Technical Report: the report should describe the project objectives, methodology, and results obtained and their significance. (Maximum 5 pages, 1-3 figures with captions, references and publications do not count against limit.)

Objectives. The objectives of the work were to 1) evaluate the constitutive relationships that describe the behavior of quartz-rich BDT rocks during the seismic stress cycle, and 2) determine if the rheology of the quartz-rich rocks are best described by ‘wet’ or ‘dry’ flow laws.

Methods. We use 1) electron backscatter diffraction (EBSD) analysis to evaluate the constitutive relationships that describe the deformation of pseudotachylyte-bearing mylonites during the seismic cycle, and 2) atom probe tomography (APT) to determine the water content of grains in the pseudotachylyte survivor clasts and in the host mylonites.

Results. With respect to Objective #1, we demonstrate that deformation is partitioned into quartz within granodiorite mylonites, where quartz initially deforms by dislocation creep (Fig. 1a, b, c, d). Grain size reduction during dynamic recrystallization results in the transition to diffusion creep (Fig. 1b, d), where fluid-assisted grain boundary sliding localizes strain in quartz-rich layers prior to the generation of pseudotachylyte. Grain size piezometry yields high differential stresses in both the host mylonites (~160 MPa) and in pseudotachylyte survivor clasts (~200 MPa), consistent with high stresses during interseismic and coseismic phases of the earthquake cycle, respectively.

These results are documented in detail in a student first-authored publication in the *Journal of Geophysical Research* (Stewart and Miranda, 2017).

