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GEOLOGICAL SURVEY OF CANADA
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The 9th International Conference on Arctic Margins (ICAM 9) Abstract Volume

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2023

Canada

ISSN 2816-7155
ISBN 978-0-660-47110-5
Catalogue No. M183-2/8941E-PDF

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The 9th International Conference on Arctic Margins (ICAM 9) Abstract Volume

M.-C. Williamson[1], B.M. Saumur[2], A.M. Savoie[3], and N. Bingham-Koslowski[1]

[1]Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario
[2]Département des Sciences de la Terre et de l'atmosphère, Université du Québec à Montréal, 201 avenue du Président-Kennedy, Montréal, Québec
[3]Canadian Museum of Nature, Natural Heritage Campus, 1740 Pink Road, Gatineau, Quebec

2023

Permanent link: https://doi.org/10.4095/331345

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

Recommended citation
Williamson, M.-C., Saumur, B.M., Savoie, A.M., and Bingham-Koslowski, N., 2023. The 9th International Conference on Arctic Margins (ICAM 9) Abstract Volume; Geological Survey of Canada, Open File 8941, 1 .zip file. https://doi.org/10.4095/331345

Publications in this series have not been edited; they are released as submitted by the author.

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INTRODUCTION

The International Conference on Arctic Margins (ICAM) is a forum for Earth scientists who study the Arctic Ocean and adjacent landmasses. ICAM was founded in 1991 by Dennis Thurston, U.S Department of Interior Bureau of Ocean Energy Management (formerly the Minerals Management Service) to promote scientific cooperation and collaboration in Arctic geoscience at a national and international level[1]. ICAM is a unique forum because, although initiated under MMS, it is not affiliated with any single organization or government. Today, ICAM is organized, hosted, funded, and conducted by scientists for scientists.

The underlying goal of the ICAM meeting is to highlight state of the art geoscientific research underpinned by national and international collaborations in the Arctic region. In recent years, multinational icebreaker expeditions have led to a wealth of new geological and geophysical data on the Arctic Ocean seafloor. In addition, recent bedrock mapping and multidisciplinary studies have improved stratigraphic correlations and tectonic reconstructions of Arctic regions through time, as well as our current understanding of widespread magmatic events and mantle geodynamics. ICAM scientific themes include geology and geophysics, mapping, remote sensing, plate tectonics, climate, and other studies that are related to Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS).

The 9th International Conference on Arctic Margins (ICAM 9) was held at the Fairmont Château Laurier, Ottawa, Canada, from June 13-15, 2022. The conference brought together over 80 participants from eight countries. The ICAM 9 Technical Program included 2 Special Sessions and 11 Technical Sessions resulting from a community effort to capture a wide range of research results ***Through the Arctic Lens***.

To mark the 30th anniversary of the founding of ICAM, two awards were presented. The ICAM Award was presented to Dennis Thurston in recognition of his role in founding and promoting the conference to the international community. A new category of award, Best Student Paper, was given for the first time to Spencer Ziegler, University of Colorado (ICAM9-TS4-3).

The 10th International Conference on Arctic Margins will be held at the University of Bremen, Bremen, Germany, in 2025. The meeting will be convened by Estella Weigelt, Alfred Wegener Institute, and Cornelia Spiegel-Behnke, University of Bremen.

[1] https://www.boem.gov/regions/international-conference-arctic-margins

The First ICAM

The first ICAM came about because of selfish motivations. In 1982 I was hired in Alaska as a geophysicist by the newly formed Minerals Management Service. I was assigned a job that nobody else wanted – mapping the US Chukchi Sea. Between 1982 and 1991, I mapped an area the size of the state of Indiana using industry seismic surveys, and the geology turned out to be fantastic. However, I ran up against the US-Russia Convention Line of 1867 and was left to speculate on what the geology was on the Soviet side. So, I thought the best way to hear and see what had been done would be to start a convention on Arctic geology and invite Russian and other scientists. I spent a full year gathering names of scientists from all over the world that worked in the Arctic and sent them inquiries and information via fax, telex, phone, and mail (there was no internet at the time). By the time of the first meeting in Anchorage in 1992, we had over 400 geoscientists in attendance. Many long-term collaborations and friendships were formed at the first ICAM and at subsequent meetings. Now, on the occasion of the 9th ICAM, I am proud of what ICAM has become and hope that it continues to serve the Arctic geoscience community.

Dennis Thurston
December 2022

Acknowledgements

We are grateful to Jeff Saarela, Canadian Museum of Nature, Courtney Onstad, Simon Fraser University, and Nicole Rayner, Geological Survey of Canada, for help in the years and months leading up to ICAM 9. Farah Gagnier and Laura Vachon, UQÀM, volunteered at the registration desk during the conference. Special thanks to Jean-Yves Blanchard for designing the website, participating in the ICAM 9 Steering Committee, and helping out with audiovisual requirements. We wish to thank Frédéric Leroulley, Grenadine Technologies, Laurence Schaller and Steven White, Fairmont Château Laurier, and Nathalie Boulet, Canadian Museum of Nature, for guiding our efforts to provide the best possible meeting experience to ICAM 9 delegates. A special note of thanks to the ICAM 9 conference sponsors for their financial support: Daniel Lebel, Jeff Harris, Kim Senger, Mark Hannington, Erin Bethell, David Lentz, Dawn Kellett, Carmen Gaina and Grace Shephard also promoted the ICAM community in Canada and abroad between 2019 to 2022. Thank you Mark Hannington for accepting to give the keynote presentation at our social event! Keith Dewing is thanked for reviewing an earlier version of this publication. MCW is indebted to Victoria Pease, Elizabeth Miller, and Bernie Coakley for sharing best practices from past ICAM meetings, and for giving generously of their time to prepare the ICAM Award to Dennis Thurston.

Marie-Claude Williamson, Benoit Saumur and Amanda Savoie

The ICAM 9 logo

The circular, blue logo symbolizes the Arctic Ocean from a polar projection with white representing the shrinking ice cover. The relief seen as a crescent represents topography within circum-Arctic landmasses, and bathymetry of submarine features within the Arctic Ocean and seaways. The maple leaf is Canada's universal symbol here coloured in green to symbolize the season during which the conference was held. One may also notice a telescopic view of the maple leaf. Telescopes enable us to gain perspective. This feature of the logo symbolizes ICAM's goal of understanding the big picture of Arctic landscapes and their evolution through geological time by means of international research collaborations, communication, and action.

Design by Marie-Claude Williamson and Alexis Shuffler (2020).

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Welcome to ICAM 9

Dear ICAM Delegates,

As president of the International Union of Geological Sciences (IUGS), I welcome you all to the 9th International Conference on Arctic margins which is hosted in Canada for the first time in nearly two decades.

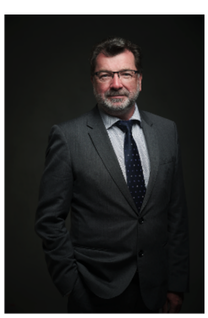
The ICAM community meets every four years to communicate new results on the geological evolution of the Arctic Ocean basin and margins, and surrounding landmasses. The Arctic regions are very susceptible to the anthropogenic-driven changes happening on Earth and as geologists we have an important role to play in documenting and communicating the evidence as well as being part of the solutions; in the energy transition where geology and soils will play an essential role.

This international effort converges with the IUGS goal of building new relationships between and among the earth and environmental disciplines, and how geoscience impacts our understanding of the evolution of the Arctic Ocean on a global scale.

As in the past, the geoscience community in Canada and beyond will benefit from the scientific discussions and new collaborations that will result from networking during ICAM 9. This process creates a path for us to work together as stewards of the Arctic, and to contribute to public policy decisions at a national and international level.

The IUGS strongly promotes public understanding and appreciation of the planet Earth and appreciate the efforts of the ICAM community to include a special session on Communicating Arctic Science.

In closing, thank you for your dedication and effort to meet at ICAM 9 and I wish you a very successful meeting.



John Ludden
President
International Union of Geological Sciences
www.iugs.org

WEEK AT A GLANCE

ICAM 9 OTTAWA 2022

Program at a glance

	SUNDAY June 12	MONDAY June 13	TUESDAY June 14	WEDNESDAY June 15
Morning	The 9th International Conference on Arctic Margins will be held in the Laurier Room *The Fairmont Château Laurier Hotel* Ottawa, Canada 	**TS7** Sedimentary Record and Crustal Architecture of Arctic Continental Margins and Basins **TS11** Neoproterozoic Circum-Arctic Tectonic Events and Correlations	**TS8** Magmatism in the Arctic Region **TS9** (1st half) Tectono-Sedimentary Elements of the Arctic and their Significance to the Energy Transition World	**TS1** From Basins to Mountains.. and Back: Circum-Arctic Paleozoic Tectonics and Geodynamics **TS3** Bedrock Geology of Baffin Island, the Labrador-Baffin Seaway and Greenland: Correlating the Frontier
Afternoon		**TS4** Geochronology in Arctic Regions **TS2** Impacts of Climate Change on Arctic Watersheds and Coastal Regions	**TS9** (2nd half) Tectono-Sedimentary Elements of the Arctic and their Significance to the Energy Transition World **TS10** Rifting, Breakup and Structural Inheritance of Arctic Continental Margins	**TS6** Seafloor Mapping in the Arctic Ocean **TS5** Remote Sensing in Arctic Regions (Poster Session)
Evening	**Registration** 5:00 to 8:00 p.m.	**SS2** Community Update: New Projects, Collaborations & Initiatives	**SS1** Communicating Arctic Science	**Social event** Canadian Museum of Nature Invited Speaker Mark Hannington University of Ottawa

SS = Special session TS = Technical session

TECHNICAL PROGRAM

Special Sessions

ICAM9-SS1

Communicating Arctic Science

Marie-Claude Williamson, Sherestha Saini

Researchers stand at the forefront of the scientific and technological advances that permeate our daily lives. While many of us are aware that science communication has an impact on evidence-based decisions and policy agendas, other benefits may not be as clear. With a laser focus on completing projects and little emphasis on communicating science, many researchers do not see the point. And yet, with the proliferation of accessible platforms and affordable technology, it is easier than ever to connect with each other and to share our work more broadly. Can communicating science to a general audience - via videos, podcasts, educational tools, field blogs, etc. – open doors to unexpected opportunities, and expand the way we communicate, connect, learn, lead, persuade, promote our projects and foster collaboration? This session welcomes a wide range of contributions on the topic of communicating Arctic science - from success stories and lessons learned in northern communities, to the ups-and-downs of communicating science on social media, to creating educational tools that bring everyday discoveries to museums, schools and homes.

