Subglacial Access Working Group Updates:

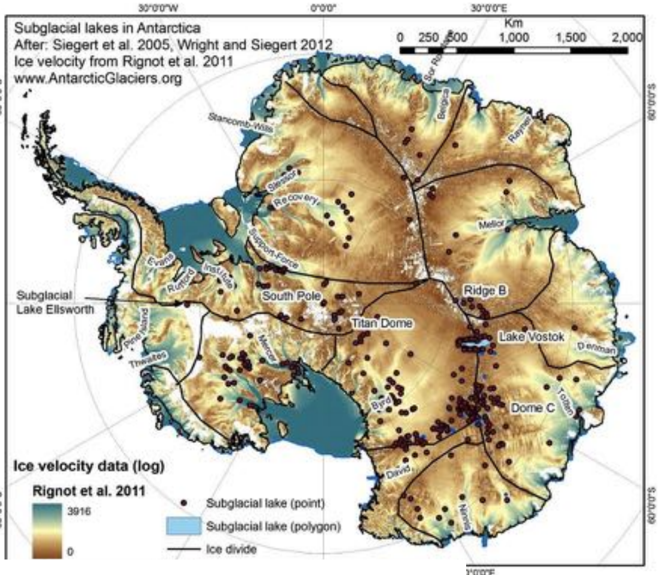
Jill Mikucki
Ross Powell
John Goodge

IDPO-SAB Meeting
6-7 March 2017

RAID at Minna Bluff 2016-17

Science aims and environments requiring subglacial access drilling

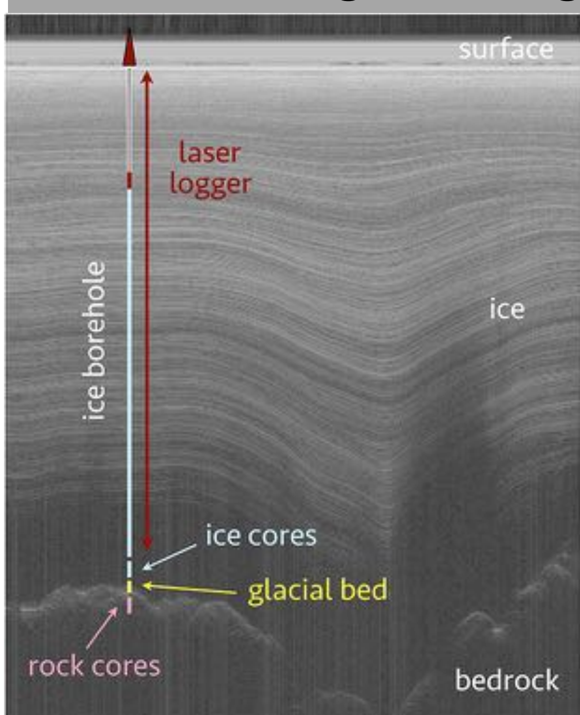
Subglacial Aquatic environment exploration:



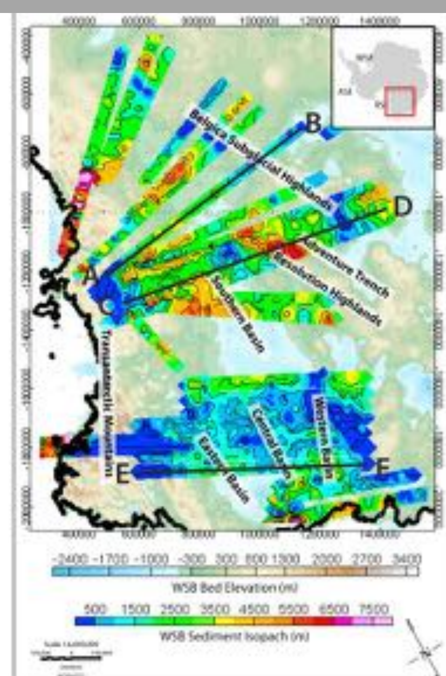
Wright and Siegert (2012)

- Bed properties
- Hydrology
- Microbiology
- Geochemistry
- Geology
- Paleoclimate data
- Geothermal flux measurements
- Understand Ice-rock interface
- Cosmogenic dating – ice sheet extent/history
- Ice Sheet Stability

Subice Geologic Drilling

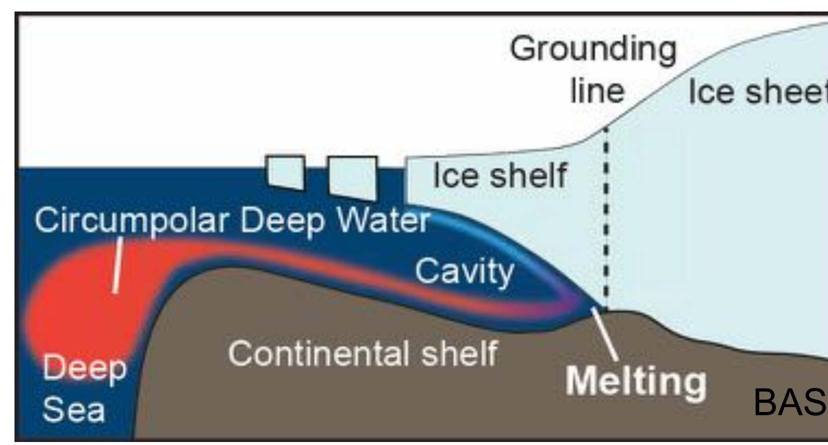


Sedimentary Basins



Frederick et al. *JGR* 2016

Grounding zone investigations
Sheer margins
Ice sheet and ice stream dynamics
Marine cavity access



First SAWG community workshop:

