The role of fabric and shear inversion on the development of fractures in shear zones

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Introduction

Coulomb failure theory suggests that shear fractures will form at an angle β from the maximum principal stress (σ_1). As shown by equations 1 and 2 the angle β can be calculated from the coefficient of internal friction (μ).

Eq. 1 $$\beta = 45° - \frac{\phi}{2}$$ Eq. 2 $$\phi = \tan^{-1}(\mu)$$

Fractures formed at these orientations have been termed Riedels (R) and Riedel primes (R') (Tchalenko, 1973). Typical friction coefficients result in β ≈30° as shown in Fig. 1 (Jaeger et al., 2007), however fractures of other orientations have also been described (Bartlett et al, 1981). These include P , X and Y fractures, also shown in Fig. 1. Y fractures follow the trend of the shear zone in which all the fractures develop.

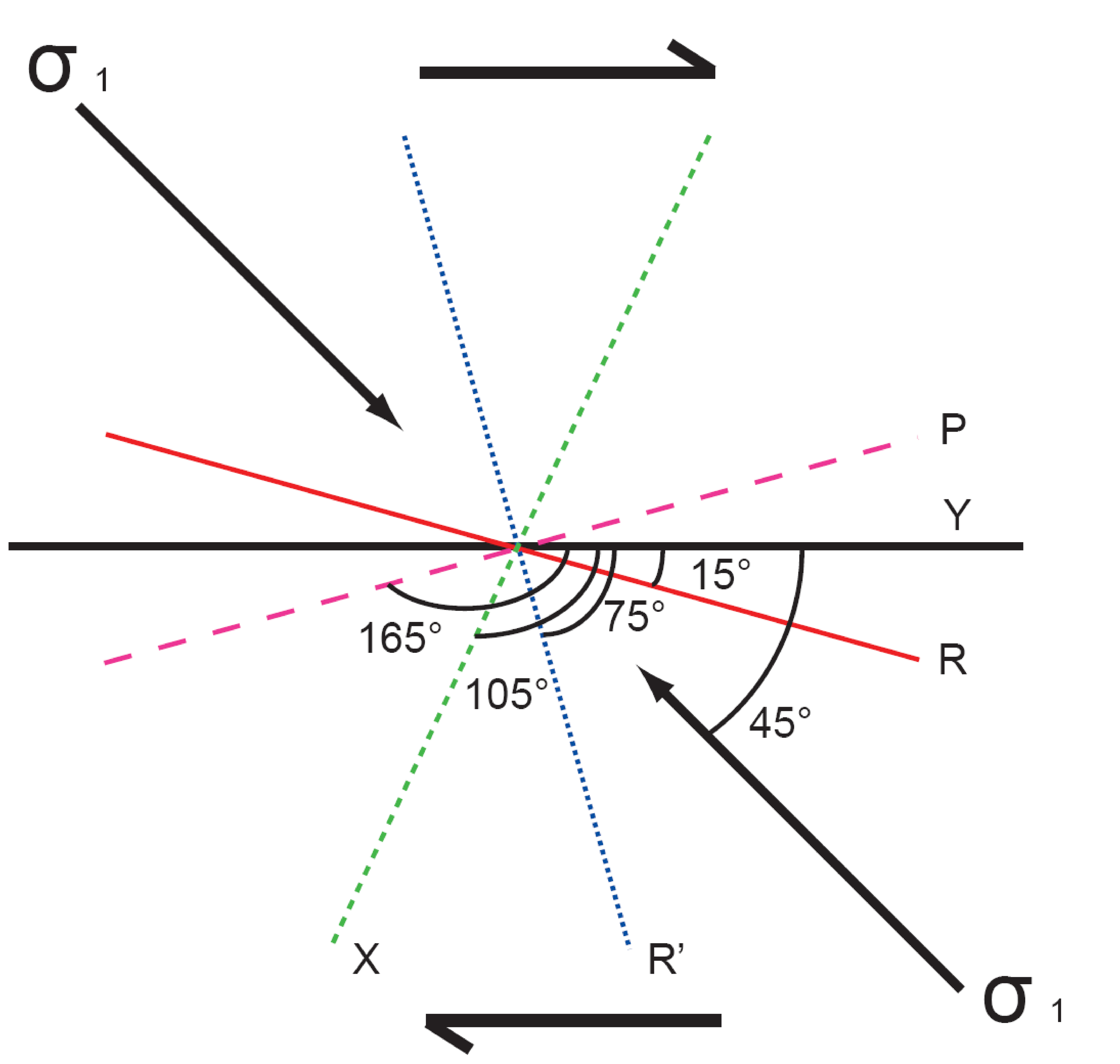


Figure 1. Orientations of predicted fractures and stress orientation in a dextral shear zone.

