fault Zones along the northeast side of the northern Sonoma Valley low are also steep dipping and have a net component of down-to-the-southwest normal slip, consistent with their position along the northeast side of the basement low (cross sections B and C). Kinematic indicators on some segments of these faults indicate a component of dextral slip is associated with the normal faulting. One N 35º W-oriented fault that cuts Sonoma Volcanics and serpentinite between the Hood Mountain and Plum Ranch Road Fault Zones (loc. 19, fig. 6), exhibits kinematic indicators showing well defined dextral, up-to-the-southwest slip. This 1.5 km-long fault segment and a parallel aerial photo lineament along Weeks Creek immediately to the northeast align with the Maacama Fault north of the Santa Rosa quadrangle and may be structures associated with a right step from the Mark West Fault to the Maacama Fault.

Melita-Los Guilicos Fault Zone and Associated Faults

The Melita-Los Guilicos Fault Zone is mapped from the vicinity of Melita southeastward into the Kenwood quadrangle. Only a short segment of the fault zone is present in the map area, but regionally, this fault zone is 1-2 km wide, consisting of N 30º W- to N 40º W- trending, en-echelon to branching fault strands that offset the Sonoma Volcanics and Pliocene fluvial gravels (Tgp) along the southwest side of the northwestern Sonoma Valley.

Fluvial deposits (Tgp) bounded on the southwest by faults of the Melita-Los Guilicos Fault Zone appear to cover or fill part of the structural basin inferred from the northern Sonoma Valley gravity low (sheet 3, Chapter B, and fig. 6). These fluvial deposits may have been deposited during extensional strike-slip faulting, as proposed to explain a related gravity low (the Oakmont low) along the projection of the northern Sonoma Valley gravity low into the adjacent Kenwood quadrangle (Langenheim and others, 2005).

Thrust Faults and Transpressional Strike-Slip faults

Taylor Mountain Fault Zone, Cooks Peak Fault Zone and Associated Faults

The upland area southwest of the Rodgers Creek Fault Zone is broken by several northwest-trending faults of late Cenozoic age that have significant components of both dip slip and strike slip. The most through-going of these faults are the Taylor Mountain and Cooks Peak Fault Zones, both of which are truncated against the active Rodgers Creek Fault Zone near the south boundary of the map area.

Together, the Taylor Mountain and Cooks Peak fault zones have transpressionally uplifted and deformed the eastern margin of the Cotati basin. Along these structures, a highly disrupted sequence of ~ 8.0 Ma and younger Sonoma Volcanics and Petaluma Formation strata have been thrust northeastward, over Sonoma Volcanics that are largely 6.3 Ma or younger. Scattered occurences of 7.3-6.3 Ma rhyodacitic tuffs along the northeast side of the Taylor Mountain Fault Zone suggest that structural repetition (ie. folding and east-vergent thrust imbrication) of the juxtaposed age sequences extends northeast of the mapped Taylor Mountain Fault Zone, but the limits of this deformation are poorly defined.

The Taylor Mountain and Cooks Peak Fault Zones are here viewed as representing an early stage in the evolution of the Rodgers Creek Fault system and probably have accommodated a significant proportion of the total dextral slip attributable to the Rodgers Creek Fault Zone since the late Miocene. These fault zones seem to have evolved in at least three stages. Stage 1, about 7 to 6 Ma, involved down to the west normal faulting along the northeast side of the Santa Rosa Plain, in conjunction with the accumulation of coarse talus breccia shed from the basin margin fault scarps. Stage 2 (about 5.2 Ma or later) involved eastward thrusting along the Cooks Peak Fault Zone, that placed 6.3 to 8.0 Ma early Sonoma Volcanics and Petaluma Formation over 5.2 to 7.3 Ma volcanics and sediments. Stage 3 involved continued contraction and strike-slip along the anastomizing, imbricate, east-vergent Taylor Mountain Fault Zone, warping of the somewhat older Cooks Peak Fault Zone over a hanging wall antiform, and local dextral offset of parts of the Cooks Peak thrust zone by younger dextral reverse faults of the Taylor Mountain Fault Zone. The Cooks Peak and Taylor Mountain Fault Zones exhibit linear topography, spring lines and sag ponds along their length, suggesting that they remained active into Quaternary time.

Taylor Mountain Fault Zone-- The Taylor Mountain Fault Zone extends northwest from its truncation at the Rodgers Creek Fault Zone at the southern boundary of Santa Rosa quadrangle, to Kawana Springs Road, where it projects beneath alluvial fan deposits of the Santa Rosa Plain. The fault zone is offset by a short, discontinuous, north-oriented fault splay parallel to, but about 1 km west of, the main trace of the Rodgers Creek Fault Zone **(**locality 14, fig. 6**).** The fault zone consists of numerous subparallel steep-dipping braided fault strands that bound at least one discernible antiformal fold in the hanging wall of the northeasternmost fault strand (cross section C). The northeasternmost strand of the Taylor Mountain Fault Zone is the most continuous and separates the rhyodacitic rocks of Cooks Peak and Zamaroni Quarry (Tsr) and overlying fault-scarp-related talus breccia (Tprb) southwest of the fault from younger Sonoma Volcanics and Petaluma Formation strata to the northeast. The strands to the southwest of this northeastern strand are interpreted to root into it. A prominent sag pond and marshy alluvial flat are present along the fault zone at the end of Warrington Road (loc. 15, fig. 6). Two prominent sag ponds, about 2 km **(**loc. 16, fig. 6**)** and about 2.3 km **(**loc.17, fig. 6**)** to the northwest of the Warrington Road marsh, are associated with linear topography, spring lines and elongate alluvial flats. The northwesternmost sag pond is in the headwall of a prominent landslide, but it marks the top of an elongate topographic bench associated with the mapped fault strand.

Cooks Peak Fault Zone—The Cooks Peak Fault Zone, southwest of the Taylor Mountain Fault Zone, consists of a deformed thrust fault that dips 38˚-37˚ to the southwest. The fault zone is cut by steeper, southwest-dipping, dextral reverse faults of the same generation and orientation as reverse faults of the Taylor Mountain Fault Zone. Displacement on the younger faults has warped the hanging wall rocks (Tsr, Tprb and Tprg) of the Cooks Peak thrust into an antiformal fold in the hanging wall block of Taylor Mountain Fault Zone. The Cooks Peak Fault Zone is best exposed along the up-tilted northeast side of the ~8.0 Ma rhyodacite (Tsr) that underlies Cooks Peak, which is exposed along strike for about 3 km. Slickensided surfaces dug out along Warrington Road **(**loc. 18, fig. 6**)** show up-to-the southwest dextral reverse slip, consistent with the overall reverse-slip exhibited by the fault zone. Faults along the contact between Tsr and overlying breccias (Tprb) on the southwest side of Cooks Peak are mapped as down-to-the southwest normal faults and inferred to record stage 1 development of strike-slip-related basins now buried beneath Santa Rosa Plain (see above discussion).

Trenton Ridge and Possible Southwest-Vergent Thrusts beneath Taylor Mountain-- West of the map area, in the Sebastopol 7.5' quadrangle, a southwest- vergent thrust fault that places rocks of the Franciscan Complex over Pliocene strata of the Wilson Grove Formation was mapped by Blake and others (1971). From its exposure near Trenton, the fault extends southeastward through an area of dissected topography mapped as Pliocene and Pleistocene fluvial deposits (QTg), probably equivalent in part to the Glen Ellen Formation. These deposits locally exhibit anomalously steep dips, suggesting that they are also cut by the Trenton Thrust Fault. In the Santa Rosa quadrangle, the fault zone is covered by younger Pleistocene and Holocene alluvial fans of the Santa Rosa Creek floodplain and evidence for surface faulting is lacking.

Beneath the Santa Rosa plain, the Trenton Thrust Fault traverses the crest of a bedrock-basement ridge, the Trenton Ridge, indicated from gravity data (see Chapter B). The thrust fault does not follow the southwest margin of the basement ridge, as would be expected if it were a major bounding structure. This relation suggests that the Trenton Thrust Fault may be part of a more complicated structure that has evolved over a long period of time. A major fault, sub-parallel to the projected trace of the Trenton Fault in the Santa Rosa quadrangle, is hypothesized to lie along the steep gravity gradient that marks the southwest side of the inferred basement ridge; its approximate trace on the Mesozoic basement surface, inferred from the gravity data, is shown on the geologic map and structure sections **(**see also Chapter B**).**

Castle Rock Thrust--The Castle Rock Thrust is a southwest-vergent west-northwest-trending imbricate thrust zone mapped for about 2 km in the northeastern part of the Santa Rosa quadrangle. It continues at least several kilometers southeastward into the Kenwood quadrangle but its total length is unknown. The fault zone places Mesozoic Franciscan Complex rocks and the Coast Range Ophiolite over andesitic to rhyodacitic flows, breccias and tuffs of the Sonoma Volcanics, which are as young as 3.2 - 3.4 Ma. The Castle Rock Thrust is here considered to be of the same generation and geometry as the Gates Canyon and Petrified Forest Thrust Zones mapped immediately north in the Mark West Springs 7.5'quadrangle (McLaughlin and others, 2004). All of these thrusts merge with or abut the Maacama Fault Zone and offset 2.8 – 4.8 Ma Sonoma Volcanics and associated sedimentary rocks. Offset equivalents of these thrust zones have not been recognized on the west side of the Maacama Fault Zone. Movement along these thrust faults probably accounts for much of the latest Pliocene and younger contractional deformation responsible for the Mayacmas Mountains upland between the Napa Valley and the Sonoma and Rincon Valleys. This contractional deformation may still be occurring, as suggested by the youthful, steep dissected and incised topography of the Mayacmas Mountains. Earthquakes of magnitudes less than M 4, with focal mechanisms that favor northeast- or southwest-vergent thrusting also occur sporadically over a broad region east of the Maacama Fault Zone and west of the Sacramento Valley (Preiss and others, 2002; Wong, 1990; 1991). Seismicity in the map area, however, is dominated by strike-slip with components of transtension or transpression, and locally, by dominant extension (Wong, 1991; Wong and Bott, 1995).

Extensional Faulting Associated with Strike-slip Faulting and Basins

Although the structure in Santa Rosa and Kenwood 7.5' quadrangles is dominated by the major northwest-trending strike-slip faults of the right-lateral Rodgers Creek-Healdsburg-Maacama fault system, most of these faults exhibit variable components of transpressional and transtensional dip-slip, and some of them are dominantly compressional or extensional.

