MagellanPlus workshop "Greenland Ice Sheet evolution revealed by drilling a transect on the Baffin Bay – West Greenland margin (909-Full)"

SUMMARY

A three-day workshop was held 12-14 September 2018 at the Geological Survey of Denmark and Greenland (GEUS) in Copenhagen with a prime focus on developing IODP proposal 909 "Cenozoic evolution of the northern Greenland ice sheet". The scope of proposal 909 is to retrieve a composite late Cenozoic sedimentary succession by transect drilling on the Baffin Bay - West Greenland margin that can elucidate the evolution and past dynamics of the Greenland Ice Sheet. The workshop was attended by 33 participants from Denmark, US, UK, Germany, Canada and Italy, of which 10 were early stage researchers. Presentations by keynote speakers and participants interchanging with plenary discussions occupied the agenda of the first two days, while the third day focussed on revising proposal 909-Full1. This revision included clarifying linkages between hypotheses and methods, improving the integrated experimental design, discussing operational issues and selecting alternate sites. The workshop also included proponents of US-led proposal-814 "Assessing the history of the south Greenland Ice Sheet and its interaction with ocean circulation, climate, and sea level" and provided an opportune forum for discussing scientific, technical and logistical challenges that are shared by both proposals. The Magellan meeting was crucial for completing the submission of 909-Full2 on 1st October 2018, followed by a positive review received from SEP in January 2019. As a result, the proposal has advanced to the external review stage. We aim to submit a Full3 proposal in October 2019.

SCIENTIFIC BACKGROUND

A key goal of the IODP science plan is to understand how ice sheets and sea level respond to climate warming. The potential for rapid retreat and thinning of the Greenland Ice Sheet with concomitant consequences for sea level rise has generated much attention recently, but the long-term history of glaciation and ice-sheet dynamics and how it has affected, or been influenced by, the oceans and tectonic boundary conditions are poorly constrained. This is highlighted by recent studies indicating that the Greenland Ice Sheet may been much more dynamic than previously suggested. Hence Greenland may have been ice free over large parts for extended periods over the last the last 2.8 Myr[1-3], during the so-called super-interglacials. Of the factors that may impact on ice sheet stability, significant uncertainties include the role of Arctic/North Atlantic ocean currents, subglacial geology and topography, crustal heat flow, and interhemispheric teleconnections, e.g. sea-level, meridional deep-water circulation, and planetary albedo. Improved understanding of ice-ocean-climate-tectonic interactions will provide important clues to what the future holds across both short- and long-term timescales. Instrumental records are short and so the geological past, especially the late Cenozoic and periods with atmospheric CO_2 concentrations near present or predicted levels, holds the key information with which to elucidate the complexity of these interconnections.

The Greenland margins contain extensive, thick Cenozoic sedimentary successions that form the principle archives for reconstructing the evolution of the Greenland Ice Sheet. The aim of proposal 909 is to retrieve a composite stratigraphic succession, representing the Late Cenozoic era from Oligocene/early Miocene to the present, that can address current knowledge gaps in the evolution and variability of the GrIS. It is proposed to drill along a transect crossing the northwest Greenland margin, where seismic-stratigraphic results have revealed high-accumulation-rate drilling targets, e.g.

contourites and hemipelagites, as well as potential marine deposits intercalated in glacigenic wedge deposits.

WORKSHOP DAY 1

After a brief introduction, presentations were given by lead proponents Paul Knutz and Joe Stoner outlining the scientific objectives and status of proposals (respectively) 909 and 814. The SEP comments to 909-Full1 concerning the integrated experimental design and the site characterization data were highlighted. A prime goal of the workshop was to address these issues. Stoner commented on the current *Joides Resolution* schedule, limiting North Atlantic missions to 2022-23, and the concern of "proposal pressure", which could become critical if Full-2 versions were not submitted by the next October deadline.

The day progressed with two sessions of oral presentations that included keynote talks by Bierman and Stoner. Paul Bierman provided a state-of-the-art summary on the application of cosmogenic isotopes to interpret long-term weathering history of Greenland. To unravel Greenland Ice Sheet conditions during potential super-interglacials, the need for dense sampling for cosmogenic nuclides across glacial/interglacial transitions was stressed; however, with the caveat that large samples of sandy material are needed. Multiple isotope analyses paired with source-area tracing were considered as essential. Joe Stoner's keynote presentation addressed proxy-based linkages between the marine sediment archive and Greenland Ice Sheet variability, mainly based on results from previous deep ocean drilling around southern Greenland (Eirik Ridge). The talk outlined outstanding questions on the Greenland Ice Sheet (e.g. how old?, how stable?, role in Mid-Pleistocene transition?) and provided a synopsis of previous research and scope of the new drilling sites.

The keynote presentations were complemented by 10 session talks across a variation of themes: (1) terrestrial interglacial deposits (Bennike); (2) ice sheet processes, modelling and tectonics (Hvidberg, Keisling, Solgaard), (3) seismic-stratigraphy of the Greenland margins (Perez, Uenzelmann-Neben, Nielsen); and (4) studies focusing on paleoclimate proxies for Greenland Ice Sheet variability (Hatfield, Thomas, de Vernal). An ongoing theme of the discussion breaks was how the various proxies (cosmogenic isotopes, organic "biomarker" molecules, sediment geochemistry), geophysical data and ice-climate modelling could be integrated to inform us of Greenland Ice Sheet evolution, on orbital as well as sub-orbital time scales. After closing the programme of the first day, a conference dinner was held in a central Copenhagen restaurant, where networking and discussions continued in a more informal environment.

WORKSHOP DAY 2

The agenda began with a keynote address by Chuang Xuan on the development of a high-resolution late Cenozoic chronology in NE Baffin Bay. Xuan gave a state-of-the-art summary of the recent advances in paleomagnetic dating, including the possibilities and limitations of using geomagnetic intensity for dating late Cenozoic sediments. This is important for proposal 909 since for several of the proposed drill sites we estimate high accumulation rates, and thus the sediments may record paleomagnetic excursions that can provide additional chronological constraints. Sources of error were also discussed, e.g. diagenetic overprinting of magnetite. The afternoon session started with a keynote talk by Karsten Gohl on the challenges and experiences in drilling ice-proximal sites, based mainly on examples from the Antarctic margins. The major obstacles for achieving complete stratigraphic sections were variations in lithology, presence of large dropstones, unconformable sections as well as poor biostratigraphic resolution, e.g. related to reworking or low microfossil abundance. In addition, the influence of weather and icebergs on the drilling operations were deliberated. On the more positive side, recent improvements in site selection and drilling techniques have resulted in better recoveries from glaciated margins, e.g. 63% for site 374-U1521 (Ross Sea) cored to 650 mbsf. The final part of the presentation summarized the scope and drilling plan for Exp. 379 (January-March 2019). This forthcoming expedition is aimed at recovering a composite Miocene-Pleistocene succession across the Amundsen Sea margin, and thus is highly relevant for proposal 909. The final keynote talk was given by Sean Gulick who presented deep drilling results from Alaskan and Antarctic margins and the lessons learned from planning to implementation. Gulick provided examples of age-depth models from sites drilled by Exp. 341 expedition (Alaskan margin) illustrating the problem of obtaining robust sedimentation rates in the case of non-unique solutions to the paleomagnetic stratigraphy.