ICAM9-SS2

Community Update: Arctic Research Programs & Projects

Marie-Claude Williamson, Marie-Andrée Dumais

This special session will consist of invited presentations that highlight the past five years of Arctic research programs and projects at Geological Surveys and universities.

ICAM9-TS1

From Basins to Mountains…and Back: Circum-Arctic Paleozoic Tectonics and Geodynamics

Benoit Beauchamp, Keith Dewing

Paleozoic rocks exposed in circum-Arctic landmasses record complex tectonic and geodynamic processes that occurred along the margins of Laurentia and adjacent areas. These processes include a post-rift passive margin in the Cambrian; exotic terranes in the Ordovician-Silurian that were later amalgamated to the continents in Devonian time; and a transition from passive margin to orogenic belts that culminated in the latest Devonian and resulted in high relief mountains that shed their detritus all over the old continents of North America and Europe. And yet, over a short period of time across the Devonian to Carboniferous transition, Caledonide and post-Caledonide mountains were eroded and/or collapsed, giving rise to rift basins formed in the footprint of these massive orogenic belts. This session welcomes multi-disciplinary contributions in stratigraphy, sedimentology, detrital geochronology, structural geology, tectonics and geophysics that shed light on and establish geological connections and correlations between these events. We particularly encourage contributions on the origin, timing and evolution of the remarkable Paleozoic tectonic and geodynamic transformations that occurred along the margins of Laurentia and all over the circum-Arctic regions at a time of great upheaval in the lithosphere.

ICAM9-TS2

Impacts of Climate Change on Arctic Watersheds and Coastal Regions

Samantha Jones, Zoe Walker

The Arctic, including its coastlines and watersheds, is experiencing rapid climate change compared to other regions around the globe, and future projections include continued warming, additional ice loss, and increased precipitation. In response to these changes, urgent action is needed to document environmental changes and understand the effects on communities, ecosystems, and the economy as a foundation for adaptation and decision-making - an undertaking that will require international collaboration and the recognition of the importance of Traditional Knowledge. The Arctic is a complex system affected by the liberation of additional carbon from thawing permafrost landscapes, changes to the hydrologic cycle, the albedo feedback fueled by the loss of ice and snow, and other local and global environmental changes. This session aims to highlight a broad spectrum of multidisciplinary research that addresses these connections and feedbacks, and contributes to the understanding of the impacts of climate change on Arctic coastlines and watersheds. We welcome contributions on field-based, laboratory and modeling studies ranging in scale from local case studies to pan-Arctic projects that include, but are not limited to, present-day conditions as a baseline for future change, new approaches and methodologies, predictions and projections, risk and uncertainty analyses, long-term trend observations, and community-based monitoring projects.

ICAM9-TS3

Bedrock geology of Arctic Canada, the Labrador-Baffin Seaway and Greenland

Benoit Saumur, Nikole Bingham-Koslowski, Stephen Johnston

Remote circum-Arctic areas provide unique challenges and logistics for mapping of both onshore and offshore geology. Nevertheless, such work provides key constraints for geodynamic and paleogeographic reconstructions and contributes first-order insights on resource potential. From a North American perspective, the bedrock geology of Arctic Canada and Greenland, and the links between the two, are still debated. The Phanerozoic Labrador-Baffin Seaway between Canada and Greenland presents its own logistical challenges leading to gaps in data availability and quality (e.g., geophysical, well/borehole, bedrock mapping and sampling, etc.), particularly on the Canadian side of the seaway. This session welcomes a wide variety of contributions on the bedrock geology of Arctic Canada and Greenland, and the offshore geology and dynamics of the Labrador-Baffin Seaway. Representing a combination of two broad fields, this session will stimulate multidisciplinary discussion with regards to paleogeographic reconstructions and regional correlations.

ICAM9-TS4

Geochronology in Arctic Regions

Jeremy Powell, David Schneider, Nicole Rayner

Geochronological studies underpin our understanding of the tectono-stratigraphic evolution of the Arctic Ocean, submarine features, continental shelves and adjoining landmasses. Over the past decade, high-resolution age determinations have led to additional constraints on the opening of the Eurasia and Amerasia basins, the involvement of plume-related magmatism in the development of the Arctic Ocean, and the timing of terrane translation and accretion along circum-Arctic margins. However, the timing and magnitude of these tectonic events are still debated because the logistical challenges associated with marine surveys and fieldwork at high latitudes lead to a scarcity of geochronological data in many parts of the Arctic. This session invites contributions on all aspects of geochronology applied to Arctic regions, including, but not limited to, tephrochronology, low-temperature thermochronology and novel methods and geochronometers that contribute to improving our knowledge of circum-Arctic stratigraphy, structural history, tectonics and geodynamics.

ICAM9-TS5

Remote Sensing in Arctic Regions

Erin Bethell, Jeff Harris, Marie-Claude Williamson

Arctic regions are characterized by a lack of continuous vegetation, resulting in spectacular exposures of bedrock and surficial deposits. As such, the Arctic provides an ideal environment for remote sensing applications within the Earth Sciences. These applications include remote predictive mapping of lithologies, minerals, alteration patterns, structural lineaments, terrane boundaries and other geological features; remote identification of such features is particularly useful in the lead up to “boots-on-the-ground” geological mapping. When combined with geophysical datasets, satellite images can facilitate the search for mineral deposits, while other remote sensing approaches enable an evaluation of climate change impacts on the landscape, coastlines and waterways. We welcome contributions on all of these topics from a wide range of sub-disciplines, with a particular focus on new developments in machine learning techniques applied to remote sensing of Arctic regions. This session is sponsored by the Geomatics Division of the Geological Association of Canada.

ICAM9-TS6

Seafloor Mapping in the Arctic Ocean

David Mosher, Kai Boggild, Catalina Gebhardt, Martin Jakobsson, Bernard Coakley, Kelly Hogan

During the past decade, an unprecedented number of icebreaker expeditions have led to a wealth of new data on the evolution of the Arctic Ocean. As a result, our knowledge of the Arctic Ocean seafloor has increased exponentially. For example, high-resolution bathymetric surveys of circum-Arctic continental margins and submarine features such as the Chukchi Plateau, Alpha Ridge, Mendeleev Rise, Lomonosov Ridge and Gakkel Ridge provide an abundance of new information that confirms – and in some cases challenges - our current understanding of their origin. This new knowledge opens the door to a deeper understanding of the geological history of the Arctic Ocean while also providing research tools for future sustainable management of the Arctic Ocean in response to increasing vulnerabilities and environmental pressures. We propose a session on seafloor mapping that provides a framework for discussion of new data and knowledge acquired over the past decade. We welcome contributions that include, but are not limited to, integrated high-resolution morphologic information and seafloor data obtained from multibeam surveys, and new insights from the analysis of geological samples with implications for the tectonic history of Arctic basins, margins and seafloor elevations.

ICAM9-TS7

Sedimentary Record and Crustal Architecture of Arctic Continental Margins and Basins

Lara Peréz, Estella Weigelt, Thomas Funck, John Shimeld, Alex Normandeau

The architecture of polar margins and basins records the tectonic, oceanographic and glacial history of the evolution of our planet. The Arctic Ocean has been continuously evolving from a closed estuarine basin to a wide-open ocean, at times covered by ice. Major tectonic events such as the opening of gateways, formation of successor basins and subsidence of landmasses have changed the morphology and structure of the Arctic margins and basins. These events have triggered changes in the oceanographic patterns that ultimately influenced the nucleation and oscillation of ice sheets and sea ice. As a result, contourites and glacial-related features are widespread along circum-Arctic margins. The present-day trend of global warming and the undeniable shrinking of sea ice and ice sheets worldwide have fostered an increased interest in the knowledge of past climate changes and their associated environmental consequences. Within this session, we welcome contributions in geology, geophysics and tectonics that are related to the past and present evolution of the Arctic margins and basins.

ICAM9-TS8

Magmatism in the Arctic Region

Kim Senger, Frances Deegan, Victoria Pease, Christian Tegner, Jean Bédard, Sverre Planke, Harmon Maher, Jennifer Galloway

The High Arctic Large Igneous Province (HALIP) is a major tectono-magmatic element of the Arctic region which comprises extensive continental flood basalts, intrusive sills and dykes, and alkaline rocks. The onshore portion of the HALIP is exposed in Svalbard, Franz Josef Land, the New Siberian Islands and the Canadian Arctic Islands. Offshore, the HALIP is exposed at the Alpha-Mendeleev Ridge and in the Barents Sea. The effects of HALIP magmatism and other igneous provinces are also preserved in the sedimentary record of circum-Arctic basins. The limited data available from these remote areas of the Arctic region have left many first-order scientific questions open to debate. This session welcomes contributions that cover a wide range of topics related to the Arctic magmatism including, but not limited to, petrology, geochemistry, stratigraphy, sedimentology, geophysics, and paleoenvironmental studies. Contributions that focus on deep and shallow magma generation and differentiation; on the timing of magmatic events in the Arctic Ocean and circum-Arctic basins; on correlations of offshore and onshore magmatic events; and on the climate impact effects on regional and global scales are particularly encouraged. This session is sponsored by the Volcanology & Igneous Petrology Division of the Geological Association of Canada.

