ROLE OF FLUID ON DEFORMATION IN MID-CRUSTAL SHEAR ZONES, RAFT RIVER MOUNTAINS, UTAH

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ABSTRACT

Fluids are commonly invoked as a primary cause for weakening of the rheology of detachment shear zones. However, fluid related mechanisms (e.g. pressure-solution, reaction enhanced ductility, reaction softening, development of fabric, and the precipitation of phyllosilicates) are not well understood. Fluid-facilitated reaction and mass transport leads to rheological weakening and strain localization and the departure from experimental failure laws derived in the laboratory. This study focuses on the Miocene detachment shear zone associated with the Raft River metamorphic core complex. The detachment shear zone is localized in the Proterozoic Elba quartzite, which unconformably overlies an Archean basement complex, and consists of an alternating sequence of white quartzite (~90% quartz, ~10% muscovite) and muscovite-quartzite schist. Previous work demonstrates abundant evidence of chemical, physical, and isotopic water-rock interactions in the Raft River detachment shear zone. Here, we investigate the relationship between fluid inclusions, microcracks, brittle fractures, and microstructures in the quartzite mylonite. Thin section analyses reveal the presence of micocracks, fluid inclusion planes, and isolated fluid inclusion clusters. Microcracks tend to be perpendicular to the mylonitic foliation. They are also filled with quartz, which has a distinct fabric, not as strong as the mylonitic fabric, suggesting that microcracks healed while the shear zone was still at conditions favorable for quartz crystal plasticity. Fluid inclusion planes are transgranular and occur in two conjugate orientations, at ~60° from the mylonitic foliation. Fluid inclusions are also present as intergranular clusters. Our results show ductile overprint of brittle microstructures, which suggest that, during exhumation, the detachment shear zone may have crossed brittle-ductile transition repeatedly, providing opportunities for fluid to permeate the detachment shear zone.

INTRODUCTION

Crustal strength differentiates depending on crustal depth with the upper featuring brittle behavior while mid and lower crust experience ductile flow. Crustal strength tends to fail before the brittle or ductile experimental strength envelope. Metamorphic core complexes are studied for their in-situ nature of deep crustal material. Exhumed fault rocks experience weakening through a variety of fluid driven fluid reactions. These reactions pressure-solution, reaction enhanced ductility, reaction softening, development of fabric, and the precipitation of phyllosilicates (Behr and Platt, 2014). The goal of this proposal is to investigate the relationship between fluid flow and strain localization on the rheology and strength of mid-crustal shear zones.

The presence of fluids during deformation in the mid-crustal detachment shear zone is attested by numerous studies based on oxygen and hydrogen stable isotope, that demonstrate fluids from the metamorphic, magmatic, or meteoric origin, are able to permeate the shear zone and interact with the deforming minerals (e.g. Kerrich and Rehrig, 1987; Smith et al., 1991; Fricke et al., 1992; Morrison, 1994; Losh, 1997; Morrison and Anderson, 1998; Mulch et al., 2007; Gébelin et al., 2011, 2014; Gottardi et al., 2011, 2015; Carter et al., 2015). Fluid penetration in the brittle upper crust facilitated cataclasis associated with faulting, which reduces the local grain size and can increase permeability and enhance fluid flow into and along the fault zone. However, the physiomechanical processes that allow surface fluids to penetrate beyond the brittle-ductile transition remain poorly understood (e.g. Connolly and Podladchikov, 2004; Fusseis et al., 2009; Menegon et al., 2015).

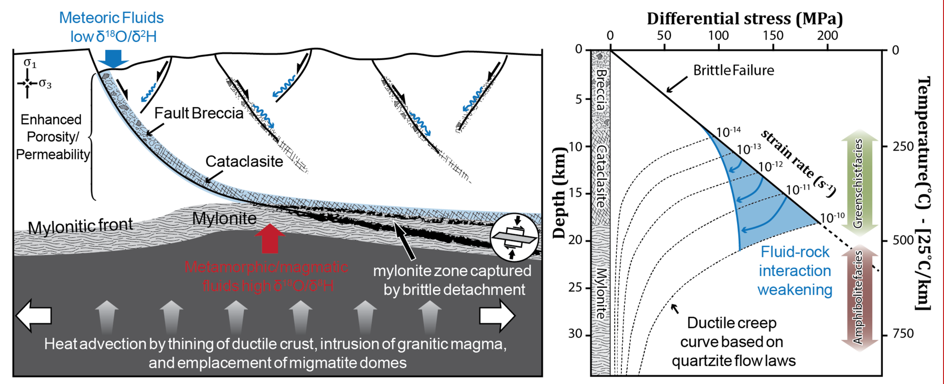


Figure 1: Fluid-rock interaction in a detachment system associated with the formation of a metamorphic core complex (from Gottardi et al., 2018).

