AGU Fall Meeting 2016

Poro-elastic Properties of Whillan's Ice Stream Till: Implications for Basal Stick-Slip

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Whillans ice stream, West Antarctica, flows rapidly from the West Antarctic ice sheet into the Ross Ice Shelf. Regions of highly compacted till, termed sticky-spots, pin the ice in place. Upstream ice flow increases driving stress, until minor changes in buttressing stresses from tides affecting the ice shelf cause the main sticky-spot to fail, triggering diurnal or semidiurnal stick-slip events. The mechanical and hydrological properties of the till partially control the basal conditions, generation and persistence of the sticky spots, and thus the dynamics of the rupture and healing processes. Here we present laboratory tests on core samples of the till beneath Whillan's Ice Stream collected in the 1989-1993 field seasons.

Two types of tests were performed on till cores: stepped loading and cyclic loading. In the stepped loading test, the effective stress was increased from 0.1 to 10 MPa in a series of steps, and the permeability measured at each step. Cyclic loading tests consisted of a series of effective stress oscillations with 24 h period lasting 5-10 d each, increasing in amplitude from 20-150 kPa. The permeability was measured after each set of oscillations to investigate the role of cyclic loading in driving enhanced compaction. Compressional wave velocity (V_p) was also measured during both test sequences.

We observe sample initial porosities of ~30% and permeabilities of ~$3x10^{-17}$ m^2. During stepped loading tests, porosity is reduced to ~20% and permeability to ~$8x10^{-18}$ m^2. V_p ranged from 2.2-2.95 km s^{-1} and was well fit by an effective medium model. Application of this model to V_p obtained by field seismic surveys is consistent with low (~50 kPa) effective vertical stresses in the uppermost till. Cyclic loading sequences reduced porosity by 4% and permeability by an order of magnitude. A transient numerical model based on our data shows that over the tidal timescale, a layer of stiffened till ~10 cm thick should develop. We suggest that this provides one mechanism to generate and maintain sticky spots and modify the stiffness of the system.