ICAM9-TS9

Tectono-Sedimentary Elements of the Arctic and their Significance to the Energy Transition World

Sergey Drachev, Harald Brekke, Erik Henriksen, Thomas Moore

The Arctic Ocean and surrounding continental shelves host large sedimentary basins that preserve the geological record of the past 1.6 Ga of the Earth history. These basins bear potentially huge hydrocarbon resources including biogenic methane and gas hydrates. Combined with the rapidly degrading permafrost, methane and gas hydrates also represent significant sources of greenhouse gases. Since the beginning of this century, the Arctic has seen an increase in national and international multidisciplinary studies related to climate studies, the United Nations Convention on the Law of the Sea (UNCLOS), and the ongoing search for non-renewable resources. During this period, a wealth of new geological and geophysical data has been generated, including conventional marine multichannel seismic data from areas previously inaccessible for seismic vessels owing to diminished Arctic Sea ice. We invite presentations discussing recent results on sedimentary accumulations, as well as papers providing overviews of large sedimentary basins in terms of their geology and hydrocarbon potential, and their importance during the transition to future world energy needs.

ICAM9-TS10

Rifting, Breakup and Structural Inheritance of Arctic Continental Margins

Peter Klitzke, Christian Schiffer, Marie-Andrée Dumais

In circum-Arctic regions, the collapse of mountain belts was followed by Palaeozoic and Mesozoic continental rift phases that culminated in the formation of new ocean basins in the Cenozoic. The influence of structural grains from previous tectonic events, proto-continental breakup and rifting, seafloor spreading and rifted margin structures, is acknowledged but poorly understood. In the case of the Norwegian and Greenland margins, inheritance linked to multiphase rifting, the Caledonian orogeny and/or Precambrian structures are known to have imposed a dominant control on margin development. In contrast, the effects of inheritance are far less constrained along circum-Arctic continental margins. This session provides a forum for discussions on the topic of Mesozoic and Cenozoic extensional episodes and continental breakup, as well as on the role of structural inheritance. We aim to bring together a diversity of sub-disciplines including plate tectonics, geophysics, geodynamic modelling, igneous, metamorphic and structural geology, sedimentology and geochemistry.

ICAM9-TS11

Neoproterozoic Circum-Arctic Tectonic Events and Correlations

Jean-Baptiste Koehl, Victoria Pease, Peter Klitzke

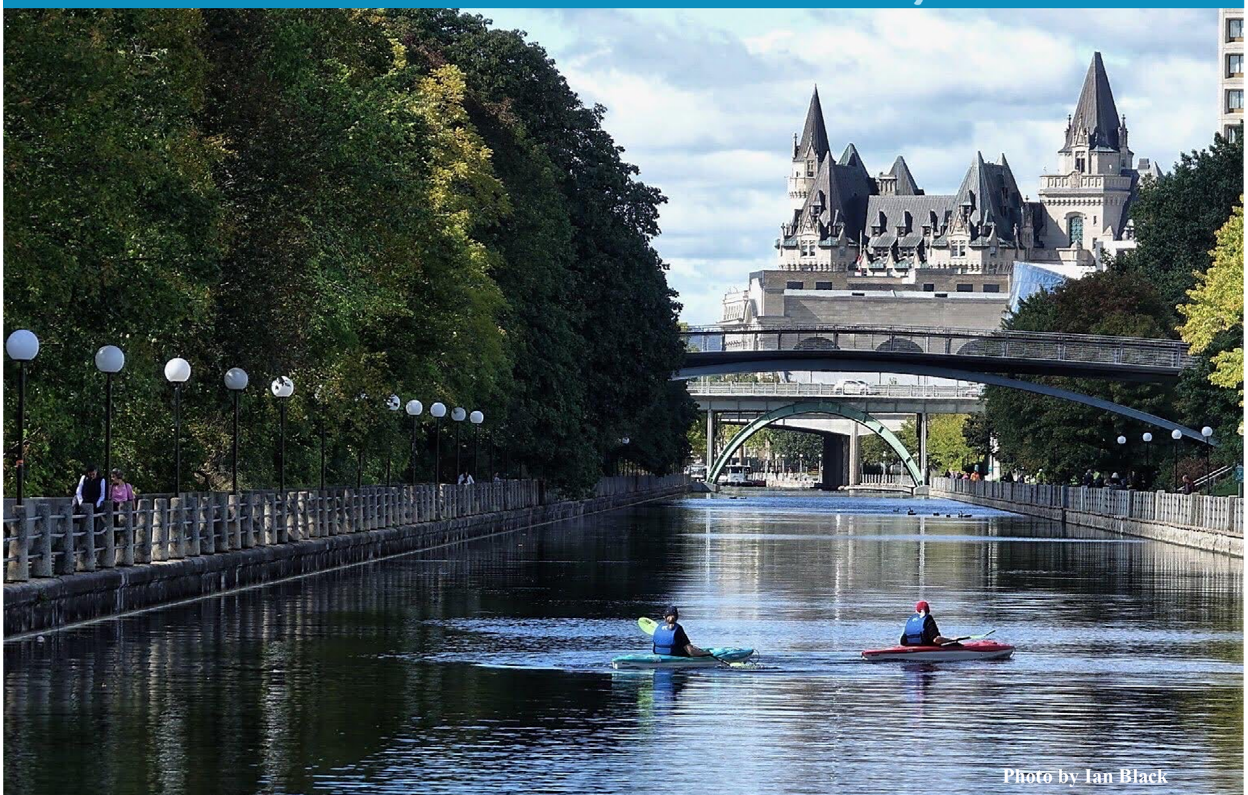
In Neoproterozoic times, present-day Arctic regions were involved in a succession of tectonic episodes including both continental accretion and extension. The extent and kinematics of some of these events, such as the Grenvillian orogeny, are relatively well constrained and correlated. However, other tectonic events are more loosely constrained and large uncertainties exist in Pan-Arctic correlations, which result in significant variations between (full-) plate reconstructions for Arctic regions, especially in the late Neoproterozoic. To fully decipher this complex tectonic system, it is key to study this remote, sparsely studied region using integrated, multi-scale and multi-disciplinary analyses from surface to the crust and into the mantle. We welcome contributions from all relevant disciplines that facilitate our understanding of Neoproterozoic tectonic cycles, their occurrence, and formation processes, including but not limited to plate tectonics, geophysics, geodynamic modelling, igneous, metamorphic and structural geology, palaeomagnetism, sedimentology, geomorphology, geochemistry and petrology.

ICAM 9 CIMA 9

The 9th International Conference on Arctic Margins

La 9ième Conférence internationale sur les marges arctiques

Through the Arctic lens
Par la lentille de l'Arctique



ABSTRACTS

ICAM9-SS1-1

Empowering the open sharing of Arctic Research

Sherestha Saini, Natalie Sopinka

sherestha.saini@cdnsciencepub.com

From burying teabags in soil to measure decomposition to flying drones over fjords to identify whales, there are countless ways to study the Arctic. There are also countless ways to communicate those studies. At Arctic Science, an open access peer-reviewed journal, we support communication of natural and applied science and engineering research related to northern polar regions. We also encourage publication of integrative science papers where research presented encompasses Indigenous Knowledge, social sciences, and natural or applied science. While publishing papers is the typified role of an academic journal, we're trying to do things differently. One of our major goals is to be a platform to engage and inform northern communities living in the Arctic who are most impacted by the effects of climate change, and for whom access to this knowledge is critical for their well-being. We're committed to open science and strive to minimize barriers to knowledge sharing for communities and co-producers. This presentation will focus on ways that the journal is communicating research findings to diverse audiences using a variety of science communication tools. We will share examples from Arctic Science authors and editors to showcase ways to go "beyond the paper" by using plain language to communicate research in paper summaries and graphical abstracts. We will also highlight initiatives that create space for perspectives from Indigenous researchers, scholars, and community members engaged in Arctic science, including unique publishing formats (e.g., essays, video interviews, commentaries) to ensure respectful reporting of Indigenous-led and community-based participatory research.

ICAM9-SS1-2

GEM-GeoNorth: An evolving approach to Indigenous engagement

Kate Clark

kate.clark@nrcan-rncan.gc.ca

Bridging the gap between geoscience research and community or regional priorities can be a challenge for communicators in government, industry, and academia. The Geological Survey of Canada (GSC) has worked in Canada's North for 180 years, and relationships with Indigenous Canadians have been varied and complex. Technological, social, and legal advances in the past three decades have both mandated and enabled increased participation of Canadian Northern and Indigenous peoples in research taking place within their territories. As these movements gained momentum, the GSC embarked on a new push to upgrade mapping of northern Canada through the Geo-Mapping for Energy and Minerals (GEM) Program. Beginning in 2008 and renewed twice (2013, 2020), GEM has steadily built internal capacity, and intentionally built external relationships with the objective of maximizing the benefits of geoscience for Northerners. As Canada itself embarks on an era of reckoning and reconciling with its past, the GEM program has learned, listened, and changed.