REGIONAL GEOLOGY

This research project is focused on the Miocene detachment shear zone associated with the Raft River metamorphic core complex (Figure 1; e.g. Compton 1977; Wells, 1997; Wells et al., 2000). The Miocene detachment shear zone is localized in the Proterozoic Elba quartzite, which unconformably overlies an Archean basement complex, and consists of an alternating sequence of white quartzite (~90% quartz, ~10% muscovite) and muscovite-quartzite schist. The mylonitic foliation is defined by flattened and elongated muscovite grains. The foliation is sub-horizontal, shallowly dipping to the East, and follows the gentle domal shape of the core complex. The lineation, expressed by stretched muscovite grains on the foliation planes, is clearly top-to-east sense of shear (Compton, 1980; Wells, 1997, 2001, Sullivan, 2008; Gottardi and Teyssier, 2013). Quartz microstructures display dominant quartz recrystallization subgrain rotation, and limited grain boundary migration (Gottardi and Teyssier, 2013). Previous work demonstrates abundant evidence of chemical, physical, and isotopic water-rock interactions in this detachment shear zone (Gottardi et al. 2011, 2015; Methner et al., 2015). The goals of this project are to characterize the orientation, composition, and entrapment conditions of fluid inclusions in the Raft River detachment shear zone.

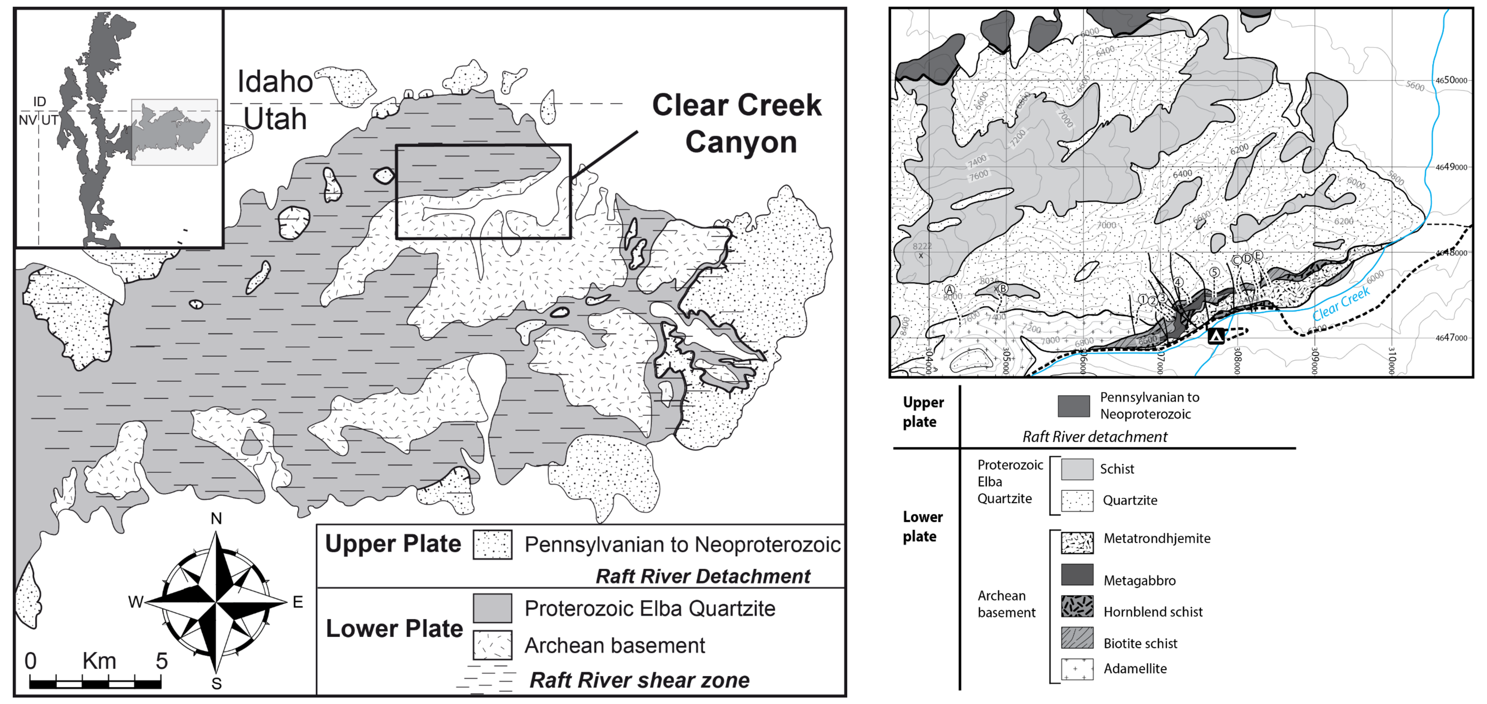


Figure 2: (left) Simplified regional geologic map of the eastern Raft River Mountains, with location of the Clear Creek Canyon (study are). (right) The shear zone is localized in the Elba quartzite. The Quartzite mylonite is composed of ~90% quartz and ~10% muscovite. (right) Detailed map of the study area, the Clear Creek Canyon. Modifed from Gottardi and Teyssier (2013), and Gottardi et al. (2015).

Figure 3: (left) Vertical profile through the Raft River detachment shear zone. The shear zone is localized in the Elba quartzite. The Quartzite mylonite is composed of ~90% quartz and ~10% muscovite. (right) Picture of the Raft River Mountains detachment shear zone at Clear Creek Canyon.

GOAL

The goal of this project is to investigate the relationship between fractures, microcracks, fluid inclusions, and microstructures in quartzite mylonites from the detachment shear zone associated with the Raft River metamorphic core complex..

