

In addition, a series of 16 slug tests were performed in 6 of the boreholes over a period of one week in early June. The slug tests were performed at various times of the day and in different weather conditions to help investigate the temporal changes in the system. Responses varied from an overdamped slow drain to an underdamped oscillatory response. Analysis of the slug tests in correlation with data retrieved from down-hole sensors provides valuable insight into the development of subglacial and englacial hydrologic systems as well as spatial and temporal changes that occur.

C62A-0920 1330h POSTER

Motion of a Temperate Glacier Over Hard and Soft Beds: Subglacial Experiments at Engabreen, Norway

Thomas S. Hooyer¹ (608-263-4175;

tshooyer@facstaff.wisc.edu); Neal R. Iverson²; Urs H. Fischer³; Denis Cohen²; Miriam Jackson⁴; Peter L. Moore²; Gaute Lappégard⁵; Jack Kohler⁶

¹Wisconsin Geological Survey, 3817 Mineral Point Rd., Madison, WI 53705, United States

²Dept. Geological and Atmospheric Sciences, Iowa State University, Ames, IA 50011, United States

³Laboratory of Hydraulics, ETH-Zentrum, Zurich CH-8092, Switzerland

⁴Norwegian Water Resources and Energy Directorate, Middlethuns Gate 29, PO Box 5091 Majorstua, Oslo N-0301, Norway

⁵Dept. Geography, U. of Oslo, PO Box 1042, Oslo N-0316, Norway

⁶Norwegian Polar Inst., Polar Env. Center, Tromsø N-9005, United States

Recent work on basal motion of wet-based glaciers has focused on the role of debris, either entrained in ice sliding over bedrock or in a water-saturated layer dividing ice from rock. In the first case, debris in contact with bedrock is known to add resistance to basal motion but is thought to account for only a minor fraction of basal shear stress. Deformation of wet sediment separating ice from rock is thought to commonly reduce resistance to basal motion, although controversy persists regarding whether resistance to such deformation is viscous or predominately frictional and rate-independent.

During two spring field seasons, we have conducted experiments with instrumented hard and soft beds beneath Engabreen, a temperate glacier in Norway where the Svartisen Subglacial Laboratory provides human access to the bed beneath 220 m of ice sliding at 0.1-0.2 m/d. In one experiment, a smooth granite tablet (0.09 m²) was installed flush with the bedrock surface so that debris-charged basal ice (2-11 % debris by volume) slid across it. The shear traction on the tablet, total normal stress, water pressure at the tablet surface, and upward heat flux were measured. In the other experiment, a trough (2 m x 1.5 m x 0.5 m deep) was blasted in the rock bed and filled with 2.5 tons of simulated till. Instruments recorded shear (tiltmeters), dilation and contraction, total normal stress, and pore-water pressure. Pore pressure was manipulated by feeding water to the base of the till with a high-pressure pump, operated in a tunnel in rock 4 m below the bed surface.

Inconsistent with the leading abrasion theory, shear traction on the rock tablet during two consecutive field seasons was about 100 kPa and depended sensitively on effective normal stress, which fluctuated in response to water-pressure variability. Deformation of till required low effective normal stresses associated with high pore-water pressures, highlighting the frictional nature of till. Shear strain decreased downward in the bed due to increasing friction with depth and the consequent suppression of force imbalances on individual grains (Iverson and Iverson, 2002, *J. Glaciol.*, no. 158). Overall, results from both experiments indicate that rock friction associated with both abrasion and till deformation may play a major role in resisting basal motion of wet-based glaciers.

