Structure and Petrology of the Kern Canyon Fault, California: A Deeply Exhumed Strike-slip Fault

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Annual Project Summary

Judith S. Chester
Texas A & M University
Department of Geology and Geophysics
College Station, TX 77843
Tel: 979-845-1380; Fax: 979-845-6162
e-mail: chesterj@geo.tamu.edu

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Investigations Undertaken

The mesoscopic structure and petrology of the Kern Canyon Fault at Engineer Point, Isabella Lake, California, (Figure 1; Chester, 2001) is characterized to better understand the physical and chemical processes that control earthquake nucleation and rupture propagation along mature faults in the seismogenic zone of the continental crust. The 140 km long Kern Canyon fault is an exhumed, large displacement, strike-slip fault in batholithic, metasedimentary and metavolcanic rocks of the southern Sierra Nevada (Moore and du Bray, 1978). The central and northern portions of the fault represent an older, wider zone of ductile shearing referred to as the proto Kern Canyon fault (PKC), a regionally extensive, synplutonic dextral shear zone that may be the southern continuation of the axial intrabatholithic break (ABI) of the Sierra Nevada (e.g., Saleeby, 1992). To the south, the proto-Kern Canyon and Kern Canyon faults diverge just north of Isabella Lake. The Kern Canyon fault (KC), generally regarded as a narrow, brittle fault zone of Cenozoic age, continues to the southwest along the eastern side of Engineer Point and under the auxiliary dam for Isabella Lake. At Engineer Point, the fault consists of a broad fractured and mineralogically altered damage zone several hundred meters thick (Ross, 1986). The fault is located along and strikes approximately parallel to the eastern shoreline of the peninsula. Correlation of offset plutonic and metamorphic rocks across the Kern Canyon fault in the vicinity of this peninsula suggests dextral separation of approximately 15 km (Ross, 1986; Moore & du Bray, 1978). Previous reports also suggest that there may have been a significant component of dip-slip in this region (Treasher, 1948; Engel, 1963; Saleeby, 1992).

The initial portion of this study, carried out with contributions from L.Neal (TAMU), R Wintsch (Indiana University), and Fred Chester (TAMU), focused on documenting the overall petrology and structure of the fault zone at Engineer Point (Chester, 2001). Fault rock structures, relative intensity of hydrothermal alteration, and protolith rock types were mapped at a scale of 1:6000. Mesoscopic scale fracture density traverses and fault and fracture orientations have been measured at the regional and fault zone scales. Approximately 30 oriented samples representative of the various protoliths and fault-rocks were collected for optical microscopy and quantitative microprobe analyses. More recent work has focused on characterizing the 1) mesoscopic structure of the fault core through trenching and detailed mapping (in collaboration with D. Kirschner, Saint Louis University), 2) microscopic damage and host rock alteration as a function of distance from the cataclastic zone, and 3) distribution of small faults, joints and alteration in the damage zone of the fault.

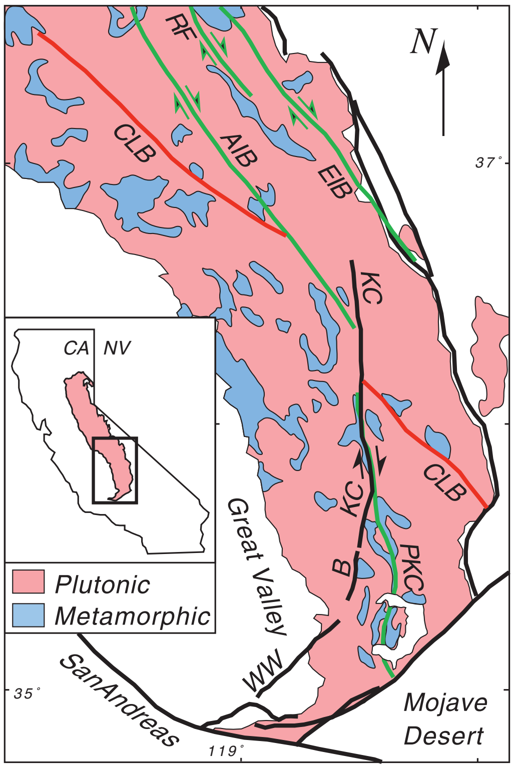

Figure 1. Map of the southern Sierra Nevada batholith showing the location of the Kern Canyon fault zone (KC) relative to other tectonic features, including the axial intrabatholithic break (ABI), cryptic lithospheric boundary (CLB), eastern intrabatholithic break (EBI), proto-Kern Canyon fault (PKC), Rosy Finch shear zone (RF), Breckenridge fault (B), and White Wolf fault (WW) (modified from Saleeby and Busby, 1993, and Kistler, 1993).