Extensional faults in the map area generally have N10°W to N20°W orientations, and many are curvilinear, bending northward (clockwise) from more northwesterly orientations that exhibit dextral slip. Faults with the most significant components of normal slip bound the relatively deep sedimentary basins in the map area, as defined by gravity data (Chapter B; also Langenheim and others, 2006a). These basin-bounding faults are covered or obscured by Quaternary deposits in many places. Other normal faults are parallel to the basin-margin faults and formed largely in response to west-southwest-east-northeast extension across the right-stepping Rodgers Creek-Healdsburg-Bennett Valley-Maacama fault system.

Most of the sedimentary basins in the region are interpreted as strike-slip-related basins. However, the sedimentary histories of these basins are variable, complex, and incompletely known. Sedimentary fill in some basins can be shown to be coeval with movements along the basin-bounding faults, whereas other deposits predate basin formation and represent structurally isolated remnants of pre-basin sedimentary sections. Sediment in some basins post-dates basin-margin faults at least in-part. Some extensional basins may be overprinted by younger transpression (McLaughlin and others, 2005b; Langenheim and others, 2006b; McLaughlin and others, 2006).

Extensional Strike-slip Faulting along northeast side of Santa Rosa Plain

Evidence for extensional strike-slip faulting along the northeast side of the Santa Rosa Plain comes from an extensive unit of breccia in the lower part of the Petaluma Formation (Tprb) largely composed of clasts of rhyodacitic volcanic rocks and minor intercalated lenses of fluvial gravel (Tprg). The breccia overlies the 7.9 Ma rhyodacite of Cooks Peak along the hanging-wall of the Cooks Peak Fault Zone. The breccia consists largely of unsorted ground up rock deposited as talus or debris flows, with many clasts having conspicuous slickensided surfaces. Most of the debris in the breccia appears to be derived from the rhyodacite of Cooks Peak and from the 7.3 Ma rhyodacitic rocks of Zamaroni Quarry. The breccia dips beneath the Santa Rosa plain southwest of Taylor Mountain and Cooks Peak and is interpreted to be a fault scarp breccia deposited along the eastern side of the Cotati basin. The unnamed normal fault at the base of the breccia is part of a system of transtensional strike-slip faults that bound the Cotati basin, that formed about 7 to 6 Ma. Other southwest-side-down normal faults of this system may be buried beneath the alluvial fill of the Cotati basin (cross section C). These normal faults represent the first stage of faulting associated with evolution of the Taylor Mountain and Cooks Peak Fault zones as described above. Northeast-vergent thrusting associated with the Taylor Mountain and Cooks Peak Fault Zones uplifted and exposed the extensional strike-slip margin of Cotati basin.

Recognition of 6 to 7 Ma fault-scarp talus breccia along transtensional faults at the uplifted northeastern edge of Cotati basin implies that the basin formed in an extensional setting prior to the modern Rodgers Creek Fault Zone, which truncates and offsets the breccia. We infer that the breccia is associated with early stages in the evolution of the Rodgers Creek and Healdsburg Fault Zones. The truncation of these earlier extensional faults and the Taylor Mountain and Cooks Peak Fault Zones by the active Rodgers Creek Fault Zone has additional implications for the history of slip transfer between faults of the Rodgers Creek-Healdsburg-Bennett Valley-Maacama fault system. Transfer of slip from the Rodgers Creek Fault to the Maacama Fault via the Bennett Valley Fault Zone and Santa Rosa pull-apart basin apparently postdates truncation of the older more northwest-trending Taylor Mountain and Cooks Peak Fault Zones by the Rodgers Creek Fault Zone. Any slip partitioned from the Healdsburg segment of the Rodgers Creek Fault Zone to the Maacama Fault must occur northwest of the Santa Rosa pull-apart basin, outside of the map area. It is not clear, however, how slip was partitioned eastward (if at all) prior to re-orientation and truncation of the Taylor Mountain and Cooks Peak Fault Zones.

Principal extensional faults bounding Santa Rosa Pull-apart Basin--The Santa Rosa pull-apart basin is a geomorphically youthful structural basin formed in the 5- to 6 km-wide dextral right step between the south end of the Maacama Fault Zone to the northeast and Rodgers Creek-Healdsburg Fault Zone on the southwest (fig. 6). The basin margins are moderately steep fault-controlled topographic escarpments.

Faults aligned with the northeastern escarpment of Rincon Valley include the Mark West, the Northeast Kenwood Valley, the Mount Hood and Plum Ranch Faults (fig. 6). The Northeast Kenwood Valley Fault is up to the southwest, dips steeply to the northeast and cuts across the southwest side of a prominent local subsidiary basin that predates the Santa Rosa pull-apart Basin and is delineated by gravity data (the northern Sonoma Valley gravity low, fig. 6; Chapter B; Sheets 2 and 3 and cross section C). The Mark West Fault Zone appears to align with and intersect the southernmost strands of the Maacama Fault Zone (see previous section on strike-slip faulting). However, the steep escarpment along the northeast side of Rincon Valley suggests that the fault may have a significant up-to-the-northeast component of normal slip there. The Mount Hood and Plum Ranch faults, as discussed in the strike-slip faulting section, exhibit components of normal slip, having accommodated extensional deformation along the northeast side of the Kenwood Valley. The Mount Hood and Plum Ranch faults could also have accommodated some younger slip during opening of the Santa Rosa pull-apart basin, although documented offsets constrain faulting only to be younger than the ~3.3 to 4.4 Ma fluvial and lacustrine deposits of Humbug Creek (unit Tgp).

Faults bounding the southwest side of Santa Rosa pull-apart basin include the Rodgers Creek and Matanzas Creek Fault Zones both of which are dominantly strike-slip faults described in the previous section.

The east side of the Santa Rosa Pull-apart basin is bounded by the Spring Valley strand of the Bennett Valley Fault Zone, also described and discussed in some detail in the section on strike-slip faulting. The north-trending orientation of the Spring Valley strand of the Bennett Valley Fault Zone is favorable for accommodation of significant dextral normal slip. Pure dextral and dextral normal slip are indicated in the fault zone at Spring Valley Reservoir County Park, where striae on fault surfaces plunge at 0 to 76 degrees.

An anomalously steep, somewhat curvilinear, north -oriented stepped escarpment along the western side of Rincon Valley is interpreted to be fault related. The inferred faulting is assigned to the Brush Creek Road Fault Zone (fig. 6). The western side of Rincon Valley is draped by undeformed Quaternary alluvial fan deposits (Qhpf) above tilted and folded silty to gravelly Pliocene-Pleistocene (0.8-1.2 Ma) fluvial deposits (QTg). The pronounced structural discordance **(**cross sections B and C**)**, suggests that the basin formed since ~1.2 Ma.

Subsidiary Extensional Faults--Several subsidiary branching and curvilinear normal faults are present between the Brush Creek Road Fault Zone and the Healdsburg Fault Segment of the Rodgers Creek Fault Zone. These include the south branch of the Larkfield Fault Zone and the Parker Hill Road-Detention Home Fault Zone. In the Santa Rosa 7.5’ quadrangle, these faults appear to be dominantly dip-slip faults that accommodate some of the extension generated between the Healdsburg Fault Segment and the Maacama Fault Zone. To the north, however, strands of the north branch of the Larkfield Fault Zone locally exhibit sinistral slip, suggesting that the kinematics of slip transfer in the right stepover are complex. Two strands of the Parker Hill Road-Detention Home Fault Zone exhibit prominent small basins with closed depressions and linear drainages (ie. locality 11, fig. 6) suggestive of control by late Pleistocene or younger faulting. These faults are inferred to be splays from the Healdsburg Fault Segment. Similarly, the south branch of the Larkfield Fault Zone is associated with elongate alluvial depressions, spring lines and local ponds and splays northward from the Healdsburg Fault Segment. Although its geomorphic expression strongly suggests Pleistocene displacement, it is not clear if the south branch of the Larkfield Fault Zone has ruptured in the Holocene.

Folds and Structural Highs and Lows

In the map area only a few folds are continuous enough to be mapped for significant distances at the surface. Although obscured by Quaternary deposits that post-date folding, the Rincon Valley and Melita synclines trend toward and presumably are offset by the Spring Valley strand of the Bennett Valley Fault Zone. Complex anticlinal folds (antiforms) in the Taylor Mountain area are generally associated with imbricate zones of thrust faults, which in places truncate or breach the folds at the surface.

Several major structures in the basement are inferred from the gravity data (Chapter B). Some structural lows (for example, Cotati and Windsor basins) have no clear surface expression.

The structural basins and highs are fault bounded and appear to be first order structures on which folds mapped at the surface are superposed (cross sections A-C, and figs. 5 and 6, Sheet 2).

The principal folds mapped at the surface (fig. 6) and the geology associated with structural highs and lows discussed in Chapter B, are briefly described below.

Rincon Valley and Melita Synclines

The RinconValley and Melita Synclines are mapped from northwest Rincon Valley southeastward to the junction of Rincon and northern Sonoma Valleys. In northwest Rincon Valley bedding (Fox and others, 1973) and marker beds mapped from air photos (this study) in Pliocene and Pleistocene gravels (QTg) clearly delineate a synclinal fold that plunges southeastward beneath unconformably overlying Pleistocene and younger deposits. Along the steep escarpment bounding the northeast side of Rincon Valley, the fluvial gravels of unit Tgp dip southwest, toward the projected axis of the Rincon Valley syncline and these gravels are inferred to underlie unit QTg beneath central Rincon Valley (cross sections B and C). The axis of the Rincon Valley Syncline projects toward the northward projection of the Spring Valley Segment of the Bennett Valley Fault Zone northwest of Melita, but it is not clear if it is offset by the fault zone due to Quaternary cover deposits and modification of the area by residential development since the 1950's. The Melita syncline, east of the projection of the Spring Valley Segment of the Bennett Valley Fault Zone, is inferred from bedding attitudes in unit Tgp and flow structures in the Sonoma Volcanics but its location is not well constrained and hence this feature is shown only on the structure index map (fig. 6). A direct connection of the axes of Rincon Valley and Melita Synclines is precluded by the uncertainty of continuation of the Spring Valley segment of the Bennett Valley Fault Zone beneath northern Sonoma Valley.

Calvary Cemetary and Bennett Valley-Grange Hall Synclines

Northwest-striking folds are present along the southwest side of Bennett Valley (fig. 6), where they are superposed on the Bennett Valley structural high. The Calvary Cemetary Syncline is defined largely on the basis of bedding attitudes in strata of the Petaluma Formation (Tp). The Bennett Valley-Grange Hall Syncline is defined on the basis of bedding attitudes and by a marker zone of diatomaceous shale (Tpd), interbedded with Petaluma Formation gravel and siltstone (Tp) and Sonoma Volcanics, that wraps around the southeast side of the fold. Although obscured by landsliding, continuity of the marker zone in the southwest limb of the Bennett Valley-Grange Hall Syncline suggests the fold continues northwestward between the Southern Rodgers Creek Segment and the Matanzas Creek Fault Zone. Thus the Calvary Cemetary Syncline and the Bennett Valley-Grange Hall Syncline may be connected.