C62A-0921 1330h POSTER

Subglacial Environment Inferred from Bedrock-Coating Siltskins, Mendenhall Glacier, Alaska

Carissa L Carter¹ (831-426-6232; ccarter@es.ucsc.edu)

David P Dethier² (ddethier@williams.edu)

Robert Newton³ (rnewton@science.smith.edu)

¹University of California Santa Cruz, Earth Sciences Department 1156 High St., Santa Cruz, CA 95064, United States

²Williams College, Geosciences Department 947 Main St., Williamstown, MA 01267, United States

³Smith College, Department of Geology Clark Science Center, Northampton, MA 01063, United States

In the past two decades, retreat of the Mendenhall Glacier near Juneau, Alaska has exposed a bedrock ridge spotted with 'siltskins', patchy coatings of calcite-cemented clay to sand-sized lithic grains. Coatings range from 0.5 to 20 mm thick and occur in two distinct morphologies. Striated siltskins are thin, located mainly on stoss faces, and preserve local striation direction. Thicker, corrugated skins preserved on lee faces consist of parallel microridges elongated downslope.

Thin section analysis shows that siltskins consist of a basal, calcite-rich layer overlain by microlaminated layers of calcite-cemented lithic grains. Microstrata in layers of corrugated siltskins display complex internal structures including wavy microlaminae, truncated cross-bedding, convolute forms, and pockets of larger grains. SEM/EDS analysis of siltskin laminae and surfaces show laterally persistent Ca/Si differences. Isotopic values of ΔO^{18} and ΔC^{13} ranged from -19.52 to -12.74 and -6.18 to -3.44, respectively in five samples of cement, consistent with deposition from subglacial waters of varying isotopic concentrations and with derivation of carbon from inorganic sources.

Regulation processes probably caused precipitation of the basal calcite layer from ice enriched in Ca. After the basal layer reached a limiting thickness, deposition of microlaminae of the upper layer dominated. The relatively thick corrugated siltskins we studied are depositional features enhanced by erosional processes. Wave-lengths of parallel microridges generally range from 1 to 10 mm and apparently formed as sediment-rich water dripped or oozed down lee slope rock faces. Ice-rock separation, flow energy, and the amount and grain size of transported sediment controlled the layering and depositional forms.

Deposition of siltskins depended on macro-scale processes in the glacier system, outcrop-scale features of the rock ridge, and micro-scale interactions of the ice, bedrock, and thin films of water in the regulation layer. Siltskins probably formed when a subglacial cavity system was active on the rock ridge, probably within the last 60 years. Siltskins provide clues about how micro-scale hydrologic processes interact with larger-scale subglacial systems.

C62A-0922 1330h POSTER

Are Dewatering Structures Necessary Criteria for Identifying Melt-out Till?

Anders Eskil Carlson (541-737-1201; carlsand@geo.orst.edu)

Department of Geology and Geophysics University of Wisconsin, 1215 W. Dayton St. Weeks Hall, Madison, WI 53706, United States

One of the most common characteristics used to identify melt-out till is the presence of dewatering structures, or sorted sediment zones formed during melt-out. However, calculation of the pore water discharge required to sort sediment (critical discharge) and 1-dimensional modeling of melt-out suggest that geothermally driven melt-out produces insufficient water to sort or transport sediment. Assuming pore water pressure within the till equals total pressure on the system, I use geotechnical data from the clayey Keweenaw Formation till of eastern Wisconsin to determine the critical discharge of the till. This till can transport up to 1.6 m³ of water/year/m² without pore water pressure exceeding total pressure. Measured melt rates from valley glaciers and estimated melt rates for ice sheets produce 2 to 3 orders of magnitude lower discharge than the maximum discharge that can pass through the pore space of Keweenaw Formation till. Using basic laws of soil mechanics, I constructed a 1-dimensional model of a geothermally melted, stagnant ice block to analyze pressure distribution during melt-out and to determine the conditions under which dewatering structures can form. During every model run, the pore water pressure within the till never exceeded the total pressure in the till. This suggests that an additional source of water is necessary to form dewatering structures. The additional amount of water needed would require rapid melting of the ice block, which contradicts field observations of debris covered, stagnant ice existing for long periods of time (e.g. 10s to 1000s of years). Therefore, the majority of the water must come from an external source if dewatering structures are to form. Thus, calculation of critical discharge and modeling of stress distribution during melt-out argue that even low permeability, clayey till can dewater without forming sorted dewatering structures. This suggests that the use of dewatering structures as a criterion for recognition of melt-out till may be invalid, and that the lack of dewatering structures in till does not need to be explained by a lodgement or deforming bed genesis.