The oral sessions included 6 presentations addressing (1) late glacial to Holocene environments (Seidenkrantz, Jennings, Hogan), (2) Oligocene temperature gradients (Sliwinska), (3) depositional development of the trough-mouth fan system targeted by 909 proposal drilling (Knutz), and (4) mapping of drilling hazards in 3D seismic data (Cox). During the afternoon coffee break posters were presented (Newton, Rebschläger, Reilly and Strunk). In addition, Sean Gulick presented the IODP proposal process, which re-kindled the debate from Day 1 on the submission strategy and the critical issue of timing in light of the *Joides Resolution* sailing plan. The final task of Day 2 was to form break-out groups and initiate the work that lay ahead on improving proposal 909. This resulted in two groups: one group addressing the SEP comments on proxy data and one group working on comments related to site characterization data.

WORKSHOP DAY 3

Carrying on from the previous day, the 909 proponents assembled in a “multi-proxy” group and a “site survey” group. A general question for the “proxy” group was how to make connections between the fragmented land-based record, e.g. missing sections, and the margin wedge stratigraphy. This was transformed into another question: what combination of proxies allows us to infer stages of Greenland Ice Sheet coverage, ranging from absent ice sheet to full glaciation in Greenland? The primary result was the design of a diagnostic template, describing how the combination of different proxy results will provide information on glacial response and paleo-environmental settings associated with five overall stages of ice sheet configuration. The stages were defined as: (1) pre-glacial - no ice, (2) super-interglacial - mountain glaciers only, (3) interglacial - terrestrial ice cap similar to the late Holocene, (4) deglacial – retreating marine-based ice cap, and (5) full glacial conditions with the ice sheet reaching the shelf edge. Additionally, the template links the different glaciation stages with the 7 proposed drilling sites in NE Baffin Bay. The “site survey” group focussed on addressing the SEP remarks to the site characterization data. This included contingency plans in case of poor core recoveries and making a plan for prioritizing all the sites. The site survey data submitted for 909-Full1 was found to be inadequate, although the quality and potential of the available seismic data was recognized. Hence, it was important to augment the site characterization data base for the next submission phase. Time was spent at the seismic work station to define drilling targets and identify alternate sites. In parallel with developing proposal 909, the proponents of 814 were busy identifying sites in the Davis Strait off SE Greenland using the extensive seismic data base at GEUS.

OUTCOME AND FUTURE PLANS

The MagellanPlus workshop was successful in building up the multidisciplinary expertise needed to fully address the critical issues concerning the integrated experimental design and site characterization data of proposal 909-Full1. The scientific input and solutions that were generated during the meeting proved to be crucial for the ensuing revision phase. Proposal 909-Full2 was submitted on 1st October 2018 followed by additional data submitted to the IODP Site Survey Data Bank. The response from SEP (25th January 2019) was that the proposal was significantly improved, and that the panel recommends an external review. As the next step, we will submit a Proponent Response Letter (May 2019) and then aim for submission of a Full-3 proposal in October. Also, more drill sites will be added to the Site Survey Data Bank. High-resolution seismic profiles that can support the identification of addendum sites on the shelf margin will be acquired in August 2019, as part of a scientific expedition to West Greenland/Baffin Bay with the Danish navy vessel *Lauge Koch*.

1 Bennike, O., Knudsen, K. L., Abrahamsen, N., Bocher, J., Cremer, H. & Wagner, B. Early Pleistocene sediments on Store Koldewey, northeast Greenland. *Boreas* **39**, 603-619, doi:DOI 10.1111/j.1502-3885.2010.00147.x (2010).
2 Reyes, A. V. *et al.* South Greenland ice-sheet collapse during Marine Isotope Stage 11. *Nature* **510**, 525-528 (2014).
3 Schaefer, J. M. *et al.* Greenland was nearly ice-free for extended periods during the Pleistocene. *Nature* **540**, 252-255 (2016).

Images from the Magellan workshop on Greenland Ice Sheet evolution (GEUS, Copenhagen)

MagellanPlus Workshop on Greenland Ice Sheet evolution, 12-14 September 2018

Venue: GEUS, Øster Voldgade 10, 1350 Copenhagen (Theodor Sorgenfrei Auditorium)

Ice breaker: Geological Museum, Øster Voldgade 5 - 7, 1350 København, 11th Sept. 19:00-21:00

Conference Dinner: "Den Lille Fede", Store Kongensgade 17, 1264 København, 12th Sept., 19:00

Organizers: Paul Knutz, pkn@geus.dk (GEUS), Joseph Stoner (Univ. Oregon), Anne de Vernal (GEOTOP), John Hopper (GEUS), Mads Huuse (Univ. Manchester), Anne Jennings (INSTAAR).

FIRST DAY (12th Sept)

8:30 *Registration and refreshments*

9:00 **Welcome and introduction**

9:10 **Background, objectives and status of current drilling proposals:**

- IODP 909: Paul Knutz *et al.*
- IODP 814: Joseph Stoner *et al.*

10:00 *Discussion and short break*

Chair Session 1: Paul Knutz/Joseph Stoner

10:15 **Application of cosmogenic isotopes to interpret long-term weathering history** (KEYNOTE)
Paul Bierman, Lee Corbett, Jeremy Shakun

10:45 **Mountain building and the build-up of the Greenland Ice Sheet**
Anne Solgaard, Johan Bonow, Peter Langen, Peter Japsen, Christine Hvidberg

11:00 **The Greenland cross-shelf glaciations: new insights from the Central-East Greenland Margin**
Lara Pérez, Tove Nielsen, Paul Knutz

11:15 **Assessing the Pleistocene stability and behavior of the Greenland ice sheet using proxy records from Lake El'gygytgyn, Arctic Russia**
Benjamin Keisling, M. Helen Habicht, Isla S. Castañeda, Julie Brigham–Grette, Robert DeConto

11:30 **Ice sheet variability during interglacials**,
Christine Hvidberg, Lisbeth Nielsen, Guðfinna Aðalgeirsdóttir, Vasileios Gkinis, Roman Nuterman.

11:45 **Interglacial deposits from ice-free Greenland**
Ole Bennike

12:00 *Lunch break*

Chair Session 2: Anne Jennings/Mads Huuse

13:00 **Linking the marine sediment archive to Greenland Ice Sheet variability: Past and (hopefully) future ocean drilling around south Greenland (**KEYNOTE)
Joseph Stoner

13:30 **Early traces and the development of deep water circulation at the Eirik Drift, south of Greenland: An indication for climate modifications**
Gabriele Uenzelmann-Neben

13:45	**The Davis Strait Drift Complex and the interaction with extreme shelf edge glaciations offshore southwest Greenland** Tove Nielsen, Antoon Kuijpers
14:00	*Discussion and short break*
14:15	**Eirik Ridge marine sediments: A Plio-Pleistocene archive of the past behavior of the south Greenland Ice-Sheet** Robert Hatfield, Joseph Stoner, Benjamin Freiberg, Brendan Reilly, Alberto Reyes, Anders Carlson, Brian Beard
14:30	**Looking back to Greenland's future: Stable isotope constraints on the interaction between Arctic sea ice, precipitation, and land ice** Elizabeth K. Thomas
14:45	**Plio-Quaternary climate of the Baffin Bay area: The need for new sedimentary records** Anne de Vernal, Aurélie Aubry, Claude Hillaire-Marcel
15:00	*Discussion*
17:00	*End of Day One*

SECOND DAY (13th Sept)

