

SCEC Rheology Workshop Field Trip

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Cucamonga Canyon, San Gabriel Mountains

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The second day of the 2023 SCEC Rheology Workshop features a field trip to local exposures of shear zones that were exhumed by deformation along the San Andreas Fault System. We are headed to the Cucamonga mylonites (lower crust) and the Black Belt mylonites (middle crust) exposed in Cucamonga Canyon, near Rancho Cucamonga.

Geologic Background in the context of SCEC

The SCEC5 Community Rheology Model (CRM) involves building a provisional rheology model around a 3D geologic framework for Southern California, which is described by the Lithotectonic Block Model (Crouch and Suppe, 1993; Oskin et al., 2016; Hauksson and Meier, 2019). In this model, each distinct block is defined by basement geology, surface

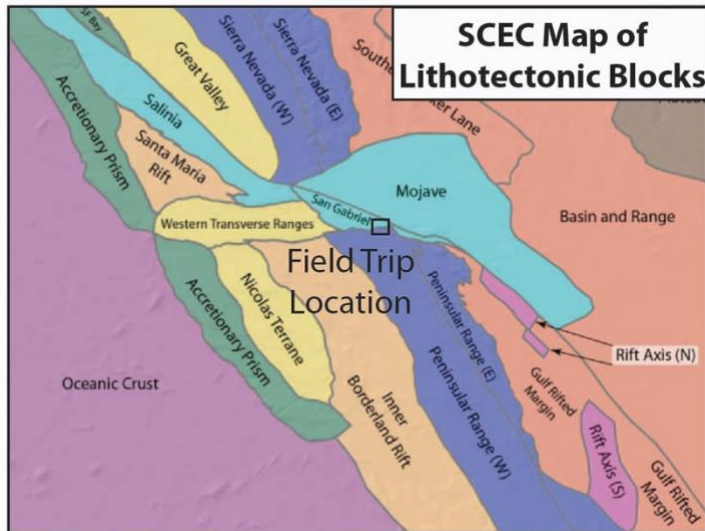


Figure 1. The SCEC 5 Lithotectonic Blocks of Southern California. The field trip locality is in the SE corner of the San Gabriel Block, where the Cucamonga Fault, San Jacinto, and San Andreas Faults converge.

geology, and geophysical data, and the block boundaries largely correlate with major faults that have contributed to the evolution of the San Andreas Fault (SAF) transform boundary (Fig. 1). The geologic framework for Southern California is largely superimposed upon blocks of basement rocks containing inherited ductile fabric which record their past tectonic histories. This has implications for the geometry and rheology of brittle structures which may be influenced by older rock fabrics that act as stress guides for strain localization along the major faults that define the lithotectonic blocks (e.g., Schulte-Pelkum et al., 2020). **This is of critical importance for the SCEC5**

CRM because the geometry and rheological properties of the ductile roots of those major faults are also likely to be controlled by pre-existing fabrics in basement rocks.

There are few places in Southern California where ductile roots of major fault zones are exposed at the surface, but the southeast corner of the San Gabriel lithotectonic block (Figure 1) exposes a thick section of sheared Late Cretaceous arc rocks that represent some of the deepest exposures of crust in the region (Figure 2). The close association of the Quaternary faults that bound the San Gabriel lithotectonic block (Cucamonga Fault, San Jacinto) and the Cretaceous ductile shear zone fabrics in the block demonstrates the potential for older rock fabrics to act as stress guides for younger, brittle structures associated with the San Andreas Fault system (e.g., Schulte-Pelkum et al., 2020). In addition, this location provides unparalleled exposure of deep

crustal rocks that provide insight into the rock compositions that characterize the San Gabriel Lithotectonic Block. Together, the Cucamonga and Black Belt mylonites represent two sub-parallel ductile shear zones marking major deep-crustal compositional and rheological boundaries, and will provide useful field context for understanding shear zone fabric development and compositional variability as part of refining the CRM. Our field trip location is focused on the lower crustal Cucamonga mylonites and middle crustal Black Belt mylonites that comprise the shear zone exposed in the SE San Gabriel Block. We will make two traverses through the mylonites exposed in Cucamonga Canyon; the first traverse will be in the Cucamonga mylonites, and the afternoon's traverse will be through the Black Belt mylonites.

