



Chapman Conference on the Exploration and Study of Antarctic Subglacial Aquatic Environments (SAE)

**Baltimore, Maryland USA
15–17 March 2010**

Conveners

- Martin J. Siegert, University of Edinburgh (UK)
Mahlon C. Kennicutt II, Texas A&M University, (USA)

Program Committee

- Robin Bell, LDEO, Columbia University (USA)
Jemma Wadham, University of Bristol (UK)
Kay Bidle, Rutgers, The State University New Jersey (USA)
Sergey Bulat, Petersburg Nuclear Physics Institute (Russia)

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Environments (SAE)**

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Meeting At A Glance

Monday, 15 March

08.30-09.00	Coffee
09.00-09.30	Introductions – Session 1
09.30-10.30	Keynote Speaker
10.30-11.00	Session 1 (cont.)
11.00-11.30	Morning Break
11.30-12.30	Session 1 (cont.)
12.30-13.30	Lunch on your own
13.30-14.30	Poster Session
14.30-15.00	Session 2
15.00-15.30	Keynote Speaker
15.30-16.00	Afternoon Break
16.00-19.00	Session 2 (cont.)
19.00-21.00	Dinner on your own

Tuesday, 16 March

08.30-09.00	Coffee
09.00-10.30	Keynote Speaker – Session 3
10.00-11.00	Session 3 (cont.)
11.00-11.30	Morning Break
11.30-12.30	Keynote Speaker
12.30-13.30	Lunch on your own
13.30-14.30	Poster Session
14.30-15.30	Session 4
15.30-16.00	Afternoon Break
16.00-19.00	Session 4 (cont.)
19.00-21.00	Chapman Conference Dinner (reservation/prepaid)

Wednesday, 17 March

08.30-09.00	Coffee
09.00-11.00	Session 5
11.00-11.30	Morning Break
11.30-12.30	Session 5 (cont.)
12.30-13.30	Lunch on your own
13.30-14.30	Poster Session
14.30-15.30	Session 5 (cont.)
15.30-16.00	Afternoon Break
16.00-16.30	Panel Discussion 1
16.30-17.00	Panel Discussion 2
17.00-17.30	Panel Discussion 3
17.30-18.00	General Discussion and Concluding Remarks
19.00-21.00	Dinner on your own



Scientific Program

Time	Monday March 15	Tuesday March 16	Wednesday March 17
08.30. – 09.00	Coffee	Coffee	Coffee
	Introductions Session 1. SAE as Habitats for Life	Session. 3 Sedimentary Records	Session 5. SAE Project Updates
09.00-09.30	Introductions by Co- Chairs: Martin Siegert (UK) and Chuck Kennicutt (US)	3.1 Keynote, Michael Bentley (UK) (774090) Subglacial Lake Sedimentary Processes and Sediments: Potential Recorders of Past Climate and Ice Sheet Changes	5.1 Valery Lukin (RUS) (790556) Russian Plans/Activities for Drilling into and Sampling Subglacial Lake Vostok
09.30- 10.00	1.1 Keynote, Mark Skidmore (US) (788714) Microbial Communities in Antarctic Subglacial Aquatic Environments (SAE)	3.1 Keynote (cont.)	5.2 Neil Ross (UK) (787435) Subglacial Lake Ellsworth: its History, Recent Field Campaigns and Plans for its Exploration.
10.00-10.30	1.1 Keynote (cont.)	3.2 Eugene Domack (US) (787536) Subglacial Lake Environment and Facies Revealed by Larsen B Ice Shelf Disintegration	5.3 WISSARD Slawek Tulaczyk (UC Santa Cruz) (786551) The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) Project: an Integrated Study of Marine Ice Sheet Stability and Subglacial Life Habitats in West Antarctica

Time	Monday March 15	Tuesday March 16	Wednesday March 17
10.30-11.00	1.2 Jill Mikucki (US) SAE (787606) Blood Falls, Antarctica: Insights into Subglacial Microbial Energetics	3.3 Slawek Tulaczyk (US) (799325) Formation and Preservation of Long-Term Paleoclimatic and Paleoenvironmental Records in Subglacial Lake	5.4 Robin Bell (US) (799998) Melt and Freeze Couplet in Central East Antarctica
11.00-11.30	Morning Break	Morning Break	Morning Break
	Introductions Session 1. SAE as Habitats for Life (cont.)	Session 4. SAE Technology Challenges	Session 5. SAE Project Updates (cont.)
11.30-12.00	1.3 David Pearce (UK) (802774) The Search for Life in Former Subglacial Lake Hodgson, Antarctica	4.1 Keynote, Peter Doran (US) (781456) Environmental Protection and Stewardship of Subglacial Aquatic Environments.	5.5 Reed Scherer (US) (787613) What Can Tiny Fossils Teach Us About WAIS History & Subglacial Processes?
12.00-12.30	1.4 Jemma Wadham (UK) (784567) Examining the Potential for Methanogenesis in Antarctic Subglacial Aquatic Environments	4.1 Keynote (cont.)	5.6 Sun Bo (CHINA) (783170) Glaciological and Geophysical Studies in Dome A, East Antarctica
12.30-12.30	Lunch on your own	Lunch on your own	Lunch on your own
13.30-14.30	Poster Session	Poster Session	Poster Session
	Session 2. SAE Hydrology and Ice Sheets Interactions	Session 4. SAE Technology Challenges (cont.)	Session 5. SAE Project Updates (cont.)
14.30-15.00	2.1 Keynote, David Marchant (US) Subglacial Floods (785500) The Geomorphic Signature of Subglacial Floods	4.2 Matthew Mowlem (UK) (788555) Probe Technologies for The Direct Measurement and Sampling of Subglacial Lake Ellsworth	5.7 Robert Bindschadler (US) (794141) Surprises Seen in the Sub-Ice Shelf Environment

Time	Monday March 15	Tuesday March 16	Wednesday March 17
15.00-15.30	2.1 Keynote (cont.)	4.3 David Blake (UK) (787425) The Development of a Hot-Water Drill to Access Sub-Glacial Lake Ellsworth	5.8 Christoph Mayer (GER) (787528) Subglacial Lake Regimes for Different Lake Categories
15.30 – 16.00	Afternoon Break	Afternoon Break	Afternoon Break
	Session 2. SAE Hydrology and Ice Sheet Interactions (cont.)	Session 4. SAE Technology Challenges (cont.)	Session 6. General Discussion and Future Directions
16.00-16.30	2.2 Adrienne Block (US) (787671) The Role of Subglacial Lakes in the Onset and Maintenance of Recovery Ice Stream, East Antarctica	4.4 Michael Gerasimoff (US) (799480) UW-Wisconsin (ICDS) WISSARD Drilling Program: Environmental Stewardship, Engineering, and Scientific Objectives	6.1 Panel Discussion #1 – SAE Habitats, Hydrology and Ice sheet Interactions - Speakers from Day 1
16.30-17.00	2.3 Leigh Stearns (US) (787566) Subglacial Drainage Events Under Outlet Glacier End-members: Byrd Glacier and Whillans Ice Stream	4.5 Bill Stone (US) (787392) ENDURANCE: Two Missions to Antarctica and Paths to Advanced Sub-Glacial Science Autonomy	6.2 Panel Discussion #2 - Sedimentary Records and Technological Challenges – Speakers from Day 2
17.00-17.30	2.4 Timothy Creyts (US) (800002) Drainage of Subglacial Water Systems Beneath Ice Sheets	4.6 Alberto Behar (US) (801014) The Subglacial Lake Exploration Device (SLED) Camera	6.3 Panel Discussion #3 - Future Plans for SAE Exploration and Research - Speakers from Day 3
17:30-18.00	2.5 Jacob Walter (US) (787310) How Well Do Subglacial Lakes Act as Hydraulic Jacks?	4.7 Ross Powell (US) (781228) Assessing Grounding Zones and Sub-Ice-Shelf Cavity Processes Using Direct Sampling and Robotic Instrumentation	6.4 General Discussion Concluding Remarks – Co-Conveners
19.00 -21.00	Dinner On your own	Chapman Conference Dinner (reservation/prepaid)	Dinner On your own

POSTER SESSION SCHEDULE

Poster Session will be held in the Harborview Ballroom, Monday, Tuesday, and Wednesday from 13.30 to 14.30.

Achberger, A.	Expression of a Bacterial Ice Binding Protein from 3,519 m in the Vostok Ice Core
Barbante	Trace Elements and Metalloids in Accreted Ice From Sub-glacial Lake Vostok, Antarctica
Beem, L.	High Resolution GPS Measurements Of Ice Surface Velocity Changes On And Around Active Subglacial Lakes, Whillans And Mercer Ice Streams, West Antarctica
Bidle, K.	The Use Of Analytical Flow Cytometry And High-Speed Cell Sorting To Assess The Abundance And Viability Of Ancient Ice Microbes
Bulat, S.	Biochemical Study of Lake Vostok Accretion Ice
Carter, S.	Taking The Pulse: Laser Altimetry And Radar Sounding As A Means To Verify Ice Sheet Water Models At Subglacial Lakes
Christner, B.	Biologically and Chemically Clean Subglacial Access Drilling
Cockell, C.	Subglacial Life and the Search for Life Beyond Earth
Doyle, S.	Evidence for Microbial Metabolism at -15°C in an Antarctic Subglacial Environment
Fricker, H.	Synthesising Multiple Remote Sensing Techniques for Analysing Subglacial Hydrologic Systems: Application on MacAyeal Ice Stream, West Antarctica
Hodgson, D.	Exploring Former Subglacial Hodgson Lake, Antarctica: Geomorphology, Limnology and Palaeolimnology
Jean Baptiste, P.	New Helium Isotope Measurements In The Accreted Ice of The Subglacial Lake
Jiang, J.	Scanning Detection Of Multiscale Significant Trend-Changes In Ice-core Records
Langley, K	Low-frequency Radar Profiles of the Recovery Lakes
Leitchenkov, L.	Potential Proxies Held in Sediment Inclusions From Ice Cores Of The Vostok Station Borehole

- MacGregor, A. Modeling The Spatial Variation Of Englacial Radar Attenuation: Application To The Vostok Flowline and Implications For The Detection of Subglacial Lakes
- Matsuoka, K. Detecting Wet Ice-sheet Beds Across Antarctica Using Radar: A Feasibility Assessment Using Three-dimensional Temperature And Radar Attenuation Models
- Pattyn, F. Antarctic Subglacial Lake Discharges
- Peters, L. Seismic Imaging Of The Subglacial Plumbing System
- Scambos, T. A Sudden Outburst Flood Event Beneath Crane Glacier: Evidence, Causes, and Ice Dynamic Effects
- Schroeder, D. Comparative Subglacial Hydrology of Thwaites Glacier, West Antarctica, Using Basal Specularity
- Siegert, M. Subglacial Lake Vostok: A Review of Geophysical Data regarding Its Physiographical Setting
- Takano, Y. Enantiomer-specific Isotope Analysis For Chiral Amino Acids in Antarctic Sub-glacial Environment: Proposal
- Takano, Y. Crustal Uplifting Rate Associated With Late-Holocene Glacial-isostatic Rebound at Skallen and Skarvsnes, Lützow-Holm Bay, East Antarctica: Evidence of a Synchrony in Sedimentary and Biological Facies on Geological Setting
- Tranter, M. Chemistry of Vostok Accretion Ice And Pore Waters Beneath The Kamb and Bindschadlers Is Consistent With Microbial Life Beneath The Antarctic Ice Sheet
- Vick, T. Microbial Responses During The Transition To Polar Night in Permanently Ice-covered Antarctic Lakes Trista J. Vick and John C. Priscu Montana State University, Department of Land Resources and Environmental Science, 334 Leon Johnson Hall, Bozeman, Montana, 59717
- Vogel, S. On The Role of Subglacial Bio/Geochemical Processes In Global Biogeochemical Cycles - Results From Kamb Ice Stream And ANDRILL
- Wright, A. The Identification And Physiographical Setting of Antarctic Subglacial Lakes: An Update Based On Recent Discoveries

ABSTRACTS

Expression of a Bacterial Ice Binding Protein from 3,519 m in the Vostok Ice Core

Achberger, Amanda Achberger Amanda M; Brox Timothy; Raymond James A; Doyle Shawn M; Christner Brent Craig; Skidmore Mark L A.M. Achberger, S.M. Doyle, B.C. Christner, Biological Sciences, Louisiana State University, Baton Rouge, LA; T. Brox, M.L. Skidmore, Department of Earth Sciences, Montana State University, Bozmen, MT; J.A. Raymond, , University of Nevada, Las Vegas, NV

A bacterium recovered from the Vostok ice core at a depth of 3,519 m was found to possess an ice binding protein (IBP) homologous to those found in some cold-adapted marine bacteria and diatoms. The IBPs which have been described have been shown to alter the freezing and recrystallization processes in ice. Comparison of the ice crystalline structure in samples frozen with and without the IBP from the Vostok bacterial isolate demonstrates its ability to alter the ice structure, which could provide cells in the cryosphere with distinct survival advantages. Experiments on the temperature-dependent regulation of the IBP gene indicated that it was expressed at 4 degrees C, but not at temperatures above 10 degrees C. Our results provide evidence for a molecular adaptation to icy conditions and for a low temperature stress response that appears distinct from the classical bacterial cold-shock response.

Trace Elements and Metalloids in Accreted Ice From Sub-glacial Lake Vostok, Antarctica

Barbante, Carlo Barbante Carlo; Planchon Fridiric; Hong Sungmin; Gabrielli Paolo; Gabrieli Jacopo; Turetta Clara; Boutron Claude; Petit Jean-Robert; Bulat Sergey; Hong Sungmin; Cescon PAolo; Cairns Warren; Cozzi Giulio C. Barbante, J. Gabrieli, P. Cescon, Environmental Sciences, University of Venice, Venice, ITALY; P. Gabrielli, Byrd Polar Research Center, The Ohio State University, Columbus, OH; F. Planchon, Section of Geochemistry - Geology Department, Royal Museum for Central Africa, Bruxelles, BELGIUM; C. Boutron, J. Petit, LGGE, CNRS, Grenoble, FRANCE; S. Bulat, Division of

Molecular and radiation Biophysics, Petersburg Nuclear Physics Institute, RAS, St Petersburg, RUSSIAN FEDERATION; S. Hong, S. Hong, Polar Sciences, KOPRI, Incheon, KOREA, REPUBLIC OF; C. Barbante, F. Planchon, P. Gabrielli, J. Gabrieli, C. Turetta, W. Cairns, G. Cozzi, IDPA, CNR, Venice, ITALY

We report here the abundances of 25 elements (Li, Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Co, Cu, Zn, As, Se, Rb, Sr, Mo, Ag, Cd, Sb, Ba, Pb, Bi to U) and REE concentration determined by ICP-SFMS in the deepest of the Vostok ice core. The reliable determination of these metals and metalloids has been performed in the different types of ice encountered below 3271 m until 3659 m depth corresponding to atmospheric ice, glacial flour and to accreted ice originating from the freezing of Lake Vostok waters. From atmospheric ice and glacial flour, the relative contributions of primary aerosols were evaluated for each element using chemical mass balance approach in order to provide a first order evaluation of their partition between soluble (sea-salt) and insoluble (wind-blown dust) fraction in the ice. Sea-salt spray aerosols are the main source of impurity to the ice and contribute largely to Na, Mg and K levels, and in a lesser extent to Ca, Sr, Rb, Li and U. For other elements such as Al, V, Cr, Mn, Fe, Co, Cu, Zn, Mo, Sb, Ba and Pb as well as the non sea salt fraction of Mg, K, Ca, Sr, Rb, Li and U, dust inputs appear to primarily control their deposition variability. For As, Se, Ag, Cd and Bi, primary aerosols are not consistent with the observed levels and other sources are likely important. For the glacial flour, the comparable levels of elements with the overlying atmospheric ice suggest that incorporation of abrasion debris at the glacier sole is limited in the sections considered. For the accreted ice originating from the subglacial Lake Vostok, a contrasting situation is observed between a solute-rich accreted type-1 where large aggregates are encountered and solute-poor accreted ice type-2 devoid of any visible inclusions.