SUBGLACIAL ACCESS WORKING GROUP
SCIENCE PLANNING WORKSHOP

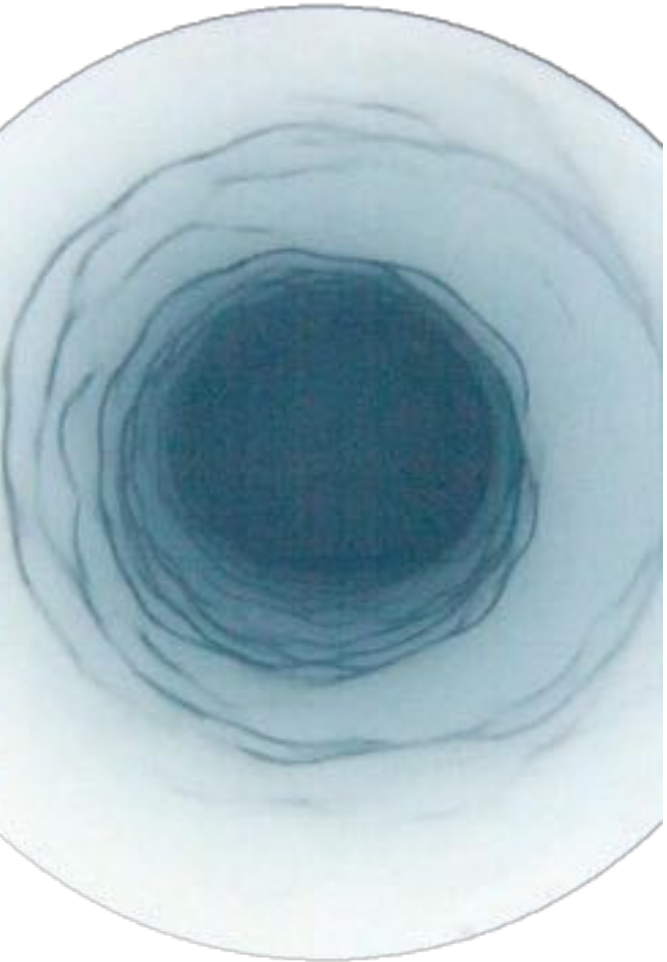
May 21-23, 2016

Herndon, Virginia, USA

PARTICIPANTS

Mary Albert	Dartmouth -- IDPO
Sridhar Anandakrishnan	Penn State Univ
Greg Balco	Berkeley Geochronology Center
Terry Benson	IDDO/PSL
Matt Charette	WHOI
Knut Christianson	University of Washington
Beata Csatho	University at Buffalo
Chris Fritsen	NSF
John Goodge	UMD
Bart Hogan	Stone Aerospace Inc.
Alexandra Isern	NSF
Mike Jackson	NSF
Rongsong JIH	DOS
Nathaniel Lifton	Purdue University
Brad Lipovsky	Harvard
W. Berry Lyons	Ohio State University
Ken Mankoff	PSU
Jill Mikucki	University of Tennessee - Knoxville
Anders Noren	CSDCO / LacCore – Univ. of Minnesot
Frank Rack	University of Nebraska---Lincoln
Reed Scherer	Northern Illinois University
Britney Schmidt	Georgia Institute of Technology
Judy Shiple	ASC
Vickie Siegel	Stone Aerospace
Matthew Siegfried	Scripps Institution of Oceanography
Rolf Sinclair	Centro de Estudios Cientificos, Valdivia
Mark Skidmore	Montana State University
Kristina Slawny	IDDO
Perry Spector	University of Washington
Leigh Stearns	University of Kansas
William Stone	Stone Aerospace
John Stone	University of Washington
Slawek Tulaczyk	EPS/UCSC
Donald Voigt	Penn State University
Julia Wellner	University of Houston
Thom Wilch	NSF
Dale Winebrenner	University of Washington
Duncan Young	University of Texas Institute for Geoph

SAWG science priorities guided by the Antarctic strategic vision document



- Multidisciplinary campaign to understand why the Antarctic ice sheets are changing now and how they will change in the future.
- How do Antarctic biota evolve and adapt to the changing environment?
- Borehole logging and observations to understand Universe evolution and fate
- As well as access to the Leverett/Russell Glacier region in West Greenland, and the Northeast Greenland Ice stream, potential subglacial lakes near Thule, Greenland.

Addressing these priorities requires subglacial access tools

Key Deliverables from the SAWG Workshop:

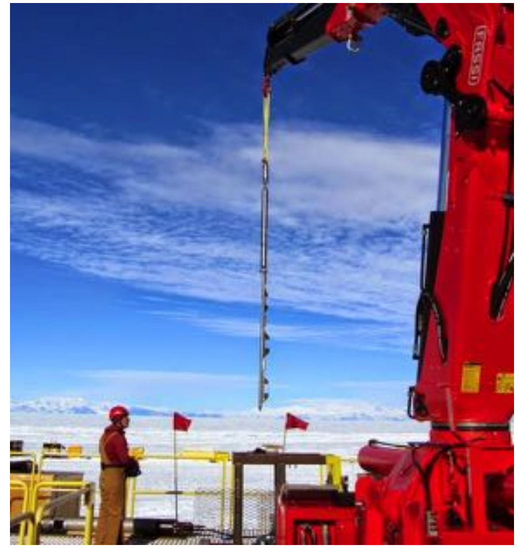
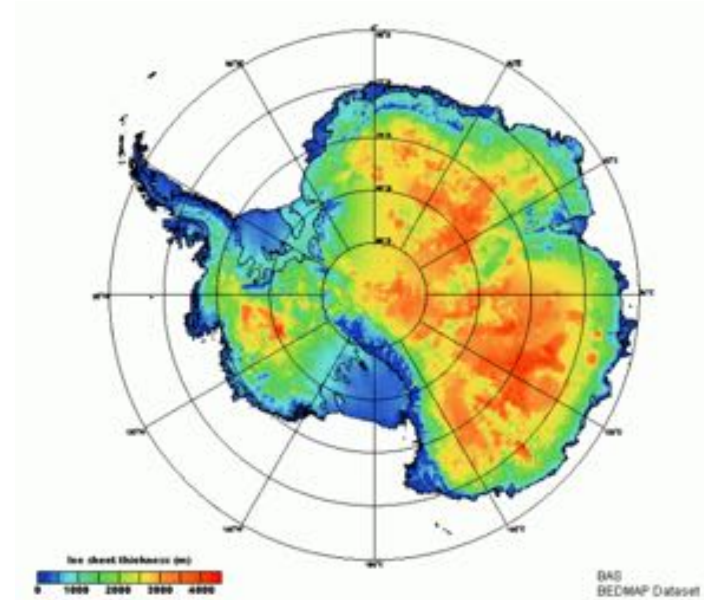
4 white papers detailing community science priorities
Contributions to the IDPO LRSP

Subglacial Access Community White Papers

- Ross Sector
- Continental Interiors
- Subglacial Aquatic Environments
- Thwaites Glacier Region (Ice shelves and Ice streams)

Summary
Compelling research questions
Scientific Rationale
Drilling parameters
Sampling requirements
Target location(s)
Target timeline
Logistical requirements



Exploration of subice environments require:

- Access to the full dynamic range of depths
- Basal-ice collection capabilities (drilling/coring in mixed media, permafrost)
- Access holes that remain open for diverse sampling tools
- Melters with sample collection capabilities
- Borehole monitoring/Observatories and *in situ* measurements
- Temporal and spatial variation (diversity of environments)
- Clean access
- ROV/Scouting and sampling capabilities below ice shelves, along grounding zones and larger lakes

RAID, WISSARD Drill, ScHWD...

