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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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NON-TECHNICAL ABSTRACT

There are many outstanding questions regarding faults and earthquakes. One of these questions is related to the strength of faults and why some faults generate earthquakes and others do not. Faults of normal strength should generate significant amounts of heat due to frictional sliding during an earthquake event. Many earthquake-producing faults such as the San Andreas fault do not, however, appear to generate much heat. This apparent lack of heat could be due to the faults being anomalously weak or else due to efficient dissipation of heat away from the fault zone. To investigate the amount of (paleo)heat that has been produced along some faults, we have collected samples across two exposed fault zones in the San Andreas fault system. Minerals from these samples have been analyzed in the laboratory in order to obtain temperature-time data that can provide some constraints on the temperature histories experienced by the samples. The results of these analyses provide some constraints on the temperature histories of the samples and also on the fluid-rock interactions that have occurred in the fault zones. These data combined with other isotopic and elemental data collected by the PI and collaborators have provided important information about earthquake generation in San Andreas type faults.

TECHNICAL ABSTRACT

Although the stress / heat-flow paradox of the San Andreas fault has been debated for several decades, there is yet no widely accepted resolution to the problem. New results from the SAFOD drilling project on the San Andreas and similar drilling projects of other active faults around the world are helping to resolve this paradox. Similarly, our study and other detailed structural and thermochronologic studies of exhumed faults are providing important constraints on the evolution, thermal history, and strength of (paleo)seismogenic faults.

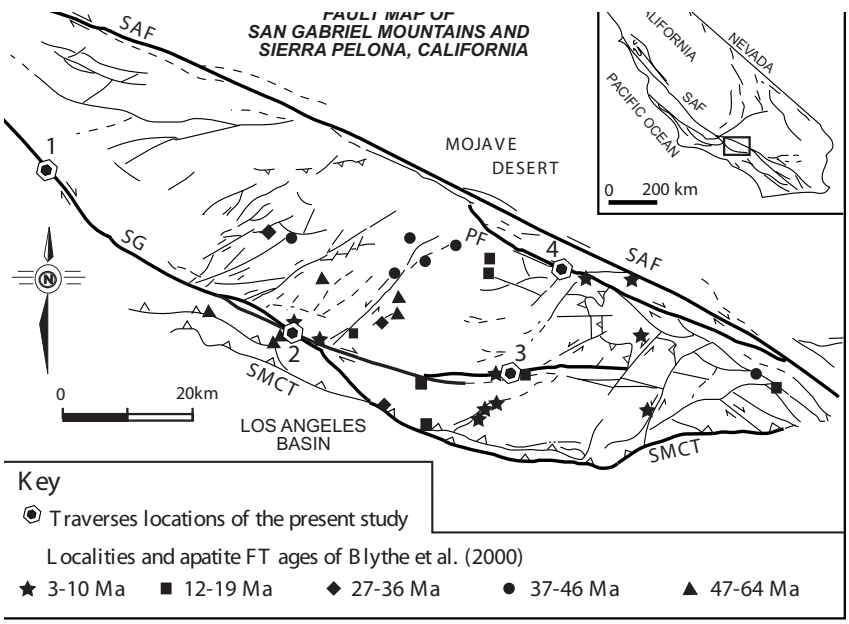

Figure 1 - Sample locations 1 through 4 are located along the San Gabrield and Punchbowl faults. Fission-track dates published by Blythe et al. (2000) provide important constraints and context for interpreting the data collected in this study.

We have obtained fission-track and U-Th/He data for apatites and zircons from two inactive strike-slip faults in the San Andreas system (the San Gabriel and Punchbowl faults) that have been exhumed approximately 2 to 5 kilometers (Figure 1). The San Gabriel fault samples were collected in traverses near Whitaker Peak, the "Earthquake locality", and along Bear Creek. The Punchbowl samples were collected approximately 1 km south of the “Devils Chair” area in the County Park. Fission-track data have been obtained for 41 apatite and 8 zircon samples in collaboration with Dr. John Garver of Union College. U-Th/He data has been obtained for more than 20 apatite and 6 zircon samples in collaboration with Dr. Peter Reiners of Yale University. Apatite fission-track dates are between 51 and 25 Ma from Whitaker Peak, 54 and 24 Ma from the Earthquake locality, 44 to 9 Ma from the Bear Creek locality (excluding one sample), and 15 and 7 Ma from the Punchbowl locality. Zircon FT dates from the Bear Creek locality range from 61 to 39 Ma. The U-Th/He dates are all younger than 40 Ma (Figure 2).

The fission-track and U-Th/He dates vary systematically with distance from the fault cores along individual traverses; though, they do not young monotonically towards the faults, which would be expected if there had been sustained elevated temperature along the faults. The ages are inversely correlated with uranium concentration of the apatite grains (Figure 3). There is also a moderately good correlation between the dates and concentrations of mobile elements in host rocks that yielded the apatite and zircon separates. These correlations are consistent with mobilization of elements during localized fluid flow in the fault zones’ cores and/or damage zones. The fluid-rock interactions experienced by the samples make it less straigthforward to interpret the thermal history experienced by the rocks in and adjacent to the faults. We are still in the process of interpreting the data.

