Experimental Constraints on the Rheology and Seismicity of Subducting Lithosphere and the Slab-Wedge Interface

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1. Experiments on antigorite and lawsonite to investige the role of dehydration reactions on fault strength and slip stability at high pressure and temperature conditions.

2. Development of techniques and approaches to control pore-fluid pressure at high P&T conditions and to scale results to natural settings.

3. Experiments and supporting thermal models to investigate dynamic frictional weakening in serpentinite.

Publications

Chernak, L., G. Hirth, Syn-deformational antigorite dehydration produces stable fault slip, Geology, 39, 847-850, doi:10.1130/G31919.1, 2011.

Kohli, A. H., D. L. Goldsby, G. Hirth, T. E. Tullis, Flash weakening of serpentinite at near-seismic slip rates, J. Geophys. Res., doi:10.1029/2010JB007833, 116, B03202, 2011.

Kelemen, P. B., G. Hirth, Reaction-driven cracking during retrograde metamorphism: Olivine hydration and carbonation, Earth and Planet. Sci. Lett., 345-348, 81-89, http://dx.doi.org/10.1016/j.epsl.2012.06.018, 2012.

Hirth, G., S., Guillot, Rheology and tectonic significance of serpentinite, Elements, 9, 107-113, doi:10.2113/gselement.9.2.107, 2013.

Proctor, B., T. M., Mitchell, G. Hirth, D. Goldsby, F. Zorzi, G. Di Toro, Dynamic weakening of serpentinite gouges and bare-surfaces at seismic slip rates, J. Geophys. Res., 119, 8107-8131, doi:10.1002/2014JB011057, 2014.

Auzende, A. -E., J. Escartin, N. P. Walte, S. Guillot, G. Hirth, D. J. Frost, Deformation mechanisms of antigorite serpentinite at subduction zone conditions determed from experimentally and naturally deformed rocks, Earth and Planet. Sci. Lett., 411, 229-240, doi:10.1016/j.epsl.2014.11.053, 2015.

Proctor, B., G. Hirth, Role of pore fluid pressure on transient strenght changes and fabric development during serpentinite dehydration at mantle wedge conditions, Earth and Planet. Sci. Lett., provisionally accepted.

Deformation experiments on antigorite and lawsonite show very different behavior during dehydration: for antigorite, we observe "slow slip" events with little AE (acoustic emission). In contrast, for lawsonite, we observe unstable slip (stick-slip) with prominent AE. These data have implications for understanding the role of dehydration reactions on seismicity in subducting slabs. Results from Okazaki et al., in prep. (Fig. 1).

Motivated by our earlier work (Chernak and Hirth, 2011) - we developed a new technique to drain the pore-fluid produced during dehydration reactions in high P experiments (this is routinely done for low P experiments, by preivously not accomplished for experiments at mantle conditions). The data document the large effect of pore-fluid pressure on the weakening produced during dehydration. Weakening shown for the undrained experiment occurs after <1% reaction. Nonetheless, in all experiments on antigorite, deformation remains stable. Microstructural observations indicate deformation involving a "pressure solution" type process - which is inherently stable. Results from Proctor and Hirth - provisionally accepted (Fig. 2).

To scale these results to natural conditions, we use the ratio of the temperature ramp rate (controlling reaction rate) to the strain rate (or displacement rate). For slabs, this ratio is in the range of 0.1 to C/micron based on thermal models of the subduction interface. Fig. 3 shows that unstable slip observed for lawsonite is insensitive to the ratio. In contrast, the unloading slope observed for the stable antigorite samples scales almost linearly with the ratio of T ramp rate/displacement rate. (Okazaki et al., in prep.).

