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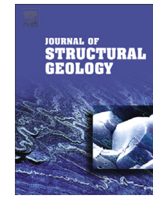

The influence of fault geometry on small strike-slip fault mechanics

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A B S T R A C T

Meter-scale subvertical strike-slip fault traces in the central Californian Sierra Nevada exhibit geometric complexities that significantly contribute to their mechanical behavior. Sections of faults that opened at depth channelized fluid flow, as evidenced by hydrothermal mineral infillings and alteration haloes. Thin sections show a variation in the style of ductile deformation of infill along the fault, with greater intensities of deformation along restraining bends. Orthorectified photomosaics of outcrops provide model geometries and parameter constraints used in a two-dimensional displacement discontinuity model incorporating a complementarity algorithm. Model results show that fault shape influences the distribution of opening, and consequently the spatial distribution of fluid conduits. Geometric irregularities are present at many scales, and sections of opening occur along both releasing and restraining bends. Model sensitivity tests focus on boundary conditions along the fault: frictional properties on closed sections and fluid pressure within sections of opening. The influence of the remote stress state varies along a non-planar fault, complicating the relationships between remote stresses, frictional properties, slip, and opening. Discontinuous sections of opening along model faults are similar in spatial distribution and aperture to the epidote infill assemblages observed in the field.

1. Introduction

Faults have irregularly shaped surfaces, and often are composed of discontinuous segments. Such irregularities cause the mechanical behavior of faults to deviate from that of the idealized planar structure. Understanding opening and slip on faults at depth is crucial to many economic and scientific applications. For example, economic geologists have noted ore deposits along geometrically complex faults for nearly a century (Cox et al., 2001; Hulin, 1929; Micklethwaite et al., 2010; Newhouse, 1940; Sibson, 1994). Fault shape also influences dynamic rupture processes, affecting both earthquake and aftershock behavior (Harris et al., 1991; Micklethwaite and Cox, 2004; Ryan and Oglesby, 2014; Sibson, 1985).

This study is motivated by new field observations of meter-scale left-lateral faults in the central Sierra Nevada, California (Fig. 1). The faults considered in this study are within the Lake Edison Granodiorite (Kle), a fine-to medium-grained biotite hornblende granodiorite (Lockwood and Lydon, 1975) and one of several Late Cretaceous granitoid plutons in the area (Segall et al., 1990; Stern et al., 1981). Glaciation has exposed fractures meters to kilometers in length, exhumed from depths between 4 and 15 km (Ague and Brimhall, 1988). Fracture is used here as a general term, and includes both opening-mode and shearing-mode structures. Earlier work in this area suggests that the faults developed from a single set of subvertical, subparallel joints that likely formed during cooling of the pluton (Bergbauer and Martel, 1999; Segall and Pollard, 1983a, 1983b). The greater Bear Creek valley has been studied as a natural laboratory for investigations of fault mechanics for several decades (for example, Bürgmann and Pollard, 1992, 1994; Davies and Pollard, 1986; Griffith et al., 2008; Lockwood and Lydon, 1975; Martel et al., 1988; Pachell and Evans, 2002; Pennacchioni and Zucchi, 2013; Segall et al., 1990).

This study expands on previous work to elucidate the effect of non-planar fault shape on opening and deformation of fault infill. It is suggested here that fault shape controls opening, and therefore controls the spatial distribution of fluid flow along these faults, as evidenced by mineralized sections of opening and local alteration of the host rock (Bürgmann and Pollard, 1992; Christiansen and Pollard, 1997; Griffith et al., 2009, 2010; Martel et al., 1988; Segall and Pollard, 1983b; Segall and Simpson, 1986; this study).