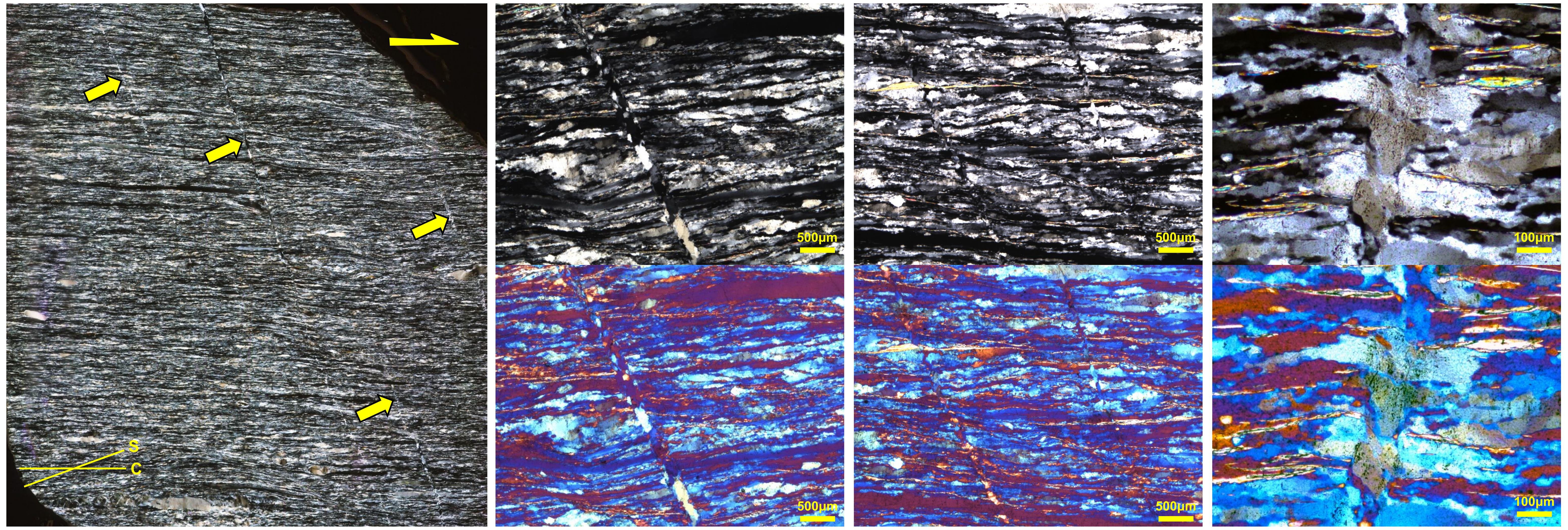
METHODS

- **Thin Section Analysis to** investigate the presence of microcracks, fluid inclusion planes, and isolated fluid inclusion clusters.
- **Universal Stage** to examine the fluid inclusion plane in 3D.
- **Microthermometry** to constrain entrapment conditions (temperature/pressure) of the fluid inclusions. The analysis will also provide information about the salinity and amount of dissolved gasses within aqueous inclusions.

