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Geology of the Right Stepover Region between the Rodgers Creek, Healdsburg, and Maacama Faults, Northern San Francisco Bay Region

A Contribution to Northern California Geological Society Field Trip Guide, June 6-8, 2003

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NORTHERN CALIFORNIA GEOLOGICAL SOCIETY FIELD TRIP, JUNE 6-8, 2003:

GEOLOGY OF THE RIGHT STEPOVER REGION BETWEEN THE RODGERS CREEK, HEALDSBURG AND MAACAMA FAULTS, NORTHERN SAN FRANCISCO BAY REGION

Field Trip Leaders for Saturday June 7: Bob McLaughlin and Andrei Sarna-Wojcicki, U.S. Geological Survey, Menlo Park, CA

Introduction

This Open file report was written as part of a two-day field trip on June 7 and 8, 2003, conducted for the Northern California Geological Society. The first day of this field trip (June 7) was led by McLaughlin and Sarna-Wojcicki in the area of the right- step between the Rodgers Creek-Healdsburg fault zone and the Maacama fault. The second day of the trip (June 8), was led by David Wagner of the California Geological Survey and students having recently completed MS theses at San Jose State University (James Allen) and San Francisco State University (Carrie Randolph-Loar), as well as a student from San Francisco State University whose MS thesis was in progress in June 2003 (Eric Ford). The second day covered the Rodgers Creek fault zone and related faults of the Petaluma Valley area (the Tolay and Petaluma Valley fault zones).

The report presented herein is the guide for the first day of the NCGS field trip. The complete guide for both days includes this contribution as well as the separate contributions of David Wagner, James Allen, Carrie Randolph-Loar and Eric Ford, and is available through the Northern California Geological Society.

Itinerary and descriptions of field trip stops Saturday June 7:

8:30 AM--Assemble Saturday morning in the parking area at the Bechtel house at the Pepperwood Ranch, and load into vehicles. See the included map figures and today's roadlog for directions to stops. We encourage attendees to condense into as few vehicles as possible to minimize the number of vehicles that we need to keep track of and to more easilly accommodate room for parking along busy roads in the field area. We will return to the Bechtel house at the end of the day.

- ♦ From the Bechtel house, drive on gravel ranch road ~ 1.0 mi. NW along the Maacama fault zone to a fenceline gate at the crest of a prominent ridge. Walk to the top of knob to the east of parking spot, with elevation marked as 1524' on Mark West Springs 7.5' quadrangle.

Stop 1. Pepperwood Ranch, 360° overview of right-stepover area.–

At this first stop we will provide an overview of the regional geology and significant crustal features of this part of the northern San Francisco Bay region (See figures 1A-C, 2, and 3).

- ♦ The overview is along the eastern side of a broad 1 km-wide zone of faults associated with the Maacama fault zone in this area. You are standing on a large block of graywacke sandstone within Central Belt melange of the Franciscan Complex. Numerous other melange blocks, including high-grade blueschist, eclogite, chert and metabasalt, occur in this melange

- ♦ Tilted against the Maacama fault zone on the southwest is basalt of the Sonoma Volcanics (^{40}Ar / ^{39}Ar dated at 5 Ma), overlain by a thin unit of rhyodacitic ash flow tuff (>3.1< 5 Ma), in turn overlain by younger Plio-Pleistocene fluvial gravel. The fluvial gravel is derived from the Mesozoic basement and Tertiary volcanics, and contains obsidian clasts from at least 2 distinct obsidian sources.

- ♦ Tilted against the Maacama fault on the northeast is the volcanic and sedimentary section of Franz Valley, which is also present as several isolated outliers along the ridge traversed by the Maacama fault zone. The Franz Valley volcanic and sedimentary rocks consist of a locally preserved, thin, undated basalt and a thin layer of gravel at the base, overlain by a thick sequence of 3.4 to 2.8 Ma (^{40}Ar / ^{39}Ar ages) siliceous ash flow and air fall tuff. Basaltic andesite occurs higher in the ash flow section, along with intercalations of volcanic-clast gravel and lacustrine silts and diatomites. Younger volcanic-clast gravel with obsidian clasts, unconformably overlies the volcanic rocks.

- ♦ To the northeast of Franz Valley and Knights Valley are the Mayacmas Mountains, consisting of uplifted basement of Franciscan Complex rocks and ophiolitic and sedimentary rocks of the Great Valley sequence, capped by the 3.3 Ma and younger Sonoma Volcanics of Mount St. Helena and the Palisades area. To the northwest of Mount St.Helena, along the crest of the Mayacmas Mountains, is the 2.2 Ma rhyolite and dacite of Pine Mountain , which is associated with the 2.2 Ma and younger Clear Lake Volcanics of The Geysers geothermal region. The Mayacmas Mountains northwest of Mount St. Helena are underlain by a voluminous felsic pluton. The Geysers pluton extends in the subsurface at least 20 km northwestward, and to an unknown depth below 3 km. The pluton is within 1 km of the surface beneath The Geysers, and it is within about 2 km of the Maacama fault at depth northeast of Alexander Valley. Magma that may be associated with the lower part of The Geysers pluton is considered to underlie the Mayacmas Mountains and The Geysers steam field.

- Note that the Maacama fault zone here, and the entire right stepover area betweeen the Healdsburg and Maacama faults, is largely an upland instead of the lowland normally expected in an extensional right-stepping dextral fault system. Also note that the adjacent principal valleys of the area (Calistoga-Napa, Knights, Alexander, Dry Creek and Franz Valleys), as well as intervening ridges generally trend W-NW, oblique to the more N-NW-trending active Rodgers Creek, Healdsburg, and Maacama strike-slip faults. The Maacama fault clearly cuts across the W-NW trend of the valleys and ridges.

- The valley and ridge topography in this area, especially NE of the stepover area, appears to be controlled by W-NW trending, steeply to moderately NE-dipping faults with significant components of reverse slip. These reverse and thrust faults offset 3.3 Ma volcanics and fluvial gravels. Some of the thrust faults are seismically active.

- Slip surfaces on faults that offset Neogene rocks within the stepover area are of highly variable orientations and show kinematic evidence of dextral, sinistral and normal slip, consistent with dominant E-W extension.

From Stop 1 we will turn around and retrace our path past the Bechtel house and continue to the intersection with Franz Valley Road.

- **Mileage log begins at Pepperwood Ranch entrance at the intersection with Franz Valley Road.--O mi.**

-Turn right on Franz Valley Road. Travel downhill to intersection with Porter Creek Road.
-Turn right on Porter Ck. Road and drive 1.5 mi to pullout and outcrop of east-dipping gravels.

Mi=1.5 --
Stop 2. View of east-dipping, folded Plio-Pleistocene fluvial gravels that overlie Sonoma Volcanics –

At this stop view fluvial gravels which overlie the Sonoma Volcanics. Southwest of this locality, these gravels depositionally overlie a 4.83 Ma ash flow (Lawlor tuff) and a 4.89 Ma basalt. To the northeast, the gravels are folded into a syncline and tilted against the Maacama fault zone.

- The gravels are dominated by rounded and subrounded clasts derived from the Tertiary volcanic section, including rare pebbles of obsidian. Clasts derived from the Central Belt of the Franciscan Complex are also a prominent clast component. Previous workers correlated these sediments with the Glen Ellen Formation.

- ♦ Sediment paleoflow (Figure 4A), based on clast imbrication and on channel orientation, was generally toward the west, probably in a braided stream system. This paleoflow direction dominates the entire right stepover area, indicating flow was nearly orthogonal to the active strike-slip faults of the stepover area. Maximum clast size data (Figure 4B) for the stepover area also indicates NE to SW transport with a general pattern of decrease in maximum clast size toward the SW. This pattern suggests that neither sediment transport nor local sediment supply were influenced by strike-slip faulting, leading us to conclude that strike-slip faults had not encroached into this area at the time of deposition of these gravels.