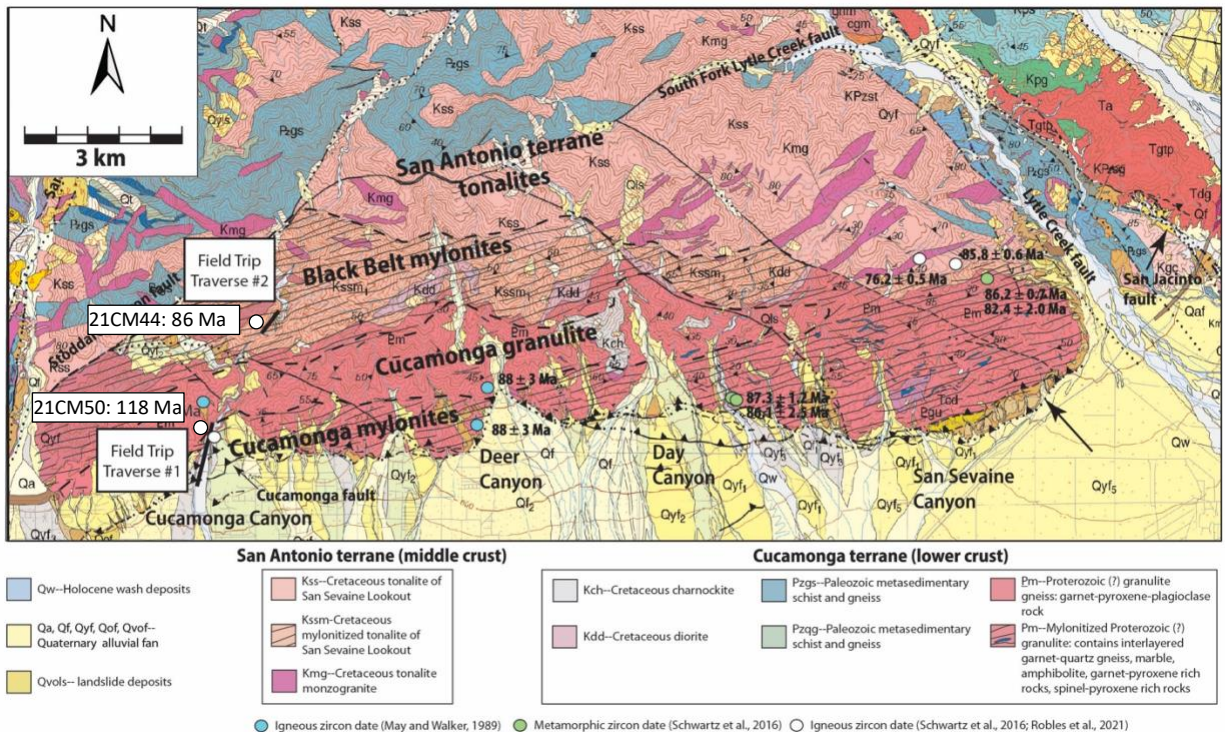


Figure 2. Geologic map of SE part of San Gabriel lithotectonic block showing the lower crustal Cucamonga terrane and the middle crustal San Antonio terrane. The Black Belt mylonites are developed in tonalites of the San Antonio terrane and separate the two terranes. Modified after Morton and Miller, 2003.

Geology of the Cucamonga mylonites and Black Belt mylonites

The host rocks to the Cucamonga mylonites contain interlayered Jurassic(?) metasedimentary and Early to Late Cretaceous metaplutonic rocks that were metamorphosed during the Late Cretaceous at granulite-facies conditions at 835 to 750°C and at ~8 kbar (~30 km depth), consistent with conditions in the lower crust (Barth and May, 1992). The Jurassic(?) metasedimentary rocks consist of layered quartzites, marbles and quartzofeldspathic gneisses. The Early to Late Cretaceous plutonic rocks crystallized from 175-86 Ma at 800 to 740°C based on U-Pb zircon petrochronology (Schwartz et al. in revision). These plutonic and metasedimentary rocks were subsequently metamorphosed and ductilely deformed into mylonites at 30 km depth under granulite-facies conditions during the Late Cretaceous (88-74 Ma). The Cucamonga mylonites form a ~1 km-thick shear zone along the southern margin of the Cucamonga terrane (May and Walker, 1989) where they are cut by the Quaternary Cucamonga

Thrust Fault (dip = 35-25°) (e.g., McPhillips and Scharer, 2018; Morton and Miller, 2003; Morton and Matti, 1987).

