We drilled 53 boreholes in the ablation zone of Storglaciaren, a polythermal glacier in northern Sweden, to characterize the englacial hydraulic system. Eighty percent of the holes connected to an englacial system, as indicated by a drop in water level within the borehole during drilling and subsequent diurnal fluctuations in water level, suggesting input from surface melt. Our expectation was that these connections would be Rothlisberger-type conduits with elliptical cross-sections. To our surprise all englacial connections but one were made to cracks in the ice. The one exception was a Rothlisberger-type conduit intercepted by a borehole drilled 11 m away from a moulin. Video images from a camera lowered into the boreholes revealed that the cracks varied in width from about 1 cm to several cm. However, we believe the warm drill water escaping from the borehole into the cracks during the initial connection melt-enlarged the openings. The plunge of the cracks is quite steep, typically near vertical, but the lateral extent is unknown. Cracks were observed at depths between 20 and 158 m below the glacier surface, with a few relatively close to the glacier bed. The location of each crack was associated with a band of clear ice, suggesting some refreezing during its lifetime. The clear ice also made observations difficult at times. Orientation of the shallow cracks (less than 50 m depth) was parallel to the observed surface crevasses, while deep cracks were generally oriented perpendicular. Most cracks exhibited some natural water movement, speeds of 0.1- 1 cm/s (laminar). Water pressures were generally close to the total overburden pressure of the ice, but were less than the local overburden estimated relative to crack depth. These results suggest that alpine glaciers are highly fractured with cracks existing at all depths. Whether the cracks are formed in situ or are advected from surface areas higher on the glacier is unclear. The cracks are the main conveyor of englacial water suggesting that models of flow through a network of fractures may be more appropriate for glaciers than the classic Rothlisberger approach.

C12B-03 1420h

Englacial Crevasses: Observations and Theory.

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Recent observations on the Bench Glacier and other temperate glaciers in the coastal mountains of Southeast Alaska have shown the existence and importance of crevasses that crack over the full glacier depth. Direct video and hydrologic observations show these pervasive crevasses to be rapidly evolving and laterally and vertically extensive. Hydrologic monitoring demonstrates that the crevasses are connected to the surface, basal, and englacial hydraulic systems, and form part of the seasonal development of the englacial water system. We present data, including englacial video, of evolving crevasses at depths from 100 to 200m. The data demonstrate the existence and extent of crevassing well below the region of surface crevassing and into the region of fully compressive stresses (non-deviatoric). Preliminary theoretical work is presented discussing the role of water weight driven crevasse propagation. The theory addresses the propagation speeds of crevasses. It is concluded that crevasse propagation may be controlled by the available volume flux of water in the hydraulic system, not by classic crack propagation considerations. Some of the effects of modeling crevassing in 3 dimensions, as opposed to 2 dimensions, is discussed, where it is concluded that 3 dimensional crevassing should allow crevasses which greatly facilitate the creation of a connected and through draining glacial hydraulic system.

C12B-04 1435h

The role of hydrologically-driven ice fracture in drainage system evolution on an Arctic glacier

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Observations from Ellesmere Island suggest that a connection between surface and subglacial drainage on a predominantly cold glacier is made abruptly in spring by hydrologically-driven propagation of fractures from the ice surface to the glacier bed. Where ice is 150 m thick, water ponded to a depth of 6.9 m within a supraglacial stream system before a permanent connection to the bed was established. Multiple premonitory drainage events preceded the final drainage of the ponded water, implying that fracturing is necessary, but insufficient, to establish a permanent link between the surface and subglacial drainage systems. Refreezing of water that penetrates the first fractures to form may reseal the connection, while flow resistance within the subglacial system may delay the onset of continuous through-flow. A large volume of ponded water seems to be required to enlarge fractures sufficiently by melting to maintain continuous drainage, while feedbacks between subglacial hydrology and ice dynamics may assist in maintaining the connection and initiating subglacial outflow.