In this study we perform a number of shear experiments in clay (Fig. 2) in an attempt to reproduce and understand fracture patterns observed in a rock outcrop in northern Minnesota. A cake of clay is subjected to shear by movement in opposite senses of two plates on which the clay rests. The experimental set-up is shown in Fig. 2. The rate of displacement of the plates is held constant in each experiment. We examine the effects of anisotropy of the clay, shear-sense inversion, and rotation associated with shear, as possible mechanisms responsible for the fracture orientations that do not agree with those predicted by Coulomb theory.

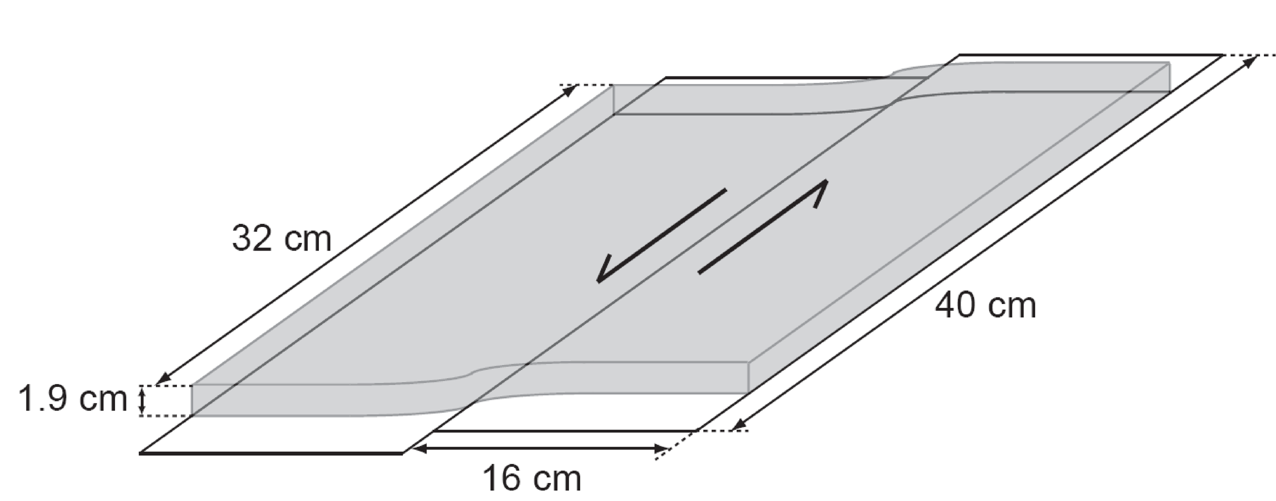


Figure 2. A schematic figure of the experimental set-up. The gray indicates clay. Not shown is the driving mechanism for moving the plates.

Methods

•Kaolinite was chosen for the experiments because kaolinite and greywacke, the rock type present in outcrop, have similar coefficients of internal friction, of approximately 0.6 (Krantz, 1991; Jaeger et. al., 2007).