Return to cars and drive back to the northeast on Porter Creek Road, past Franz Valley Road intersection. Continue driving northeastward along Porter Creek Road, where highway work has been conducted to mitigate active landslides in highly sheared melange and serpentinite along the Maacama fault. Watch for entrance to Camp Neuman on the right.

Mi= 6.2 Entrance to Camp Neuman
Stop 3. Camp Neuman Conference Facility exposures of Maacama fault zone

At this locality we see a relatively well exposed segment of the southern Maacama fault. This is one of the best natural exposures of the southern part of this fault zone. Along this part of the Maacama fault zone, interbedded, steeply east dipping or overturned gravel, silt and ash flow tuff (3.3 Ma) are juxtaposed with each other, and locally, against Franciscan rocks (Figure 5). In places the gravel and tuff may be depositional on the Franciscan, but several closely spaced nearly vertical fault strands cut the late Tertiary volcanic and sedimentary section. The faulting is aligned along the Franciscan -Tertiary contact. Scattered seismicity is associated with this part of the fault zone. Southeast of this area the Maacama fault is largely covered by landslides and alluvium. The fault trends into northeastern Rincon Valley in Santa Rosa 7.5' quadrangle, where a rhombic extensional basin occurs between the northern Rodgers Creek fault and the southern-most Maacama fault (Figure 1B).

Leave Camp Neuman and turn right (east) onto Porter Creek Road.
Intersect Calistoga-Petrified Forest Rd.
Turn left (northeast) on Petrified Forest Rd for 1.0 mi to the Petrified Forest

Mi= 7.2- Entrance to the Petrified Forest
Stop 4. Lunch Stop and visit to the Petrified Forest—

The Petrified Forest is privately owned and there is an entrance fee to view the excavations (~$4-$5?). We will have lunch here (~45 min) where you can also view the petrified tree excavations if you choose.

- Numerous very large in-situ, silicified, conifer trees can be seen. The trees were buried 3.34 to 3.19 mya during eruption of the ash flow tuffs of the Petrified Forest area. Based on preservation of the tree roots and the areal orientations of the trees, it can be determined that most fell toward the W-SW (Figure 6). We interpret this to suggest that the paleosurface sloped SW, and (or) that the ash flow that buried the trees moved toward the W-SW. This direction is consistent with westward paleoflow measurements in fluvial gravels that overlie and are intercalated with the ash flow tuff section (Figure 4A).

After lunch, assemble in parking area, load vehicles and proceed approximately 2.5 mi eastward again on Porter Creek Road, toward Calistoga.

At approximately mi= 9.7, turn left onto Franz Valley School Rd.
Drive west along Franz Valley School Rd to stop 5 along the northeast side of Franz Valley.

Mi=14.6-ViewAsh flow tuff section of Franz Valley
Stop 5. Ash flow tuff section of Franz Valley

At this locality we will view rhyodacitic ash flow tuff with a distinct tephra fingerprint, that is radiometrically dated (^{40}Ar / ^{39}Ar) at 2.85 Ma. This tuff is high in the Sonoma Volcanics section (Figure 3) and is among the youngest dates in the Sonoma, but the volcanics are also overlain by more tuff and andesite (^{40}Ar / ^{39}Ar age in progress). The tephrochonologic fingerprint and age of the Franz Valley tuff section, together with presence of the 3.34 Ma Putah tuff and underlying fluvial gravel section, have enabled us to match the Franz Valley section to tephra and gravel about 24 km to the NW, on the SW side of the Maacama fault (Figures 1B, C). We will discuss this correlation and the implied slip rate for the Maacama fault further at this and a later field trip stop.

Return to vehicles and proceed westward to intersection of Franz Valley School Road with Franz Valley Road.

Turn right (north) on Franz Valley Road.
At intersection with Spencer Road turn left, then jog to right (north).

At approximately mi =18.4, intersect Highway 128.

Turn left on Highway 128 and drive NW through Knights Valley.

View Mount St. Helena to right; Franciscan melange can be seen along east side of Knights Valley, locally overlain by erosionally isolated remnants of Sonoma Volcanics

At the divide between Knights and Alexander Valleys, re-cross the Maacama fault.

Relatively intact Franciscan graywacke is seen in the road cuts of divide area dissected by Maacama Creek.

At approximately mi=25.2 intersect Chalk Hill Road.

Turn left (south) on Chalk Hill Road, drive approximately 2.5 mi to Chalk Hill.

Mi=27.7- Exposures of air fall and water lain tuff along Chalk Hill Road--

Stop 6. This well exposed ash unit displays abundant syn-depositional structures including grading, convolute structures, loading and current transport features. The ash unit correlates with a local tuff that abuts the eastern side of the Maacama fault in Franz Valley (tuff of Devils Kitchen). The tuff of Devils Kitchen is dated at >3.22< 3.34 Ma, based on its stratigraphic position in Franz Valley relative to other well dated tuffs. We are still determining the detailed suite of local and more widespread tuffs in the region, and hope to use their distributions in fault blocks of the right stepover, to better constrain long term Neogene slip rates (Figure 3).

-Return to vehicles and drive back to the north, to intersection with Highway 128.

At approximately mi= 30.2, Turn left on Highway 128.

Drive NW along Maacama fault zone in Alexander Valley to intersection with Alexander Valley Road at mi=33.7.

Turn right on Alexander Valley Road

Turn left on Red Winery Road and drive NW along NE side of Alexander Valley parallel to Maacama Fault zone.

Junction with The Geysers-Healdsburg Road at mi=36.5

Turn right.

Mi=36.9 –38.5--Geysers Road section

Stop 7. View Sonoma Volcanics and fluvial gravel right-laterally offset by the Maacama Fault zone--

Drive up The Geysers Road, obliquely down-section, through Sonoma tuff, basalt and underlying fluvial gravel that is vertical to steep dipping, to where the Maacama fault crosses the road. Park along northwest side of The Geysers Road, near private gate, just after crossing the Maacama fault.

The road is caving-in near where the fault crosses the road and only one lane is still open here.

We will inspect the gravel outcrops in this cut and then drive back down The Geysers Road to the lower part of the outcrop section and look at the overlying volcanic units.

Based on geochronology and tephrochronologic correlations, the ash flow tuff in the upper part of the volcanic section includes the Putah tuff and a tuff that is part of the 2.85 Ma ash flow tuff section of Franz Valley (Figures 2, 3). Based on the correlative volcanic units and the similarity of the volcanic-stratigraphic sequence along the Geysers Road to the section truncated by the Maacama fault on the SW side of Franz Valley, we propose an offset of about 24 km along the Maacama fault since 2.85 Ma (Figure 1B). We will discuss this proposed offset and the implied slip rate.

-Return to vehicles and drive back to The Geysers-Healdsburg junction with Highway 128, then SE to Jimtown store at junction of Highway 128 and Alexander Valley Road at approximately mi=43.2.

Turn right (SW) on Alexander Valley Road

Cross the Russian River at mi=43.8

Turn left onto Healdsburg Ave

♦ Cross Healdsburg fault zone at mi=47.0

Intersect Dry Creek Road-mi= 48.6

From Dry Creek Road access Highway 101 South

Travel south of Healdsburg and exit Highway 101 at Old Redwood Highway off-ramp (mi ~51.5).