The foliation in the Cucamonga mylonites strikes NW and dips moderately (40-50°) to the NE. Stretching lineations in the mylonites plunge shallowly to the west, indicating sinistral, top-to-the-west sense of shear, consistent with oblique strike-slip motion in the granulite-facies shear zone. Quaternary brittle reverse faults imbricate the Cucamonga section and are primarily concentrated near the Cucamonga fault zone. These faults record multiple phases of motion and reactivation, including reverse, normal and strike-slip motion. Field observations suggest that the imbrication is primarily localized along the thrust at the southern end (Cucamonga thrust) which emplaced deep-crustal arc rocks on Quaternary sediments, while other brittle faults in the section have relatively minor displacement. The Quaternary Cucamonga Fault strikes E-W and dips gently (25-35°) towards the north (McPhillips and Scharer, 2018).

The Cucamonga mylonites primarily record two phases of deformation (Figure 3). D₁ deformation is restricted to the Cucamonga granulites and involved top to the south reverse motion. D₂ deformation involved oblique sinistral reverse (top to the SW motion) and is spatially and temporally associated with intrusion of comagmatic Late Cretaceous tonalite and diorite. In the southern part of the section, within the Cucamonga Granulite, D₂ reactivated older gneissic foliation planes. D₂ is also observed in the Black Belt mylonites (see below).

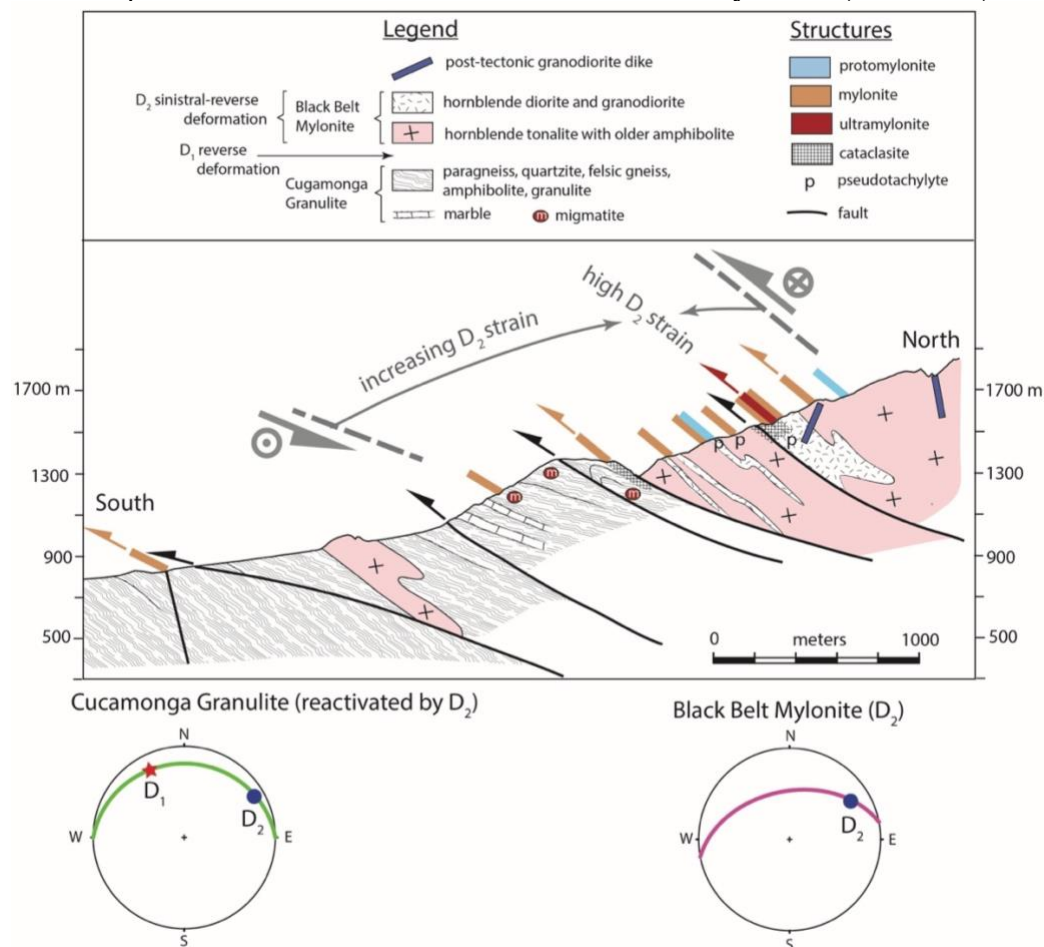


Figure 3. Schematic cross-section through the Cucamonga mylonites illustrating the relationship between preexisting fabrics (D₁ and D₂) with Quaternary reverse faults. This field trip examines relationships in the Cucamonga granulitic mylonites at the southern end of the transect and the Black Belt mylonites to the north.