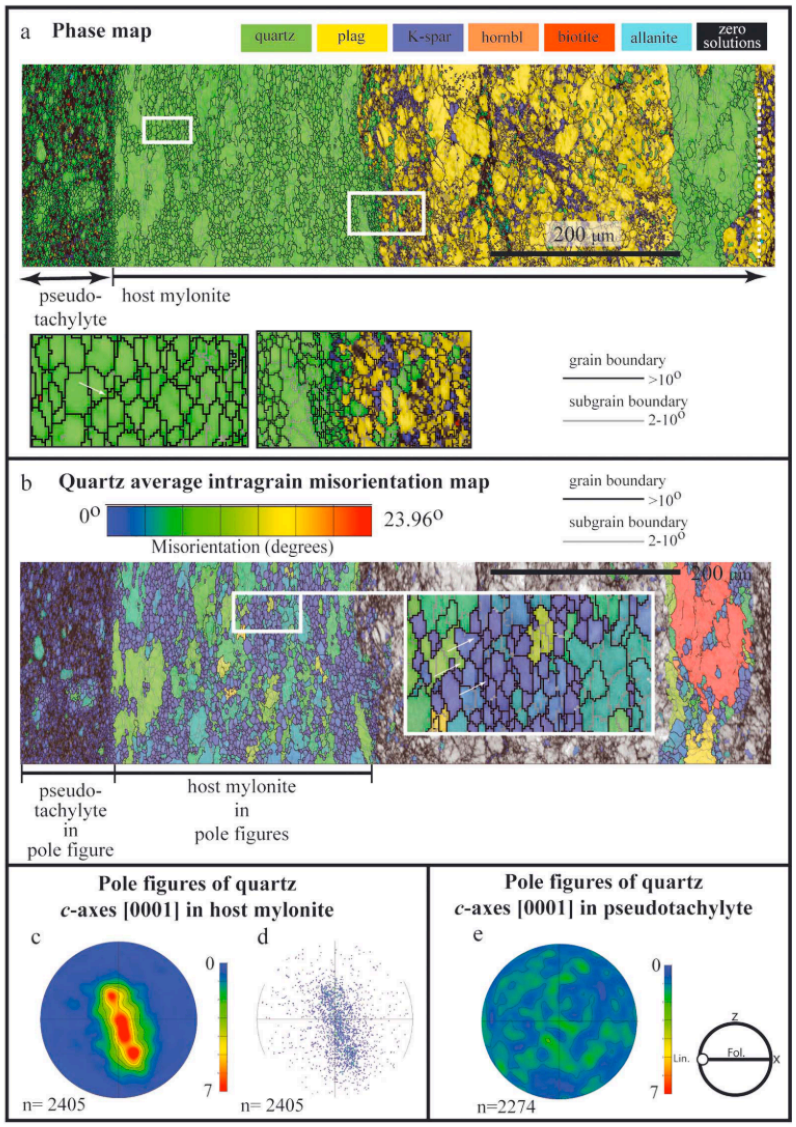

Fig. 1. EBSD maps and pole figures from host mylonite and pseudotachylyte as featured in Figure 6 of Stewart and Miranda (2017). A) EBSD phase map showing quartz dislocation creep microstructures in host mylonite. B) EBSD quartz average intragrain orientation map showing low-strain recrystallized grains in blue, and higher-strain grains in warmer colors. The abundant four-grain junctions (white arrows in inset) indicate the onset of grain size sensitive deformation and grain boundary sliding in the recrystallized grains of the host mylonite. c) Contoured pole figure of quartz c-axes in host mylonite quartz showing strong CPO consistent with dislocation creep d) Scatter plot pole figure of quartz c-axes in host mylonite showing strong CPO but also some randomized orientation of blue grains, indicating the onset of grain size sensitivity in recrystallized grains. E) Contoured pole figure of quartz c-axis orientations from pseudotachylyte indicating absence of CPO.

Results, continued. With respect to Objective #2, we completed APT work in July 2018 as part of a no-cost extension granted in April 2018. We analyzed 6 prepared tips extracted from grains within the area analyzed by EBSD. The EBSD maps show that the survivor clasts are nearly pure quartz, with rare plagioclase, potassium feldspar, and biotite (Fig 2a). The grain size is extremely fine (average diameter < 2 m), and there are ubiquitous four-grain junctions indicative of grain size sensitive deformation by grain boundary sliding, which is supported by the randomized orientations of the grains (Fig. 2b). We used a focused ion beam scanning electron microscope (FIB-SEM) to mill out a profile across several grains with four-grain junctions (Fig 2c). The profile was used to make 11 “tips” for APT analyses, with Tip M1 shown on the right and Tip M11 on the left of the profile. Our APT analyses indicate the presence of structural water (OH molecules) through the volume of quartz pseudotachylyte survivor clast grains; the imaging shows a uniform distribution of structural water throughout the grains. These results indicate that ‘wet’ quartz flow laws are more appropriate for quantifying the rheology of BDT rocks during the seismic stress cycle.

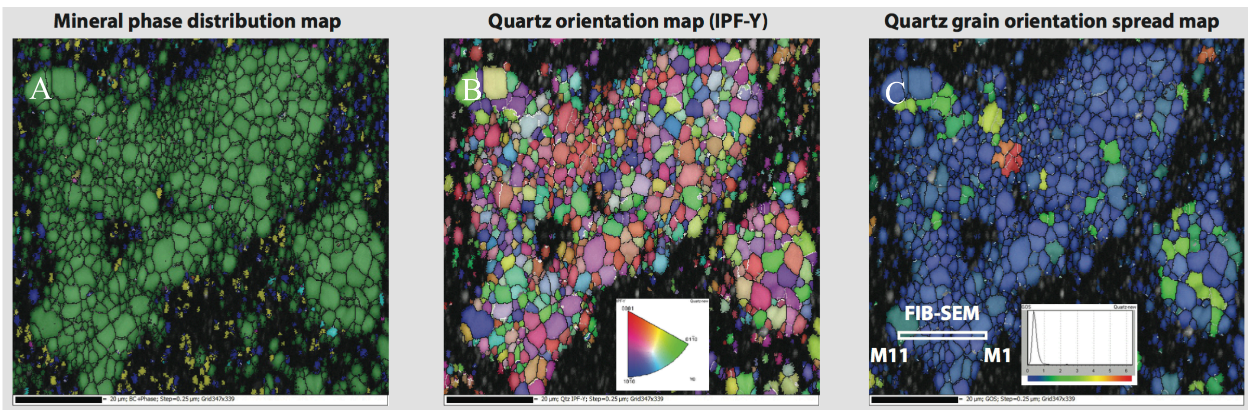

Fig. 2. EBSD maps of pseudotachylyte survivor clasts that were subsequently analyzed by APT. a) Phase map. Green = quartz; yellow = plagioclase; blue = K-feldspar; magenta = biotite; cyan = allanite. B) Quartz inverse pole figure parallel to stage-Y (IPF-Y) orientation map showing dissimilar orientations of adjacent quartz grains. C) Quartz grain orientation spread map, where blue grains have no lattice distortion, and warmer colored grains indicate a greater amount of lattice distortion.