Chair Session 3: Anne De Vernal/Elizabeth Thomas

09:00	**Developing a high-resolution late Cenozoic chronology in NE Baffin Bay** (KEYNOTE) Chuang Xuan
09:30	**A review of Subpolar Gyre variability based on multiproxy investigations from the Irminger Sea, Labrador Sea and Baffin Bay regions** Marit-Solveig Seidenkrantz et al.
09:45	**Ice Shelf Facies: Modern and Paleo examples from NW Greenland** Anne Jennings, Brendan Reilly, John Andrews, Joseph Stoner, Maureen Walczak, Alan Mix, Martin Jakobsson.
10:00	**Glacimarine sediment volumes in the Petermann Fjord area since the Last Glacial Maximum** Kelly Hogan, Martin Jakobsson, Larry Mayer, Katrine Juul Andresen, Tove Nielsen, Egon Normark, Alan Mix.
10:15	*Discussion and coffee break*
10:45	**Air temperature gradient across the North Atlantic during the Oligocene** Kasia Sliwinska, Diederik Liebrand, Tim Van Peer, Claus Heilmann-Clausen, Stefan Schouten.
11:00	**The depositional history of the Melville Bugt trough-mouth fan and its implication for GrIS evolution** Paul Knutz, Andrew Newton, Mads Huuse, John Hopper, Ulrik Gregersen, Karen Dybkjær, Emma Sheldon
11:15	*Discussion*
12:00	*Lunch*

Chair Session 4: Brendan Reilly/Andrew Newton

13:00	**Challenges and experiences in drilling ice-proximal sites** (KEYNOTE) Karsten Gohl
13:30	**Presentation on the shallow hazard aspects within the Pitu 3D for site 10A/B** David Cox

13:45 **Shelf records of paleo-ice sheets based on deep drilling results from Alaskan and Antarctic margins** (KEYNOTE)
Sean Gulick, John Jaeger, Alan Mix, Amelia Shevenell, Amy Leventer

14:15 *Discussion and coffee break*

14:30 *Poster presentations*

Seismic geomorphology and evolution of the Melville Bugt Trough Mouth Fan, Northwest Greenland
Andrew Newton, Mads Huuse, Paul Knutz, Simon Brocklehurst

Glacial and Deglacial stable isotope endmembers from the Labrador Sea
Janne Repschläger, Hubert Vonhof, Paul Knutz, Ralph Schneider

Chronostratigraphic modeling of complex depositional systems: Lessons from the Bengal Fan, implications for ice proximal environments
Brendan Reilly, Joseph Stoner, Robert Hatfield, Benjamin Freiberg, Fenna Bergmann, Michael Weber, Peter Selkin, Tilmann Schwenk, Volkhard Spiess, Christian France-Lanord

One million years of glaciation and denudation history in west Greenland
Astrid Strunk *et al.*

15:00 **The proposal process in IODP**
Sean Gulick

15:30 *Discussion*

16:00 **Organizing group work on improving proposal 909**

17:00 *End of Day Two*

THIRD DAY (14th Sept)

09:00 **Proposal working groups**

Preparing proposal 909-Full1 to the Full2 stage:

- Multi-Proxy group (Jennings and others)
- Site Survey group (Gohl and others)

Proposal 814: Identifying Davis Strait sites on GEUS seismic data (Stoner, Nielsen and others).

12:00 *Lunch*

13:00 **Continuation of proposal work**

15:00 *Meeting Round-up*

Last name	*First name*	*Affiliation*	*Country*	*Contact*	*Expertise*
Bennike	Ole	GEUS	DK	obe@geus.dk	Quaternary Geology/Paleoclimate
Bierman	Paul	University of Vermont	US	pbierman@uvm.edu	Inorganic Geochemistry
Cox	David	Manchester University	UK	david.cox@manchester.ac.uk	Marine Geophysics
de Vernal	Anne	Univ. Québec Montreal	CAN	devernal.anne@uqam.ca	Micropaleontology/Paleocean.
Funder	Svend V.	Univ. Copenhagen	DK	svf@snm.ku.dk	Quaternary Geology/Paleoclimate
Gohl	Karsten	Alfred Wegener Inst.	DE	karsten.gohl@awi.de	Marine Geophys/Sedimentology
Gulick	Sean S.	Univ. Texas	US	sean@ig.utexas.edu	Marine Geophys/Sedimentology
Hatfield	Rob	Oregon State Univ.	US	rhatfield@ceoas.oregonstate.edu	Marine Sedimentology
Hogan,	Kelly A.	British Antarctic Survey	UK	kelgan@bas.ac.uk	Marine Geophys/Sedimentology
Hopper	John R.	GEUS	DK	jrh@geus.dk	Marine Geophysic
Huuse	Mads	Manchester Univ.	UK	Mads.Huuse@manchester.ac.uk	Marine Geophys/Sedimentology
Hvidberg	Christine	Univ. Copenhagen	DK	wdk760@ku.dk	Glaciology/Paleoclimate
Jennings	Anne	Univ. Colorado	US	Anne.Jennings@colorado.edu	Micropaleontology/Paleocean.
Keisling	Benjamin	Univ. Massachusetts	US	bkeisling@geo.umass.edu	Ice Sheet/Climate Modelling
Kjær	Kurt	Univ. Copenhagen	DK	kurtk@snm.ku.dk	Quaternary Geology/Paleoclimate
Knutz	Paul C.	GEUS	DK	pkn@geus.dk	Marine Geophys/Sedimentology
Larsen	Nicolaj K.	Aarhus University	DK	nkl@geo.au.dk	Quaternary Geology/Paleoclimate
Morigi	Caterina	University of Pisa	IT	caterina.morigi@unipi.it	Micropaleontology/Paleocean.
Newton	Andrew N.W.	Queen's Univ. Belfast	UK	A.Newton@qub.ac.uk	Marine Geophys/Sedimentology
Nielsen	Tove	GEUS	DK	tni@geus.dk	Marine Geophysics
Pearce	Christof	Aarhus University	DK	christof.pearce@geo.au.dk	Organic Geochem/Paleocean.
Perez	Lara	GEUS	DK	lfp@geus.dk	Marine Geophysics
Reilly	Brendan	Oregon State Univ.	US	breilly@coas.oregonstate.edu	Sedimentology
Repschläger	Janne	Max Planck Inst. Chem.	DE	J.Repschlaeger@mpic.de	Micropaleontology/Paleocean.
Rosing	Salik A.	GEUS	DK	saro@geus.dk	Oceanography/Modelling
Seidenkrantz	Marit-Solveig	Aarhus University	DK	mss@geo.au.dk	Micropaleontology/Paleocean.
Strunk	Astrid	Aarhus University	DK	astrid@geo.au.dk	Inorganic Geochemistry
Sliwinska	Kasia	GEUS	DK	kksl@geus.dk	Micropaleotology/Paleocean.
Solgaard	Anne M.	GEUS	DK	aso@geus.dk	Glaciology/Paleoclimate
Stoner	Joseph	Oregon State Univ.	US	jstoner@coas.oregonstate.edu	Sedimentology/Paleomagnetics
Thomas	Elizabeth	University of Buffalo	US	ekthomas@buffalo.edu	Organic Geochemistry
Uenzelmann-Neben	Gabriele	Alfred Wegener Inst.	DE	Gabriele.Uenzelmann-Neben@awi.de	Marine Geophysics
Xuan	Chuang	Univ. Southampton	UK	C.Xuan@soton.ac.uk	Paleomagnetics

ORAL PRESENTATIONS

Cosmogenic isotopes and the interpretation of Greenland's long-term weathering history (KEYNOTE)

Paul Bierman[1], Lee Corbett[1], Jeremy Shakun[2]

[1]*University of Vermont, Vermont, USA*

[2]*Boston College, Massachusetts, USA*

In and around Greenland, cosmogenic nuclides, primarily Be-10 and Al-26, have been measured in samples from presently-exposed surfaces that were once glaciated, from surfaces under the ice sheet, and in sediment eroded from and transported away from these surfaces. Such sediment is carried by glaciers and outwash streams, stored as fjord-bottom sediments, moved onto the shelf, and eventually deposited offshore where it accumulates and can be recovered, providing a record of cosmogenic nuclide concentrations in the past. Such data have bene interpreted, through the use of forward models, as both a record of past erosion and past exposure histories.