Recommendations emerging from the SAWG workshop (Priority 1):

1. Evaluate practicality of acquiring WISSARD Drill system and operating it under IDDO:

Rationale: There is significant pressure for use of the WISSARD drill by the SAWG community because it is currently the only deep HWD available. Three out of four of the SAWG white papers identify this tool as important towards addressing their science goals.

2. Develop IDPO Science Requirements for clean access drilling

Rationale: A vast majority of priority drilling targets require access to ‘wet’ environments and 1) would therefore trigger environmental stewardship requirements and 2) provide high scientific return for retrieving samples that have been collected in a clean manner.

Recommendations emerging from the SAWG workshop (Priority 1):

3. Develop science requirements and a conceptual plan for a hot water drill capable of creating access holes in ice depths of 2,500m or greater for deeper targets (i.e. sites around Thwaites, interior sedimentary basins).

Rationale: access holes to depths greater than 1000 m. BAS currently has a drill that can go to 2500m now, thus the technology is available and it is anticipated that there will be proposal pressure from the SAWG community for this technology.

P1: Need for drillers and engineers on staff for technical continuity

Recommendations emerging from the SAWG workshop (Priority 2):

1. Build a scalable, modular hot water access drill for creating access holes in ice from 50 m up to approximately 2,500 m depth with modular potential to be used for clean access.
Rationale: provide access holes for addressing science priorities around sea-rise, understanding dynamics in the Ross Sea region and obtaining samples from aquatic environments.

2. Develop concept plans for modular clean access capabilities for existing and future drills.
Rationale: clean access capabilities should be developed for the ScHWD.

Advocate for increased efficiencies and investments in logistical support and international partnerships.
Rationale: Many drilling and coring projects are limited by logistical support including traverse capabilities, weight and power requirements of tools, etc.

Progress on developing IDPO Science requirements for clean access drilling: Scalable Hot Water Drill

Filtration Sled Equipment - IDDO
(UV Equipment not shown)

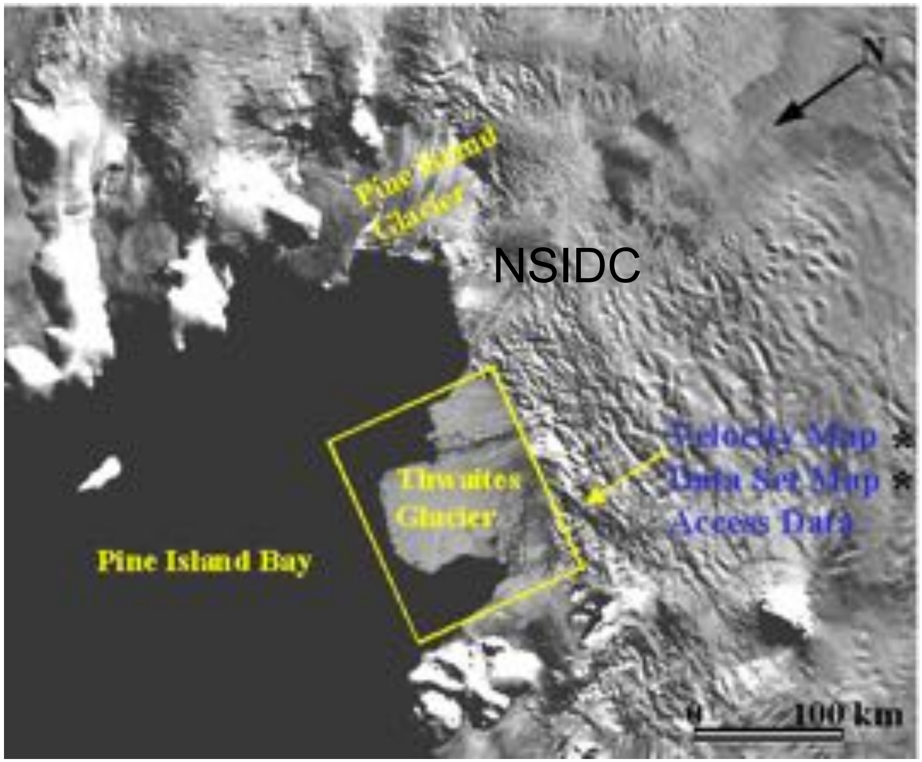
- Reduce bioload and chemical contaminants
- Filtration and UV treatment, monitoring ports, ease of use
- Comments from science community representatives on a modular cleaning unit for
- J. Mikucki (SAWG, Microbiology, WISSARD, MIDGE) Berry Lyons (geochemistry), Peter Doran (TAB), Matt Siegfried (geophysics) and Brent Christner (Microbiology, WISSARD, SALSA)
- In collaboration with IDDO engineers (Chris Gibson, Krissy, Mary)

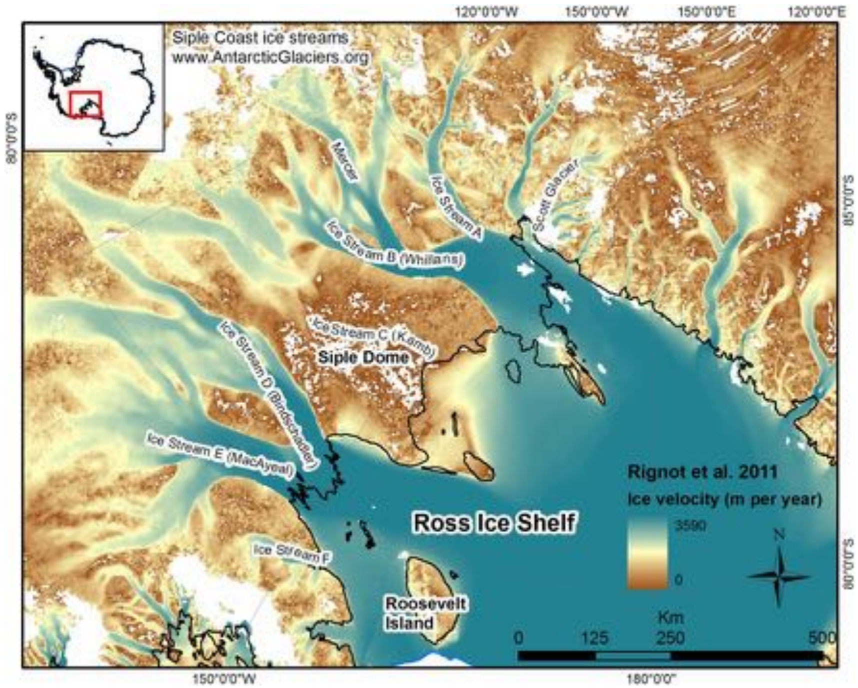
Project updates:

RAID
Pirrit Hills
SALSA

Upcoming:

Thwaites Initiative submissions
Ross Ice Shelf
Sheer margins
Greenland subglacial lakes
dry valley aquifers
Greenland bedrock
grounding zones





RAID UPDATES:

RAID SCIENCE PLANNING WORKSHOP – March 2-3 in La Jolla

John Goodge
Jeff Severinghaus

Strong field season for operations:

- Smooth traverse to Minna Bluff (site A-1)
- Drill rig set-up, drill operations, rigging down, and move back to MCM

Challenges:

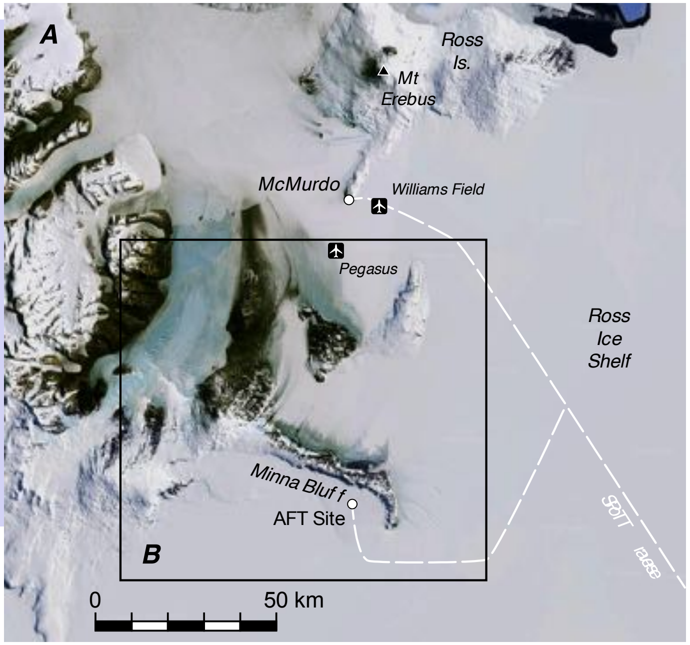
- Firn thickness – snow accumulation an Minna Bluff much higher than anticipated
- Original estimates 35-45 m; only ~50 m of augers on hand
- Extra augers ordered from NZ supplier
- Ultimately reached 79 m (still no seal)

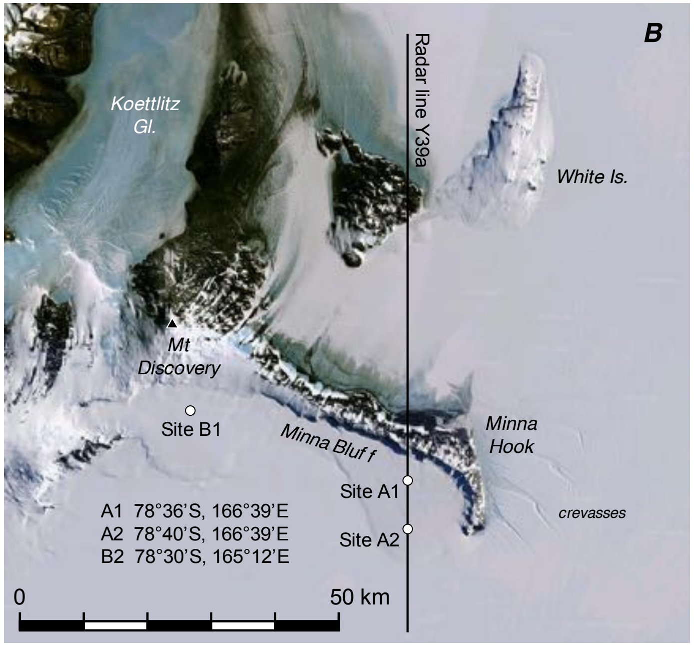
Other delays: augers did get stuck during the process; but were successful – full confidence that work on the Plateau will be successful (~120m)
Unfortunately – RAID team had to decamp before getting through the firn

Outcomes:

- No ice drilling or rock coring
- Lots of lessons learned on drill process and capabilities