The northern margin of the Cucamonga terrane is marked by a 600 m-thick mylonitic shear zone that tectonically juxtaposes it against the mid-crustal tonalites of the San Antonio terrane (~5-7 kbar, ~18-25 km) (May and Walker, 1989; Barth et al., 1995). These mylonitic rocks are primarily developed in the tonalites and diorites of the San Antonio terrane, and are known as the ‘Black Belt mylonites’ (Alf, 1948). The Black Belt mylonitic fabric is strongest at the sharp boundary with the Cucamonga terrane, and decreases in intensity to the north, towards the interior of the San Antonio terrane. The Black Belt mylonites are hosted by biotite hornblende tonalites and hornblende diorites that crystallized in the Late Cretaceous from 88 - 85 Ma at 725-799°C based on U-Pb zircon petrochronology (Schwartz et al., in revision). U-Pb titanite petrochronology shows that mylonitic fabric developed within the tonalites in the Late Cretaceous at 83 Ma, shortly after crystallization, and at temperatures 650-550°C. The mylonitic foliation in the Black Belt strikes SW and dips moderately (56-67°) to the NW. Stretching lineations plunge gently (10-13°) towards the NE, consistent with top-to-the-southwest, strike-slip motion in the amphibolite-facies shear zone. Discrete brittle faults occur, but are less common away from the Cucamonga Fault.

In the Black Belt mylonite belt, D₂ mylonites form a ~1.5- 2 km thick zone of ductile deformation within Late Cretaceous tonalites and diorites (Figure 3). However, individual mylonitic shear zones are thin (tens of meters thick and sometimes less), spaced, and cluster to form high- and intermediate-strain zones. Zones of the highest strain coincide with a thick sheet of diorite surrounded by a tonalitic host. The spacing and occurrence of the mylonite was controlled by the emplacement of individual sheets of tonalite and diorite. Zones of the highest D strain inside the tonalite/diorite intrusion are interlayered with Late Cretaceous cataclasite and pseudotachylyte.

Tuesday Morning Traverse #1: Cucamonga mylonites

Locality #1: Garnet gneiss and charnockite (21CM50a and b).



U-Pb zircon crystallization ages in the garnet gneiss are 118 Ma (dark interior with CL imaging) and luminescent rims record metamorphism at ~78 Ma, at 776° C. U-Pb zircon petrochronology of charnockite host rock to the granulite mylonites shows Late Cretaceous crystallization. Zircon cores yield crystallization ages of 118 Ma, and rims record metamorphism at 78 Ma, at temperatures of 727° C. The gneissic foliation is oriented 155°, 50° SW.

Figure 4. Outcrop photo of garnet gneiss showing location of sample 21CM50b. Charnockite sample 50a was taken from just above the garnet gneiss. Photo taken looking towards NW. Orientation markings on sample show orientation of gneissic foliation.

Locality #2: Mylonitic tonalite and garnet-bearing mafic gneiss (21CM49a and b)

The mylonitic tonalite is dominated by plagioclase and hornblende, and has a U-Pb zircon crystallization age of ~86 Ma (luminescent interior with CL imaging), and rims record metamorphism at ~77 Ma at temperatures of 738° C. There is also some Permian inheritance in the zircon population. The garnet bearing mafic gneiss has U-Pb zircon crystallization ages of ~88 Ma (dark interiors with CL imaging) and rims record metamorphism at ~74 Ma, at temperatures of 789° C.



Figure 5. Photo looking NE towards outcrop of mylonitic tonalite and garnet gneiss.



Figure 6. Photos of mylonitic tonalite (left) and garnet gneiss (right) samples collected from locality #2 within the Cucamonga mylonites.

