2008 SCEC Annual Report

Slip rates within the San Andreas fault system in the San Bernardino Valley

Sally McGill, *California State University, San Bernardino*
Ray Weldon, *University of Oregon*
Katherine Kendrick, *U.S. Geological Survey*
Lewis Owen, *University of Cincinnati*

Introduction and Motivation

The San Bernardino strand of the San Andreas fault has one of the largest discrepancies ever noted between geologically and geodetically estimated slip rates. Until recently, the Holocene slip rate of the San Bernardino strand was thought to be 24.5 mm/yr (Weldon and Sieh, 1985), whereas estimates of the rate from elastic block modeling of geodetic data were at least 5 times smaller (Meade and Hager, 2005, Becker and others, 2005). Meade and Hager (2005) argued that the fact that the San Bernardino segment of the San Andreas fault is likely to be late in its earthquake cycle is insufficient to account for the discrepancy between the geologic and geodetic rates by means of a viscoelastic rheology. Instead they suggested that either the geologic slip rate decreases markedly a short distance southeast of Weldon and Sieh's (1985) site at Cajon Creek, as a result of slip transfer to the San Jacinto fault, or that the slip rates of the San Andreas and San Jacinto faults (and the eastern California shear zone) have varied in a complementary way over time scales of multiple earthquake cycles, with each fault zone accounting for different proportions of the plate boundary slip during different time periods.

Our SCEC-funded work suggests that the San Andreas fault slip rate averaged over the past ~30 ka does indeed decrease southeastward from 24.5 mm/yr at Cajon Creek (Weldon and Sieh, 1985) to ~19 mm/yr at the Pitman Canyon landslide (Weldon and Owen, unpublished data), to 13 mm/yr at Badger Canyon (McGill and others, 2008) to 11 mm/yr at Plunge Creek (McGill and others, 2008a,b). We suspect that most of this southeastward decrease in slip rate occurs within the 16 km stretch of the fault between Cajon Creek and Badger Canyon, where the Glen Helen strand of the San Jacinto fault zone parallels the San Andreas, only 2.5 km away from it. It is within this region that transfer of slip from the San Andreas to the San Jacinto fault is most likely to occur, and it is within this region that we see the most dramatic decrease in slip rate from 24.5 mm/yr at Cajon Creek to 13 mm/yr at Badger Canyon. The slip rate at Plunge Creek is similar to the rate at Badger Canyon, within the uncertainties.

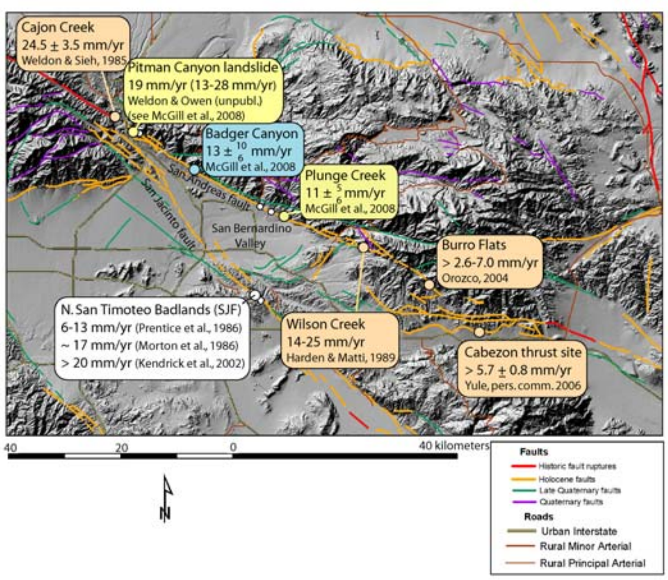

Figure 1: Geologic slip rate estimates for the San Bernardino and San Gorgonio Pass sections of the San Andreas fault and for the northern San Jacinto fault.