- RETURN: 2017-2018 season

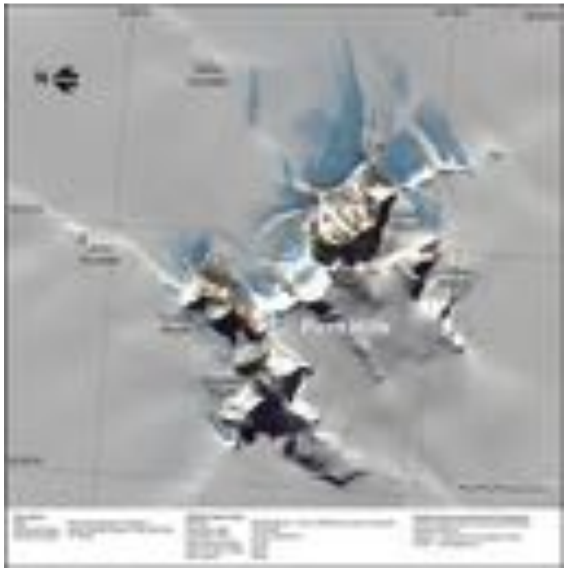




RAID

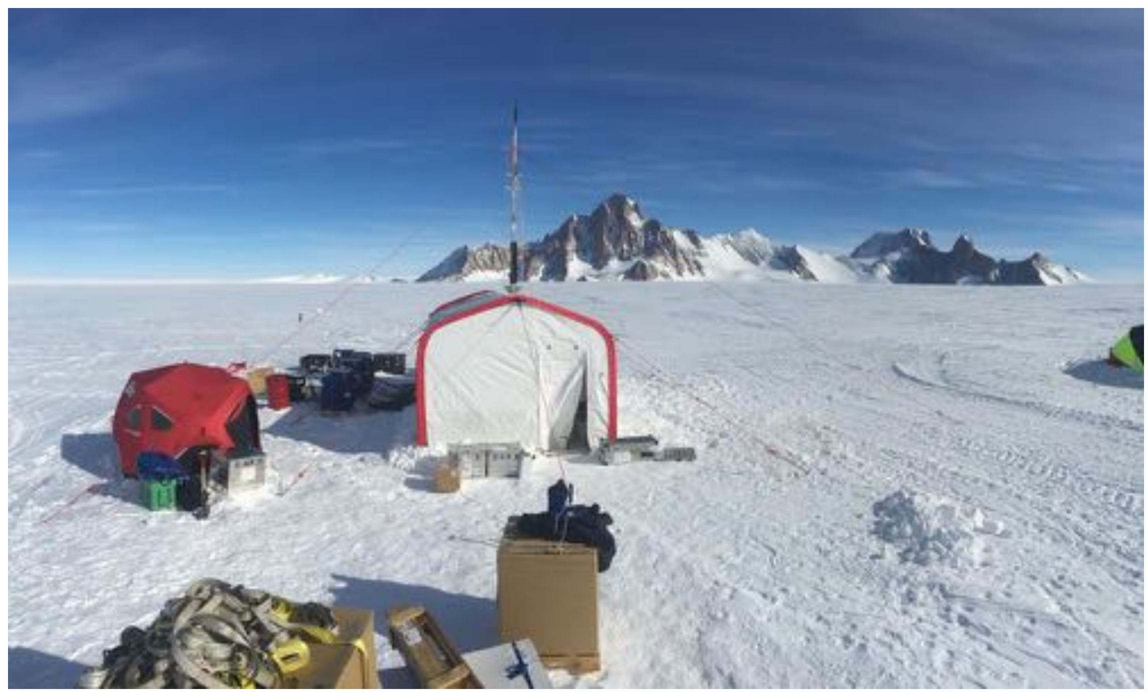
RAPID ACCESS ICE DRILL

Antarctica: Exposed Rock Beneath the West Antarctic Ice Sheet



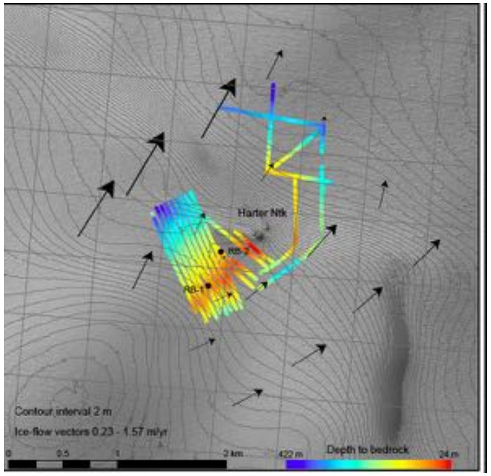
Pirrit Hills
John Stone - POC

AIM: Understand ice sheet response to known climate conditions
TOOL: exposure dating of subice bedrock core = evidence of deglaciation in the past to specific periods of warmer climate



Agile Sub-Ice Geological (ASIG) Drill

Update from Pirrit Hills
John Stone



ASIG drill demonstrated drilling ice and rock using fluid circulation through a continuous drill string does indeed work.

Plan: Collect two bedrock cores one below100 m of ice and one below 200 m of ice

100m Hole
Hydrofracture of the ice in the 100 m hole halted operations a few meters from bedrock

Hydrofracture occurred by circulating drilling fluid, but before daily drilling operations (still working on understanding this issue)

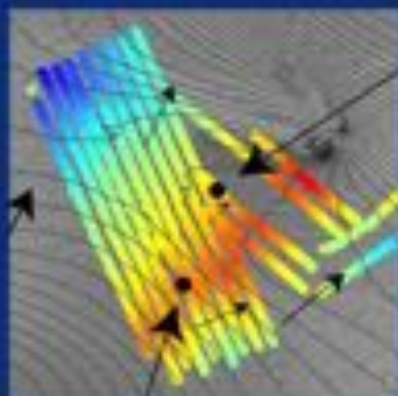
200m Hole
Success! 8m bedrock collected beneath 150 m of ice
Rock core recover was 100%
Ice recovery above bed - partially successful

- ~60% recovery from an 8m ice core (from 142-150m depth)
- Highly fractured from drilling (or inherent property of the basal ice at this site?)

Challenges:
Firn – problem for the ASIG drilling pilot hole with a 4" PICO corer (inefficient)
Auger string – worked better and faster (1.5 days instead of 6)

Limitation – time required to filter cuttings out of the drill fluid

Pirrit Hills 2016/17 – ASIG drill



- *50% successful*
- *First hole abandoned after hydrofracture in basal ice*
- *Second hole produced 8 m of core beneath 150 m of ice*

Pirrit Hills 2016/17 – ASIG drill

- *50% successful*
- *First hole abandoned after hydrofracture in basal ice*
- *Second hole produced 8 m of core beneath 150 m of ice*

Subglacial Antarctic Lakes Scientific Access (SALSA): Integrated study of carbon cycling in a hydrologically-active subglacial environment

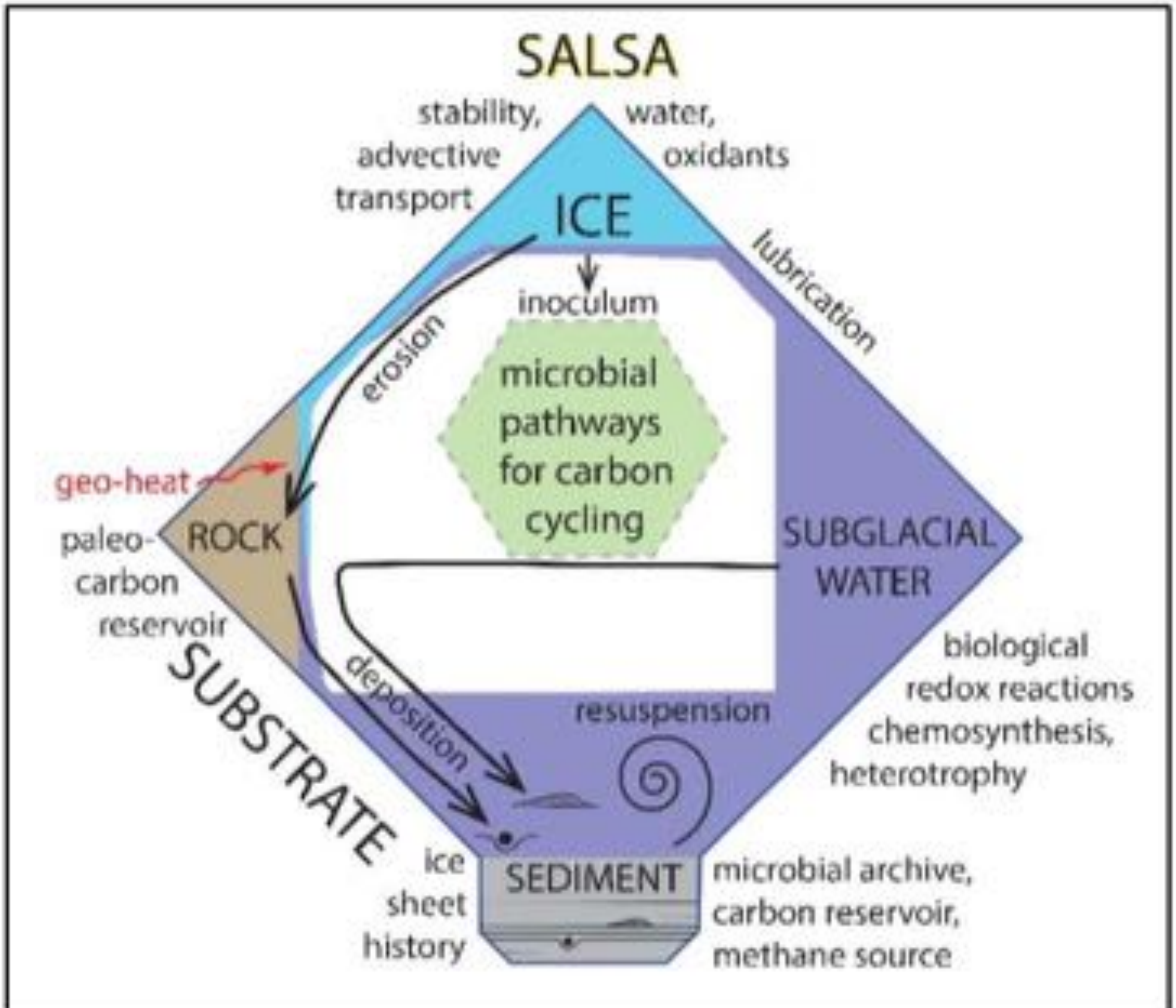
2016/17 Field Season Goals November – January:
GPS relocation team