Results

At Engineer Point, the Kern Canyon fault displays at least three distinct phases, an early phase of ductile shear within an S-C phyllonite, a subsequent phase of brittle faulting characterized by a zone of cataclastic fault rocks, and a later stage of minor faulting along thin, iron-rich gouge zones.

Structure

The intensity of brittle deformation (subsidiary faults, joints and microfractures) increases towards the cataclastic fault (Figure 2). Regional mesoscale fracture intensity is approximately10 to 20 fractures per meter. Between about 200 m and 20 m from the fault, deformation intensity steadily increases from 10 to 40 fractures per meter. At 20 m, the intensity ranges from 40 to greater than 200 fractures per meter with localized regions displaying fracture intensities too high to be quantified at the mesoscopic scale. Although highly variable, the density of fluid inclusion planes (healed microfractures) in quartz grains increases towards the

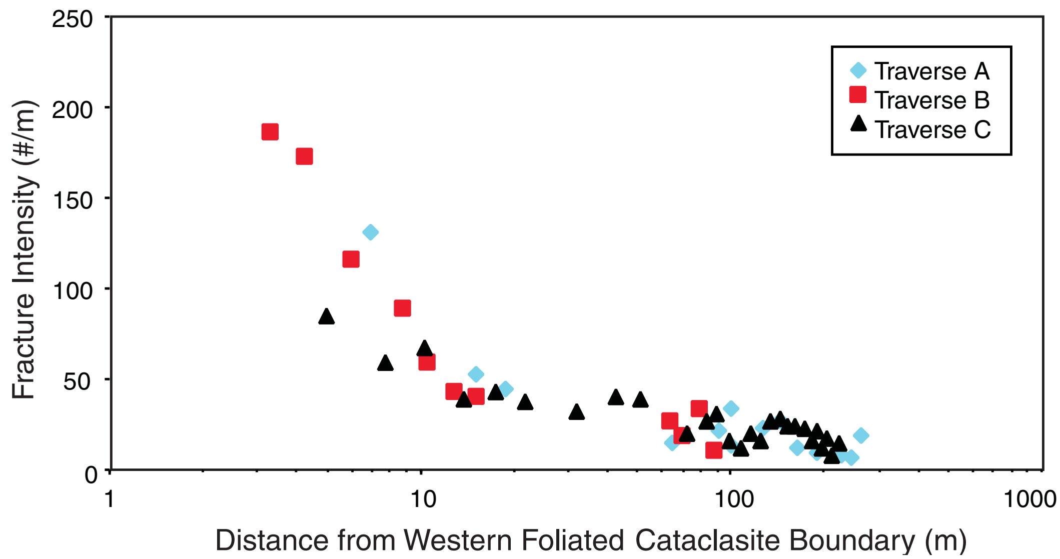

Figure 2. Intensity of open fractures, veins, and subsidiary faults in the Wagy Flat granodiorite as a function of distance from the western cataclastic fault-core boundary.

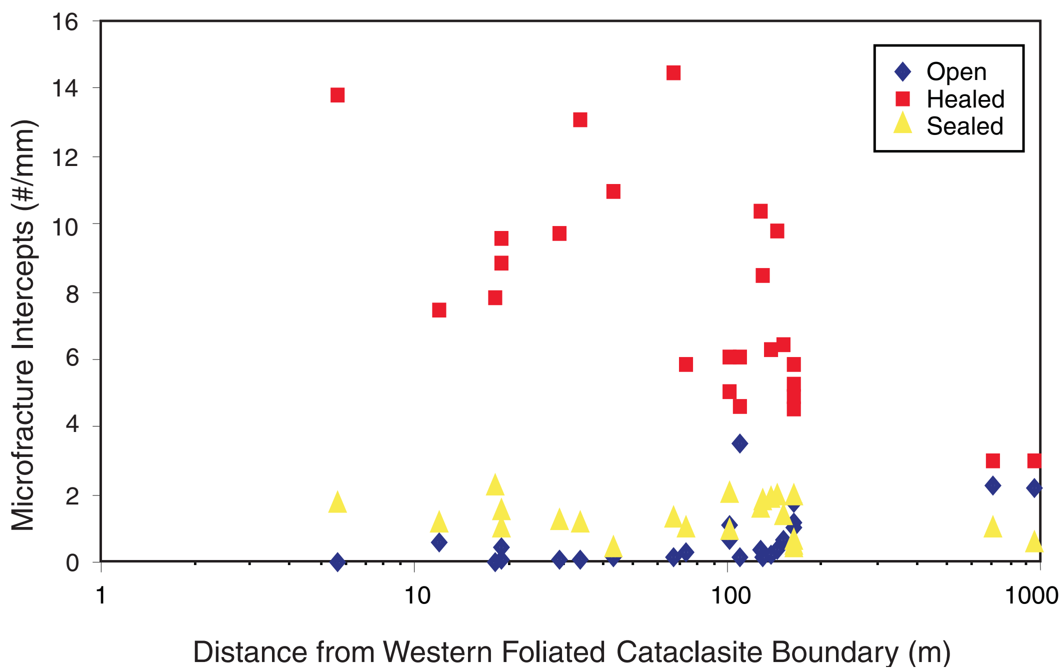

Figure 3. Intensity of open, sealed and healed microfractures in quartz grains as a function of distance from the western cataclastic fault-core boundary.

