<table>
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<tr>
<th>Time</th>
<th>Event</th>
<th>Speaker(s)</th>
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<tr>
<td>1:30-3:30</td>
<td><strong>field trip of Whidbey Island Glacial Geology</strong> - walking along beach from Camp Casey</td>
<td>K. Licht</td>
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<tr>
<td>3:30-3:35</td>
<td>Welcome - opening remarks</td>
<td>K. Licht</td>
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<tr>
<td>3:35-4:00</td>
<td>NSF update/information</td>
<td>Doug Kowalewski</td>
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<tr>
<td>3:40-3:55</td>
<td>Antarctica is now the Best Mapped Continent</td>
<td>Paul Morin and the Staff and Students of the Polar Geospatial Center</td>
</tr>
<tr>
<td>3:55-4:10</td>
<td>Progress toward a Rapid Access Ice Drill (RAID) for reconnaissance drilling of deep ice, bedrock, and borehole observatories on the Antarctic Plateau</td>
<td>Jeff Severinghaus, John Goodge, Ryan Bay</td>
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<tr>
<td>4:10-5:30</td>
<td>Science communication Workshop</td>
<td>John Meyer</td>
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<tr>
<td>5:30</td>
<td>Dinner</td>
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<tr>
<td>8:30-8:40</td>
<td>Licht - announcements</td>
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<tr>
<td>8:40-8:55</td>
<td>Upper mantle and transition zone seismic structure of Antarctica and adjacent ocean basins from full waveform adjoint tomography</td>
<td>Douglas A. Wiens, Andrew J. Lloyd, Hejun Zhu, Jeroen Tromp, Andrew Nyblade, Sridhar Anandakrishnan, Richard Aster, Audrey Hierta, J. Paul Winberry, Teryy Wilson, Ian Dalziel, Samantha Hansen, Patrick Shore</td>
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<tr>
<td>9:00-9:20</td>
<td>INVITED: Continental arc initiation, magma fluxing, and termination recorded in Ross Orogen of Antarctica</td>
<td>Demian Nelson, John Cottle, Grahan Hagen-Peter</td>
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<tr>
<td>9:25-9:40</td>
<td>Apatite and zircon double-dating thermochronologic constraints on the low temperature thermal history of the central Transantarctic Mountains</td>
<td>Christine Kassab, Stuart Thomson, Kathy Licht</td>
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<tr>
<td>9:45-10:00</td>
<td>New Information on the theropod dinosaur <em>Cryolophosaurus ellioti</em> from the Early Jurassic Hanson Formation of the Central Transantarctic Mountains</td>
<td>Nathan Smith, William Hammer, Peter Makovicky</td>
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<tr>
<td>10:00-10:40</td>
<td><strong>coffee break</strong></td>
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<tr>
<td>10:40-10:55</td>
<td>Geohistory Drives the Evolution of Life History Traits and Genome Architecture in Extant Terrestrial Microfauna</td>
<td>Byron Adams, Bishwo Adhikari, Xia Xue, Breana Simmons, Becky Ball, Jeb Barrett, Diana Wall</td>
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<tr>
<td>11:00-11:15</td>
<td>Landscape Evolution of the Ice Free Areas Driven by Uniquely Antarctic Processes</td>
<td>Jaako Putkonen, Ted Bibby, Daniel Morgan, and Greg Balco</td>
</tr>
<tr>
<td>11:20-11:40</td>
<td>INVITED: Multispectral Mapping of the Transantarctic Mountains: Key Geologic and Biologic Insights to Augment Traditional Field Investigations</td>
<td>Mark Salvatore</td>
</tr>
<tr>
<td>11:45-12:00</td>
<td>The Polar Rock Repository: a resource for Antarctic earth science</td>
<td>Anne Grunow</td>
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<tr>
<td>12:00-1:30</td>
<td>Lunch</td>
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<tr>
<td>1:30-1:45</td>
<td>A middle Pleistocene through middle Miocene moraine sequence in the central Transantarctic Mountains, Antarctica</td>
<td>Allie Balter, Gordon Bromley, Greg Balco, Holly Thomas, Margaret Jackson</td>
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<tr>
<td>1:50-2:05</td>
<td>Subglacial chemical weathering in the Transantarctic Mountains traced through meteoric ¹⁰⁷Be</td>
<td>Joseph Graly, Kathy Licht, Marc Caffee</td>
</tr>
<tr>
<td>2:10-2:25</td>
<td>Dating of blue-ice sediments and implications for moraine formation, central Transantarctic Mountains</td>
<td>Michael Kaplan, Kathy Licht, Gisela Winckler, Joerg Schaefer, Jennifer Lamp, Christine Kassab, Joseph Graly, Katrin Lindback</td>
</tr>
<tr>
<td>3:15-3:45</td>
<td><strong>coffee break</strong></td>
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<tr>
<td>3:45-4:00</td>
<td>ALL poster introductions - lower level</td>
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<tr>
<td>4:00-5:00</td>
<td>Poster session</td>
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<td>5:30</td>
<td>Dinner</td>
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<td>Time</td>
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<tr>
<td>8:30-8:40</td>
<td>Licht</td>
<td>Ellsworth-Whitmore Mountains Crustal Block: Linking Outcrop Geology to Deep Earth Processes</td>
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<tr>
<td>9:00-9:15</td>
<td>Licht</td>
<td>Provenance fingerprints of Weddell Sea Embayment ice stream tills can be used to trace past ice flow paths</td>
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<tr>
<td>9:20-9:35</td>
<td>Nichols</td>
<td>Post-Last Glacial Maximum Thinning History of the Foundation Ice Stream Adjacent to the Pensacola Mountains</td>
</tr>
<tr>
<td>9:40-10:00</td>
<td>Tulaczyk</td>
<td>INVITED: Subglacial Geology and Predictability of Antarctic Ice Sheet Evolution</td>
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<tr>
<td>10:00-10:40</td>
<td>Branecky Begeman</td>
<td>Spatially variable geothermal heat flux in West Antarctica: evidence and implications</td>
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<tr>
<td>11:00-11:20</td>
<td>Shen</td>
<td>INVITED: Lithospheric structure of west and central Antarctica and its tectonic implication</td>
</tr>
<tr>
<td>11:25-11:40</td>
<td>Tinto</td>
<td>INVITED: ROSETTA-Ice Surveys - Exploring the Duality of the Ross Ice Shelf</td>
</tr>
<tr>
<td>11:45-12:00</td>
<td>Neuhaus</td>
<td>Temperature profiles along the Whillans Ice Stream measured using a Distributed Temperature Sensor</td>
</tr>
<tr>
<td>12:00-1:30</td>
<td>Lunch</td>
<td>Chemical weathering in Permafrost assessed using Magnesium Isotopes</td>
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<tr>
<td>1:30-1:45</td>
<td>Heindel</td>
<td>INVITED: Soil Phosphorous Availability Links the Geosphere and the Biosphere in the McMurdo Dry Valleys, Antarctica</td>
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<tr>
<td>1:50-2:10</td>
<td>Malin</td>
<td>Wind-Driven Rock Abrasion in the Ice-Free Valleys, Antarctica: Rates and Controls</td>
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<tr>
<td>2:15-2:30</td>
<td>Kurz</td>
<td>Cryoturbation rates in an Antarctic volcanic terrain: preliminary results from Mount Morning</td>
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<tr>
<td>2:55-3:10</td>
<td>Sletten</td>
<td>Origin of Ground Ice in Beacon Valley, Antarctica based on Paleoenvironmental Reconstruction utilizing Permafrost Core</td>
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<tr>
<td>3:10-3:20</td>
<td>Licht</td>
<td>Announcements</td>
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<tr>
<td>3:15-4:30</td>
<td></td>
<td>Discussion on future of deep field camps (optional)</td>
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<tr>
<td>4:00-5:00</td>
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<td>Dinner</td>
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**Posters**

- Patterned ice stream basal micro-seismicity reveals bedforms: Grace Barcheck, Susan Schwartz, Slawek Tulaczyk
- Improved Glacier Area Estimate from Remote Sensing: Case Study of Petermann Glacier: Marie Bergelin and Douglas R. MacAyeal
- Old ice in the Allan Hills: Howard Conway, Laura Kehrl, Nick Holschuh, Seth Campbell, Nicole Spaulding, Andrei Kurbatov, Nelia Dunbar, William McIntosh
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<thead>
<tr>
<th>Title</th>
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<tr>
<td>Origin of rift-related alkaline magmatism in northwest Ross Sea, Antarctica</td>
<td>Kathryn Durkin, Kurt Panter, Paterno Castillo, Susan Krans, Chad Deering, William McIntosh, John Valley, Kouki Kitajima, Phillip Kyle, Stanley Hart, Jerzy Blusztajin</td>
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<tr>
<td>Hercules Dome: A deep ice core site for inferring past stability of the West Antarctic ice sheet</td>
<td>T.J. Fudge, Eric Steig, Knut Christianson</td>
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<td>Insights into the evolution of the Antarctic Ice Sheet from cosmogenic nuclide analysis in the Ellsworth Mountains</td>
<td>Andrew Hein, David Sugden, John Woodward</td>
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<td>Whichaway are the algae?</td>
<td>Theresa Hudson, Kathy Licht</td>
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<tr>
<td>Shallow ice radar expression of TAM glaciers within Ross Ice Shelf, and a new method to distinguish mechanisms of ice sheet thinning</td>
<td>Skye Keeshin, Robin Bell, Christine Siddoway, Gina Jozef, Kirsty Tinto, Isabel Cordero, Nick Frearson, Indrani Das and ROSETTA-Ice Team</td>
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<tr>
<td>Exposure dating of freshly exposed rock clasts in the Mt. Achernar blue-ice area</td>
<td>Jennifer Lamp, Gisela Winckler, Joerg Schaefer, Michael Kaplan, Kathy Licht</td>
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<td>Investigating the Cause of Mantle Melting Beneath the Southernmost Volcanoes on Earth, Upper Scott Glacier, East Antarctica</td>
<td>Kurt Panter, Jenna Reindel, John Smellie, William McIntosh</td>
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<td>The Antarctic Search for Meteorites (ANSMET) after 40 years: contributions to planetary materials research, the search for ancient ice, and the understanding of meteorite stranding surfaces</td>
<td>John Schutt, James Karner, Ralph Harvey</td>
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<td>Geology and crustal Structure underlying Ross Ice Shelf: New Perspectives from ROSETTA-Ice Project airborne investigations</td>
<td>Christine Siddoway, Kirsty Tinto, Robin E. Bell, Indrani Das, and ROSETTA-Ice Team</td>
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<tr>
<td>High-Resolution Body Wave Tomography of the Ross Sea Embayment, Antarctica</td>
<td>Austin White-Gaynor, Andrew Nyblade, Douglas Wiens, Rick Aster, Peter Gerstoft, Peter Bromirski, Ralph Stephen</td>
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Antarctica is now the Best Mapped Continent

Morin, P. and the Staff and Students of the Polar Geospatial Center

Department of Earth Sciences, University of Minnesota

In recent years we have seen a leap forward in geospatial imagery resources, sub-meter remote sensing, open source software, and high performance computing. The Polar Geospatial Center (PGC) and the Antarctic science community have created a series of community-defined products that are now becoming available.

The most notable of these datasets is the Reference Elevation Models of Antarctica (REMA) by Ian Howat and M.J Noh of the Ohio State University. When complete, this mosaicked Digital Elevation Model (DEM) will have an 8m posting with a spherical accuracy of less than one meter. In comparison, the DEM of most of the Western United States is at a 10m posting with less accuracy. Additionally, PGC is choosing the best of the 50,000 – 2,000 km² DEMs and continuing the processing to a 2m posting for key areas of the continent including geology and stations. PGC is using base data such as sub-meter imagery and REMA to produce map series for areas of high scientific interest. The most recent of these is to support activity around Shackleton Glacier Camp. The series includes two overview maps of the region and over 250 - 1:50k image maps. Other, more specialized products are being created. Together with Mark Salvatore of Northern Arizona University, PGC is developing methods for using multispectral sub-meter commercial imagery to identify approximate physical properties of all geologic outcrops on the continent. Biologists will not be left out as the multispectral data is also being used to identify liquid water and chlorophyll.
Progress toward a Rapid Access Ice Drill (RAID) for reconnaissance drilling of deep ice, bedrock, and borehole observatories on the Antarctic Plateau

Jeff Severinghaus1, John Goodge2, Ryan Bay3


The bedrock geology map of Antarctica is mostly white, and fundamental data sets such as geothermal heat flow and ice sheet basal material properties are either scarce or absent. These zeroth-order gaps in knowledge conceal the history of assembly of the Antarctic craton, and hamper modeling of future sea level rise due to sliding of grounded ice. Traditional ice coring takes about 5 years and upwards of $50M per hole, and seldom returns bedrock samples. Yet the search for ice older than 1 Ma (motivated by the mystery of the mid-Pleistocene Transition from 41-kyr to 100-kyr glacial cycles) requires fast access to ice very near the bed at low marginal cost, in reconnaissance mode. Glaciological ice flow studies increasingly require multiple boreholes along transects, rather than ice cores per se.

To address these needs and speed up the rate of scientific discovery, we have built a drilling system (RAID) that can penetrate 3000 m of ice in 48 hours in non-coring mode, and then take short cores of basal ice, mud, and bedrock with high scientific value. Legacy boreholes will remain open for at least 5 years after drilling, so that borehole logging and instrumental observation of heat flow, ice optical properties and age, ice deformation, seismicity, and particle physics can be done. We estimate that 5 holes per season can be drilled.