In this talk, we will explore the guiding principles and evolution of GEM-GeoNorth's approach to Indigenous engagement, and lessons learned from the past decade.

ICAM9-SS1-3

Make Outreach a Part of your Field Plan: Highlights from Astronaut Training in Labrador

Cassandra Marion

cmarion@ingeniumcanada.org

Scientific research that is shared, clearly understood and appreciated by a public audience will increase the value of the work and increase its impact on society. It also plays an important role in engaging and attracting the next generation to join STEM fields. As Arctic scientists we need to do a better job of sharing our research, our distinctly spectacular experiences and our passion with the public, as very few Canadians will get the opportunity to experience the Arctic. It takes a lot of planning, from applying for funding and permits, organizing field gear and logistics, budget, safety training, coordinating the field team and their scientific objectives and so on. Outreach and education should be on of that list, as an important part of the field plan.

This presentation will illustrate the Outreach approach used in a recent field expedition to the Mistastin Lake impact structure in northern Labrador led by Western University. One of the primary objectives of the trip was to train two astronauts in field geology in preparation for future missions to the Moon. My role was two-fold: basecamp manager and part of the training team; and secondly, as a representative of Ingenium, the expedition's education and outreach documentarian. In the latter role, I collected a variety of digital media and kept a log of our activities that was and continues to be used for social media, presentations across the country, school visits, youth programing etc.

Foremost among the lessons learned: plan ahead and don't do it alone. Assign someone the responsibility. Find delivery partners to broaden your audience and increase your reach. In addition to your field crew's institutions, reach out to not-for-profit education organizations, museums, science centres, clubs, local school boards, teachers and the media.

ICAM9-SS1-4

Performing Process on the Page: Science Poetics

Samantha F. Jones

samantha.jones3@ucalgary.ca

"this tiny body / made slight // a whisper."

—from "Ocean Acidification" by Samantha Jones

Science poetry is one form of sci-art that can be used as a science communication tool and as a method to explore and understand scientific concepts and processes.

The poems "Studying the Freshet" (forthcoming in Arctic, 75(1)) and "Spring Pulse" (the Association of Polar Early Career Scientists 2021 Polar Poetry Contest winner) explore the spring melt season in a connected Arctic lake, river, and coastal ocean system. Word selection and arrangement in these poems communicate natural processes, while narrative and imagery are used to transport the reader to the field. In this way, poetic text can be used to simulate an experience as well as explain concepts or phenomena. The act of creating science poetry requires careful examination of the relationship between the poet (or narrator) and the environment, therefore writing science poetry is a practice of critical reflection.

The poem, "Ocean Acidification" was first published in the online literary journal, WATCH YOUR HEAD, in March 2021. It was later developed into a short multimedia production with the International Alliance to Combat Ocean Acidification, the MEOPAR Ocean Acidification Community of Practice, The Ocean Foundation, and Manaia Productions. "Ocean Acidification" explains the urgency of the other carbon problem through narrative and visual elements. The narrative explores impacts of Ocean Acidification (OA) and factors that exacerbate OA, including some specific to the Arctic and cold regions, while using metaphor and poetic imagery to communicate the key messages. The layout of the poem text on the page is a series of six circles that progressively break down. This format mimics the dissolution of carbonate exoskeletons and the stresses on individual organisms, as well as the deterioration of the larger system. In this way, the story and visuals work together as an artistic simulation that performs the OA process on the page.

The generation of science poetry is interdisciplinary in nature and the product can attract audiences from diverse backgrounds to a shared space for discussion and innovation. Science poetry can be used to present ideas and research outcomes in an accessible format to non-specialists, and can be enjoyed by experts who continue to advance their respective fields.

ICAM9-SS1-5

Sharing your science with non-specialists by leveraging digital tools

Barbara Ustina, Joel Houle

barbara.ustina@nrcan-rncan.gc.ca

We live in a time of unsettling change in our northern regions. Arctic scientists see the impact of our changing climate firsthand: melting glaciers, rising sea levels, and slumping permafrost, among other signs. While researchers bear witness to changes in the North, it's the northern communities and Indigenous peoples who face these new realities and risks in very direct and deep ways. As observers on the forefront in the North, it's more important than ever to share your science beyond your own colleagues and decision makers. Appealing to a broader audience that wants to know what's at stake and how to adapt can lead to new opportunities and inspire change.

A foundation of clear, concise communications is what supports excellent public engagement with science. Simply Science is the online platform for Natural Resources Canada to share our science through articles, podcasts and videos. We're a small team that provides advice and production services directly to our scientists and experts. You can see our items on our own YouTube, SoundCloud, and social media channels as well as on our own webpage.

The great thing about digital storytelling is that you don't need to be a video or audio expert to do it. With a smartphone and a good internet connection, you hold the power of creative storytelling in your own hands.

This presentation will provide an overview of digital storytelling. We'll look at how to focus your story, how to present your information, and why it's important to capture people's attention from the beginning. We will also highlight some of the most-shared Simply Science stories and social media posts that focus on Arctic Science. If time permits, we will share some technical tips and tricks to writing a great article, taking photos, preparing for a podcast, and recording your own video in the field.

ICAM9-SS2-1

Introducing the POLARIS project – uncovering deep-to-surface connections

Grace E. Shephard, and collaborators

grace.shephard@geo.uio.no

The geological evolution of the Arctic is as long-lived as it is complicated. Over the last 400+ million years, the Arctic has experienced extreme terrane mobility, massive volcanic events, and the opening and destruction of oceans. These processes have environmental impacts like mountain building, anoxic ocean events, ice-sheet formation, and mass-extinctions. To study these interactions, the Arctic must be studied as a unique part of a 4-dimensional whole-Earth domain. However, the spatial connections (including vertically, down to the core boundary, and horizontally over 1000s kms over plates), through to their time-dependent evolution are still poorly understood. This is particularly true for the deep mantle connection, e.g. subducted slabs and mantle plumes, which is particularly under-explored for the Arctic. A new project – POLARIS evolution of the Arctic in deep time - aims to honour these scales and processes by linking the geodynamic evolution of the deep mantle and surface Arctic.

POLARIS will focus on three main elements; plate tectonics, mantle structure and convection, and large-scale volcanism. A major hypothesis to be tested will be whether there is a causal link between major episodes of Arctic volcanism; namely the Siberian Traps, the High Arctic LIP, the North Atlantic IP and the Iceland Plume. Objectives from the project include building digital, self-consistent plate reconstructions back to the Late Paleozoic (419 Ma), constructing palaeogeographic maps, characterising Arctic subduction processes (including via seismic tomography, numerical models), exploring potential plume origins and dynamics of major magmatic events, evaluating true-polar wander (TPW) episodes, and engaging the community via an interactive website.

POLARIS is funded for four years by the Norwegian Research Council, and will be hosted at the University of Oslo. Developments from the POLARIS project will be available at www.polarisdigital.org. Collaborations and discussions from the wider Arctic community are very welcome, including building upon those already established over the recent years.

ICAM9-SS2-2

GoNorth[2]– Geosciences in the Northern Arctic

Kim Senger, and collaborators

kim.senger@unis.no

Thirteen Norwegian research and education organizations, collectively known as GoNorth, have promoted a comprehensive, cross-disciplinary program to investigate the Arctic Ocean. GoNorth proposes a wide-ranging program to acquire new and essential knowledge about the oceanic areas, from the sea floor and subsea geology, through the water column, to the surface sea ice. Education will be an important part of the program. Exploring the Arctic Ocean is a challenging task, because of the harsh environment and the costs of getting access to icebreakers. GoNorth therefore has to organize its activities not by the work packages, but by research cruises. These include research cruises in 2022 to Svalbard’s northern margin using the Norwegian icebreaker Kronprins Håkon (KPH), in 2023 to the Gakkel Ridge (a joint expedition with KPH and German icebreaker Polarstern led by AWI) and in 2024 to the Morris Jesup Rise-Yermak Plateau (a joint expedition with KPH and the Swedish icebreaker Oden led by Stockholm University with involvement from GEUS). The GoNorth initiative was inspired by the United Nations' Continental Shelf Commission's decision in 2009 to support the Norwegian claim for an extended continental shelf north of Svalbard, into the Nansen Basin. Geology and geophysics were therefore the initial central topics. The area north of Svalbard contains several geological enigmas.

Major scientific questions include: 1) Why is the passive, extensional continental margin north of Svalbard unusually narrow, with main characteristics similar to sheared margins? 2) Why is the hydrothermal activity along the ultra-slow spreading Gakkel Ridge similar to much faster spreading ridges? 3) What was the climatic, glacial and palaeo-oceanographic development of the Arctic during the past ~65 million years?

These key questions will be addressed in three geological work-packages (WP1-3) within GoNorth. Another important goal of GoNorth is to develop and test new polar technologies (WP4). Furthermore, GoNorth will embrace polar oceanographic and marine biological research (WP5-6). The GoNorth program follows an Earth System approach linking research topics from the atmosphere to the upper mantle. WP7 represents a cross-cutting theme on geo-politics. In this contribution we outline GoNorth’s objectives and plans for the coming

[2]www.sintef.no/projectweb/gonorth/

years, including an overview of the multi-disciplinary work packages and highlights of the ongoing research projects affiliated with the project.