Holland Drive Antiform

The Holland Drive Antiform is a northwest-striking fold between the Southern Rodgers Creek segment of the Rodgers Creek Fault Zone and the Calvary Cemetary Syncline. The antiform appears to tightly fold a sequence of andesitic flows and breccia and rhyodacitic tuffs and intrusive rocks. This structure continues for about 1.5 km along-strike southeast of Holland Drive, beyond which it is not discernible.

Taylor Mountain Antiform and associated Folds Southwest of the Rodgers Creek Fault Zone

The Taylor Mountain Antiform is distinguishable for about 1.5 km along the southwest flank of Taylor Mountain. The fold is flanked to the northeast by the Taylor Mountain Fault Zone and to the southwest by steep dip-slip faults and Cooks Peak Fault Zone. This structure is interpreted as a fault-breached anticline in the hanging wall block of the Taylor Mountain Fault Zone (cross section 2).

Two other en-echelon folds sub-parallel to the Taylor Mountain Antiform have been mapped for distances of about 0.5 km. These folds, one synclinal and the other anticlinal, are based on map relations in highly faulted, poorly exposed terrain and appear to be local features only.

Immediately east of the Sonoma County Fairgrounds and southwest of the Southern Rodgers Creek segment of the Rodgers Creek Fault Zone, several tight, discontinuous folds with northeast trends are mapped in gravel and diatomite (Tpd) of the Petaluma Formation interbedded with Sonoma Volcanics. The axes of these folds are truncated by the active Southern Rodgers Creek segment and their orientation suggests they formed within a stress field unrelated to the presently active strike-slip faults or they are in a clockwise-rotated fault block.

Geophysically Inferred Structural Highs and Lows

Weeks Creek High

In the northeastern corner of the Santa Rosa 7.5' quadrangle Mesozoic basement rocks consisting of melange of the Franciscan Complex Central Belt and rocks of the Coast Range Ophiolite form a basement block associated with gravity and magnetic anomalies. The Weeks Creek High that strikes east-southeast into the Kenwood quadrangle is defined on the basis of a gravity high that probably reflects dense Franciscan Complex rocks (Chapter B). The Weeks Creek High is flanked by the Castle Rock Thrust and a normal fault cutting the thrust to the northeast and by the Plum Ranch and Mount Hood normal faults to the southwest.

Magnetic highs apparently reflect several narrow zones of serpentinite mapped along imbricated and folded thrust faults in the Franciscan Complex rocks bounded by the Mount Hood and Plum Ranch Fault Zones (cross sections B and C).

The Weeks Creek Fault, a northeast-dipping normal fault, bisects the upthrown block of Franciscan Complex and ophiolitic basement with no obvious expression in the magnetic or gravity data. The Castle Rock Thrust and younger normal fault that bound the northeast side of the Weeks Creek high apparently juxtapose Franciscan Complex and ophiolitic basement rocks to the southwest, against a thick section of comparably less dense and non-magnetic Sonoma Volcanics and gravels northeast of the fault. The geometry of faults bounding the Weeks Creek High suggest that the fault block has an overall horst-like geometry (Sheet 2, cross section C; see also Chapter B).

Northern Sonoma Valley Structural Low

The Northern Sonoma Valley Low was previously discussed in the context of the Melita-Los Guilicos Fault Zone. Significantly, the gravity low does not follow the axis of the present northern Sonoma Valley but crosses the valley obliquely. The gravity low extends beneath the northeast side of Rincon Valley, apparently reflecting a basement depression located northeast of the Melita and Rincon Valley synclines (cross sections B and C; fig. 6; figs. 7 and 8, Chapter B). This basement depression appears to be filled with 4.6- 4.8-Ma Sonoma Volcanics and minor Pliocene gravels (Tgp) and is likely floored by rocks of the Franciscan Complex structurally interleaved with rocks of the Coast Range Ophiolite.

Formation of the Northern Sonoma Valley basement depression must partly postdate the 4.8 - 4.6-Ma and younger Sonoma Volcanics and overlying 4.5 to 3.1 Ma gravels of Humbug Creek (Tgp). Earlier initiation of the structural depression is possible, although no definitive sedimentologic data link deposition to faults bounding the inferred structural low. Paleoflow in the Pliocene Gravels of Humbug Creek (Tgp) was toward the northwest, in what appears to have been a through-going fluvial system. No basin margin-facies are recognized in these deposits, although the paleoflow data suggest that uplands topography existed to the northeast by the time of gravel deposition 4.5 to 3.1 Ma.

Bennett Valley High

The Bennett Valley High is a significant basement high that underlies much of the Santa Rosa pull-apart basin. The northeast side of the high is approximately bounded by the Bennett Valley Fault Zone and the southwest side is approximately bounded by the Rodgers Creek Fault Zone (fig.6; Chapter B, figs.7 and 8). This structural high appears to locally affect the course and orientation of faulting and the location of seismicity in the right-stepped area between the Southern Rodgers Creek segment of the Rodgers Creek Fault Zone and the Bennett Valley and Maacama Fault Zones (Chapter B).

The Bennett Valley High extends southeastward beneath central and southwest Bennett Valley, where the oldest exposed rocks are 4.5 – 5.0 Ma andesitic flows and breccias of the Sonoma Volcanics. Unlike the Weeks Creek High, the Bennett Valley High is not obviously coincident with surface exposures of Mesozoic basement rocks. Although the geometry of this gravity high indicates that dense basement rocks are close to the surface, the deepest water wells in this area (approximately ≤ 200 m) bottom in basaltic andesites of the Sonoma Volcanics (Tsb). However, along the Southern Rodgers Creek segment of the Rodgers Creek Fault Zone, slivers of ophiolitic rocks and Franciscan Complex rocks are exposed at the surface in a few places.

Folds on the southwest side of the Bennett Valley High, which include the Taylor Mountain Antiform and several small-amplitude folds near the Sonoma County fairgrounds (fig. 6), are mostly in the hanging walls of northeast-vergent reverse faults associated with uplift and exhumation along the northeast side of Santa Rosa Plain and Cotati Basin. These and other small folds are not obviously expressed in the gravity data, due perhaps to rooting of the folds and associated thrusts above the shallow top of the Mesozoic basement **(**cross section C) or to fold amplitudes too small to resolve in the gravity survey (see Chapter B).

Trenton Ridge High

The Trenton Ridge High, as indicated in the earlier discussion of the Trenton Fault, is a poorly understood structure that includes the southwest-vergent Trenton thrust fault but appears to be underlain by other deeper faults and (or) folds. The ~ S 60°E trending Trenton Ridge High extends into the Santa Rosa quadrangle west of downtown Santa Rosa, approximately in line with the northwestward projection of the northeast-vergent Taylor Mountain and Cooks Peak thrust zones. A recently drilled water well (fig. 5) just north of the crest of the Trenton Ridge High in westernmost Santa Rosa quadrangle, however, failed to reach Mesozoic basement, encountering strata of the Miocene and Pliocene Petaluma Formation to a depth of 213 m (700 feet). No wells are known to have penetrated Mesozoic basement in the vicinity of the ridge crest (Valin and McLaughlin, 2005; E. Taylor, USGS, written commun., 2006).

Windsor Basin Low

The southeastern part of the Windsor Basin is associated with a prominent gravity low (Chapter B) that extends into the northwestern part of the Santa Rosa 7.5' quadrangle beneath Santa Rosa Plain northeast of Trenton Ridge High and southwest of the Healdsburg segment of the Rodgers Creek Fault Zone. The gravity data (Chapter B) suggest that the Windsor Basin is about 1-2 km deep at the northwest corner of Santa Rosa quadrangle. Exposures on the uplifted northeastern side of the Windsor Basin include the 6.3 Ma Roblar tuff, the 4.83 Ma Lawlor Tuff, and 4.9 -5.0 Ma andesitic rocks of the Sonoma Volcanics, intercalated with the Petaluma Formation. These deposits are overlain (probably unconformably) by 2.8-Ma and younger tilted and folded Pliocene and Pleistocene fluvial strata, which are in turn overlain unconformably by Pleistocene and Holocene alluvial fan deposits. The section of Pliocene and Pleistocene fluvial deposits in the adjacent Mark West Springs and Healdsburg quadrangles is significantly thicker and more continuous than strata of equivalent age on the southwest (Cotati basin) side of the Trenton Ridge High (McLaughlin and others, 2004; and McLaughlin, unpublished field data).

Pliocene and Miocene (6.3 Ma and younger) shallow marine strata of the Wilson Grove Formation are exposed along the west side of the Windsor Basin Low west of the Santa Rosa quadrangle. The Wilson Grove Formation apparently interfingers with coeval fluvial and estuarine facies of the Petaluma Formation beneath the Windsor Basin. The relationship of the Neogene fill of the Windsor Basin to the fill in basins south of the Trenton Ridge High is not clearly defined at present.

Bellevue Low of Cotati Basin

A prominent west-northwest-trending basin low beneath the Holocene and Pleistocene alluvial fans and basin deposits of the Santa Rosa Plain is south of the Trenton Ridge High. Gravity data (Chapter B) together with the surface and subsurface geology suggest that this gravity low, here referred to as the Bellevue Low (delineating one of several subsidiary gravity lows that collectively form the greater Cotati basin), is filled with about 2 km of sedimentary and volcanic deposits. The Bellevue Low is flanked to the northeast by the uplifted Cotati basin margin, which includes structurally disrupted volcanic and sedimentary rocks on the southwest side of the Taylor Mountain and Cooks Peak Fault Zones. Subsurface information from deep water wells and several oil and gas exploration wells indicate the basin fill includes 8.0 - 5.0 Ma Sonoma Volcanics and intercalated strata of the Petaluma and Wilson Grove Formations, unconformably overlain by about 160 m of Quaternary to late Pliocene alluvial and lacustrine deposits (cross sections B and C).

The Bellevue Low and the geometry of the Cotati Basin has recently been studied in the context of earthquake hazards (McPhee and others, 2005; McPhee and others, 2007). During the M 7.9 San Francisco Earthquake of 1906 and again during the moderate M 5.6-5.7 earthquake sequence along the Healdsburg segment of the Rodgers Creek Fault in 1969 (Steinbrugge, 1970; Wong and Bott, 1995; Hecker and Kelsey, 2006), the downtown area of Santa Rosa was heavily damaged by seismic shaking. The geometric configuration of thick sedimentary fill in the northeastern Cotati Basin strongly influenced the distribution of damage during both of these earthquake events (McPhee and others, 2005; McPhee and others, 2007).