Importantly, the scientific need for multiple holes over large areas in a single season cannot be met by the traditional Antarctic logistics model of fixed field camps supported by LC-130s; instead, a mobile sled-mounted traverse that is agile and self-contained is needed. Accordingly, we have designed and built RAID to be self-sufficient in all respects except for crew changeouts by Twin Otter (no LC-130 support). RAID will operate initially in the general region of South Pole for logistical reasons, but is designed for the altitudes and temperatures of the Gamburtsev region. Importantly, RAID cannot penetrate wet beds for subglacial biological stewardship reasons, so all bed penetration will be in frozen conditions.

Field testing of the complete RAID system commenced in December 2016 near McMurdo, at a small piedmont glacier on the south side of Minna Bluff in 700-m thick grounded ice, and will continue in the 2017-2018 season. A RAID science workshop was held in La Jolla, CA in March 2017. More information, and opportunities to participate in RAID, can be found at rapidaccessicedrill.org
Thursday Talks
Upper mantle and transition zone seismic structure of Antarctica and adjacent ocean basins from full waveform adjoint tomography

Douglas A. Wiens\textsuperscript{1}, Andrew J. Lloyd\textsuperscript{1}, Hejun Zhu\textsuperscript{2}, Jeroen Tromp\textsuperscript{3}, Andrew Nyblade\textsuperscript{4}, Sridhar Anandakrishnan\textsuperscript{4}, Richard Aster\textsuperscript{5}, Audrey Huerta\textsuperscript{6}, J. Paul Winberry\textsuperscript{6}, Terry Wilson\textsuperscript{7}, Ian Dalziel\textsuperscript{8}, Samantha Hansen\textsuperscript{9}, Patrick Shore\textsuperscript{1}

\textsuperscript{1}Dept. Earth and Planetary Sci., Washington University in St. Louis, St. Louis, MO
\textsuperscript{2}Department of Geosciences, The University of Texas at Dallas, Dallas, TX
\textsuperscript{3}Department of Geosciences, Princeton University, Princeton, NJ
\textsuperscript{4}Department of Geosciences, Pennsylvania State University, University Park, PA
\textsuperscript{5}Department of Geosciences, Colorado State University, Fort Collins, CO
\textsuperscript{6}Department of Geological Sciences, Central Washington University, Ellensburg, WA
\textsuperscript{7}Byrd Polar Res. Center & School of Earth Sci., Ohio State University, Columbus, OH
\textsuperscript{8}Institute for Geophysics, Jackson School of Geosciences, The University of Texas, Austin, TX
\textsuperscript{9}Department of Geological Sciences, The University of Alabama, Tuscaloosa, AL

The upper mantle and transition zone beneath Antarctica and the surrounding oceans have been among the poorest-imaged regions of the Earth’s interior, due to sparse coverage by seismic instrumentation. Seismic studies incorporating seismic arrays temporarily deployed on the Antarctic continent have recently increased resolution, but most of these studies are limited to the areas of Antarctic covered by the seismic arrays, and to depths of less than 250 km. In this study we use the newly acquired datasets along with a full waveform adjoint inversion method to image Antarctica and the surrounding ocean basins to depths of 700 km. We use data from over 300 far-southern hemisphere seismic stations recording 270 earthquakes ($5.5 \leq M_w \leq 7.0$) that occurred between 2001-2003 and 2007-2016, and calculate full-waveform synthetics for 3D earth models using a spectral element method. The inversion assimilates phase observations from the entire 3-component waveforms, including reflections and overtones, thus providing much better resolution of poorly instrumented regions. Within East Antarctica, the new model reveals internal seismic heterogeneity and differences in lithospheric thickness. For example, fast seismic velocities extending to 200-300 km depth are imaged beneath both Wilkes Land and the Gamburtsev Subglacial Mountains, whereas fast velocities extend to only 100-200 km depth beneath the Lambert Graben and Enderby Land and are missing beneath portions of Dronning Maud Land, demonstrating thinner and younger or tectonically disrupted lithosphere in those areas. Slow upper mantle velocities are imaged beneath the West Antarctic coast extending from Marie Byrd Land to the Antarctic Peninsula, consistent with thin lithosphere and low viscosity upper mantle inferred by glacial isostatic uplift models using GPS data. This region of slow velocity only extends to 150-200 km depth beneath the Antarctic Peninsula, whereas elsewhere it extends deeper, and into the transition zone beneath Marie Byrd Land. The slow anomalies along the Amundsen Sea coast connect to a regional velocity anomaly offshore beneath Peter I Island and regionally elevated bathymetry, suggesting a thermal anomaly associated with a larger geodynamic process.
Continental arc initiation, magma fluxing, and termination recorded in the Ross Orogen of Antarctica

Demian Nelson¹, John Cottle¹, Graham Hagen-Peter²

1. University of California, Santa Barbara, CA, USA
2. Aarhus University, Aarhus, Denmark

The Ross orogen of Antarctica is a 3500 km-long continental arc that formed during subduction of paleo-Pacific oceanic lithosphere beneath East Antarctica in the late Neoproterozoic—early Paleozoic. Studying the now-exposed roots of this ancient subduction zone yield important insight into the tectonic and magmatic processes that occur during convergence as well as the mechanism(s) by which subduction is terminated. Detailed geologic studies of regionally extensive, ‘pre-subduction’, (meta)sedimentary rocks reveal that metamorphism and thickening of the Pacific margin of East Antarctica began at least as early as 620 Ma. This was followed, between 580 and 490 Ma by emplacement of large volumes of subduction-related granitoids, with a major magmatic flux event at c.505 Ma. The geochemistry of these rocks is consistent with derivation from an enriched sub-continental lithospheric mantle source, with evidence for increasing assimilation of Archean crust over time. The geochemistry of the youngest, c. 495 Ma, granitoids reflects crustal thickening or underplating of fertile continental material into the source region of the arc. Widespread emplacement of ultrapotassic igneous rocks at 490 – 485 Ma reflects cessation of subduction that was potentially accompanied by foundering or delamination of the lower arc crust. The Ross orogen—an archetypal example of a long-lived “Cordilleran-style” continental arc—is important in the global context because it enables us to elucidate key variations in both small- and large-scale petrologic, tectonic and geodynamic processes and how they vary temporally and spatially. These data neatly complement information available from modern subduction zones and enables construction of more accurate models that attempt to explain the complete subduction cycle.
Apatite and zircon double-dating thermochronologic constraints on the low temperature thermal history of the central Transantarctic Mountains

Christine Kassab¹, Stuart Thomson², and Kathy Licht¹

¹Dept of Earth Science, IUPUI, Indianapolis, IN; ²Dept of Geoscience, University of Arizona, Tucson, AZ

(U-Th)/He and fission track ages from apatite (AHe, AFT) and zircon grains (ZHe, ZFT) were analyzed from six samples of the lower, middle and upper formations of the Beacon Supergroup (Pagoda, Buckley, and Falla Formations, respectively). These low-temperature thermochronometers are useful for investigating denudation, uplift, and landscape evolution of the central Transantarctic Mountains. Samples were analyzed from the upper Shackleton Glacier region and the Queen Alexandra Range, west of Beardmore Glacier. Samples were not collected from a single stratigraphic section/elevation profile, but were collected from locations within ~50 km of each other. All apatite and zircon (U-Th)/He and FT ages are substantially younger than depositional age, indicating that the sedimentary package was heated to at least 260°C by one or more post-depositional events. These events have been postulated to be either burial beneath a now-eroded Mesozoic sedimentary basin or heat associated with either magmatic intrusions (Ferrar dolerite) or a higher transient geothermal gradient.

Initial cooling histories are similar at the two locations; ZFT ages range from 155-180 Ma. This indicates that the initial reheating event was a regional one. Following initial reheating, the two locations have diverging thermal histories over time. Continued cooling occurred at a faster rate in the Queen Alexandra Range, with <10 Ma between the ZFT and ZHe ages, compared to 15-30 Ma between the ZFT and ZHe ages for the Shackleton Glacier region. The lowest temperature thermochronometers (AFT and AHe ages) indicate that the latest stages of cooling were separated by at least 25 million years in these two regions. The lowermost unit, the Pagoda Formation, has an AFT age of 70 Ma at Shackleton Glacier and an AFT age of 45 Ma in the Queen Alexandra Range.

Independent of stratigraphic position, a spatial pattern is apparent from these samples and shows that rocks closer to the Ross Ice Shelf show a trend to younger ages and longer mean AFT track lengths, reflecting greater total erosion of these samples relative to those further inland. This supports the idea of greater isostatic flexural uplift of the TAM towards the ice shelf. Youngest ages closest to the margin imply this uplift initiated at around 35 Ma.

Acquisition of more thermochronologic data from a large regional sample set is now underway to evaluate the nature, timing, and patterns of erosion, and isostatic flexural and peak uplift of this region to explore more fully the complex links between tectonics, climate, and glacial incision in construction of the TAM.
New Information on the theropod dinosaur *Cryolophosaurus ellioti* from the Early Jurassic Hanson Formation of the Central Transantarctic Mountains

*Nathan Smith¹, William Hammer², Peter Makovicky³*

¹Natural History History Museum of Los Angeles County, ²Augustana College, ³The Field Museum of Natural History

The crested theropod, *Cryolophosaurus ellioti*, was discovered in the Early Jurassic Hanson Formation (~194Ma) of the Central Transantarctic Mountains. Excavations in 1991 recovered the skull, numerous vertebrae, and appendicular elements. Originally described as an allosauroid, recent phylogenetic analyses recovered *Cryolophosaurus* as either a basal member of Tetanurae, or outside a Ceratosauria + Tetanurae clade, often allied with Early Jurassic coelophysoids. These three hypotheses posit markedly different patterns of theropod evolution, with the former two implying more ghost lineages and rapid diversification in the Early Jurassic. We describe new material of *Cryolophosaurus* collected in 2010-11, newly prepared specimens, and CT scans of the skull. New material includes a second *Cryolophosaurus* braincase and two left fibulae, demonstrating the presence of at least two individuals in the quarry. The new specimens exhibit a mosaic of character data, with traits of the braincase (e.g., leaf-shaped parasphenoid, grooved along dorsal and ventral edges; pneumatic occipital condyle) present in basal tetanurans (e.g., *Allosaurus, Dubreuillosaurus*); whereas two vertebral traits (posterior cervical neural spine tables expanded into a distinct bowtie-shape; mid-caudals with low lateral ridges extending between the transverse processes and prezygapophyses) are shared with *Dilophosaurus*. Pectoral girdle features (e.g., short scapular acromion process set at oblique angle to blade; short, rounded ventral process of coracoid; swollen coracoid tubercle extending as oblique ridge) are similar to *Dilophosaurus* and coelophysoids; and hindlimb traits (e.g., thick fibular crest of tibia, which extends as low ridge to proximal end; oblique crest on lateral face of cnemial process; broad, shallow medial fossa of fibula; elongate, obliquely oriented iliofibularis tubercle of fibula) are shared with *Dilophosaurus* and several basal members of Ceratosauria and Tetanurae. These anatomical data argue against allosauroid affinities of *Cryolophosaurus*, but also introduce character conflict both supporting and contradicting the two alternate hypotheses of relationships. New phylogenetic datasets that sample taxa comprehensively from early dinosaurs and theropods, as well as basal members of Ceratosauria and Tetanurae, will be required to resolve the phylogenetic relationships of *Cryolophosaurus* with more confidence, and thus provide insight into patterns of theropod diversification during the Early Jurassic.
Geohistory Drives the Evolution of Life History Traits and Genome Architecture in Extant Terrestrial Microfauna

Byron Adams¹, Bishwo Adkhikari¹,², Xia Xue¹, Breana Simmons³,⁶, Becky Ball¹, Jeb Barrett⁵, and Diana Wall⁶

¹Department of Biology and Monte L. Bean Museum, Brigham Young University
²USDA-ARS, Plant Sciences Department, University of Arizona
³Department of Math and Science, East Georgia State College
⁴Global Institute of Sustainability, Arizona State University
⁵Department of Biological Sciences, Virginia Tech University
⁶Department of Biology, Colorado State University

All organisms are composed of the same biologically cycling elements (carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur) but the proportions of these elements vary widely across landscapes as a function of geohistory, and according to their evolutionary history and functional traits. This is a big deal because it a) suggests that the geological processes that result in varying stoichiometric ratios of rate limiting nutrients in biological processes can drive the evolution of organismal life history traits, and b) it sets defining constraints on contemporary trophic complexity and the transfer of energy through ecosystems.

We hypothesize that geological history and landscape evolution overprint contemporary ecosystems with elemental stoichiometric ratios that place limits on the evolution of life history traits. We predict that organisms will respond to these strong agents of selection through changes in life history traits that are ultimately reflected in the structure of their genomes.

The presence of bioavailable phosphorus (P) differs significantly across the Transantarctic Mountain (TAM) landscape where it is highly correlated with age of exposure and the composition of glacial tills. Terrestrial habitats with very old surface exposures have relatively little bioavailable phosphorus whereas as younger tills typically are much more phosphorus rich. Thus, provenance and weathering play an instrumental role in patterns of distribution and abundance of this important nutrient in the TAM.

Terrestrial ecosystems in the TAM from the Pliocene to the present were likely quite similar to the ecological communities we see today, characterized by low phylogenetic diversity and ecological complexity. The current distribution and abundance of organisms across the landscape is best explained by physical factors, such as temperature, salinity, available water and nutrients. Biotic interactions in the TAM, such as competition and predation, appear to have relatively little influence on contemporary community structure and functional complexity.

