Southern California Earthquake Center Final Technical Report

Historic and paleoseismic behavior of the south-central San Andreas Fault between Cholame and the Carrizo Plain

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Collaborative project with Lisa Grant and Eric Runnerstrom, University of California, Irvine and Dallas D. Rhodes, Georgia Southern University

Summary of major accomplishments of SCEC-funded research

In this project, we strove to improve our understanding of the rupture potential of the San Andreas Fault (SAF) in the Parkfield-Cholame-northern Carrizo Plain area, and provide data for evaluating models of fault behavior and seismic hazard in Southern California. This was accomplished by 1) analysis of offset landforms and historic survey data along the northern portion of the 1857 rupture, 2) geologic and geomorphic mapping of the southern Cholame segment of the SAF, and 3) paleoseismological investigations indicating the earthquake history over the last millennium.

Our main results are the following:

We used boundary element models of frictionless strike-slip fault segments to quantify how fault geometry and strength change earthquake surface offset distributions. We produced normalized plots of surface offset distribution expected from rupture along low-friction fault segments with strength contrasts of 1/4, 1/3, 1/2, 1, 2, 3, and 4 for a range of fault segment geometries. These plots may be used with offset data to constrain the strength of two coplanar, adjacent fault segments. Applying this method to the Cholame and Carrizo segments of the SAF suggests that the offset increases where the fault deepens; in addition, the observed offset gradient at the segment boundary requires a 2/3–1/4 strength ratio of the Cholame to the Carrizo segment. (Hilley, et al., 2001).

We conducted a paleoseismic study on the SAF southeast of Cholame, California, to investigate the record of earthquakes along an 80 km paleoseismic data gap between Parkfield and the Carrizo Plain. At the LY4 site, located 37.5 km southeast of Highway 46 along the SAF, we excavated a number of trenches on the distal end of an alluvial fan that emanates from the Temblor Mountains to the northeast. We found evidence of three and possibly four ruptures recorded within the stratigraphy. These events include an event loosely bracketed by cal A.D.1030 to 1300 and cal A.D. 1390 to 1460, the 1857 Fort Tejon earthquake, and a possible later historic ground fracturing event. Three-dimensional serial excavation of an alluvial fan edge indicated 3.0 +/- 0.70 meters of near fault brittle accumulated offset from the 1857 earthquake. (Stone, et al., in press; and Young, et al., in review).

Because the northern end of the 1857 Fort Tejon earthquake ruptured through the Cholame segment, this area holds potentially valuable paleoseismic information. Careful mapping of this little-studied fault segment and the associated landforms has allowed us to interpret the geometry of the fault-zone strands and interactions among them. The complexity may indicate a difference in downdip fault surface continuity or interactions between basement rock and younger, less consolidated material near the surface. (Stone, 1999).

Changes since 1855 in reported section-line lengths and positions of survey monuments that span the San Andreas fault (SAF) were used to measure displacement interpreted to be from the 1857 Fort Tejon earthquake in south-central California. In 1855 - 1856 James E. Freeman established township and range lines across the SAF between Rancho Cholame and the northern Carrizo Plain. We inspected more than 12 of the section corners in the field and collaborated directly with Runnerstrom and Grant at UC Irvine on the interpretation of line length changes of more than 10 m across the SAF between 1855 and 1893. This change *may be* explained by ~15 m slip along the SAF in 1857 in this area. It must decrease in the upper most 50 m to about 3 m, given the Young et al. results (Runnerstrom, et al., in review).

The outcome of this work comprises all or a portion of 1 M.S. thesis and 2 Ph.D. dissertations at Arizona State University. It was performed in formal collaboration with Dr. Lisa Grant, University of California, Irvine and informally with Dr. Dallas D. Rhodes, Georgia Southern University. Importantly, it was published or is in review in the form of 4 scientific journal articles, all with the *Bulletin of the Seismological Society of America*. Along with the directly involved personnel, at least 10 other students from Arizona State University, Georgia Southern University, the Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy, and UC Irvine worked at the study sites for at least one day, gaining important training in complex logistical efforts and earthquake geology. In addition, we ran several field trips for fellow earthquake scientists and local interested lay people along the SAF in this area. We developed a good repor with the suspicious local private landowners and helped them to understand the importance of earth science investigations.