Travel SE along Old Redwood Highway to Eastside Road intersection at mi=53.4

Travel SW along Eastside Rd to exposures of marine Pliocene Wilson Grove Formation along the Russian River

Mi=57.9—Wilson Grove Formation
Stop 8. View fossiliferous Pliocene and late Miocene marine strata of the Wilson Grove Formation

At this locality observe pebbly, near shore marine sandstone of the Pliocene Wilson Grove Formation (Figures 1B, C, and 2). The Pliocene age of these strata possibly overlaps the late Pliocene and Pleistocene age of fluvial deposits that overlie 3.1 Ma Sonoma Volcanics northeast of the Healdsburg fault. About 2 km south of this locality, near Trenton, the

Wilson Grove Formation includes the ~6.3 Ma Roblar tuff, which is also present in fluvial, lacustrine and estuarine strata of the Miocene and Pliocene Petaluma Formation to the southeast (see presentation by James Allen, NCGS field trip guide for 5/8/03). Petaluma Formation strata are recognized locally along the southwest side of the Healdsburg and Rodgers Creek faults as far northwest as northwestern Santa Rosa. The distribution of marine and fluvial strata of overlapping ages on either side of the Santa Rosa plain southwest of the Healdsburg and Rodgers Creek faults implies that a Miocene-Pliocene shoreline transition is buried beneath Quaternary alluvium of the Santa Rosa-Russian River plain. Paleoflow in the coeval fluvial deposits east and southeast of the Wilson Grove Formation and in younger gravels that overlie the marine section was to the west. Younger alluvial fans overlap and incise older, more deformed fans westward. This suggests that fluvial systems prograded W-SW over the Plio-Quaternary shoreline, in response to westward tilting, volcanism and uplift east of the Santa Rosa plain. Neogene geology and structure of the area beneath the Santa Rosa – Russian River plain will be discussed in further detail at the next stop.

-Return to vehicles and travel 0.3 mi. SW from Wilson Grove locality along Eastside Road, to Trenton Road intersection at mi=58.2

Turn left. Travel to Trenton.

Turn left at Trenton onto River Road at mi=59.0.

Turn left onto Slusser Road from River Road at mi=62.3.

Travel north on Slusser Road to intersection with Laughlin Road south of Sonoma County airport, at mi=63.5.

Turn right onto Laughlin Road, travel a short distance, and pull off road at Slusser Vineyards-mi=63.9.

Mi=63.9—Pleistocene and younger fluvial deposits of Laughlin Rd. Stop. 9.—View Pleistocene – Holocene (?) terrace deposits and basin-bounding late Quaternary normal fault along west side of the Santa Rosa plain

At this locality we will view gently west-tilted Quaternary fluvial gravel exposed in a road cut along Laughlin Road south of the County airport. The gravels display channeling, cross-bedding and clast imbrication that indicate westward paleoflow. The clast suite in these gravels is derived both from Mesozoic (Franciscan, Coast Range ophiolite and Great Valley sources) and from Tertiary volcanic sources, including source areas for rare obsidian pebbles. Previous workers correlate this strata with the Glen Ellen Formation, although we interpret this unit to be younger and incised into more deformed gravels to the northeast that also were mapped as Glen Ellen Formation by previous workers

- ♦ We have studied the compositions of obsidian pebbles in these Plio-Pleistocene fluvial deposits, and have geochemically correlated the obsidian clast types with two distinct in-situ sources of obsidian in the Sonoma Volcanics (Figure 7). From the distribution of the differently sourced obsidian clasts in the gravels and paleoflow data, we can approximate how the obsidian clasts were transported from their source areas. We have, in turn, used these data to model approximate displacements of the obsidian clast lithofacies in the gravels across the Healdsburg-Rodgers Creek and the Maacama-Bennett Valley fault zones (Figure 8).

- ♦ This model suggests an offset since ~ 2.85 Ma on the order of 10 to 19 km for the Healdsburg-Rodgers Creek fault zone, and about 13 km (probably a minimum) for the Maacama-Bennett Valley fault zone.

- ♦ Combined with a larger offset determination for the Maacama fault based on correlation of the offset volcanic and sedimentary sections of Franz Valley and The Geysers Road, cumulative slip across the stepover area since ~ 2.85 Ma, has been 23km and 43 km. This suggests a cumulative slip rate of ~33 ± 10km since 2.85 Ma, or a rate of ~11.6 ± 3.5 mm/yr since 2.85 Ma.

- ♦ The upper part of the exposure consists of flat-lying reddish colored gravel, 1-2 m thick, unconformably capping underlying channeled and west-tilted gravels. The undated red gravel unit forms the extensive flat terrace of the county airport area, and columnar structure and carbonate veining beneath the red gravel is probably related to paleosol development.

- ♦ At the east end of the road cut, red-colored Holocene (?) soil and colluvium drape a steep-dipping, down-to-the-east normal fault. This fault cuts the channeled Pleistocene gravel and the unconformably overlying red gravel, tilting these units to the SW in the footwall block.

- ♦ Bouguer gravity maps over this part of the Santa Rosa plain (Figure 9) indicate that these flatlands are underlain by a 2.5-3.0 km -deep structural depression filled with low density sediment (R.C. Jachens, personal commun., 2000). The Quaternary normal fault observed here is considered to be part of a set of N-S-trending extensional faults that bound the west side of this buried basin (Windsor basin). The northeast side of this basin is bounded by the Healdsburg fault zone. The Healdsburg fault appears to have low density sediment thrust to the NE, beneath the surface expression of the fault: a relationship suggesting that the fault has a component of reverse slip and that it dips moderately to the NE. The south side of Windsor basin is bounded by a W-NW-trending structural sill separating the Windsor basin from Cotati basin (also 2.5-3.0 km-deep) to the south . The sill between Windsor and Cotati basins is apparently asssociated with the SW-vergent Trenton thrust fault, which is exposed at the surface only at Trenton. At Trenton, the fault thrusts Franciscan rocks to the SW, over the Wilson Grove Formation.

- The senses of slip of the faults which bound these basins are consistent with the present stress pattern for the area from earthquake focal mechanisms (Figure 1B), and indicate that the crust accommodates dominant EW extension over these basins and (or) NS compression, which has segmented and isolated the Windsor and Cotati basins.

- The large volume of soft, low density fill in these basins and the structural architecture of the basins beneath the Santa Rosa plain has important earthquake hazard implications for ground shaking and surface rupture potential, as well as important implications for understanding the ground water hydrology of the basins.

END OF 6/7/03 ROAD LOG.