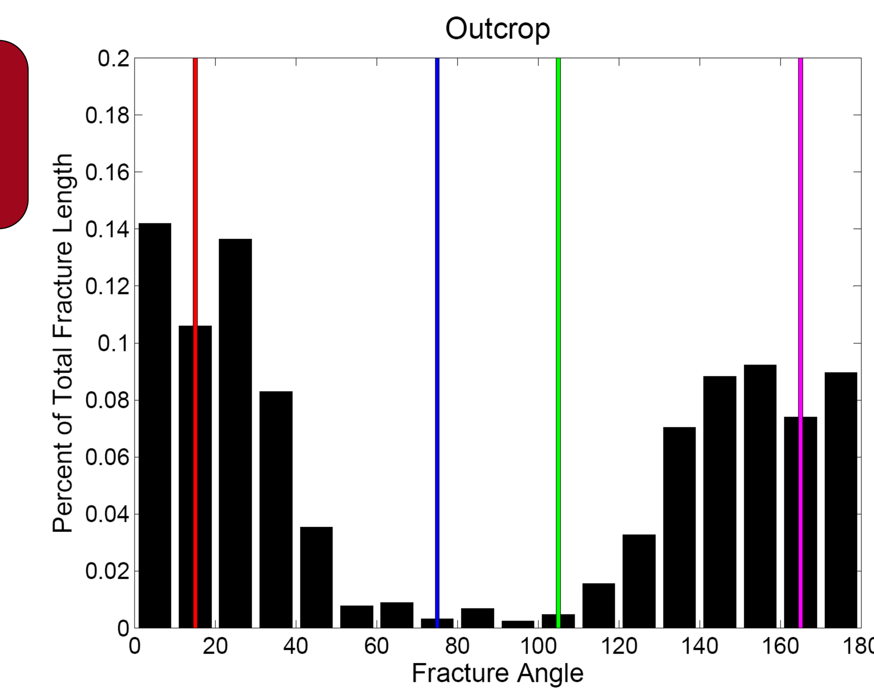
•Kaolinite clay was mixed with 31% water by weight to simulate fracturing similar to that observed in greywacke in outcrop. This consistency was used because as water content increases the clay deforms more plastically.

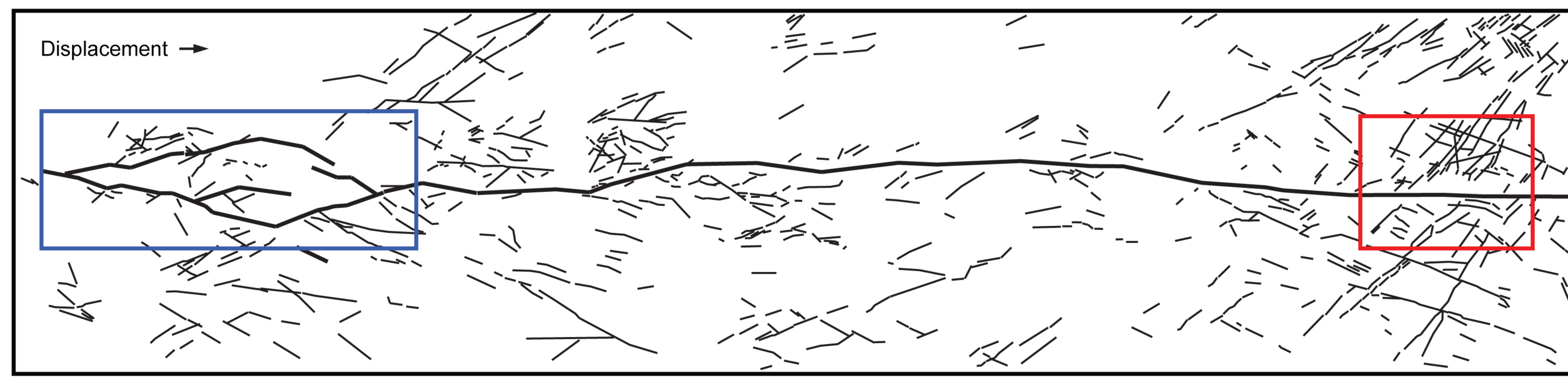
•During the experiments two equal sized plates moved parallel to one other at a speed of 0.05 mm/sec (Fig. 2).

Results

Figure 3. (below) A fracture map of one of five fracture zones observed at the Pike River Dam in northern MN. The red box indicates the area photographed in Fig. 7, the blue box indicates the fractures used for inversion analysis in Fig 5.

Figure 4. (right) Histogram shows that the majority of the fractures measured in outcrop are best interpreted as Riedels, assuming right lateral shear. However there are also a significant number of what are either P fractures or Riedel fractures depending on the sense of shear during propagation.