Phosphorus is the most limiting element in DNA transcription and translation such that P availability is directly coupled to high demands for the protein synthesis that is required for organismal growth and development. Using field and laboratory approaches we show that conspecific TAM nematodes from high versus low bioavailable P environments contain greater somatic P concentrations and have evolved 1) faster growth rates, 2) earlier reproduction, 3) shorter reproductive cycles, 4) smaller body size, 5) increased rates of transcription, and 6) increased rRNA gene copy number. These findings have important implications on the evolution of organismal life history traits and ultimately the development of trophic complexity in terrestrial ecosystems.
Landscape Evolution of the Ice Free Areas Driven by Uniquely Antarctic Processes

Jaakko Putkonen1), Ted Bibby2), Daniel Morgan3), and Greg Balco4)

1) Harold Hamm School of Geology and Geological Engineering, University of North Dakota, Grand Forks, ND
2) Department of Earth Science, University of California, Santa Barbara, CA
3) Earth and Environmental Sciences, Vanderbilt University, Nashville, TN
4) Berkeley Geochronology Center, Berkeley, CA

The two percent of the Antarctic area that is ice free evolves unlike any other part of the Earth. This is due to the long lasting and ongoing glaciation and the resulting lack of water and moisture that are plentiful at other terrestrial permafrost areas.

Many of the currently ice free areas in Antarctica, although few and far in between, have been at least partially free of ice for millions of years. Several of those areas are known to contain rich records of past ice advances and they potentially contain signs of other surface processes or biological remains. To determine how fast these surfaces are evolving in million year time scale we analyzed cosmogenic nuclides in surficial boulders, bedrock, and regolith along the Transantarctic Mountains. We also set up soil traps and repeat photo sites to establish the current rate of regolith transport along the surfaces. We found that exposed bedrock surfaces degrade at rates of 0.25-2 m/Ma (dependent on lithology), and the regolith surfaces degrade at rates of 0.2-3 m/Ma. These rates are among the slowest on Earth.

It is notable that while the regolith degrades the subsurface (0.02-1 m depth) remains undisturbed even on slopes. The repeat photography and soil traps revealed a slow rate of current near surface (0-0.02 m depth) transport. Resulting in a thin near surface layer that may have a separate history and origin than the rest of the regolith below it.

A number of small debris covered valley glaciers have been located in Antarctica. Debris covered glaciers are also found in other parts of the Earth where cold climates prevail, but what makes them unique in Antarctica is that some of them harbor ice that is millions of years old. The preservation of the ancient ice is unexpected in an environment where exposed glacial ice sublimates today at a rate of several cm/a. The debris covered glaciers are lowered at a rate of ~20 m/Ma. Therefore these ancient debris covered glaciers are long lasting but slowly deflating parts of the landscape and uniquely Antarctic phenomena.

Combined our results reveal a landscape where both bedrock and regolith surfaces have been slowly but continuously eroding in the past and today. As the ice free areas have been subaerially exposed for millions of years this rate of degradation has resulted in a loss of rock and regolith of several meters across the landscape, and continuous lowering of the debris covered glaciers of tens of meters.
High-resolution multispectral sensors, including DigitalGlobe’s WorldView-2 and WorldView-3, provide meter-scale multispectral data over the entirety of the Transantarctic Mountains with rapid repeat times. Efforts to calibrate and atmospherically correct these data to provide quantitative compositional information have proven successful in identifying spectral variability and matching these observations to both field and laboratory investigations. These data have not only been used to support and supplement prior field investigations, but have also been used to drive future field studies and to make predictions about surface properties to be validated in the field. Such synergistic efforts have been widely successful, but have also demonstrated the need for continued data processing and method refinement as new data become available and as calibration techniques continue to improve.

This presentation will specifically focus on past and ongoing efforts to spectrally map the Shackleton Glacier region to complement supported field investigations during the 2017-2018 austral summer. Collaborative efforts to identify variability in ice-free surface compositions from orbit and to validate these observations in the field are vital to understand the utility of orbital mapping efforts on both local and regional scales. The presentation will also provide a summary of ongoing and future efforts to improve data processing techniques and to expand this work to continental scales.
The Polar Rock Repository: a resource for Antarctic earth science
Anne Grunow

Byrd Polar & Climate Research Center, Ohio State University

The Polar Rock Repository (PRR) is a NSF funded facility created to preserve and provide scientific access to rock, terrestrial drill core, unconsolidated till/soil and marine dredge sample collections from Antarctica and the southern oceans. Preserving existing polar collections at the PRR for future research fulfils an obligation under the Antarctic Treaty (Article III. Section 1c) and the Scientific Committee on Antarctic Research, Antarctic Data Management (2009) directive of providing free, full and open access to metadata and collections.

The PRR collection includes more than 43,000 samples (along with associated materials such as field notes, annotated air photos, maps, and thin sections) that are made available for research use. In addition to the physical samples and their basic metadata, the PRR archives supporting materials from the collector, images of the samples, field maps, air photos, thin sections and any associated bibliography/DOI’s.

The PRR uses a modern Collection Management System created at the BPCRC that allows for organization of the rock sample database completely via web browser, letting Repository staff to update and import samples and view reports from anywhere in the world. An advanced search engine for the PRR website allows scientists to “drill down” into search results using categories and look-up object fields similar to websites like Amazon. Results can be viewed in a table, downloaded as a spreadsheet, or plotted on an interactive map that supports display of satellite imagery and bathymetry layers. Samples can be requested by placing them in the ‘shopping cart’.

The easy discoverability of the PRR samples using the online search and shopping tools helps scientists with research planning, particularly given how logistically difficult, financially expensive and the high environmental impact of conducting Antarctic field research.
A middle Pleistocene through middle Miocene moraine sequence in the central Transantarctic Mountains, Antarctica

Allie Balter\textsuperscript{1}, Gordon Bromley\textsuperscript{1,2}, Greg Balco\textsuperscript{3}, Holly Thomas\textsuperscript{1}, Margaret Jackson\textsuperscript{4}

\textsuperscript{1}University of Maine, \textsuperscript{2}National University of Ireland Galway, \textsuperscript{3}Berkeley Geochronology Center, \textsuperscript{4}Dartmouth College

Ice-free areas at high elevation in the central Transantarctic Mountains preserve extensive moraine sequences and drift deposits that comprise a geologic record of former East Antarctic Ice Sheet thickness and extent. We are applying cosmogenic-nuclide exposure dating to determine the ages of these moraine sequences at Roberts Massif and Otway Massif, at the heads of the Shackleton and Beardmore Glaciers, respectively. Moraines at these sites are for the most part openwork boulder belts characteristic of deposition by cold-based ice, which is consistent with present climate and glaciological conditions. To develop our chronology, we collected samples from \textasciitilde30 distinct ice-marginal landforms and have so far measured \textasciitilde100 \textsuperscript{3}He, \textsuperscript{10}Be, and \textsuperscript{21}Ne exposure ages. Apparent exposure ages range from 1-14 Ma, which shows that these landforms record glacial events between the middle Pleistocene and middle Miocene. These data show that the thickness of the East Antarctic Ice Sheet in this region was similar to or thicker than present for long periods between the middle Miocene and today. The time range represented by these moraine sequences indicates that they may also provide direct geologic evidence for East Antarctic Ice Sheet behavior during past periods of warmer-than-present climate, specifically the Miocene and Pliocene. As the East Antarctic Ice Sheet is the largest ice sheet on earth, understanding its sensitivity to warm-climate conditions is critical for projections of ice sheet behavior and sea-level rise in future warm climates.
Subglacial chemical weathering in the Transantarctic Mountains traced through meteoric $^{10}Be$

Joseph Graly$^1$, Kathy Licht$^1$, Marc Caffee$^2$

1: Indiana University Purdue University Indianapolis
2: Purdue University

Sediments emerging from Antarctic ice sheets often have a weathered character, containing substantial inventories of clays, oxides, and oxyhydroxides formed through chemical weathering. The origin of these chemical weathering products is not necessarily well constrained; clays and oxyhydroxides may have formed during pre-glacial diagenesis, interglacial exposure, or through subglacial processes. If active subglacial chemical weathering plays a major role in altering the chemistry of Antarctic sediment, then Antarctic subglacial processes would have a significant impact on ocean and atmospheric chemistry, which in turn control the Earth’s climate. If most Antarctic weathering features formed during earlier epochs, Antarctica’s climate impact is minimal.

To test and develop tracers of the sources of Antarctic weathering, we measured the concentration of meteoric $^{10}Be$ in 3 Antarctic sediments: a sediment rich in clays and oxyhydroxides where rounded, faceted clasts of diverse geologic origin suggest active subglacial processes, a sediment more lithologic uniformity and clast angularity suggesting local transport from an aerially exposed region, and an artificial sediment created by grinding a clay and oxide rich sedimentary rock. The subglacial sample is enriched in clays and oxyhydroxides compared to the surrounding bedrock clasts. These three test cases are designed to represent subglacial processes, previous aerially exposure, and diagenetic processes without subglacial chemistry, respectively. Because $^{10}Be$ forms in the atmosphere and is deposited on the Earth surface, we expect it to be delivered directly to aerially exposed sediment and to subglacial sediments through basal melting of the ice. However, any $^{10}Be$ incorporated in the Mesozoic rocks would have been lost to decay over the isotope’s 1.4 Ma half-life. Without chemical activity, we expect meteoric $^{10}Be$ to remain adsorbed to the sediment where it is deposited; chemical weathering causes $^{10}Be$ to become incorporated into clays, oxides, or oxyhydroxides.

All three samples, along with a control sample of mid-latitude quaternary sediment, were subjected to a series of sequential extractions designed to target adsorbed, clay, oxyhydroxide, and oxide phases. The concentration of $^{10}Be$ in each of the extracted phases was measured at Purdue’s PRIME lab. The three Antarctic samples differ dramatically both in the total concentration of $^{10}Be$ and the phases into which it is partitioned. The artificial sample of ground rock has order of $10^7$ $^{10}Be$ atoms/g, with nearly all of it occurring in the adsorbed phase. The sample where previous exposure is assumed has order of $10^9$ $^{10}Be$ atoms/g, also predominately in the adsorbed phase. The sample where active subglacial processes are evidenced has order of $10^8$ $^{10}Be$ atoms/g, with most $^{10}Be$ in the oxyhydroxide or oxide phases. This suggests that the previously exposed sample has received substantial $^{10}Be$, but with little chemical weathering, whereas the subglacial sample has experienced oxidative chemical weathering. Furthermore, the concentration of $^{10}Be$ in the subglacial processes sample corresponds with the oxygen content of the ice necessary to develop the clays and oxides of the sediment in a subglacial environment. This preliminary study strongly supports to development of $^{10}Be$ as a tracer of subglacial chemical processes in Antarctic settings.
In blue ice areas in East Antarctica, sediments accumulate at the surface, including near the heads of major outlet glaciers. Eventually, they form blue ice moraines, such as in places where ice flowing off the East Antarctic plateau is interrupted by protruding mountain peaks that divert flow, cause convergence into outlet glaciers, and deliver sub- and englacial debris to the ice sheet surface. Ablation sustains upward-moving flow.

We show that blue ice sediment-moraines in the central Transantarctic Mountains contain a relatively untapped and direct and quasi-continuous archive of East Antarctic Ice Sheet behavior. The deposits contain information on former ice surface change, velocity, and ultimately the behavior of the EAIS. Given the blue ice moraines still overlie glacier ice – linked into to the ice sheet – this archive is sensitive to major changes in outlet glacier behavior. In this presentation, we show that these types of moraine sequences can be well-dated with in situ cosmogenic $^{10}$Be-$^{26}$Al-$^{3}$He measurements.

We focused primarily on a comprehensive blue ice moraine at Mt Achernar, at the head of the Law Glacier. We also studied a blue ice moraine at Mt. Howe, at the head of Scott Glacier. Both sites contain surface sediments that started to accumulate well before marine isotope stage 2 or the global Last Glacial Maximum (LGM). With distance from active (relatively clean) Law Glacier ice, we obtain coherent $^{10}$Be-$^{26}$Al-$^{3}$He ages from the Late Holocene to the hundred-thousand-year timescale. During the entire period of time represented, that is, several hundred-thousand years, only 10s of meters of ice surface change are observed. The ice surface has been getting generally lower since about 20,000 years ago.