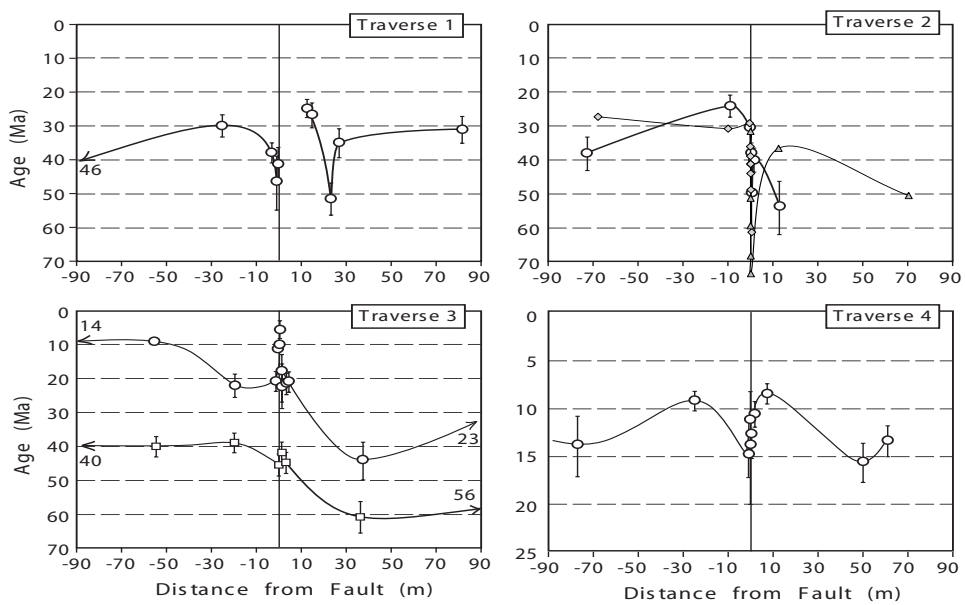

Figure 2 - Fission-track data for apatites (all traverses) and zircon (traverse 3). Distance is orthogonal to the fault. Arrows point to data beyond +/- 90m from the faults. Additional apatite data (filled triangles) for traverse 2 is from the publication of d’Alessio et al. (Geology, 2003)

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.

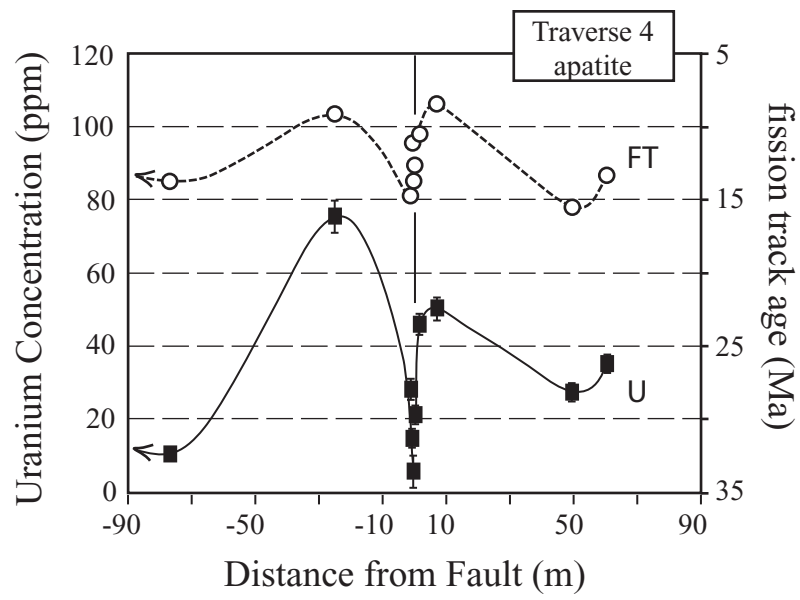

Figure 3 - Example of inverse relation between fission-track age and uranium concencentrations in apatite grains that was documented in this study. Inverse relation is potentially due to fluid interactions with apatite grains in the core and/or damage zone(s) of the fault.

Reports / Publications

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 U., 101 pp.

Kirschner, D.L., Cuevas, D., El-Shafei, M., and Garver, J. (2003). Heat generation and strength of seismogenic faults constrained by fission-track data. EOS Trans. AGU, 84(46), Fall Meet. Suppl., Abstract S41G-05.

Kirschner, D., Garver, J., Reiners, P., El-Shafei, M., and Cuevas, D. (2004). Constraints on heat generation along two (paleo)seismogenic faults in California from U-Th/He and fission-track data. EOS Trans. AGU 85(47), Fall Meet. Suppl., Abstract.