CHAPTER B. GEOPHYSICAL FRAMEWORK OF THE SANTA ROSA 7.5' QUADRANGLE, CALIFORNIA

By V.E. Langenheim, R.J. McLaughlin , D.K. McPhee, C.W. Roberts, and C.A. McCabe

INTRODUCTION

Nearly half of the Santa Rosa 7.5’ quadrangle, California, is located within the Santa Rosa Plain (fig. 7). This region is covered by young sedimentary deposits that may mask key structural elements related to the development of the transform margin east of the San Andreas fault. The center of the quadrangle is traversed by the Rodgers Creek and Healdsburg Faults, major faults within the San Andreas system north of San Francisco. The faults are aligned, but their connection is covered by young deposits near downtown Santa Rosa.

Gravity and magnetic data are useful for projecting the geology mapped at the surface into the subsurface. Gravity data reflect density variations within the upper and middle crust and are particularly well suited for determining the shape of Cenozoic basins because of the significant density contrast between dense Mesozoic basement rocks and lighter Cenozoic rocks. Magnetic data reflect magnetization variations within the crust and are well suited for mapping the distribution of rock types that contain magnetite. In the Santa Rosa 1:24,000-scale quadrangle, these rock types include serpentinite and some generally more mafic rock types within the Sonoma Volcanics.

This chapter discusses various gravity and magnetic anomalies within the Santa Rosa quadrangle. Several filtering techniques were used to enhance anomalies produced at different depths within the crust. In particular, gravity anomalies over the Santa Rosa Plain define a complex basin configuration that provides a foundation for groundwater flow models and ground motion simulations. Gravity and magnetic data map the connection between the Rodgers Creek and Healdsburg faults beneath downtown Santa Rosa. These data also define a dense, mafic block beneath Bennett Valley that may influence development of the Santa Rosa pull-apart basin (fig. 7).

GRAVITY AND MAGNETIC DATA AND METHODS

About 460 gravity stations were used to produce an isostatic gravity map of the quadrangle (Map B; fig. 8). Sources of data include surveys by the California Geological Survey (formerly the California Division of Mines and Geology; Chapman and Bishop, 1974; Youngs and others, 1985), and the U.S. Geological Survey (this study; Langenheim and others, 2006a). Gravity stations are non-uniformly distributed in the region (Map B). Station spacing is on average 1 station per 1 km^2. Detailed profiles which were collected to support geothermal resource assessments in the area, cover downtown Santa Rosa and the southern part of Bennett Valley (Youngs and others, 1985). Accuracy of the data is estimated to be on the order of 0.1 to 0.5 mGal. For details on processing of these data, see Langenheim and others (2006a).

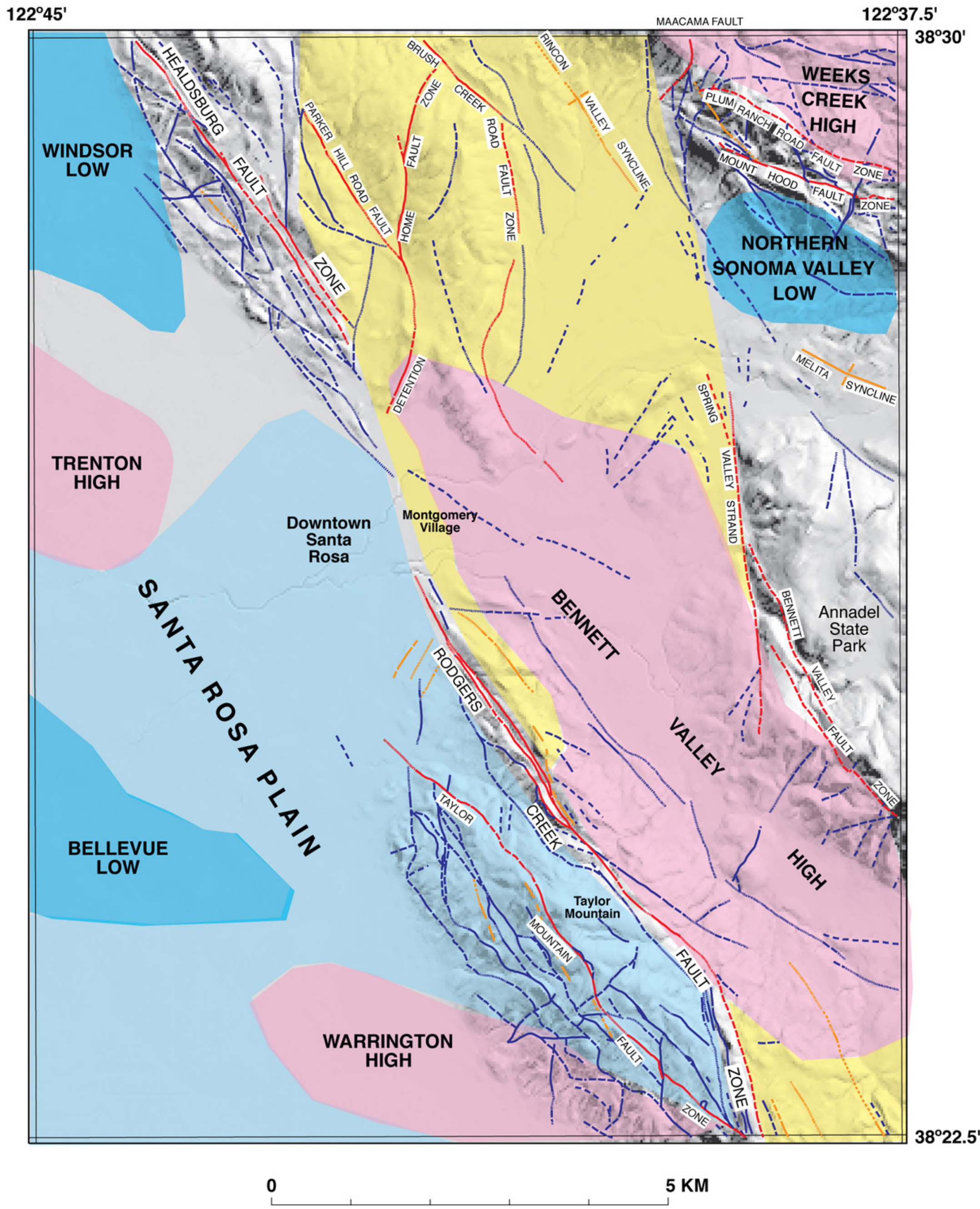


Figure 7. Index map of geographic and geophysical features. Gravity or structural highs shown in pink, gravity or structural lows shown in blue. Pale blue is outline of larger Cotati Basin within the Santa Rosa quadrangle. Yellow outlines extent of the Santa Rosa pull-apart basin.

Magnetic data consist of total-field observations collected along flight lines oriented east-west, flown at 300 m above the land surface, and spaced 500 m apart (U.S. Geological Survey, 1997). Because of topographic relief in some places, the aircraft was not always able to maintain a constant altitude above the ground surface and typically passed closer to the ridge tops (as close as 176 m) than to the bottoms of the intervening valleys (as far as 480 m). Data were collected about every 10 m along the flight lines.

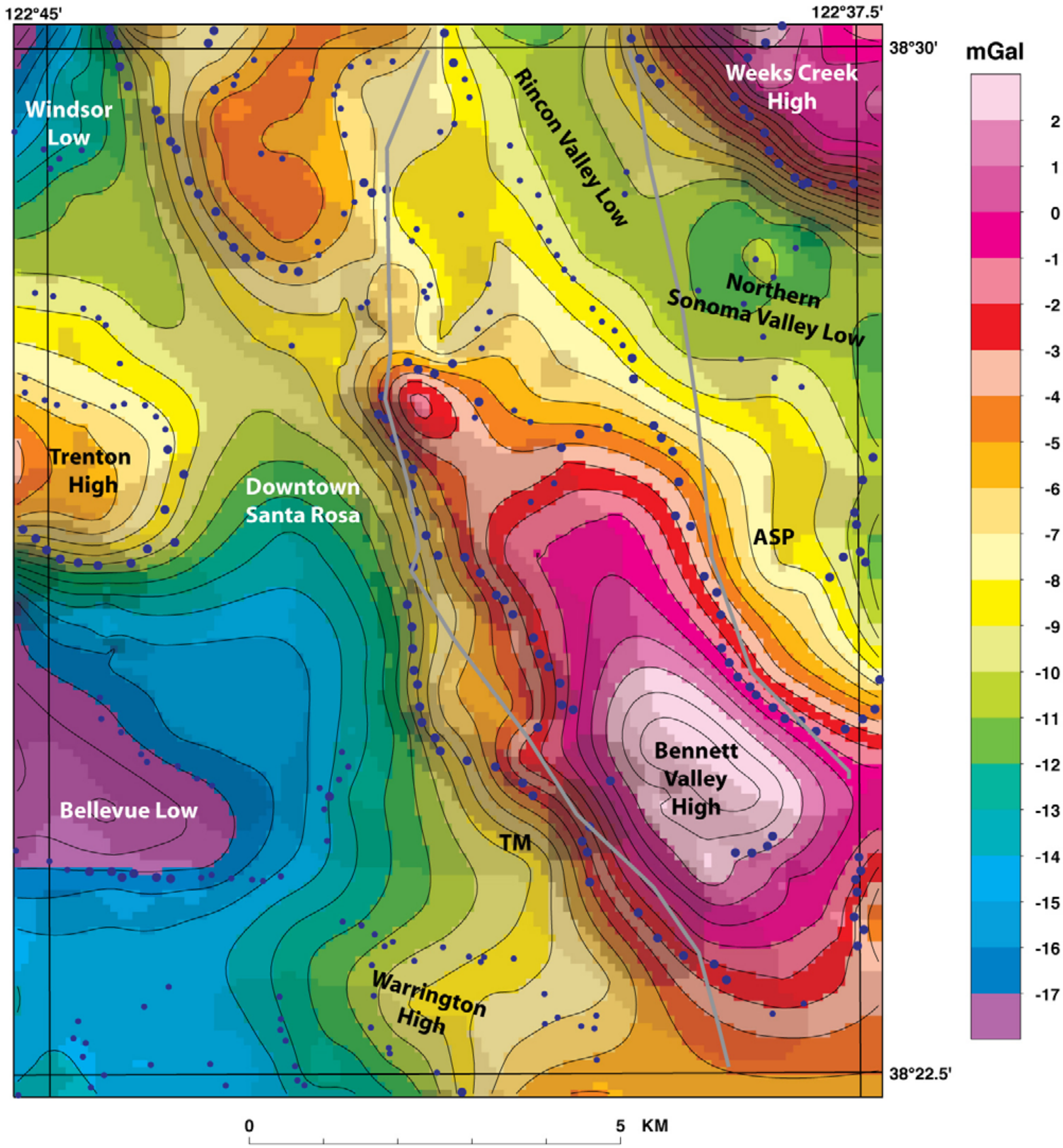


Figure 8. Color-contour version of the isostatic gravity field. Dark blue dots mark density boundaries. ASP, Annadel State Park; TM, Taylor Mountain. Gray lines mark extent of the Santa Rosa pull-apart basin.