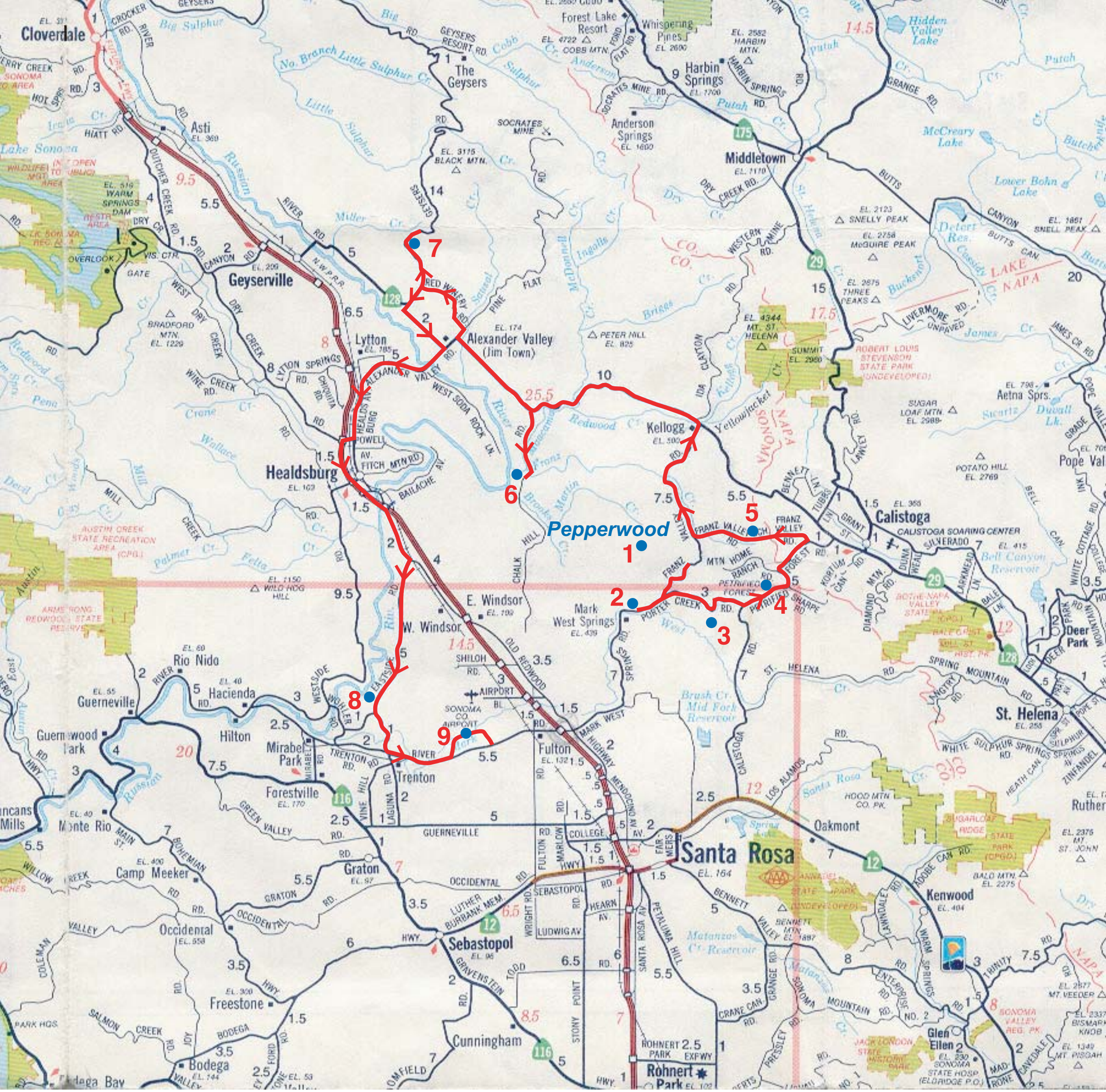


Figure 1A. Road map for Day 1 stops, June 7, 2003.

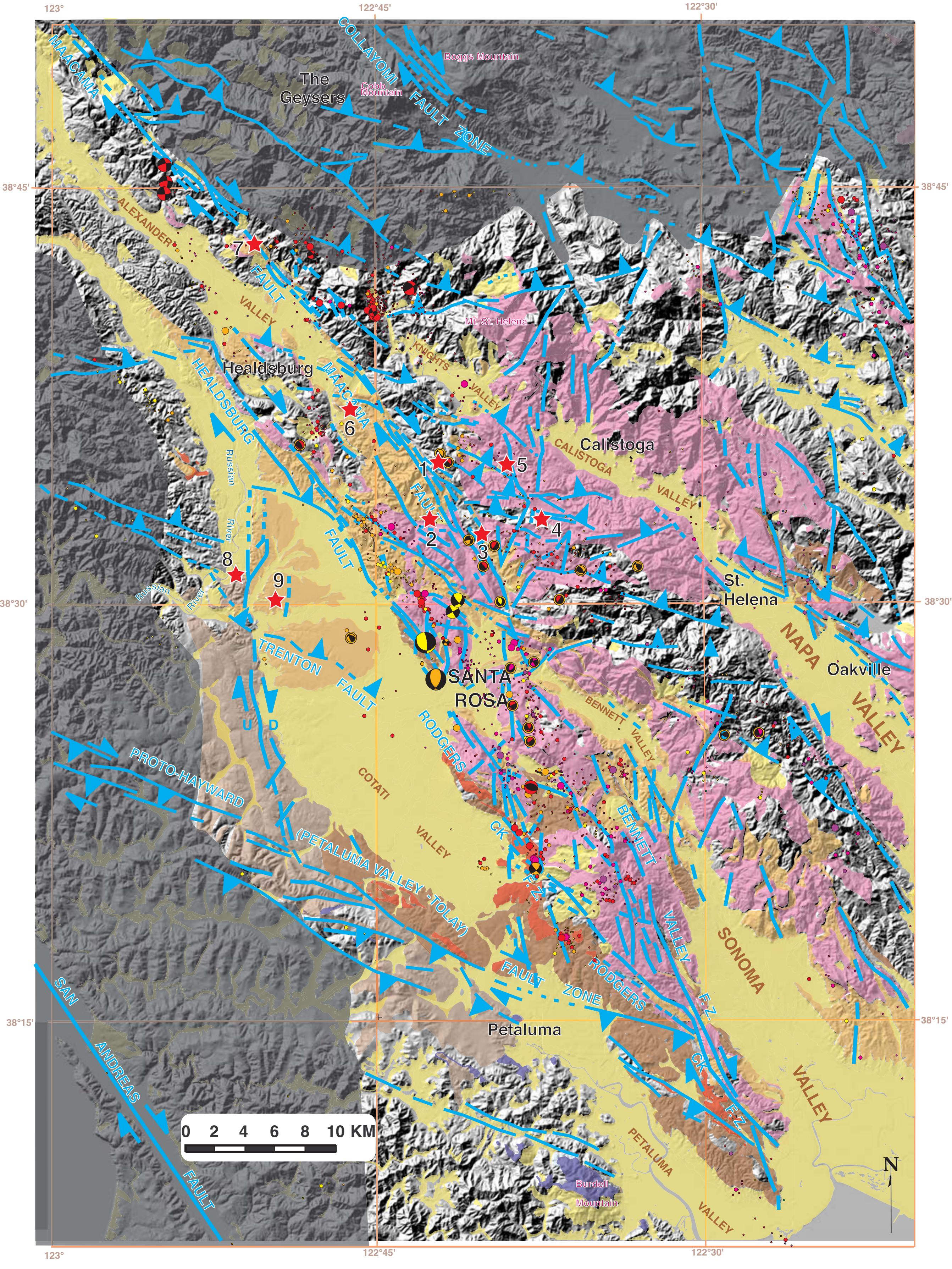
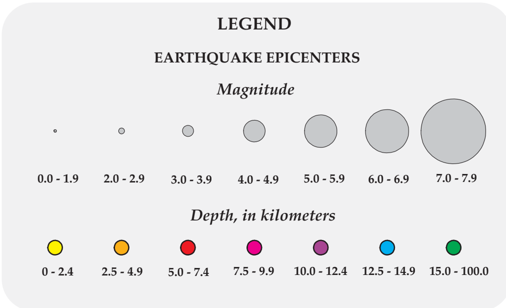


Figure 1B. Geology of Miocene and younger deposits in the right-stepover region of the Rodgers Creek-Healdsburg-Maacama fault system. Red stars indicate field stops for 6/7/03.