High Resolution GPS Measurements Of Ice Surface Velocity Changes On And Around Active Subglacial Lakes, Whillans And Mercer Ice Streams, West Antarctica

Beem, Lucas Beem Lucas; Tulaczyk Slawek M; Walter Jake; Joughin Ian R; Smith Benjamin Eaton; Fricker Helen Amanda L. Beem, S.M. Tulaczyk, J. Walter, , University of

California Santa Cruz, Santa Cruz, CA; I.R. Joughin, B.E. Smith, Applied Physics Laboratory, University of Washington, Seattle, WA; H.A. Fricker, Scripps Oceanographic Institute, University of California San Diego, San Diego, CA

In late 2006 an extensive subglacial water system was discovered beneath Whillans and Mercer ice streams, West Antarctica, using Ice Cloud and land Elevation Satellite (ICESat) laser altimeter data. A more comprehensive, continent-wide study has now detected more than 120 active lakes. Active subglacial lakes are the most dynamic known elements of Antarctic subglacial hydrology and can create regional-scale changes in the distribution and pressure of subglacial water, which could affect ice flow rates. Ice streams can go through large changes in flow patterns over short periods of time. The Kamb Ice Stream stagnated very rapidly ~150 ybp. Observations show Whillans Ice Stream is slowing and widening. Much of the modulation of ice stream dynamics is believed to derive from changes in basal conditions, which include variations in subglacial water pressure, hydrological drainage patterns and thermal regime. The active lakes detected by ICESat have shown patterns of filling and draining on the timescale of just six years (2003-2009), with total basal water flux of multiple km³ a⁻¹ below the Whillans Ice Stream alone. In late 2007, we deployed ten continuous Global Positioning System (GPS) receivers directly over and proximal to two of the lakes of the Whillans/Mercer system: Subglacial Lakes Whillans (SLW) and Mercer (SLM). This data permits analyses of subglacial lake level variations and coincident velocity fluctuations; it also provides a continuous record of lake activity, whereas ICESat only samples twice a year. At the time of the Chapman Conference, more than two years of data will have been acquired that document surface velocity and elevation changes in this region. Over this period, SLM has filled consistently. Preliminary results provide no clear evidence that surface velocity above and adjacent to SLM has been significantly influenced by this lake filling. SLW filled for at least the first 14 months of observation and drained in mid 2009; GPS provides the exact timing of the drainage. Precise knowledge of SLW's activity is especially important because the lake will be drilled in 2012-2013 by the WISSARD project. The results of our survey will offer insights into the effects of the dynamics of the Whillans Ice Stream and the ultimate goal of deriving a constitutive relationship, which accurately describes the dependence of ice stream flow on

activity of subglacial lakes, that can be incorporated into prognostic ice sheet models.

The Subglacial Lake Exploration Device (SLED) Camera

Behar, Alberto Behar Alberto Enrique A.E. Behar, In Situ Instruments, NASA/JPL, Pasadena, CA

SLED camera: The Subglacial Lake Exploration Device (SLED) camera is a miniaturized, propelled, ice-borehole optical recording device designed to observe the borehole ice properties, water-ice > interface, distribution of basal debris, suspended particles in > water columns, and sediment surface properties. The development of SLED is supported by NASA under a separate Award. SLED will perform the following functions at both SLW and the grounding-line sites: record the borehole ice properties, investigate the marine ice interface, examine distribution of entrained debris in basal ice, observe geometry of ice-water interface; inspect the water column for suspended particles as well as possible aquatic organisms, search for visual evidence of water stratification and/or horizontal/vertical motion; investigate the sea/lake floor for evidence of erosional and sedimentary processes (glacial flutings, subaqueous sediment failures, debris flows, deltas, drainage channels, etc.), record signs of possible bioturbation and/or evidence of benthic organisms. Algal mats have been observed on the sea floor beneath the recently disintegrated Larsen Ice Shelf (Domack et al., 2005) and marine crustaceans at the edge of the grounded ice of the more open marine environment at McKay Glacier (Powell et al., 1996). In addition to biological exploration, we intend to use the camera to examine the structures of the sea floor, looking for evidence of grounding zone wedges that may mark the historic location of the grounding line during glacier retreat episodes (Anderson and Shipp, 2001). We will design the camera to look up at and across the base of the ice shelf. This first-ever view may well reveal aspects of the > ocean-ice heat and mass exchange processes, which may depend on interface roughness.

Melt and Freeze Couplet in Central East Antarctica

Bell, Robin Bell Robin E; Creyts Timothy T; Wolovick Mike; Spector Perry; Studinger Michael; Jordan Tom A; Frearson Nick; Ferraccioli Fausto; Corr Hugh; Braaten David Alan; Damaske Detlef R.E. Bell, T.T. Creyts, M. Wolovick, P. Spector, M. Studinger, N.

Frearson, , Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY; D.A. Braaten, Center for Remote Sensing of Ice Sheets, Kansas University, Lawrence, KS; T.A. Jordan, F. Ferraccioli, H. Corr, , British Antarctic Survey, Cambridge, UNITED KINGDOM; D. Damaske, , Federal Institute for Geosciences and Natural Resources, Hanover, GERMANY

The Gamburtsev Subglacial Mountains, encased in 1-4.5 kilometers of ice, are the most poorly understood mountain range on Earth. During the International Polar Year, the first systematic aerogeophysical survey was flown over this region and acquired over 120,000 line km of laser, radar, gravity and magnetic data. These deeply dissected mountains ranges are characterized by a well developed alpine valley system with large cirques along the ridge lines. Along the southeastern edge of the Gamburtsev Mountains, along a valley head, the ice sheet internal layers are deflected downwards over a region 12 km long and 4 km wide. In this valley head, internal layers that are regionally over 750m above the ice sheet bed intersect the base of the ice sheet. This distinctive pulled-down geometry of the internal layers suggests that up to 20km³ of ice has been removed at melt rates up to centimeters per year. Discontinuous bright basal reflectors 100-500m long in the valley suggest basal water in pockets. Any water produced by basal melt would be driven down the hydrologic potential to the east into a 20 km long 2-3.5 km wide east-west trending valley bounded by 150-200m high hills. Along the northern (upflow) side of the valley, a distinct internal reflector emerges from the valley wall in the typically echo-free base of the ice sheet. This near-bed internal layer can be clearly traced up to 10 km to the south of the valley. The near-bed reflector is generally found 150m- 700m above the base of the ice sheet and has amplitudes of 10-30dB. The low end of the amplitudes is similar to the internal layers at the same depth while the high end of the amplitude is similar to the reflection from the ice sheet bed. We interpret this strong near-bed reflector as the contrast between the meteoric and basal freeze-on (accretion) ice. At the eastern end of the east-west trending valley, the bright reflector bulges over the southern edge of the bounding hills. Above this near-bed reflector bulge, the internal layers are conformable with the near-bed reflector and not the underlying topography. We interpret these unusual internal layers as a melt freeze couplet. The drawn down internal layers point towards the production of basal

melt while the strong near-bed reflector is indicative of freezing to the base of the ice sheet. These melt-freeze events likely occur over much longer periods than dynamic observations have been made. The widespread accretion of 100's of meters of ice to the base of the ice sheet would have ramifications for ice sheet mass balance, accumulation, ice sheet models and the fidelity of ice cores.

Subglacial Lake Sedimentary Processes And Sediments: Potential Recorders of Past Climate And Ice Sheet Changes

Bentley, Michael Bentley Michael; Christoffersen Poul; Hodgson Dominic; Tulaczyk Slawek M; Smith Andrew; Le Brocq Anne M. Bentley, A.M. Le Brocq, Department of Geography, University of Durham, Durham, UNITED KINGDOM; P. Christoffersen, Scott Polar Research Institute, University of Cambridge, Cambridge, UNITED KINGDOM; D. Hodgson, A. Smith, , British Antarctic Survey, Cambridge, UNITED KINGDOM; S.M. Tulaczyk, Earth and Planetary Sciences Department, University of California, Santa Cruz, CA

The development of funded programs to drill into Antarctic subglacial lakes means that there is an imminent prospect of retrieving the first sediments from an extant lake. These sediments are potentially important for at least three reasons. Firstly they may record change in the conditions at the base of the ice sheet. For example, it is possible that the composition of subglacial lake sediment may vary on glacial-interglacial cycles, with varying amounts or composition of dust or other components of sedimentary input, or episodic change from movement of subglacial water. Second, some lakes may preserve non-glacial sediments from intervals of ice sheet retreat or collapse, or from preglacial conditions. In both these cases a major attraction of using subglacial sediment is that many lakes are thought likely to contain sediments substantially older than the record provided by ice cores. The third reason is that the sediments may not only act as a habitat for life, particularly at the relatively nutrient-rich sediment-water interface, but they may also preserve a record of past life in the form of organic geochemicals, including DNA, in the sediment. In order to assist future planning, site selection, and identifying appropriate analytical techniques, we review what is known about sediments from formerly subglacial lakes in Antarctica and elsewhere, including from both geophysical data and direct sampling. We also discuss what we might reasonably

speculate about their physical characteristics from analogies with surface glacier-fed and glacier-contact lakes, and from known limnological and glaciological processes. This includes consideration of the three likely main pathways for sediment for subglacial lake sediment: rain-out of englacial sediment at the lake ceiling, rain-out of subglacial sediment from basal debris layers, and transport of sediment by meltwater drainage into the lake. We also discuss the likely sediment-landform associations that may exist along subglacial lake margins. From this we develop a conceptual model of subglacial lake sedimentation, focussing especially on likely processes and sediments in lakes Vostok, Whillans and Ellsworth. Finally, we discuss the implications of the likely sediment characteristics for the coring technologies that will be adopted to retrieve such sediment sequences.

The Use Of Analytical Flow Cytometry And High-Speed Cell Sorting To Assess The Abundance And Viability Of Ancient Ice Microbes

Bidle, Kay Bidle Kay; Natale Frank K. Bidle, F. Natale, Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ

It is currently unknown whether ancient ice samples, which have been exposed to harsh environmental conditions, are amenable to flow cytometry and high speed cell sorting, even though these analytical techniques pose several major advantages. For example, they require small sample volumes (<1 ml) for analysis, while yielding extensive information on cell abundance and physiological state. They are also amenable to single cell genomics, which provides unprecedented access to the genomic material of yet-uncultured taxonomic groups, greatly facilitating the discovery of novel metabolic capabilities. We applied emerging techniques in analytical flow cytometry to quantify the total and metabolically active microorganisms in Antarctic ice samples ranging 100 Kyr to 8 Myr, in order to assess the relative proportion of viable vs. dead cells and to explore genetic strategies of DNA repair in ancient ice microbes. We recently established that, even after 8 million years of cosmic radiation bombardment, viable microbes and microbially derived DNA could be recovered from buried glaciers in the Dry Valleys of the Transantarctic Mountains, Antarctica. Given the strong influence of cosmic flux on DNA degradation in ancient ice samples, we hypothesize that the degree of DNA damage increases with time and

that viable 8 Myr old bacteria possess particularly effective and novel DNA repair mechanisms for which we can obtain genetic signatures. Our analyses suggest that fluorescence staining and flow cytometry analysis is feasible for microbes encased in ancient ice. We have been able to optically discriminate between abiotic, glacial till particles and nucleic acid-containing, bacteria in our ice meltwater samples upon staining with SYBR-Gold or SYTO-13 and ultimately determine the microbial abundance. At the same time, we used flow cytometry to assess ice microbe viability with fluorescent LIVE/DEAD stains and relate the percent viability to ice age. We discriminated between active and dormant bacteria via markers for respiratory activity by staining dilute meltwater cultures with the redox dye 5-Cyano-2,3-Ditoly Tetrazolium Chloride (CTC), which is reduced intracellularly in respiring cells to an insoluble, fluorescent precipitate. Based on our sample types (i.e., microbes encased in a frozen state for at least 100 Kyr), our results suggest that the maximum recommended concentration (5 mM) and extended incubation times (24 h) are necessary to detect active microbes in these samples, given their inherently low metabolic rates and growth rates in situ.

Surprises Seen In The Sub-Ice Shelf Environment

Bindschadler, Robert Bindschadler Robert; Behar Alberto Enrique; Truffer Martin; Stanton Timothy P; Kim Stacy R. Bindschadler, , NASA, Greenbelt, MD; A.E. Behar, , Jet Propulsion Laboratory, Pasadena, CA; M. Truffer, Geophysical Institute, University of Alaska, Fairbanks, AK; T.P. Stanton, , Naval Postgraduate School, Monterey, CA; S. Kim, , Moss Landing Marine Laboratories, Monterey, CA

We are pursuing the hypothesis that the heat of ocean waters is responsible for increased ice thinning, retreat and flow acceleration of the ice sheet edge in the Pine Island region of West Antarctica. While awaiting sufficient logistic support to begin sustained ocean profiling and directly observe the sub-ice-shelf environment of the Pine Island Glacier ice shelf, our novel methods were tested during the 2009-2010 field season in Windless Bight, 20 miles northeast of McMurdo Station, Antarctica. There, an 8-inch diameter access hole was drilled through the 180-meter thick ice shelf using a relatively light and transportable hot-water drilling system. A borehole camera revealed the scalloped nature

of the melted borehole, obtained what we believe to be the first-ever pictures of the underside of an ice shelf, and captured video of a Lyssianasid amphipod as it explored our borehole. Upon recovery, we also discovered what appear to be jelly tentacles on the camera cable. Proof of higher life forms more than 20 kilometers from even seasonally open water and underneath thick floating ice suggest a more expansive biological footprint in the Ross Sea region than previously held. Initial ocean profiler data collected upon initial lowering into the 800-meter deep water cavity confirm expected values of salinity and temperature. Subsequent profiles will provide more valuable data on the temperature, salinity and current structure and how these vary with time, including tidally forced oscillations.