Isotope analyses clearly indicate that some parts of the Greenland Ice sheet (GIS) have effectively eroded the bed, reducing cosmogenic nuclide concentrations to at most a few thousand atoms/g, the equivalent of only hundreds of years of surface exposure. These low concentrations likely result from interglacial exposure to deeply penetrating muons through tens of meters of rock; some residual nuclides could even predate the expansion of the GIS at the dawn of the Pleistocene. In other areas, high concentrations of both Be-10 and 26-Al indicate minimal erosion and long periods of burial – the result of cold-based ice, frozen to the bed, sub-glacially preserving the landscapes it overran.

Today, most sediment transported by the ice and moving through outwash streams contains scant Be-10 and 26-Al, suggesting it was sourced from erosive, warm-based areas of the ice sheet's bed. Cosmogenic analyses of marine sediment cores around Greenland indicate that this was not always the case. Early in the records, before the Pleistocene, decay-corrected Be-10 concentrations were much higher and then lowered over time, suggesting the progressive stripping of pre-glacial regolith. Ratios of Al-26/Be-10 vary but are higher than would be expected had ice cover been continuous. Together, these data suggest a persistent but dynamic Greenland Ice Sheet which retreated during at least some interglacial periods to expose sediment source areas to cosmic radiation.

Significant issues remain in the interpretation of nuclide concentrations in marine sediment cores including: 1) Unknown lag time from ice sheet transport to deposition off shore, 2) the need for masses of sandy material sufficient to extract 20-40 grams of pure quartz from short core intervals in order to optimize analytical precision and accuracy without blurring the record, 3) well-defined age models for cores, and 4) better constraint on sediment source areas. A high accumulation rate drill site that preserved sediment from several well-dated terminations and had a well-defined source area would allow much less ambiguous interpretation of the cosmogenic record in marine sediment in terms of ice sheet history and process.

Mountain building and the build-up of the Greenland Ice Sheet

Anne M. Solgaard[1], Johan M. Bonow[2], Peter L. Langen[3], Peter Japsen[1] , Christine S. Hvidberg[3]

[1]*GEUS,* [2]*Södertörn University,* [3]*University of Copenhagen*

Topography constitutes a major control on ice sheet build-up and stability. Recent studies have shown that the landscapes in both West and East Greenland were flat and low-lying in the Miocene and that the present-day mountains were shaped after two phases of uplift since that time. We present results of a study investigating the implications of this mountain building history for ice sheet growth in Greenland over the past 10 million years. Ice sheet initiation is studied using the topography before uplift and after each phase of uplift by applying different forcing conditions relevant for the late Cenozoic, which was characterised by long-term cooling superimposed by cold and warm excursions. We do this using an ice-flow model in off-line combination with an atmospheric general-circulation model. Our results show, that the increase in Greenland elevation over the past 10 million years augments the effect of the climatic deterioration in the late Cenozoic and that without the second phase of uplift, the Greenland Ice Sheet would have been more sensitive to the changes in climate over the past millions of years. We also find, that as the topography increases along the East coast of Greenland, the main ice-sheet nucleation area relocates from North to East Greenland.

The Greenland cross-shelf glaciations: new insights from the Central-East Greenland Margin

Lara F. Pérez, Tove Nielsen, Paul Knutz

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The Greenland Ice Sheet (GIS) is the largest glacial area in the Northern Hemisphere, covering most of the onshore Greenland. Offshore the ice sheet has influenced the Greenland margins construction conditioning their morphology. However other control factors such as tectonic and oceanographic events have an imprint in the stratigraphic architecture of the Greenland margins. Thus, the sedimentary record preserved around Greenland has registered the glacial oscillations of the Northern Hemisphere, as well as the influence of other conditioning factors in the development of a permanent ice sheet on Greenland. Existence of a glaciated hinterland and tidewater glaciers in Greenland date back to Eocene and Miocene. However, the Greenland margins reveal marked differences in the history of the cross-shelf glaciations. Along the Central-East Greenland margin, early cross-shelf glaciation occurred off Blosseville Kyst during late Miocene and early Pliocene followed by major ice-stream activity off Scoresby Sund during early Quaternary and glacial advance off Liverpool Land in late Quaternary. Higher resolution of the Quaternary data off Liverpool Land suggests that the intense ice-stream of the Scoresby Sund fjord was gradually taken over by the northern-placed ice-stream of Kong Oscar Fjord during Pleistocene, and later moved farther north to Kejser Franz Joseph Fjord. Overall, a no-coupled development of the cross-shelf glaciations along Central-East Greenland Margin occurred from late Miocene to Present. The no-coupled pattern in the cross-shelf glaciations can be extrapolated to all the Greenland margins. Despite the lack of an accurate age model in several sectors of the Greenland margins, seismic reflection profiles together with the few existing boreholes and wells reveal differences in the modes and timing of cross-shelf glaciation. In the Northeast Greenland margin the first cross-shelf glaciation is estimated to occur during middle Miocene, followed by Pliocene ice sheet advance across the southern Greenland margins. In contrast, the first evidences of cross-shelf glaciation along the West Greenland margin are estimated from late Pliocene in the central to northern area. These differences in the evolution of the Greenland Ice Sheet could be related to variations in the oceanographic pattern around the Greenland margins, besides tectonic, atmospheric and climatic events.

Assessing the Pleistocene stability and behavior of the Greenland ice sheet using proxy records from Lake El'gygytgyn, Arctic Russia

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Understanding the behavior of ice sheets during past warm interglacial periods is critical for predictions of sea-level rise in a warming world. Although the Greenland ice sheet likely contributed to sea-level highstands during past interglacial periods, assessments of the causes and extent of interglacial ice loss in Greenland have been hindered by the lack of continuous temperature records from the high northern latitudes that span multiple interglacial stages. The drill core from Lake El'gygytgyn, Arctic Russia, provides unparalleled insight into changes in Arctic temperature and precipitation over the last 3.6 Ma. Here we assess the stability of the Greenland ice sheet over the last 800,000 years using a hybrid three-dimensional ice-sheet model forced with records of temperature and precipitation from Lake El'gygytgyn. We show that different temperature reconstructions imply different potential contributions to sea-level highstands during past interglacial periods. Proxy records disagree on the amplitude and length of interglacial warmth, which impacts the modelled Greenlandic contribution to interglacial sea-level highstands. For MIS 19 through the Holocene, we evaluate the minimum and maximum interglacial sea-level contributions from Greenland implied by pollen-, and brGDGT-, and productivity-based proxy reconstructions. We show that the Lake El'gygytgyn proxy reconstruction results in the most dynamic ice sheet, and implies that Greenland may have contributed up to ~6m to the MIS11 sea level highstand and ~2m to the Eemian sea level highstand. Our results suggest that the terrestrial climate record from Lake El'gygytgyn may be exceptionally useful for understanding long-term circum-Arctic temperature change and thus ice histories, and provide a framework for evaluating Greenland's contribution to other Pleistocene sea level fluctuations.