fault core relative to background levels (Figure 3). The regional mesoscale fracture fabric is characterized by two steeply dipping fracture sets that strike approximately N05˚E and N60˚W. The outer portion of the damage zone at Engineer Point displays a strong preferred orientation characterized by a steeply dipping fracture set striking N60E, and a weaker set that reflects the regional fracture fabric. Subsidiary faults in the inner damage zone form a quasi-conjugate set of steeply dipping, strike-slip faults with a bisector at ~ 50˚ to the Kern Canyon fault. The joint and subsidiary fault fabric at Engineer Point is consistent with right-lateral, strike-slip motion.

The phyllonite zone trends N20-40E and is approximately 10 m wide, containing a narrow layer of concentrated shear bounded by a protophyllonite that grades into altered host rock. The zone displays an S-C fabric with right-lateral C' surfaces. The nearly vertical intersection of surfaces and the asymmetry indicate right lateral, strike-slip shear also dominated in the phyllonite zone.

Alteration

Zones of alteration bound the cataclastic fault core and phyllonite zone. Within the damage zone of the cataclastic fault, brittle fractures display alteration halos. As the cataclastic fault core is approached, fracture spacing decreases and the width of alteration halos increase. This relationship contributes to progressive increase in host-rock alteration noted at the macroscopic-scale. Hydrothermal alteration also is evident within the fault core. Fault-core samples will be used to define the alteration products associated with the brittle phases of faulting.

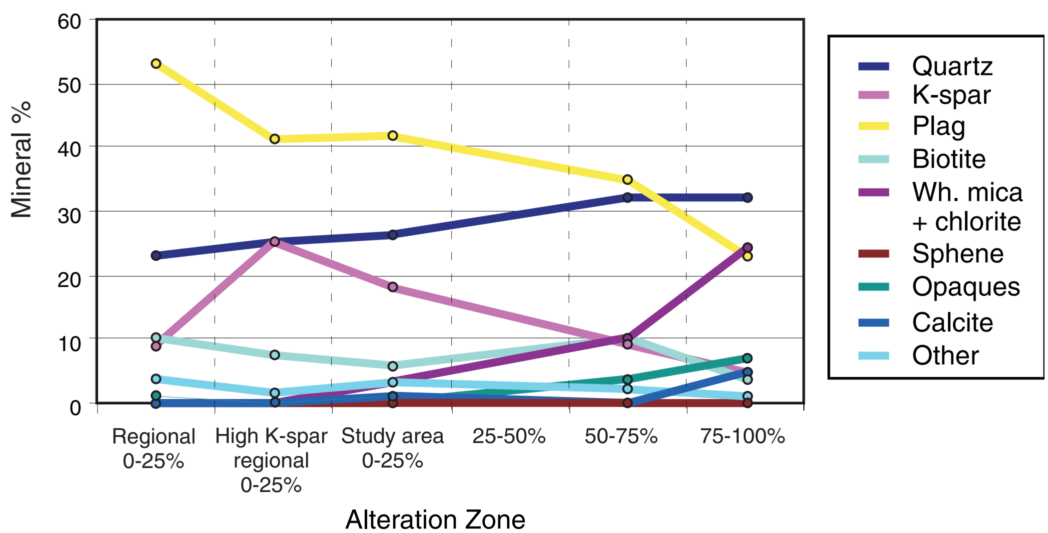

Figure 4. Mineralogy of the fault zone rocks by alteration index (Neal, 2002).

Syndeformation-alteration reactions associated with the ductile phase of shear in the phyllonite zone were characterized along the southern traverse, at K16, where the phyllonite zone is spatially separate from the cataclastic zone. The protolith, a coarse-grained granodiorite composed of zoned plagioclase (An_{40-45} cores to An_{25} rims), potassium feldspar, biotite, quartz, sphene and minor amounts of hornblend, displays a progression in alteration. The outermost domain is characterized, in part, by the pseudomorphic replacement reactions of anorthite to albite (An_{02-00})+muscovite+calcite; biotite to chlorite, and sphene to rutile+quartz. Protophyllonite contains mica shears composed of phengitic mica with strong lattice preferred orientation and well-developed mica contiguity. Alteration is associated with healing, sealing and recrystallization of quartz, and consumption of feldspars. Modes indicate that development