URL: http://arctic.eas.ualberta.ca/sarah/resume.html#publicns

C12B-05 1450h INVITED

Fracture Mechanics of Ice Shelves

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The importance of large-scale fracture processes has recently been emphasized by the break-up of ice shelves on the Antarctic Peninsula and underlines the need for incorporation of fracture mechanics into models of ice sheet dynamics. Key components for fracture mechanics models include qualitative models of the brittle processes in ice shelf fracture and experimental measurements of fundamental fracture parameters. We have adopted an integrated experimental and theoretical approach which is validated against field and satellite measurements. Our procedure has been first to quantify experimentally and physical behaviour of Antarctic ice core, then to use these measurements in fracture criteria describing the spatial distribution of crevasses, the depth and height of top and bottom crevasse penetration and the effect of tidal flexure. Up to now these have been crack initiation criteria. Here we discuss two extensions to our work: 1) to describe the statistical nature of ice fracture; 2) to describe crack propagation in ice. We find there that the statistical nature of ice shelf fracture can arise from the inhomogeneous size distribution of initiation cracks. We infer that crack propagation in ice can have strong environmental controls. We describe how these aspects of ice fracture can be incorporated into ice shelf models.

C12B-06 1510h

A Description Of Crevasse Formation Using Continuum Damage Mechanics

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Continuum damage mechanics describes the progressive deterioration of material subjected to loading. For polycrystalline ice, a local isotropic damage evolution law coupled to Glen's flow law allows the description of creep to failure. The damage evolution law has been derived from mesoscopic tests performed in traction and shearing. Damage initiation is controlled by a size dependent stress threshold, which has been inferred from published data of laboratory experiments. Crack healing is considered by a simple dynamic law. The rheology of the damaged ice is implemented in a FE model to describe the formation of crevasses at a macroscopic scale. A level set method is applied to model the evolution of the glacier geometry. The main purpose of this investigation is the modelling of the destabilization of large ice masses from hanging glaciers. The rupture of large ice chunks has been computed for different hanging glaciers in Switzerland. Numerical results compared with field observations and measurements showed good agreement. The ability of the model to describe phenomena connected to crevasse opening seems to be promising for other glaciological applications such as rift opening or ice stream margin formation.

C12B-07 1525h

An Investigation Into the Causes and Limiting Factors of an Active Rift on the Amery Ice Shelf: Fieldwork and Modeling Results

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The Amery Ice Shelf rift system, colloquially known as the "Loose Tooth", consists of two longitudinal (parallel-to-flow) rifts that formed about 15 years ago, and two transverse rifts that together with the western longitudinal rift, form a triple junction. A variety of satellite imagery spanning more than one decade has shown that the transverse rifts have both been actively propagating over the past decade, and have been, on average, speeding up (Young et al, this session). This past Antarctic field season (2002-2003), we instrumented the main transverse rift with 6 GPS and 8 vertical component seismometers. Results indicate that there are several periods of high seismic activity during which the rift widens rapidly. Comparison of experimental values of the critical stress intensity factor (a measure of the strength of the ice) with the stress acting at the tip of the rift calculated for an elastic ice shelf, suggest that the rift should propagate unstably. In an attempt to resolve this paradox we consider two possible explanations. First we examine the effect of a viscoelastic rheology of ice on dissipation of the stress at the tip of the rift; the associated time scale competes with the time scales attached to the loading mechanisms which control the rate of stress accumulation. In contrast the effect of an array of longitudinal crevasses on the stress field concentrated ahead of the rift is largely geometrical. Rift propagation is hindered because the crevasses create areas that are effectively weaker than the surrounding ice. We use a boundary element model to evaluate the effect of an array of crevasses on the stress concentrated at the tip of the rift.