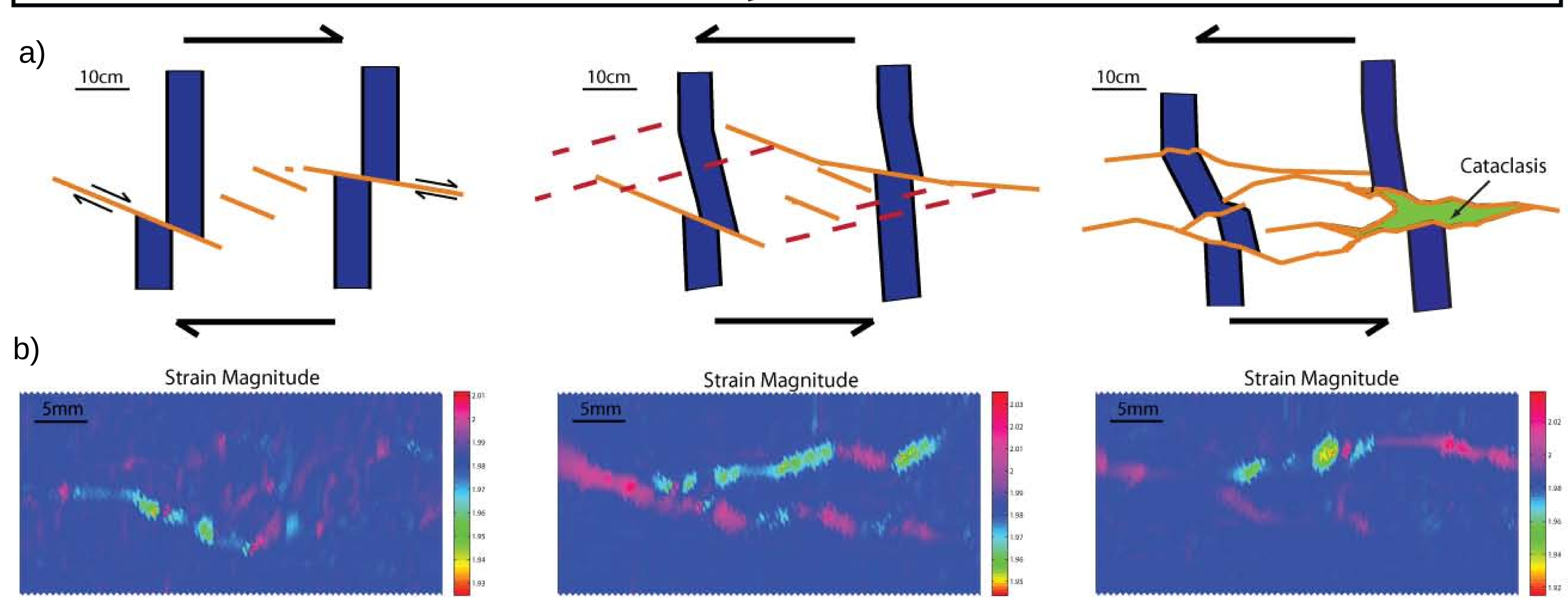


Figure 5. (above) a) A schematic of the interpreted fracture development in outcrop. For purposes of comparison with the experiments the schematics are reflected across the vertical axis. b) Strain based on displacement vector fields developed using Particle Image Velocimetry (PIV). Each figure corresponds to the analogous stage of deformation in the schematic outcrop fracture map directly above (a). The strain figures highlight the change in strain along fractures as second-stage Riedels develop.