Ice sheet variability during interglacials

Christine S. Hvidberg[1], Lisbeth T. Nielsen[1], Guðfinna Aðalgeirsdóttir[2], Vasileios Gkinis[1], Roman Nuterman[3].

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The Greenland ice sheet has evolved in response to past climate change ever since its formation. Its stability in our warming climate is not well known, and the understanding of its variations during previous warm interglacials is also limited. Geological constraints of the minimum extent during previous warm periods is eroded by subsequent advances or covered by the ice sheet. Paleoclimatic records from ice cores provide constraints on the climate and ice thickness (Vinther et al 2009), but is limited to a few ice cores from the central areas and they reach only back to approximately 125 kyrs ago. Here we present results from a study of the evolution of the Greenland ice sheet through the Holocene (Nielsen et al. 2018), and we further discuss the ice core constraints on the ice sheet extent and variation in the Eemian, 110-130 kyrs ago. We use a suite of different ice-core-derived climate histories for the Holocene to investigate the evolution of the Greenland ice sheet through the deglaciation, the Holocene thermal maximum and up to present day. The Holocene thermal maximum was a period 8–5 kyr ago when annual mean surface temperatures in Greenland were 2–3°C warmer than present-day values. We use climate histories based on new interpretations of the isotope

records (Gkinis et al. 2014), which results in a more pronounced thermal maximum compared to previously used climate records. Furthermore, our records inform of snow accumulation rates in the early Holocene. Our studies show that the Greenland ice sheet retreated to a minimum volume of up to ~1.2 m sea-level equivalent smaller than present in the early or mid-Holocene, and that the ice sheet has continued to recover from this minimum up to present day. Climate records without a pronounced thermal maximum in the early Holocene result in smaller ice losses continuing throughout the last 10 kyr. In all our runs, the ice sheet is approaching a steady state at the end of the 20th century. Our studies show that the Greenland ice sheet evolves in response to climate variations on shorter and longer timescales and that the pattern of the response is complex. Variations in accumulation rate, temperature and sea level influence the ice sheet differently, resulting for example in different timescales and patterns of buildup and retreat of the ice sheet. We discuss these characteristics and compare with estimates of the Greenland ice sheet in the Eemian (NEEMmembers 2013).

Nielsen, L.T., G. Adalgeirsdottir, V. Gkinis, R. Nuterman, and C.S. Hvidberg. 2018. The effect of a Holocene climatic optimum on the evolution of the Greenland ice sheet during the last 10kyr. Journal of Glaciology, 64, 477-488. doi: 10.1017/jog.2018.40.

Interglacial deposits from ice-free Greenland

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Interglacial deposits in Greenland are referred to the Early, Middle and Late Pleistocene. The richest Early Pleistocene floras and faunas come from the Kap København Formation, which is a succession of clay, silt and sand in eastern North Greenland. The formation has been divided into member A and B. Member A is at least 50 m thick and is dominated by laminated clay and silt with rare shells of marine bivalves and tests of foraminifers. Member B is 40–50 m thick and dominated by two sandy units, which are separated by a more fine-grained unit. The sediments in member B were deposited in coastal, marine and fluvial environments. The Kap København Formation contains a wealth of well-preserved remains of marine and non-marine plants and animals. Vascular plants include a mixture of boreal and arctic species. Taxa such as larch, spruce, white cedar, yew, myrtle and red osier dogwood belong to the first group, whereas dryas and mountain sorrel belong to the second. All remains of wood come from small trees or shrubs and growth rings are narrow to extremely narrow, which indicate that the mean July temperature was about 6–7°C higher than today. The Greenland ice sheet could hardly have survived such warm summers and the Arctic Ocean was not covered by sea ice all year round. The fossil flora shows that the area was dominated by forest-tundra, which grew in an oceanic type of subarctic climate. At least 210 species of beetles are resent in the fauna, an impressive and surprising number when compared with the modern day beetle fauna of Greenland that comprises ~ 36 species. Ants are absent from modern Greenland, so it is remarkable that four species of ants are represented in the Kap København fauna. The insect fauna shows that humid terrestrial biotopes, forests and alpine biotopes dominated, but some species live in dry environments, including steppe and saline ponds. The dating of the Kap København Formation is based on a number of different methods, of which the most important are biostratigraphy, palaeomagnetic studies and amino acid analyses. The biostratigraphically most important groups are mammals and foraminifers. The occurrence of the extinct rabbit *Hypolagus* sp. and the extant hare *Lepus* sp. in member B is particularly important. These genera co-occurred in North America during the period from ~ 2.3 to 2.0 Ma. This is in good agreement with the latest age estimate based on benthic foraminifers, which indicates an age for member B of ~ 2 Ma, perhaps corresponding to one of the super interglacials that have been documented in Arctic Russia. Other deposits that are referred to the Early Pleistocene are the Île de France Formation, the Store Koldewey Formation and the Lodin Elv Formation in East Greenland as well as the Pátorfik beds in West Greenland. The faunas and floras of these successions show similarities with the Kap København Formation. Species-rich floras and faunas from the Last Interglacial Stage are mainly found in central East Greenland and north-west Greenland; the fossil assemblages comprise a number of warmth-demanding species, such as tree birch that do not live so far north at the present, as well as many beetle species that do not occur in Greenland today. The mean July temperature was probably ~ 5°C higher than at present. These deposits have mainly been dated using optically luminescence dating. All interglacial deposits in Greenland are covered by till or show glaciotectonic features, but the glacial limit during the Last Glacial maximum in Greenland is poorly constrained. However, a growing body of data from the Greenland shelf indicates that the Greenland ice sheet covered most parts of the continental shelf during the LGM, and the ice margin may have extended to the shelf edge.

Linking the marine sediment archive to Greenland Ice Sheet variability: Past and (hopefully) future ocean drilling around south Greenland (KEYNOTE)

Joseph Stoner

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Review of the results from past drilling and talk about the challenge and opportunities that future drilling could provide and approaches required to make that successful

Early traces and the development of deep water circulation at the Eirik Drift, south of Greenland: An indication for climate modifications

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The sediment record at Eirik Drift, a sediment drift at the slope south of Greenland, provides an archive of modifications in pathway and intensity of the Western Boundary Undercurrent (WBUC), since the drift was formed under the influence of the WBUC and lies closely downstream of the current's origin in the deep-water formation centres of the Nordic Seas. Modifications in the WBUC are the result of alterations in deep-water formation in the Nordic Seas and thus reflect climate changes such as warm and cold periods. A reconstruction of the the palaeocirculation of the WBUC at Eirik Drift since the early Miocene revealed a strong WBUC during warm climate conditions, and in phases of climate cooling with interpreted enhanced sea-ice extent we interpreted weak WBUC influence. Therefore, a southward re-location of the deep-water formation regions along with a shift of the deep current system during the cool phases has been suggested (Müller-Michaelis and Uenzelmann-Neben, 2014). This shift implies that the main North Atlantic deep-water route affected Eirik Drift mainly during warm phases and that during cool phases only weak branches of the circulation system flowed over Eirik Drift

Müller-Michaelis, A., Uenzelmann-Neben, G., 2014. Development of the Western Boundary Undercurrent at Eirik Drift related to changing climate since the early Miocene. Deep Sea Research Part I: Oceanographic Research Papers 93, 21-34.