Locality #3: Cucamonga mylonites are cut by a splay of the Quaternary Cucamonga Fault and its subsidiary brittle deformation (21CM53). The mylonitic fabric is oriented 266°, 70° NW and the layer of foliated gouge is oriented 238, 62° NW.

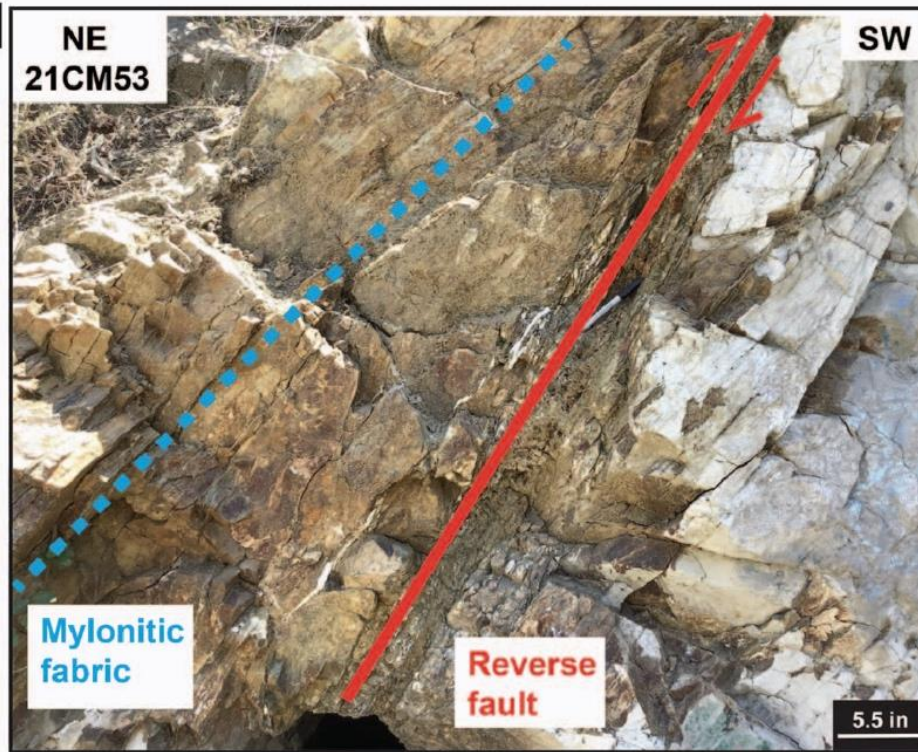


Figure 7. Outcrop photo looking east at Cucamonga mylonites cut by brittle, reverse fault associated with Cucamonga Fault. Bottom of photo shows a small mine adit or burrow into the damage region of the fault.

Tuesday Afternoon Traverse #2: Black Belt mylonites

Locality #4: Hornblende tonalite (21CM44a)

U-Pb zircon ages of the hornblende tonalite are Late Cretaceous, with crystallization 89-86 Ma. This massive outcrop of hornblende tonalite exhibits a gradation in fabric development over a few 10s of meters. On the southern end of the outcrop, there is a weaker foliation present, with some tight folds of the foliation apparent (Figure 8a). Towards the north, the foliation strengthens, and alternating layers of mylonites, cataclasites, and pseudotachylyte(?) seams can be identified (Figure 8b). Mylonitic foliation orientation is $258, 48^{\circ}$ NW. A key outcrop in these alternating layers shows a brittle fabric precursor to mylonitic fabric development. In this outcrop, foliated, brittle cataclasites are reworked by co-planar foliated mylonitic fabrics to various degrees, and alternating parallel layers of these variably mylonitized cataclasites are separated by narrow seams of co-parallel pseudotachylytes(?).



Figure 8a. Photo of massive outcrop of hornblende diorite in the Black Belt, view to the NW. Tight folds visible in center of photo. Foliation strikes SW and dips moderately to the NW.



Figure 8b. Photo of alternating layers of mylonites, cataclasites, and pseudotachylyte(?) seams. The brittle cataclasites are overprinted by mylonitic fabric. The pseudotachylyte seams are most commonly located at the interface between overprinted cataclasites and mylonites. Sample locality 21CM45.