ICAM9-SS2-3

The pan-Canadian EON-ROSE research initiative: Applications to Arctic Geoscience

Katherine Boggs, and collaborators

kboggs@mtroyal.ca

EON-ROSE (Earth-System Observing Network - Réseau d'Observation du Système terrestrE) is a pan-Canadian research collaboration designed to study entire Earth Systems from the ionosphere through the crust deep into the mantle. Our vision is to install ~1400 powered and telemetered observatories across the Canadian landmass to monitor space weather, atmospheric, environmental and solid Earth processes. Each observatory will contain a combination of broadband seismometers, Global Navigational Satellite System (GNSS) receivers, infrasonic and pressure sensors, weather stations, cameras (video and still), riometers, permafrost thermometers, and gas sensors. EON-ROSE is an inclusive collaboration between Canadian universities, federal - provincial - territorial government research groups, not for profit organizations, industry and international partners. The motivation behind EON-ROSE is to continue and expand the scientific momentum in North America gained from the Canadian LITHOPROBE (1984 to 2004) and US EarthScope (2005 to 2019) research and data collection initiatives.

The critical zone, as defined by the US National Science Foundation in 2001, is the region that supports most life on Earth from the top of the vegetation to the bottom of the aquifer. Critical zone science examines important societal issues such as landslides, carbon sequestration in the near-surface, impact of climate change on soil development and access to potable drinking water. A 2017 analysis of US Critical Zone Observatories (CZO) determined a critical lack of Arctic CZOs, we propose implementing a McKenzie Delta CZO to fill this gap. Canada's only highway access to the Arctic Ocean is the Dempster highway with the Inuvik to Tuktoyaktuk extension (ITE) that runs along the eastern margin the McKenzie Delta. The ITE is constructed on permafrost, thawing permafrost is a construction nightmare that requires constant monitoring. Thawing permafrost also threatens much northern infrastructure such as buildings, pipelines and exposes coastal towns such as Tuktoyaktuk to erosion in regions where the permafrost is the glue that holds the landscape together. There is also significant, poorly constrained, seismic activity across the Mackenzie delta, Richardson Mountains and Beaufort Sea. EON-ROSE observatories could constrain the seismic characteristics in these regions, while monitoring this new Arctic Critical Zone Observatory.

ICAM9-SS2-4

Where Geology Meets Jurisprudence: implementation of Article 76 of the United Nations Convention on the Law of the Sea in the Arctic

David C. Mosher, Kai Boggild*

david.mosher@nrcan-rncan.gc.ca

In 2019, Canada submitted to the United Nations an area of approximated 1.2 million km2 as its extended continental shelf (the area beyond its 200 M limit) in the Arctic. The United Nations Convention on the Law of the Sea gives the coastal State sovereign rights over the resources of the seabed and beneath the seabed within their extended continental shelf. Canada's submission followed on those of Norway, Denmark and Russia. The only remaining Arctic coastal State, United States, has yet to file. The outer limits of the extended continental shelf are determined according to the prescriptions outlined in Article 76 of the United Nations Convention on the Law of the Sea (UNCLOS). These include, amongst other criteria, aspects on the shape of the seafloor (base and foot of the continental slope), sediment thickness in the adjacent basins, and morphological and geological connectivity of seafloor elevations with adjoining landmasses.

A unique aspect of the Arctic Ocean basin is the interconnected seafloor elevations within the basin that transect the entirety of the basin; including Alpha Ridge and Mendeleev Rise, Lomonosov Ridge and Chukchi Plateau. These features, which are morphologically and geologically continuous with the landmasses of both North America (Canada, Greenland and U.S.) and Asia (Russia), allow each coastal State to extend their limits seaward a significant distance in the implementation of Article 76. In some cases, these limits extend to the 200 M limit of opposite States. Since establishment of the ECS is a scientific process and not a political or diplomatic one, it results in significant areas of overlap between States.

Each coastal State files with the Commission on the Limits of the Continental Shelf (a body of scientific experts established by the Convention) for consideration their proposed outer limits along with the scientific data that justify these limits. The Russian submission is currently under consideration but other Arctic coastal States are far behind in the queue. However, these rights are inherent irrespective of the fact that the outer limits are not clearly defined and irrespective of the fact as to whether the coastal State occupies these waters.

Article 77, Paragraph 3 …"The rights of the coastal State over the continental shelf do not depend on occupation, effective or notional, or on any express proclamation."

These sovereign rights include responsibility for management of marine scientific research, so any foreign State (particularly member States of the UNCLOS treaty) must request permission of the coastal State to conduct marine scientific research within its extended continental shelf.

Article 246, Paragraph 2 …"Marine scientific research in the exclusive economic zone and on the continental shelf shall be conducted with the consent of the coastal State."

As a result of the morphology of the Arctic basin and ensuing extended continental shelf areas as prescribed under UNCLOS, most, if not all of the Arctic basin falls within the extended continental shelf of one of its coastal States. Given the extensive areas of overlap between States and the marine scientific research requirements of all States, rather than be problematic, the Arctic should be an exemplary region of pronounced international scientific collaboration and data sharing.

ICAM9-TS1-1

Two stages of the Ordovician M'Clintock Orogeny, Canadian High Arctic

Thomas Hadlari*, Nicole Rayner

thomas.hadlari@canada.ca

Pearya terrane is a complex association of Proterozoic crystalline basement, sedimentary, volcanic, and granitic rocks underlying the northern portion of Ellesmere Island. The M'Clintock orogeny is an early to mid-Ordovician deformation event of Pearya terrane that is interpreted as a terrane amalgamation event wherein Pearya terrane lay outboard of the Laurentian continental margin, or the accretion of an arc to the Laurentian margin. Intrusive rocks of Thores Suite were considered to be ophiolitic fragments, but are recently recognized as arc-related granitoids emplaced at ca. 480-469 Ma that contain old continental, likely Laurentian, inheritance. Prior to our study the oldest evidence of the M'Clintock orogeny was a U-Pb titanite age of 475 ±1 Ma from the Ayles Fiord granodiorite, a concordant intrusion within schistose basement rocks of Pearya terrane. Rocks deformed by the M'Clintock orogeny are unconformably overlain by the Cape Discovery Formation, which contains Late Ordovician fossils.

To better understand the M'Clintock orogeny we analysed new samples collected in 2017 and revisited mineral separates of the previously dated Ayles Fiord granodiorite. Our results indicate that the earliest stage of the M'Clintock orogeny was underway by 481±2 Ma (syn-tectonic granitoid) based on a revised age for the Ayles Fiord pluton. εHf zircon values of -12.3 to -7.8 (Tdm 2.2-1.9 Ga), and Archean inheritance in the Ayles Fiord pluton as well as primarily ca. 2.5 Ga inherited zircon (with a single analysis of 1.9 Ga inherited zircon) in a sample of Thores Suite on Bromley Island indicate that both of these plutonic suites ascended through old continental crust, not a juvenile arc. Turbidite deposits of the Maskell Inlet Complex yielded a unimodal detrital zircon population centred on 475 Ma with a maximum depositional age of 465.3 ±3.9 Ma. εHf ranges from -8 to +10 but primarily between -6 to +1 (Tdm 1.9-1.6 Ga). These zircons are likely arc-derived, with εHf values that are generally consistent with Paleoproterozoic continental crust as the source for the granitoid melts. The last stage of the M'Clintock orogeny is bracketed by the 465.3 ±3.9 Ma maximum depositional age of the Maskell Inlet complex, which is folded and unconformably overlain by dacite at the base of the Cape Discovery Formation dated at 451.6±4.1 Ma.

ICAM9-TS1-2

Early Ordovician to mid Silurian tectonic development of the northern margin of Laurentia, Canadian Arctic Islands

Keith Dewing*, Thomas Hadlari

keith.dewing@nrcan-rncan.gc.ca

Two sedimentary cycles are described from the northern margin of Laurentia in the Canadian Arctic Islands between Early Ordovician and mid Silurian time. Each cycle started with an unconformity, rapid subsidence and an influx of clastic material, followed by decreasing sediment accumulation rates and carbonate sedimentation. The first cycle extends from the Tremadoc to late Katian (~480 to 448 Ma) and spans the Christian Elv to Thumb Mountain formations. The second cycle was from late Katian to Ludlow (448 to 426 Ma; Irene Bay to Allen Bay formations).

The Tremadoc to Katian cycle on northern Laurentia is marked by the development of a shelf margin escarpment and two thick evaporite units that were deposited in intraplatformal basins. εNd values from the incompletely sampled interval were ca. -18. The second cycle was marked by an intraplatformal basin dominated by mudstone deposition, a shift to more positive εNd values, followed by a carbonate platform margin stepback, and the appearance of organisms of Siberian affinity. The intraplatform basins that developed during deposition of the Ordovician Baumann Fiord and Irene Bay formations had restricted lateral extents from NW Greenland to the central Canadian Arctic Islands.

The development of aerially restricted intraplatform basins, the change in εNd values, shelf margin stepback and appearance of Siberian faunal elements are interpreted to be caused by tectonic events along the northern margin of Laurentia. The first cycle is interpreted as response to crustal thickening caused by the M'Clintock orogeny on Pearya and onset of subduction dipping under Laurentia. An extensive Middle Ordovician (Darriwillian) unconformity is not associated with a change in subsidence rate or a change of facies above and below, but is normally faulted. It is interpreted as a migrating forebulge or increase in crustal buoyancy due to breakoff of a subduction slab. The second cycle is synchronous with a Late Ordovician minor faulting event on the SE part of Pearya terrane and volcanic units in the deep water Clements Markham basin. The presence of aerially restricted intraplatform basins that are interpreted to be synchronous with tectonic events on Pearya terrane implies that Pearya was close to its current location by Late Ordovician time.