The Development of a Hot-Water Drill to Access Sub-Glacial Lake Ellsworth

Blake, David Blake David M D.M. Blake, Technology & Engineering, British Antarctic Survey, Cambridge, UNITED KINGDOM

Access to Sub-Glacial Lake Ellsworth (SLE) is scheduled for the 2012/13 Antarctic summer season. A hot water drill is to be developed to produce an initial hole diameter of 36 centimetres to enable an instrumented probe to enter the lake. The design of the drill will build on previous concepts and developments used by the British Antarctic Survey (BAS) for hot water drilling in Antarctica. SLE is to the south of the Ellsworth Mountains and with a ground transportation route to a blue ice runway at Patriot Hills. For the drilling programme at SLE, all equipment, materials and fuel will be carried from South America to Patriot Hills via airborne heavy lift. With a maximum aircraft load of 19 tonnes, attention to the maximum size of components and the overall weight is necessary to ensure materials can be transported by air. The drilling hose at over 3200 metres and the winch will be the largest component needed to be transported as one item. A procedure has been produced and will be adopted to ensure all of the components are cleaned before they are used at SLE. Biological filtering will be employed to remove viruses and product from the water supply. The electrical supply, pumps and ancillary items will be housed in a field camp adjacent to the access hole. Sufficient fuel is to be provided in 205 litre drums to support the field site and enable two separate accesses of the lake. The drill is being developed and assembled at BAS in Cambridge and will be

tested before delivery to SLE.

The Role of Subglacial Lakes in the Onset and Maintenance of Recovery Ice Stream, East Antarctica

Block, Adrienne Block Adrienne E; Bell Robin E; Flowers Gwenn E; Pimentel Sam; Studinger Michael; Frearson Nick A.E. Block, Earth and Environmental Sciences, Columbia University, New York, NY; A.E. Block, R.E. Bell, M. Studinger, N. Frearson, , Lamont-Doherty Earth Observatory, Palisades, NY; S. Pimentel, Department of Earth and Ocean Science, University of British Columbia, Vancouver, British Columbia, CANADA; G.E. Flowers, Department of Earth Sciences, Simon Fraser University, Burnaby, British Columbia, CANADA;

The Recovery Ice Stream drains 8

Biogeochemical Study of Lake Vostok Accretion Ice

Bulat, Sergey Bulat Sergey; Alekhina Irina; Chuvochina Maria; Lipenkov Vladimir; Lukin Valery; Barnola Jean-Marc; Wagenbach Dietmar; De Angelis Martine; Leitchenkov German L; Marie Dominique; Normand Philippe; Petit Jean-Robert S. Bulat, I. Alekhina, M. Chuvochina, , Petersburg Nuclear Physics Institute, St Petersburg, Gatchina, RUSSIAN FEDERATION; V. Lipenkov, V. Lukin, , Arctic and Antarctic Research Institute, St Petersburg, RUSSIAN FEDERATION; S. Bulat, I. Alekhina, M. Chuvochina, J. Barnola, M. De Angelis, J. Petit, , Laboratory of Glaciology and Geophysics of Environment CNRS, Grenoble, FRANCE; D. Wagenbach, Institut für Umweltphysik, University of Heidelberg, Heidelberg, GERMANY; G.L. Leitchenkov, , Institute for Geology and Mineral Resources of the World Ocean, St Petersburg, RUSSIAN FEDERATION; D. Marie, , Station Biologique de Roscoff, Roscoff, FRANCE; P. Normand, Ecologie Microbienne, Université Claude Bernard-Lyon I, Lyon, FRANCE

The objective was to perform complex biogeochemical study of accretion ice of the subglacial Lake Vostok, East Antarctica with the ultimate goal to discover alien life in this extreme icy environment. The additional task was to prove our previous scenario (Bulat et al., 2004) by complementary analyses including gas content, dissolved organic carbon (DOC), major ion chemistry, mineralogy of sediments, microbial cell enumeration and 16S rRNA genes sequencing. As a result, total gas content proved to be 2-3 orders of magnitude lower than in glacier ice. Meanwhile a giant

mica-clay sediment inclusion within the mono-crystal lake ice showed an unusual content of oxygen, carbon dioxide and methane. Mean DOC levels were found to be less than 20 pbb. Major ion chemistry showed enrichment of magnesium and calcium sulfates along with sulfides in ice with sediment inclusions only. Amongst the latter sulfide minerals like pyrite were also identified. Accordingly, possible redox couples are rather limited in supporting chemolithoautotrophic life forms. The molecular microbiology study constrained by Ancient DNA research criteria showed that the ice until depth 3659 m contains the very low microbial biomass (Table 1). The only ice containing mica-clay inclusions allowed the detection of unusual gas content and recovery of few bacterial phylotypes all passing contaminant controls but not fitting groups expecting to discover. The latter included the well-known chemolithoautotrophic thermophile (unexpected). In contrast, the deeper accretion ice with no sediment present and gas content close to detection limit gave no reliable signals. Since Antarctic subglacial lake environments are thought to analogues for extraterrestrial icy environments, their ability to support microbial life is willingly considered unquestionable. However, amongst them the Lake Vostok can be viewed as very special with extremely low biomass giant aquatic body on the Earth, exploration of which is highly prone to forward-contamination.

Russian Plans/Activities For Drilling Into And Sampling Subglacial Lake Vostok

Bulat, Sergey, Bulat Sergey; Lukin Valery S. Bulat, , Petersburg Nuclear Physics Institute, St. Petersburg, RUSSIAN FEDERATION; V. Lukin, Arctic and Antarctic Research Institute, St. Petersburg, RUSSIAN FEDERATION

The Russian Federation has developed a national ongoing project on the drilling into, and sampling of, subglacial Lake Vostok, East Antarctica. The goal is to explore this extreme icy environment in a multifaceted way, to identify the form and levels of life that exist there. The project is funded by the Russian Federal Service for Hydrometeorology and Environmental Monitoring (ROSHYDROMET) and is available for open for collaboration. In the season 2009/2010 drilling operations will be restarted from the depth 3559 m (about 150 m towards ice-water boundary) in the new borehole called 5G-2 (previously in the 2008/2009 season within the 5G-1 borehole the drill stack was lost as a consequence of borehole inclination). The 2009/2010 season will be devoted to developing the deep the

borehole between 3680 and 3690 m. The new accretion ice including the inclusion-rich 'thermophile-containing' horizon (Bulat et al., 2004; Lavire et al., 2006) (around 3608 m) will again be recovered and its complexity studied. The following season (2010/2011) the drill will enter the lake. This entry will be performed using a thermal drill and clean silicone oil as a drill liquid, which will replace the kerosene mix at the borehole bottom. During the lake entry sensors for oxygen content (and some other parameters) will be invoked to get the initial gas values directly at the moment of the contact. In addition, the lake water will be supposedly sampled into special wall-warmed bathometers placed within the drill to be studied unfrozen in clean labs. The season after (2011/2012) the lake water raised up to dozens meters within the borehole 5G-2 and subsequently allowed to freeze will be re-drilled to get sharply frozen lake water (from different horizons ranging from dirty at the top to clean at the bottom) for later complex investigation. During that season, or the season after a special set of biophysical instruments developed now in the Petersburg Nuclear Physics Institute (now a member of Russian national research centre for nuclear physics and nanotechnology - Science, 2009, 461, 1028) will be sent into the water body with a battery of common ocean observatory sensors, visible and infra-red light cameras, spectrometers/fluorimeters and special water samplers loaded on a board of several submersible titan modules, firstly as ROVs hooked on a special line and operated with the help of a trolling reel and then - as AOVs. Such activities will be in a line with environmental stewardship in exploration of unique aquatic environments under the thick Antarctic ice sheet.

Taking the "Pulse:" Laser Altimetry and Radar Sounding As A Means To Verify Ice Sheet Water Models At Subglacial Lakes.

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With the recent multiyear acquisition of satellite laser altimetry, it is now possible to observe the movement of subglacial water through entire basins. The last four decades of airborne radar sounding campaigns have brought unprecedented resolution of ice thickness, ice structure and basal properties for nearly the entire Siple Coast drainage. Within the last decade several models have been developed and implemented to explain both the production and transport large scale transport of water beneath the Antarctic ice sheet. Recent advances to the classical jökulhlaup theory have been developed to explain the timing, magnitude, and evolution of episodic subglacial water flow. Verification of both the long term transport and flood evolution models has been limited to mass budgets for entire basins or focused on individual events. Using an thermomechanical ice sheet model to provide englacial temperatures distribution and basal melt rate, RES data on ice thickness and basal reflections we develop self consistent method for modeling basal water distribution and imaging basal water systems. This model is then tested in several locations throughout the Siple Coast where subglacial lakes are known to cluster and for which a hydraulic linkage has been demonstrated. Even the older RES data proves highly useful for linking individual lakes. The satellite altimetry often reveals lakes previously undetected, but still visible in the RES data. In summary close coupling of the multiple lines of geophysical data with an ice sheet model has the potential to reveal a unprecedented level of detail about the subglacial water system and its affect on the flow of the overlying ice.

Biologically and Chemically Clean Subglacial Access Drilling

Christner, Brent Christner Brent Craig; Priscu John C; Mikucki Jill; Gerasimoff Michael; Bolsey Robin; Lebar Done; Bentley Charles R B.C. Christner, , Louisiana State University, Baton Rouge, LA; J.C. Priscu, , Montana State University, Bozeman, MT; J. Mikucki, , Dartmouth College, Hanover, NH; M. Gerasimoff, R. Bolsey, D. Lebar, C.R. Bentley, , University of Wisconsin, Madison, WI

Environmental stewardship is a foremost priority during the exploration of pristine Antarctic subglacial environments. The WISSARD (Whillans Ice Stream Subglacial Access Research Drilling) project will implement the biologically and chemically cleanest technologies practicable during all phases of drilling and subglacial access. A

2007 National Research Council report (Exploration of Antarctic Subglacial Aquatic Environments: Environmental and Scientific Stewardship) and the Scientific Committee on Antarctic Research 2009 Code of Conduct for the Exploration and Research of Subglacial Aquatic Environments recommend that the numbers of microbial cells contained in or on the volume of any material or instruments added to or placed in these environments should not exceed that present in an equivalent volume of deep ice. We intend to conform to these recommendations and plan to rigorously test the technology prior to any attempt at subglacial access. To penetrate the 700-800 m of overlying ice, a hot water drilling system has been designed which will have approximately 80 L min flow capacity and be capable of drilling and maintaining holes of up to 25 cm in diameter for 8 days. Integrated within the drilling system are large-scale water purification, filtering, ultraviolet radiation, and heat sterilization modules, which will remove dissolved organic carbon (DOC) species and sterilize the effluent. The volume of liquid water generated when drilling each borehole will be at least 41 m the residence time of water through the system is approximately 8.5 hours, and after 8 days of borehole operations, the borehole fluid should be completely circulated through the system at least 20 times ($\sim 920 \text{ m}^3$). These specifications, together with the estimated concentration of cells and DOC in the ice and from contamination, were used to determine WISSARD clean system requirements. To continuously purge contaminants during 8 days of borehole operations, our clean access drilling system requires the capacity to remove at least 9×10^6 cells and 5 kg of DOC from the drilling fluid. <http://brent.xner.net/>

Subglacial Life and the Search for Life Beyond Earth

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The assessment of the habitability of other planetary bodies is necessarily constrained by what we know about life on the Earth. Increasingly, the community has recognised that some of the most promising sites for prebiotic chemistry or extant life beyond Earth are subglacial environments. These environments include: the ocean of the Jovian moon, Europa, and possibly Callisto; bodies of liquid water within the Saturnian moons, Enceladus and Titan; and subglacial environments on Mars. Subglacial environments on the Earth are likely to differ from these environments in some important respects, such as the presence of allochthonous organic carbon in terrestrial ices produced by the photosynthetic biosphere. However, the diversity of anaerobic redox couples using elements derived from the lithosphere and gases produced in situ provide important insights into the thermodynamic and kinetic constraints to life in extraterrestrial subglacial environments. Furthermore, the contamination control procedures and exploration technologies used to explore terrestrial subglacial environments yield new procedures and ideas for the sampling and analysis of extraterrestrial subglacial environments.

Subglacial Lake-district Reveals East Antarctic Heat Flux Anomaly

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Unlike the West Antarctic ice sheet, which lies over a crustal rift that has volcanism on its flanks and associated elevated geothermal heat flux, the East Antarctic ice sheet (EAIS) lies on generally aseismic continental crust that exhibits little volcanic activity. The majority of subglacial lakes found in EAIS are believed to be formed because at a 'normal' background geothermal heat flux of $\sim 50 \text{ mW m}^{-2}$, the ice is sufficiently thick to be at the pressure melting point. Here we identify from ice sounding radar data from East Antarctica a cluster of six subglacial lakes, within a circular area of radius 70 km. One of the lakes, which sits astride an ice-divide, has a clear down warping of internal layers. A forward model is used to match the layer trajectory and shows that the subglacial melt rate to be very much greater than typical values for East Antarctica

and the estimated geothermal heat flux is three times the assumed continental background. The estimated volume of produced melt water is discussed. We show that the enhanced geothermal heat flux required for melting coincides with a granitic body, and contend that the elevated heat is caused by radiogenics rather than volcanism. The subglacial lake-district and underlying granitic body marks the inland boundary of the Cook Ice Streams; a body of ice with an established retreat signature. Between the upstream lake-district and the ice-shelf terminus lies a hitherto undiscovered subglacial basin. There is widespread evidence of water within the deep basin. Mechanisms by which the lubricated bed of the ice stream could affect ice-sheet dynamics in the area are discussed. Although the water depth of the lake is unknown the high melt-rate of the overlying ice column suggests a short residency time. The lake is identified as a target to drill through and recover a sediment core that could potentially reveal the Pliocene history of EAIS.

Drainage of Subglacial Water Systems Beneath Ice Sheets

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Dynamic lakes that cause ice surface elevation change require ample generation and supply of water from upstream sources. The hydraulic system delivers water to these lakes either through a distributed or channelized morphology. In this paper, we investigate the effects of subglacial water drainage resulting from spatially distributed water sheets. In our model, the weight of overlying ice is supported by both water pressure and various sizes of bed protrusions that penetrate the water sheet. Each of the various sizes bears a different magnitude of the overlying ice based on a linear stress recursion that balances forces at the bed. Previous results have shown that water depth can be a multi-valued function of both effective pressure (ice overburden minus water pressure) that drives sheet closure and hydraulic gradient that drives water flow (Creyts and Schoof, 2009). Curvature and structure of this multi-valued water depth function depend on the protrusion size distribution. Switches between different branches of the water depth relationship correspond to either the establishment or shut-

down of a 'connected' (or efficient) drainage system. We build upon and extend previous work to show how along-path discharge affects water depth and switches from one state to another. We conclude by relating state behavior to subglacial conditions where dynamic lakes are found.