Moreover, because incipient blue ice moraine ridges are actively forming near the moraine/Law ice boundary, we can use cosmogenic nuclides on recently emerged material to learn about rates of surface sediment accumulation. Dating of cobbles and boulders recently emerged allows insight into rates of upward movement and/or surface lowering, prior to instrumental observations. On recently emerged sediments, a new set of cosmogenic ages show that all material reached the surface within the last 100 years or so; these samples have been actually sitting on the surface for less than ~100 years or so, given some amount of cosmogenic nuclide concentration must have started to accumulate before reaching the surface. Moreover, comparison of $^{10}$Be and $^{3}$He on the recently emerged cobbles, on the incipient moraine, will allow empirical determination of non-cosmogenic component of $^{3}$He in the Ferrar Dolerite, which has broader impacts for cosmogenic studies elsewhere in Antarctica.
Rapid early-Holocene deglaciation in the Ross Sea

Perry Spector\textsuperscript{1}, John Stone\textsuperscript{1}, Seth Cowdery\textsuperscript{1}, Brenda Hall\textsuperscript{2}, Howard Conway\textsuperscript{1,y}, Gordon Bromley\textsuperscript{2,3}

\textsuperscript{1}Department of Earth and Space Sciences, University of Washington, Seattle, WA, USA
\textsuperscript{2}School of Earth and Climate Sciences and Climate Change Institute, University of Maine, Orono, ME, USA
\textsuperscript{3}School of Geography and Archaeology, National University of Ireland Galway, Galway, Ireland

The West Antarctic Ice Sheet (WAIS) is regarded as vulnerable to unstable retreat because much of it rests below sea level on a bed that deepens inland. The ice sheet likely collapsed during at least one Pleistocene interglacial period, and an incipient collapse may be underway in the Amundsen Sector. Deglaciation of the Ross Sea following the last ice age provides an important opportunity to examine the stability of marine ice sheets and their susceptibility to changing environmental conditions. Insufficient chronology for Ross Sea deglaciation has helped sustain (i) the theory that this region contributed significantly to Meltwater Pulse 1A (MWP-1A), an abrupt 9-20 m eustatic sea-level rise 14.6 kyr B.P., and (ii) the idea that Ross Sea grounding-line retreat occurred gradually in a “swinging gate” pattern hinged north of Roosevelt Island.

We will discuss recently published deglaciation records, based on \(^{10}\text{Be}\) exposure ages of glacial deposits, for Beardmore, Shackleton, and Scott Glaciers in the southern Transantarctic Mountains, which delivered ice to the central Ross Sea. Abrupt thinning of these glaciers 9–8 kyr B.P. coincided with deglaciation of the Scott Coast, ~800 km to the north, and ended with the Ross Sea grounding line near Shackleton Glacier. This indicates that much of the ice in the central and western Ross Sea was evacuated in a single brief period of deglaciation and grounding-line retreat ~9-8 kyr B.P., thereby ruling out the earlier conception of gradual and progressive grounding-line retreat along the Transantarctic Mountains. Rapid recession occurred despite stabilizing conditions of falling relative sea level. Thus two factors could have influenced rapid deglaciation in the southern Ross Embayment: (i) enhanced melting at the grounding line and (ii) unstable retreat into deep marine troughs to the south.

Data-constrained ice-sheet models indicate that the Ross Sector only contributed 3-4 m to sea level during the entire deglaciation. We show that much of this meltwater was released 5-6 kyr after MWP-1A, which indicates that the Ross Sector did not significantly contribute to this event. After ~8 kyr B.P., the Ross Sector ceased contributing significantly to global sea level rise.
The solid Earth exerts influence on overriding ice sheets and glaciers by controlling the spatial pattern of key basal parameters such as heat-flux, sediments, and topography. In this presentation, we focus on the two regions, the Beardmore glacier and the Crary Ice Rise (CIR), that demonstrate the influence of geologic processes on the topographic control of glaciers and ice sheets. These insights are primarily gained through active source seismic experiments that reveal the geologic structure of each region. Discharge of the East Antarctic Ice Sheet through the Transantarctic Mountains is dominated by a few relatively large outlet glaciers. The behavior of these glaciers is fundamental to understanding the response of the East Antarctic Ice Sheet to changing climates. However, to date only minimal geophysical surveys have targeted these glaciers. To illuminate the role of geological controls on fast flow, we conducted an integrated geophysical survey on the Beardmore Glacier that included ice penetrating radar, GPS, passive seismic, and active seismic observations. Our study sampled an area where the fast flowing main trunk of the glacier is directed around a slow moving "sticky spot". These results reveal that the main trunk of the glacier resides in a deep basin (> 2 km below sea level), while the slow moving sticky spot is underlain by bedrock bump (nearly at sea level). The large topographic offset is consistent with previous geologic studies that suggested a large fault in the middle of the Beardmore Glacier. Additionally, the fast moving region is underlain by a thick sedimentary deposit, while the sticky spot is hard bedded. Thus, similar to ice streams draining both of Antarctica's ice sheets, the geologic structure and presence of a soft bed appears to exert significant influence on the behavior of outlet glaciers flowing through the Transantarctic Mountains. We next focus on ice rises that form within the interior of ice shelves and provide significant buttressing to grounded ice. The CIR is located just downstream of the Whillans Ice Stream’s grounding line, a fast moving ice stream draining the West Antarctic Ice Sheet. Seismic data reveal a complex sedimentary structure is present beneath the CIR. This indicates that the topographic high responsible for the ice rise is not due to an elevated region of exposed bedrock. Instead, it appears that the topographic high has been formed as the result of the regions tectonic history and the interactions with the overriding ice sheet. Each of these two study areas highlight the influence of geologic structure on glacier and ice sheet behavior.
Posters
Patterned ice stream basal micro-seismicity reveals bedforms

Grace Barcheck, Susan Schwartz, Slawek Tulaczyk
Univ. of California, Santa Cruz

Patterns in seismicity emanating from the bottom of fast-moving ice streams and glaciers may indicate localized patches of higher basal resistance—sometimes called 'sticky spots', or otherwise varying basal properties. These seismogenic basal areas resist an unknown portion of the total driving stress of the Whillans Ice Plain (WIP), in West Antarctica, but may play an important role in the WIP stick-slip cycle and ice stream slowdown. To better understand the mechanism and importance of basal seismicity beneath the WIP, we analyze seismic data collected by a small aperture (< 3km) network of 8 surface and 5 borehole seismometers installed in the main central sticky spot of the WIP. We use a network beamforming technique to detect and roughly locate thousands of small (magnitude < 0), local basal micro-earthquakes in Dec 2014, and we compare the resulting map of seismicity to ice bottom depth measured by airborne radar. The number of basal earthquakes per area within the network is spatially heterogeneous, but a pattern of two ~400m wide streaks of high seismicity rates is evident, with >50-500 earthquakes detected per 50x50m grid cell in 2 weeks. These seismically active streaks are elongated approximately in the ice flow direction with a spacing of ~750m. Independent airborne radar measurements of ice bottom depth from Jan 2013 show a low-amplitude (~5m) undulation in the basal topography superposed on a regional gradient in ice bottom depth. The flow-perpendicular wavelength of these low-amplitude undulations is comparable to the spacing of the high seismicity bands, and the streaks of high seismicity intersect local lows in the undulating basal topography. We interpret these seismic and radar observations as showing seismically active sub-ice stream bedforms that are low amplitude and elongated in the direction of ice flow, comparable to the morphology of mega scale glacial lineations (MSGLs), with high basal seismicity rates observed in the MSGL troughs. These results have implications for understanding the formation mechanism of MSGLs and well as understanding the interplay between basal topographic roughness, spatially varying basal properties, basal resistance to fast ice flow, and ice stream stick-slip.
Improved Glacier Area Estimate from Remote Sensing; Case Study of Petermann Glacier

Marie Bergelin\textsuperscript{1)}, and Douglas R. MacAyeal\textsuperscript{2)}

\textsuperscript{1)}Harold Hamm School of Geology and Geological Engineering, University of North Dakota, Grand Forks, North Dakota, USA. \textsuperscript{2)}Department of the Geophysical Sciences, The University of Chicago, Chicago, Illinois.

Remote sensing is an efficient method for monitoring and mapping temporal dynamics of glaciers. It allows real-time and long-term studies over large areas, which are located in remote, inaccessible and inhospitable environments. Glacier studies related to mass balance and dynamics are crucial to evaluate changes in climate, due to glaciers being sensitive indicators. Changes in glacier area have been widely used to indicate a glacier’s response to climate change. Calculation of glacier area may be used as input for volume-area scaling techniques. Area calculation and mapping of glaciers and therefor snow-ice cover through remote sensing predominantly relies on the reflective characteristics of snow and ice and the fact that they have high reflectance in the visible region and low reflectance in the mid-infrared. Numerous techniques have been developed in the demand for an improved estimation of glacier area for varied applications. Four of these techniques are as followed: manual delineation, spectral ratios, spectral indices, and digital image classification.

In this study, the suitability of the two most common automatic glacier area mapping techniques were evaluated using Landsat 8 image for the Petermann Glacier: (1) Spectral ratio of NIR/SWIR and (2) spectral indices for Normalized-Difference Snow Index, NDSI. Various thresholds were evaluated for both spectral ratio and NDSI. These two automatic techniques were compared to a manual digitization as it has an accuracy of greater than 99% for detecting snow and ice cover.

With both visual comparison and evaluation of classification model, NDSI value of 0.35 or greater was found to be best fitted for Petermann Glacier in calculating glacier area. Misclassification from the classification model was mostly caused by snow in shadowed areas not being classified as snow cover, and debris-ice cover not being classified as snow cover, caused by similar spectral reflectance as the surrounding environment.
Recent drilling in the Allan Hills Blue Ice Area of East Antarctica recovered ~2.7 million-yr-old ice from a stratigraphically disturbed section of core. Here we explore the potential for extracting a continuous ice-core record back to 1 million yr. We used a ground-based 7-MHz ice-penetrating radar to image the thickness and internal structures in the ice. We tracked two dated tephra layers (115kyr, and 205kyr) that out-crop in the ablation zone, upstream along a flow line into the accumulation zone (Fig.1). The dated isochrones provide constraints for a flowline model to estimate the age structure of ice at a potential core site at S76.747 E159.118, where the bed is relatively flat and ice thickness is ~1170m. Based on the continuity of the englacial radar-detected isochrones, we expect continuous stratigraphy to depths of at least ~1000m. In this case, we anticipate ice from the Last Glacial Maximum will be at a depth of ~170m, ice from the Eemian between 720 and 770m, ice from MIS7 between 780 and 880m, and the possibility for finding 1 million-yr-old-ice about 30m above the bed.

Figure 1: 7-MHz radar echogram along a flowline in the Allan Hills Blue Ice Area.
Origin of rift-related alkaline magmatism in northwest Ross Sea, Antarctica

Kathryn Durkin1, Kurt Panter², Paterno Castillo1, Susan Krans3, Chad Deering4, William McIntosh5, John Valley6, Kouki Kitajima7, Philip Kyle8, Stanley Hart9, Jerzy Blusztajin9

¹Scripps Institution of Oceanography, Univ. of California San Diego, La Jolla, CA, 92093; ²Dept. of Geology, Bowling Green State Univ., Bowling Green, OH, 43403; ³Dept. of Earth and Environmental Sciences, Michigan St. University, East Lansing, MI, 48824; ⁴Dept. of Geology & Mining Engineering & Sciences, Michigan Tech Univ., Houghton, MI, 49931; ⁵New Mexico Bureau of Geology and Mineral Resources, Socorro, NM, 87801; ⁶Dept. of Geoscience, Univ. of Wisconsin-Madison, Madison, WI, 53706; ⁷Dept. of Earth & Environmental Science, New Mexico Tech, Socorro, NM, 87801; ⁸Woods Hole Oceanographic Inst., Woods Hole, MA, 02543

Alkaline magmatism of the West Antarctic rift system in the NW Ross Sea (NWRS) extends from the chain of shield volcanoes along the coast of northern Victoria Land to the numerous seamounts on the continental shelf and within the oceanic Adare Basin. Our new dating and preliminary geochemical results confirm that the seamounts are Pliocene-Pleistocene in age and petrogenetically akin to the mostly Miocene volcanism on the continent as well as to a much broader region of alkaline volcanism that encompasses areas of West Antarctica, Zealandia, and Australia which were contiguous prior to Gondwana’s breakup ~100 Ma, suggesting that the magmatism is interrelated. Available data also show that mafic alkaline magmas (>6 wt% MgO) erupted across the transition from continent to ocean have a systematic increase in Si-undersaturation, P2O5, Sr, Zr, Nb, LREE concentrations, LREE/HREE and Nb/Y ratios. Neodymium and Pb isotopes also increase whereas Sr ratios decrease ocean-ward. The variations are not explained by crustal contamination or by changes in degree of mantle partial melting but are likely a function of the thickness and age of mantle lithosphere. The sub-lithospheric source appears to have low 87Sr/86Sr (≤ 0.7030) and δ18O (≤ 5.0‰), high 143Nd/144Nd ~0.5130) and 206Pb/204Pb (≥ 20) ratios, and was derived from recycled subducted material prior to Gondwana breakup that was transferred to the lithospheric mantle by small degree melts to form amphibole-rich metasomes. Later melting of the metasomes produced silica-undersaturated liquids that reacted with the surrounding peridotite. This reaction occurred to a greater extent as the melt traversed through thicker and older crust continent-ward. Melting was triggered by major episodes of extension beginning in the Late Cretaceous but did not produce alkaline magmatism directly. Significant delay of ~30 to 20 Ma between extension and magmatism was likely controlled by conductive heating and the rate of thermal migration at the base of the lithosphere.

In this study, we plan to verify or nullify the above hypotheses by analyzing more seamount and continental samples. A main focus will be crustal influences on magmatism. The few available Os isotopes do not show a systematic continent to ocean pattern as do the Sr-Nd-Pb isotopes and, thus, we plan to collect additional Os data as well as Sr-Nd-Pb isotopes.