Major Scientific Accomplishments

Inferring Segment Strength Contrasts and Boundaries along Low-Friction Faults Using Surface Offset Data, with an Example from the Cholame-Carrizo Segment Boundary along the San Andreas Fault, Southern California

Rupture segmentation arises from changes in fault geometry and strength. We use boundary element models of frictionless strike-slip fault segments to quantify how fault geometry and strength change earthquake surface offset distributions. Using these relationships between fault geometry, strength, and surface offsets we can infer fault strength from the surface offsets in cases where the fault geometry can be independently constrained. This article includes normalized plots of the surface offset distribution expected from rupture along low-friction fault segments with strength contrasts of 1/4, 1/3, 1/2, 1, 2, 3, and 4 for a range of fault segment geometries. These plots may be used with offset data to constrain the strength of two coplanar, adjacent fault segments. This analysis is applied to the Cholame and Carrizo segments of the San Andreas Fault. The available surface offset data suggest that the offset increases where the fault deepens; in addition, the observed offset gradient at the segment boundary requires a 2/3–1/4 strength ratio of the Cholame to the Carrizo segment. (from Hilley, et al., 2001).

Recent rupture history of the San Andreas Fault southeast of Cholame in the northern Carrizo Plain, California

We conducted a paleoseismic study on the San Andreas fault (SAF) southeast of Cholame, California, to investigate the record of earthquakes along an 80 km paleoseismic data gap between Parkfield and the Carrizo Plain. At the LY4 site, located 37.5 km southeast of Highway 46 along the SAF, we excavated a fault-perpendicular trench on the distal end of an alluvial fan that emanates from the Temblor Mountains to the northeast. We found evidence of three and possibly four ruptures recorded within the stratigraphy. The only age constraints are radiocarbon dates on a paleosol three units (50 cm) below the oldest event horizon, and the presence of recently introduced exotic pollen species in an upper unit. The radiocarbon dates indicate there have been at least three surface rupturing events at the LY4 site since Cal A.D. 1058-1291. Exotic (historic) pollen in the top of a unit possibly cut by the youngest event suggests that an earthquake affected at the LY4 site close to 1873-4 A.D. (from Stone, et al., in press).

3-D Excavation and Recent Rupture History along the Cholame Segment of the San Andreas Fault

We have conducted a paleoseismic study along the Cholame segment of the San Andreas fault to determine the dates of earthquakes and the amount of lateral offset of an alluvial fan from the 1857 Fort Tejon earthquake. Excavations at the Las Yeguas (LY4) site include 5 fault perpendicular trenches, 2 parallel trenches, and several hand dug trenches. Abruptly truncated sand and silt layers that are not correlative to units across the fault zone indicate the oldest earthquake, L2. Event L2 is loosely bracketed by the laminated silt age of cal A.D.1030 to 1300 in LY4-99 and the cal A.D. 1390 to 1460 age estimate of sandy silt units 13 and 5. The vertical offset, shearing and fracturing of silty sand and gravel units that appear to overlie the main break in units from event L2 suggests the youngest rupturing event, L1. Event L1 is constrained by the A.D. 1390 to 1460 age and historical artifacts that are at least 140 years old. L1 is likely the 1857 Fort Tejon earthquake. Tectonic silt-filled fractures that dissect historic gray-tan silts and

sands suggest a ground shaking event or a triggered slip event, L0, which occurred after 1857. Three-dimensional serial excavation of an alluvial fan edge (unit 4) indicated 3.0 +/- 0.70 meters of near fault brittle accumulated offset from the 1857 earthquake. (from Young, et al., in review).