- Service 8 existing GPS Stations
- Relocate 3 stations
- Conduct temporary GPS experiments

University of Nebraska-Lincoln (UNL) Drill Team:

- Prepare containers for science traverse to Camp 20 (Subglacial Lake Mercer)
- Inspect and inventory all components of the drill system
- Prepare shopping list for 2017-18 work
- Receive the HRU (Hose Reel Unit) from USAP cargo vessel - late January 2017
- Stage hot water drill system and prepare other traverse modules for staging at Camp 20, which may include:
    - Sled-mounted scientific laboratories (Sediment and Chemical Units)
    - One LARS (Launch and Recovery System) sled
    - Knuckle boom crane
    - One generator
    - Power distribution module (PDM)

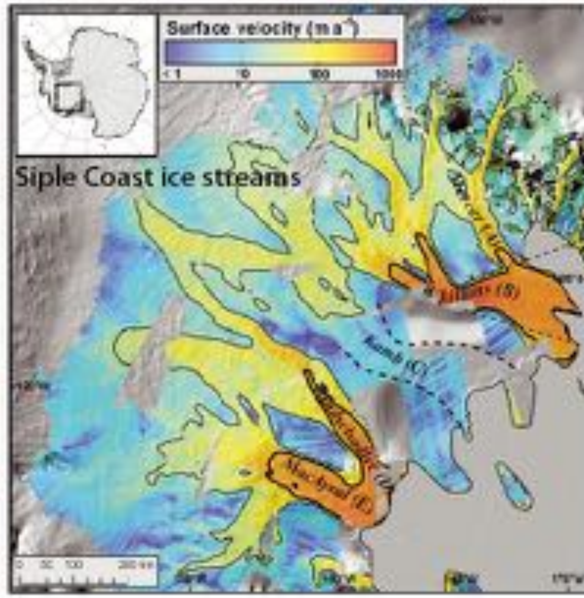
https://salsa-antarctica.org

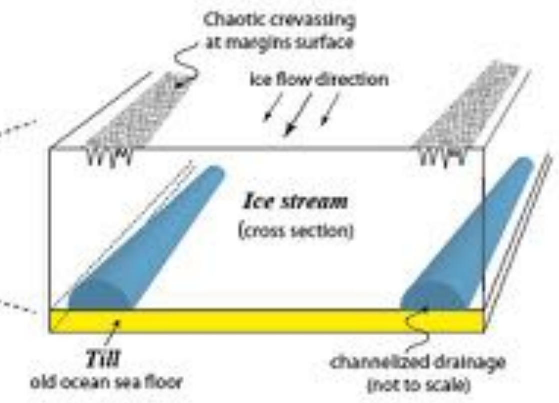

SALSA
stability, advective transport
water, oxidants
ICE
inoculum
lubrication
erosion
microbial pathways for carbon cycling
geo-heat
paleo-carbon reservoir
ROCK
SUBGLACIAL WATER
biological redox reactions chemosynthesis, heterotrophy
deposition
resuspension
SUBSTRATE
ice sheet history
SEDIMENT
microbial archive, carbon reservoir, methane source

Estimated Ice thickness of Lake Mercer:
1095m

Other SAWG science community initiatives

Shear margins – Thwaites, Siple Coast ice streams

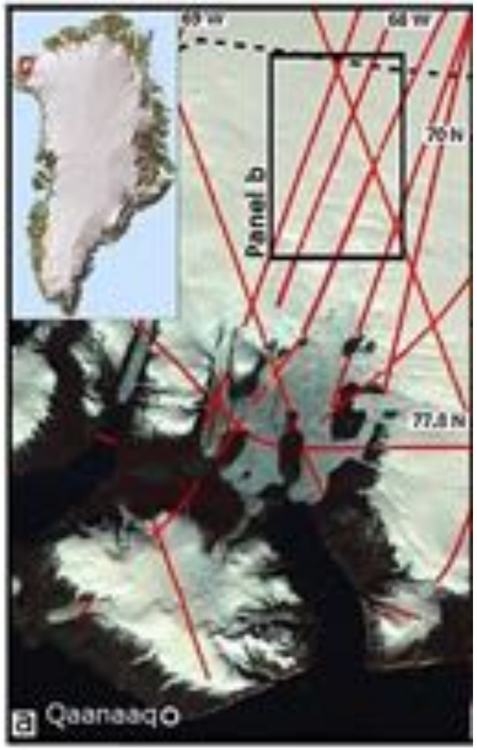


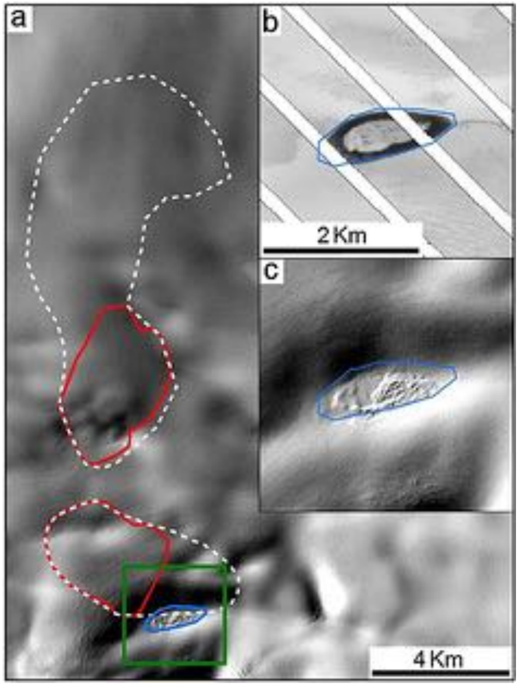


Le Brocq et al. [2009]