EXPLANATION

Rock Unit Descriptions

Fluvial and landslide deposits (Holocene - mid-Pleistocene)--

Fluvial and lacustrine deposits (mid-Pleistocene - Late Pliocene)-- Fluvial gravel, sandstone and siltstone, largely sourced from and locally intercalated with upper Sonoma Volcanics. Locally, source of detritus is predominantly pre-Miocene basement; Deposits include locally conspicuous obsidian clast detritus; and minor nonmarine diatomite. Includes Huichica and Glen Ellen Formations

Sonoma Volcanics (Late Pliocene - Late Miocene)--Basalt, andesite, and silicic flows, breccias, and tuffs, with radiometric ages ranging from ~7.0 Ma- 2.5 Ma, locally intercalated in lower beds of mid-Pleistocene to late Pliocene fluvial deposits

Nonmarine to marine transitional deposits (Pliocene to middle Miocene)-- locally beneath Sonoma Volcanics and interbedded with 6 Ma and older Tolay and older volcanic rocks of Burdell Mountain. Includes:

Fluvial, lacustrine and-brackish water sediments. Includes Petaluma Formation and Gravel of Cotati

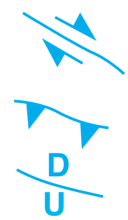
Shallow marine shoreline and shelf facies deposits. Includes Wilson Grove Formation

Tolay Volcanics and associated volcanic rocks (late to middle Miocene)--Volcanic rocks, ~6 my- to 10my old, that occur between Rodgers Creek-Healdsburg and Proto-Hayward (Petaluma Valley-Tolay) Fault Zones, intercalated in nonmarine to marine transitional deposits. Compositions range from basalt to rhyolite.

Volcanic Rocks of Burdell Mountain (middle Miocene)--Volcanic rocks of basaltic to dacitic composition, ~10 my-to 12 my old, that occur southwest of Proto-Hayward (Petaluma Valley-Tolay) Fault Zone, largely intercalated with marine deposits of Nonmarine to marine transitional sequence.

Pre-Miocene basement

Map Symbols



strike-slip fault

thrust fault

normal fault

Figure 1C. Map Explanation. Neogene and younger geology draped on shaded relief map from 30m DEM's (Graham, 1997, U.S.G.S. digital Open File Map 97-745b). Geology coverage in part from Wentworth and others, 1997, U. S. Geological Survey digital Open-File Map 97-744). Geologic revisions are from this investigation, geologic mapping in progress and aerial photo lineament interpretative work. Earthquake locations and focal mechanisms for period 1969-present contributed by D. Oppenheimer (U.S.G.S.), 2001, and by S. Walter (U.S.G.S.), 1994 and 2001. Locations of largest shocks (M 5.0-5.9) of October, 1969 Santa Rosa earthquake sequence, are relocated according to Wong and Bott (1995, B.S.S.A., v.85, no.1, pp.334-341). Focal mechanisms with yellow borders are selected 1984 and later earthquakes with M≤ 2.4.

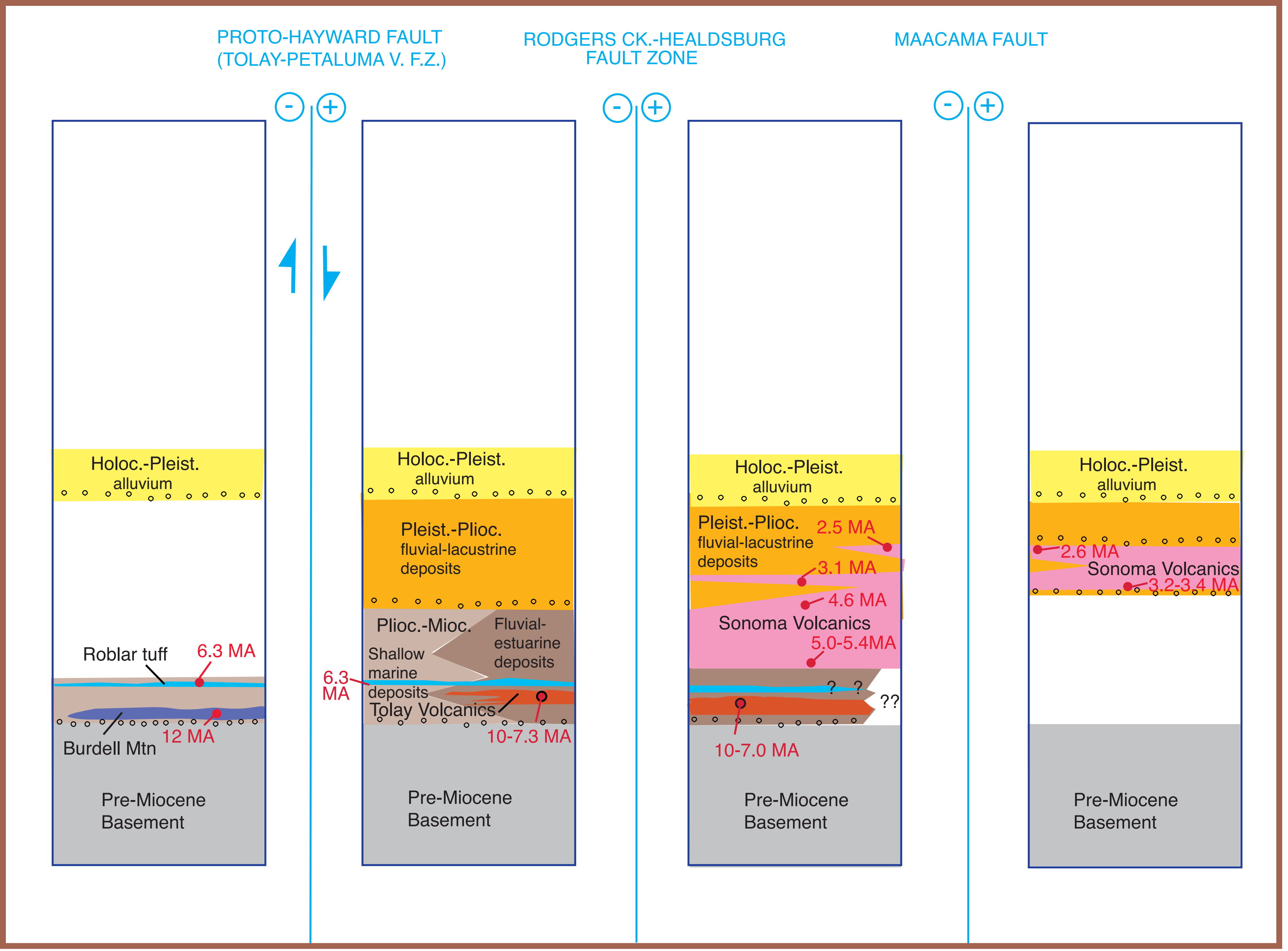


Figure 2. Comparative stratigraphy from SW to NE in fault blocks displaced by faults of Rodgers Creek-Healdsburg-Maacama right-stepover fault system.