C12C MCC: 3004 Monday 1600h

Planetary Permafrost I *(joint with B, P)*

Presiding: **C McKay,** NASA Ames Research Center**; R T Pappalardo,** University of Colorado, Boulder

C12C-01 1600h

Formation of Obliquity-Driven Subsurface Ice Deposits on Mars: Study With a General Circulation Model

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The discovery by Mars Odyssey of large deposits of subsurface ice in regions where surface ice is no longer stable has raised questions about putative past climatic conditions under different orbital states. We have used the GFDL Mars General Circulation Model (MGCM) as a tool for examining these questions, and suggest that these deposits may be quasi-stable permafrost remnants from an earlier period of high obliquity, covered by a sublimation lag deposit formed when the mean annual temperature exceeded the local frost point temperature. We have incorporated a thermal and vapor diffusion code into our GCM to simulate the

behavior of water in the regolith and the processes that move water from the atmosphere to the surface and back. Water in the regolith may exist as vapor, ice or adsorbate, in relative abundances dependent upon the soil temperature and ambient pressure. The model results show the effectiveness of ice as a means to reduce the local thermal inertia, thereby reducing annual maximum temperatures and increasing the probability that surface ice deposits of a given thickness will survive throughout the warmer summer, and hence build, essentially, a permafrost layer over obliquity timescales. The development of an ice sheet beneath a sublimation lag appears similar to glacial remnants found in the Antarctic Dry Valleys beneath tens of centimeters of sublimation till. On Earth, these deposits have existed, largely unchanged, for millions of years. On Mars, we suggest that these mid-latitude deposits are several hundred thousand years old, at mostthe remnant deposits of the past few martian obliquity cycles. The development of a sublimation lag of a few tens of centimeters seems to be enough to retain ice in these regions until the next high obliquity period.

C12C-02 1615h INVITED

The Distribution of Near-Surface Ground Ice from Neutron and Gamma-Ray Spectroscopy on Mars, the Moon, and Mercury

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Neutron and gamma-ray spectroscopy have been applied to the Moon and Mars in order to map the abundance of hydrogen within their uppermost meter of soil These investigations will be extended to Mercury using the neutron and gamma-ray spectrometers that are part of the payload of the Messenger mission. Significant enhancements in hydrogen were observed within the permanently shaded crater bottoms near both poles of the Moon using this technique and shown, through arguments of stability, to most likely be in the form of water ice [Feldman et al., J.G.R., 106, 23,231, 2001]. Simulations of the signature of hydrogen in neutrons for the measured topography at the lunar poles, yields an estimated H2O abundance of 1.5 percent by mass within the permanently-shaded areas. Radar backscatter observations from Mercury [Harmon et al., Nature, 369, 213, 1994] have discovered anomalous enhancements within permanently shaded craters near both poles of Mercury of same-sense polarization that are most readily interpreted as near-surface water ice. We will have to wait until about 2010 to verify this interpretation using neutron spectroscopy. After 1.5 years in orbit about Mars, three reservoirs of water-equivalent hydrogen have been delineated. Two of them at high northern and southern latitudes run upward of 20 percent H2O by mass, and the third at equatorial to mid latitudes extends between 2 percent and 13 percent by mass.

C12C-03 1630h INVITED

Theory of Ground Ice on Mars and Implications to the Neutron Leakage Flux

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Near-surface ground ice (subsurface ice in the upper several meters of the surface) is an important component of the global cycles of water and the behavior of the martian climate. It represents a substantial reservoir of water that can dynamically exchange with the atmosphere on timescales comparable to that of oscillations in the planet's orbit. As the martian obliquity increases or decreases, the global atmospheric humidity also increases or deceases. In response to this and changes in the regolith temperatures, ground ice can undergo cycles of sublimation and condensation, such that the upper meter or two of the martian regolith can become alternately ice-saturated and desiccated. The rate of sublimation and condensation is fast enough to respond to orbital changes, but slow enough that the distribution of ice in one year may not reflect the climate conditions of that year, but instead reflect an average over the previous thousand or so years. Therefore, the present day distribution of ground ice reflects some measure of the longer-term martian climate. In this work we present new calculations of the geographic and depth distribution of ground ice on Mars and draw comparisons with the inferred distribution of ice from Mars Odyssey Neutron Spectrometer observations of the neutron leakage flux. We find that ground ice is stable at relatively shallow depths on Mars, at an ice table such that ice-cemented soil occurs beneath a dry-soil layer, similar to the configuration of ground ice found in the Antarctic Dry Valleys. Predicted ice-table depths vary, but values average around a few centimeters. We also find that the measured geographic distribution of leakage neutrons in the martian southern hemisphere is extremely consistent with a presence of ground ice at a depth in diffusive equilibrium with atmospheric water vapor. The amount of water vapor that best corresponds to the measured neutron flux is near 20 precipitable micrometers, somewhat more water vapor than is presently observed on an annual average basis. This water vapor content corresponds to a longer-term average of a thousand or so year