The Davis Strait Drift Complex and the interaction with extreme shelf edge glaciations offshore central West Greenland

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The waters between Greenland and Canada form an important oceanic connections between the Arctic and Atlantic oceans. The shallow Davis Strait is central in this context, as it constitutes a bathymetric hurdle for the exchange of water masses. Regional seismic stratigraphic analysis has revealed a large-scale contourite drift complex located in the south-eastern Davis Strait and adjacent Labrador Sea slope, i.e. the Davis Strait Drift Complex (DSDC). Ties to nearby wells put forward that the depositional history of the DSDC spans the mid Miocene to Recent times, thus revealing paleoceanographic changes during the history of the Greenland Ice Sheet (GIS). An oceanographic setting similar to the present-day may be expected to have occurred in interglacial times, while a current slow-down and change of the circulation pattern occurred in glacial times.

The eastern flank of DSDC reach into a basin area that connects to the central West Greenland margin, where large-scale glacial trough-mouth-fans (TMFs), deposited by the GIS during multiple periods of shelf glaciations, dominates the outer shelf and slope areas. During less severe glaciations the basin area was outside direct ice contact and thus receive little glacial input, but owing to a long run-out potential of the glacial debris flows that are the building blocks of the TMFs, records from the most extreme shelf edge glaciations reach the basin area. Thus, during extreme glacial periods, the basin is dominated by glacial derived deposition, while current related DSDC deposits dominate deposition during interglacial periods.

Eirik Ridge marine sediments: A Plio-Pleistocene archive of the past behavior of the south Greenland Ice-Sheet (sGIS)

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In contrast to the terrestrial record, marine sediments can provide well-dated evidence of ice-sheet retreat through multiple glacial-interglacial cycles if sediment provenance can be linked to points of ice-sheet discharge. The Eirik Ridge is an extensive marine sediment drift, south of Greenland, that accumulates glacio-fluvial sediments exported from southern Greenland, ice-rafted debris from the Greenlandic and Laurentide ice-margins, and sediment advected along the path of the deep western boundary current (DWBC). As a result of sustained seismic and coring efforts over the last several decades our understanding of sedimentation patterns over the drift, and the signals they record, has improved to the point that it is now viable to think that the Plio-Pleistocene behavior of ice-sheets and the variability in DWBC flow can be reconstructed from Eirik Ridge sediments.

Magnetic, geochemical, mineralogical, and radiogenic properties of Eirik Ridge marine sediments indicate two primary lithogenic sediment sources to the drift during interglacials; Precambrian basement from southern Greenland and Paleogene volcanics from Iceland (and East Greenland). To isolate and characterize sGIS variability we developed silt-size magnetic and radiogenic end-member fingerprints capable of discriminating Icelandic sourced sediments (DWBC transported) from those originating from southern Greenland (sGIS erosional products). Using core MD99-2227 (3460 mwd; the same location as ODP Site 646) we reveal a recurring sediment texture and sediment provenance signature that points to increased wasting and retreat of the sGIS in response to increased CO_2 and insolation during glacial terminations and interglaciations. Temporal variations in these signatures suggest considerable retreat of the sGIS during marine isotope stages (MIS) 5e, 9, and 11 that contrasts with more modest retreat in the Holocene and MIS 7. Ongoing fingerprinting work examines records across a depth transect of IODP sites U1305 (3459 mwd; 80km south of MD99-2227) and U1306 (2272 mwd; 160km east of MD99-2227) over the last 150kyrs. The comparison of these records allows the impact of the DWBC, and its influence on Eirik Drift sedimentation, to be better evaluated, and by including a focus on glacial sedimentation patterns we can potentially characterize and separate inputs from the Laurentide ice-sheet. We will discuss the application of these particle size specific fingerprinting tools to other areas around Greenland and the potential to use them during earlier periods when the sGIS may have been significantly smaller that its Late-Pleistocene extent.

Looking back to Greenland's future: Stable isotope constraints on the interaction between Arctic sea ice, precipitation, and land ice

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Quantifying ice sheet responses to climate change is critical for predicting sea level rise in a warming world. In particular, sea ice retreat is predicted to cause increased precipitation, and if more precipitation falls as snow, this may offset ice sheet mass balance losses caused by rising temperature. In contrast, increased rainfall may accelerate ice sheet mass loss.

Past climate and ice sheet histories provide natural experiments for quantifying the interaction between sea ice, precipitation, and land ice. The character of temperature and precipitation variability near the margins of the Laurentide and Greenland ice sheets remains largely unknown, however, so direct comparison of climate and ice sheet reconstructions currently is not possible. I will present leaf wax hydrogen isotope and long-chain alkenone pilot data that reflect terrestrial precipitation isotopes and ocean temperature spanning multiple previous interglacials from ODP Site 646 on the Eirik Drift. These proxies may also be applied at sites in Baffin Bay to reconstruct precipitation and temperature variability on western Greenland. Such data may be paired with ice sheet reconstructions and modeling to address the sensitivity of ice sheets to temperature and precipitation.

Plio-Quaternary climate of the Baffin Bay area : The need for new sedimentary records

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The Ocean Drilling Program (ODP) Leg 105 in 1985 permitted the recovery of Cenozoic sediments in Baffin Bay, which demonstrated very large amplitude variations in ice sheet activity (ice rafted debris) and climate (pollen and spores) on surrounding lands as well as productivity and ocean conditions (dinocysts and other microfossils). However, poor sediment recovery at ODP holes 645 and generally poor preservation of biogenic carbonate and silica prevented the setting of a reliable and accurate chronostratigraphy and led to poorly constrained paleoclimatological and paleoceanographical interpretations. Taking advantage of enhanced experience of IODP for drilling in sea-ice conditions, as well as of progresses with proxy understanding in the Baffin Bay and in the development of a reference biostratigraphy based on dinocysts, established recently in the adjacent Labrador Sea, we expect that the proposed drilling in Baffin Bay will provide the needed more continuous sedimentary records to document the regional climate history and the timing of glacial activity, notably at the onset of the Northern Hemisphere glaciation during the Pliocene and with special attention to the status and instabilities of the Greenland Ice Sheet.

Developing a high-resolution late Cenozoic chronology in NE Baffin Bay (KEYNOTE)

Chuang Xuan

University of Southampton, England, UK.

A review of Subpolar Gyre variability based on multiproxy investigations from the Irminger Sea, Labrador Sea and Baffin Bay regions

Marit-Solveig Seidenkrantz[1], Estelle Allan, Camilla S. Andresen, Cristina Fasting Christiansen, Anne de Vernal, Katrine Elnegaard Hansen, Anne Jennings, Karen Luise Knudsen, Antoon Kuijpers, Christof Pearce, Kerstin Perner, Sofia Ribeiro, Christina Sheldon, Marie-Alexandrine Sicre, Longbin Sha, Sandrine Solignac, Nicolas Van Nieuwenhove and Laerke-Corinn Ulner

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Ice Shelf Facies: Modern and Paleo examples from NW Greenland