Osmium isotopes in conjunction with other data will be used to assess the effect of lithospheric thickness as well as the degree of crustal contamination on the evolution of alkaline magmas and what magma plumbing and timescales of magmatic processes may provide on rift architecture.
Hercules Dome: A deep ice core site for inferring past stability of the West Antarctic ice sheet

T. J. Fudge, Eric Steig, Knut Christianson

University of Washington

The response of the Antarctic ice sheet to climate change is a central issue in projecting global sea-level rise. While much attention is focused on the ongoing rapid changes at the coastal margin of the West Antarctic ice sheet (WAIS), paleoclimate and paleo-ice sheet observations provide the only constraint on how the ice sheet changes over long timescales. Whether WAIS collapsed during the last interglacial (~130,000 to 116,000 years ago) remains an unsolved problem in Antarctic glaciology. Hercules Dome, positioned 100km up from the “Bottleneck” which links the East and West Antarctic ice sheets, is uniquely situated to record the glaciological and climatic effects of changes in extent of WAIS.

Hercules Dome was identified decades ago as a potential deep ice-core site due to the deep ice, stable divide position, undisturbed internal radar layering, and consistent annual layering in the firn. The surface air temperature, and hence the stable isotopic ratio of the ice, at Hercules Dome is particularly sensitive to the reduced extent of WAIS due to the pattern of atmospheric circulation that is established. In addition, Hercules Dome is unlikely to have changed elevation significantly which might otherwise complicate interpretation of the temperature history. In addition to the goals associated with the previous interglacial, an ice core from Hercules Dome will provide the highest resolution record of atmospheric gases yet recovered from interior East Antarctica. The combination of moderate accumulation and cold temperature preserves trace gases which cannot be obtained in previous ice cores in West Antarctica. Site conditions will also permit borehole paleo-thermometry to provide only the second direct measurement of the glacial-interglacial temperature change from Antarctica.

In this talk, we explain motivations for deep drilling at Hercules Dome and summarize efforts to begin a deep drilling program.
Insights into the evolution of the Antarctic Ice Sheet from cosmogenic nuclide analysis in the Ellsworth Mountains

Andrew Hein, David Sugden, John Woodward

University of Edinburgh, School of GeoSciences, Drummond St., Edinburgh, EH8 9XP, UK
Northumbria University, Department of Geography, Newcastle upon Tyne, NE1 8ST, UK

The Ellsworth Mountains stand above the West Antarctic Ice Sheet close to its centre and inland of the floating Filchner-Ronne Ice Shelf. The mountains act as a dipstick for the half of the Antarctic Ice Sheet that flows into the Weddell Sea. Our field campaign in the southernmost mountains and subsequent analysis suggests the following. The earliest ice sheets were warm based and eroded a trimline that now stands 600-1900 m above the present ice surface. This erosion predates the Quaternary and is best explained by the Mid-Miocene ice sheets that extended offshore at a time preceding the erosion of large glacial troughs. Blue-ice moraines have been forming in the mountains for at least 1.4 million years. This and the lack of evidence of deglaciation during interglacials confirms models of interglacial regional ice sheets based on uplands such as the Ellsworth-Whitworth massif. Ice thickness varied with Quaternary glacial cycles, probably in response to sea level fluctuations causing migration of the grounding line of the Filchner-Ronne Ice Shelf. Ice remained near its Last Glacial Maximum thickness until 10 ka. An episode of marine instability saw the ice surface drop suddenly by 400 m in the mid-Holocene around 6.5 ka.
In 2014 an IUPUI field group discovered desiccated algae at Whichaway Nunataks, along the margin of the Recovery Ice stream in the Weddell Sea sector of Antarctica. Extremophile algae are well-documented in both the McMurdo Dry valleys and the coastal areas of the continent but have not been previously described at this site, which is ~1000 m elevation and >400 km from the edge of the Filchner Ice Shelf; the MAT is ~ -30°C. The algal material was found on the side of a ~2 m high ice-cored hillock covered in angular-subangular sandstone and mudstone with no evidence for ponded water in the area. Both the sample and the mat from which it came are desiccated and entwined around gravel-sized sediment, a test with dilute HCl revealed the presence of carbonates, likely within the sediment. AMS radiocarbon dating resulted in an age of 2,360 ± 30 14C yrs (445 cal yrs BC) with d13C -7.4‰. Examination with a stereoscopic microscope revealed that the algae forms convoluted, sheet-like structures within the larger mat. These preliminary observations reveal macroscopic characteristics similar to *Nostoc commune* (colonial cyanobacteria), which has been described in the Dry Valleys and Victoria Land. We are exploring suitable methods to more accurately classify the sample and characterize biological molecules. Identifying the algae will reveal more about the sample’s environment as well as Antarctica’s environment.
Using IcePod airborne instrumentation, the ROSETTA-Ice Project has so far collected 55 east-west profiles and 12 north-south tie lines of shallow and deep ice penetrating radar over Ross Ice Shelf (RIS). Distinct reflections in the shallow ice radar (SIR) clearly define areas of ice in the profiles that originated from each of the Transantarctic Mountains glaciers, identifiable in sequential profiles spaced 10 to 50 km apart. SIR also images the base of the ice sheet, when thickness is <450m. The new data verify that RIS thickness decreases between the grounding line and the calving front, and they reveal that the glacier-ice thicknesses for Beardmore, Nimrod, Byrd, and Mullock Glaciers also decrease. A majority of change in thickness of the ice sheet is attributable to strain (e.g. Thompson et al., 1984), and a lesser amount arises from basal processes at the ocean-ice interface. We devised a new means to assess the latter, using glacier-ice delimited in SIR profiles as a marker for thickness change. Other inputs are ice sheet velocity from Rignot (2017), time elapsed along flow lines from Moholdt (unpub), and vertical strain from RIGGS (Thompson et al. 1985). The objective is to identify areas of basal melting or freeze-on that may aid in the refinement of models of ocean circulation and ice shelf stability.

We first mapped the margins and top of within-shelf glacier ice using reflections in the SIR. These provide markers for accurate measurement of depth-to-reflector and glacier-ice thickness. For Beardmore and Nimrod Glaciers, a comparison of profiles between L530 and L870 encompasses the along-flow change over a 350 km distance. (Line numbers reflect position within ROSETTA-Ice survey, with lower numbers toward South.) The thickness from the surface to the reflector provides a measure of ‘upper’ ice thickness, $T_a$ (formed by accumulation, firm compaction and strain). $T_a$ increases from 127 to 155 m (38 m change, or +30% of the original thickness). Beardmore glacier-ice thickness, $T_g$, decreases from 232 to 140m, a change of 92 m (-40%). $T_a$ for Nimrod Glacier increases from 100m to 140 m, then the reflector again rises to 100m depth. Nimrod glacier-ice thins from 215 to 167 m.  Our calculations show that the amount of thinning unrelated to strain is -0.4 m/yr to -0.1 m/yr (-4 m to -1 m decadal change) for these two glaciers, a potential indication of basal melting.

Changes in Byrd and Mullock Glaciers were measured from profile L720 to L870, a distance of 150 km. Byrd glacier-ice thins by 210 m over this distance, while Mullock Glacier thins from 270 to 0 m, and disappears. SIR profiles reveal a dramatic thinning and rise of the RIS base beneath Mullock Glacier and the west margin of Byrd Glacier, while the depth-to-reflector remains unchanged. Mullock Glacier ice disappears entirely, and the thickness is halved for the west side of Byrd Glacier. The drastic decrease in thickness of shelf ice that coincides with the disappearance of the glacier-ice reflector suggests high rates of basal melting.

The mapped reflectors offer a new means to investigate the basal processes affecting shelf thickness. The change in thickness that is not attributable to strain may be a result of processes at the base of the ice shelf (melting, freeze-on) that can be mapped and made available for use in circulation models. The method may be readily applied to evaluation of other ice shelves for which shallow ice radar data exist.
Exposure dating of freshly exposed rock clasts in the Mt. Achernar blue-ice area

Jennifer Lamp¹, Gisela Winckler¹,², Joerg Schaefer¹,², Michael Kaplan¹, Kathy Licht³

¹Lamont-Doherty Earth Observatory, Palisades, New York
²Department of Earth and Environmental Sciences, Columbia University, New York
³Department of Earth Sciences, IUPUI, Indianapolis, Indiana

Blue ice commonly forms in regions where ice flow is obstructed by mountainous terrain. Due to sublimation and enhanced wind scouring at these sites, ice ablates, subsequently initiating flow of underlying ice towards the surface; this upward flow allows for entrained debris and sediment to be exposed subaerially from depth. In Antarctica, blue-ice areas can be found where ice flow from the East Antarctic Ice Sheet (EAIS) is hindered by the Transantarctic Mountains. In this study, we examine sediments freshly exposed in discrete bands in a blue-ice area situated along the margin of Law Glacier at Mt. Achernar in East Antarctica.

At Mt. Achernar, a moraine sequence which stretches ~5 km inland from the Law Glacier margin overlies glacial ice with till thicknesses up to 1 m. This deposit is sensitive to changes in the EAIS, and is therefore a valuable record of past ice sheet fluctuations and climate. The moraine has been dated using cosmogenic nuclides (¹⁰Be, ²⁶Al, ³He) from post-MIS 2 (i.e., < 20 ka) near the ice margin to > 100 ka for the furthest inland samples with minimal evidence of burial and re-exposure.

Here, we seek to complement this existing dataset by examining rock clasts freshly exposed in three sediment-rich bands in actively sublimating ice near the Law Glacier margin. We view these bands as currently forming moraine ridges, which will eventually be part of the larger aforementioned moraine complex. We use cosmogenic nuclides to determine the surface exposure duration of sandstone and dolerite cobbles that lie directly on the ice surface at these locations. Exposure ages from ¹⁰Be in quartz and ³He in pyroxene indicate that these cobbles have been at or very near the ice surface for <100 years in some cases. These results suggest that sublimation or upward ice flow is relatively fast, as a large nuclide inventory did not accumulate while the sample was near the ice surface during transport. This dataset, along with measurements of surface exposure ages on the Mt. Achernar moraine sequence, also highlight the suitability of blue-ice areas for cosmogenic nuclide exposure dating. In other applications of this technique in Antarctica (for example, the dating of drop moraines and till from cold-based alpine cirque glaciers), resulting age models are often complicated by nuclides inherited during previous exposures, an issue that does not seem to be present at the Mt. Achernar blue-ice moraine. Additionally, we believe that our measured ³He concentrations in freshly exposed dolerite clasts can be used as a measurement of the non-cosmogenic ³He component in Ferrar dolerite, which may be applicable to other cosmogenic surface exposure studies in the region.
Mt. Early and Sheridan Bluff are two basaltic volcanoes located at 87° South latitude at the head of the Scott Glacier, southern Transantarctic Mountains (TAM). These Early Miocene volcanoes lie ~800 km from any other exposed volcano and ~200 km inland from the shoulder of the West Antarctic rift system, which is the foci of most Cenozoic volcanism in Antarctica. Here we employ a geochemical approach to help constrain the cause of volcanism. There are three possible mechanisms for mantle melting in this region; 1) lithospheric extension, 2) lithospheric delamination and 3) mantle plume activity. Distinguishing which mechanism is responsible based solely on geochemical data from basalt is problematic, particularly in a continental setting. However, new geochronological and geochemical data from Mt. Early and Sheridan Bluff offer important constraints on factors that control mantle melting and can be evaluated with respect to recent geophysical investigations in this region of the TAM.

Field observations reveal that Mt. Early and Sheridan Bluff are monogenetic edifices that erupted over a very short time-period. Preliminary \(^{40}\)Ar/\(^{39}\)Ar dates suggest that Mt. Early is older than previously determined and closer in age to Sheridan Bluff (~19 Ma). The basaltic pillow lavas, lavas and dikes are porphyritic with phenocrysts of olivine, plagioclase and clinopyroxene. Whole rock MgO range from 4 to 10 wt.% and have restricted SiO\(_2\) (48 to 50 wt.% contents). The basalts vary from alkaline (up to 6 wt.% Ne-normative) to subalkaline (up to 6 wt.% Hy-normative). The alkaline basalts that occur at both Mt. Early and Sheridan Bluff are more strongly enriched in incompatible elements (e.g., La 33-49 ppm, Ba 270-484 ppm, Sr 712-1009 ppm), have La/Yb\(_N\) ratios >10 and show prominent Pb negative anomalies with only slight K negative anomalies on primitive mantle normalized, multi-element diagrams. Subalkaline basalts (only at Sheridan Bluff) have lower concentrations of incompatible elements (e.g., La 14-16 ppm, Ba 110-144 ppm, and Sr 358-380 ppm), La/Yb\(_N\) ratios <5, and lack Pb and K negative anomalies but show minor P negative anomalies.

The geochemistry suggests that the generation of both alkaline and subalkaline basalts is likely controlled by variations in the degree of partial melting of a compositionally similar mantle source. The change in the degree of partial melting would have to be sudden based on the coexistence of both compositional types at Sheridan Bluff. Melting triggered by passive extension is not likely to cause such a rapid change. Arrival of a mantle plume at the base of the East Antarctic craton beneath the TAM would stimulate melting, however, the very small volume of the volcanism does not support this. Lithospheric delamination may be the most viable mechanism for triggering volcanism in this region. The removal of old and cold mantle lithosphere from the base of the East Antarctic craton and its replacement by warmer asthenosphere has been proposed for this region based on geophysical evidence (Heeszel et al., 2016; Weisen et al., in review).

Heeszel et al. (2016) JGR, 121, 1758-1775.
The Antarctic Search for Meteorites (ANSMET) after 40 years: contributions to planetary materials research, the search for ancient ice, and the understanding of meteorite stranding surfaces.