C12C-04 1645h

Microbial Metabolism in Permafrost and Ice

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Metabolic rates of microbial communities at low temperature have not been systematically studied, despite discoveries of microbes that survive with very little nutrient in ice, permafrost, and deep open-ocean sites, and despite interest in possible life on Mars and Europa. We investigated the temperature-dependence of growth rates kg, maintenance rates km, and survival rates ks, using existing data on kg(T) for permafrost bacteria, on km(T) using radiotracers, and on ks(T) using geochemical methods. Data were collected for temperatures from 28°C to -40°C. The rates for the three modes are consistent with a single activation energy U $\approx$ 100-110 kJ/mol, and they scale as kg(T):km(T):ks(T) $\approx$ 107:104:1. The rate ks(T) for survival of a dormant microbial community is found to be roughly that required solely for repairing molecular damage due to amino acid racemization + DNA depurination. We conclude that for living microbes the rate of molecular repair equals the rate of molecular damage. There is no indication of a threshold temperature for metabolism, at least down to -40°C. To assay microbial life in the coldest terrestrial environments (down to -55°C) and in future to search for present or past life on Mars, we have designed a miniaturized biospectral logger that will fit into a 4-cm borehole in ice, permafrost and rock. The logger will use side-directed laser beams at wavelengths 224 and 370 nm to detect autofluorescence of biomolecules and discriminate against mineral autofluorescence. Six channels will map fluorescence spectra and a seventh channel will measure light scattered from dust (in ice) or rock (in permafrost). Fluorescent biomolecules of interest include tryptophan, tyrosine, NADH, FAD, F420, chlorophyll, bacteriorhodopsin, porphyrins, pyoverdin, PAHs, humic acid, and fulvic acid. The logger will be able to detect microbial concentrations as low as 1 cell cm-3 in clean ice.

C12C-05 1700h INVITED

Permafrost Landscapes on Earth: Lessons for Mars and Europa

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The cold and hyper-arid Dry Valleys of Antarctica have long been recognized as having environmental conditions on Earth closest to those on Mars. They contain valuable clues about the presence and character of ice in the permafrost, and about surficial processes on Mars. Extensive regions in the Dry Valleys are commonly mantled by poorly sorted glacial or rock fall material ranging in size at the surface from boulders to small pebbles. The abundance of coarse material at the surface reflects vertical sorting due to re-current thermally induced volumetric changes and to vertical cracks forming (and closing) in the upper few meters of the permafrost, as well as removal of fines from the surface by eolian transport. In Beacon Valley, an area underlain by massive ice, the low relief (1 to 10 m) ground surface with scattered 50-100m-wide depressions is veneered with $\sim$0.5m of sublimation till. The existence of this till, which formed over 1-10 million years as debris initially contained in the ice accumulates at the surface, demonstrates the long-term persistence of ice under surface conditions seemingly unsuitable for ice to exist. Polygonal patterned ground, with a typical polygon size of $\sim$20 m, is characteristic of extensive sediment-covered areas and some exposures of bedrock in the Dry Valleys. The thin snow cover, which is due to the hyper-arid conditions and high winds, is conducive to extreme ground cooling and frequent permafrost cracking in the winter. The cracks tend to be vertical, and as they grow and interact, they form polygons. Due to the paucity of surface water, the cracks do not tend to fill with water during the warm season; instead, they fill with sand. Although water is scarce, polygonal patterned ground reflects sufficient ice in the upper potion of permafrost ($\sim$2-3 percent by volume) to permit thermal stresses to develop on scales vastly larger than the grain scale. Recurrent cracking along pre-existing cracks and addition of sand from the surface progressively forms sand-wedges that reach 5 m in width. Wedge growth involves surface divergence in the center and compression at the sides, which results in distinct troughs bordered symmetrically by ridges that delineate the polygons. The ratio of the polygon radius to the divergence rate (0.1-1 mm a^{-1}) yields a characteristic time scale of 10^4-10^5 years for wedge growth to pervasively disrupt or renew the surface, but this depends on the frequency of permafrost cracking and the amount of material available for infilling open cracks. The striking micro-relief associated with growing sand-wedges, the symmetrical ridges along a linear trough that are most clearly developed in frozen sediments, closely resemble troughs with paired ridges on Europa, which implies recurrent cracking and near-surface introduction of material into the cracks with potential implications about ice thickness. Inclined areas with significant subsurface ice can show diverse indications of gravitationally-induced flow, including rock glaciers with prominent surface ridges and lobes. They reflect differential down-valley motion that can be detected through remote sensing on both the Earth and Mars. Transverse ridges are also common on rock glaciers, and ongoing theoretical analyses suggest that they merit special attention because they may contain rich information about subsurface ice. This includes the thickness and spatial extent of massive ice layers, and the rheology of these layers and the surrounding permafrost.