Locality #5: Hornblende tonalite mylonite and pseudotachylyte (21CM47a and b)

U-Pb zircon ages of hornblende tonalite host rock are Late Cretaceous, showing crystallization at 86 Ma and metamorphism at 79 Ma at temperatures $\sim 753^{\circ}\text{C}$. There is a strong mylonitic foliation in this locality, and the foliation is oriented $210, 76^{\circ}\text{NW}$. Kinematic indicators in the mylonites are consistent with sinistral, top-to-southwest sense of shear. The mylonitic fabric contains seams of pseudotachylyte (verified by thin section) that range in thickness from a few mm to a few cm in width. Where present, the pseudotachylyte seams are co-planar with the mylonitic foliation. U-Pb ages of metamorphic titanite aligned with mylonitic foliation are ~ 83 Ma, suggesting Late Cretaceous mylonitic fabric development. The co-planar texture of the pseudotachylytes with these mylonites indirectly points to a Late Cretaceous age of pseudotachylyte development.

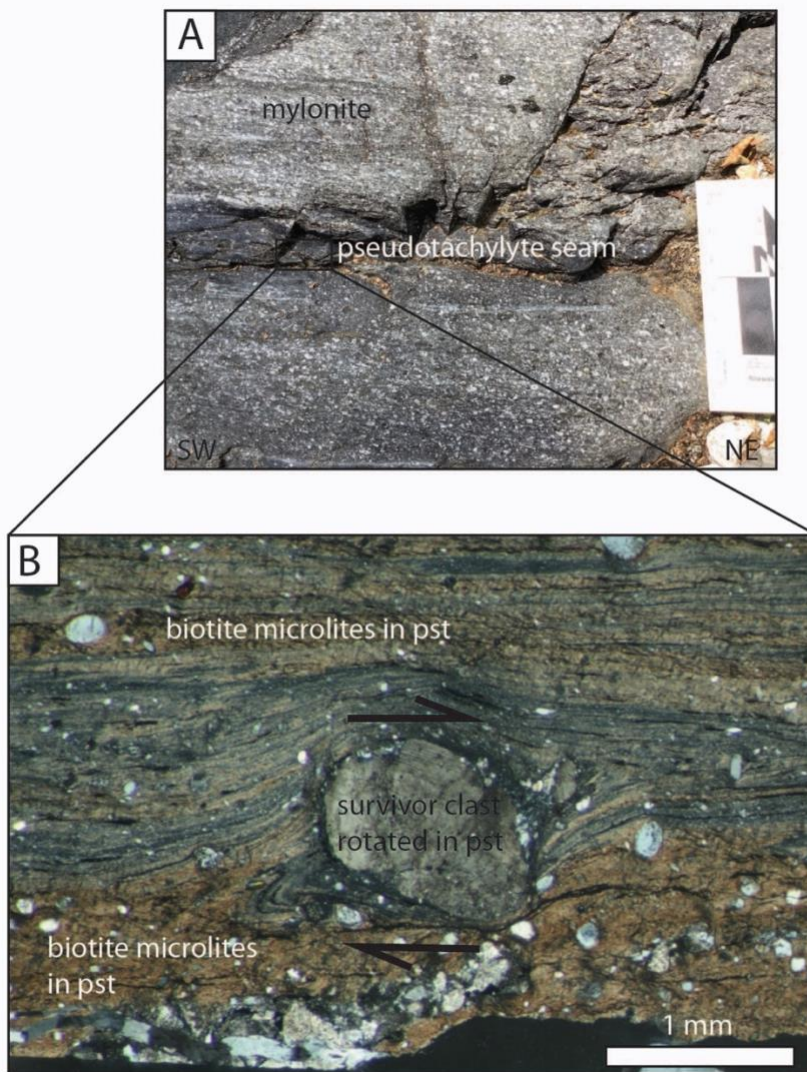


Figure 9. Outcrop and thin section photos of pseudotachylyte seam in hornblende tonalite mylonite. A) Outcrop photo of pseudotachylyte seam within mylonite, viewed looking towards NW. Mylonitic foliation is co-planar with pseudotachylyte seam. B) Photomicrograph of thin section derived from pseudotachylyte (pst) seam. Survivor clasts show clockwise rotation within pst seams, which is the same sense of shear (top-to-SW) in the host mylonite.



Figure 10. Outcrop photo of pseudotachylyte (pst) seam in hornblende tonalite mylonite. Photo shows clear top-to-SW sense of shear in mylonites.

Field Trip Locality and Sample Location Map



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