John Schutt, James Karner, and Ralph Harvey
Case Western Reserve University, Cleveland, OH 44106

Importance of Antarctic meteorites to planetary research: After 40 field seasons, over 22,000 meteorite recoveries by the ANSMET program have proven of monumental importance to the characterization of meteorites and their parent bodies. A practical indicator of the significance of meteorites recovered by ANSMET shows that over 1600 peer-reviewed major journal articles have used ANSMET meteorites as their major source of data. ANSMET meteorites are in particular demand because a continuous supply of new materials is made available rapidly and free of charge to the world's scientific community. The average number of samples provided for research in each year, over the 40 year lifetime of the program, is about 540. ANSMET samples (from asteroids) have provided a profoundly detailed view of the early solar nebula, including continuous and widely varying sets of initial conditions, compositions, volatile activity, and processes. Likewise, ANSMET meteorites paved the way for the recognition that meteorites found on Earth could be derived from other planetary bodies (Righter, K, et al., 2015).

Contributions to the search for ancient ice in Antarctica: Cassidy (2003) proposed that very old ice could be found where meteorites with relatively long terrestrial residence ages are found. Meteorites with terrestrial residence ages of approximately 900,000 years have been found on the blue icefields at the Allan Hills. Recent research on the old ice at the Allan Hills has determined that some of the ice may be as old as 2.7 m.y (Yan, 2017). Stranded ice may be a consistent feature of meteorite recovery areas (Harvey, 2003).

Contributions to the understanding of meteorite stranding surfaces: We have conducted preliminary studies of ice chemistry and ice motion at a few meteorite stranding sites in an attempt to quantify our suppositions as to the glaciological nature of these special places. Oxygen isotope studies have shown large changes over short distances indicating varied sources of the ice or perhaps significant environmental changes over time. Ice motion studies have proven that very slow moving to stagnant ice is present where meteorite concentrations are present.

Geology and Crustal Structure underlying Ross Ice Shelf: New Perspectives from ROSETTA-Ice Project airborne investigations

Christine Siddoway1, Kirsty Tinto2, Robin E. Bell2, Indrani Das2, and ROSETTA-Ice Team

1Dept. Geology, Colorado College, Colorado Springs, CO 80903
2Lamont-Doherty Earth Observatory, Columbia University, 61 Route 9W, Palisades, NY 10964

One objective of the ROSETTA-ICE integrated system science project is to investigate the geological makeup and structure of the crust beneath the Ross Ice Shelf (RIS), using gravity and magnetics data. The ROSETTA-Ice airborne survey, two-thirds completed, is achieving a large increase in data resolution over the Ross Ice Shelf Geophysical and Glaciological Survey (RIGGS) of the 1970s. The new data reveal marked contrasts in gravity and magnetics characteristics of the eastern vs. western sectors of the survey region (Marie Byrd Land side vs. Transantarctic Mountains side), and a distinct lithospheric boundary 300 km east of the TAM.

The MBL side displays high amplitude magnetic anomalies, lower densities and shallower bathymetry, consistent with mapped characteristics of the crust beneath the proximal grounded ice of West Antarctica. The TAM side, in contrast, consists of relatively dense crust, with low amplitude magnetic anomalies, similar to patterns known from CTAM airborne geophysical datasets; in addition, the greatest seawater depths are found beneath the western RIS. Both regions’ bathymetry is dissimilar to Ross Sea bathymetry, which is dominated by glacial sedimentary deposits, as mapped by prior oceanographic cruises. Bathymetry of the seafloor beneath RIS, obtained using gravity inversion methods, instead shows prominent, sharp features having high relief, suggestive of structural control, prominent basement architecture, and a lesser presence of sedimentary cover, largely restricted to fault-troughs. The Central High, a fault-bounded bedrock structure that was seismically imaged in the Ross Sea and cored at Deep Sea Drilling Program Site 270, is discovered to continue beneath RIS, forming a broad basement feature that spans or contains the lithospheric boundary between the two contrasting regions of crust. Well-separated from the Transantarctic Mountains front, this southern continuation of the Central High and concomitant tectonic boundary appear to control the bathymetry beneath the Ross Ice Shelf, giving rise to a partition in the characteristics of oceanographic circulation systems.

The partition observed in the crustal geology, bathymetry and ocean circulation carries over and is evident in the shallow-ice radar characteristics of East Antarctica- versus West Antarctica-derived ice. Glacier-ice components of the floating ice sheet are identifiable and can be tracked as discrete features in sequential lines of radar data, providing reliable markers that can be used to gauge the effects of ocean-ice sheet interactions. Siple Coast ice streams display only small changes in thickness that are unaccounted for by strain. Preliminary work suggests that basal melting is enhanced for TAM glacier-ice in the west, that speculatively is influenced by the crustal structural control on bathymetry and ocean circulation. Ongoing ROSETTA-Ice research using additional data to be collected in 2017 will examine the longheld view of the Transantarctic Mountains as the fundamental geological boundary separating distinct lithospheric provinces in the Ross Ice Shelf region, and more fully investigate geological influences on ocean and ice sheet.
High-Resolution Body Wave Tomography of the Ross Sea Embayment, Antarctica

Austin White-Gaynor¹, Andrew Nyblade¹, Douglas Wiens², Rick Aster³, Peter Gerstoft⁴, Peter Bromirski⁴, Ralph Stephen⁵

¹. Penn State University; ¹. Washington University in St Louis; ³. Colorado State University; ⁴. University of California San Diego; ⁵. Woods Hole Oceanographic Institution

The West Antarctic Rift System (WARS) is one of the least understood continental rift system on the planet. The ~1000 km wide WARS includes the Ross Sea Embayment between Marie Byrd Land and the Transantarctic Mountains (TAMS). Active volcanism on Ross Island continues to challenge our understanding of the generally quiescent rift system. Previous regional-scale body wave tomographic investigations have identified areas of low seismic wave speeds to ~200 km depth beneath Ross Island. However, the spatial extent of the low velocity structure across the entirety of the WARS remains poorly constrained due to the insufficient resolution of upper mantle structure under the Ross Sea Embayment away from Ross Island. We utilize teleseismic P wave observations recorded on the RIS/DRIS network, which consists of 34 seismometers deployed across the Ross Ice Shelf, along with data from nearby POLENET and TAMSEIS stations to better resolve this region. Relative P wave travel time residuals from 1300 teleseismic events, obtained using a multichannel cross-correlation method, have been inverted for a seismic velocity model of the upper mantle throughout the Ross Sea Embayment. Our results suggest that the low wave speed structure under Ross Island extends roughly halfway across the Embayment and south along the Transantarctic Mountains. This observation is consistent with a two-phase rifting history for the WARS in which broad, late Cretaceous rifting between Marie Byrd Land and the TAMS transitioned to more focused rifting along the TAMS margin in the Cenozoic.
Friday Talks
Schopf (1969) pointed out that the Cambrian-Permian succession exposed in the topographically isolated Ellsworth Mountains at the head of the Weddell Sea, is characteristic of the Transantarctic margin of the East Antarctic craton. Dalziel and Elliot (1982) proposed that the Ellsworths represented one of four major crustal blocks making up West Antarctica that moved relative to each other and to East Antarctica during Gondwanaland fragmentation. A number of paleomagnetic studies have demonstrated the viability of Schopf’s original suggestion, implying that the Ellsworths represent a displaced segment of the Permo-Triassic Gondwanide orogen derived from the Natal embayment between the Kalahari and East Antarctic cratons (Watts and Bramall, 1981; Grunow et al., 1987; Randall and MacNiocaill, 2004). This conclusion is supported by strong geological evidence (Dalziel, 2008), but has recently been questioned on the basis of airborne geophysical data (Jordan, 2017) and detrital zircon provenance analysis (Castillo et al, 2017). Both approaches have led to the conclusion that the Ellsworth-Whitmore block originated along the Transantarctic margin of the East Antarctic rather than in the Natal embayment. The paleomagnetic data appear to be compatible with either position.

Regardless of their original position, it is clear that the Ellsworth-Whitmore crustal block was displaced during the initial fragmentation of the supercontinent, and that this displacement took place after the Gondwanide orogeny and emplacement of the Karoo-Ferrar Large Igneous Province, but prior to the formation of the oceanic lithosphere now forming the floor of the Weddell Sea, Southwest Indian Ocean, South Atlantic Ocean and Scotia Sea. It is the mechanism that is in question. The most likely explanation, in general terms, is that this displacement, together with the mirror image displacement of the Lafonian (Falkland/Malvinas) microplate of present-day South America (Dalziel et al., 2013), was driven by mantle flow resulting from the formation of a Karoo-Ferrar plume ‘backstopped’ by Kalahari, East Antarctic and Rio de La Plata cratons and associated with roll-back of the subducting Pacific Ocean floor lithosphere.

Till from the margin of the major ice streams of the Weddell Sea Embayment contains detrital minerals with distinct age populations and mineralogy. These differences mean that they can be used as provenance tools to reconstruct past ice stream dynamics and determine the origin of iceberg-rafted debris (IRD) in the marine sediment record. U and Pb isotopic compositions of over 5000 detrital zircons have been measured from onshore and offshore tills. Distinctive zircon age populations for each ice stream include - Institute Ice Stream: 560 Ma and 1070 Ma, Foundation/Academy Ice Streams: 505 Ma and 1030 Ma, Recovery Glacier: 530 Ma and 1610 Ma, and Slessor Glacier: 2260 Ma, 2345 Ma, and 2415 Ma. Many, but not all of these peaks are consistent with local bedrock sources suggesting measurable input from unexposed subglacial sources. Ar-Ar ages from detrital hornblende and biotite from the Foundation/Academy Ice Stream are different from the zircon ages from the same samples. For example, zircon ages are typically 600 Ma and younger, but the primary hornblende peak is at 200 Ma. In contrast till from the northern margin of Recovery Glacier has similar Ar-Ar age peaks as the zircon data. In addition to being useful ice flow tracers, this suite of geochronometers suggest that regional heating during the Mesozoic reached the Pensacola Mountains, but not the Shackleton Range.

Fe-oxide host minerals were also analyzed from the ice stream tills. Foundation Ice Stream tills have the most ilmenite, Academy Glacier tills have abundant magnetite, and only Recovery Glacier tills contain Mn-bearing minerals, which may be eroded from subglacial granitoids. Offshore in the Weddell Sea, the Ronne (west), Hughes (central), and Filchner (east) sectors have distinguishable U-Pb zircon and Ar-Ar source signatures in both till and IRD. From west to east, offshore tills and IRD both typically show a decreasing proportion of Mesozoic grains and an increasing proportion of Proterozoic grains. Statistical analyses will be used to evaluate possible ice flow paths of the ice streams for the last glacial maximum.
Post-Last Glacial Maximum Thinning History of the Foundation Ice Stream, Adjacent to the Pensacola Mountains.

Keir A Nichols¹, Brent M Goehring¹, Greg A Balco², Claire Todd³, Kathleen Huybers³

¹Tulane University  
²Berkeley Geochronology Center  
³Pacific Lutheran University

We present a suite of in situ $^{14}$C surface exposure ages from nunataks at the Schmidt Hills, Antarctica, which constrain the deglacial history of the adjacent Foundation Ice Stream (FIS). The FIS drains ice from East and West Antarctica into the Weddell Sea Embayment (WSE), a relatively understudied sector of the Antarctic Ice Sheet. Exposure dating studies in the Schmidt Hills utilizing the long-lived nuclide $^{10}$Be are hampered by the inheritance of nuclides from previous of exposure. Inheritance, likely a result of the preservation of the bedrock surfaces beneath cold-based ice, means that no post-Last Glacial Maximum (LGM) exposure ages are observed the Schmidt Hills. Existing in situ $^{14}$C Schmidt Hills exposure ages are inconsistent with ages constraining the post-LGM ice history of the FIS in the upstream Williams and Thomas hills, which has created a spatial gap in our knowledge on the deglacial history of the ice stream and results in unrealistically steep LGM ice surface reconstructions. We measured the concentration of the cosmogenic nuclide $^{14}$C from erratic boulders along an elevation transect, from the modern ice surface at 250 m asl up to 950 m asl. The 5730 yr half-life of $^{14}$C means that short (20-30 ka) periods of burial are sufficient to cause substantial $^{14}$C decay and approach resetting of a surface. Furthermore, samples will be saturated in $^{14}$C following ca. 35 ka of exposure, indicating that their location has been ice-free for at least ca. 35 ka, and thus was above the maximum LGM ice surface. Our results indicate that the FIS was up to 300 m thicker than at present during the LGM, constrained by the lowest-elevation saturated samples. Our exposure ages show a minimum of 100 to 300 m of vertical ice thinning between 7 ka to the present, which is consistent with $^{10}$Be deglacial histories from the Williams and Thomas hills, suggesting a more realistic LGM ice slope between the locations. Furthermore, our transect indicates that the FIS reached its present-day configuration by between 4 and 1 ka, consistent with Holocene $^{10}$Be exposure ages from the Williams and Thomas hills.
Climate changes are overall the primary determinant of Antarctic Ice Sheet volume variability over time. However, climate sensitivity of individual drainage basins may be influenced by geologic factors such as geothermal heat flux, distribution, thickness, and rheological properties of subglacial sediments, as well as by subglacial groundwater systems. These factors are difficult to characterize and map out at spatial scales, resolution, and accuracy that may be relevant to numerical ice sheet simulations. This paucity of constraints may be misinterpreted as lack of importance of geologic factors in ice sheet evolution. I will review recent case studies to argue that the role of subglacial geology in determining past and future ice sheet response to climate forcings should be rigorously evaluated.
Spatially variable geothermal heat flux in West Antarctica: evidence and implications