Displacement across the Cholame segment of the San Andreas Fault Between 1855 and 1893 from Cadastral Surveys

Changes since 1855 in reported section-line lengths and positions of survey monuments that span the San Andreas fault (SAF) were used to measure displacement interpreted to be from the 1857 Fort Tejon earthquake in south-central California. In 1855 - 1856 James E. Freeman established township and range lines across the SAF between Rancho Cholame and the northern Carrizo Plain. At least 26 1-mile sections lines spanned the SAF in the area between present day Highways 46 and 58. Each section line was marked by monuments at the midpoint and endpoints. Section lines across portions of the SAF were resurveyed in 1893 by J. M. Gore. We projected changes in line length onto the fault zone to measure displacement. The measurements indicate right lateral displacement of 16.4 ± 4.8 meters across the fault zone. This finding is based on historic data and a small data set. The resulting tectonic displacement exceeds the maximum reported geomorphic offsets (~ 6 m) attributed to the 1857 earthquake along the Cholame segment. While we recognize great uncertainties in the data, we tentatively conclude that total displacement in the 1857 earthquake along the SAF over this ~2 km wide aperture was significantly greater than 3 m slip previously reported for the Cholame segment from narrower aperture geomorphic and trenching studies. These differences may be compatible if slip along the fault increases down dip rapidly from ~ 3 m at the surface to ~ 20 m within several hundred meters of the surface. Our inference of high slip along this portion of the Cholame segment in 1857 is at odds with most rupture models of the central San Andreas fault and suggests that geomorphic offsets may not represent total displacement across the fault zone. (from Runnerstrom, et al., in review).

Importance of Science and Technology Center funding through SCEC

The most important outcomes from the association of our research and its support from the Center were the intangible but very important informal peer review of our work as it proceeded, the enhancement of its interpretation with discussion and comparisons with Center colleagues' research, and indirectly the higher regard for the students coming from our group who had experience working with SCEC. In 1996, Arrowsmith was new to the paleoseismology field and joined forces with Grant whose reputation was already established through the significant work of her Ph.D. along the SAF in the Carrizo Plain. This partnership brought us into SCEC and from there, we interacted regularly with other Center colleagues. These were largely the Earthquake Geology group, but also some of the Master Model and Earthquake Source Process and Regional Deformation colleagues. This interaction enhanced the learning of the ASU team as some went to visit other study sites, as well as entertained field reviews at the Cholame site. Our students still have yet to directly reap the benefits of their Center ties, but a glimmer of the enchanced recognition is suggested by better job placement and more interesting job opportunities for them upon graduation. The distance from ASU to Southern California precluded more interactions that might have been possible such as classes at other institutions and joint advising. We did not take advantage of the infrastructure support from the Center.

Outreach Accomplishments of Particular Note

Interpretation of earthquake hazards for Arizona and California

One of the greatest earthquake hazards for Arizona is a damaging earthquake in Southern California. We would not feel the ground motion, but the disruption of commerce and social ties to Southern California would be tangible. Direct earthquake hazard to the Yuma area is significant. Our association with SCEC was manifest locally by Arizona state government service by Arrowsmith as the ASU representative of Arizona Earthquake Information Network and a member of Arizona Council for Earthquake Safety. Numerous television and print inquiries as well as public lectures on earthquakes provided opportunities to explain them and talk about SCEC as an important guiding structure in their investigation. In addition, our research was directly associated with efforts by Arrowsmith as external reviewer for the California Earthquake Prediction Evaluation Council.

Earthquake geology training and collaboration with Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

We hosted Laura Colini of the Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy, for one year in 2000 and 2001. Along with her main research efforts in Earthquakes and Landscape Development in the Central Appenine, Italy, she worked with us (in particular, Ph.D. candidate Jeri J. Young) at the LY4 earthquake geology site along the SAF and gained important experience in paleoseismology of strike-slip environments. This collaboration continues beyond the SCEC-funded research in Jeri Young's recent several month visit to Rome where she worked on faulting projects in Gargano, eastern Italy.

