2007 SCEC PROPOSAL REPORT

Project title: Resolving crustal deformation between Cajon Pass and Biskra Palms

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Objective
To sharpen or eliminate discrepancies between geodetic and geologic slip rate estimates for the southern San Andreas fault between Biskra Palms and Cajon Pass.

Introduction
Geodesy-based estimates of fault slip rate differ fundamentally from geological estimates in that geodetic inferences are not derived directly from displacement of upper crustal faults but rather from present-day far-field block motions. In the simplest model of earthquake recurrence, periodic earthquakes keep pace with constant far-field block motion (Reid, 1910). The rate of far-field motion inferred using geodesy would thus provide an estimate of fault slip rate averaged over a small number of slip events under this simplest scenario. It is widely appreciated that far-field block motions can be difficult to disentangle from complex crustal strain fields, particularly transient strains associated with the relaxation of stresses caused by large recent earthquakes (e.g., Dixon et al., 2003). This difficulty can introduce substantial uncertainty in estimates for far-field motion determined using geodesy. However, even in the absence of such uncertainty, far-field loading is nevertheless difficult to interpret in terms of fault slip rate if fault zones exhibit clustering behavior (Friedrich et al., 2003; Weldon et al., 2004). If episodes of relatively frequent fault slip events are separated by periods of relative quiescence then the relationship between rates is less obvious. According one end member model, far-field block motion would continue to closely match slip rate averaged over a small number of events, analogous to the simple periodic case. If true, it would imply that either (1) fault slip per event is variable, such that fault displacements sum to far-field block motion on average despite changes in the frequency of slip events, or (2) clustering of earthquakes is accompanied, perhaps driven, by associated changes in far-field block motion. Models of the first type have been further subdivided into Time-Predictable (implying an upper strain threshold) and Slip-Predictable (implying a lower strain threshold) (Shimazaki and Nakata, 1980). Data from the Wrightwood site on the San Andreas fault, one of the only locations along any fault zone in the world for which the slip history is known in sufficient detail to test these models with confidence, indicate that neither model seems to match the observed slip history well (Weldon et al., 2004). Another end member model for clustering behavior involves constant far-field motions such that fault slip rate inferred from geodesy would not be expected in general to agree with slip rate averaged over a small number of events. Geodetic rate estimates would instead represent longer-term averages over periods for which the relatively high frequency fluctuations in short-term slip rate give way to a steady long-term average. Observed differences between geodetic, paleoseismologic, and geomorphologic

slip rate estimates may thus provide us with important new insights into the nature of earthquake recurrence. However, many obstacles remain in our ability to combine such diverse data sets. First among these obstacles is the sparse data presently available to address such questions. The southern San Andreas fault zone provides one of the best opportunities to overcome this limitation because it has been the focus of intensive research for decades. We propose to address a glaring deficiency in geodetic measurements over an important and geologically well-studied part of the southern San Andreas fault zone, which exhibits one of the most acute discrepancies between geodesy- and geology-based rate estimates in the world.

The Strain Gap

The section of the San Andreas fault zone between Cajon Pass and Biskra Palms is an important location to address the issue of earthquake recurrence. This and neighboring segments of the fault zone have been the subject of several recent intensive geological and geodetic investigations using elastic models (Becker et al., 2004; Meade and Hager, 2005), Airborne Laser Swath Mapping (Bevis et al., 2005), tectonic geomorphology (e.g., Harden and Matti, 1989; van der Woerd et al., 2006; Fletcher et al., 2006), paleoseismology (Weldon and Seih, 1985; McGill et al., 2002; Philibosian et al., 2006), and other techniques. The southernmost stretches of this segment of the fault zone do not appear to have ruptured for at least three hundred years (McGill et al., 2002; Philibosian et al., 2006), and may therefore be relatively undisturbed by large-amplitude near-field perturbations to the strain field that would be expected immediately following large earthquakes. The surface geology of this part of the San Andreas is uncharacteristically complex (Matti and Morton, 1993; Yule and Sieh, 2003). Geophysical investigations reveal that this complexity is also a feature of the subsurface (Seeber and Armbruster, 1994; Anderson et al.. 2004; Carena and Suppe, 2004; Langenheim et al., 2006). Enigmatically, the present-day strain field in the vicinity of this part of the fault zone does not appear to match the geological rates on any time scale (e.g., Becker et al., 2004; Meade and Hager, 2005; Fig. 2). Geodetic rate estimates are as low as ≤ 5 mm/yr in striking contrast to late-Pleistocene/Holocene rates in the range of 12 to 30 mm/yr (e.g., Weldon and Sieh, 1985; Harden and Matti, 1989; Van der Woerd et al., 2006; Fletcher et al., 2006). Meade and Hager (2005) demonstrate that this discrepancy is not likely to reflect strain broadening associated with the late stage of the earthquake cycle. The range of rates represented by the various studies may depend on site location, time scale, and/or the techniques employed, and, as described below, several possible explanations to account for these differences have been proposed. Understanding these differences would lead directly to improved understanding of (1) how geodetic loading rates relate to fault slip rate, (2) temporal and/or along strike variation in San Andreas slip rate, (3) the relative rates of slip between the San Jacinto and San Andreas fault zones, and (4) the likelihood of a through-going rupture of the San Andreas from Biskra Palms to Cajon Pass.

