Heat-flow constraints of seismogenic faulting from thermochronology studies of apatites, zircons, and K-feldspars in two exhumed faults of the San Andreas system

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Investigations Undertaken

No definitive conclusion(s) has been reached regarding the strength of the San Andreas fault and other faults in the San Andreas system -- are the faults anomalously weak or do the faults have normal strength? Scholz (2000) has argued that the San Andreas fault has normal strength, similar to most faults in continental crust. He interprets the orientation and magnitudes of the maximum and minimum horizontal stresses for the San Andreas fault to be related to transpressional plate-boundary motion especially adjacent, and north of, the Mojave Desert. In regard to heat flow, Scholz (2000) does not discount the fact that heat is generated by seismic slip on the fault. Rather, he suggests that *"….the heat-flow model is flawed, probably in its assumption that all heat transfer is governed by conduction*." Advection of heat away from the fault by fluids would decrease the heat flow immediately over the fault and potentially produce localized upwellings of warm water and irregular distribution of high and low heat-flow values at the land surface (similar to what has been documented for heat flow in mid-ocean ridges).

If advection is responsible for the dissipation of heat away from the fault, then it most likely occurs close to the land surface where fluids are most readily able to move through interconnected pores and fractures. Unfortunately, most of the heat-flow data for the San Andreas fault have been collected close to the land surface where the potential for groundwater flow and heat advection are greatest. Williams and Narasimhan (1989) showed that groundwater flow across the San Andreas fault could effectively disperse any fault-generated, heat flow anomaly near the fault. In order to minimize the potential dispersion of heat by groundwater, it will be necessary to get heat flow data from deep boreholes. This will be possible, for example, in the deep drill hole near Parkfield, which is an attempt in part to obtain heat flow data and fluid flow information directly in the San Andreas fault that will help to resolve the stress / heat-flow paradox.

This project has taken a different approach to determining the strength of faults in the San Andreas system by obtaining thermochronologic data of fault rocks and host rocks that formed and deformed at depth by seismogenic slip. The study has focused on the Punchbowl and San Gabriel faults in the San Gabriel mountains. These faults were chosen because they are the most deeply exhumed large-displacement faults in the San Andreas system and were the main components of the San Andreas transform system in the central Transverse Ranges of southern California during the Miocene and Pliocene. Miocene (12 to 5 Ma) faulting on the main strand of the San Gabriel fault accounted for 42 to 60 km of right-lateral separation. After the late Miocene, most of the transform displacement in the central Transverse Ranges occurred 30 km northeast on the Punchbowl fault and on the presently active trace of the San Andreas fault. Total right-lateral separation on the Punchbowl fault is approximately 44 km. The rocks in these faults probably only experienced long-term temperatures below approximately 100 to 150 °C on the basis of the preserved mineral paragenesis.

Thermal pulses generated by individual earthquakes dampen rapidly away from the fault and become indistinguishable by direct measurement within a couple of months after faulting (McKenzie and Brune, 1972; Lachenbruch, 1986). Depending on the ambient temperature and amount of heat generated during an individual seismic event, the absolute temperature rise experienced by the fault rocks and adjacent host rocks can increase drastically, even to the level needed to partially melt the rock. Although melt products are not ubiquitous in faults, they are common enough in quartzofeldspathic fault rocks in the mid-crust to indicate that seismically induced transient temperature increases of hundreds of degrees Celsius do occur in some faults. If the recurrence interval of seismic events is short relative to the characteristic length scale for thermal diffusivity, then an anomalous temperature increase will develop adjacent to the fault with increasing number of seismic events (Lachenbruch and Sass, 1980).

Fission-track analyses of apatites and zircons have been obtained from these faults since they are proven monitors for documenting time-temperature histories of rocks between approximately 120 and 240 °C, which is in the range of temperature increase that would be produced by a normal strength fault at 2 to 5 km depth. This coming year U-Th/He data is also being obtained from the same apatite and zircon samples. Collectively, these thermochronometers are providing spatial and temporal data on heat flow localized along these faults. These constraints are being incorporated into a finite-element heat-flow model to delimit the strength of these faults during deformation / seismogenic slip.

Between 10 to 30 samples were collected along traverses across the strike the fault at each locality (Figure 1). Sample spacing increased with increasing distance from the fault to a distance of hundreds of meters. Apatites and zircons were separated successfully from forty nine samples at Saint Louis University using standard techniques of crushing, grinding, sieving, Wilfley table washing, magnetic separating, and settling in heavy liquids. This was a time-consuming process!