C

C12C-06 1715h

Origin of Sublimation Polygons in the Antarctic Western Dry Valleys: Implications for Patterned Ground Development on Mars

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Two hypotheses have been developed in order to address the age, origin, and evolution of surface polygons in the western Dry Valleys region of southern Victoria Land. Resolution of this debate has direct relevance and implications for patterned ground in ice-rich terrain on Mars. One hypothesis, the dynamic hypothesis, states that growth of sand-wedges pervasively deforms sediment across polygonal terrain, recycling sediment from troughs to polygon centers and back again over time scales of thousands of years. A second hypothesis, the stability hypothesis, states that deformation associated with sand-wedge polygons, particularly those that form over buried ice, is restricted to polygon troughs; the implication is that polygon centers may contain undisturbed soils >1 million years old. Evidence comes from field data that show that the age, origin, and morphology of polygons that form over buried ice in the western Dry Valleys region is tied collectively to the location and rate of sublimation of underlying ice. In Beacon Valley, sublimation of debris-rich ice produces a dry surface lag that insulates and slows loss of remaining ice. Sub-zero temperature cycling of near-surface ice and soil creates tensile stresses that result in a network of hexagonal cracks, extending upward from buried ice toward the ground surface. Where fines sift downward into open thermal-contraction cracks, a coarse-grained lag deposit forms on top of the ice. Owing to spatial variations in till texture, rates of sublimation vary across the ice surface. High rates occur below coarse-grained lags that cap contraction cracks; low rates are found at polygon centers beneath fine-grained low porosity/permeability debris. Measured concentrations of in-situ produced cosmogenic 3He in two depth profiles through sublimation till show a steady decrease with depth, indicating negligible recycling of surface materials on million-year time scales. These data suggest that once polygon troughs deepen sufficiently, they trap windblown snow and initiate a negative feedback that slows further sublimation of the underlying ice. This negative feedback involves the development of secondary-ice lenses at the base of polygon troughs. In-situ ashfall deposits in Beacon Valley provide evidence that polygons are stable landforms that persist for >1 million years and that underlying ice there is >8.1 million years old. The high-centered sublimation polygons of Beacon Valley may be analogous to the latitude-dependent polygons and basketball-textured terrain on Mars.