We also found some unexpected, but rather exciting APT results. Atomic density profiles of Si, O, OH, and SiO in Tip M3 reveal a tube-like structure that has a higher density of these elements and species with respect to the surrounding sample volume (Fig. 3). This structure is not observed in any of the other analyzed tips, and Tip M2

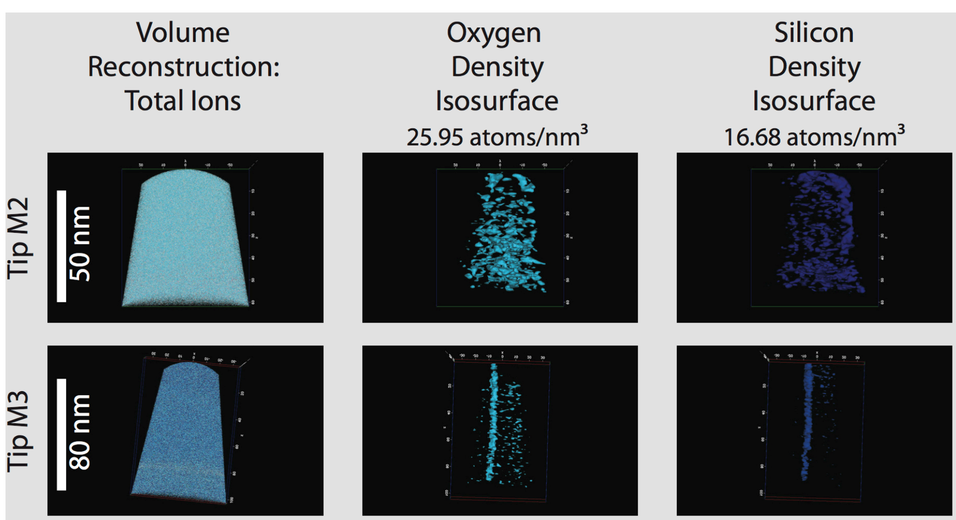

Fig. 3. A comparison of APT data from Tip M2 and Tip M3. Left column: volume reconstruction for all ions. Middle column: oxygen density isosurfaces. Right column: silicon density isosurfaces. Tip M3 shows the tube-like structure in the density isosurface visualizations.

is shown in Fig. 3 to demonstrate this contrast. In Tip M3, the higher density material is consistent with the presence of an amorphous solid where closer packing of atoms in the absence of a crystalline structure may contribute to the higher density. Given that pseudotachylyte survivor clasts were analyzed by APT, it is likely that the amorphous material is former melt from the pseudotachylyte. The tube-like structure bears resemblance to a partially-healed fracture, and may be indirect evidence for creep cavitation in the presence of pseudotachylyte melt. Creep cavitation involves the coalescence of cavities along grain boundaries to make macroscopic cracks. These results suggest that melt-assisted creep cavitation may be a process that initiates macroscopic failure and possibly earthquake rupture.

Timeline of results:

1) Electron Backscatter Diffraction (EBSD) analysis on pseudotachylyte samples with M.S. student Craig Stewart as part of his thesis research (February - May 2017)
2) M.S. student Craig Stewart graduates and is awarded a M.S. Geology degree (May 2017)
3) Presentation of EBSD results in a co-authored poster with M.S. student Craig Stewart at SCEC Meeting (September 2017)
4) Publication of our EBSD results in the *Journal of Geophysical Research* (December 2017):

   Stewart, C.* and **Miranda, E.A.**, (2017). The rheological evolution of brittle-ductile transition rocks during the earthquake cycle: evidence for a plastic precursor to pseudotachylyte in an extensional fault system, South Mountains, Arizona. *Journal of Geophysical Research, Solid Earth,* doi:10.1002/2017JB014680

5) Pseudotachylyte sample preparation for atom probe tomography analysis; this involves probe-polishing a rock billet and cutting to 2 cm x 2 cm size so that a smooth sample surface exists prior to analysis (June 2018)
6) I traveled to the University of Alabama July 9-13, 2018, for atom probe tomography analysis in collaboration with Dr. Alberto Perez-Huerta.
7) I was an invited speaker at the Rheology Workshop associated with the 2018 SCEC Meeting. I presented the results of the EBSD study in the workshop.
8) I attended the 2018 Annual SCEC Meeting and presented a poster with co-author Dr. Perez-Huerta in which we summarized the EBSD and APT results.