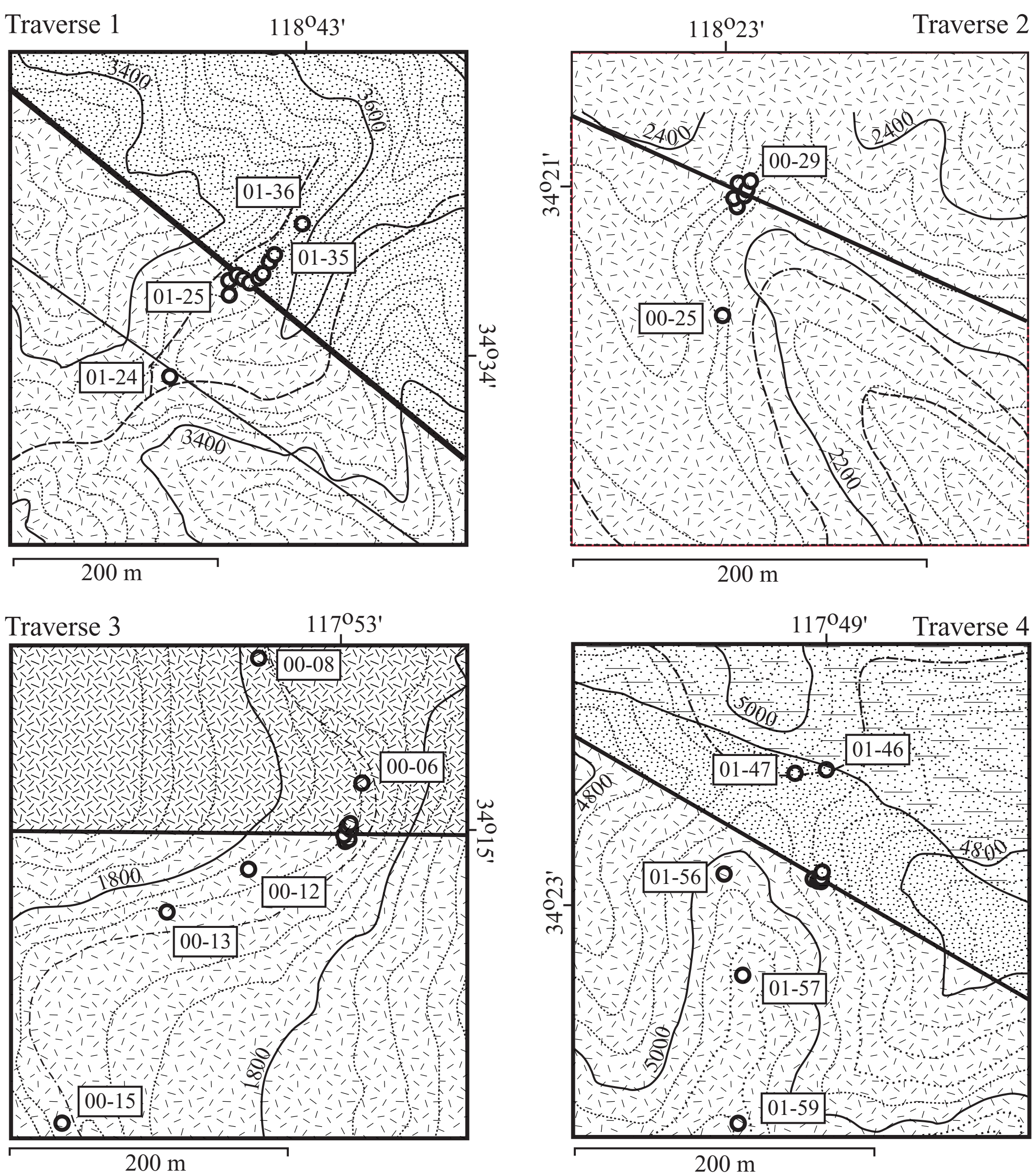

Figure 1 - Some sample locations collected from three traverses across the San Gabriel fault and one locality on the Punchbowl fault.

Results

The fission track data were collected in the laboratory of Dr. John Garver, Union College. Standard procedures were followed in the preparation, irradiation, and analyses of the apatite and zircon grains. Samples were irradiated at the Oregon State Nuclear Reactor. Mohamed El-Shafei, a post-doctoral student and collaborator in this project, did the fission-track counting of the apatites. John Garver was responsible for the analysis of eight zircons samples. The data are presented in figure 2.