The aeromagnetic data were corrected for diurnal fluctuations in the Earth's field and the International Geomagnetic Reference Field (Langel, 1992), updated to the dates of the survey, was subtracted from the observations to yield total-magnetic-field anomalies. The anomaly values were interpolated to a square grid (grid interval, 200 m x 200 m) using a minimum curvature algorithm (Briggs, 1974) and are represented by contours on top of geology (Map C) and in color-contour form (fig. 9).

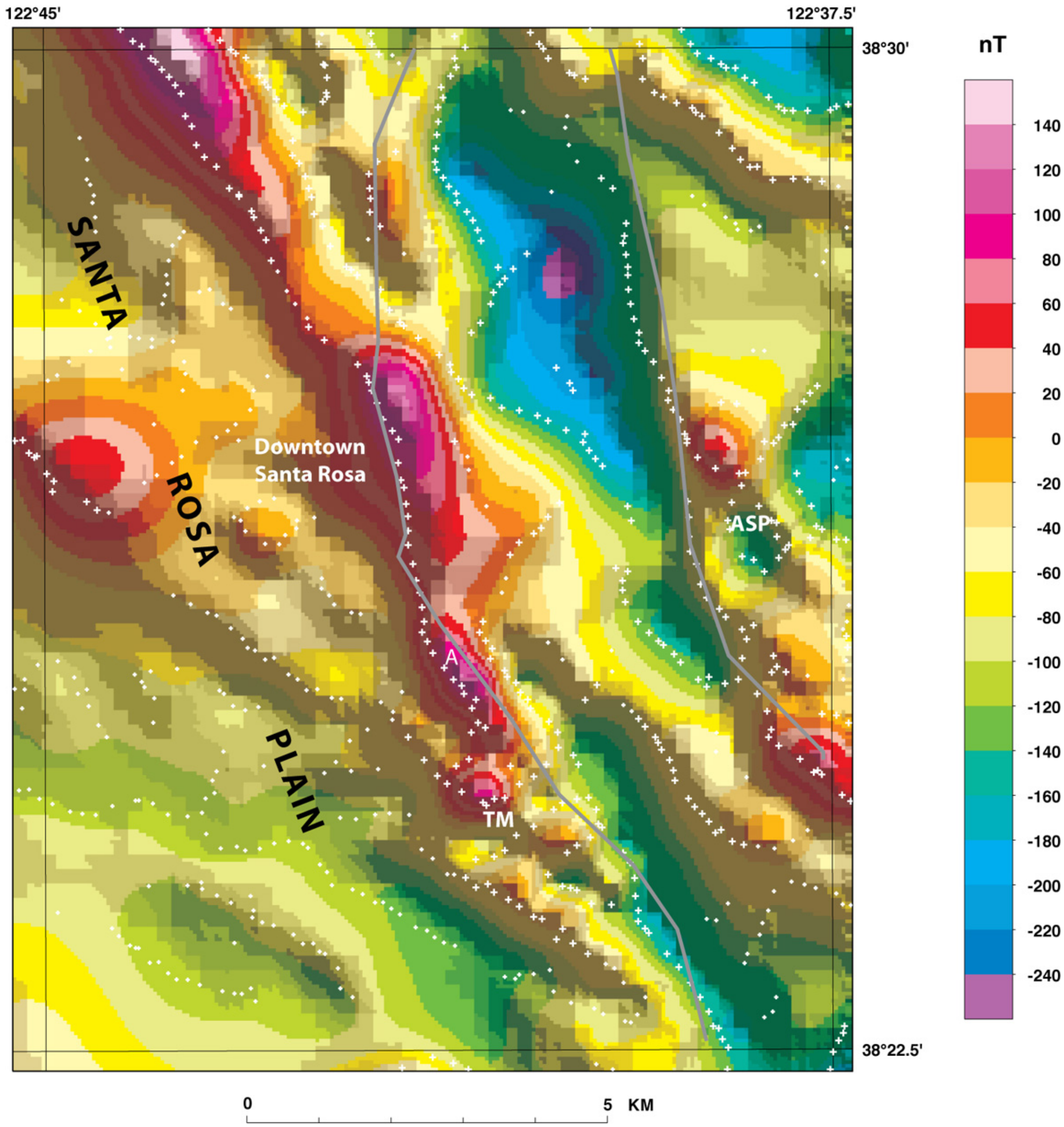


Figure 9. Color-contour version of the aeromagnetic field. White crosses mark magnetic boundaries. A, aeromagnetic anomaly west of the Rodgers Creek Fault Zone discussed in text. ASP, Annadel State Park; TM, Taylor Mountain. Gray lines mark extent of the Santa Rosa pull-apart basin.

Filtering Methods

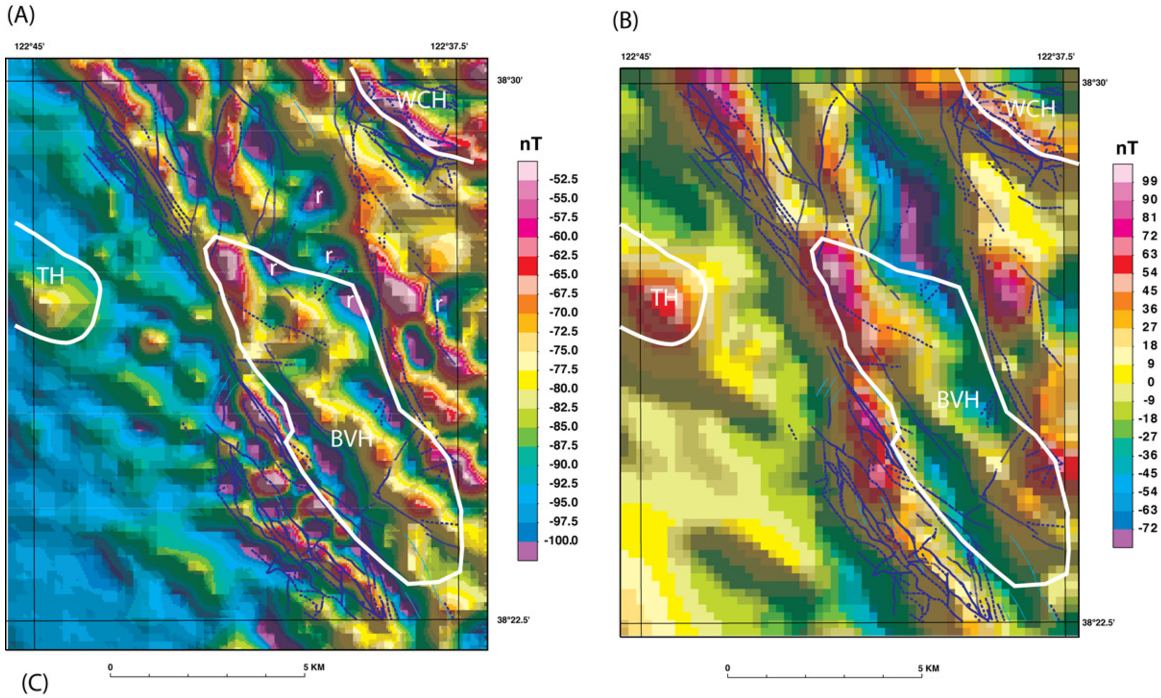
Gravity and magnetic anomalies are produced by a variety of sources of variable size and depth. Superposition of anomalies from multiple sources can result in interpretational ambiguities. For example, both Mesozoic serpentinites and some Tertiary volcanic rock types are capable of producing magnetic anomalies but may be characterized by anomalies of differing wavelengths (or characteristic length). Shallow sources typically cause short-wavelength anomalies, whereas deep sources cause long-wavelength anomalies. Generally, the Tertiary volcanic rocks, comparatively thinner and shallower than Mesozoic serpentinite or ophiolite, should produce shorter-wavelength, noisier anomalies. Several analytical techniques were applied to the geophysical data to distinguish particular anomaly characteristics, such as wavelength or trend.

To emphasize both short-wavelength anomalies caused by shallow sources (for example Tertiary volcanic rock) and long-wavelength anomalies (for example serpentinite or ophiolite), a match filter was applied (Phillips, 2001). Match filtering separates the data into different wavelength components by modeling the observed anomalies as a sum of anomalies from distinct equivalent source layers at increasing depths (see Phillips, 2001). Figure 10 shows the resulting separated fields produced by the dipole equivalent-source layers at 0.44, 1.22, and 3.41 km depths. Another method, the first vertical derivative of the magnetic data (fig. 11), suppresses longer-wavelength trends caused by more deeply buried magnetic rock types (Blakely, 1995). A third method to sharpen the effects of near-surface sources involves analytically upward continuing the magnetic or gravity field by a small interval (100 m for the magnetic data; 1 km for the gravity data because of the non-uniform distribution of gravity stations) to generate a regional or smoothed field. Upward continuation is the transformation of magnetic or gravity data measured on one surface to those that would be measured on a higher surface (farther from the source); this operation tends to smooth the data by attenuation of short-wavelength anomalies (Dobrin and Savit, 1988). This smoothed, upward continued field is then subtracted from the unfiltered field to produce a residual field. The unfiltered and residual fields (figs. 8 and 12 for the gravity field, figs. 9 and 13 for the magnetic field) illustrate the effectiveness of this approach to highlight subtle geologic features. Note that the various versions of the magnetic field filtered to enhance shallow or high-frequency anomalies (figs. 10a, 11, 13) show similar features.

To help delineate structural trends and gradients expressed in the gravity field, a computer algorithm was used to locate the maximum horizontal gravity gradient (Cordell and Grauch, 1985; Blakely and Simpson, 1986). Concealed basin faults beneath the valley areas on the Santa Rosa quadrangle were mapped using horizontal gradients in the gravity field (red circles on Map B). Gradient maxima occur approximately over steeply dipping contacts that separate rocks of contrasting densities. For moderate to steep dips (45° to vertical), the horizontal displacement of a gradient maximum from the top edge of an offset horizontal layer is always less than, or equal to, the depth to the top of the source (Grauch and Cordell, 1987). Magnetization boundaries (Map C) were calculated in a similar way as described in Blakely and Simpson (1986), using the magnetic potential field produced from the residual magnetic field shown in figure 13.