C63A MCC: 130 Saturday 1800h

Nye Lecture (joint with H, GC)

Presiding: S Marshall, University of Calgary

C63A-01 1800h

Consider an Ice Stream

Robert Bindschadler (bob@igloo.gsfc.nasa.gov)

NASA Goddard Space Flight Center, Code 971, Greenbelt, MD 20771, United States

Forty years ago, John Nye was one of the leaders who introduced the rigors of classical physics to glaciology. His elegant treatments frequently took advantage of the then recent discovery that ice could be approximated as a plastic material. With this viewpoint, Nye was able to explain the shape of ice sheets and glaciers, to predict the expected pattern of stress and velocity within a glacier, and to derive the advance and retreat of a glacier from the record of accumulation and ablation. These advances have given generations of glaciologists tools to interpret the excellent observational record of glacier behavior and variation. In the 1980s, glaciologist, weaned on these works of Nye and of other similarly adept colleagues, carried their lessons to West Antarctica to study ice streams, the vast conveyor belts of ice that discharged nearly as much Antarctic ice as the much larger East Antarctic ice sheet. Ice streams were a glaciological conundrum. Despite the gently sloping surface, these broad features roared along, moving fastest when the gravitational impetus was least. After two decades of research, ice streams still have not given up all their secrets, yet much is now known. Internal deformation is negligible. Basal friction is frequently nil leaving the shattered margins as the primary means to avoid rapid wastage of the ice sheet. Within the margins, the resistive force results from a delicate balance of heat and evolving ice fabrics. Nevertheless, the bed beneath an ice stream cannot be ignored. It is ultimately the state of the underlying marine sediment that determines whether the ice stream can slide at all. There too, the heat balance is critical with an influx of water required to keep the bed wet enough to let the streams glide along. Ice stream research has been the portal through which glaciologists have seen and identified the complexities of West Antarctic ice sheet dynamics. Remarkably, nearly all time scales seem important. Ice stream positions in past millennia conform to radically different flow patterns while on the scale of hours an ice stream's motion is halted completely, then released to move at surge-like speeds, in tempo with the tides. Explaining these complexities constantly reminds us that the rigorous physics applied to ice so effectively by Nye still work.

C72A MCC: 120 Sunday 1330h

The Role of Microstructure and Layering in the Physical Properties, Metamorphism, and Deformation of Snow Covers I (joint with A, H)

Presiding: M Schneebeli, Swiss

Federal Institute for Snow and Avalanche Research; J Johnson, U.S. Army Engineer Research and Development Center

C72A-01 1330h INVITED

Snow Layering and Spatial Heterogeneity

Matthew Sturm (907-353-5183; msturm@rrel.usace.army.mil)

U.S. Army Cold Regions Research and Engineering Laboratory-Alaska, P.O. Box 35170, Ft. Wainwright, AK 99703-0170, United States

Snow packs are made up of snow layers, each differing in physical and microstructural properties from those above and below. The sequence and characteristics of the layers affect the electromagnetic, thermal, physical and mechanical properties of the pack. Layer boundaries are also important in determining the strength of the pack and the transport of air, water and heat through it, though relatively little attention has been focused on the nature of the boundaries themselves. In general, layers are used (some times tacitly) as the basis for spatial extrapolation of properties, with the assumption that layers are laterally homogeneous. On ice sheets and large glaciers, this assumption may be valid, but in seasonal snow covers the layers vary laterally at multiple scales (10⁻¹ to