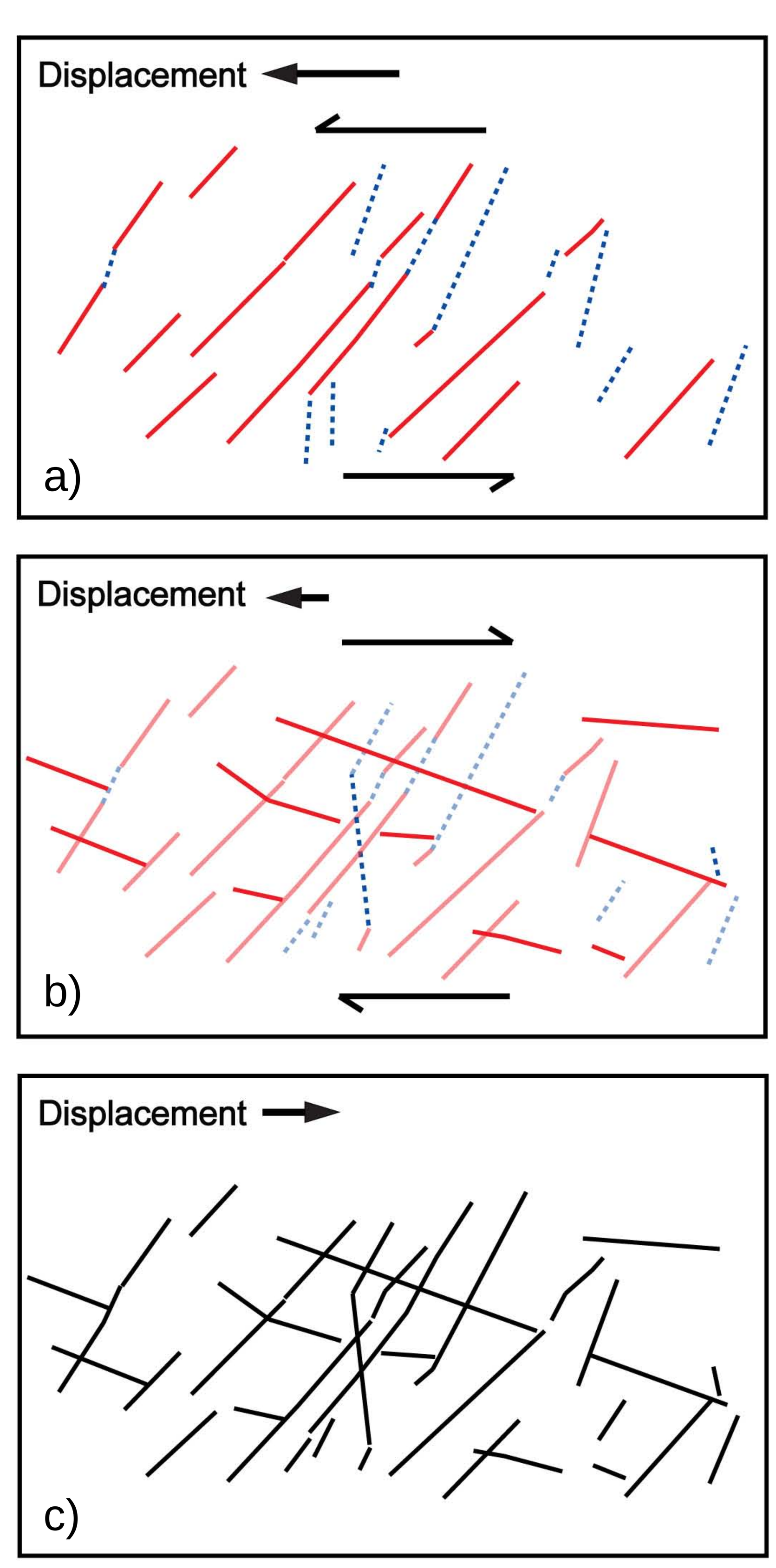


Figure 6. (left) a) A schematic fracture map after large left-lateral displacement. R and R' fractures are red and blue respectively, as shown in Fig. 1. b) A schematic fracture map after shear inversion. The bold lines indicate fractures formed during the second shearing event. The displacement arrow indicates that the overall displacement is left lateral while the latest shear increment is right lateral. Notice that the high angle fractures have undergone a minor amount of clock-wise rotation. c) Final fracture orientations and displacement.

Figure 7. (below-left) An outcrop photo of one of the fracture zones (Fig. 5). The fractures used for the schematic reconstruction in Fig. 7 are highlighted. This is a flat glacially smoothed outcrop is in rocks of the Vermilion district. The rock is composed of interbedded greywacke, slate and tuff derived from weathering of an Archean volcanic arc.

Conclusions

•The evidence for shear-sense inversion in outcrop suggests that nearly all of the natural fractures are Riedel fractures formed during separate shear events in opposite directions.

•The presence of a fabric in outcrop, though not as strong as the fabric created in the experiments, was likely responsible for the propagation of Riedel fractures at angles higher than predicted by Coulomb theory.

•Rotation of the fractures from the orientations of propagation is likely negligible due to the small overall displacement along the shear zone.

References and Acknowledgments

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