Some models for southern California kinematics include along strike variation in San Andreas fault slip rate, either by slip transfer from the San Andreas to the eastern California shear zone in the general vicinity of Biskra Palms (Nur et al., 1993; Du and Aydin, 1996), and/or by transfer of slip from the San Jacinto fault to the San Andreas fault between Crafton Hills and Cajon Pass (Morton and Matti, 1993). The structure of the San Bernardino basin determined by gravity, aeromagnetic, and seismicity data indicates that the basin was formed by progressive displacement along the San Jacinto fault zone over the last 1.5Ma with little influence from the San Bernardino strand (Anderson et al., 2004). Temporal variation in fault slip rate, or hidden slip that is not recorded by present sites of geological investigation could also contribute to the apparent discrepancy. However, as noted by Becker et al. (2004), "uncertainties [in the SCEC V3 data set] are …particularly high around the San Bernardino Mountains," which lie adjacent to the San Bernardino strand (cf. Figure 1). Present geodetic control for this region is not sufficient to distinguish among competing hypotheses. Improving resolution of the present-day crustal velocity field using GPS is a straightforward means of improving our understanding of the tectonic setting of this complex region, with important implications for spatial versus temporal variation of slip rate and the nature of earthquake recurrence on the southern San Andreas fault.

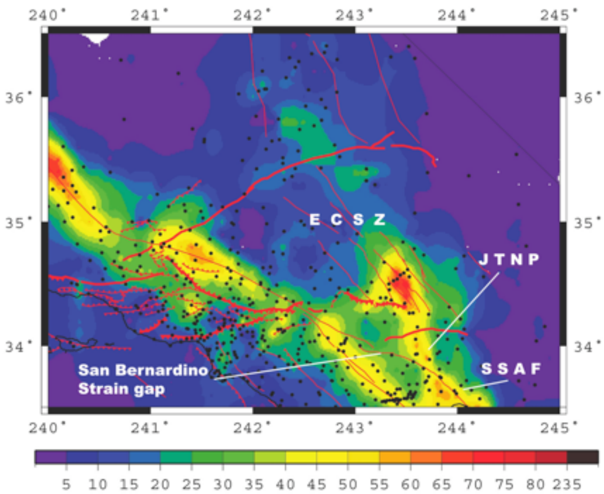

Figure 1. Maximum shear strain rate determined from SCEC V3 Crustal Motion Map from Hernandez et al. (2005) showing anomalously low strain rates through the San Bernardino region (labeled San Bernardino Strain gap). Geological rate estimates determined at locations in and around this segment of the fault suggest slip rates that are a factor of two to six times larger than those determined using geodesy. Dots represent GPS stations of the SCEC crustal motion map. Notice the general absence of stations in the vicinity of the strain gap. The details of the strain field in this area could help to resolve the cause of the apparent discrepancy, such as transfer of strain from the northernmost San Jacinto fault to the San Andreas south of Cajon Pass, or the transfer of strain from the southernmost San Andreas to the eastern California shear zone (ECSZ) through Joshua Tree National Park (JTNP).

2007 Accomplishments

In October 2007, we planned on re-occupying a number of benchmarks that were previously observed by a group led by Sally McGill at CSU-SB between 2002 and 2005. In the days leading up to departure, two large forest fires broke out in the northern San Bernardino National Forest, located to the south and west of our intended sites. After talking to the rangers at the National Forest office and being assured that the all-forest closure wouldn't affect our research, we headed to the region to deploy our equipment. Once we arrived in Big Bear we went to the ranger station to verify that we could still access our intended sites, and then were told that the all-forest closure was in full affect and we wouldn't be able to leave the main highway without chance of arrest. This severely hampered our attempts to reoccupy all the stations we had intended on reaching. We were able to observe 2 sites to the north of the forest (LUCS and PT65) along with 1 site (PITS) along the Rim of the World Scenic Byway and 1 site (RICU) near Landers to the east of the forest. McGill's group observed LUCS and PT65 each 5 times between 2002 and 2005, while PITS had just one previous observation in 2005. LUCS, PT65, and RICU all had prior data in the SCEC GPS database that we obtained to add to the recent observations. These new measurements were added with data collected by McGill's group. That data consisted of 6 campaigns to a total of 12 sites from 2002-2005 (NORC, SANO, CLSA, 6106, BRYN, U471, 6108, AWHD, HIGH, KELL, PT65, and LUCS) and also from 1 campaign in the San Bernardino Mountains (A325, CHER, DEAD, DIVD, JRH1, LUNE, MEAD, MEEK, MILL, MONA, ONYX, PITS, and WMTN). With the fires now over, we plan to return to San Bernardino to observe the remaining sites in the San Bernardino Mountains this year.

