RESEARCH FOCUS

The enigmatic San Gorgonio Pass

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The largest discontinuity along the San Andreas fault occurs in the San Gorgonio Pass (SGP) region of Southern California. Here, the San Bernardino and Coachella Valley strands (from the northwest and southeast, respectively) disaggregate into a family of irregular and discontinuous right-lateral, reverse, thrust, and oblique-normal faults (Fig. 1) (Allen, 1957; Matti et al., 1985; Matti and Morton, 1993; Yule and Sieh, 2003; Langenheim et al., 2005). Seismological studies also show that crustal deformation here is diffuse and distributed primarily on strike-slip and thrust faults at depths of ~5–20 km (Jones et al., 1986; Seeber and Armbruster, 1995; Magistrale and Sanders, 1996; Hauksson, 2000; Carena et al., 2004). Deformation along the San Andreas fault zone in the SGP region is therefore broadly distributed, in contrast to regions to the north and south where deformation is restricted to a much narrower zone.

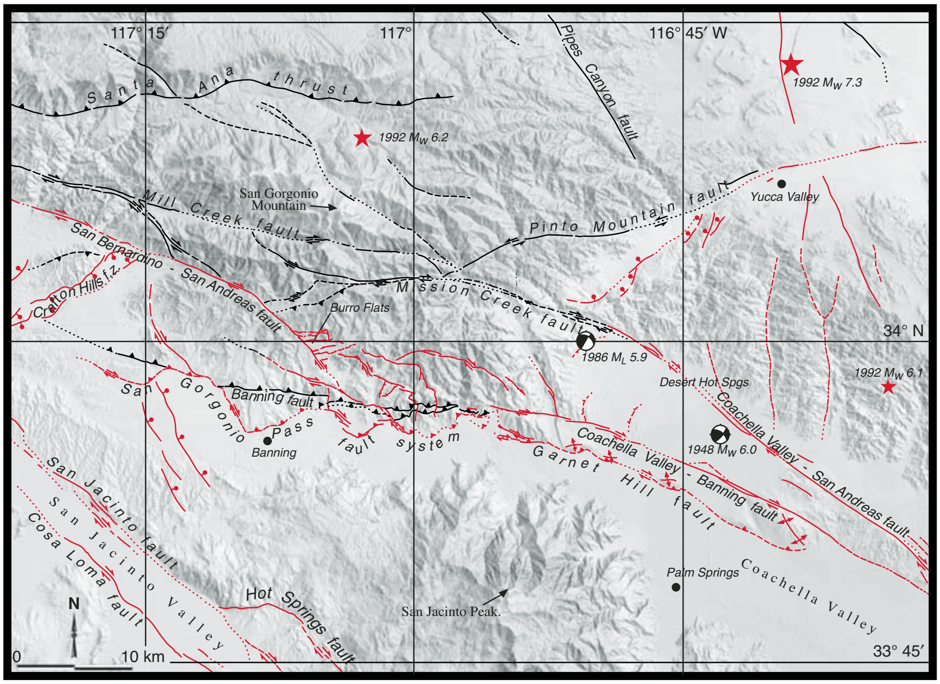

Figure 1. Shaded-relief topographic map of San Gorgonio Pass (SGP) region. Traces of active faults shown in red, inactive faults shown in black. Mapping from Allen (1957), Matti et al. (1985), and Yule and Sieh (2003). Beach-balls show epicenter and oblique slip during earthquakes on the north-dipping San Gorgonio Pass–Garnet Hill fault system at depth. Stars show epicenters of other earthquakes on faults outside of SGP.

Interpretations of the surface and subsurface data have produced competing three-dimensional (3-D) kinematic models for the SGP region. All models include a combination of thrust and strike-slip faulting. Based on their analysis of aligned nodal planes and slip vectors, Seeber and Armbruster (1995) proposed that a throughgoing, near-vertical strike-slip fault exists at depth beneath the active SGP thrust. In this model, the thrust has "beheaded" the active San Andreas fault in the upper 5 km of the crust. A second model envisions the San Andreas fault zone as a complex system of strike-slip and north-dipping thrust faults that transfer dextral-oblique slip through the SGP region (Matti and Morton, 1993; Magistrale and Sanders, 1996; Yule and Sieh, 2003; Carena et al., 2004). A third model is based on the analysis of gravity and aeromagnetic data that identify a buried magnetic source beneath the SGP. Langenheim et al. (2005) interpreted this to be a block of San Gabriel and/or Mojave/San Bernardino Mountains basement. In this model, a thrust-bounded wedge of Peninsular Ranges basement has been inserted beneath the Banning and SGP thrust faults and above the buried magnetic block.

