Onset of Strain Localization in Sheared Glacial Till
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Summary
Strain localization plays a key role in determining the frictional stability of brittle shear zones, which in turn influences the tectonic and seismic/coseismic behavior of fault zones and deforming glacial till. Recent studies show that seismic, stick-slip motion occurs in dilatant till layers. It appears that dynamic stresses and fluid migration during localized shear may induce stick-slip instability. However, the laboratory data necessary to test such hypotheses are incomplete. We report on detailed laboratory experiments to measure the onset of shear localization of Caesar till sampled from the Scitico Lobe of the Laurentide Ice Sheet, collected in central Ohio, USA.

Experiments
Shear creep experiments are ideally suited to assess the onset of shear localization due small amounts of strain during creep. Shear stress is held constant for 45 minutes then increased by steps of 5% of the steady state shear strength. The amount of shear strain during each step is less than 0.1 during stable creep. The amount of shear strain before creep is varied from 0 to 2.6. Layer thickness decreases with strain up to 0.7 then remaining constant. Creep experiments were employed to study frictional creep and the localization of strain. Creep was induced after an initial shear strain ranging from 0 to 2.6 to investigate the role of shear fabric on deformation. In creep experiments, shear stress increments began at ~2/3s of the shear strength and continued until tertiary creep occurred. Stress steps were 5% of the shear strength and we determined the resulting strain rate and layer dilation.

Creep experiments show a transition from distributed deformation to localized deformation at low strains. Velocity steps show that Caesar till is a velocity-strengthening material, with the critical slip distance decreasing with strain up to 0.7 then remaining constant. Creep experiments show that dilatancy after a stress step decreases exponentially from ~10μm per strain of zero to ~2μm at a shear strain of 1. Beyond strains of 1 a variation in dilatancy is observed. Decreasing initial layer thickness decreases dilatation by the same factor at low strains, but has no effect at strains of 1 or greater. These results imply that shear becomes more localized over a finite distance in a velocity-strengthening material beyond the onset of localization variation in strain and driving velocity do not change the characteristics of strain localization. Localized deformation in till implies shallow deformation, which does not stabilize fast glacial slip and may lead to stick-slip motion.

Experimental Setup
Blocks: 10 x 10 cm² contact area
1. Blocks grooved 0.8 mm with a wavelength of 1 mm
2. Double-direct shear apparatus with reservoir open to the atmosphere
3. Experiments conducted at 0.5, 1, and 5 MPa normal stress

Sample Characteristics
Caesar till collected in central Ohio, USA, from the Sciitico Lobe of the Laurentide Ice Sheet
- Samples are air-dried and sieved to less than 1 mm
- Bulk sample: 98.9% sand/1.0% silt/0.1% clay
- Experimental range: 98.7% sand/2.1% silt/0.1% clay

Fabric Development
Layer dilation implies that fabric develops rapidly at low shear strains then remains constant. Changing layer thickness and normal stress only effect dilation and fabric development at low shear strains. Increased shear strain reduces the resulting shear strain rate from stress increases.

Conclusions
1. Velocity Dependence of Friction
Caesar Till is a velocity-strengthening material at all shear strain and normal stresses tested.

2. Fabric Development
Changes in layer dilation shows that fabric develops gradually until a shear strain of 1, then remains constant until a shear strain of 2.

3. Shear Localization
During distributed deformation, dilation scales with layer thickness. By a shear strain of 1, layer thickness does not effect dilatation implying a transition from distributed to localized deformation. Localized shear decreases shear strain rate.

Knee Fault
Granular Till Layer
Medium Fault
Grain

L0
L1
L2
L3

Shear Strain
Time x 10^-3 (s)

Shear Stress (MPa)

Layer Thickness (mm)

Layer thickness (corrected for shear dilation) is near constant by a shear strain of 0.2.

The velocity dependence of friction is calculated from:

\[ \ln \left( \frac{V}{V_0} \right) = \alpha - \beta S \]

All experiments show velocity-strengthening frictional behavior (positive a, b).

SEM imagery of experiment p1344 shows heterogeneous distribution of high stress leads to greater dilation.