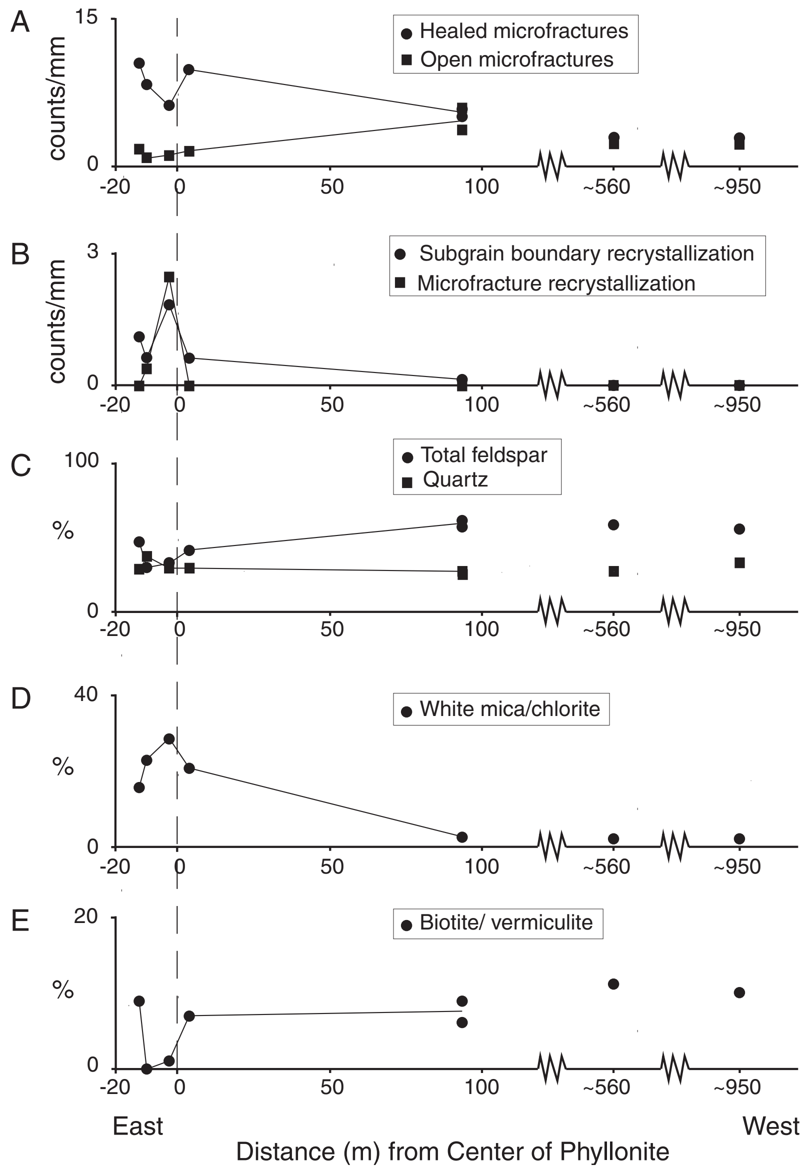

Figure 5. Characterization of microfracture density, recrystallization, and mineralogy of samples collected along traverses across the phyllonite zone.

of protophyllonite is accompanied by significant loss of aqueous silica (Figure 4). The phyllonite is marked by almost complete transformation of feldspar to mica with only a small increase in quartz (Figure 5). The significant volume loss of aqueous silica indicates that advective flow of fluids removed silica from the zone and that fluids entering the fault zone were under-saturated in silica. Given silica solubility relations, fluids under-saturated in silica with respect to quartz could 1) come from lower pressure regions, 2) come from lower temperature regions, and/or 3) be introduced in such large volumes relative to the rock volume that only small degrees of under-saturation lead to significant losses in silica from the phyllonite.

The present characterization of the structure and petrology of the Kern Canyon fault at Engineer Point will provide the basis for the future detailed structural, petrologic and geochemical analyses to identify the mechanisms of fault slip and the role of chemical reactions in the seismogenic zone. Future work will concentrate on investigating slip localization to the cataclastic zone and investigation of mineral reactions within each structural domain to identify the key element exchange reactions and determine to what extent and at what scale the cataclastic fault system was open or closed.

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Non-Technical Summary

In order to reduce the loss of life and property as a result of the occurrence of large-magnitude earthquakes, we must increase our understanding of the physical and chemical processes that govern repeated earthquake generation along large-displacement continental fault zones. Geologic field investigations of large-displacement faults that are exposed at the Earth's surface offers a cost- effective way to investigate the internal structure, mineralogy, and chemistry of fault zones in detail, and is complementary to other approaches such as deep drilling and geophysical (indirect) imaging. We will use a variety of techniques in the laboratory to analyze rocks collected in the field. These data will be used to help constrain and test existing hypotheses for fault weakening and earthquake generation. In addition, data gathered from this study will help guide future field, experimental, and theoretical investigations of the earthquake process.