AIM: Understand sheer induced melting, mechanical properties and margin migration mechanisms
Tools: access to bed, borehole arrays

Greenland subglacial lakes





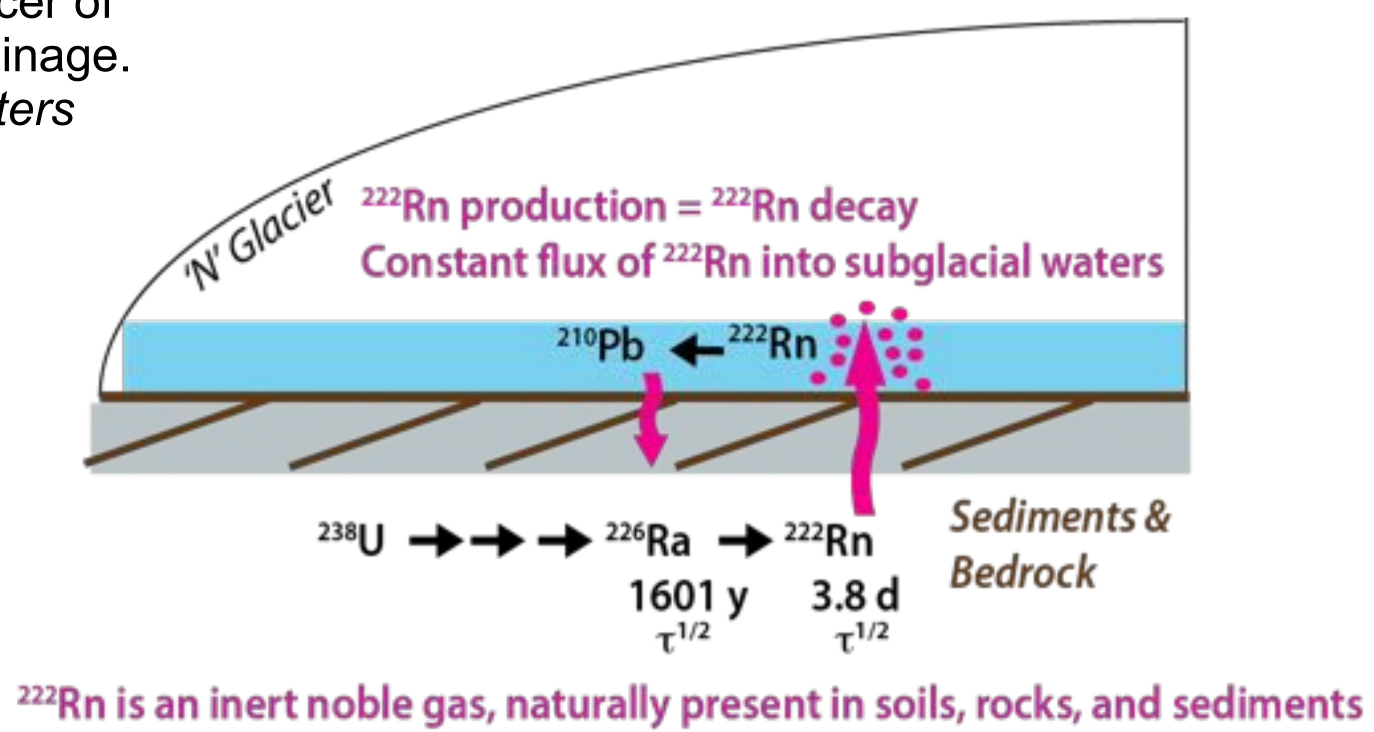
Palmer et al. 2013
http://onlinelibrary.wiley.com/doi/10.1002/2013GL058383/full#grl51161-fig-0004

Two lakes, (~8 and ~10 km^2) in NW Greenland

AIM: Subglacial lake dynamics: hydrology, geomicrobiology, geochemistry
Tools: Clean access hot water drilling
- ~40 km from the ice margin
- Ice thickness =757 and 809 m of ice

Greenland Subglacial Lake Science Drivers: Radon: a unique tracer of subglacial hydrology

Linhoff, B.S., Charette, M.A., et al. (2017) Utility of 222 Rn as a passive tracer of subglacial distributed system drainage. *Earth and Planetary Science Letters*



⇨ **Distributed system meltwater will be enriched in radon (and nutrients/trace metals) due to enhanced water-sediment interactions (not channelized)**

Bhatia et al., (2011) J. Glaciol.

Other SAWG science community initiatives

Greenland: Bedrock core and subglacial lake access

LETTER — Joerg Schaefer and Jason Briner

doi:10.1038/nature20146

Greenland was nearly ice-free for extended periods during the Pleistocene

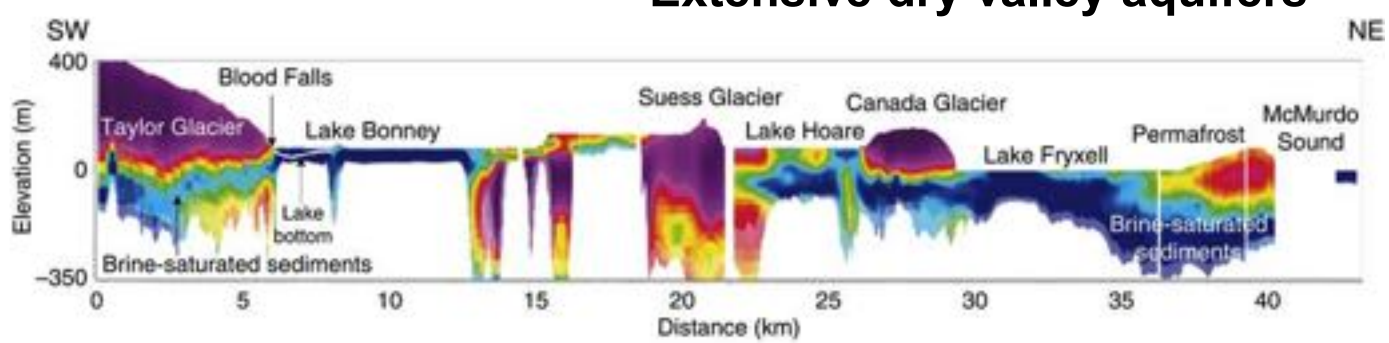
Joerg M. Schaefer[1,2], Robert C. Finkel[1,3], Greg Balco[4], Richard B. Alley[5], Marc W. Caffee[6], Jason P. Briner[7], Nicolas E. Young[1], Anthony J. Gow[8] & Roseanne Schwartz[1]