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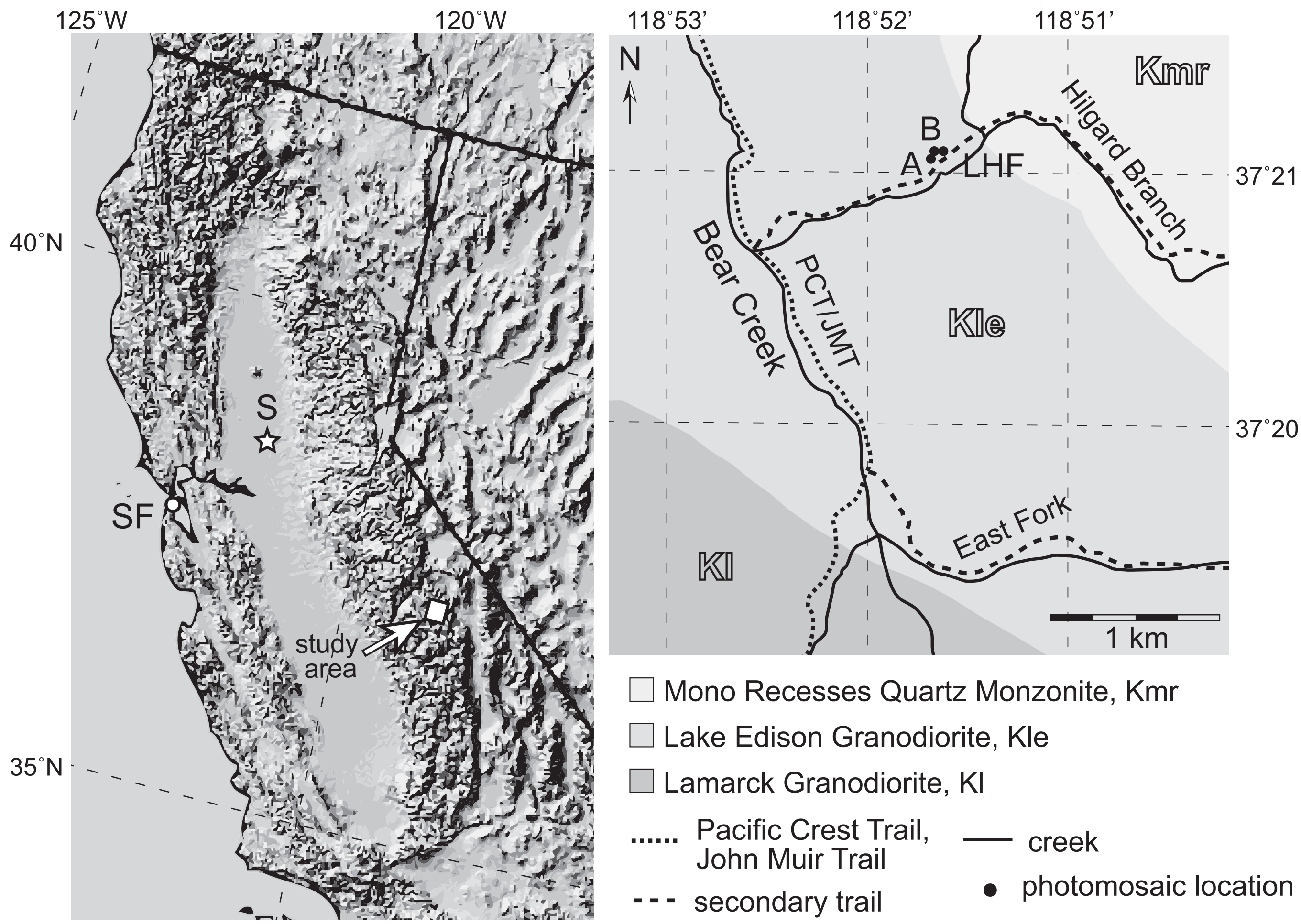

Fig. 1. Bear Creek study area in the central Sierra Nevada, California. Left is a topographic map, from the National Atlas of the United States (http://nationalatlas.gov). Right is a geologic map, based on work by Lockwood and Lydon (1975), with photomosaic localities of Fig. 2 identified.

Furthermore, fault shape may contribute to the localization of ductile deformation within fault infill. The mechanical modeling presented in this study is constrained by field observations and the mechanical behavior of a representative fault from the study area is evaluated. The effect of several factors on slip and opening distributions along these faults are highlighted, including fault shape, two frictional properties, and fluid pressure within the sections of opening.

2. Methods

Field observations were collected from glacially polished outcrops of the Lake Edison Granodiorite using photomosaics and cylindrical core samples. Photomosaics were constructed by digitally orthorectifying each photograph along the outcrop, using a square metal frame included in each photograph as a guide and scale, then appropriately arranging and merging the overlapping photographs. Structures and textures were then mapped from these photomosaics, adding to the measurements and observations noted in the field. Core samples were drilled adjacent to and along several faults using a one inch diameter bit, and thin sections were made from those samples. Field work focused on an area in the Bear Creek valley along the Hilgard trail, which branches east from the Pacific Crest and John Muir Trail (Fig. 1).

The numerical results are calculated by a two dimensional displacement discontinuity boundary element model (DDM) in conjunction with a complementarity solver. These quasi-static experiments provide the horizontal deformation along vertical strike-slip faults and within the surrounding elastic host rock. Fault slip is driven by a remote stress loading. The Ritz et al. (2012) model is further developed to include fluid pressure along sections of opening, because evidence for fluid flow is observed in outcrop. Ductile deformation of the fault infill is not included in this elastic model, but can be indirectly modeled by adjusting contact boundary conditions along the fault; ductile deformation of the host rock cannot be taken into account. The full model description is outlined in Appendix A. Matlab® code is provided in the supplementary material. Right-lateral shear stresses and tensile stresses are positive.

3. Field observations

3.1. Overview of study area and previous work

Studies of the geochronology, field relations, and hydrothermal mineral assemblages indicate that faults in the Lake Edison Granodiorite developed from subvertical cooling joints, which formed soon after emplacement (Bergbauer and Martel, 1999; Segall et al., 1990). The sheared joints are primarily left-lateral strike-slip faults, as evidenced by the offsetting of aplite dikes and mafic xenoliths, as well as exposed slickenlines which typically plunge less than 20° (Griffith et al., 2008; Martel et al., 1988; Segall