ICAM9-TS1-3

Architecture of the Caledonian foldbelt of the western Nordaustlandet Terrane, Svalbard

Karsten Piepjohn*, Nikola Koglin, Frithjof Bense, Tim Gibson, Katrin Meier, Alexie Millikin, Ross P. Anderson

karsten.piepjohn@bgr.de

The western part of the Nordaustlandet terrane consists of the late Mesoproterozoic metasedimentary Brennevinsfjorden Group, Tonian volcanic rocks of the Kapp Hansteen Group, Tonian sedimentary units of the Lomfjorden and Murchisonfjorden supergroups and Cryogenian to Paleozoic deposits of the Hinlopenstretet Supergroup. The boundaries between the major stratigraphic groups are represented by disconformities. The entire succession is characterized by very low-grade metamorphic conditions. Sedimentary structures like cross-bedding and ripple marks as well as Neoproterozoic fossils are still well preserved. To the west, the Nordaustlandet terrane is separated from the Meso- and Paleoproterozoic rocks of the West Ny-Friesland terrane by the Veteranen Line.

Compared to the multi-stage structural evolution of the Caledonian deformation in the Northwestern Basement Province and in the West Ny-Friesland terrane, the structural style of the deformation in the western part of the Nordaustlandet terrane is relatively simple and characterized by only one phase of E-W shortening. In eastern Ny-Friesland west of Hinlopenstretet, the Neoproterozoic and Paleozoic rocks of the Lomfjorden and Hinlopenstretet supergroups are characterized by the formation of km-scale, chevron-like synclines and anticlines with subvertical fold axial planes and steeply east- and west-dipping, up to 5 km thick, fold limbs. East of Hinlopenstretet, the Neoproterozoic and Paleozoic strata of the Murchisonfjorden and Hinlopenstretet supergroups are affected by west-vergent, km-scale fold-structures with several km-thick, subvertical to overturned short limbs. The folding is accompanied by the development of a mostly east-dipping fracture-cleavage S1 and the formation of local west-directed zones of reverse and thrust faults. The orientation of the west-vergence in both limbs of the large-scale fold-structures is supported by way-up criteria (ripple marks, crossbedding) and the cutting relation of bedding/cleavage, reverse faults and the orientation of subordinate fold-structures on the fold limbs.

Although the structural style of deformation in eastern Ny-Friesland is similar to that of the Ellesmerian Fold-and-Thrust Belt on Ellesmere Island, the folding in the western Nordaustlandet terrane can be related to the Caledonian orogeny, as the Newtontoppen Granite has intruded the folded succession 430 Ma ago (Myhre 2005). However, the occurrence of several stages of Caledonian deformation in the Northwestern Basement

Province and the West Ny-Friesland terrane contrasted against the single stage of deformation in the Nordaustlandet terrane and indicates that the three terranes experienced a different tectonic history during the Caledonian orogeny and were juxtaposed not before the late Caledonian sinistral ductile strike-slip motions along the Billefjorden Fault Zone and the Veteranen Line.

ICAM9-TS1-4

Paleozoic Fold-and-Thrust Belt Development in Arctic Alaska and the Adjacent Offshore Region

Christopher Connors*, William Craddock, David Houseknecht, Samuel Heller

connorsc@wlu.edu

Conventional wisdom holds that Paleozoic contractional deformation in Arctic Alaska ceased by Middle to Late Devonian with a transition to extensional tectonics and passive margin development in the Late Devonian to Early Mississippian. Newly available 3D and recently reprocessed 2D seismic reflection data (including both pre-stack, time-migrated and post-stack, depth-migrated data) combined with zircon fission track (ZFT) age distributions of pre-Mississippian strata from exploration wells provide spatial and temporal details of this deformation and enable an update to existing interpretations. Our new observations from the Franklinian megasequence show that while pre-Mississippian contractional deformation was ubiquitous, local shortening continued for much of the late Paleozoic.

Regional seismic mapping, constrained by a prominent pre-Mississippian unconformity, indicates that Paleozoic fold-and-thrust belts in Arctic Alaska and the adjacent Beaufort Sea shelf generally trend east-west (present-day coordinates), with a complex interplay of vergence directions. South-vergent belts, likely Devonian in age, are common in the North Slope east of the Colville River, the western Beaufort Sea shelf, and nearshore Point Barrow (Nuvuk) area. East of the Colville River, onshore Neoproterozoic–Lower Paleozoic strata include Early Devonian ZFT central ages that likely formed in-situ, while equivalent northern onshore–offshore strata have older ages that likely reflect sediment provenance.

West of the Colville River, in the central National Petroleum Reserve in Alaska (NPRA), Devonian Franklinian and Mississippian–Pennsylvanian Ellesmerian strata display north-vergent contractional structures whose ages are constrained by growth strata and distinct,

though subtle, unconformities. Farther north in NPRA, this north-vergent thrust belt impinges on older south-vergent structures, likely in Pennsylvanian–Permian time. The ages of the growth strata and unconformities are constrained by biostratigraphic data from multiple exploration wells. The north-vergent belt in part overlaps spatially with an area of Mississippian–Permian ZFT central ages.

Beneath the northeastern North Slope, near the Canning River, pre-Mississippian contractional fabrics influenced the subsequent reactivation of south-vergent contractional structures in likely Permian time, contributing to the formation of the Mikkelsen high.

The relationships described herein indicate a more complex late Paleozoic tectonic history than previously recognized for Arctic Alaska and the adjacent offshore region. Further study is warranted to determine the relationships of these contractional belts to those of the Canadian Arctic Islands, and the broader implications for the late Paleozoic tectonic evolution of the Arctic.

ICAM9-TS1-5

Orogens and fluids in the central high Arctic Polaris Zn district, Nunavut

Elizabeth C. Turner*, Jordan P. Mathieu, Daniel J. Kontak, Mostafa Fayek

gaynariver@gmail.com

The Polaris district (450 km x 130 km) in the Canadian central high Arctic contains numerous carbonate-rock-hosted Zn+Pb showings (including the past-producing Polaris deposit; ~20 Mt at 17% Zn+Pb) and rare, significant Cu showings. The Paleozoic geodynamics of the region produced stratigraphy, structures, crustal fluids, and fluid-mobilising events that combined to result in two different styles of base-metal mineralisation. The district is hosted by lower to middle Paleozoic carbonate strata deposited at low paleolatitude in the Franklinian basin, a broad continental-shelf region dominated by carbonates and punctuated by evaporites, underlain by cratonic rocks, and flanked to the north by coeval deep-water shale and carbonate rocks. Tectonic events that affected these strata syn- and post-depositionally include (a) late Silurian far-field deformation, associated with the Caledonian orogeny, which produced north-trending folds and thrusts on and flanking a central uplift; and (b) late Devonian south-directed stress that produced the west-trending Ellesmerian fold-thrust belt in the northernmost part of the district. Results of a comprehensive, mutually

informing and constraining suite of entirely in situ microanalytical approaches (optical and SEM petrography; fluid inclusion microthermometry; evaporate mound analysis; trace element analysis by LA-ICP-MS; in situ stable isotope analysis by SIMS) identified two Ellesmerian-related topographically-driven fluid events that produced two different types of base-metal mineralisation. (A) Initially, seawater-derived crustal fluid that had acquired extra salinity through subsurface evaporite dissolution and metals from organic-rich subsurface mudrock was displaced southward by a hydrostatic head caused by meteoric recharge in highlands of the Late Devonian Ellesmerian orogen. The displaced brine delivered metals to localised, pre-existing, structurally and stratigraphically controlled accumulations of isotopically light sulfide, previously reduced via BSR. Mixing of the local and transported fluids caused rapid precipitation of disequilibrium-textured main-ore phases (skeletal galena; colloform sphalerite) in those showings that had pre-existing sulfide. Where conditions were favourable, additional, isotopically heavier sulphate in the transported fluid was then reduced by TSR, precipitating crystalline sphalerite, galena, and dolomite. (B) Subsurface migration of the low-latitude meteoric-derived fluid then yielded the main-ore phases (Cu sulphides; calcite) in Cu-dominated showings, using Cu leached from local redbeds in the basement. The Zn-dominated mineralisation of the abundant regional showings formed a pre-ore stage in the Cu-dominated, localised showings; the gangue associated with the Cu-mobilising meteoric-derived fluid formed the post-ore phase in the Zn-dominated showings. These studies validate the topographically driven fluid model in sedimentary-rock-hosted ore districts using direct geochemical evidence.

ICAM9-TS1-6

Post-Orogenic Carboniferous Origin of Sverdrup Basin

Benoit Beauchamp*, Anirudh Bhargava, Daniel Alonso-Torres, William Matthews, Pierre Thériault

bbeaucha@ucalgary.ca

The origin of the Sverdrup Basin is linked to the Ellesmerian orogeny. This conclusion is based on key observations: 1) Middle to Late Devonian Ellesmerian deformation, associated erosion, and sedimentation proceeded diachronously from north to south. 2) End of the orogeny roughly coincides with the Devonian-Carboniferous boundary (DCB) as shown by stratigraphic relationships and emplacement of post-orogenic granitoid plutons. 3) Widespread erosion of Ellesmerian highlands continued after the end of deformation as shown by deep erosion levels beneath the sub-Carboniferous angular unconformity. 4) Exhumed granitoids in the north shed 360 Ma detrital zircons in incipient Carboniferous rift depressions. 5) Rifting proceeded from north to south, probably starting in the earliest Carboniferous on Crockerland and expanding southward through Viséan, Serpukhovian, Bashkirian and Moscovian pulses. 6) Serpukhovian "within-plate" basalts occur on N Axel Heiberg and NW Ellesmere islands, but not anywhere else. 7) Mid-Moscovian end of rifting is recorded by rapid drowning of carbonate reefs and full connection with the open ocean indicating onset of rapid passive subsidence and foundering of rift shoulders. 8) Late Moscovian to Kasimovian thermal subsidence resulted in carbonate progradation of a succession that is twice as thick along the southern basin margin than along the northern margin; these rocks pass into deep-water mudrocks along the basin axis.