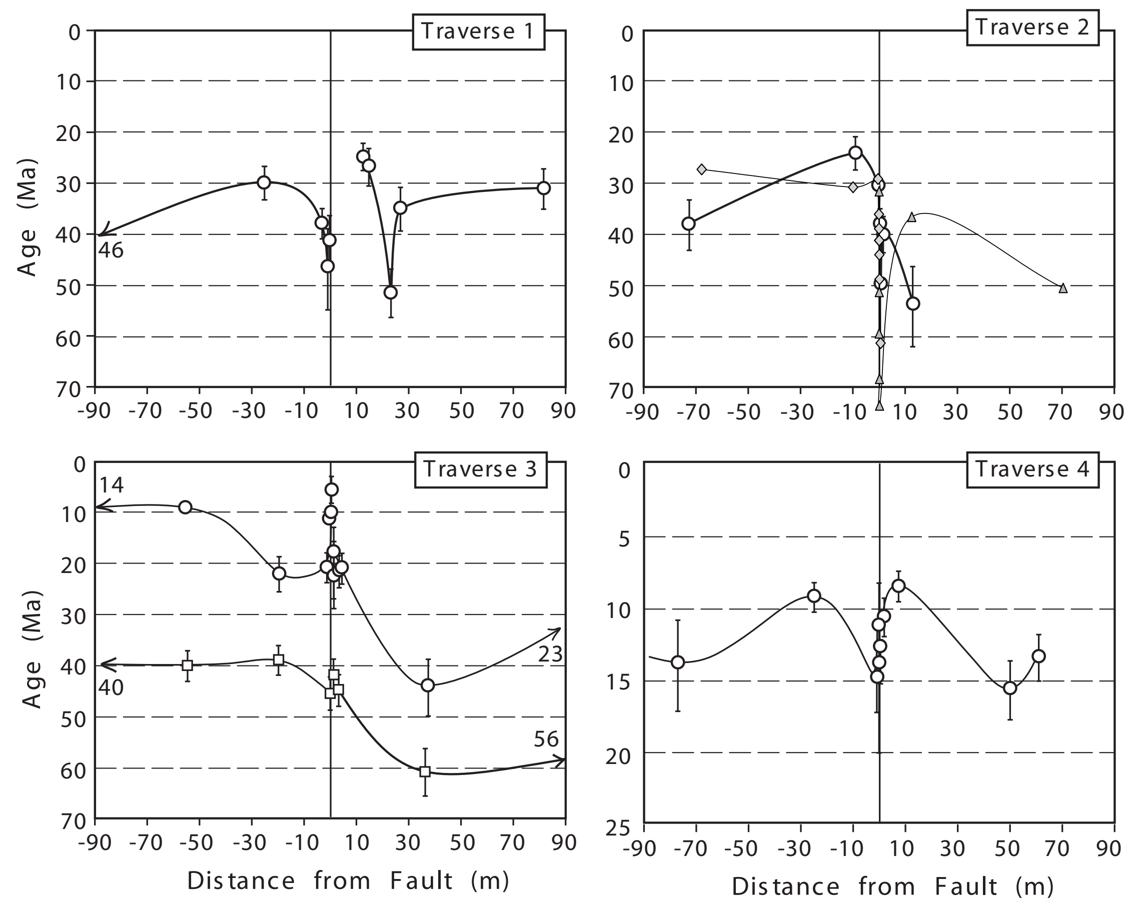

Figure 2 - Fission-track data for apatites (all traverses) and zircon (traverse 3). Distance is orthogonal to the fault. Arrows point to data beyond +/- 90m from the faults. Additional apatite data for traverse 2 is from the publication of d'Alessio et al. (Geology, 2003)

The fission-track dates are neither constant on each side of the fault nor decrease monotonically in proximity of the faults. Consequently, the data are not easily interpreted in terms of heat production and heat flow from the faults when they were active. We are in the process of investigate the factors that are controlling the variations in ages. What is clear is that apart from a few apatite ages in traverse 3, none of the ages were completely reset when the faults were active in the Miocene. Most likely there was not sufficient heat production in the faults to elevate the temperatures experienced by the samples and completely reset the fission-track ages. This result would weakly support the hypothesis that these faults were weak when generating earthquakes.

Non-Technical Summary

The strengths of many large plate-boundary faults such as the San Andreas are not well known. To help determine the strengths of such faults, we have obtained data from two non-active faults in the San Andreas system. These data are providing time-temperature histories for the two faults when they were active 5 to 10 million years ago. An average of 10 samples were collected and analyzed from four localities. The data are difficult to interpret in terms of heat production in the faults, and thus we are not yet able to provide good constraints on the strengths of these two faults. More work is being done to determine what has controlled the variations in the data.

Reports / Publications

The results of a portion of this study have been published in the Masters thesis of David Cuevas, Saint Louis University, and presented at the Fall meeting of AGU, 2003. A manuscript will be submitted for publication in the near future.

Cuevas, D. (2003) Heat-flow constraints on the strength of seismogenic faulting using fission-track data from the San Andreas fault system, California. MS thesis, Saint Louis University, 101 pop.

Kirschner, D., Cuevas, D., El-Shafei, M., and Garver, J. (2003) Heat Generation and Strength of Seismogenic Faults Constrained by Fission-Track Data. AGU Abstracts F1089.