GEOPHYSICAL ANOMALIES

The isostatic gravity data reflect density variations within the upper to middle crust (Simpson and others, 1986). Dense rock types are Mesozoic basement rocks and the basaltic-andesite flows in the Sonoma Volcanics and outcrops of these rock types should coincide with gravity highs. A gravity high reaching an amplitude of +2 mGal is present over exposed Franciscan Complex rocks in the northeast corner of the map area. A small outcrop of Franciscan rock (fcm) within the Healdsburg Fault is located at the edge of a modest gravity high north of downtown Santa Rosa. However, the most prominent gravity high within the quadrangle is present within Bennett Valley (values of +4 mGal) and is not marked by extensive outcrops of either Franciscan Complex or serpentinite. The western edge of the Bennett Valley gravity high coincides with the complex zone of faulting associated with the Rodgers Creek Fault; its eastern edge roughly coincides with the southernmost 4-5 km extent of the Bennett Valley Fault Zone.



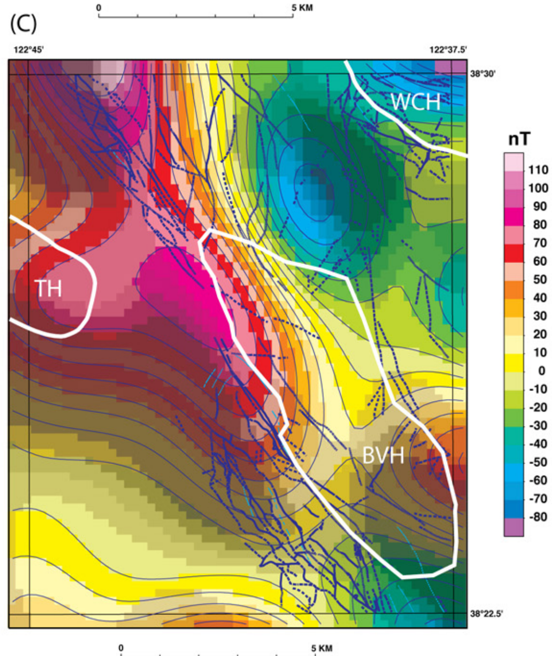


Figure 10. Match-filtered versions of the aeromagnetic field. (A) Shallow sources, equivalent depth of 0.44 km. "r", magnetic lows that may be caused by reversely polarized flows in the Sonoma Volcanics. (B) Medium-depth sources, equivalent depth of 1.22 km. (C) Deep sources, equivalent depth of 3.41 km. White lines outline gravity highs discussed in the text. BVH, Bennett Valley high; TH, Trenton high; WCH, Weeks Creek High. Dark blue lines are faults from Map A.

The source of this gravity high is not obvious from surface outcrops. A small outcrop of serpentinite (Jos) in the Rodgers Creek Fault Zone is located above the horizontal gradient marking the western edge of the Bennett Valley gravity high. A small outcrop of Franciscan Complex (fcm) is exposed in a deeply incised drainage less than 1 km to the southeast of the serpentinite. This indicates that Mesozoic basement rocks may be relatively close to the surface and that the source of the Bennett Valley gravity high may be dense mafic and ultramafic rocks associated with the serpentinite (see discussion in Chapter A). Another source candidate, however, is dense basaltic andesite of the Sonoma Volcanics (Tsb). These rocks are extensively exposed throughout the Santa Rosa quadrangle but do not always coincide with gravity highs. For example, the area east of the Bennett Valley fault zone in Annadel State Park and the hills north of downtown Santa Rosa are

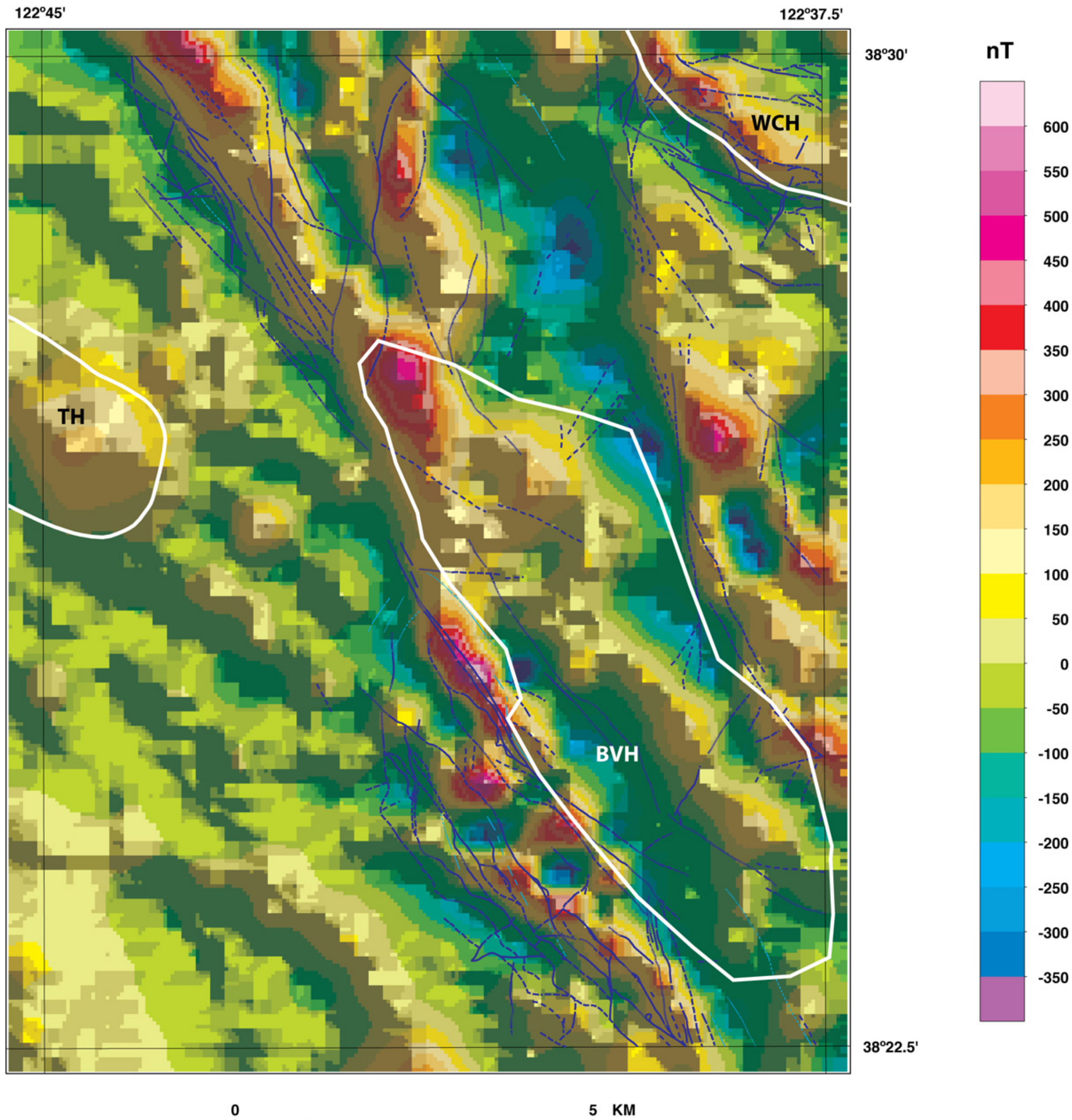


Figure 11. First vertical derivative of the magnetic field (shifted over its sources). See Figure 10 for explanation. Dark blue lines are faults from Map A.

both characterized by values of -5 mGal or less. Furthermore, a minimum thickness of 1-2 km of basaltic-andesite is required to account for the 5-10 mGal anomaly, assuming a density contrast of 0.10 g/cm^3 relative to the average crustal density (2.67 g/cm^3) and assuming an infinite slab geometry. An oil-test well (Williams Jacobs No. 1) located about 1.5 km east of the southeast corner of the quadrangle encountered "basalt" at a depth of 305 m (Youngs and others, 1985). Despite a minimum thickness of 390 m of basalt encountered in this well, the gravity value at the well is still 10 mGal lower than the apex of the Bennett Valley gravity high. This means that if basaltic andesite is the source of the Bennett Valley gravity high, it still would need to be ~1.5 km or thicker in Bennett Valley. This is unlikely given the thickness of these volcanic rocks known from regional geologic mapping.

The absence of an equivalent magnetic high, either in the unfiltered (fig. 9) or filtered fields (fig. 10), coincident with the Bennett Valley gravity high suggests that the source is not highly