The transition from Ellesmerian orogeny to Sverdrup rifting can be explained by a reverse application of the critical taper theory via the following steps: 1) Release of compressional deviatoric support around the DCB led to rapid isostatic rebound of the orogen, intrusion and crystallization of granitoid bodies through decompression, and widespread erosion. 2) Then gravitational collapse of the orogen occurred due to excess potential energy through normal faulting in the upper crust, mostly along reversed thrust faults above a pre-existing detachment, and proceeding from north to south like falling dominos. 3) Stretching and thinning of the ductile lower crust and upper mantle beneath the detachment caused asthenosphere upwelling and volcanism along the rift's northern margin. This suggests extensional deviatoric stress was at play from at least the Serpukhovian onward, compounding and accelerating the gravitational collapse that had started earlier. 4) Shoreface erosion associated with the Bashkirian transgression led to complete peneplanation of the orogen's surface. 5) Passive subsidence following the end of extensional tectonics proceeded differentially through cooling and densification of the asthenosphere with the northern rift margin remaining more thermally buoyant, and therefore subsiding less, than the southern margin.

ICAM9-TS1-7

Carboniferous-Permian rift systems in Svalbard

Aleksandra Smyrak-Sikora*, Kasper Høj Blinkenberg, Alvar Braathen, Anders Dahlin, Julian Janocha, Erik P. Johannessen, Teresa Mosociová, Snorre Olaussen, Per Terje Osmundsen, Kim Senger, Lars Stemmerik, Camilla L. Würtzen

aleksandras@unis.no

The Norwegian archipelago of Svalbard is the exposed north-western corner of the Barents Shelf with rocks that record the geological history back to the Archean. The pre-Neogene bedrock of Svalbard experienced several deformation events that are preserved across the Arctic, from Svalbard westwards across North Greenland to Arctic Canada.

Late Paleozoic deposition was largely affected by the evolution of north-south striking fault zones in Svalbard. The Devonian sedimentary basins that formed due to the collapse of the Caledonian orogen later became structural highs sourcing clastic sediments to the mid-Carboniferous (mainly Bashkirian–Moscovian) to early Permian (?) rift basins. The onset of rifting in Svalbard corresponds to a change in climate represented by a shift in continental deposits from coal-bearing fluvial Lower Carboniferous sediments to mid-Carboniferous red siliciclastics deposited in an arid climate. The syn-rift succession consists of mixed carbonate-, evaporite- and siliciclastic deposits indicating the influence of eustatic sea level variations in addition to evolving structural segmentation of the area and formation of narrow rift basins. The remnants of four such rift basins with up to 1500 m syn-rift successions are exposed onshore Spitsbergen, the largest island of Svalbard archipelago, and include the Billefjorden Trough (1500 m), Inner Hornsund Trough (600 m), St. Jonsfjorden Trough (600 m) and Lomfjorden Trough (70 m). Borehole and seismic data indicate presence of basins east of Lomfjorden Trough.

In this contribution we present a synthesis of recent and ongoing studies that address the tectono-stratigraphic evolution of the Carboniferous–Permian succession in Svalbard with an emphasis on the Billefjorden and Inner Hornsund troughs. The use of high-resolution georeferenced digital outcrop models allows more detailed mapping of faults and syn-tectonic sedimentary units and enables better understanding of the rift basin evolution. The well-studied Billefjorden Trough initiated as a system of semi-isolated subbasins developed in response to overall symmetrical subsidence. Half-graben geometry developed during the rift climax, followed by rift basin reorganisation, narrowing of main depocenter and karstification along uplifted fault blocks. The evolution of faults can be traced from their nucleation, through fault growth and linkage to their abandonment. The Inner Hornsund Trough also exposes spectacular growth faults impacting the syn-rift deposition along the regionally extensive Sørkapp-Hornsund High. This basin also records a transition from continental to paralic deposits into marine-dominated units. However, the Inner Hornsund Trough differs from the Billefjorden Trough by the lack of evaporites and lower subsidence rates.

ICAM9-TS1-8

Heavy mineral analysis of Yukon Koyukuk Basin sandstones

Simone Seminara, Victoria Pease, Jenny Omma, Jaime Toro

simone.seminara@geo.su.se

This work investigates the sedimentary units inside the Yukon Koyukuk basin (YKB) in Alaska, a complex successor basin located south of the Brooks Range. The emplacement of the Brooks Range ophiolite onto the Arctic Alaska continental margin marks the beginning of Brookian folding and thrusting in northern Alaska. This orogenic event occurred in latest Jurassic to Early Cretaceous time, in response to southward subduction of the passive margin of the Arctic Alaska terrane (AAT) beneath an unknown island arc terrane. The early YKB is thought to be the forearc basin of an oceanic arc that collided with Arctic Alaska during the rotation of the AAT from the Canadian margin in the Cretaceous. When did subduction stop and how did it impact YKB evolution?
To try and answer these questions we will investigate to sedimentary deposits of the YKB, which include the following units from Patton et al. (2009):

- Kvg comprises mostly sandy turbidites at the base of the section. Deep water facies in the NE YKB are part of a paleo-axial system that flowed east at the longitude of the Alatna River and SE farther east. The axial system was fed by tributary flow from the rising Brooks Range to the north and the more subdued Koyukuk terrane to the south.

- Kmc is a Cretaceous conglomerate and sandstone unit that sits above Kvg. The Kmc conglomerate is poorly sorted and rich in rounded mafic igneous clasts. Fossils of Early Cretaceous marine molluscs suggest a shallow marine depositional environment.

- Kqc at the top of the section consists of Cretaceous conglomerate, sandstone, and shale. The Kqc conglomerate is well sorted and consists almost entirely of rounded metamorphic clasts, while the Kqc shale contains late Early Cretaceous to Late Cretaceous plant fossils which documents the transition to a non-marine environment.

Using the QEMSCAN (quantitative evaluation of minerals by scanning electron microscopy) technique to define the heavy mineral population, we will present a pilot heavy mineral study of the Cretaceous YKB units to identify the source regions that fed the basin. By comparing different sedimentary packages along a >100 km N-S traverse along the Koyukuk river from Allakaket to south of Hughes, we hope to determine if and when sedimentation changed from oceanic arc- to continent-derived input and to tie it to the collisional process. This work forms part of the on-going PhD studies of the first author.

ICAM9-TS1-9

Integrated aeromagnetic and structural map of the margin north of Ellesmere Island and Greenland

Antonia Ruppel, Karsten Piepjohn

antonia.ruppel@bgr.de

The Palaeozoic Ellesmerian fold-and-thrust belt and the Cenozoic Eurekan deformation have left geological traces along the present continental margin of North America, the Queen Elizabeth Islands, Northeast Greenland, and along the west margin of the Barents Shelf. Structures of the Ellesmerian fold-and-thrust belt can be associated with the approach and docking of the Pearya Terrane and Spitsbergen against the northern margin of Laurentia in the earliest Carboniferous and were overprinted by a complex network of regional distinct thrust zones and strike-slip faults associated with the Eurekan deformation during the final break-up of Laurasia.

The datasets of several aeromagnetic surveys combined with structural findings obtained from consecutive CASE (Circum-Arctic Structural Events) expeditions provide a unique substantiated data base and contribute to a better understanding of the tectonic evolution along the continental margin and final opening of the Arctic Ocean. Aeromagnetic data, which cover the Vendom Fiord region, Nares Strait, Northern Ellesmere Island, the NE continental margin of Greenland were reevaluated with detailed structural analyses from North Slope (Alaska), Banks Island, Ellef Ringnes Island, Ellesmere Island (Canada), northern Greenland and Svalbard. Aeromagnetic maps enable for a more confident interpretation of punctual field observations, e.g. related to ancient magmatic and tectonic processes that affected the continental margin, and allows a more accurate calculation of the shapes, depths, and compositions of their products, including dyke swarms, sills, regional fault systems, and sedimentary basins. Here, digital enhancement techniques enable to trace the extent of major tectonic fault systems whereas the depth of magnetic source estimation target both shallower sources (e.g. volcanic rocks and dykes) and deeper basement-related sources by applying different window sizes and parameters. The combination of terrestrial field observations including mapping, structural geology, and airborne aeromagnetics both on- and offshore enables to provide (i) detailed case studies as well as (ii) a regional structural map of the northern margin of Ellesmere Island and northern Greenland, in which the onshore geological units, structures and fault zones can be traced towards the shelf areas.