Development of structural geology exercise on flow from SCEC velocity map

In order to provide a relevant and illustrative exercise on deformation and flow fields, Arrowsmith developed a simple class exercise based on the velocity gradients that students could measure off of the Horizontal Deformation Velocity Map (http://www.scecdc.scec.org/group_e/release.v2/). The students make velocity profiles parallel and perpendicular to the SAF and then calculate the deformation rate. This then can be related to larger structures developed to large finite strains and the consideration of the time necessary to build them at active deformation rates. This also has been incorporated (with due SCEC credit) into the textbook: Ragan and Arrowsmith, *Structural Geology: an introduction to geometrical techniques, 4th edition*, in revision.

SCEC-supported publications

Refereed publications

Young, J. J., Arrowsmith, J R., Colini, L., and Grant, L. B., 3-D excavation and measurement of recent rupture history along the Cholame segment of the San Andreas Fault, *Bulletin of the Seismological Society of America: Special Issue on Paleoseismology of the San Andreas fault*, in review, 2002. SCEC Publication 581.

Runnerstrom, E. E., Grant, L. B., Arrowsmith, J R., Rhodes, D. D., and Stone, E. M., Displacement across the Cholame segment of the San Andreas Fault between 1855 and 1896 from cadastral surveys, *Bulletin of the Seismological Society of America: Special Issue on Paleoseismology of the San Andreas fault*, in review, 2002. SCEC Publication 586.

Stone, E.M., Grant, L., and Arrowsmith, J R., Recent rupture history of the San Andreas Fault southeast of Cholame in the northern Carrizo Plain, California, *Bulletin of the Seismological Society of America*, in press, 2002. SCEC Publication 495.

Hilley, G. E., Arrowsmith, J R., and Stone, E. M., Using microseismicity and surface offset data to define fault segment boundaries along low friction faults, with an example from the Cholame-Carrizo segment boundary along the San Andreas Fault, Southern California, *Bulletin of the Seismological Society of America*, *91*, 427-440, 2001. SCEC Publication 470.

Abstracts:

Young, J. J., Colini, L., Arrowsmith, J R., and Grant, L. B., Recent Surface Ruptures Along the Cholame Segment of the San Andreas Fault, *EOS Transactions AGU*, *81*, 48, F925, 2000.

Hilley, G. E., Arrowsmith, J R., and Stone, E. M., Using microseismicity and surface offset data to define fault segment boundaries along low friction faults, with an example from the Cholame-Carrizo segment boundary along the San Andreas Fault, southern California, *EOS Transactions AGU*, *80*, 17, 1999.

Stone, E. M., Arrowsmith, J R., and Grant, L. B., Recent rupture history of the San Andreas Fault southeast of Cholame in the northern Carrizo Plain, California, *EOS Transactions AGU*, *80*, 46, 735, 1999.

Stone, E. M., Arrowsmith, J R., Rhodes, D. D., and Grant, L. B., Fault zone geometry and historic displacement along the Cholame segment of the San Andreas Fault, southern California, *EOS Transactions AGU*, *79*, 45, 612, 1998.

Arrowsmith, J R., Potential for earthquake rupture and M 7 earthquakes along the Parkfield, Cholame, and Carrizo segments of the San Andreas Fault, Seismological Research Letters, 68, 2, 323, 1997.

Appendices

M.S. and Ph.D. students

Jeri Young, Ph.D. candidate, Earthquake Geology along the Cholame Segment of the San Andreas Fault (working title), Arizona State University. Expected completion 2003.

George Hilley, Ph.D., Landscape development of tectonically active areas, Arizona State University, May 2001. Currently an Alexander von Humboldt post doctoral scholar at the University of Potsdam, Institute of Earth Sciences.

Elizabeth Stone, M. S., Geomorphology, Structure, and Paleoseimology of the central Cholame Segment, Carrizo Plain, California, Arizona State University, May 2000. Currently a Staff Geologist at Ninyo and Moore Geotechnical and Environmental Sciences Consultants.

No Post-Doctoral Associates were supported at ASU by SCEC

We received no SCEC-related awards

Human Dimensions

Our research group is a small one of a single professor and several students with collaborators at UC Irvine and Georgia Southern University. We profited greatly from participation in the greater SCEC community.