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Ice shelves stabilize marine terminating ice sheets and are important features to include in paleo ice sheet reconstructions. It has been difficult to interpret paleo ice shelves from marine core sediments because so little is known about the sub ice shelf environment and the characteristics of a sub ice-shelf facies in the Arctic. During marine research expedition OD1507 with Swedish icebreaker *Oden* in summer 2015, a.k.a. *Petermann 2015 Expedition*, we collected sediment cores and surface samples from Hall Basin and Robeson Channel, leading toward the Arctic Ocean, and from Petermann Fjord, including cores obtained from beneath the modern ice tongue at sites 15 and 25 km from the grounding line; these cores provide key information to identify ice tongue/ice shelf facies in the Arctic. The Petermann Ice Tongue extended to the outer fjord since at least 1876, as observed during the Nares Expedition. Calving events in 2010 and 2012 reduced the ice tongue length to about 45 km, which allowed ship access to the middle to outer fjord for acquisition of geophysical mapping and piston and gravity cores from sites recently covered by the ice tongue. We present CT (computed tomography) imaging, sediment grain size, and foraminiferal assemblage analysis of sub ice tongue cores OD1507-03UW and -05UW to show lithofacies, sedimentology and faunal characteristics of the sub ice tongue environment and to reconstruct the environmental changes and ice tongue history in the fjord from the middle Holocene to present. OD1507-3UW and -05UW, taken on a sill at 570 m wd, 25 km from the grounding line and in the basin 15 km from of the grounding line in 840 m wd, respectively. Sub-ice tongue sediments from 03UW on the sill are bioturbated, but retain stratification, and are characterized as very poorly sorted, very fine to medium silt devoid of coarse clasts. Sediments in 05UW are strongly laminated with no visible bioturbation and devoid of coarse clasts. The coarsest laminae comprise very fine sand and coarse to medium silt while the finer parts of the laminae are very fine silt to clay. Multicore tops distributed in the fjord have abundant, diverse fauna with *Stetsonia horvathi* being the most abundant species near the modern ice tongue front while *Elphidium excavatum* forma *clavata* and *Cassidulina neoteretis* dominate the assemblages in the outer fjord. The foraminifers in the upper 2 cm beneath the ice tongue occur in low abundances and are very small, but living specimens of many species suggest that a low abundance fauna beneath the ice tongue is sustained by advected food and likely is renewed by advected individuals. Agglutinated species dominate and *Elphidium excavatum* is rare or absent. We use the information about the modern sub ice tongue environment to interpret lithofacies, grain size properties and foraminifers in several OD1507, HLY03, and 2001LSSL cores from Hall Basin and Robeson Channel, where, beneath a bioturbated mud unit covering most of the Holocene, the cores contain a thick, distinctly laminated silt and clay unit devoid of coarse clasts and containing sparse foraminiferal fauna. From comparison with the sub ice tongue facies and biostratigraphy in Petermann Fjord, we hypothesize that the widespread laminated clay unit was deposited beneath ice shelves extending from the Humboldt and Petermann glaciers during deglaciation in the early Holocene. Intervals of ice-shelf instability and consequential activity at the grounding line are are marked by IRD layers, shifts in sediment composition (mineralogy and XRF) and faunal assemblages changes that punctuate the overall record of ice retreat archived in the laminated clay.

Glacimarine sediment volumes in the Petermann Fjord area since the Last Glacial Maximum

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Petermann Glacier is a large fast-flowing outlet glacier in NW Greenland, draining about 4% of the present-day ice sheet by area. Despite its location in the remote and often ice-choked northern part of the ice sheet

its fjord and adjacent continental margin are now the best surveyed offshore areas around the entire ice sheet. Here we consider the sediment infill in the fjord that has occurred since grounded ice (as Petermann Ice Stream) separated from the Innutian Ice Sheet, during the last deglaciation, and retreated into the fjord. Acoustic facies and their geometries allow us to interpret the major sedimentary processes which include the rainout of fine-grained material, probably from meltwater plumes, and the down-slope redeposition of material. We calculate postglacial sediment volumes from high-resolution sub-bottom profiler data and seismic reflection profiles, and we attempt to derive subglacial sediment fluxes for the retreating Petermann Glacier. This is done by linking the calculated volumes to the known deglacial history for the area (so far) which is based on submarine glacial landforms in the fjord and terrestrial evidence. A major stillstand occurred around 7200 years BP depositing material on the sill at the fjord-mouth and in Hall Basin to the north. Sediment flux estimates are discussed in comparison with other flux estimates for modern and palaeo-ice streams. Determining the depositional processes and sedimentary architecture of the units in this environment provide excellent context for interpreting older glacier-influenced sediment units and their architecture.

Air temperature gradient across the North Atlantic during the Oligocene

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One of the most characteristic features of the modern icehouse climate in the North Atlantic region is a pronounced air temperature gradient between Northwestern Europe and Greenland. This east-west temperature gradient results from a strong meridional oceanic circulation pattern: the North Atlantic Drift transports warm and saline surface waters from the low latitudes towards the Arctic region, along the coast of Northwestern Europe. In the Arctic, cold and fresh water sinks and flows southwards along the east Greenland margin (North Atlantic Deep Water).

The precise timing of the development of these oceanic patterns is still uncertain due to inconclusive existing data. To better understand climate change over the North Atlantic region during the Earth's early icehouse phase, we present mean annual air temperatures (MAAT) derived from branched glycerol dialkyl glycerol tetraethers from locations around the northern Atlantic Ocean. Our record spans Upper Eocene-Lower Miocene successions (~35 to ~28Ma) from marine sites in Denmark and the Labrador Sea (ODP Site 647A) and Newfoundland drift deposits (IODP Expedition 342 Sites U1411 and U1406). A comparison between MAAT records in these locations and the published MAAT record from the Greenland Sea (ODP Site 913) makes it possible for the first time to deconvolve high and low latitude air temperature signals in the region. Furthermore, our record suggests the presence of a ca.4°C MAAT gradient across the eastern and western flanks of the mid latitude North Atlantic during the middle Oligocene.

The depositional history of the Melville Bay trough-mouth fan and its implication for GrIS evolution

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The Greenland Ice Sheet (GrIS) is a major freshwater reservoir and a key component of the global climate system so understanding its past dynamic behaviour is crucial for underpinning climate model predictions. New data and results has been produced from late Quaternary records but the long-term history and dynamics of the GrIS is only sparsely understood. The Melville Bugt and Upernavik trough-mouth fans are constructed by a series of prograding units deposited by sediments that were eroded and transported by glaciers streaming into Baffin Bay. Due to favourable geological conditions, e.g. presence of thick sedimentary basins and sustained margin subsidence, top-sets of the glaciated margin succession are extremely well preserved. The seismic stratigraphic record indicate eleven major phases, or mega-cycles, of ice stream advance over the northwest Greenland continental margin since the onset of shelf-based glaciation at around 2.7 Ma. The ice advance mega-cycles corresponds to long-term changes in the configuration of sedimentary depocentres, interpreted as shifts in ice stream pathways. Based on calculated sediment volumes and the available chronological evidence, including results from stratigraphic coring in 2012 (Exp. 344S), an age model has been constructed for the trough-mouth fan system. Accordingly, we observe an abrupt reorganization of ice stream flow at the start of the Mid-Pleistocene Transition about 1 Myr ago, when uniform ice advance across the margin was replaced by focussed fast-flowing ice streams. Moreover, the age model in combination with evidence of shelf strata onlapping the glacial unconformities, alludes to a linkage between shifts in ice stream pathways and relatively high sea-levels during extreme interglacials.

Challenges and experiences in drilling ice-proximal sites (KEYNOTE)

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Ice-proximal drill cores from continental shelves and near-margin continental rises contain important records of regional ice stream and outlet glacier advance and retreat processes and provide, therefore, key data for understanding and reconstructing ice sheet dynamics. However, drilling at ice-proximal sites, specially on the shelves, has its particular challenges and risks. DSDP Leg 28 (Ross Sea) was the first and ODP Legs 113 (Weddell Sea), 119/188 (Prydz Bay), 151 (Spitzbergen/Fram Strait), 152/163 (SE Greenland margin), 178 (Ant. Peninsula) were the next follow-up ship-based scientific deep-drilling expeditions to polar continental margins. They all had a varying degree of failure and success. More advanced drilling technology on JR and smarter strategies helped enlarge the success of IODP Expeditions 318 (Wilkes Land margin) and 374 (Ross Sea). With our first multi-barrel seabed drilling expedition to an Antarctic shelf (Amundsen Sea), we could demonstrate that MeBo, or a similar seabed drilling device, is a viable and low-cost tool for shallow drill cores at particular sites on the shelf that are beyond the penetration depths of conventional coring. Yet, the lack of continuous core recovery as well as the sea-ice and iceberg risk remain as strongest challenge for all ship-based drilling expeditions. This presentation will summarize the challenges and experiences from past ice-

proximal polar drilling expeditions. I will explain the various issues we have been discussing with IODP to mitigate the risks to prepare for the upcoming IODP Expedition 379 to the Amundsen Sea Embayment (early 2019), where many of the science objectives, stratigraphic targets and challenges are closely related to those of the IODP proposal #909 to the NW Greenland margin.