RESULTS

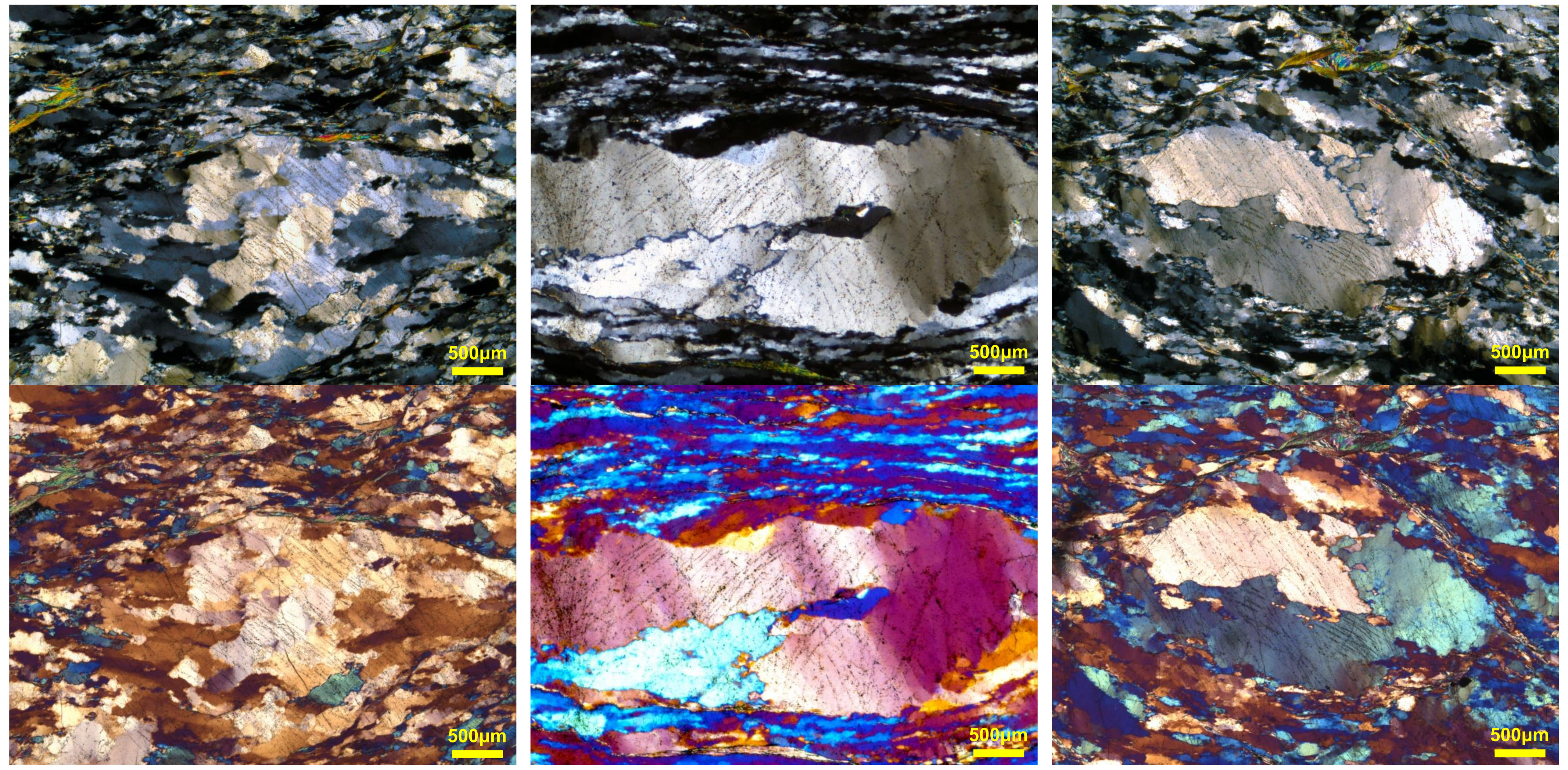
Microcracks

Microcracks tend to be oriented at high angle to the mylonitic foliation (see yellow arrows). They are filled with quartz, which has a distinct fabric, not as strong as the mylonitic fabric, suggesting that microcracks healed while the shear zone was still at conditions favorable for quartz crystal plasticity. Fluid inclusions are abundant within the quartz fill and seem to be forming fluid inclusion planes that are subparallel with the walls of the microcracks.



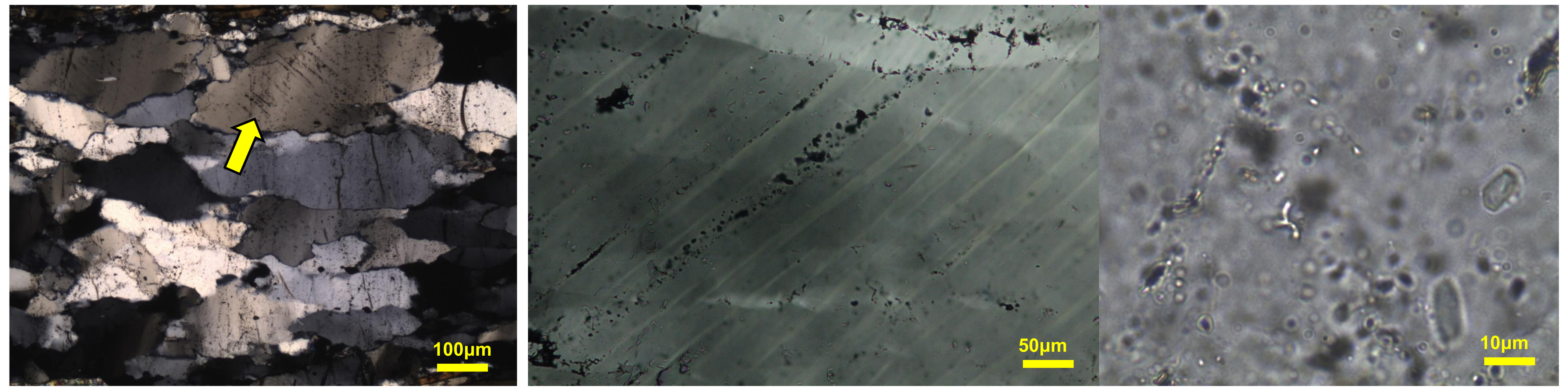
Fluid Inclusion Planes

Fluid inclusion planes cross multiple grains (transgranular), and single grains and subgrain boundaries (intergranular). They occur in two conjugate orientations, dipping at ~40-60° from the mylonitic foliation, as observed in thin sections. Additional work using the universal stage in required to properly measure the orientation of the fluid inclusion planes in 3D. These fluid inclusion planes cut across elongate quartz grains that define the mylonitic foliation and can be 100s of microns long. They typically preserve a high number of fluid inclusions (10^2-10^3).



Fluid Inclusion Clusters

Grain boundaries fluid inclusion clusters are also observed The Elba quartzite mylonite contains an abundance of deformation lamellae. Deformation lamellae are commonly decorated with fluid inclusions (yellow arrow). These grain boundary fluid inclusions are small (<3µm) and irregular shaped.



FUTURE WORK

- Use a universal stage to accurately measure the orientation of the trangranular and intergranular fluid inclusion planes.
- Characterize the orientation of the fluid inclusions with respect to the foliation and lineation of the quartzite mylonite.
- Characterize the orientation of the fluid inclusions with respect to the quartz fabric.
- Document the size of the fluid inclusions.
- Constrain the composition and the entrapment conditions of the fluid inclusions using microtherometry.

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