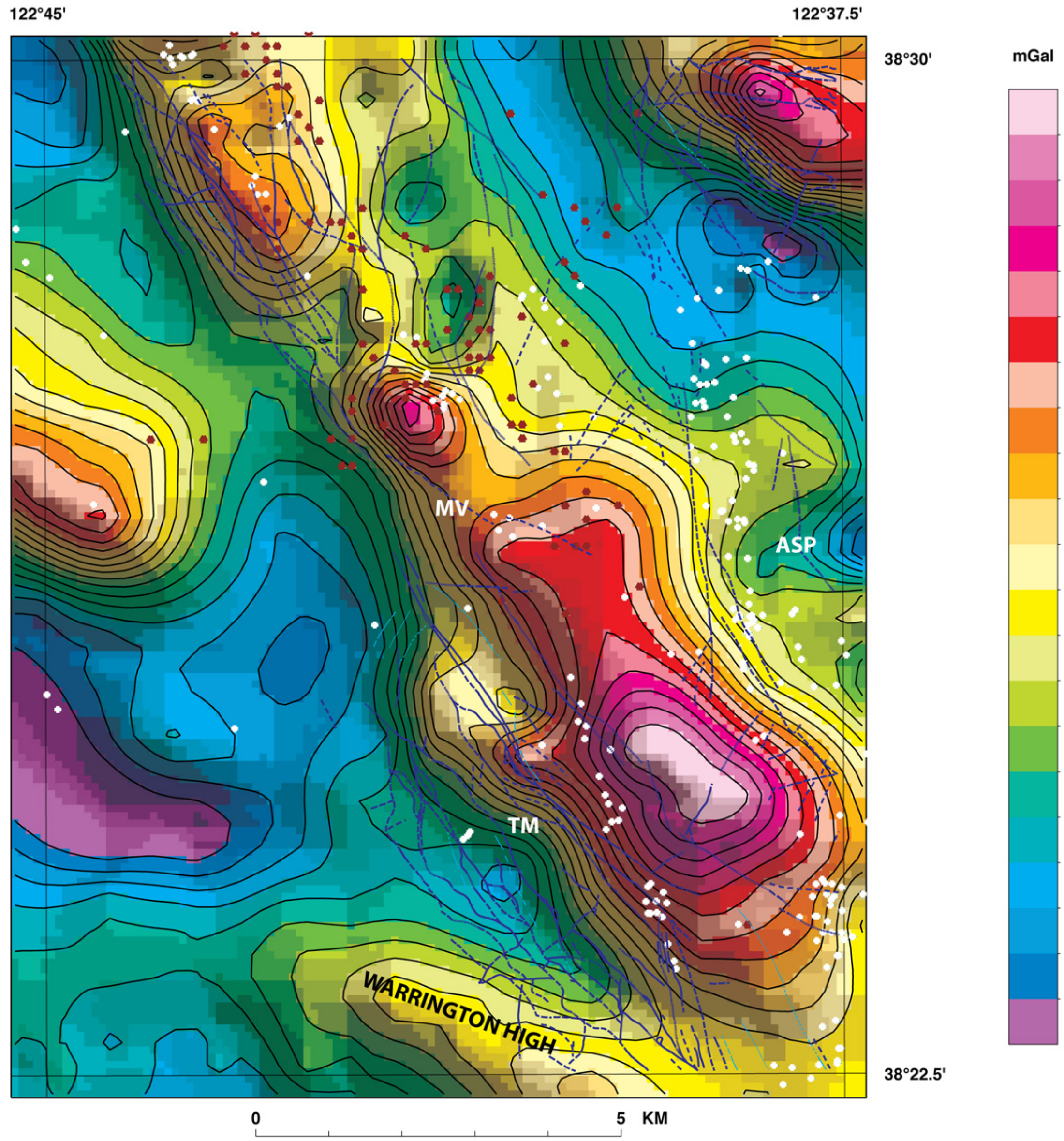


Figure 12. Residual gravity field after subtraction of upward-continued field. MV, Montgomery Village. White dots, double-difference relocated seismicity of Waldhauser and Ellsworth (2000). Brown dots, aftershocks of the 1969 Santa Rosa earthquakes (J.D. Unger and J.P. Eaton, written commun., 1970; Wong and Bott, 1995). Dark blue lines are faults from Map A.

serpentinized. Serpentinized ultramafic rocks are more magnetic and less dense than their unaltered counterparts (Saad, 1969). The region of the gravity high is bisected by a 100-200 nT magnetic high that appears to arise from a shallow source that reaches close to the surface (fig. 10a, 10b). In the magnetic field filtered to enhance deeper sources, the Bennett Valley gravity high coincides with moderate magnetic values. The magnetic data suggest that the source of the dense but relatively non-magnetic rocks beneath Bennett Valley is Franciscan Complex greenstone or ophiolitic rocks whose magnetic minerals have been destroyed by Tertiary hydrothermal alteration.

Further insight into the source of the Bennett Valley gravity high may be gleaned by examining its possible offset equivalent on the west side of the Rodgers Creek and Healdsburg

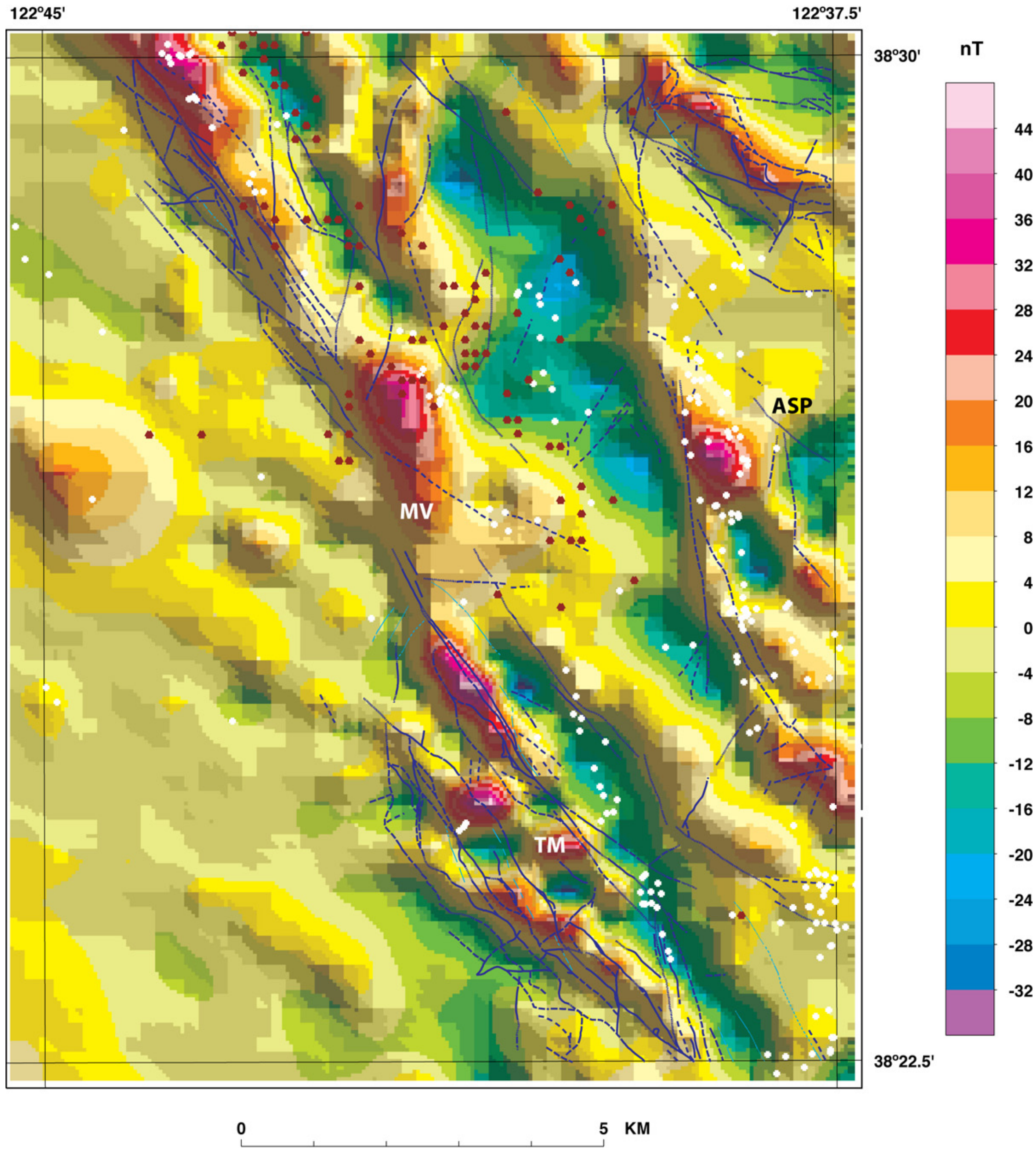


Figure 13. Residual magnetic field after subtraction of upward-continued field. ASP, Annadel State Park; MV, Montgomery Village; TM, Taylor Mountain. White dots, double-difference relocated seismicity of Waldhauser and Ellsworth (2000). Brown dots, aftershocks of the 1969 Santa Rosa earthquakes (J.D. Unger and J.P. Eaton, written commun., 1970; Wong and Bott, 1995). Dark blue lines are faults from Map A.

Faults. McLaughlin and others (2005a) proposed about 28 km of right-lateral displacement on the Rodgers Creek Fault based on correlation of a distinctive rhyodacitic fault scarp breccia near Taylor Mountain with a similar sequence exposed in the Sears Point quadrangle. Assuming 28 km of displacement, the offset equivalent of the Bennett Valley gravity high source is west-northwest of Healdsburg and consists of Coast Range ophiolite surrounded by rocks of the Franciscan Complex (Graymer and others, 2006b). These exposures also coincide with high gravity values (Roberts and others, 1990) and a narrow magnetic high (Roberts and Jachens, 1999).

The presence of the Bennett Valley gravity high within the Santa Rosa pull-apart basin may restrict where one may place the connection between the Rodgers Creek and Bennett Valley-Maacama Faults through Bennett Valley. The north-striking part of the Bennett Valley fault (Spring Valley segment) may step to the east or change to a northeasterly strike at its southern end as evidenced by the uninterrupted and linear northeast edge of the gravity high. Seismicity (Waldhauser and Ellsworth, 2000) also appears to be concentrated along the margins or outside of the gravity high (fig. 12). Perhaps the source of the gravity high, presumably mafic rock, is more rigid than the surrounding basement rocks and concentrates stress along its margins (Campbell, 1978).

Gravity lows reflect the presence of lower-density rocks, primarily Cenozoic sedimentary and volcanic rocks. The lowest values are present over the Santa Rosa Plain in the southwest part of the quadrangle, reaching as low as -19 mGal near the intersection of Stony Point Road and Hearn Road (Map B). This gravity low, here referred to as the Bellevue gravity low (figs. 7, 8; see also Chapter A), is part of an even larger gravity low, named the Cotati low, that extends another 10 km southwest of the Santa Rosa quadrangle. The Warrington high (figs. 7, 8) marks the southern margin of the Bellevue low.

Another prominent gravity low, reaching values as low as -14 mGal, is present in the northwest corner of the quadrangle; again, this low is part of a larger gravity low, called the Windsor low, that extends 7 km to the northwest of the northern edge of the map area. These two gravity lows are separated by a gravity high that is part of a larger, west-northwest-striking gravity ridge, named the Trenton Ridge, that extends 7 km west of the western edge of the quadrangle towards outcrops of Mesozoic basement. Downtown Santa Rosa is at the intersection of the gravity highs marking the Rodgers Creek-Healdsburg Faults, the Trenton Ridge gravity high, and the Cotati gravity low. The location of the local basin re-entrant beneath downtown Santa Rosa coincides with damage patterns from the 1906 San Francisco and 1969 Santa Rosa earthquakes, suggesting that the basin geometry contributed to enhanced ground motions during these earthquakes (McPhee and others, 2007).

The 6-km wide right step between the Rodgers Creek and Maacama Fault Zones produces a pull-apart basin (Santa Rosa pull-apart basin) that is well expressed topographically but poorly expressed in the gravity field, consistent with arguments based on geologic evidence that the basin formed only during the past 1 Ma (McLaughlin and others, 2005b). The low-density fill of the Santa Rosa pull-apart basin is masked by the Bennett Valley gravity high. Only in Rincon Valley and the northern Sonoma Valley does the gravity image thicker Cenozoic fill. These local accumulations appear to be related to folding in that the Rincon Valley gravity low coincides with the Rincon Valley syncline and the northern Sonoma Valley gravity low is parallel to the Melita syncline. The axis of the syncline is southwest of the gravity low, perhaps because of asymmetry at depth; alternatively, the fold may not be related directly to the genesis of the northern Sonoma gravity low.