Drilling Site 7A Identification, Expected Stratigraphy and Geohazards - A study using High Resolution 3D seismic

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Shelf records of ice sheets based on Alaska and Antarctica (KEYNOTE)

Sean Gulick

Jackson School of Geosciences, University of Texas - Austin, Texas, USA

POSTER PRESENTATIONS

Glacial and Deglacial stable isotope endmembers from the Labrador Sea

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The modern Atlantic Meridional Overturning Circulation (AMOC) is supposed to be stabilized by the formation of Labrador Sea Water (LSW) since about 7 ka BP. Despite its importance in the modern ocean circulation, it is suggested that deepwater formation in the Labrador Sea is a unique feature in the Holocene and is supposed to be absent during the last Glacial period. Glacial low $\delta^{13}C$ signatures in benthic foraminifera from sediment cores situated in the outflow pathway of modern Labrador Sea Water (LSW), are interpreted as a northward intrusion of AABW up to latitudes of 50 °N at 2800 m wd in the western North Atlantic, as they resemble glacial Antarctic Bottom Water (AABW). This interpretation is recently questioned, as changes in the endmember composition of the Glacial North Atlantic Deep Water (GNADW) also need to be considered with respect to glacial AMOC circulation. This may also include potential changes in the Labrador Sea endmember due to a stagnation and alteration of the deepwater body under a complete sea ice cover.

In order to decipher the water mass structure and composition in the Labrador Sea during the last Glacial and the Deglaciation and better understand its interaction with changes in the extent of the Greenland and Labrador ice sheets, we combine existing benthic datasets from the Labrador Sea with new data from cores situated in the Inner Labrador Sea at different water depths (1278 m, 2525 m, 2677 m, and 3295 m). Thereby our study aims to identify the subsurface to deep stable isotope and temperature signature from the glacial

Labrador Sea. In this contribution we will present first stable isotope data obtained from benthic foraminifera at from the Greenland shelf and the Labrador continental margin.

Chronostratigraphic modeling of complex depositional systems: Lessons from the Bengal Fan, implications for ice proximal environments

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Establishing high-resolution chronologies in complex lithogenic depositional systems, such as deep-sea fans and glaciated margins, can be challenging. Recent drilling of the Lower Bengal Fan during International Ocean Discovery Program (IODP) Expedition 354 recovered a transect of seven sites containing thick Pleistocene turbidite and sand deposits that could not be dated continuously using traditional Pleistocene stratigraphic methods. We investigate chronology and uncertainty for these sediments using a novel age-depth modeling approach that factors litho-, magneto-, bio-, cyclo-, and seismic stratigraphic constraints, based on results from IODP Expedition 354 and analysis of the GeoB97-020/027 seismic line. The initial chronostratigraphic framework is established using regionally extensive hemipelagic sediment units and only age-depth models of fan deposits that respect the superposition of channel-levee systems across the seven sites are accepted. In doing so, we reconstruct signals of regional sediment accumulation rate and lithogenic sediment input that are consistent with more distal and more ambiguous Bay of Bengal and Bengal Fan records. This chronology allows us to discuss the Middle to Late Pleistocene Bengal Fan evolution within the context of sea level, climate, and tectonic controls.

The Eirik Ridge and Greenland Margin sediments proposed for drilling in IODP Proposals 814-Full and 909-Full will likely face similar issues to sediments recovered from the Bengal Fan, with limited preservation of foraminifera, large glacial-interglacial variations in sediment accumulation rates, and possibly limited recovery in the more proximal depositional environments. System specific chronostratigraphic models, adapted from methods developed for the Bengal Fan, will help quantify uncertainty in sediment age and provide a framework for other expedition research goals.

Seismic geomorphology and evolution of the Melville Bugt Trough Mouth Fan, Northwest Greenland

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The Melville Bugt graben offshore Northwest Greenland contains a several kilometre-thick sedimentary succession spanning the Early Cretaceous to the present. In the last decade high-resolution seismic reflection surveys have been collected across the graben and we use them here to investigate the glaciogenic succession comprising the Melville Bugt Trough Mouth Fan (MB-TMF). The MB-TMF seismic stratigraphy is characterised by rapid progradation (over 100 km since ~2.8 Ma) and truncation or subsidence of topset strata. The variable topset character is thought to relate to the repeated growth and retreat of the Greenland Ice Sheet, and in particular grounded ice streams, across the shelf since ~2.8 Ma. The 3D seismic reflection data reveal the preservation of several sets of glacial lineations that confirm the presence of grounded ice on the continental shelf at various stages during the MB-TMF development. A seismic geomorphological and facies analysis of the prograding clinoforms shows repeated observations of debrites and gully systems. Such features on a glaciated margin have typically been taken to infer gravity-driven processes and the occurrence of meltwater-related hyperpycnal flows in areas proximal to the ice sheet – e.g. the ice sheet reached the shelf outer. Bottomset contourites are thought to provide insight into the evolution of the West Greenland Current in Baffin Bay through the Pleistocene, with deposition starting in the late Calabrian (1.8 - 0.781 Ma). Large-scale stratigraphic mapping shows that the sedimentary strata within the Melville Bugt graben was preferentially eroded and likely provided an important control on the initial late Pliocene and Early Pleistocene excavation of the trough. This process helped to create a topographic low between the accumulation of older late Pliocene and Early Pleistocene glacial deposits in the west of the trough and the coastal Precambrian basement to the east, perhaps aided by tectonic adjustments of the underlying Melville Bugt Ridge. This topographic low was then exploited by later glaciations as the main depocentre migrated south. As accommodation became limited in the south, ice sheet flow was then forced to flow between the two main depocentres, leading to progradation of the shelf toward Baffin Bay. This study builds on recent work in the region and provides a major insight into the late Pliocene and Pleistocene seismic geomorphology of the MB-TMF and the concomitant history of the Greenland Ice Sheet in northeastern Baffin Bay.

One million years of glaciation and denudation history in west Greenland

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The influence of major Quaternary climatic changes on growth and decay of the Greenland Ice Sheet, and associated erosional impact on the landscapes, is virtually unknown beyond the last deglaciation. Here we quantify exposure and denudation histories in west Greenland by applying a novel Markov-Chain Monte Carlo modeling approach to all available paired cosmogenic ^{10}Be-^{26}Al bedrock data from Greenland. We find that long-term denudation rates in west Greenland range from 450 m Myr-1 in low-lying areas to 2 m Myr-1 at high elevations, hereby quantifying systematic variations in denudation rate among different glacial landforms caused by variations in ice thickness across the landscape. We furthermore show that the present day ice-free areas only were ice covered ca. 45% of the past 1 million years, and even less at high-elevation sites, implying that the Greenland Ice Sheet for much of the time was of similar size or even smaller than today.