Sub-glacial Lake Environment and Facies Revealed by Larsen B Ice Shelf Disintegration

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The identification of subglacial lake sediments in ancient sequences is difficult to infer because subglacial lakes are the most inaccessible deposystems for direct study of process/product. To date the best available analogs are recent deep basins previously covered by the Larsen Ice Shelf system. The collapse of the Larsen-B Ice Shelf (LIS-B) and subsequent rapid retreat of the Crane Glacier resulted in the formation of 15 km long fjord. The fjord trough is characterized by the presence of three deep (>1000 m) and narrow (~1 km wide) basins. The basins are separated by more elevated thresholds whose morphology of elongated ridges and gutters sub-parallel to the axis of the fjord, is interpreted as sub-glacial bed forms that formed as the result of deposition of subglacial till--beneath grounded ice. At the time of ice grounding, the basins existed as sub-glacial lakes. More than 40 m of horizontally stratified sediments are present within the deepest of the fjord basins. A kasten core of the uppermost 2.6 meters of sediment documents that recent sediments were deposited at a high rate (2 m/year) under open marine conditions following ice shelf retreat. The underlying sediments likely were deposited in a sub-glacial lake setting; these sediments will be jumbo piston cored during cruise NBP10-01, during January-February 2010. Our working hypotheses are that these sediments were deposited (a) over the past ~ 30 years,

roughly since the onset of the decrease in the extent of the ice shelves in the region, or (b) a relatively steady, less extraordinary sedimentation rate within the quiet environment of the sub-glacial lake. This second interpretation may be supported by the high penetration shown by the sub-bottom acoustic profiles, down to the reflector at the base of the 40-m thick layered fill. This observation suggests the presence of a relatively fine grain-size, without appreciable variations. In fact, episodes of coarse grain size and/or acoustic facies changes would be expected in case major environmental changes. If we assume that the LGM was the last time the ice was grounded within the fjord, the average sedimentation rate of the layered fill would be of the order of few hundred cm/kyr a rate comparable to that of the Palmer Deep record on the opposite side of the Antarctic Peninsula. What is unique here is that this record would have been deposited in a sub-glacial lake environment, since the ice cover is known to have persisted in the area for the entire Holocene. Moreover, this extraordinary record would have also recorded the abrupt transition to an open sea setting, with accelerated ice discharge following the break-up of the ice shelf. This sedimentary record, and other similar, yet unsampled sedimentary sequences, provide a window through which to decipher the dynamics of the sub-ice processes that result in and accompany the loss of ice mass and its transfer to oceanic systems.

Environmental Protection and Stewardship of Subglacial Aquatic Environments

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Antarctic subglacial aquatic environments have been documented for some time using remote sensing (geophysical) techniques, but only very recently have there been plans devised and implemented to enter and study these environments directly. The long lead up to the sampling of these lakes is largely related to the logistical difficulty of doing so, but also due to the cautious approach warranted by the pristine nature of the environments, and their almost completely unknown capacity to sustain viable ecosystems. It is because of the need for caution that the U.S. National Science Foundation requested guidance from the

National Academies to address standards of responsible exploration of subglacial aquatic environments. In response, the National Research Council of the National Academies created the Committee on the Principles of Environmental and Scientific Stewardship for the Exploration and Study of Subglacial Environments. The committee made 13 recommendations towards this end. The NRC study and recommendations will be reviewed in this talk as well as an assessment of the study's impact, including ongoing international development of a Code of Conduct to explore and protect Antarctic subglacial waters.

Evidence for Microbial Metabolism at -15°C in an Antarctic Subglacial Environment

Doyle, Shawn Doyle Shawn M; Achberger Amanda M; Montross Scott N; Brox Timothy; Suematsu Kohei; Skidmore Mark L; Christner Brent Craig S.M. Doyle, A.M. Achberger, B.C. Christner, Biological Sciences, Louisiana State University, Baton Rouge, LA; S.N. Montross, T. Brox, M.L. Skidmore, Earth Sciences, Montana State University, Bozeman, MT; K. Suematsu, The Institute of Low Temperature Science, Hokkaido University, Sapporo, JAPAN; Analysis of the gases entrapped in sediment-rich basal ice from the Taylor Glacier, an outflow glacier of the East Antarctic Ice Sheet, have revealed anomalies with respect to the concentrations of CO₂ and CH₄ (>1000 times atmospheric) and O₂ (<1

The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) Project: an Integrated Study of Marine Ice Sheet Stability and Subglacial Life Habitats in West Antarctica

Fricker, Helen Fricker Helen Amanda; Tulaczyk Slawek M; Powell Ross D; Priscu John C; Anandakrishnan Sridhar; Christner Brent Craig; Fisher Andrew T; Holland David M; Jacobel Robert W; Mikucki Jill; Mitchell Andrew Charles; Scherer Reed P; Severinghaus Jeff H.A. Fricker, J.P. Severinghaus, IGPP, Scripps Institution of Oceanography, La Jolla, CA; S.M. Tulaczyk, A.T. Fisher, University of California, Santa Cruz, Santa Cruz, CA; R.D. Powell, R.P. Scherer, Northern Illinois University, DeKalb, IL; S. Anandakrishnan, Pennsylvania State University, State College, PA; R.W. Jacobel, St. Olaf College, Northfield, MN; J.C. Priscu, A.C. Mitchell, Montana State, Bozeman, MT; B.C. Christner, Louisiana State, Baton Rouge, LA; J. Mikucki, Dartmouth College, Hanover,

NH; D.M. Holland, New York State University, New York, NY

WISSARD is a 6-year NSF-funded project which involves 13 PIs at 9 institutions that will use an interdisciplinary science approach to study the subglacial environment of the Whillans Ice Stream in West Antarctica. It is split into three sub-projects: LISSARD (Lake and Ice Stream Subglacial Access Research Drilling); RAGES (Robotic Access to Grounding-zones for Exploration and Science); and GBASE (GeomicroBiology of Antarctic Subglacial Environments). LISSARD focuses on investigating the role of active subglacial lakes in controlling temporal variability of ice stream dynamics and mass balance. RAGES concentrates on stability of ice stream grounding zones which may be perturbed by increased thermal ocean forcing, filling/draining cycles of subglacial lakes, and/or internal ice stream dynamics. GBASE addresses metabolic and phylogenetic diversity, and associated biogeochemical transformations in subglacial lake and grounding zone environments. These sub-projects are connected scientifically through common interest in coupled fluxes of ice, subglacial sediments, nutrients and water, as well as by the common need to characterize and quantify physical, chemical and biological processes operating subglacially. The project will focus on the lower Whillans Ice Stream, where three hydrologically connected subglacial environments that lie within close geographical proximity can be accessed: a subglacial lake (Lake Whillans); wet subglacial sediments including the grounding-zone wedge; and the sub-ice-shelf cavity. Direct sampling will yield seminal information on the glaciological, geological and microbial dynamics of these environments and test the overarching hypothesis that active hydrological systems connect various subglacial environments and exert major control on ice sheet dynamics, geochemistry, metabolic and phylogenetic diversity, and biogeochemical transformations of major nutrients within glacial environments. We will present an overview of the hypotheses, time-line, significance as well as the challenges that we foresee.<http://www.wissard.org>

Synthesising Multiple Remote Sensing Techniques for Analysing Subglacial Hydrologic Systems: Application on MacAyeal Ice Stream, West Antarctica

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MacAyeal Douglas Reed H.A. Fricker, S.P. Carter, IGPP, Scripps Institution of Oceanography, La Jolla, CA; T.A. Scambos, T.M. Haran, , National Snow and Ice Data Center, Boulder, CO; I.R. Joughin, , University of Washington, Seattle, WA; C.H. Davis, , University of Missouri-Columbia, Columbia, MO; D.R. MacAyeal, , University of Chicago, Chicago, IL

We present an analysis of the active hydrologic system of MacAyeal Ice Stream (MacIS), West Antarctica from a synthesis of multiple remote sensing techniques: satellite laser and radar altimetry; satellite image differencing; and hydrostatic hydropotential mapping (using a satellite-derived digital elevation model (DEM) and a bedrock DEM from airborne-radio echo sounding). Combining these techniques augments the information provided by each one individually, and allows us to develop a protocol for studying subglacial hydrologic systems in a holistic manner. Our study reveals five large active subglacial lakes under MacIS, the largest of which undergoes volume changes of at least 1.0 km³. We discuss the hydrologic properties of this system and present evidence for links between the lakes. At least three of the lakes are co-located with sticky spots. We also find evidence for surface elevation changes due to ice dynamic effects (not just water movement) caused by changes in basal resistance. We show that satellite radar altimetry is of limited use for monitoring lake activity on fast-flowing ice streams with surfaces that undulate on (~10 km) length scales. Finally, to assess whether there is a link between lake flooding and ice dynamics, we examined the largest lake for flow speed changes during fill and drain cycles with several ASTER images. Ice velocity mapping using ASTER image pairs spanning periods when the lake is drained show flow speeds up to 40 m/yr slower than when the lake is filled. We infer that flow speed decreased as a result of increased basal resistance (from zero to non-zero as the ice encountered the basal sediments). The scale of the slowdown is similar to modeled results on nearby ice streams.

UW-Wisconsin (ICDS) WISSARD Drilling Program: Environmental Stewardship, Engineering, and Scientific Objectives

Gerasimoff, Michael Gerasimoff Michael M. Gerasimoff, Space Science and Engineering Center, University of Wisconsin, Madison, Madison, WI

WISSARD is an ambitious sub-glacial exploration program encompassing the disparate needs of the LISSARD, GBASE, and RAGES projects. Accessing the sub-glacial environment requires hot-water-drilled bores ranging from a about 15 to 50 cm diameter, dependent on science requirements, anticipated occupation period, and resulting allowance for freeze-back. Calculations indicate 1 to 3 megawatts is required for drilling and related processes. LISSARD and GBASE projects require smaller bores and lower heat flux, but environmental stewardship and the scientific objectives impose challenging aseptic requirements. The RAGES project deploys a submarine ROV via the largest bores, requiring the largest heat flux. Maintaining the bore for periods that might exceed 300 hours by recirculating salt-contaminated water presents engineering and operational challenges. We present our current design embodiment encompassing drilling, filtration and related systems addressing critical engineering, environmental stewardship, scientific deployment and other issues. www.wissard.org

Exploring Former Subglacial Hodgson Lake, Antarctica: Geomorphology, Limnology and Paleolimnology

Hodgson, Dominic Hodgson Dominic; Roberts Steve; Bentley Michael; Smith James; Verleyen Elie; Vyverman Wim; Leng Melanie; Sanderson David; Johnson Joanne; Hodson Andy D. Hodgson, S. Roberts, J. Smith, J. Johnson, , British Antarctic Survey, Cambridge, UNITED KINGDOM; M. Bentley, Dept. Geography, University of Durham, Durham, UNITED KINGDOM; E. Verleyen, W. Vyverman, Dept. Biology, University of Ghent, Ghent, BELGIUM; M. Leng, Isotope Geoscience Lab, NERC, Keyworth, UNITED KINGDOM; D. Sanderson, , SUERC, East Kilbride, UNITED KINGDOM; A. Hodson, Dept. Geography, University of Sheffield, Sheffield, UNITED KINGDOM

Direct exploration of subglacial lakes buried deep under the Antarctic Ice Sheet has yet to be achieved. However, at retreating margins of the ice sheet, there are a number of locations where former subglacial lakes are emerging from under the ice but remain perennially ice covered. We present a study of Hodgson Lake (72° 00.549'S, 068° 27.708' W), including its geomorphology, limnology and palaeolimnology. Thick perennial ice cover persists over the lake today and the waters have remained isolated from the atmosphere. Nutrient concentrations within the ranges of

those found in the accreted lake ice of Lake Vostok. TOC and DOC are present, but at lower concentrations than in continental rain. No organisms were detected using light microscopy. Increases in SO₄ and cation concentrations at depth and declines in O₂ provide some evidence for sulphide oxidation and very minor bacterial demand upon O₂. However, in general the chemical markers of life in the water are inconclusive. The palaeolimnology of the lake was studied using a 3.8 m sediment core dated using a combination of radiocarbon, OSL, and relative palaeomagnetic intensity dating. Four stratigraphic zones (A–D) were identified. Zones A–C were deposited between Marine Isotope Stages 5–2 and zone A during Stage 1. The palaeolimnological record tracks changes in the subglacial depositional environment linked principally to changing glacier dynamics and mass transport and indirectly to climate change. There is no evidence of overriding glaciers being in contact with the bed reworking the stratigraphy or removing this sediment. This suggests that the lake existed in a subglacial cavity beneath overriding LGM ice. In zone D there is a transition to finer grained sediments characteristic of lower energy delivery coupled with a minor increase in the organic content. Evidence of biological activity is sparse. TOC varies from 0.2 to 0.6

Scanning Detection of Multiscale Significant Trend-Changes in Ice-core Records

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Abstract The author has developed four scanning algorithms for detecting coherency of multiscale significant changes in subseries means, variances and trends between two time series and the subseries correlation changes respectively (Jiang, 2009). Here we present one of the four, the scanning F-test for detecting multiscale change-points in subseries trends (regressions to time), specially for drilling cores which are recorded in unequal intervals. Scanning detections of changes in subseries means and variances in sediment cores were demonstrated by Jiang et al.(2007). These algorithms feature grafting the wavelet technique onto the classical statistic test and giving statistic criteria at a confidence level, as well as automatic and objective detection on various time scales.

As an example, the algorithm was employed to two series of average values of $\delta^{18}\text{O}$ and of $\delta^{15}\text{N}$ in trapped gases of the Vostok ice core (<http://nsidc.org/data/nsidc-0107.html>). The primary results in contour patterns (Fig. 1) feature generally that the $\delta^{18}\text{O}$ (Fig.1a) have 21 significant change-points, which is more frequent than that in the $\delta^{15}\text{N}$ with 15 change-points (Fig.1b), the coherency (Fig.1c) between Fig.1a and b appears mainly positive before 142.7 Ky BP while negative after then on longer time-scales. Key references: Jiang, J., X. Gu, and J. Ju, "Significant changes in subseries means and variances in an 8000-year precipitation reconstruction from tree rings in the southwestern USA", *Ann. Geophys.*, 2007, 25: p1519–1530, www.ann-geophys.net/25/1519/2007/ Jiang, J.: "Scanning detections of multi-scale significant change-points in subseries means, variances, trends and correlations", in < 2009 Sixth International Conference on Fuzzy Systems and Knowledge Discovery>, V5:609-613, IEEE Press.

Low-frequency Radar Profiles of the Recovery Lakes

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Four new large sub-glacial lakes (SGLs) were identified recently at the head of the Recovery Glacier ice stream in East Antarctica, using MODIS imagery and ICESat elevation data. The surface areas of these lakes would make them among the largest SGLs in Antarctica, second only to Lake Vostok. Beyond their size, the Recovery Lakes (RL) are compellingly located just at the onset of fast flow in the Recovery Ice Stream, suggesting a linkage between the presence of water at the bed and the initiation of rapid ice flow. In January 2009, the Norwegian-US IPY traverse passed over the RL area, en route from South Pole to Norway's Troll Station (Fig.1). Here we present low frequency radar data collected over the RLs during the traverse, and examine the evidence for their existence based on the reflectivity of the basal reflector and on the relative flatness of the basal interface.