Work completed 2008

A. Purdue Canyon

Weldon has collected samples for Be-10 dating from 12 or more large, well exposed boulders on the Qoa-d surface (Weldon, 1986) surrounding Purdue Canyon (near Cajon Pass). This surface has been offset 1.3 ± 0.1 km by the San Andreas fault (Figure 2). Weldon's student, Sean Bemis, has prepared four samples for dating, from four different Qoa-d remnants, two on each side of the fault. Results from the accelerator are expected soon and will guide decisions on further dating at this site. A date on Qoa-d at Purdue Canyon will provide a tightly constrained slip rate for the San Andreas fault at this location (near Cajon Pass) for the past 50-70 ka (expected age of the surface). The offset measurement is unusually precise and bracketed in both its lower and upper limits. A paleochannel that originated from Purdue Canyon and was later filled with 85 m of Qoa-d alluvium is offset 1.4 km (see dashed red line in figure 2). A younger channel of Purdue Canyon later incised into the Qoa-d deposit and was subsequently offset 1.2 km (see solid red line in figure 2). The Qoa-d deposit post-dates the filled paleochannel and predates the younger channel, and so its offset is constrained between these two measurements. Restoration of 1.3 km of slip also realigns the channel of Cajon Creek as well (figure 2).

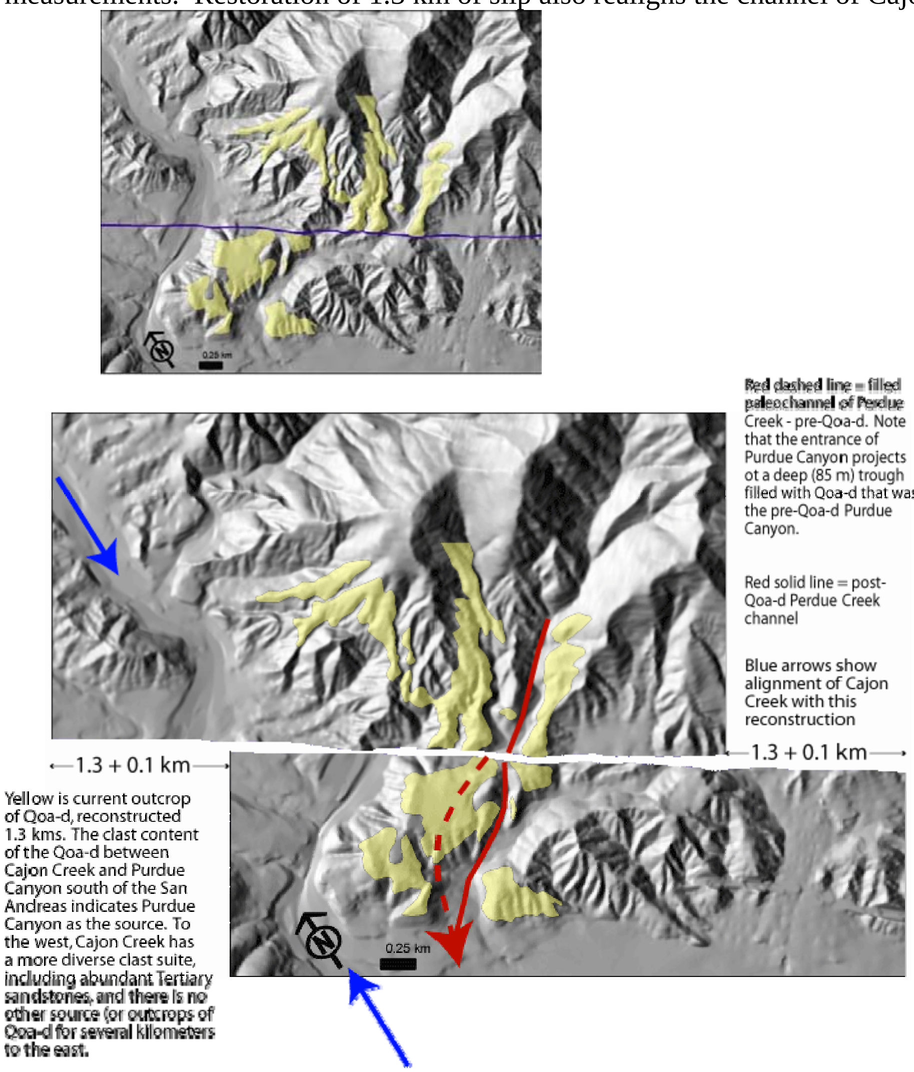

Figure 2: (a, upper) Lidar base map with Qoa-d outcrops near Purdue Canyon shown in yellow. San Andreas fault in blue. (b, lower) Same map with 1.3 km of right-lateral slip restored. See additional text within figure itself.

B. Badger Canyon