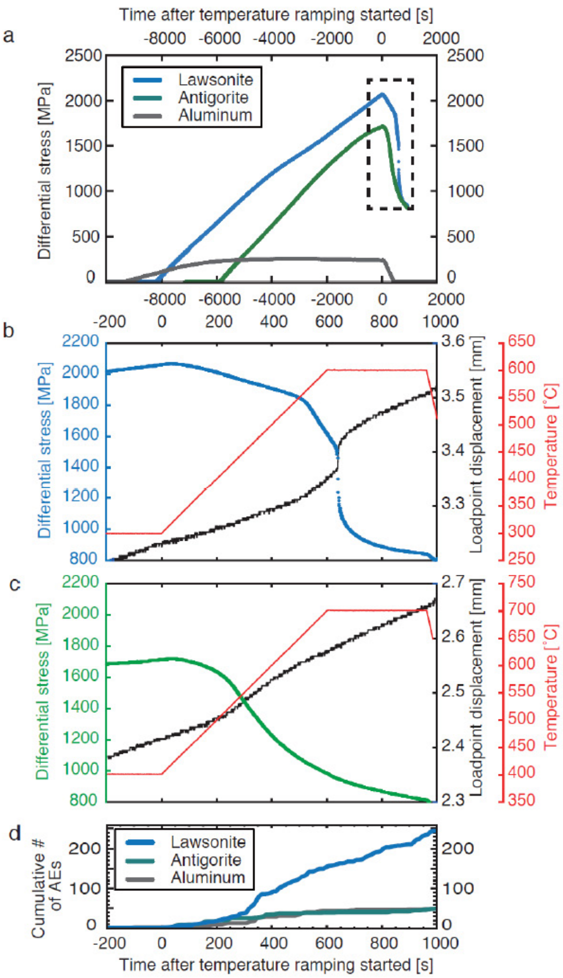


Figure 1.

We also performed experiments to evaluate what happens when rapid slip is imposed onto a fault zone rich in serpentine - for example when an earthquake ruptures into a stably creeping serpentinite patch (Fig. 4). These test document extreme dynamic weakening. The slip velocity at which dynamic weakening is observed increases in the presence of gouge - but for

Figure 2.