Magnetic anomalies indicate serpentinite, mafic Mesozoic basement rocks, or flows within the Sonoma Volcanics. Magnetic anomalies caused by the Sonoma Volcanics tend to be short-wavelength and discontinuous, especially in the filtered versions of the magnetic data to enhance shallow sources, whereas anomalies caused by serpentinite tend to be more linear and coherent. For example, the Taylor Mountain and Annadel State Park areas with extensive exposures of Sonoma Volcanics are characterized by discontinuous residual magnetic anomalies (figs. 10a, 11, 13). Discontinuous anomalies west and northwest of Taylor Mountain may reflect Sonoma Volcanics. Some of the pronounced magnetic lows in Rincon Valley may reflect reversely polarized flows within the Sonoma Volcanics ("r" on fig. 10a). An example of a typical magnetic anomaly caused by serpentinite is the linear, northwest-striking magnetic high in the northeast corner of the quadrangle that coincides with a belt of Jurassic serpentinized ultramafic rocks (Jos; Map C). A similar northwest-striking magnetic anomaly (A on fig. 9) extends northwest from an outcrop of serpentinite in the Taylor Mountain area. This anomaly continues across the young surficial deposits of downtown Santa Rosa and connects with a band of magnetic highs along the Healdsburg Fault. The western edge of the magnetic anomaly coincides with the prominent gravity gradient marking the western edge of the Bennett Valley gravity high. The combination of the gravity and magnetic gradients allows us to map the main basement break along the Rodgers Creek-Healdsburg Faults in the quadrangle (Maps B, C). The linear aeromagnetic anomaly just northwest of the serpentinite outcrop (A on fig. 9), however, is on the west side of the mapped strand of the Rodgers Creek Fault, suggesting perhaps that the main, long-term strand of the fault may not be exactly coincident with the neotectonic strand.

Magnetic gradients also mark the north-striking faults of the Santa Rosa pull-apart basin, with magnetic highs on the upthrown sides of the faults, except perhaps near Bennett Mountain. The Brush Creek Road Fault Zone bounding the northwest side of the pull-apart basin coincides with a scalloped magnetic gradient. The mapped trace of the Spring Valley segment of the Bennett Valley Fault Zone coincides with a north-striking linear magnetic gradient for about 3 km. The gradient steps 200-300 m west of the inferred trace of the fault north of Spring Valley reservoir. However, the Spring Valley segment of the Bennett Valley fault zone is not imaged by the gravity data, instead a north to northwest-striking gravity low cuts across Rincon Valley, with even slightly lower values on the upthrown side of the fault. The lack of a clear gravity expression argues for minor vertical displacement on the fault. The Brush Creek Road Fault Zone is only poorly expressed, coinciding with a very gentle gravity gradient, with the high on at least the upthrown side of the fault.

Aftershocks of the 1969 Santa Rosa earthquakes (J.D. Unger and J.P. Eaton, written commun., 1970; Wong and Bott, 1995) generally form a northwest-striking zone that parallels the Rodgers Creek-Healdsburg Fault (figs. 12, 13), except in the area of elevated gravity and magnetic values north of Montgomery Village (figs. 12, 13). Here there is a northeast-elongated cluster of earthquakes that parallels a northeast-striking feature in the magnetic field filtered to enhance shallow features (fig. 13). This cluster is also centered on the region where the Brush Creek Road and the Detention Home-Parker Hill Road Fault Zones merge into the Rodgers Creek-Healdsburg Fault Zone. The structural complexity seen at the surface is mimicked by the three-dimensional structure seen in the potential-field and seismicity data.

In the Santa Rosa Plain part of the quadrangle, magnetic anomalies are of smaller amplitude than east of the Rodgers Creek and Healdsburg Faults. This most likely reflects the generally weak magnetic properties of the Cenozoic surficial deposits and the resultant smoothing and attenuation of magnetic anomalies caused by buried magnetic rocks. It is also exacerbated by the inability of the airplane to maintain a constant draped altitude above the ground surface. Nonetheless, the gravity high associated with the concealed Trenton Ridge coincides with a 100 nT magnetic high, suggesting its source consists of serpentinite and associated mafic rocks. A weak, 20-nT magnetic ridge extends about 5 km west-northwest from the Warrington Ridge area; it is also marked by a gravity ridge (Warrington high; fig. 8) with an amplitude of 2-3 mGal. Given its orientation within the current stress field, this ridge is likely thrust related, either an uplifted block along a concealed thrust fault or an anticlinal fold. Another even more subtle west-northwest striking, 3-km long magnetic gradient may connect to the prominent gravity and magnetic anomalies associated with the Trenton Ridge, although the width of the more subtle anomaly is considerably narrower (and possibly shallower) than the magnetic anomaly associated with the Trenton Ridge. The subtle anomaly is just one of several similar anomalies along the eastern side of the Santa Rosa Plain.

The Trenton Ridge is a major buried feature that separates two main subbasins beneath the Santa Rosa Plain. Although the exact depth to the top of the ridge is not known, it may be shallow enough to influence groundwater flow in the Santa Rosa Plain. Although the structures that led to the formation of the ridge are not mapped at the surface, they also may be shallow enough to influence groundwater flow. One of these structures may be the Trenton Thrust Fault, mapped west of the Santa Rosa quadrangle. Seismic simulations that use the basin configuration derived from the gravity data indicate that the ridge influences the intensity of shaking caused by a 1906-like earthquake (Aagaard, 2006).

The northeast corner of the quadrangle is characterized by both gravity and magnetic highs associated with a belt of Jurassic serpentinized ophiolitic rocks (Jos). The southern boundary of the magnetic and gravity high coincides with the Mount Hood Fault Zone and the southern edge of a belt of Jurassic serpentinized ultramafic rocks. The northern boundary of the magnetic high coincides with the Plum Ranch Road Fault Zone. Both of these faults are mapped as down-to-the-southwest normal faults (Chapter A). The Mount Hood Fault appears to also mark the northeast edge of a trough of thicker basin-fill deposits, marked by the northern Sonoma Valley gravity low (figs. 7, 8). that strike east-southeast onto the Kenwood quadrangle.

CONCLUSION

Gravity and aeromagnetic data provide constraints on the subsurface geology within the Santa Rosa 7.5' quadrangle. Important constraints from the gravity include those on the basin configuration beneath the Santa Rosa Plain and beneath Rincon and Bennett Valleys. The alluvial deposits of the Santa Rosa Plain conceal a complex buried basement topography that may enhance shaking in future earthquakes. The lack of a clear basin-induced gravity low within the Santa Rosa pull-apart basin in Rincon and Bennett Valleys may be masked by a dense basement block that appears to influence faulting and seismicity. Gravity and magnetic data map the main basement boundary along the Rodgers Creek-Healdsburg Faults where it is concealed beneath surficial deposits in downtown Santa Rosa. These data have important implications not only for the tectonic evolution of the area, but also for hydrogeologic studies. The Trenton Ridge may act to partition groundwater beneath the Plain; this needs to be tested with hydrologic information.

ACKNOWLEDGEMENTS AND CREDITS

Many property owners in the map area were cooperative and supportive in this investigation and are herein acknowledged. We thank Mr. and Mrs. C. J. Merner, Mr. R. Williams, Mr. D. Running, Mr. L. O'Brian, and Dr. T. Stashak for their help in accessing lands in the northeastern Santa Rosa Quadrangle. The Armstrong family (Cloverleaf Ranch) provided access to their property in the northwestern part of the map area. We thank Mr. and Mrs. J. Jones, the Witt family, Mr. B. Axell of Jackson Family Farms Vineyards, the Bertram family (Bertram Vineyards) and Mr. and Mrs. S. Adams for their help with access logistics in the Taylor Mountain area. Property owners who provided access or background information for work in the Bennett Valley area include the Guanella family, Mr. and Mrs. C. Stevens, Mr. and Mrs. G. Bunas and Mr. J. Johnson. T. Meyskens and J. McCray, Rangers for Sonoma County Regional Parks and Recreation are herein gratefully acknowledged for their cooperation in assisting us with access to roads and trails in Spring Valley Reservoir and Hood Mountain County Parks. J. Crossman, M. Baumgratz and W. Noel, of California State Parks and Recreation Department also helped with access and permits for our work within Annadel State Park.

Sonoma County Water Agency provided rock samples and water well drilling information, which were helpful in determining subsurface stratigraphy in parts of the Santa Rosa Plain. We also thank J. Howard of California Division of Safety of Dams (DSOD) for providing helpful background information regarding the construction of and pre-dam conditions in the area of Santa Rosa Creek Reservoir.

Numerous colleagues are involved in related cooperative investigations within or adjacent to the map area, including: D. Wagner, K. Clahan and S. Bezore (California Geological Survey); C. Hitchcock (William Lettis and Associates); Ahmed Nisar (MMI Engineering, Inc); C. M. Wentworth, R.W. Graymer, R.C. Jachens, J. Rytuba, T. Brocher, R. Simpson, T. Boatwright, D. Schwartz, K. Maher, J. Tinsley and S. Hecker, (all at the U.S. Geological Survey, Menlo Park, CA); D. Sweetkind and E. Taylor (U.S. Geological Survey, Denver, CO); and C. Farrar (Water Resources Division, U.S. Geological Survey, Lake Tahoe, CA). All of these scientists have contributed intellectual and scientific support to this mapping investigation and we herein thank them for productive discussions and exchanges of information in the office and field.

Additional scientific support from the U.S. Geological Survey that has contributed significantly to this mapping investigation includes paleontologic support provided by S.W. Starratt (diatoms) and E. Wan (benthic foraminfers), C.L. Powell, II. (invertebrate fossils), and C.A. Repenning (vertebrate fossils).

Laboratory support for tephrochronology including separation and analysis of tephra and database maintenance was provided by E. Wan and D. Wahl (U.S. Geological Survey, Menlo Park). Rock grinding and analytical support for radiometric dating was provided by D. Shamp (U.S. Geological Survey, Menlo Park).

McLaughlin also thanks D. L. Zieglar, retired exploration geologist, Chevron Oil Company for the several discussions we have had on the subsurface geology of the Santa Rosa Plain from oil and gas well logs. These discussions provided useful insights into the regional stratigraphy of the Tertiary volcanic and sedimentary section.

Funding for this mapping investigation was provided by the National Cooperative Geologic Mapping and National Earthquake Hazards Reduction Programs of the U.S. Geological Survey.

This geologic map report was reviewed by Russell Evarts (U.S. Geological Survey, Menlo Park, CA), Donald Sweetkind (U.S. Geological Survey, Denver, CO) and David L. Wagner (California Geological Survey, emeritus, Independence, CA). Geologic Names were reviewed by C.L. Powell, II (U.S. Geological Survey, Menlo Park, CA). The digital database was reviewed by Zenon C. Valin. The helpful suggestions and comments of these reviewers are herein gratefully acknowledged.

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