C12C-07 1730h INVITED

Geomorphic Indicators of Ground Ice on Mars and Evidence for Climate Change

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Until recently, indications of the presence of ice in the near surface of Mars, outside the polar caps, has depended upon the interpretation of morphology from imaging data. Early work in this area was based primarily on Viking orbiter images where several large landforms (100s to 1000s of meters in scale) were interpreted to be related to the presence of ice in the regolith or upper crust. These include lineated valley fill, concentric crater fill, softened terrain, and polygons, and are typically found between the latitudes of 30°-60° N and S. Without direct measurements of the presence of water, the interpretations rely on analogies with Earth's periglacial and glacial morphologies as well as geophysical modeling of ice-rich soils and crustal material. New spacecraft data from the Mars Global Surveyor and Mars Odyssey missions have significantly added to the family of morphologies with ground-ice affinities. From the high spatial resolution images acquired by Mars Orbiter Camera (MOC) a new array of polygons have been detected which range in size from 25-200 m and show strong latitudinal gradients above 50°. A possibly related morphology exhibiting a regularly spaced surface texture resembling the texture of a basketball is also found in these high latitudes. A number of morphologies indicating viscous flow on steep slopes are found in the mid-latitudes and are consistent with an ice-rich soils deforming under martian surface conditions. A continuous deposit, meters-thick and interpreted to be ice rich is observed at latitudes above 60°, but that is in a degraded condition at lower latitudes (formerly ice-rich) and absent in the equatorial regions (within 30°). The neutron spectrometer on the Odyssey spacecraft made direct measurements of hydrogen which shows clearly the presence of high water-ice abundance (>70% by volume) in the surface soils in the northern and southern latitudes above 60°. This critical observation ties in well with theoretical modeling of ice stability under current martian surface conditions. The array of morphologies interpreted to be ice-rich are thus strongly supported by direct measurements of water ice for those observed at latitudes >60° and for those at lower latitudes for conditions in the past when ice was stable to lower latitudes. This array of landforms provides an excellent research environment to investigate periglacial features formed in a very cold environment with long term climate change.

C12C-08 1745h INVITED

Icy Satellites: Perpetual Permafrost

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The ice-rich moons of the outer solar system are worlds of perpetual permafrost. By analogy to the terrestrial roles of silicates and water ice, surface materials of these worlds commonly consist of components that are respectively refractory and volatile at local environmental conditions. We consider the physical properties, volatile components, and geomorphological characteristics of outer planet satellite surfaces and shallow regoliths as analogs to permafrost environments. Near-surface temperatures of 40 to 165 K preclude melting of water-ice, except where endogenic activity has increased surface temperatures locally. However, water and/or more volatile ices can be transported in the vapor phase, and can liquefy in the deeper subsurface. In the water-ice-poor regolith of Io, SO2 and possibly H2S are volatile ices that can be transported in the vapor phase and can liquefy at depth, resulting in degradation and local collapse of the ground surface. Sublimation degradation is especially evident in images of Callisto, where slow diffusive loss of CO2 is the likely erosive agent. On Neptune's large moon Triton, nitrogen plays the role of a permafrost volatile, near its melting temperature in a regolith of more refractory ices. Most large icy satellites probably have water-rich subsurface oceans, and it has been proposed that Europa's subsurface ocean might sustain life. Frigid surface temperatures and severe charged particle radiation preclude near-surface metabolism, but organisms could potentially survive within deeper regions and local upwelling plumes that approach the ice melting temperature.

C21A MCC: 3010 Tuesday 0800h

Advances in Glacier Geophysics I

(joint with G, H, OS, PP)

Presiding: **B Kulessa,** Queen's University of Belfast**; T Murray,** University of Leeds

C21A-01 0800h INVITED

Ice stream D, West Antarctica, subglacial conditions from a combined seismic reflection, refraction, gravity and radar survey

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A high resolution reflection seismic profile on ice stream D, West Antarctica, has revealed the presence of dilatant till beneath the far upstream sections of the ice stream. The characteristics of the reflection from the base of the ice stream (such as phase, magnitude, angle-dependence of amplitude, etc.) are clear indicators of the acoustic impedance of the material beneath the ice. We detect an extremely low acoustic impedance (product of density and seismic velocity) over much of the region, which we interpret as dilatant, actively deforming till. This discovery is particularly surprising given the location of the experiment: in the "tributary" region of the ice stream, 10s of kilometers upstream of the location where the "onset of ice streaming" has been hypothesized to occur. Our experiment was conducted in the region of moderate flow speeds ($< 100\ \mathrm{m \cdot a^{-1}}$), and suggests that the onset region of the ice stream could be substantially farther upstream than previously thought. We combine the reflection seismic work with phase-coherent radar data to differentiate between basal roughness and subglacial acoustic impedance. In addition, we use refraction and gravity data to constrain deeper structure. A joint reflection/refraction seismic and gravity experiment successfully imaged sedimentary basins beneath the ice stream that are clearly associated with locating the boundaries of the ice stream. Finally, we report on the expanded capabilities that are possible with a new shothole drill, ranging from high resolution internal layer imaging to Moho reflections.