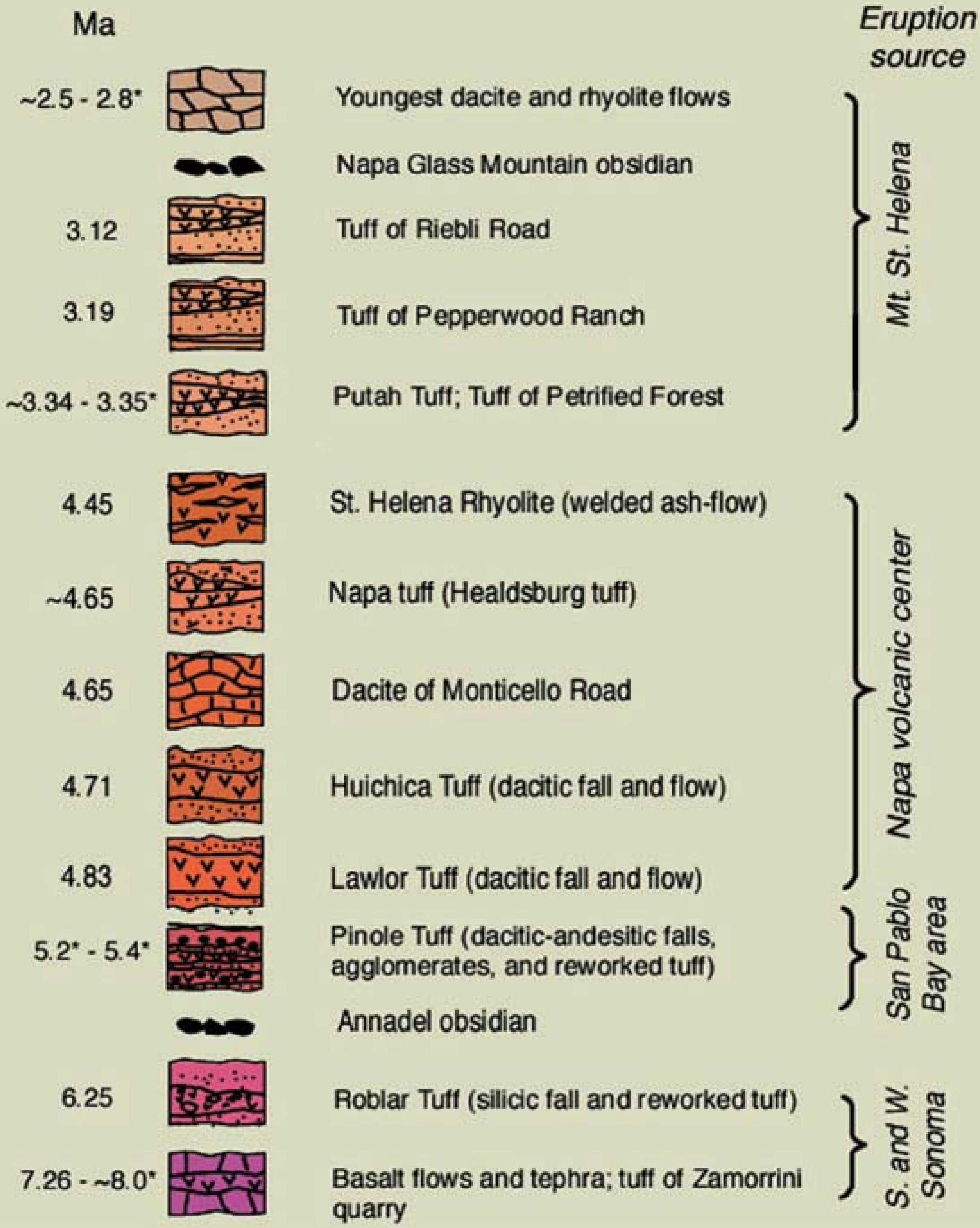


Figure 3. Composite Stratigraphy and Chronology of the Sonoma Volcanics
[Ages by ^{40}Ar/^{39}Ar, USGS & BGC; except *, by K-Ar]

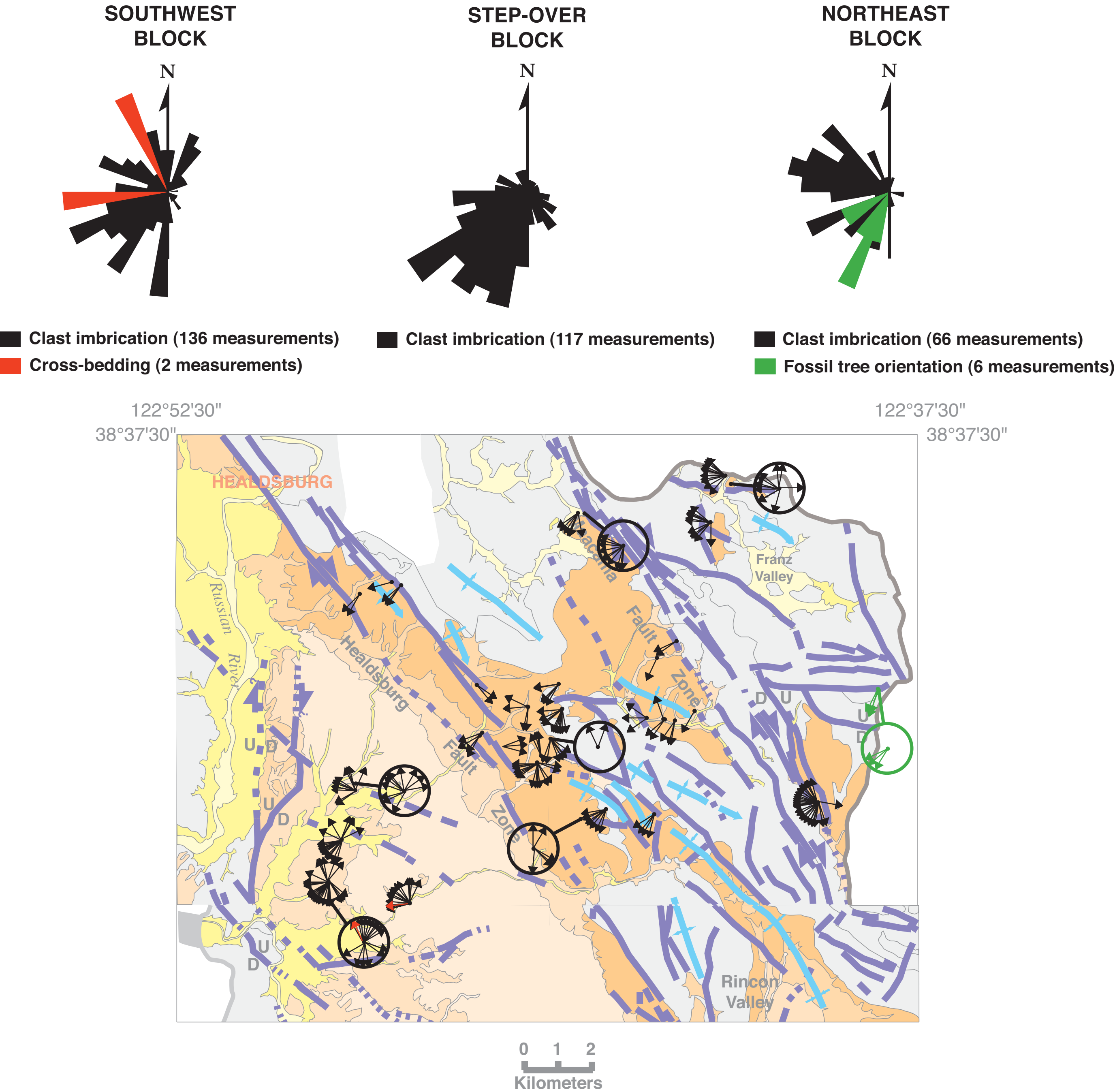


Figure 4A. Paleoflow pattern in Plio-Pleistocene fluvial gravels across right-stepover region.