Potential Proxies Held In Sediment Inclusions From Ice Cores Of The Vostok Station Borehole

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The borehole at the Vostok Station has been drilled into an accreted ice layer originating from refreezing of the lake water. This layer contains random sediment inclusions, nine of which have been studied using state-of-the-art analytical techniques. Six inclusions comprise soft aggregates mainly consisting of clay-mica minerals and micron-sized quartz grains while three others contain quite large rock clasts. Electron microscopy of soft inclusions extracted from a depth of 3559 m have revealed small (several micron-sized) particles of sulfide minerals (molybdenite, sphalerite and pyrite). Two principal ways of their origin could be suggested: i) disintegration of ancient metamorphic rocks by glacial erosion and deposition over the western lake shore (exaration) and ii) recent endogenous processes in a depth. Pyrite shows typical cubic-shaped crystalline morphology which is unlikely to be preserved in the course of ice exaration as this mineral is quite soft. Moreover, under highly oxidative conditions expected in the lake due to oxygen accumulation upon ice melting pyrite particles should not be resistant but rather replaced by iron oxide followed by iron oxihydroxide as a final product. Molybdenite and sphalerite were detected in the assemblage with pyrite and provide an extra support for in situ formation of mineral assemblages by recent endogenous activity pointing out their rapid trap in accretion ice. Such endogenous activity in a depth provides evidence for hydrothermal activity in the Lake Vostok (additionally to some other arguments). Rock clasts from two inclusions (3582 and 3607 m) consist of poorly-rounded quartz and minor amounts of accessory minerals and is classified as quartzose siltstone. 21 grains of zircon and 5 grains of monazites (from 2-5 to 30-40 μm in size) have been identified in the siltstone and dated by SIMS SHRIMP-II. Two age clusters have been recognized for these detrital grains, in the ranges 0.8–1.2 Ga and 1.6–1.8 Ga. The largest inclusion (3608 m) contains 13 poorly-rounded rock clasts (ranging in size from 0.5 to 3.5 mm) which were identified as sandstones and siltstones. Most of clasts is dominated by quartz; one clast consists completely of apatite; and two clasts have considerable quantity of feldspar. 11 zircons and 11 monazites were detected in these rocks

and next step of study will include additional SHRIMP analysis to define ages of this U-bearing minerals. The compositions of the rock clasts suggest that the bedrock situated to the west of Lake Vostok is sedimentary. The age data on the detrital accessory minerals (studied so far in two inclusions) allow us to speculate that the provenance of these sedimentary rocks – the Gamburtsev Mountains and Vostok Subglacial Highlands, is mainly represented by Paleoproterozoic and Mesoproterozoic- Neoproterozoic crustal provinces.

Modeling the Spatial Variation Of Englacial Radar Attenuation: Application To The Vostok Flowline And Implications For The Detection Of Subglacial Lakes

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Knowledge of the spatial variation of englacial radar-attenuation rates is poor, but it is needed to accurately infer englacial and basal properties from ice-penetrating radar data, including the location of subglacial lakes. Attenuation rates depend on the spatial variation of temperature and soluble impurity concentrations. Because temperature and impurity concentrations are measured only at the surface or in boreholes or ice cores, models of their spatial variation are required to predict attenuation rates in ice sheets. Here we evaluate several models of the spatial variation of attenuation rates and present an example of their application along a flowline that crosses over Lake Vostok, East Antarctica, and through the Vostok ice core. The first and simplest possible model is a uniform, depth-averaged attenuation rate everywhere along the flowline; the next simplest model uses spatially varying temperatures from a thermomechanical ice-sheet model, but assumes uniform impurity concentrations. Subsequent models also use radar-layer depths and/or velocities from the ice-sheet model to extend Vostok impurity-concentration data along the flowline and predict their spatial

variation. We find that models that include spatially varying temperatures predict large differences in roundtrip attenuation (> 10 dB) compared to the model that assumes a uniform attenuation rate; these differences are large enough to confound subglacial lake detection. Models that include the spatial variation of impurity concentrations introduce smaller (< 5 dB) changes to the roundtrip attenuation. This work shows that an attenuation-rate model tied to an ice-core site can be satisfactorily extended spatially using radar-layer depths and a temperature model. The application of such models to ice-penetrating radar datasets will permit more reliable detection of subglacial lakes, particularly in regions with large ice-thickness changes.

The Geomorphic Signature Of Subglacial Floods

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There is geomorphic evidence in the Transantarctic Mountains supporting the idea of catastrophic drainage of, and erosion from, subglacial lakes in East Antarctica; the erosional features include vast tracts of scoured-bedrock terrain, bedrock-channel systems, and scabland topography. Some of the meltwater tracts extend for over 50 km in length, and may be linked to extensive offshore channels. Our aim is to use geomorphology to help understand the dynamics of subglacial meltwater flow and its role in glacial erosion and deposition. The bedforms in the Dry Valleys area give an insight into the locations, magnitude, and frequency of subglacial outbursts in a large area that was formerly the bed of an expanded East Antarctic ice sheet. Our mapping results show that the subglacial channels are anastomosing, with potholes at junctions and reverse gradients in longitudinal profiles. Flood magnitudes are inferred to be on the order of the Lake Missoula floods (e.g., huge discharges associated with recession of the Laurentide ice sheet). Modeling studies point to a source for meltwater in interior East Antarctica, with the possibility that significant water bodies were temporarily held in place by a transient ice dam (cold-based ice) on the inland flanks of the Transantarctic Mountains. The latest flood to cross the Dry Valleys region likely dates to middle Miocene time. Younger floods may have occurred, but the meltwater

most probably passed through over-deepened troughs (not yet fully developed at the time of the Miocene floods) that today lie beneath modern outlet glaciers. One unknown is the fate of sediment eroded by these subglacial floods; sedimentary deposits, if they existed, have not been identified in exposed areas of the continent. One possibility is that much of the debris may ultimately have frozen onto the basal ice and was carried out to the continental shelf. A second unknown is the ecological and climate impact of large volumes of freshwater discharging into the Ross Embayment, particularly during the mid-Miocene when ablation (via melting) of the ice surface may have preconditioned the Southern Ocean to abrupt change.

Detecting Wet Ice-sheet Beds Across Antarctica Using Radar: A Feasibility Assessment Using Three-dimensional Temperature And Radar Attenuation Models

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Diagnosing subglacial conditions using observed radar power returned from the bed (bed-echo intensities) requires a correction for the dielectric attenuation through the ice overburden. This attenuation depends on ice temperature and chemistry, so it is spatially varying. The difference between the specular reflectivities of wet and dry beds is up to 25 dB. A depth-averaged attenuation-rate difference of ~ 4 dB/km (one way) in 3-km-thick ice can therefore easily confound interpretations of subglacial conditions. A recent estimate of the spatial variation of attenuation rates in central West Antarctica shows that they vary by up to 5 dB/km within a ~ 120 -km by ~ 120 -km area. These observations motivate a reassessment of the conventional belief that brighter and dimmer beds can be simply interpreted as wetter and drier beds, respectively. We estimated the three-dimensional attenuation-rate field for the entire Antarctic ice sheet using an existing temperature-dependent attenuation-rate model and temperatures from a thermomechanical model. For these initial calculations, we ignore spatial variations in chemistry, since previous attenuation-rate estimates at ice-core sites showed that ice

chemistry is of secondary importance. To mitigate uncertainties related to the poorly known spatial variation in geothermal flux we evaluated the robustness of our results using several geothermal-flux models that were calibrated using borehole-temperature profiles and the locations of known subglacial lakes and ice streams, where the bed is presumed to be wet. Bed reflectivity is assigned based on the temperature model and the bed-returned power is predicted. We discuss properties of depth-averaged attenuation across Antarctica and potential pitfalls related to the diagnosis of subglacial conditions using radar.

Subglacial Lake Regimes For Different Lake Categories

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Since the first discovery of subglacial lakes in the late 1960s the knowledge about subglacial water bodies has changed dramatically. First only a small number of lakes (17) were identified in the centre of the Antarctic Ice Sheet, including Lake Vostok. The development of ideas concerning internal hydrological conditions and mass exchange with the ice sheet took a long time to develop. Since the mid 1990s about 280 subglacial lakes have been discovered underneath the ice sheet, ranging from some kilometres to about 250 km in dimension, being covered by an ice layer from less than 2 km up to more than 4 km thick. The lakes are located at several characteristic locations across Antarctica. Also the interaction between lakes and the surrounding ice sheet is highly variable ranging from likely closed systems with very little mass exchange to water bodies with extensive, rapid and possibly periodical water discharges. Here we provide a comprehensive summary of the principal conditions regarding the internal physical conditions influencing subglacial lakes, their mass exchange with the ice sheet above, and the consequences for both, lake and ice dynamics. Subglacial lakes occur in specific locations defined by subglacial topography and the related effective hydrostatic pressure distribution, ice dynamics and geothermal conditions. The lakes physical conditions depend on these parameters, which in return

determine the interaction level of the lake. For example, lakes at the head of fast flowing ice streams could play a much stronger role in terms of ice-sheet dynamics than lakes in inner-continental basins. Also ice thickness plays an important role in the hydrodynamic regime of subglacial lakes. The generation of different lake categories, in relation to their specific settings, allows us to describe the overall physical conditions and the potential interaction level of subglacial lakes with their environment.

Blood Falls, Antarctica: Insights Into Subglacial Microbial Energetics

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The subglacial environment is one of the most difficult portions of the cryosphere to access and only recently, in collaboration with large-scale drilling projects, are ecologists beginning to explore the more remote reaches of the subglacial biome. The subglacial environment beneath the Taylor Glacier, a cold-based polar glacier in the McMurdo Dry Valleys, Antarctica supports a metabolically and genetically diverse biosphere that can be used as a model for other subglacial systems. The Taylor Glacier's subglacial discharge, Blood Falls, is a brine remnant from Pliocene marine waters that is inhabited by cryo- and halotolerant organisms that are related to marine species. Surface meltwater does not penetrate to the base of the Taylor Glacier and no oxygen is detected in outflow waters suggesting that anoxia is an important regulator of microbial energetics. Limited organic carbon supply from the absence of contemporary photosynthesis appears to have influenced the choice of metabolic pathways employed by this subglacial community. Molecular data and biogeochemical measurements indicate that chemoautotrophic activity is present and suggests that subglacial systems can be sustained independent of allochthonous fixed carbon inputs. Isotopic measurements of iron, sulfur and oxygen have shown that chemoorganotrophic or heterotrophic growth on ancient marine organics coupled to Fe(III) or sulfate respiration drives a catalytic sulfur cycle resulting in a subglacial system that is net iron reducing. As we move forward with the exploration of subglacial systems, existing models, such as the Taylor Glacier system we describe here, will provide important insight

into ecosystem structure and function and will provide relevant tools for the examination of the geomicrobiology of other subglacial environments.

Probe Technologies for The Direct Measurement and Sampling of Subglacial Lake Ellsworth

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The direct measurement & sampling of Subglacial Lake Ellsworth will be a multidisciplinary investigation of life in extreme environments and West Antarctic ice sheet history. The project's aims are : (1) to determine whether, and in what form, microbial life exists in Antarctic subglacial lakes, and (2) to reveal the post-Pliocene history of the West Antarctic Ice Sheet. An extensive logistics and equipment development programme will deliver the necessary resources to the location of the lake. This will include novel hot water drill technology (for lake access through ~3.4km of ice), a bespoke probe (to make measurement with sensors and to collect water and sediment samples), a gravity corer (to acquire a longer sediment core) and a thermistor string for long term monitoring of the lake. This paper details the design development of the probe system. This includes the instrumentation package, water samplers and a mini gravity corer mounted on the front of the probe. Supporting equipment required at the drill site to deploy and operate the probe is also described. The project aims to complete the experiment in a clean and environmentally responsible manner in line with principles set out by SCAR. The project will apply current knowledge of microbiological transfer and best practice in protection of pristine environments. The design philosophy of the probe and systems is to minimise cost and enhance reliability. To achieve this, the number and complexity of elements is kept to a minimum, and proven commercial off-the-shelf (COTS) technology is used wherever possible, limiting the risk and cost of bespoke system development. The probe is heavily negatively buoyant, is tethered to the surface and has only simple manoeuvrability (depth control via tether and limited rotation). The probe is ~3.5m in length and 20cm in diameter and consist of two air-filled pressure cases

separated by three carousels of water samplers all attached to a central flexible core that is attached to the tether. The bottom pressure case houses the majority of the instrument package and is tipped with a short gravity core sediment sampler (increasing total length to ~4m). The upper pressure case contains the power and communications link to the tether. Scientific return is ensured by the combined use of instrumentation returning real-time data, and acquisition of water and sediment samples for post-retrieval analyses. This provides redundancy, and enables informed deployment of the sampler systems. An onboard microprocessor and data logger enable continued operation (e.g. sampling at predetermined intervals) and archiving of instrument data in case of communications failure. Power will be supplied both through the tether and by onboard batteries, the latter being sufficient to complete the mission but with limited video footage. Probe-to-surface communications (two-way) will be via an optical link and backup wire modem using COTS technology used in several deep remotely-operated vehicles. The deployment in the field is scheduled for December 2012.

Antarctic Subglacial Lake Discharges

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Antarctic subglacial lakes were long time supposed to be relatively closed and stable environments with long residence times and slow circulations. This view has recently been challenged with evidence of active subglacial lake discharge underneath the Antarctic ice sheet. Satellite altimetry observations witnessed rapid changes in surface elevation across subglacial lakes over periods ranging from several months to more than a year, which were interpreted as subglacial lake discharge and subsequent lake filling, and which seem to be a common and widespread feature. Although less impressive, such discharges are comparable to jökulhlaups and can be modelled that way using the Nye-Röthlisberger theory. Subglacial water flow is driven by the hydraulic potential gradient, which also controls when water will be driven out of a subglacial cavity. Considering the ice at the base of the ice sheet at pressure melting point, subglacial conduits are sustainable over periods of more than a year and over distances of several hundreds of kilometers. Furthermore, the theory is useful to predict the hydrograph defining lake filling and discharge. In addition, coupling of an ice sheet model to a

subglacial lake system demonstrated that small changes in surface slope are sufficient to start and sustain episodic subglacial drainage events on decadal time scales. Therefore, lake discharge may well be a common feature of the subglacial hydrological system, influencing the behavior of large ice sheets, especially when subglacial lakes are perched at or near the onset of large outlet glaciers and ice streams. While most of the observed discharge events are relatively small ($1E1-1E2 \text{ m}^3/\text{s}$), evidence for larger subglacial discharges is found in ice free areas bordering Antarctica, and witnessing subglacial floods of more than $1E6 \text{ m}^3/\text{s}$ that occurred between 14.4 and 12.4 Ma ago.