At this site, several alluvial fans (Qf1, Qf2, Qf3 and Qf4) have been right-laterally offset from the mouth of Badger Canyon (Figure 3). No other nearby drainages are large enough nor have the correct clast lithologies to have been the source of the fans. Trenches excavated by a consulting firm in 2005 offered an opportunity to view the subsurface stratigraphy within the fans and to collect samples for radiocarbon and optically stimulated luminescence (OSL) dating, as well as for descriptions of soil profiles. The Qf3 fan, with an age of ~13 ka (OSL) to ~ 15 ka (C-14), yields a slip rate of 12.8 mm/yr (95% CI: 7.2-19.7 mm/yr). The older, Qf2-c fan yields a rate of 13.6 mm/yr (using the 27.5 ka C-14 age) or 17.7 mm/yr (using the OSL age of ~ 20 ka). A riser incised into this fan, stepping down to the Qf2-w surface yields a slip rate of 13.2 mm/yr (95% CI: 11.1-16.7 mm/yr; based on C-14 dates on detrital charcoal). No radiocarbon dates are available for Qf1, and the OSL dates from Qf1 are anomalously young—younger than the OSL dates for the Qf2 surface, which is offset less.

We have identified boulders suitable for Be-10 dating on the Qf1, Qf2-w, Qf2-c and Qf3 surface. Samples will be collected soon and dated soon. This may help to resolve the existing discrepancies between radiocarbon dates an OSL dates for Qf2-c, and the anomalously young OSL dates for Qf1. This work will also allow us to estimate the age of Qf2-w, which is the fan surface whose offset is most tightly constrained, but for which we do not yet have any direct dates. (The rate reported for Qf2-w above is based on the age of a landslide that is thought to have terminated deposition on Qf2-w). The property owner at the Badger Canyon site has not allowed us to excavate the trench on Qf2-w that we had proposed for 2008. Although this is disappointing, the Be-10 dates from boulders on the surface may be sufficient to confirm or revise the slip rate from Qf2-w reported above.