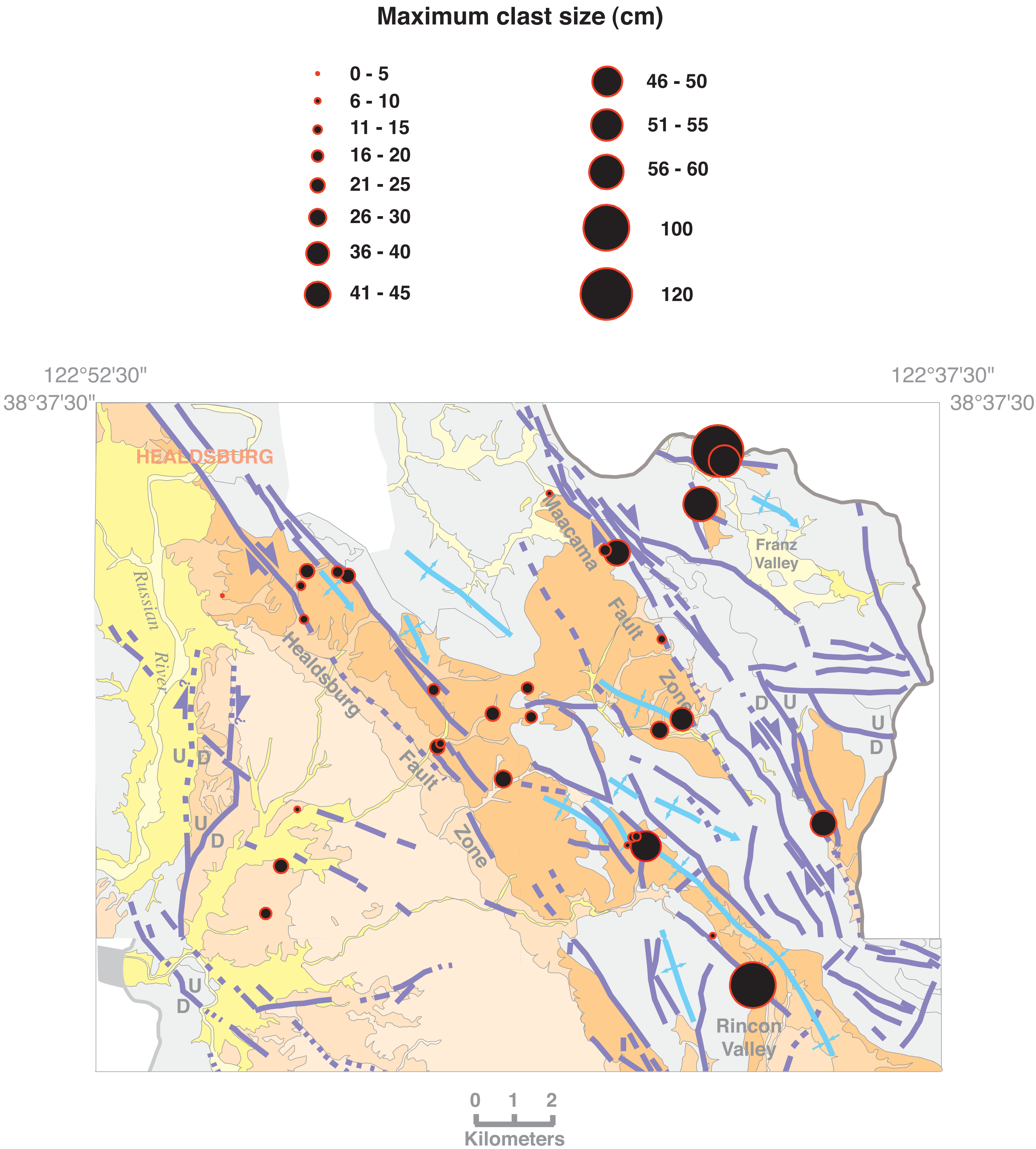


Figure 4B. Variation in maximum clast size for Plio-Pleistocene fluvial gravels across right-stepover region.

Figure 5. Prominent strand of Maacama fault zone exposed along tributary to Porter Creek on Camp Neuman conference facility property. Gravel to left (NE) of fault plane is overturned against fault contact with ash flow tuff to right (SW). View is toward SE.

Figure 6. View of a large petrified tree preserved at the Petrified Forest. Root System area of tree is in upper left part of photo (NE side of tree). Tree fell toward SW during eruption and deposition of enclosing ash flow tuff of the Petrified Forest.

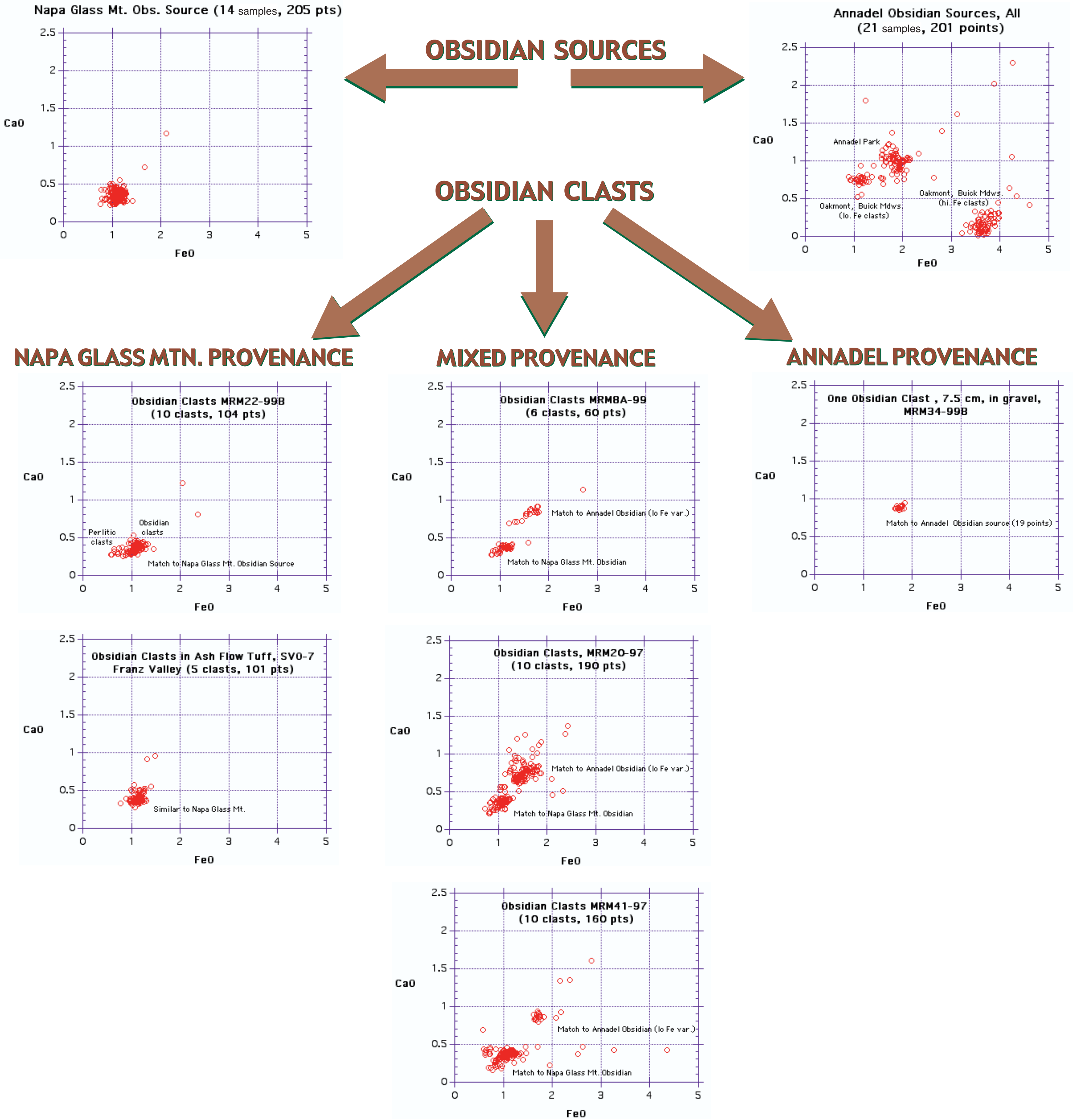


Figure 7. Geochemical signatures of obsidian pebbles from the Plio-Pleistocene gravels of the right-stepover region, compared to signatures of the 2 principal in-situ sources of obsidian in the Sonoma Volcanics.