The Search for Life in Former Subglacial Lake Hodgson, Antarctica

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Direct exploration of subglacial lakes in Antarctica has yet to be achieved. However, at the retreating margins of the ice sheet, there are a number of accessible locations where former subglacial lakes are emerging from under the ice, but which remain perennially ice covered. In this study, we describe the search for life in one such lake - Lake Hodgson ($072^{\circ}00.549'S$, $068^{\circ}27.708'W$), which has emerged from under more than 297-465 m of glacial ice during the last few thousand years. Surface sediment taken 93.4m below the ice surface was investigated using a combination of epifluorescence microscopy, scanning electron microscopy, fluorescence in situ hybridization, clone library construction and analysis and direct culture. Results are presented which include the presence or absence of life, its characteristics and detection limits. The implications for future Antarctic subglacial lake research are then discussed.

Seismic Imaging of the Subglacial Plumbing System

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Subglacial water is necessary for fast flowing ice as it can lubricate glacier beds and lower their basal shear stress. However, our current ability to image this hydrologic system is

limited to larger kilometer-scale subglacial lakes that are at least a meter thick. We present the results of a series of synthetic seismic waveform modeling exercises which suggest the possibility of detecting centimeter-scale layers of water and dilatant till beneath the kilometers-thick ice. These modeling results demonstrate a means for obtaining a better snapshot of the dynamics of the basal regime, as the subglacial plumbing system is likely important at the centimeter-scale. If seismic data are collected to capture the various reflections from the ice-bed interface, we can theoretically image the spatial distribution of the subglacial water system, especially in regions surrounding known subglacial lakes, to better understand the connectivity of basal hydrology beneath streaming ice. With synthetic seismic waveform modeling we predict the seismic reflectivity of all four potential seismic reflections for a basal layer, where we model and determine the sensitivity of these seismic waveforms to the thickness and material properties of the subglacial layer. The amplitude variation with source-receiver offset of these four basal reflections (pure compressional wave reflection, pure shear wave reflection, and the two converted wave reflections) 'reflect' the composition of the subglacial bed, defined by its elastic properties (compressional wave velocity, shear wave velocity, density). When a basal layer is greater than a quarter seismic wavelength thick, the reflections from the top and bottom of that layer are discernible, allowing the thickness and elastic properties of the basal layer to be constrained from any one of the four potential basal reflections. For a thin basal layer, whose thickness is less than a quarter seismic wavelength, the reflections from the top and bottom of this layer interfere with each other. Both a pure wave reflection and a converted wave reflection are needed to constrain the thickness and elastic properties of the subglacial bed in this instance. The striking observation from the modeling results is that the converted wave reflections exhibit a 180° phase shift in their waveforms when only a centimeter of water or dilatant till is present, in comparison to no change in the seismic waveform of a pure wave reflection. This phase shift demonstrates that converted wave reflections are quite sensitive to centimeter-scale layers of water and dilatant till beneath the ice. Thin layers of water matter in terms of what 'moves' the ice, as only a thin film of basal water or dilatant till is needed to overcome the asperities at the bed that may otherwise be inhibiting streaming ice flow. Our modeling results highlight the ability to capture

basal hydrology at the centimeter-scale, thereby providing a means of imaging the subglacial plumbing system and highlighting its overall influence in ice dynamics.

New Helium Isotope Measurements in the Accreted Ice of the Subglacial Lake

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Helium is a well-known tracer in earth sciences. It has two isotopes with contrasted proportions in Earth's reservoirs: ^3He is essentially primordial in origin whereas ^4He is produced by the radioactive decay of U and Th. When normalized to the atmospheric ratio ($R_a = 1.38 \cdot 10^{-6}$), typical $^3\text{He}/^4\text{He}$ ratios vary from $<0.1 R_a$ in continental crust, to $8 \pm 1 R_a$ on average in the upper mantle, and up to $\sim 40\text{-}50 R_a$ in products of plume-related ocean islands, such as Hawaii and Iceland, thought to derive from the lower mantle. Here, we report new helium isotope measurements in the deepest ice drilled from the accreted ice massif of the subglacial Lake Vostok. Unlike most gases, helium can be incorporated into the crystal structure of ice during freezing, making helium isotopes in the accreted ice a valuable source of information. Previous measurements (Jean-Baptiste et al., Nature 411, 2001) have shown a pronounced difference in both the helium concentration and isotope ratio between glacier ice and the refrozen lake water, with atmospheric characteristics in the glacier ice and a factor of 3 enrichment and a clear radiogenic signature from underlying the continental bedrock in the accreted ice ($[^4\text{He}] = 33.9 \pm 2.6 \text{ nmol/kg}$, $R = 0.25 \pm 0.04 R_a$). Our new data, from a depth range 3650.40 - 3656.37 m display even higher helium concentrations ($[^4\text{He}] = 161 \pm 11 \text{ nmol/kg}$). The measured isotopic $^3\text{He}/^4\text{He}$ ratios ($R = 0.127 \pm 0.008 R_a$) correspond to a mixture between atmospheric helium from the melted glacier ice and crustal helium added to lake waters with a radiogenic ratio $R = 0.007 R_a$ typical of the upper continental crust. This

increase of helium concentrations with depth in the accreted ice implies the existence of sustained helium gradient in the lake, placing new constraints on water circulation and residence time. It may also represent a steady degassing from the surrounding bedrock from both a persistent tectonic activity, and radiogenic activity. In this respect a hydrothermal circulation in the deep faults is likely and may contribute to the survival of a deep biosphere.

Assessing Grounding Zones and Sub-Ice-Shelf Cavity Processes Using Direct Sampling and Robotic Instrumentation

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Grounding zones are seen as high priority targets to investigate because models indicate these important areas strongly influence ice sheet stability and hence rates of future sea level rise. Based on our present limited data and modeling efforts, grounding zones can be influenced by: (i) internal ice stream dynamics, (ii) rates of subglacial sediment (till) supply to the grounding zone, (iii) increased melting by warming ocean waters, and/or (iv) filling/draining cycles of subglacial lakes. However, we do not completely understand the full influence or details of the important processes in grounding zones. As one of three components of a new project, WISSARD (Whillans Ice Stream Subglacial Access Research Drilling), RAGES (Robotic Access to Grounding-zones for Exploration and Science) research concentrates on the stability of the grounding zone of the fast flowing Whillans Ice Stream (WIS). RAGES is a first comprehensive attempt to investigate a sub-ice-shelf cavity in these largely unexplored systems using a complex array of newly designed and integrated instrumentation and field operational equipment. The WIS grounding zone has been the target of recent remote sensing and modeling studies (Anandakrishnan et al. 2007; Alley et al. 2007). These studies have shown that a sedimentary grounding-zone wedge is accumulating with a consequent thickening of the WIS such that ice thickness at the grounding line is greater than that of the hydrostatically-balanced floating ice of the Ross Ice Shelf. Thus the grounding line is being stabilized and it will arguably remain in the same position until sea-level rise of at least several meters overcomes the excess ice thickness (Anandakrishnan et al. 2007). Alternatively, either ocean melt of grounding-

line ice or subglacial lake discharges may enhance ice discharge, both of which increase ice stream flow to thin the grounded ice faster than at present. RAGES will collect data to assess this potentially critical situation. Further, Alley et al. (2007) have argued that if this condition occurs around all Antarctic grounding lines, then recent Antarctic ice volume changes (after the rapid initial post-LGM retreat) cannot be attributed to sea-level rise, but rather are due to direct warming. Assessing the conditions at WIS is therefore, prime for evaluating assertions that synchronous behavior of ice sheets on millennial time-scales indicate ice-sheet teleconnections by either sea level or climatic forcing (cf. Alley et al. 2007; Naish et al. 2009; Pollard & DeConto 2009).<http://wissard.org>

Subglacial Lake Ellsworth: its History, Recent Field Campaigns and Plans for its Exploration

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Direct access, measurement and sampling of Subglacial Lake Ellsworth, West Antarctica is planned for the 2012-13 Antarctic field season. This experiment aims to determine: i) the presence, character and maintenance of microbial life in Antarctic subglacial lakes; and ii) the Quaternary history of the West Antarctic Ice Sheet (WAIS). Lake Ellsworth, first observed in airborne radio-echo sounding data acquired in 1978, is located in a long, deep subglacial trough located near the head of the Pine Island Glacier catchment ~30 km from the central WAIS divide. Recent geophysical surveys have characterised the lake, its subglacial catchment and the thickness, structure and flow of the overlying ice sheet. Seismic reflection data have revealed the lake to be 156 m deep and underlain by unconsolidated sediments. This fact, its physiographical setting within a well-defined steep topography and its location close to a logistics hub at Patriot Hills, makes the lake ideal for exploration. The seismic data have been used to define a preferred lake access site at the intersection between the central axis of the lake and the downstream-most seismic profile. At this point the lake is characterised by: i) a relatively thin overlying ice column (~3.1 km); ii) a significant measured water depth (>145 m); iii) a lake floor sediment thickness of >2 m; and iv) low sedimentation rates (increasing the likelihood

for a long-term record of ice sheet history). The exploration project will build, test and deploy all the equipment necessary to complete lake access, and direct measurement and sampling, in a clean and environmentally responsible manner. Hot-water drilling will be used to melt through the overlying ice. The chemistry, micro-biology and physics of the lake environment will be investigated using a custom-built clean probe. Real-time data acquisition during probe descent will provide flexibility for opportunistic sampling. After the probe is recovered at the surface a corer will be deployed for the acquisition of a lake floor sediment core. Detailed sedimentological analysis of this core will be used to reveal changes in the lake environment, and the ice sheet, through time. This project will be a benchmark exercise in the exploration of Antarctica, and could make profound scientific discoveries regarding life in extreme environments and West Antarctic Ice Sheet history.

A Sudden Outburst Flood Event Beneath Crane Glacier: Evidence, Causes, and Ice Dynamic Effects

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Recent studies have shown that sub-glacial lake activity can have a significant local effect on the flow speed of major outlet glaciers on the great ice sheets (e.g., Byrd Glacier: L. Stearns et al., 2008 Nature Geoscience). Here we present an additional case where a large sub-glacial drainage appears to have caused a significant change in ice flow speed. The event was likely caused by the rapid elevation changes on Crane Glacier. Crane Glacier in the Antarctic Peninsula has shown a remarkable increase in speed (~8-fold) and decrease in elevation (~150 m) since the break-up of the Larsen B Ice Shelf in 2002. However, during the period November 2004 to November 2005, a portion of the lower glacier showed a sudden, localized (~2km diameter) increase in the rate of lowering, exceeding 100 m/year for a few months. The glacier accelerated at a greater rate during and after this period (as determined by a series of satellite image pairs ending with Formosat-2 images in 2008 and 2009), and the surface character of the lower

glacier changed significantly to a highly fractured serac field. Examination of the Crane Glacier fjord bathymetry by multi-beam sonar in regions now exposed due to ice shelf and glacier retreat shows a series of enclosed over-deepened basins. This suggests that a series of sub-glacial lakes existed in the lower trunk prior to ice shelf disintegration. The region of the large Crane elevation change is still ice-covered and therefore unmapped for bathymetry, but may represent an additional lacustrine basin. Changing ice surface slope in the years before the sudden drawdown can be inferred to have significantly changed the sub-glacial hydrologic pressure field. In the Crane Glacier case, acceleration during drainage may be driven by the large further increase in along-flow surface slope caused by drainage.

What Can Tiny Fossils Teach Us About WAIS History and Subglacial Processes?

Scherer, Reed Scherer Reed P R.P. Scherer, Geology & Environmental Geosciences, Northern Illinois University, De Kalb, IL

As we launch a new phase of subglacial and sub-ice shelf exploration and sampling with the WISSARD project it seems a good time to review the type of data regarding ice sheet history and subglacial processes that can be gleaned from microfossils recovered from the subglacial and englacial environment. Sediments, including short sediment cores, were recovered from beneath the southern Ross Ice Shelf in the 1970s (Ross Ice Shelf Project Site J-9) and beneath Ross ice streams in the 1990s (Upstream, Whillans and Kamb ice streams). Some sub-ice stream samples include evidence of past retreat of the ice sheet during the Pleistocene. Fossil diatoms (marine planktonic algae), with supporting evidence from cosmogenic-sourced ^{10}Be in the sediments, provided evidence that open water stretched across the West Antarctic interior at least once (though possibly multiple times) during the last ca. 1 million years (Science, 281, 82-85, 1998; GRL, 35, 2008). Unfortunately, a key hypothesis described by John Mercer in his famous "Threat of Disaster" paper (Nature, 271, 321-325, 1978) remains equivocal: Did the WAIS collapse during the penultimate interglacial, 123 ka ago? We've learned a lot about subglacial hydrology and marine ice sheet dynamics recently, but the magnitude of fluxes, especially sediment flux to the grounding line, remain conjectural. WISSARD will recover sediments from the Grounding Zone (RAGES) and a subglacial lake beneath the Whillans ice stream (LISSARD).

These sediments will provide microfossil data to address hypotheses regarding ice sheet history and subglacial processes, including constraining ice stream sediment flux via the subglacial hydrological system and particle flux to the subglacial environment from englacial debris. Microfossils will contribute to these analyses, as well as providing a qualitative assessment of the intensity of subglacial sediment shearing, based on textural data and morphologic features of the sediment and its fossils (Geology, 32, 557-511, 2004; J. Nanotech. Nanosci., 5, 96-99, 2005; J. Sed. Geol., 68, 487-469, 1998). Over the next several years, new data from WISSARD, PIG, WAIS divide, and other projects may answer not only Mercer's first question, but improve the assessment of the potential for the future disaster that he outlined.

Comparative Subglacial Hydrology of Thwaites Glacier, West Antarctica, Using Basal Specularity

Schroeder, Dustin Schroeder Dustin M; Blankenship Donald D; Young Duncan A D.M. Schroeder, D.D. Blankenship, D.A. Young, , The University of Texas Institute for Geophysics, Austin, TX

A key control on ice sheet response to climate forcing is the subglacial hydrologic boundary condition. Airborne ice penetrating radar sounding has been used with variable success to identify and characterize subglacial hydrological systems by the strength of the return from the basal interface. We present a means for improved characterization of subglacial hydrology using multiple focusing windows to separate the diffuse and specular components of the interface return. The specularity content of the basal return can indicate the presence and extent of subglacial water independent of temperature profile and impurity concentration of the ice column. We apply this technique to a gridded aerogeophysical survey over the confluence of tributaries to Thwaites Glacier, West Antarctica, a region of particular interest for its subglacial hydrology. In the context of subglacial hydraulic gradients, we compare the specularity at the confluence to that for each of the tributaries as well as for the trunk and grounding line. We also compare basal water system interpretations from specularity content to those from more traditional echo strength analysis. This survey was collected using a 60 MHz coherent ice penetrating radar with a linear frequency modulated waveform with a 15 MHz bandwidth. We discuss the potential value of this approach for the generalized

characterization of basal water systems using radar sounding data.