Carolyn Branecky Begeman1, Slawek M. Tulaczyk1, and Andrew T. Fisher1

1. University of California, Santa Cruz, Santa Cruz, California, USA

Geothermal heat flux (GHF) is an important part of the basal heat budget of continental ice sheets. The difficulty of measuring the GHF below ice sheets, which requires direct subglacial access, has limited understanding of ice sheet dynamics. We present a new GHF measurement from below the West Antarctic Ice Sheet, made in subglacial sediment near the grounding zone of the Whillans Ice Stream. The measured GHF is 88 ± 7 mW m⁻², a relatively high value compared to other continental settings, but within the range of estimated regional values indicated by geophysical models. The new GHF measurement was made ~100 km from the only other direct GHF measurement below the ice sheet, which was considerably higher, suggesting spatial variability that could be explained by shallow magmatic intrusions or the advection of heat by crustal fluids. Analytical calculations suggest that spatial variability in GHF can have as much influence on the basal thermal conditions of the ice sheet as ice thickness. Accurate GHF measurements and high-resolution GHF models may be necessary to reliably predict ice sheet evolution, including responses to ongoing and future climate change.
Lithospheric structure of west and central Antarctica and its tectonic implications

Weisen Shen, Douglas A Wiens, Sridhar Anandakrishnan, Andrew Nyblade, Richard C. Aster, Peter Gerstoft, Peter Bromirski, Samantha Hansen, David Heeszel, Audrey Huerta, Terry Wilson, Paul Winberry, Ian Dalziel, Tim Stern, and Ralph Stephen


Since 2010, increasingly high-resolution seismic models of the crust and uppermost mantle structure have been developed for continental regions where large seismic arrays are deployed, including the US and E. Asia. The new features revealed by these models have enriched the understanding to a variety of tectonic processes, such as subduction, rifting, and mountain building. In Antarctica, because of its remoteness and lack of geological exposure, many of the principal tectonic features are not well understood (e.g., the mechanism that produces the high elevation of the Transantarctic Mountains (TAM) is still under debate). A continental-scale, high resolution seismic model can help address such questions, but has not been possible until recently due to the lack of suitable seismic data. Since the early 2000s, a succession of regional broadband seismic networks, including most prominently POLENET/ANET, have been deployed across the continent. These data now sample much of the continent, including the West Antarctica Rift System (WARS) and central Antarctica, and enable us to build a revised 3-D seismic model of the crust and uppermost mantle using state-of-the-art methods. Here we present the 3-D model and discuss the major findings from the results.

To build the 3-D model, we processed more than 20-years of seismic data recorded by over 200 stations in Antarctica, and obtained P-wave receiver functions as well as the surface wave speed measured from both ambient seismic noise and teleseismic earthquakes. By combining these measurements in a Bayesian Monte Carlo framework, we estimate both the shear velocity (Vs) structure and its associated uncertainties. The final 3-D model reveals a number of lithospheric features that have not been previously described in the literature. Notably, we report an absence of thick and cold lithosphere beneath the plateau-like southern Transantarctic Mountains (sTAM). Instead of being seismically fast as the neighboring east Antarctic craton, the sTAM shows slow Vs anomaly at depths between 70 to 120 km, indicating an elevation in temperature of hundreds °C in the shallow mantle. At greater depths, a faster anomaly that is noted at depths of ~ 200km. We interpret these features as the signature of recent lithospheric foundering and the recycling of cold lithosphere into the ambient mantle, causing the upward movement of hot asthenosphere materials beneath the sTAM region. The upward flow of hot, low density mantle produced the broad high elevations of the sTAM, and also generated decompression melting that fed the Miocene volcanism in the Mt. Early region, which is the only site of Cenozoic volcanism known on the east side of the TAM front. Additionally, the absence of thick and cold lithosphere beneath sTAM implies a reduced mantle viscosity, which will affect and allow for better understanding of glacial isostatic adjustment (GIA) in this region.
ROSETTA-Ice Surveys – Exploring the Duality of the Ross Ice Shelf

Kirsty Tinto¹, Christine Siddoway², Laurie Padman³, Helen Fricker⁴, Indrani Das¹, Dave Porter¹, Scott Springer³, Robin Bell¹ and the ROSETTA-Ice Team

¹Lamont-Doherty Earth Observatory, ²Colorado College, ³Earth and Space Research, ⁴Scripps Institution of Oceanography

The Ross Ice Shelf is the largest ice shelf in Antarctica, fed by ice from both the East and West Antarctic ice sheets, and controlled by the interactions between ocean, ice and geological processes. Understanding these processes is essential to understanding the future stability of the ice shelf and ice sheets that it buttresses. The ROSETTA-Ice project is an interdisciplinary study of the Ross Ice Shelf providing a high-resolution multi-instrument survey from ice shelf surface to beneath the sea floor from an airborne platform. The ROSETTA-Ice survey is a three-year program, two-thirds complete, that aims to survey the Ross Ice Shelf at 10 km resolution. The survey grid is based on the 1970s RIGGS survey, that provides a network of point measurements to provide constraints to the high-resolution grid. ROSETTA-Ice surveys are flown using the IcePod instrument suite, mounted on an LC130. The instrument suite comprises lidar, shallow and deep ice radar, a magnetometer and gravimeters carried inside the aircraft. Ocean profiling floats have also been deployed as part of the ROSETTA-Ice program. The gravity and magnetics data allow a determination of bathymetry, using gravity inversion techniques, and a calculated depth to magnetic basement. Preliminary results from the first two survey years reveal a pronounced bedrock control on seafloor topography and a fundamental crustal boundary 300 km to the east of the Transantarctic Mountains. The boundary is marked by a clear change in the character of magnetic anomalies; in the density model of the underlying rock, derived from gravity anomalies; and in the modeled bathymetry. TAM-side geophysical signatures resemble those discovered by the CTAM airborne survey (Goodge et al. 2010). The characteristics of crust beneath the Siple Coast sector of the RIS strongly resemble those of the Central West Antarctica and western MBL airborne geophysical datasets. Both regions display sharp relief suggestive of shallow basement and structural control of bathymetry, and lack the prevalent large glacial-sedimentary landforms of the Ross Sea bed. We interpret the boundary between the two sectors of RIS to be the position of the fundamental tectonic break between the cratonic / orogenic crust of East Antarctica and the accretionary margin crust of West Antarctica.

The fundamental duality of the Ross Ice Shelf is further revealed in radar profiles, in which packets of ice from individual glaciers and ice streams can be traced along the flow of the ice shelf, showing the integrated history of surface accumulation and basal melting of the last 1000 years. The ocean-ice interactions at the base of the ice shelf are influenced by the large-scale bathymetric features controlled by the crustal boundary as well as the smaller scale features that have been influenced by glacier erosion and deposition over cycles of ice sheet advance and retreat. The ROSETTA-Ice project gives new insight into the interactions between the processes governing the Ross Ice Shelf, and highlights the need for interdisciplinary understanding of this complex system.
Temperature profiles along the Whillans Ice Stream measured using a Distributed Temperature Sensor

Sarah Neuhaus¹, Scott Tyler², Kenneth Mankoff³, Slawek Tulaczyk¹, Marion Bougamont⁴, Poul Christoffersen⁴

¹Department of Earth and Planetary Sciences, University of California, Santa Cruz
²Department of Geological Sciences and Engineering, University of Nevada, Reno
³Geological Survey of Denmark and Greenland (GEUS), Department of Glaciology and Climate
⁴Scott Polar Research Institute (SPRI), Department of Geography, University of Cambridge

Deep ice temperature profiles from fast moving sections of the Antarctic ice sheet provide important constraints on dynamic changes which affected the ice flow field within the recent centuries and millennia. One factor limiting the ability to collect such deep temperature profiles is the high failure rate for temperature sensors going through the process of re-freezing of a water-filled borehole. As a result, few such profiles exist. We present results from two 700-800m deep temperature profiles measured using a Distributed Temperature Sensor (DTS) and collected between January 2013 and December 2016. The DTS measures temperature using temperature-dependent scattering of a laser signal of known wavelength pulsed through a fiber-optic cable. It yields temperature measurements in one-meter increments along the length of the fiber within the borehole. Our measurements come from two boreholes located along the Whillans Ice Stream on the Siple Coast. Both DTS strings survived the freezing process and maintained integrity over the duration of the study enabling repeat temperature measurements of the ice column. Changes in our data from year to year reflect thermal recovery from the drilling and re-freezing process. They may also allow us to infer changes in the environment at the base of the ice.
Chemical weathering in Permafrost assessed using Magnesium Isotopes

Nicolas Cuozzo, Ronald S. Sletten, Yan Hu, Fang-Zhen Teng

University of Washington, Department of Earth and Space Sciences

While it is recognized that chemical weathering occurs in permafrost soils, there are few studies that document in-situ weathering of the frozen sediment since most weathering products are leached away. The cold and dry conditions of the Antarctic Dry Valleys provide a unique environment where weathering products are not leached and accumulate in the ice-rich phase. This study provides a novel perspective of weathering in permafrost by analyzing the chemical composition in the melt-water of thawed samples along a 30-meter permafrost core collected in Beacon Valley, Antarctica. The conditions and extent of chemical weathering are characterized by Mg isotopes, temperature, soluble salt concentration, pH, rock-ice ratio, and modeled unfrozen water content using the chemical thermodynamic models, PHREEQC and FREZCHEM. The data reveal that the Mg isotopic ratios and core composition change abruptly at 7 meters. The Mg isotopic values in the upper 7 meters illustrate that Mg is sourced from two end members with distinct isotopic compositions: (1) marine aerosols that are captured and deposited by snowfall, and (2) chemical weathering of Ferrar Dolerite. Weathering products accumulated in the ice have Mg isotopic values between the two end members, and show up to 50% of Mg in the thawed ice is derived from dolerite weathering. The upper 7 meters are also characterized by seasonal temperatures rising above -20°C, with higher soluble salt concentrations, pH values, rock-ice ratios, and percentage of unfrozen water content compared to below 7 meters. Below 7 meters, Mg isotopic values fall within the range of the marine aerosol end member with little deviation. The results show chemical weathering occurs in the upper 7 meters and provide evidence of the degree and potentially the rate of chemical weathering in permafrost. Primary controls on chemical weathering are the ice-rock ratios and the amount of unfrozen water, which is dependent on both temperature and soluble salt concentrations.
Soil Phosphorus Availability Links the Geosphere and the Biosphere in the
McMurdo Dry Valleys, Antarctica

Ruth Heindel1,2, Angela Spickard3, Ross Virginia3

1Institute of Arctic and Alpine Research, University of Colorado Boulder, Boulder CO 80309
2Department of Earth Sciences, Dartmouth College, Hanover NH 03755
3Environmental Studies Program, Dartmouth College, Hanover NH 03755

Flying into the McMurdo Dry Valleys (MDVs) from the McMurdo Sound, it is hard not
to notice distinct boundaries between regions of light and dark soils. Near the southern shore of
Lake Fryxell in Taylor Valley, a dark sinuous ridge lies in stark contrast to the lighter
surrounding soils. In nearby Miers and Garwood Valleys, sharp lines separate the dark soils of
the valley floor from the lighter valley walls. The dark soils in the MDVs obtain their color from
plentiful basalts and kenytes (a rare porphyritic phonolite), mafic volcanic rocks with high
quantities of the essential nutrient phosphorus (P) in their mineral compositions. If these
volcanic rocks weather readily and release P into the soil ecosystem, regions of dark soil may be hotspots
of P availability. Spatial patterns of soil color variation in the MDVs may thus represent an
important link between the geosphere and the biosphere through the availability of soil P.

The biogeochemical weathering of apatite, the most common P-bearing mineral, is the
ultimate source of P to soil ecosystems. To link parent material, soil color, biogeochemical
weathering, and P availability, we have looked at regional patterns of soil P concentrations and at
grain-scale indicators of apatite weathering. While dark soils do contain significantly higher
concentrations of total P (1.65 ± 0.35 g/kg dry soil in dark soils vs. 1.11 ± 0.42 g/kg dry soil in
light soils), P available to organisms does not vary by soil color (2.90 ± 2.86 mg/kg dry soil in
dark soils vs. 3.09 ± 5.32 mg/kg dry soil in light soils). Instead, our results suggest that factors
other than parent material, including soil texture, conductivity, and moisture content, control the
weathering of apatite and the retention of available P in MDVs soils. Many questions remain
about the weathering of apatite in such dry and basic soil conditions.

What is the origin of these dark soils? Kenyte, one of the mafic volcanic rocks that
contributes to the appearance of dark soil, does not outcrop in the MDVs. Instead, kenyte
outcrops across the McMurdo Sound on Ross Island, the location of Mt. Erebus, the world’s only
active phonolite volcano. Previous work has established that during the Last Glacial Maximum, a
grounded Ross Sea Ice Sheet transported these P-rich rocks across the McMurdo Sound. A series
of ice-covered proglacial lakes then conveyed the erratics up into the MDVs, depositing the
patterns of soil color we see today. The region’s volcanic and glacial histories are thus critical to
understanding variations in soil parent material and concentrations of total soil P in the MDVs.