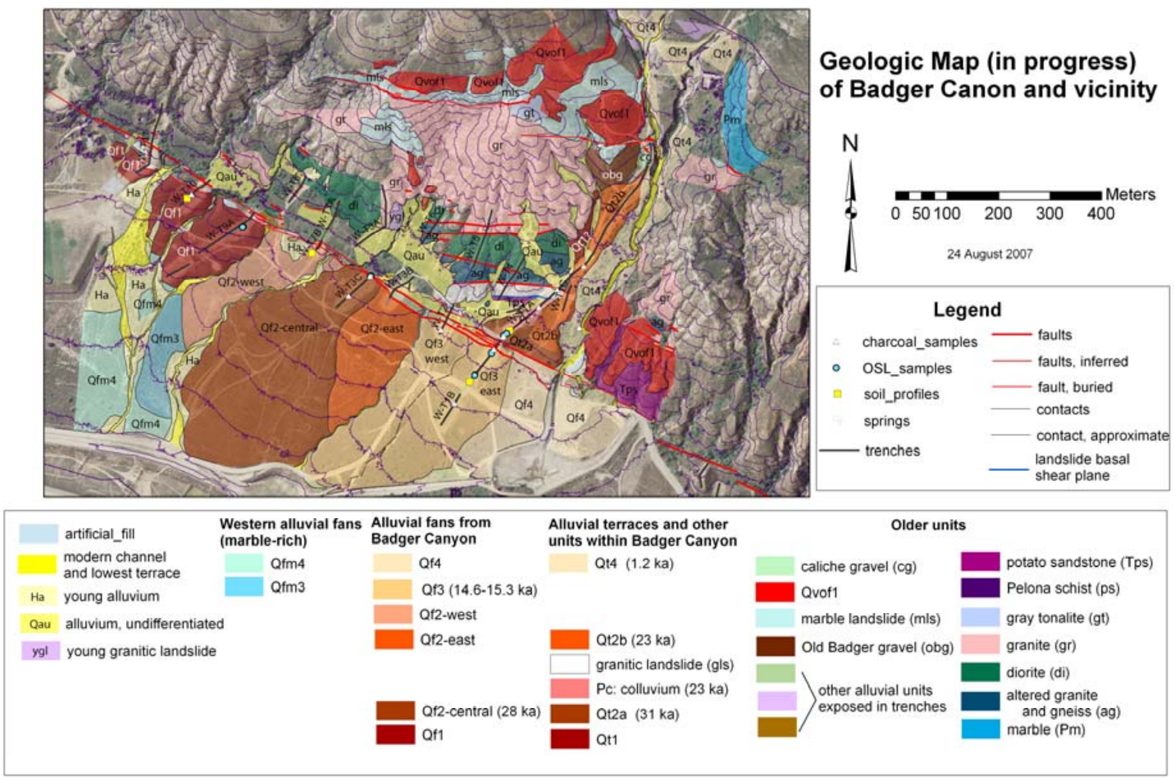

Figure 3: Geologic map showing alluvial fans offset from Badger Canyon.

C. Sweetwater Fans

During 2008, McGill extended her geologic mapping of offset alluvial fans northwestward to include a much older alluvial fan remnant (labeled Qvof1 in figure 4) that is likely offset about 2.0 km from Badger Canyon or perhaps 3.3 km from Sycamore Canyon. Although we had initially hoped to dig a pit for Be-10 dating of the Qvof1 surface, upon further inspection the surface may be too degraded to yield a reliable surface-exposure age.

The younger fans in this vicinity (labeled Qfm2, Qof1 and Qof2 in figure 4) appear to be more promising in terms of yielding a slip rate. The Qfm2 fan is rich in marble and most likely has been offset from Sweetwater Canyon, which has significantly more marble in its drainage basin than does Badger Canyon. The offset appears to be about 300 meters (Figure 5), although further mapping is needed to constrain the offset as rigorously as possible. This amount of offset is similar to the offset of the Qf2 fan from Badger Canyon (Figure 3), which is consistent with the similar degree of dissection of the two fans. The older fans (Qof1 and Qof2) have less marble, and their sources are uncertain. Qof1 appears similar in age to the Qf1 fan remnants that are offset from Badger Canyon (Figure 3), and their amount of separation from Sweetwater Canyon (~500 m) is comparable to the offset of the Qf1 fans from Badger Canyon. The limited amount of marble on the Qof1 and Qof2 fans, however, is difficult to reconcile with Sweetwater Canyon being the source, unless the marble clasts on the surfaces of these fans have weathered away. Trenching into these fans will reveal the subsurface clast lithologies, which may help in determining the correct source canyon. Trenching these fans and the Qfm2 fan will also provide samples for radiocarbon and OSL dating. The Qfm2, Qof2 and Qof1 fans are on U.S. Forest Service property. The Forest Service is open to the idea of trenching and has been cooperative so far, but environmental investigations will be required first.