Several researchers have used a relatively simple, vertical fault geometry to model the kinematics of the San Andreas fault in the SGP (Meade and Hager, 2005; Olsen et al., 2006; Smith and Sandwell, 2006). The choice to oversimplify the crustal structure at SGP relates to the limits of computing capacity and the difficulty in using dipping fault grids. Dair and Cooke (2009, p. 119 in this issue of *Geology*) have taken advantage of an ever-increasing computing capacity and the relatively new Southern California Earthquake Center Community Fault Model (CFM) (Plesch et al., 2007) to compare vertical versus dipping fault models in the SGP. By applying a 3-D numerical model to vertical and north-dipping scenarios, Dair and Cooke found that the dipping model provides a better match to the available strike-slip and uplift data for the San Andreas fault and southern San Bernardino Mountains. This innovative result implies that, at least in the case of SGP, an oversimplified fault model introduces systemic errors and yields flawed results. Given this result, it is intriguing to consider how model results may change in other regions where oversimplified fault geometries have been used.

All of the available data indicate that San Andreas fault slip decreases to a minimum of 5–10 mm/yr at the SGP, from 24 ± 3.5 mm/yr at Cajon Pass on the northwest and 12–22 mm/yr at Indio on the southeast (Weldon and Sieh, 1985; Yule and Sieh, 2003; Meade and Hager, 2005; Dair and Cooke, 2009; W. Behr, 2008, personal commun.). Even Dair and Cooke's vertical fault model reveals this trend. As they discuss, this decrease in slip can be explained by slip transfer to the west onto the San Jacinto fault zone and to the east onto the Eastern California Shear Zone. However, the geologic slip rates reported for SGP come from single fault strands, and therefore provide a minimum estimate. The broad zone of deformation defined by the active faults in Figure 1 suggests that an as yet undetermined amount of dextral slip is partitioned onto a number of structures in the SGP. It is conceivable that an additional 50% of dextral slip (3–5 mm/yr) could be carried by secondary structures (folds and faults) in SGP, increasing the total slip rate to 8–15 mm/yr. If correct, this overlaps with slip rates obtained from both the vertical and the dipping model of Dair and Cooke (2009). This point does not diminish their findings, but illustrates the need to continue this work as well as geologic slip-rate studies. For example, it would be interesting to take Dair and Cooke's study a step further and analyze a

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dipping fault model that incorporates all of the active faults in the SGP region (Fig. 1).

One overarching objective of the research in the SGP region is to answer a long-standing question: is a throughgoing San Andreas rupture possible? A definitive answer to this question has fundamental implications for forecasting the earthquake hazard in the Los Angeles region. If "yes," the region can expect relatively infrequent but very large earthquakes (~M_w 7.8) that rupture through SGP and simultaneously involve the Coachella Valley, San Bernardino, and the Mojave segments. If "no," the region can expect more frequent large earthquakes (~M_w 7) that separately rupture on either side of SGP. The available paleoseismic data show 5–6 rupture events since ca. A.D. 800 in the Mojave, SGP, and Coachella Valley regions that overlap in age by 50–100 yr (e.g., Weldon et al., 2004). Though these 5–6 events may record simultaneous very large throughgoing paleoearthquakes, it is equally possible that they represent separate, "smaller" events that were limited to either side of SGP but occurred within a 50–100 yr period.

"The Great Southern California ShakeOut," an emergency response and preparedness exercise held on 13 November 2008 (Jones et al., 2008), underscores the need for a definitive answer to the "is it possible" question above. Early in 2007, ~25 geoscientists met to decide upon a scenario earthquake for this exercise. A consensus view emerged to use a M_w 7.8 scenario earthquake on the San Andreas fault that initiates at the Salton Sea, ruptures through SGP, and ends in the central Mojave Desert. This worst-case scenario was used because the paleoseismic data cannot rule out the possibility that this type of an earthquake can occur, and many believed that it is better to prepare for a larger, more damaging earthquake. An alternative, though minority, opinion was held by some who argued in favor of a smaller scenario earthquake with limits at SGP, based on the hypothesis that the structural complexity of the SGP region forms a barrier against throughgoing rupture (Sykes and Seeber, 1985; Carena et al., 2004; Langenheim et al., 2005).

Evaluating the role that discontinuities like the SGP region play in arresting fault rupture remains a fundamental issue in earthquake science. Recent progress in this area includes analyses of historical earthquakes for which maps and coseismic slip distributions are known (Wesnousky, 2008). This novel approach shows that ruptures tend to end at >3–4 km steps (seen in map view), whereas they tend to continue through smaller geometric steps. It is intriguing to consider using this method to evaluate scenario earthquakes. For example, by studying the available active fault maps (e.g., CFM), one could test whether or not scenario ruptures violate the 3-4 km limit set by historical data, either by rupturing across a >3-4 km step or by stopping at a < 3-4 km step. At SGP, though disconnected, the active faults shown in Figure 1 reveal no step larger than 3 km. Assuming that slip occurs on all active structures in the SGP, the Wesnousky (2008) model therefore supports the M_w 7.8 ShakeOut scenario of a San Andreas fault earthquake rupturing through the SGP.

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