The predicted climate warming in the MDVs may increase water availability from glacial
melt and permafrost thaw, potentially increasing rates of biogeochemical weathering. Mineral P
currently unavailable to organisms may be released into the soil ecosystem, where it could either
be retained or transported downstream to P-limited aquatic habitats. The changing dynamic of
soil P availability is driven by both geological and biological processes in the MDVs, and
represents an area where interdisciplinary collaboration is needed.
Wind-Driven Rock Abrasion in the Ice-Free Valleys, Antarctica: Rates and Controls

Michael C. Malin1, *Bernard Hallet2, and Ronald S. Sletten2

1. Malin Space Science Systems, San Diego, CA, USA
2. Earth and Space Sciences, U. of Washington, Seattle, WA. USA

Wind is a principal geomorphic agent in dry regions of Earth and Mars, where it transports sediments and erodes rock surfaces, thereby creating diverse features ranging from bedforms (cm) to sand seas (1000’s km), shaping sand grains, rocks fragments, and bedrock landforms, and generating dust and regolith. Despite its importance, few studies have defined rates of rock abrasion under natural conditions.

We report rock abrasion rates that are well characterized through a comprehensive long-term (>30 year) field experiment in the ice-free McMurdo Valleys, Antarctica. More than 5000 rock targets of several lithologies (dolerite, basalt, and non-welded tuff) were installed at 5 heights (7, 14, 21, 35, and 70 cm above the ground) facing the 4 cardinal directions at 10 sites. Fewer targets, including some made of sandstone, were deployed at an additional site. Periodic collecting and reweighing of rock targets exposed to abrasion define the progressive mass loss, which provides a simple measure of the abrasion, after 1, 5, 10, 30 and 31 years of exposure.

Abrasion rates generally show striking consistency for a given lithology at any site, but they vary considerably from site to site owing to differences in availability of transportable sediment, wind regime, and surface roughness. At each site, rates primarily depend on target orientation relative to the dominant winds and, secondarily, on height above the ground. Abrasion rates on rock targets facing the dominant winds at our most active site, #7 in Wright Valley, averaged 21, 49, and 3400 µm/yr, respectively for dolerite, basalt, and tuff. In contrast, corresponding rates were only 2, 4, and 200 µm/yr at site 8, one of the least active sites, and yet it is only 23 km from, and directly down valley of, site 7. We discuss the spatial and directional variation in measured abrasion in the context of a wealth of information, including site-specific size distribution of surface and air-entrained sediments at various heights up to 1.4 m above the ground, sediment flux (in the early years of the experiment), aerodynamic roughness, availability of loose sediment on the ground surface, directionality of sandblasting on targets and nearby boulders, as well as theoretical considerations, and published laboratory data on aeolian rock abrasion (Greeley, et al., 1982).
Cryoturbation rates in an Antarctic volcanic terrain: preliminary results from Mount Morning

Mark D. Kurz¹, Joshua Curtice¹, S. A. Soule¹, James Bockheim², William J. Jenkins¹

1) Woods Hole Oceanographic Institution, Woods Hole MA, 02543, USA
2) University of Wisconsin, Madison, Wisconsin, 53706, USA

Cryoturbation plays a key role in shaping the landscapes in cold regions. In an effort to determine the rates of motion, and landscape modification, by freezing and thawing in Antarctic patterned ground, we collected a suite of surface samples and depth profiles in lava flow polygons on Mount Morning, Southern Victoria Land, Antarctica. The site was selected for well-defined polygons in a basaltic lava flow matrix, with a relatively simple emplacement history. Measurements of cosmic-ray-produced \(^3\)He in basaltic olivine phenocrysts were carried out by crushing and melting in vacuum at the Isotope Geochemistry Facility at WHOI (www.whoi.edu/IGF). The cosmogenic \(^3\)He(c) depth profiles, from basaltic clasts in permafrost, display a simple exponential depth dependence, suggesting minimal motion of the lava flow matrix in the top meter. A 2.5 meter transect of boulders and clasts across the polygon surface, from center to edge, have identical \(^3\)He(c) abundances, also demonstrating that there is minimal motion associated with freezing and thawing. The mean polygon \(^3\)He(c) abundances are indistinguishable from the mean from lava flow outcrop exposures, at 1-2 meter elevation above the polygon surface. The \(^3\)He exposure age of the polygon surface is 158±7 Ka, assuming no erosion or cover, which most likely reflects the lava flow emplacement age. These data suggest that the lava flow has been completely disaggregated by freezing and thawing, along with the influence of wind-blown snow and melt water percolation, but without any convection of the solid basalt clasts. The lack of evidence for convection has important implications for permafrost cryoturbation models, and demonstrates a new application of cosmogenic nuclides to landscape evolution studies.
Inundation of Beacon Valley presumably due to meltwater from Taylor Glacier has led to the formation of at least 30 meters depth of ice-cemented sandy permafrost. Lower Beacon Valley has accumulated wind-blown sand over several Ma that is kinetically sieved into thermal contraction cracks of polygonal patterned ground. Analysis of cosmogenic beryllium, aluminum, and neon in the quartz isolated from the sand samples reveals that the sediment has been accreting for at least 5 Ma at 7 m depth. These sediments serve as a unique paleo-environmental archives in the barren and hyperarid Dry Valley landscapes and may provide clues to the past glacial history of the region. After the formation of the sediments from the accumulating sands, lower Beacon Valley was apparently inundated by Taylor Glacier meltwater. The water’s origin is determined based on analysis of the ions, nontraditional isotopes, and water stable isotopes, after thawing the core and extracting the water. Apparently, the meltwater flushed previously accumulated salts in the soils and possibly in the glacial ice into the sediments. After inundation, the sediment refroze rapidly based on a complementary study of rock-water interactions that reveals little weathering at depth in the sediments. The age of the quartz in the uppermost sediments provides a maximum age for timing of inundation and suggests that this occurred within 3-5 Ma. This study provides compelling evidence of a large proglacial lake forming as recently as several Ma. The thaw depth to which the water inundated the soils may provide a rough indicator of the water temperature and longevity of the lake.
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<td>Byron</td>
<td>Adams</td>
<td>Brigham Young University</td>
<td><a href="mailto:bjadams@byu.edu">bjadams@byu.edu</a></td>
</tr>
<tr>
<td>Allie</td>
<td>Balter</td>
<td>University of Maine</td>
<td><a href="mailto:alexandra.balter@maine.edu">alexandra.balter@maine.edu</a></td>
</tr>
<tr>
<td>Grace</td>
<td>Barcheck</td>
<td>University of California Santa Cruz</td>
<td><a href="mailto:cbarchec@ucsc.edu">cbarchec@ucsc.edu</a></td>
</tr>
<tr>
<td>Marie</td>
<td>Bergelin</td>
<td>University of North Dakota</td>
<td><a href="mailto:marie.bergelin@und.edu">marie.bergelin@und.edu</a></td>
</tr>
<tr>
<td>Leslie</td>
<td>Blank</td>
<td>ASC</td>
<td><a href="mailto:Leslie.Blank.contractor@usap.gov">Leslie.Blank.contractor@usap.gov</a></td>
</tr>
<tr>
<td>Carolyn</td>
<td>Branecky-Begeman</td>
<td>University of California Santa Cruz</td>
<td><a href="mailto:cbranecyk@ucsc.edu">cbranecyk@ucsc.edu</a></td>
</tr>
<tr>
<td>Howard</td>
<td>Conway</td>
<td>University of Washington</td>
<td><a href="mailto:hcon@uw.edu">hcon@uw.edu</a></td>
</tr>
<tr>
<td>Nicolas</td>
<td>Cuozzo</td>
<td>University of Washington</td>
<td><a href="mailto:ncuozzo@uw.edu">ncuozzo@uw.edu</a></td>
</tr>
<tr>
<td>Ian</td>
<td>Dalziel</td>
<td>University of Texas at Austin</td>
<td><a href="mailto:ian@ig.utexas.edu">ian@ig.utexas.edu</a></td>
</tr>
<tr>
<td>Kathryn</td>
<td>Durkin</td>
<td>Scripps Institution of Oceanography</td>
<td><a href="mailto:kdurkin@ucsd.edu">kdurkin@ucsd.edu</a></td>
</tr>
<tr>
<td>Tyler</td>
<td>Fudge</td>
<td>University of Washington</td>
<td><a href="mailto:tfudge@uw.edu">tfudge@uw.edu</a></td>
</tr>
<tr>
<td>Joseph</td>
<td>Graly</td>
<td>Indiana University-Purdue University Indianapolis</td>
<td><a href="mailto:jgraly@iupui.edu">jgraly@iupui.edu</a></td>
</tr>
<tr>
<td>Anne</td>
<td>Grunow</td>
<td>Ohio State University</td>
<td><a href="mailto:grunow.1@osu.edu">grunow.1@osu.edu</a></td>
</tr>
<tr>
<td>Bernard</td>
<td>Hallet</td>
<td>University of Washington</td>
<td><a href="mailto:hallet@uw.edu">hallet@uw.edu</a></td>
</tr>
<tr>
<td>Andy</td>
<td>Hein</td>
<td>University of Edinburgh</td>
<td><a href="mailto:andy.hein@ed.ac.uk">andy.hein@ed.ac.uk</a></td>
</tr>
<tr>
<td>Ruth</td>
<td>Heindel</td>
<td>University of Colorado Boulder</td>
<td><a href="mailto:ruth.heindel@gmail.com">ruth.heindel@gmail.com</a></td>
</tr>
<tr>
<td>Theresa</td>
<td>Hudson</td>
<td>Indiana University-Purdue University Indianapolis</td>
<td><a href="mailto:thhudson@iupui.edu">thhudson@iupui.edu</a></td>
</tr>
<tr>
<td>Libby</td>
<td>Ives</td>
<td>University of Wisconsin-Milwaukee</td>
<td><a href="mailto:woodfor5@uw.edu">woodfor5@uw.edu</a></td>
</tr>
<tr>
<td>Michael</td>
<td>Kaplan</td>
<td>Lamont-Doherty Earth Observatory</td>
<td><a href="mailto:mkaplan@ldeo.columbia.edu">mkaplan@ldeo.columbia.edu</a></td>
</tr>
<tr>
<td>Christine</td>
<td>Kassab</td>
<td>Indiana University-Purdue University Indianapolis</td>
<td><a href="mailto:ckassab@iupui.edu">ckassab@iupui.edu</a></td>
</tr>
<tr>
<td>Skye</td>
<td>Keeshin</td>
<td>Colorado College</td>
<td><a href="mailto:skye.keeshin@coloradocollege.edu">skye.keeshin@coloradocollege.edu</a></td>
</tr>
<tr>
<td>Tori</td>
<td>Kennedy</td>
<td>Indiana University-Purdue University Indianapolis</td>
<td><a href="mailto:torkenne@umail.iu.edu">torkenne@umail.iu.edu</a></td>
</tr>
<tr>
<td>Douglas</td>
<td>Kowalewski</td>
<td>NSF</td>
<td><a href="mailto:dkowalew@nsf.gov">dkowalew@nsf.gov</a></td>
</tr>
<tr>
<td>Mark</td>
<td>Kurz</td>
<td>Woods Hole Oceanographic Institution</td>
<td><a href="mailto:mkurz@whoi.edu">mkurz@whoi.edu</a></td>
</tr>
<tr>
<td>Philip</td>
<td>Kyle</td>
<td>New Mexico Institute of Mining and Technology</td>
<td><a href="mailto:philip.kyle@nmt.edu">philip.kyle@nmt.edu</a></td>
</tr>
<tr>
<td>Jennifer</td>
<td>Lamp</td>
<td>Lamont-Doherty Earth Observatory</td>
<td><a href="mailto:jlamp@ldeo.columbia.edu">jlamp@ldeo.columbia.edu</a></td>
</tr>
<tr>
<td>Kathy</td>
<td>Licht</td>
<td>Indiana University-Purdue University Indianapolis</td>
<td><a href="mailto:klicht@iupui.edu">klicht@iupui.edu</a></td>
</tr>
<tr>
<td>John</td>
<td>Meyer</td>
<td>University of Washington</td>
<td><a href="mailto:jjmeyer@uw.edu">jjmeyer@uw.edu</a></td>
</tr>
<tr>
<td>Paul</td>
<td>Morin</td>
<td>Polar Geospatial Center</td>
<td><a href="mailto:lpaul@umn.edu">lpaul@umn.edu</a></td>
</tr>
<tr>
<td>Demian</td>
<td>Nelson</td>
<td>University of California Santa Barbara</td>
<td><a href="mailto:demian@umail.ucsb.edu">demian@umail.ucsb.edu</a></td>
</tr>
<tr>
<td>Sarah</td>
<td>Neuhaus</td>
<td>University of California Santa Cruz</td>
<td><a href="mailto:suneuhau@ucsc.edu">suneuhau@ucsc.edu</a></td>
</tr>
<tr>
<td>Keir</td>
<td>Nichols</td>
<td>Tulane University</td>
<td><a href="mailto:knichol3@tulane.edu">knichol3@tulane.edu</a></td>
</tr>
<tr>
<td>Kurt</td>
<td>Panter</td>
<td>Bowling Green State University</td>
<td><a href="mailto:kpanter@bsu.edu">kpanter@bsu.edu</a></td>
</tr>
<tr>
<td>Jaakko</td>
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<td>University of North Dakota</td>
<td><a href="mailto:jaakko.putkonen@und.edu">jaakko.putkonen@und.edu</a></td>
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<tr>
<td>Mark</td>
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<td><a href="mailto:mark.salvatore@nau.edu">mark.salvatore@nau.edu</a></td>
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<td>Weisen</td>
<td>Shen</td>
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<td><a href="mailto:weisen.shen@wustl.edu">weisen.shen@wustl.edu</a></td>
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