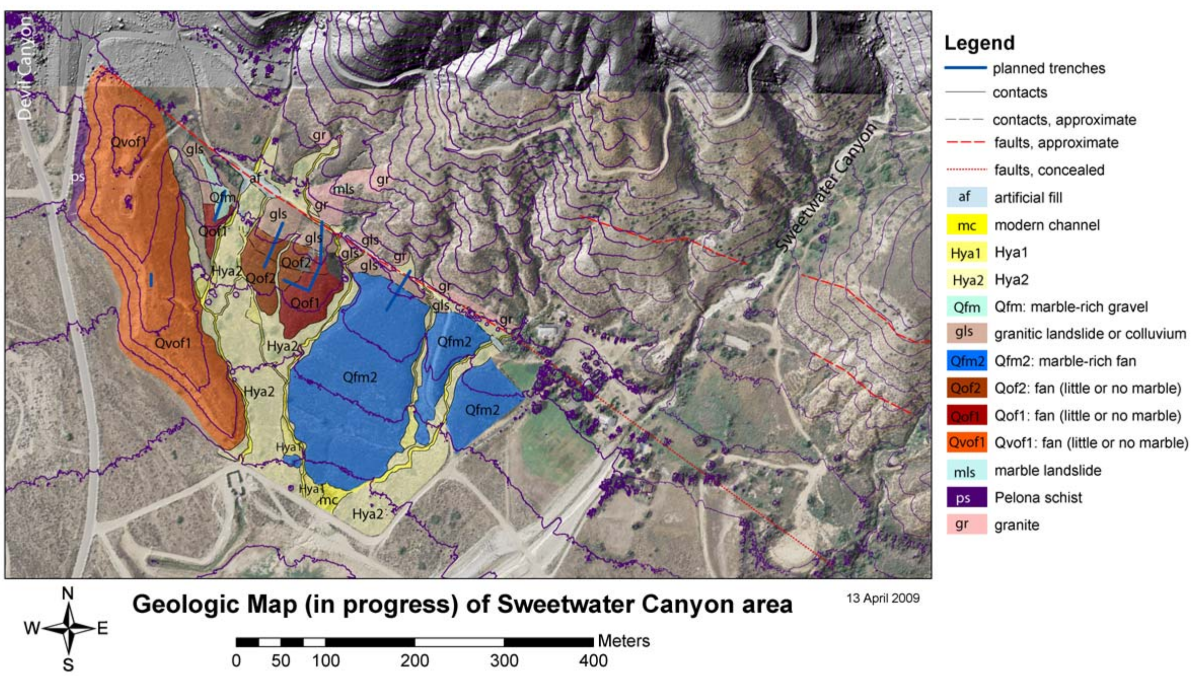

Figure 4: Geologic map of the Sweetwater Canyon area, showing the Qfm2 fan (in blue), which is rich in marble clasts and likely was deposited at the mouth of Sweetwater Canyon.