Subglacial Lake Vostok: a Review of Geophysical Data Regarding Its Physiographical Setting

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Subglacial Lake Vostok is the largest and best known sub-ice lake in Antarctica. The establishment in the 1990s of its water depth, at over 500 m, led to an appreciation that such environments may be habitats for life and may contain ancient records of ice sheet change. As a consequence, Lake Vostok catalyzed subglacial aquatic environment exploration and research. Here we discuss the discovery of the lake, and the various geophysical datasets that, in combination, reveal the physiography of the lake. We also discuss how these data have led to an appreciation of the physical chemical and biological processes in the lake. The outline of the lake is known with a relatively high degree of accuracy, such that its coastline and 'islands' within the lake are well defined. The lake is over 250 km long and around 80 km wide in one place. It lies beneath 4.2-3.7 km of ice, and exists because background levels of geothermal heating are sufficient to warm the base of the ice sheet to the pressure melting value. Seismic data, and analysis of gravity measurements, show the lake to have a bathymetry involving two distinct basins. One is small (~2000 km³) and deep (~800 M) in the southern part of the lake, where the ice core is positioned, the other larger region to the north (~10,000 km³) is also relatively shallow (~300 m). Analysis of the Vostok ice core has revealed over 200 m of ice that has been accreted to the underside of the ice sheet. This ice has provided a valuable insight into the potential biological and chemical setting of the lake. The steady inclinations of the ice-water interface (due to the lake being in hydrostatic equilibrium with the ice above), leads to differential ice-base melting (in the north) versus freezing in the south, which excites circulation within the lake and potential mixing of the water column. The nature of such circulation depends heavily on the chemical properties of the water itself, which is not known at this stage. The age of the lake is

likely to be as old as the ice sheet itself. The topographic setting in which the lake sits is far older than the ice sheet and so we can expect the lake to have developed at this site for as long as the ice sheet has been at a continental size. This means the lake is possibly as old as 14 Ma. The age of the water within the lake will be related to the age of the ice which melts into it, and the level of mixing that takes place. Estimates put that combined age at around 1 Ma.

The Identification And Physiographical Setting Of Antarctic Subglacial Lakes: An Update Based On Recent Discoveries

Siegert, Martin Wright Andrew; Siegert Martin John A. Wright, M.J. Siegert, School of GeoSciences, University of Edinburgh, Edinburgh, UNITED KINGDOM

We investigate the glaciological and topographic setting of known Antarctic subglacial lakes (following a previous assessment by Dowdeswell and Siegert, 2002, based on the first inventory of 77 lakes). Procedures used to detect subglacial lakes are discussed, including radio-echo sounding (RES, which was first used to demonstrate the presence of subglacial lakes), surface topography, topographical changes, gravity measurements and seismic investigations. Recent discoveries of subglacial lakes using these techniques are detailed, from which a revised new inventory of subglacial lakes is established, bringing the total number of known subglacial lakes to 386. Using this new inventory, we examine various controls on subglacial lakes, such as overriding ice thickness and position within the ice sheet, and formulate frequency distributions for the entire subglacial lake population based on these (variable) controls. We show how the utility of RES in identifying subglacial lakes is spatially affected; lakes away from the ice divide are not easily detected by this technique, probably due to scattering at the ice sheet base. We show that subglacial lakes are widespread in Antarctica, and it is likely that many are connected within well-defined subglacial hydrological systems.

Endurance: Two Missions to Antarctica and Paths to Advanced Sub-Glacial Science Autonomy

Siegert, Martin Stone William C.; Richmond Kristof; Gulati Shilpa; Flesher Chris; Hogan Bart; Murarka Aniket; Khulman Greg; Siegel Victoria; Doran Peter T; Johnson Andrew E; Obryck Maciej; Priscu John C; McKay

Christopher P W.C. Stone, K. Richmond, S. Gulati, C. Flesher, B. Hogan, A. Murarka, G. Khulman, V. Siegel, , Stone Aerospace / PSC, Inc., Del Valle, TX; P.T. Doran, A.E. Johnson, M. Obryck, Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, IL; J.C. Priscu, Department of LRES, Montana State University, Bozeman, MT; C.P. McKay, , NASA Ames, Mountain View, CA

Permanently ice-covered liquid water environments are among the leading candidate sites for finding evidence of extant life elsewhere in our solar system. In order to have the proper tools and strategies for exploring the extant ice-covered planetary environments, we have developed an autonomous underwater vehicle (AUV) named ENDURANCE (Environmentally Non-Disturbing Under-ice Robotic ANtarctic Explorer). ENDURANCE has just completed the second of two Antarctic field seasons with great success. Our new dataset for West Lake Bonney (WLB) includes hi-resolution sonar maps of the lake including through the connecting channel and into East Lake Bonney, 3D temperature, conductivity, pH, REDOX, photosynthetically active radiation, chl-a fluorometry and dissolved organic matter. The drop sonde science package also included a bottom imager which collected 100's of images of the benthic microbial community and an upward looking camera captured information on sediment distribution in the ice cover. ENDURANCE is a highly maneuverable, hovering autonomous underwater science platform descended from the DEPTHX vehicle, both of which were developed under NASA ASTEP funding. ENDURANCE had the specific mission of descending through a 5 meter deep melt hole in the ice cap of West Lake Bonney, Taylor Valley, Antarctica and conducting three autonomous science tasks: 1) measuring the 3D water chemistry of the lake; 2) mapping the underwater face of Taylor glacier where it enters the lake; and 3) charting the bathymetry of the lake bottom; and then 4) returning safely on its own to the melt hole – barely 0.25 m larger in diameter than the vehicle – from more than 2 kilometers radial range and rising up the hole to be retrieved for data download and servicing for the next mission. Included among these was the development of an automated sub-sea servo winch and sonde payload with its nine water chemistry probes, high definition imaging system, and bottom ranging altimeter. A specialized ice-picking behavior was developed to maximize cast initial proximity to the underside of the ice sheet and to reduce power consumption during casts. The navigation

system was comprised of a three layer filter utilizing high grade dead reckoning, ultrashort baseline localization, and machine vision. Also new were web-based glacier imaging systems and a 120-degree swath high resolution multi-beam mapping sonar system – used for both lake bottom and glacier face mapping. New power systems and a 3D situational awareness system that incorporated all vehicle geometry sensors were added in time for the 2009 West Lake Bonney mission. Many of the characteristics and capabilities of ENDURANCE –now successfully demonstrated in complex under-ice settings beneath West Lake Bonney – are the types of behaviors that will be needed for sub-ice autonomous probes to Europa, Enceladas, and other outer planet watery moons.

Microbial Communities in Antarctic Subglacial Aquatic Environments (SAE)

Skidmore, Mark Skidmore Mark L M.L. Skidmore, Earth Sciences, Montana State University, Bozeman, MT

Rock-water interactions are fundamental to the global geochemical cycles of many elements, including C, Fe, S, Si and P. These interactions are mediated by microbes in all Earth surface environments, and the SAE of Arctic and Alpine glaciers and ice sheets are no exception. Glaciological processes under ice masses, including ice sheets provide sustainable habitat for microbes, forming an aquatic environment through basal melting and providing nutrients and energy from bedrock comminution. Research over the past decade or so, largely through remote sensing techniques has demonstrated the abundance of water beneath ice sheets, including lakes, channelized drainage systems and saturated sediments and has also highlighted the interconnectivity of these water bodies. Water is a key requirement for microbial life, and its abundance beneath the Antarctic Ice Sheet indicates a significant volume of potential microbial habitat that is largely unexplored. Sampling of SAE beneath the Antarctic Ice Sheet especially for microbiological research has been limited. Examples are accreted ice from subglacial Lake Vostok in East Antarctica and saturated till from beneath the ice streams draining the West Antarctic Ice Sheet. Viable microbes have been detected in these samples and their activity measured at temperatures close to freezing in the laboratory, demonstrating that in situ activity in subglacial environments is plausible. Additional evidence for in situ subglacial microbial activity in saturated tills comes from a) physical attributes of subglacial

till particles that include etch pits, often indicative of microbially-mediated mineral weathering and b) the geochemistry of the till pore waters is consistent with biologically-driven sulfide oxidation coupled to carbonate and silicate mineral weathering as a significant solute source. The diversity and activity of subglacial microbial communities depends on the composition of the glacial flour, and the content of labile organic matter, sulfides and Fe(III) in particular, which effects the Eh and pH of the micro- and macro-environments. It also depends on the hydrological properties of subglacial system components, that controls water-rock ratios, water-rock interaction times and flow through rates, which in turn control the supply of dissolved gases and movement of nutrients and waste products generated through microbial activity. Key differences between Antarctic SAE and those beneath Arctic and Alpine glaciers that have been more extensively studied are the scale of the hydrological systems and their components, potential water residence times, which could be orders of magnitude greater in Antarctic systems and the lack of connectivity between oxygenated surface waters and the subglacial environment thus potentially leading to enhanced anoxic conditions in certain environments. These differences and their potential impact on microbial populations in Antarctic SAE will also be discussed.

Subglacial Drainage Events Under Outlet Glacier End-members: Byrd Glacier and Whillans Ice Stream

Stearns, Leigh Stearns Leigh A; Fricker Helen Amanda L.A. Stearns, , University of Kansas, Lawrence, KS; H.A. Fricker, , Scripps Institution of Oceanography, La Jolla, CA; In the past 5 years, surprisingly active networks of subglacial lakes have been found beneath the Antarctic ice sheet. However, so far the only link between subglacial outburst activity and glacier dynamics was observed on Byrd Glacier. There, an outburst flood from two relatively small lakes released $\sim 1.7 \text{ km}^3$ of water beneath Byrd Glacier, East Antarctica, and caused a ~ 10

ENDURANCE: Two Missions to Antarctica and Paths to Advanced Sub-Glacial Science Autonomy

Stone, William Stone William C. W.C. Stone, , Stone Aerospace, Del Valle, TX;

Permanently ice-covered liquid water environments are among the leading candidate sites for finding evidence of extant life

elsewhere in our solar system (e.g. on Europa and other Galilean satellites). In order to have the proper tools and strategies for exploring the extant ice-covered planetary environments, we have developed an autonomous underwater vehicle (AUV) which has generated for the first time, 3-D biogeochemical datasets in the extreme environment of perennially ice-covered Antarctic dry valley lakes. ENDURANCE (Environmentally Non-Disturbing Under-ice Robotic ANtarctic Explorer) at the time of writing this abstract is 3 days away from completing the second of two Antarctic field seasons with great success. Our new dataset for West Lake Bonney (WLB) includes unprecedented hi-resolution sonar maps of the entire lake including through the connecting channel and into East Lake Bonney, 3D (at 100 m xy and subcentimeter z resolution) temperature, conductivity, pH, REDOX, photosynthetically-active radiation, chl-a fluorometry and dissolved organic matter. The drop sonde science package also included a bottom imager which collected 100's of images of the benthic microbial community and an upward looking camera captured information on sediment distribution in the ice cover. Variation in ice thickness across the lake was acquired both by sonar and pressure transducer readings while the vehicle was at rest under the ice. A forward looking camera in conjunction with swath sonar was used to confirm the location of the ground line of Taylor Glacier at the west end of the lake. Our preliminary assessment of the data suggests that the depth of the grounding line coincides with anomalous water characteristics near the glacier face, suggesting either a subglacial discharge or some previously undocumented mixing phenomenon. ENDURANCE is a highly maneuverable, hovering autonomous underwater science platform descended from the DEPTHX vehicle, both of which were developed under NASA ASTEP funding. ENDURANCE had the specific mission of descending through a 5 meter deep melt hole in the ice cap of West Lake Bonney, Taylor Valley, Antarctica and conducting three autonomous science tasks: 1) measuring the 3D water chemistry of the lake; 2) mapping the underwater face of Taylor glacier where it enters the lake; and 3) charting the bathymetry of the lake bottom; and then 4) returning safely on its own to the melt hole – barely 0.25 m larger in diameter than the vehicle – from more than 2 kilometers radial range and rising up the hole to be retrieved for data download and servicing for the next mission. Many of the characteristics and capabilities of ENDURANCE – now successfully

demonstrated in complex under-ice settings beneath West Lake Bonney -- are the types of behaviors that will be needed for sub-ice autonomous probes to Europa, Enceladas, and other outer planet watery moons. The presentation will discuss all of the above along with quantitative engineering data on the design and field operation of the ENDURANCE autonomous science platform along with advanced concepts for sub-ice autonomous science. www.stoneaerospace.com

Glaciological And Geophysical Studies in Dome A, East Antarctica

Sun, Bo Sun Bo; Tang Xueyuan; Li Xin; Cui Xiangbin; Zhang Dong B. Sun, X. Tang, X. Li, X. Cui, D. Zhang, , Polar Research Institute of China, Shanghai, CHINA

Dome A, located in the central East Antarctic ice sheet (EAIS), is the summit of the Antarctic ice sheet. During the 21st and 24th Chinese National Antarctic Research Expedition (CHINARE 21, 2004/05; CHINARE 24, 2007/08), ground-based ice radar systems were used to a three-dimensional investigation in the central 30 km×30 km region at Dome A. The obtained high resolution datasets were transferred and interpolated into the ice thickness distribution, subglacial topography and internal layers digital elevation model (DEM). The results of the investigation indicate that the average ice thickness in the Dome A central 30 km×30 km region is 2233 m, with a minimal ice thickness of 1618 m and a maximum of 3139 m at Kunlun Station. The subglacial topography is relatively sharp, with an elevation range of 949-2445 m. The typical mountain glaciation morphology is likely to reflect the early evolution of the Antarctic ice sheet. The datasets also show some arches and troughs in isochronous ice layers. There exist some typical synclines and anticlines in ice revealed by ice-penetrating radar in some local regions. To characterize the roughness from bedrock and morphology of internal layers beneath ice sheets, a two-parameter roughness index is outlined, the two parameters are from not only FT of elevations, but also FT of surface slopes. Geometric and glacier dynamical meanings of the roughness index are analyzed and discussed. It is shown that the method can be used to conveniently demonstrates the spatial distribution of roughness, without absence of statistically geometric information, and could be used to estimate the boundary condition such as basal sliding in glacier dynamics, or differentiate the factors such as erosion/deposition or continental/marine settings in geomorphology.

A 1-D model is used to calculate the past rates of ice accumulation by internal layering. An approximate mean accumulation from 0.018 to 0.027m/yr over the past 34.6k years, along the RES profiles, was estimated. Also, we have taken the accumulation was 0.02-0.045m/yr in the past 34.6-44.6kyr, and 0.01-0.023m/yr in the past 44.6-84.6kyr along the profile. The variability of accumulation in time-space around the ice divide also was given.