Following our first campaign, we used GAMIT/GLOBK version 10.3 to process and analyze the data from the sites for which we had more than one observation. We determined individual site velocities using a stable North America reference frame (Figure 2). Our velocity estimates are shown as the blue velocity vectors. In addition to San Bernardino Mountains

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stations, we also analyzed data from our Joshua Tree National Park network, a small number of other campaign points in the general vicinity of the Eastern Transverse Ranges (including the San Bernardino Mountains), and the continuous GPS stations located in southern California. The orange and yellow vectors show the SCECv3 velocity estimates for trilateration and GPS sites, respectively. Although there are a number of monuments in the San Bernardino Mountains area, well-resolved velocities are not yet available from most. As mentioned above, we intend to return to the San Bernardino Mountains in the Fall of 2008 (using our remaining funding from 2007) to re-observe the sites that we were unable to reach due to the fires in 2007 (red circles with no accompanying velocity vector).

Notice the relatively small error ellipses for the dense GPS campaign network we have established to the east in the Joshua Tree NP region (red squares). These velocities were determined from roughly tri-annual observations over the course of 2.5 years. Based on these results, we anticipate that additional observations from the San Bernardino sites will lead to a resolution of the velocities for those stations at similar levels. In addition, two of the initial campaign sites that McGill's group observed (KELL and ONYX) have recently had permanent continuous GPS stations installed in close proximity by the Plate Boundary Observatory (P613 and P598, respectively). Future measurements at these locations should provide valuable ties. We intend to revisit the following stations in the Fall of 2008: KELL, ONYX, CHER, DEAD, DIVD, LUNE, MEAD, MEEK, MILL, MONA, PITS, RICU, and WMTN.

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We have received no salary support or student stipend support for this project from SCEC. However, this project has provided data support for University of Arizona MS student Mr. Joshua Spinler. Mr. Spinler has recently been accepted into the Department's PhD program. Mr. Spinler will continue to work on southern California tectonics for his PhD work, and will continue to be an active participate in SCEC as a PhD student.

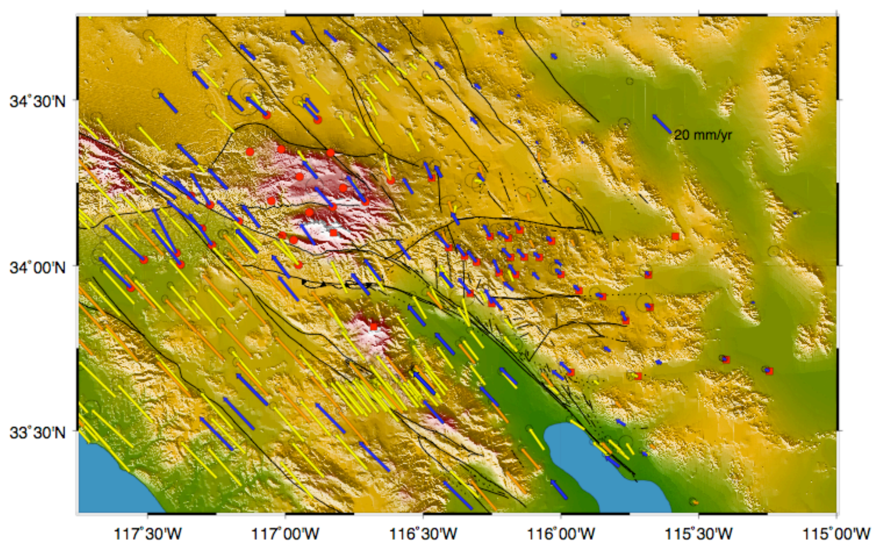

Figure 2. The southern California crustal velocity field relative to the Stable North America Reference Frame (SNARF v 1.0). Blue vectors show the University of Arizona solution. Orange and yellow vectors

show trilateration and GPS velocities in the SCEC CMM v 3. The aim of this project is a significant improvement in the velocity field in the San Bernardino Mts region, by reoccupying the GPS stations identified by large red dots.