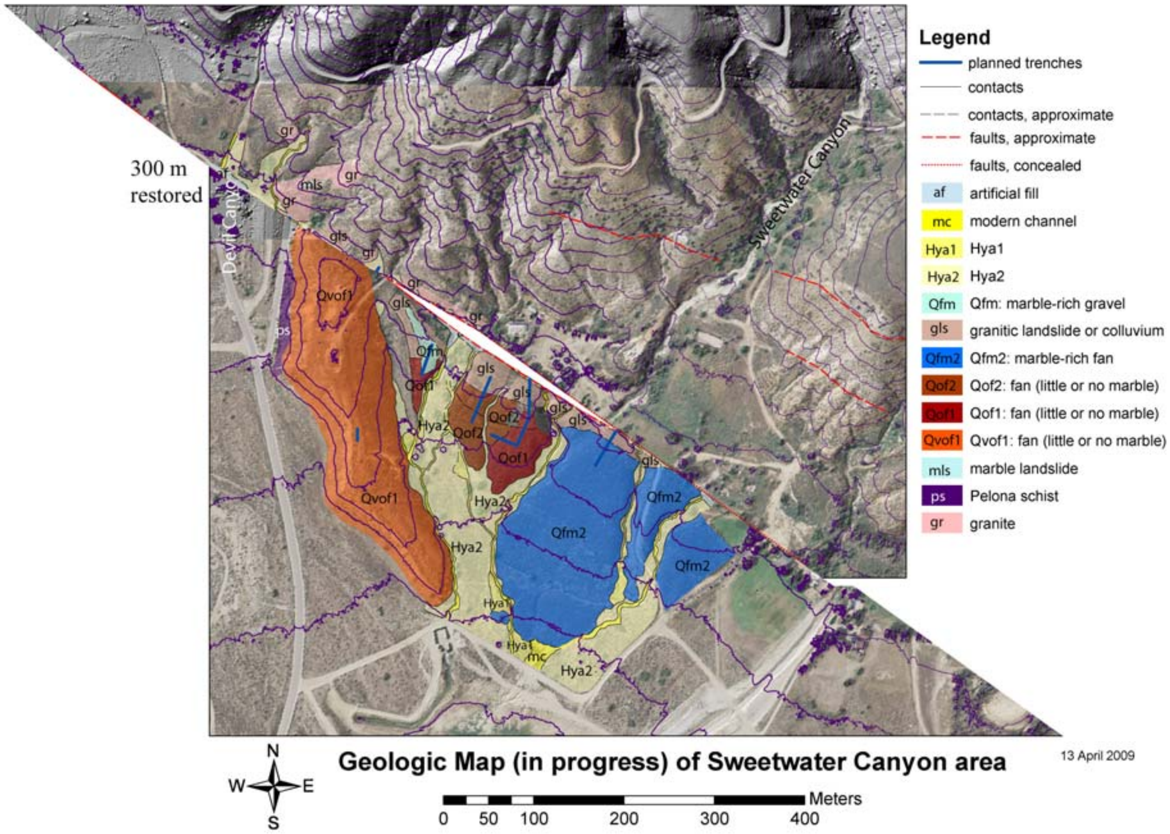

Figure 5: Geologic map of the Sweetwater Canyon area, with 300 meters of right-lateral slip restored along the San Andreas fault, so that the Qfm2 fan (blue) is aligned with Sweetwater Canyon.

References

Becker, T. W., Hardebeck, Jeanne L. and Anderson, Greg (2005). "Constraints on fault slip rates of the southern California plate boundary from GPS velocity and stress inversions." Geophysical Journal International **160**: 634-650.

McGill, Sally, Ray Weldon and Lewis Owen, 2008, Preliminary Slip Rates along the San Bernardino Strand of the San Andreas fault, Southern California Earthquake Center, 2008 Annual Meeting, Proceedings and Abstracts, **vol. 18**, pp. 165-166.

McGill, Sally, Ray Weldon and Lewis Owen, 2008, Latest Pleistocene slip rate of the San Bernardino strand of the San Andreas fault at Plunge Creek in Highland, California, *in* Tom Devine and Virgil Talbott (eds.), Geology and Hydrogeology of the Big Bear Valley and San Bernardino Mountains, Transverse Ranges, California, South Coast Geological Society Annual Field Trip Guidebook No. 35, pp. 215-224. **SCEC Publication #1233**

Meade, B. J., and Hager Bradford H. (2005). "Block models of crustal motion in southern California constrained by GPS measurements." Journal of Geophysical Research **110**(B03403): doi:10.1029/2004JB003209.

Weldon, R. J., II (1986). Late Cenozoic Geology of Cajon Pass; Implications for Tectonics and Sedimentation along the San Andreas fault. Pasadena, CA, California Institute of Technology. Ph.D. dissertation: 400 pp.

Weldon, R. J., II, and K. E., Sieh (1985). "Holocene rate of slip and tentative recurrence interval for large earthquakes on the San Andreas fault, Cajon Pass, southern California." Geological Society of America Bulletin **96**: 793-812.