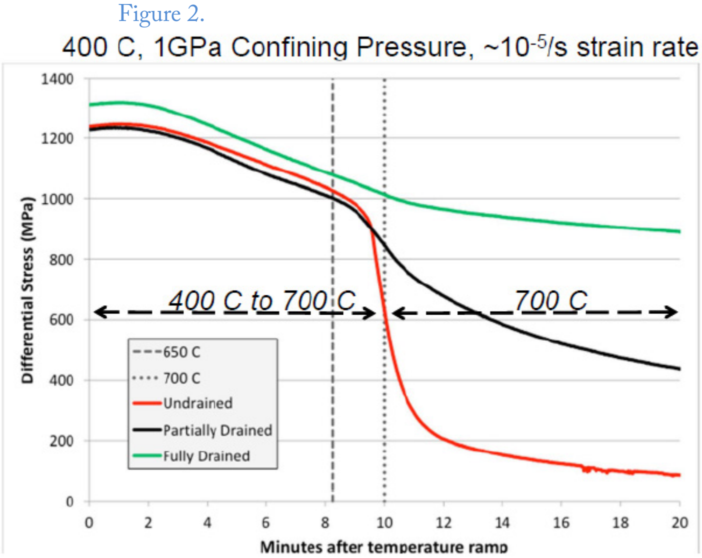
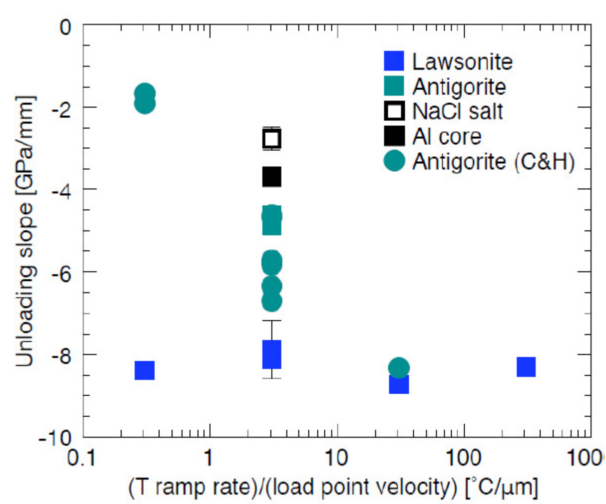
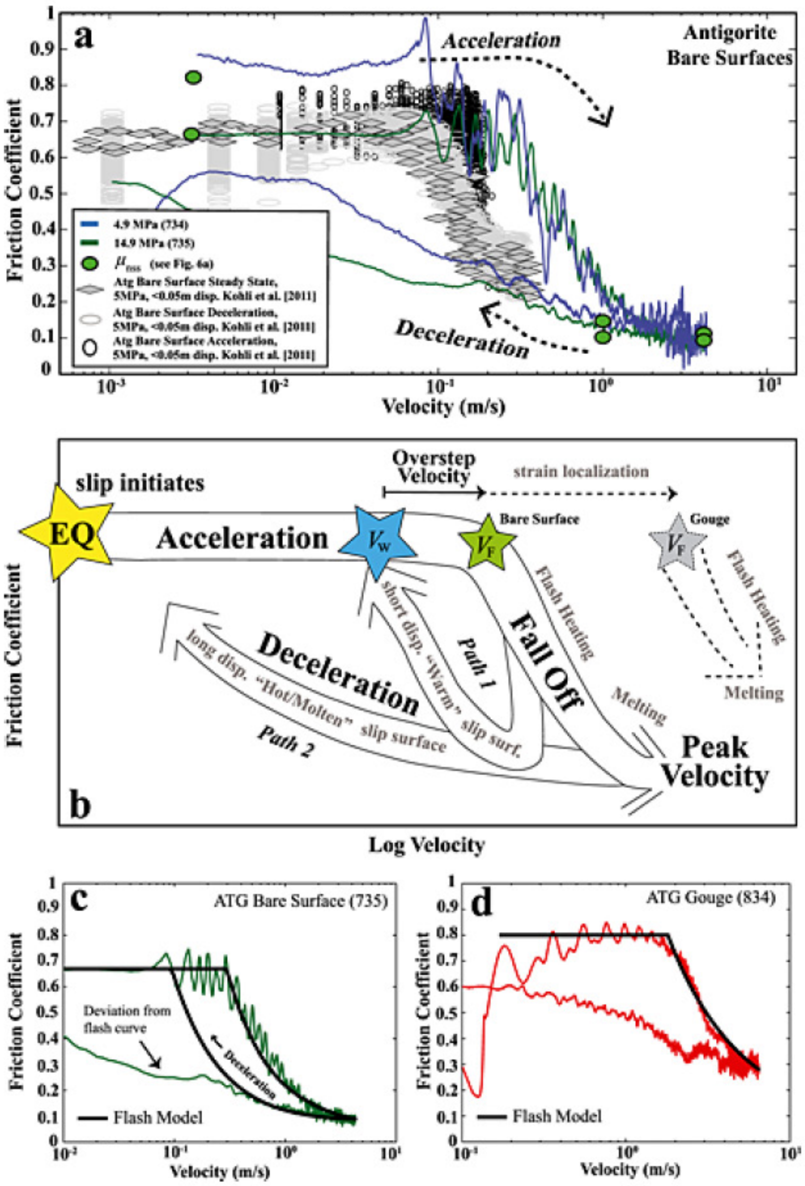


Figure 3.



experiments on either bare surfaces or with a layer of gouge - the onset of weakening is well-explained by flash weakening at asperity contacts.

Fig. 4a shows data from small displacement and large displacement experiments. In this case, we observed a significant difference in the "deceleration" path, which reflects the onset of melting for the large displacement tests. The micrograph shows glass and vesicles quenched on the slip surface of a high displacement test. The bottom two plots show comparison to friction models that incorporate flash weakening. Results from Proctor et al., JGR 2014.



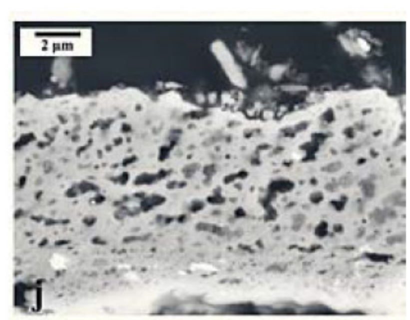


Figure 4.