Enantiomer-specific Isotope Analysis for Chiral Amino Acids in Antarctic Sub-glacial Environment: Proposal

Takano, Yoshinori Takano Yoshinori Y. Takano, Biogeoscience, JAMSTEC, Yokosuka, JAPAN

The one-handedness of terrestrial L-amino acids in the proteins and D-sugars of DNA and RNA are essential to the formation, structure, and function of biopolymers for life on Earth. D-amino acids such as D-alanine and D-glutamic acid are significant enantiomers that is physiologically essential for microbial growth and metabolic maintenance. The nitrogen isotopic difference $\Delta^{15}\text{ND-L}$ (defined as $\delta^{15}\text{ND-Ala} - \delta^{15}\text{NL-Ala}$) in peptidoglycan amino acids in bacteria such as Firmicutes and Actinobacteria (Enterococcus faecalis, Staphylococcus aureus, Staphylococcus staphylolyticus, Lactobacillus acidophilus, Bacillus subtilis, Micrococcus luteus and Streptomyces) tended to be N-depleted in D-alanine ($\Delta^{15}\text{ND-L} - 2.0\text{‰}$). These results suggest that the composition of isotopically heterogeneous components in these bacteria is primarily controlled by enzymatic pathways prior to formation of the bacterial cell wall. In contrast, the $\Delta^{15}\text{ND-L}$ of racemic alanine, simplest chiral amino acid (C3), in the pristine chemical pathway during the nucleophilic substitution reaction (SN1 type, produce 50:50 racemic mixture) identified fully homogeneous components for each enantiomer. The enantiomer-specific isotopic analysis (ESIA) method is useful in determining the origins of chirality in biogenic and abiogenic processes. Consequently, if there is an abiotic synthesis of amino acids by hydrothermal reaction processes in sub-glacial environment, theoretically the $\Delta^{15}\text{ND-L}$ will be homogeneous components. References [1] Chikaraishi et al., Determination of aquatic food-web structure based on compound-specific nitrogen isotopic composition of amino acids: Limnology and Oceanography: Methods, 7, 740-750 (2009). [2] Takano et al., Compound-specific nitrogen isotope analysis of D-, L-alanine and valine: application of diastereomer separation to $\delta^{15}\text{N}$ and microbial peptidoglycan studies:

Analytical Chemistry, 81, 394-399 (2009).

Crustal Uplifting Rate Associated With Late-Holocene Glacial-isostatic Rebound at Skallen and Skarvsnes, Lützow-Holm Bay, East Antarctica: Evidence of a Synchrony in Sedimentary and Biological Facies on Geological Setting

Takano, Yoshinori Takano Yoshinori Y. Takano, Biogeosciences, JAMSTEC, Yokosuka, JAPAN

We determined the mean crustal uplifting rate during the late Holocene along the Soya Coast, Lützow-Holm Bay, East Antarctica, by dating a marine-lacustrine transition recorded in lake sediments. We focused on temporal variations in the chemical composition of sediments recovered from Lake Skallen Oike at Skallen and Lake Oyako at Skarvsnes. Both sets of lake sediments record environmental changes associated with a transition from marine to lacustrine (fresh water) settings, as indicated by analyses of sedimentary facies for carbon and nitrogen contents, nitrogen isotopic compositions ($^{15}\text{N}/^{14}\text{N}$), and major element concentrations. Changes in the dominant primary producers during the marine-lacustrine transition were also clearly revealed by biogenic Opal-A, diatom assemblages, and gradient gel electrophoresis (DGGE) with 16S rRNA gene analysis. Geochronology based on radiocarbon dating of acid-insoluble organic carbon suggested that the environmental transition from saline to fresh water occurred at 2940 ± 100 cal yr BP at L. Skallen and 1060 ± 90 cal yr BP at L. Oyako. Based on these data and a linear approximation model, we estimated a mean crustal uplifting rate of 3.6 mm yr^{-1} for the period since the marine-lacustrine transition via brackish condition; this uplift is attributed to glacial-isostatic rebound along the Soya Coast. Based on ages obtained for the lowermost sediments (crustal basement), initial sedimentation process started by at least 5293–5559 cal yr BP (2σ) at L. Skallen and by 1383–1610 cal yr BP (2σ) at L. Oyako. The geological setting was the primary factor in controlling the emergence event and the occurrence of simultaneous changes in sedimentary and biological facies along the zone of crustal uplift. This study is useful to understand past sub-glacial environments during glacial-erosion processes.

Chemistry Of Vostok Accretion Ice And Pore Waters Beneath The Kamb And Bindschadler Is Consistent With Microbial Life Beneath The Antarctic Ice Sheet

Tranter, Martyn Tranter Martyn M. Tranter, Bristol Glaciology Centre, University of Bristol, Bristol, 0, UNITED KINGDOM

Interpretation of chemical variations in the accretion ice at the base of the Vostok Ice Core is controversial, since saline waters and thermotectonic processes are required to account for the variations observed. Here, we present a much more simple explanation of the variations based on known geophysical characteristics of the lake and simple water and solute mass balance requirements. We show that concentrated accretion ice should form over the embayment, since the embayment is recharged only with relatively concentrated lake water, and that dilute accretion ice is formed over the open lake, since the lake is recharged with relatively dilute meteoric ice. Our estimated lake and embayment water chemistries are consistent with the presence of microbially-mediated geochemical weathering within the lake. The correspondence of higher microbial counts in the more concentrated accretion ice is consistent with the presence of microbes in the surface waters of the Subglacial Lake Vostok. We compare and contrast the chemical compositions of the Vostok waters with those from tills beneath the Bindshadler and Kamb Ice Streams. Again, the chemistry of the sub-ice stream waters is consistent with the presence of microbially-mediated geochemical weathering reactions, particularly when morphological and mineralogical evidence is taken into account. Together, this work suggests that microbial life is present in the spectrum waters that make up the sub-ice sheet hydrological drainage system, which includes subglacial lakes and their inter-connections.

Formation and Preservation of Long-Term Paleoclimatic and Paleoenvironmental Records in Subglacial Lakes

Tulaczyk, Slawek Tulaczyk Slawek S. Tulaczyk, Earth Sciences, University of California, Santa Cruz, Santa Cruz, CA;

Lacustrine records provide the fundamental basis for building understanding of paleoenvironmental and paleoclimatic evolution of non-glaciated continents over timescales ranging from sub-annual to millions of years. Such records represent an important spatial

supplement to deep-sea and continental-shelf marine sedimentary archives. In Antarctica, ice cores and ice-marginal geologic records yielded a wealth of constraints on climatic and environmental changes that took place on this continent, and globally, in the last few million years. Additional data sets are needed to extend the temporal and spatial footprints of relevant observational evidence. Sedimentary sequences in Antarctic subglacial lakes will provide a new archive of paleoenvironmental and paleoclimatic records that may greatly improve the existing understanding of Antarctic and global climate dynamics. Admittedly, Antarctic subglacial lakes are isolated by thick ice from direct atmospheric forcings and inputs (e.g. dust, pollen, etc.), which are often used in reconstructing past climate and environmental changes. However, subglacial lacustrine sedimentation should still be sensitive to long-term climate changes (over timescales >10kyrs) because subglacial hydrology is fundamentally tied to the geometry, flow rates, and the thermal state of the ice sheet. These, in turn, are determined by climatic factors, such as mean annual temperatures and accumulation rates. For instance, cold and dry climatic periods should result in low basal melting rates and relatively sluggish inputs of basal meltwater into subglacial lake basins. In lacustrine records, these conditions may be then reflected in lowered sedimentation rates and reduced maximum sediment grain size because reduced subglacial water fluxes will have lowered sedimentary capacity and competence. During warmer climatic periods, increased basal melting rates should lead to higher sedimentation rates and larger maximum grain sizes. Even though the ice sheet acts as a low-pass filter for climatic changes, Milankovitch-scale climate variability has sufficiently long periodicity (>20kyr) to turn out to be a recognizable driver of sedimentary variability in subglacial lacustrine sequences accumulating over time periods covering hundreds of thousands to millions of years. This would enable application of well-established orbital tuning techniques to develop detailed timescales for subglacial lacustrine sequences. As in non-glaciated lake basins, cyclic climate forcings are likely to be convolved in subglacial lake settings with local and regional factors that have to do with changes in interconnectivity of subglacial conduits, internal ice sheet dynamics, volcanic/geothermal events, or subglacial erosion and sedimentation. The value of Antarctic subglacial lacustrine records will be greatly enhanced if such records contain transition/s from/to pre-glacial to/from

subglacial conditions. There are known examples of Northern Hemisphere lake basins, in which overriding ice sheet did not obliterate pre-glacial sedimentary sequences.

Microbial Responses During The Transition To Polar Night in Permanently Ice-covered Antarctic Lakes Trista J. Vick and John C. Priscu Montana State University, Department of Land Resources and Environmental Science, 334 Leon Johnson Hall, Bozeman, Montana

Vick, Trista Vick Trista J; Priscu John C T.J. Vick, J.C. Priscu, Land Resources and Environmental Sciences, Montana State University, Bozeman, MT

A majority of the research on the Antarctic continent occurs during the austral spring and summer (October-January), a period of continuous sunlight, when field support is readily available. Through additional logistical efforts, we were able to collect the first data on the MCM lakes during the transition from summer to winter (October-April). A combination of bacterial productivity data and 16S ribosomal RNA gene tag sequence libraries allowed us to examine ecosystem responses as photosynthetic input of new carbon stopped. Microbial protein biosynthesis increased in the east lobe of Lake Bonney and in Lake Hoare during March and April ($p < 0.05$); there was no change in protein biosynthesis in the west lobe of Lake Bonney or in Lake Fryxell. DNA replication was not affected ($p < 0.05$) by the onset of complete darkness, inferring that the bacteria do not rely directly on phytoplankton primary production as their source of organic carbon during this period. A high rate of dark ¹⁴C-labeled bicarbonate incorporation (0.01 to 0.09 $\mu\text{gC l}^{-1} \text{d}^{-1}$) in one of our study lakes (Lake Fryxell) implies that chemoautotrophic primary production is important in sustaining the ecosystem of this lake during the winter. An overall decoupling of bacterial protein biosynthesis and DNA replication also occurred during the transition to winter. Protein biosynthesis increased relative to DNA replication as darkness set in, which may signify decreasing rates of cell division. Such a shift in cellular function, in combination with continued bacterial production, indicates that bacterioplankton in the MCM lakes remain active during the polar night, but may direct more energy towards survival than reproduction. Our results indicate that concurrent measurement of protein synthesis and DNA synthesis in dark, sub-ice aquatic systems can provide important

information on the physiological state of the microorganisms present.

On the Role of Subglacial Bio/Geochemical Processes in Global Biogeochemical Cycles - Results from Kamb Ice Stream and ANDRILL

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Subglacial environments play an important role for the dynamic of ice sheets and global sea level change. While subglacial environments beneath alpine glaciers consist of relatively small drainage systems, subglacial environments in Antarctica and Greenland are complex continental scale systems, which directly connect to the ocean. Through intricate feedback mechanism subglacial processes, including processes in the sub-ice-shelf cavity, influence global ocean circulation and contribute to the fertility of the ocean. Here we present the first geochemical measurements of basal water, porewater and sediment recovered from the base of Kamb Ice Stream, West Antarctica and reviews them in the context of global geochemical cycles and potential contribution of subglacial environments to the fertility of the oceans. The results point to an oxygen depleted, sulfate rich, acidic aquatic environment favorable to the removal of sedimentary carbonate. The removal of carbon and other nutrients from the sediment and subsequent transport with the flow of basal water may constitute a significant flux. Chemical processes across the ice sheet grounding zone, a zone of high saline gradients (low solute freshwater to high saline ocean water) may trigger either deposition of solutes as observed in the ANDRILL-MIS core, or further mobilization of nutrients from sediment as hypothesized for Fe with subsequent distribution in the polar ocean. Overall subglacial environments are far from being understood and it is exciting that upcoming projects will be able to answer some of these questions in the near future. It is however important to properly understand the effect of sampling on sample chemistry when interpreting the results of these projects. Results from the ANDRILL porewater work indicate a post recovery shift of up to 1 pH. Not considering the pressure and temperature induced changes during recovery from a depth of 1000 m or more the results indicate the importance to combine insitu measurements with subsequent laboratory work.

Examining The Potential For Methanogenesis in Antarctic Subglacial Aquatic Environments

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Antarctic subglacial aquatic environments, including subglacial lakes, are a previously neglected component of the Earth's carbon cycle; a reflection of the view held until recently that the basal regions of ice sheets are dominated by abiotic and oxic conditions. Here we consider the potential of these environments as favourable habitats for methanogenic Archaea, and hence sites of methanogenesis. We employ concentrations of methane, carbon dioxide and oxygen in basal ice from three glacier/ice sheet systems with contrasting organic carbon substrates (Lower Wright Glacier, Antarctica; Russell Glacier, Greenland Ice Sheet and Finsterwalderbreen, Svalbard) in order to assess the methanogenic potential in Antarctic subglacial environments. Concentrations of methane in debris rich basal ice exceed atmospheric concentrations by up to three orders of magnitude, carbon dioxide concentrations are also elevated with respect to atmospheric values and oxygen is depleted. These observations are consistent with a diverse and active subglacial microbial community, including heterotrophs and methanogens. We go on to provide first evidence of the presence, diversity and abundance of methanogenic Archaea beneath the Antarctic and Greenland ice sheets, determined using a combination of microscopic and molecular techniques. The abundance of Archaea in the subglacial sediment samples from Antarctica and Greenland was between 10^3 - 10^5 cells per gram of sediment, and most Archaea specific 16S rDNA clones were found to be close to uncultured clones from other types of cold environments, such as ice-covered lakes and permafrost peat. Between 40 and 60

How Well Do Subglacial Lakes Act as Hydraulic Jacks?

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Recent evidence suggests that subglacial lake drainage promotes ice speed-ups (e.g. Stearns et al., 2008). While the drainage of large subglacial lakes may cause fast ice-flow downstream, filled or filling subglacial lakes may promote faster flow over them by decreasing basal resistance to flow (Sergienko et al., 2008). Since December of 2007, we have operated a network of continuously operating GPS receivers on Whillans Ice Stream (WIS), West Antarctica. The stations are located on, or near, active subglacial lakes, identified using IceSAT data (Fricker et al., 2007; Smith et al., 2009). We augmented the GPS network with passive broadband seismometers during the austral summers of 2007 and 2008, in order to more closely study the bi-daily stick-slip events occurring on the lower part of WIS (Bindschadler et al., 2002). Our results indicate that the rupture speed of the stick-slip events is dependent upon the frictional coupling of the basal layer. Yet, the subglacial layer is not homogenous across all of WIS, as the subglacial lakes provide an important outlier. Preliminary results from two stations, one on Subglacial Lake Whillans (SLW) and another station ~15 km from the SLW station, indicate that ice immediately over SLW slips less during slip events, as compared to the adjacent off-lake station. However, the SLW ice flows faster in between slip events than the adjacent station, so that averaged over a few days, the SLW ice flows 8-9 cm/day faster than the adjacent station. If extrapolated, our results suggest ice directly overlying SLW flows ~30 m/yr faster than adjacent ice. The differences in the nature of slip events and inter-event creep suggest a rapid basal transition over a mere ~15 km. Our observations may yield important information regarding mechanics and dynamics of ice stream beds at the scale of 10s of km.



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