C21A-02 0815h

Subglacial Sediments as a Control on the Location of Ice Streams C and D, West Antarctica, from Seismic Refraction and Reflection Imaging

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Ice streams discharge a majority of the inland ice from the Ross Embayment of West Antarctica. This increased ice flow is believed to be aided by a dilatant subglacial till, but the mechanisms controlling the initiation of streaming flow within the ice sheet are uncertain. The focus of our study is to image the presence of subglacial sediments and interpret their importance in ice stream velocity and location. We present the results of two refraction seismic experiments in the onset regions of ice streams C and D during the 2002 - 2003 Antarctic field season that were performed to image subglacial geology and develop a better understanding of its role in initiating ice streaming. The refraction experiments consisted of a 31.2km longitudinal profile of ice stream C (C1B) and a 34.5km transverse profile of ice stream D (DT1), giving the opportunity to image the shallow (upper 1-2km) subglacial geology in the onset regions of these two Ross ice streams. Coupled with reflection seismic data, gravity (for DT1), and GPS data, the inverse modeling of the refraction data imaged the presence of sedimentary basins in both locations. The C1B results reveal a thin (<50m) cover of sediments in the upstream (non-streaming ice) portion of the longitudinal profile that quickly thickens into a ∼600m sedimentary basin in the downstream (streaming ice) reaches. The DT1 results reveal a large sedimentary basin extending across the width of the ice stream, with a maximum thickness of ∼600m near the center of the ice stream. We determined these sediment thicknesses by creating a 2D model consisting of a sedimentary layer, whose velocity ranges from 2400m/sec to 2500m/sec, between the ice and the underlying bedrock. The thick sedimentary basins along both C1B and DT1 also correspond with increased ice velocities along the two profiles. Our results reveal that the presence of sediments is a necessary requirement for initiating ice streaming in the onset regions of the Ross ice streams. Thick sedimentary basins at the onset provide a source for the dilatant subglacial till that acts as a lubricant in aiding ice flow along the length of the ice streams. It appears that tributary C1B of ice stream C has reached the inland extent of subglacial sediments, which may mark the paleo-shoreline of the West Antarctica during complete deglaciation (presumed to have occurred within the last 600,000 years). This sediment boundary may also outline the maximum inland extent of the Ross ice streams.

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Subglacial Conditions From the Seismic Reflection Technique

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For many decades the use of seismic methods in glaciology was overshadowed by radar. Radar acquisition is quicker, easier and can be done from an aircraft. However, recent years have seen a resurgence in seismic techniques, enabled largely by improved instrumentation. Seismic data have been particularly effective at determining basal conditions and here I discuss some of our seismic reflection results. Seismic acquisition parameters can be tailored to many different targets of interest. Here I concentrate on near-vertical incidence seismic reflection data, where source-receiver offsets are small relative to the ice thickness. Energy loss can then be attributed to geometrical spreading, attenuation and transmission/reflection coefficients without any influence from amplitude- (or phase-) vs-offset effects. This makes the analysis of field records particularly straight-forward. Quantitative interpretation of the data to determine basal conditions relies on the ability to calibrate the reflection coefficient at the ice-bed interface. Hence, the seismic data need to include multiple reflections from the bed, either all the way along a profile or at a number of specific locations. The reflection coefficient is controlled by the acoustic impedance contrast at the interface, ie the change in the product of seismic velocity and density in the two materials. In most situations, the impedance of the ice is known accurately enough for that of the sub-glacial material to then be calculated and the nature of the material determined, eg. deforming sediments, non-deforming sediments, permafrost or bedrock. I present results from Antarctic ice streams. Variations in the basal conditions can be identified, which in some cases can show major transitions over short distances. Data from a number of different sites can be used to quantify the way that basal conditions control the ice flow.

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New Airborne Radar Sounding Approaches for Quantifying Basal Reflection and Scattering, With Application to Ice Stream C (and Whillans Ice Stream), West Antarctica

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