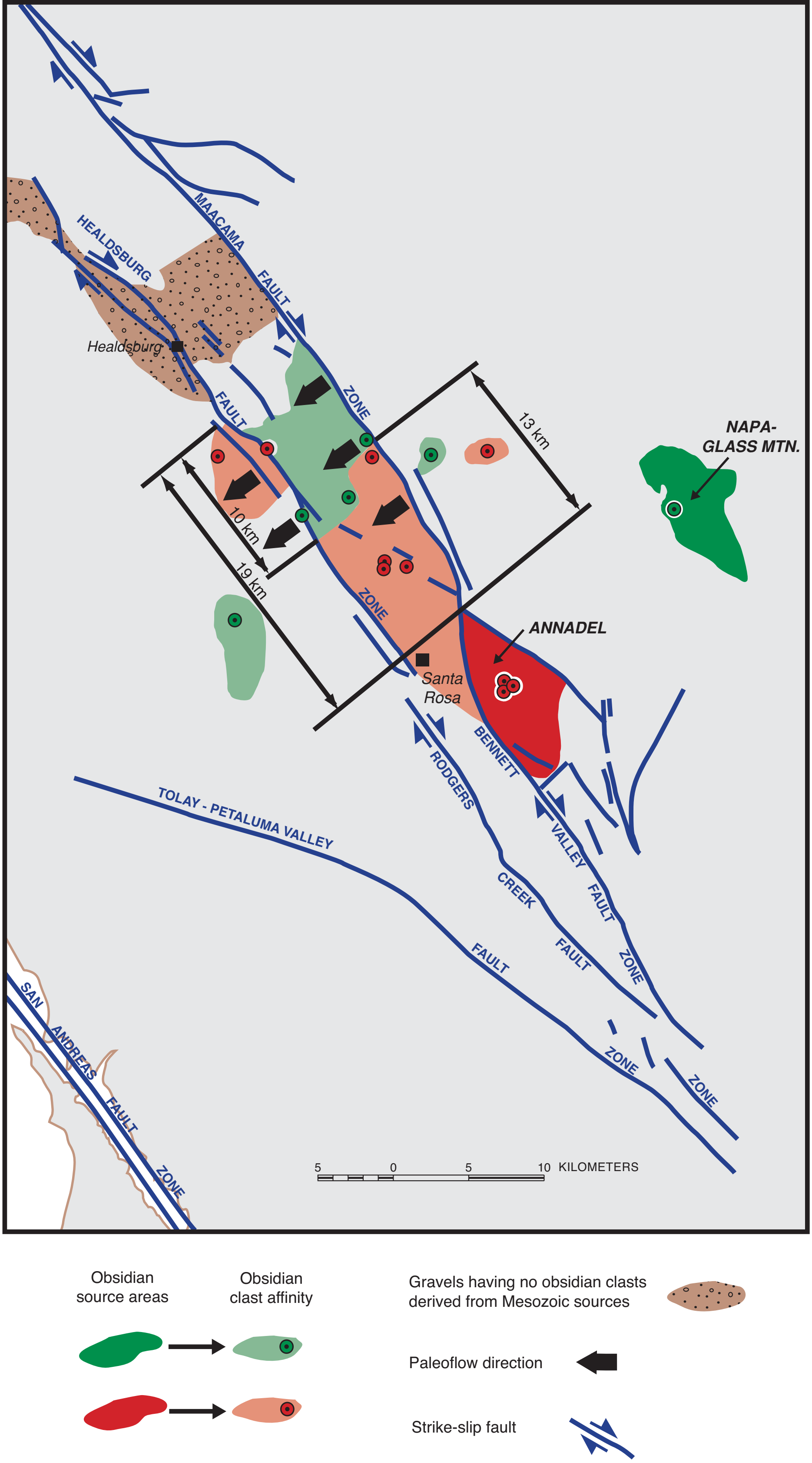


Figure 8. Model for determining displacements across faults of the right-stepover region, based on offset of obsidian pebble lithofacies in Plio-Pleistocene gravels from in-situ sources in Sonoma Volcanics. Displacement across the Maacama fault of 13 km based on obsidian clast data is here considered a minimum offset. A larger displacement of as much as 24 km is implied by offset tephra and associated sediments.

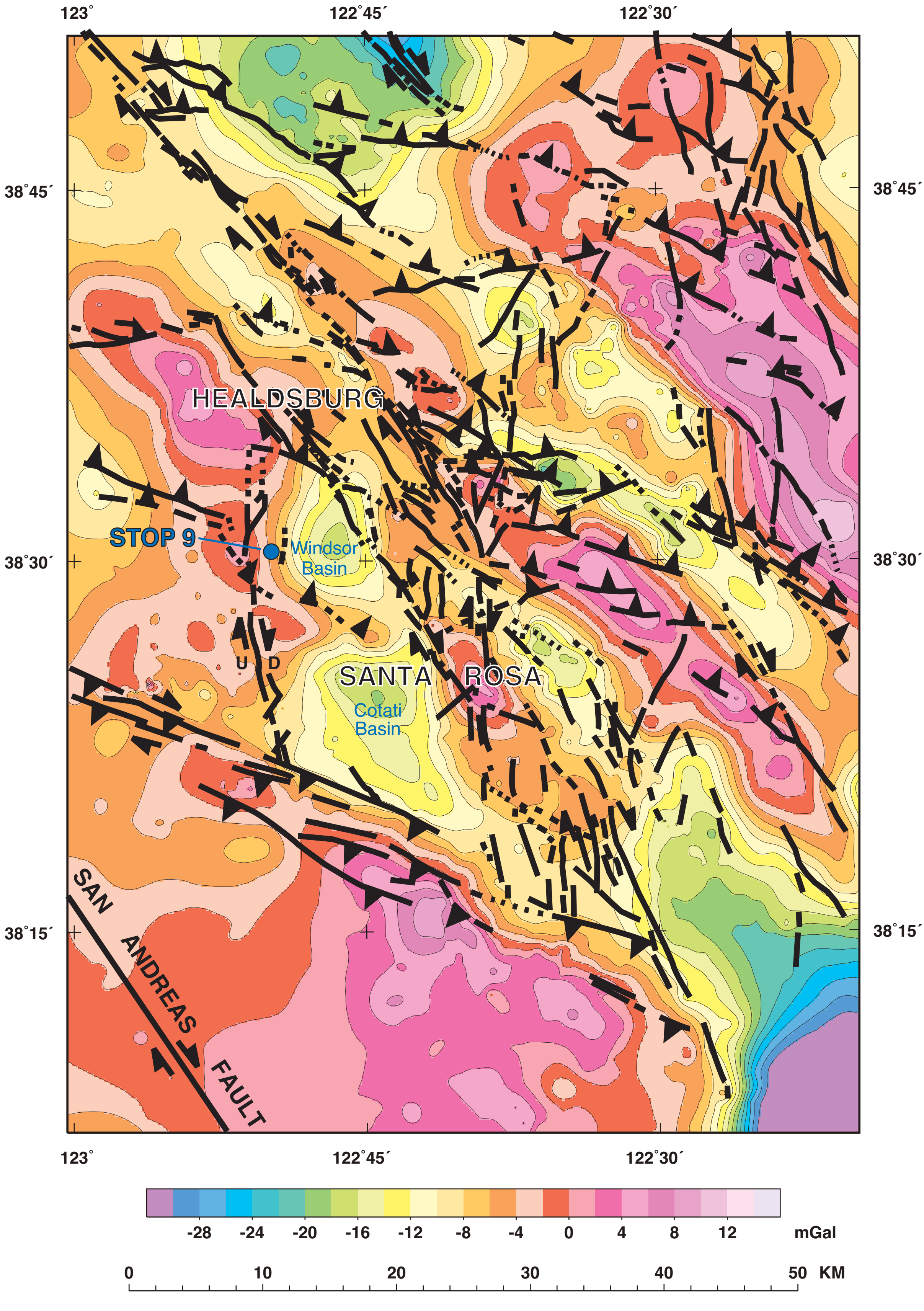


Figure 9. Gravity of the northern San Francisco Bay region, showing faults of the right-stepover area and locations of thick sedimentary sections (cool colors) associated with valleys and basins of the area. Note prominent deep basins (2.5 - 3.0 km) buried beneath Santa Rosa-Russian River plains W NW of Santa Rosa.