The Greenland Ice Sheet (GIS) contains the equivalent of 7.4 metres of global sea-level rise[1]. Its stability in our warming climate is therefore a pressing concern. However, the sparse proxy evidence of the palaeo-stability of the GIS means that its history is controversial (compare refs 2 and 3 to ref. 4). Here we show that Greenland was deglaciated for extended periods during the Pleistocene epoch (from 2.6 million years ago to 11,700 years ago), based on new measurements of cosmic-ray-produced beryllium and aluminium isotopes (^{10}Be and ^{26}Al) in a bedrock core from beneath an ice core

The GIS survived mid-Holocene temperatures somewhat warmer than those of the past millennium and many model simulations show a relatively stable GIS over the interglacials of the recent geologic past[11,12]. However, simulations also show that the warming required to remove most of the GIS is model-dependent and sensitive to external forcings and internal feedbacks, including insolation forcing, accumulation rate parameterization, and distribution and seasonality of temperature. Results imply temperature thresholds for ice-sheet stability between one[11] and a few degrees Celsius above present temperatures

AIM: Understand GRiS Stability
Tool: Enhanced ASIG drill to obtain bedrock core in Greenland

Extensive dry valley aquifers

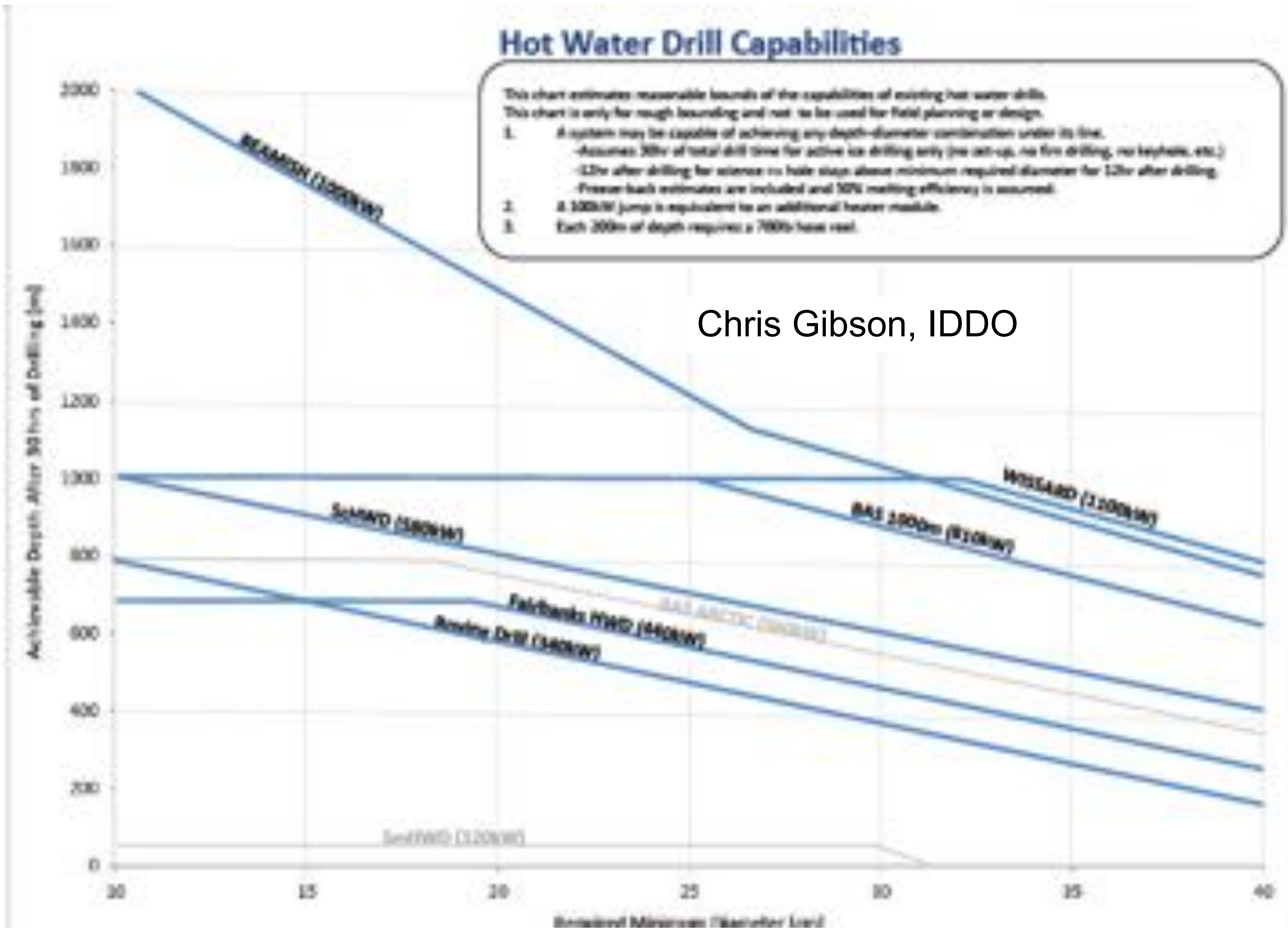


AIM: Hydrogeology and Geomicrobiology
Tool: Clean access hot water drilling

- Ice thickness ~200-500 m
- Hot water drilling, ScHWD

Depth and Diameter Capabilities of known Hot Water Drills

Gaps in US Hot Water Drilling Capabilities



Chris Gibson, IDDO

Interest from the community for targets >1000m requiring drilling:

- West and East Antarctic **subglacial lake sediments** – dating/biomarkers to elucidate ice sheet history (e.g., large part of justification for Lake Ellsworth)

- **Subglacial sedimentary basins** in East Antarctica for methane clathrate accumulation and the risk of methane release during deglaciation (e.g., Wadham et al., 2014)

- **Subglacial Basal Conditions:** Rheology of basal ice, rheology of subglacial sediments, and subglacial hydrology (in general, basal and subglacial conditions) beneath the main inland ice reservoirs in West and East Antarctica. These thick reservoirs are where most of the ice capable of large contributions to sea level rise is - but we have no direct constraints on how to represent them in numerical models of ice flow. **We have only drilled West Antarctic marine sedimentary basins situated beneath thin ice.**

- Basal and subglacial conditions at the **onsets and margins** of fast flow features in the interiors of West and East Antarctica. What controls their locations can they migrate upstream and help drain interior ice efficiently towards the ocean when coastal regions of the ice sheets are forced by warming ocean?

Next SAWG meeting: virtual
September 2017

- Slawek Tulaczyk – joining SAB; Mikucki rotating off
- Continue to engage community – build off of momentum of our first in-person meeting