ICAM9-TS2-1

Impacts of climate change on coastal Arctic environments at the Quaternary time scale

Anne de Vernal, Claude Hillaire-Marcel

devernal.anne@uqam.ca

The coastal and shelf environments of the Arctic Ocean have changed considerably through time in response to insolation and sea-level variations. During the Quaternary, for example, the global mean sea level has varied by as much as ~150 meters in relation to continental ice sheet growth and decay from cold (glacials) to warm (interglacials) stages, which led to continental shelves occupying about 50% of the Arctic Ocean area as today, to a situation where they were nearly totally emerged and/or ice-covered. Hence, sea-level variations have modified considerably the paleogeography of the Arctic and thus coastal processes, notably with the alternating emersion/submergence of the shallow Bering Land. During phases of high sea levels characterizing interglacials, the flow of Pacific waters had a strong impact on the heat and freshwater budgets of the Arctic Ocean, thus the development of sea-ice factories tightly controlling coastal processes. Beyond the impact of sea-level changes, past climate changes (surface air temperature and precipitation) certainly affected the ocean and coastal conditions, but assessing their role remains challenging. The climate records from circum-Arctic regions are rare, especially beyond the present interglacial, as glacial erosion erased most evidence on land. Relatively long paleoceanographic sedimentary records exist, but the difficulty to set their chronostratigraphy and their scarce biogenic content prevent paleoclimate estimates to be made prior to the present interglacial, at least for the Quaternary that was mostly characterized by sub-perennial sea ice. Hence the present interglacial, the Holocene, is an interval useful to study as it yields information to document the impact of climate changes from the continental shelf edge to the coastal zone. The Holocene records from onshore and marine proxy-data illustrate a strong regionalism in climate conditions across the Arctic, pointing to a complex response of the Arctic Ocean to global climate forcing. Regional parameters, the Bering Strait floodings, the openings of the Canadian Arctic channels and Nares Strait, have governed (fresh) water exchanges between the Pacific and Atlantic Oceans. In the future, sea-level rise will thus have an important impact on the Arctic climate and coastal environments. In particular, we may anticipate that a deeper Bering Strait and enhanced polar advection of low-saline warm Pacific waters, will increase both the heat and freshwater budget of the Arctic basin, in addition to fostering exchanges with the Atlantic Ocean.

ICAM9-TS2-2

Environmental changes on the Beaufort Sea shelf since 1970 CE based on micropaleontological records

Jade Falardeau*, Anne de Vernal, Marit-Solveig Seidenkrantz, Thomas Cronin, Laura Gemery, Léo Chassiot, Michael Fritz, Vladislav Carnero-Bravo, Claude Hillaire-Marcel, Philippe Archambault

falardeau.jade@courrier.uqam.ca

Microfossils were analyzed in the gravity core YC18-HB-GC01 (18 m water depth; 40 cm long) located in the Herschel basin off northern Yukon, Canada (69.544°N -138.970°W). The unique setting of the nearshore Herschel basin permitted continuous accumulation of sediment on the Beaufort Sea continental shelf. The mass accumulation rates average 0.9 ± 0.3 g cm^2 a^{-1} and the micropaleontological record covers the last 50 years at a multiannual resolution. Benthic foraminifera, calcareous and agglutinated inclusively, ostracodes, and tinitinnids composed most of the microfossil population, which are recognized tracers of past marine conditions, especially in regards to temperature and salinity. The last 50 years are marked by a distinctive shift at ~2000 CE in the foraminiferal assemblages. This shift suggests a transition from stable saline bottom waters to more variable salinities accompanied by increased primary productivity. The last two decades are also characterized by high fluxes of agglutinated tintinnids, which relate to particulate matter-rich freshwaters. On the opposite, a decline in ostracode abundance was recorded. This major change in the microfaunal community would be near synchronous with a decline in mean summer sea-ice concentration that occurred after 2003 CE in the region. We suggest that decreased sea-ice cover led to increased vertical mixing on the shelf causing lower and varying bottom-water salinity. Moreover, it may have facilitated upwelling of nutrient-rich shelfbreak waters and spreading of the Mackenzie River plume to the study site under strong easterly wind events. However, increased particulate matter supply from coastal erosion and rivers in the rapidly changing environment of the 21st century may have negative impacts on ostracodes and potentially on other microorganisms due to various physico-chemical effects, and may eventually alter primary production through light availability.

ICAM9-TS2-3

Paleoenvironmental reconstructions in the Inuvik Region: microfossils from the Cretaceous to the Holocene

Anne Van Nguyen*, Jennifer Galloway, Benoit Beauchamp, R. Timothy Patterson

annenguyen4@cmail.carleton.ca

The Inuvik Region, Northwest Territories, is characterized by sub-arctic and tundra climates and encompasses the Mackenzie River Delta, Canada's primary source of freshwater output into the Arctic Ocean from the Mackenzie River Basin (MRB). The MRB is one of the largest drainage basins in Canada, extending for approximately 1.8 million km^2 over the Western Cordillera, Interior Plain, Precambrian Shield, and the Arctic Coastal Plain. Northern basins such as the MRB are particularly sensitive to climate change, as surface air temperatures in the western Canadian Arctic have increased twice as fast as the global average since the beginning of the 20th century.

An analogous example of these high temperatures can be observed during the Cretaceous Period, which was a time of extreme warmth. Palynological analyses were completed for Lower Cretaceous shale formations in the Aklavik Range, situated within the northern confines of the MRB, in order to reconstruct the paleoenvironment and paleoclimate over the Jurassic-Cretaceous transition. Multivariate statistical analyses show palynological assemblages dominated by local plant communities that tolerated high effective moisture in the hinterland, transitioning from cool to warm between the Valanginian – ?Barremian. Ordination techniques suggest that the area was characterized by a coastal wetland paleoenvironment during this time.

In contrast, the northernmost regions of the Northwest Territories during the Holocene is dominated by sub-arctic forest, with patches of low Arctic tundra and increasing permafrost towards the north. We will use paleoecological transfer functions calibrated to modern testate amoebae distributional data to reconstruct and predict changes in water table depth in peatlands. Trends in hydrological variation in the MRB will be compared to known ocean-atmosphere interactions (e.g., solar cycles) that have influenced the paleoclimate of North America through the Neoglacial phase of the late Holocene. A multidisciplinary framework will be generated to produce a high-resolution reconstruction of past climate and hydrological change for the MRB.

ICAM9-TS2-4

Understanding seasonal variations in river inorganic carbon cycling in the context of our changing climate

Samantha F. Jones*, Patrick Duke, Araleigh Cranch, Shawn Marriott, Francis Emingak, Brent Else

samantha.jones3@ucalgary.ca

Rivers and streams are important components in the global carbon cycle. They transport carbon through watersheds and downstream toward the ocean, exchange carbon dioxide (CO_2) with the atmosphere, and may be active sites of in-situ carbon cycling. Understanding the roles of Arctic rivers in carbon cycling pathways and processes is important. Rivers deliver freshwater to the ocean, which affects carbon cycling in coastal oceans and may exacerbate ocean acidification. In addition, as Arctic regions are increasingly impacted by warming, rivers and streams may experience a change in the influence of groundwater (which is often CO_2-rich) or begin to interact with carbon stores that were previously inaccessible due to permafrost.

Seasonal variations in carbonate system parameters (e.g., dissolved inorganic carbon (DIC), total alkalinity (TA), partial pressure of CO_2 (pCO_2)) were observed in Freshwater Creek, a river in Cambridge Bay (Iqaluktuuttiaq), Nunavut, during three annual cycles from 2017 – 2019. Water samples were collected in the field and analyzed in the lab for DIC and TA, and pCO_2 was calculated using CO2SYS. Auxiliary data (e.g., in-situ temperature, conductivity, pH, dissolved oxygen) were collected in the field using sensors. Rather than using fixed dates, the seasonality of Freshwater Creek is best understood by defining seasons based on river flow conditions, the presence of terrestrial ice and snow, and connections with the upstream lake and downstream coastal ocean. Because Freshwater Creek has a relatively short length, it provides a unique opportunity to study river inorganic carbon cycling in context with the neighbouring environments.

Results show that spring melt is accompanied by high-DIC, TA, and pCO_2 river water transported downstream to the coastal ocean. This is followed by a decrease in these parameters during river peak discharge and through the falling limb of the river hydrograph. During the ice- and snow-free season (typically July – August), the inorganic carbon parameters maintain relatively low values with some variations as the season progresses and temperatures and water levels decrease. During the fall, river water levels drop and the river freezes to the ground and ceases flowing until the following spring when the cycle begins again.

Rivers like Freshwater Creek may be affected by shifting seasonal transitions and changes in Arctic precipitation patterns expected with climate change. In addition, changes in the hydraulic connectivity within the low-relief watershed that feeds Freshwater Creek may influence how water and its dissolved inorganic carbon move through the landscape and across the land-ocean interface.

ICAM9-TS3-1

An overview of the geology and tectonic evolution of the Labrador–Baffin Seaway and adjacent onshore regions

Nikole Bingham-Koslowski*, Lynn T. Dafoe, Marc R. St-Onge, Elizabeth C. Turner, Jim W. Haggart, Ulrik Gregersen, Charlotte E. Keen, Allison L. Bent, J. Christopher Harrison

nikole.bingham-koslowski@nrcan-rncan.gc.ca

The Labrador Sea, Davis Strait, and Baffin Bay offshore regions, collectively referred to as the Labrador–Baffin Seaway, and adjacent onshore areas including Baffin Island, Bylot Island, and West Greenland, comprise the northeastern Canadian and Western Greenland Arctic margins. The rocks of these areas preserve a long and complex geological history that records numerous tectonic events. This history is synthesized in a Geological Survey of Canada Bulletin, the result of significant collaboration between several governments and academic institutions. The geological evolution of the region begins with the assembly of a number of distinct Archean cratons in the early Paleoproterozoic, which resulted in the formation of the eastern Laurentian portion of the supercontinent Nuna (Columbia). Subsequent localized extension during supercontinent breakup in the Mesoproterozoic formed the Bylot basins exposed on northern Baffin Island and beneath northern Baffin Bay, as well as in surrounding onshore areas. During the early Paleozoic, sedimentary platform successions accumulated following the breakup of the supercontinent Rodinia. Deposition of these successions ceased with the closing of Paleozoic seaways and the formation of the supercontinent Pangea. Pangea underwent extension in the Labrador–Baffin Seaway region starting in the Early Cretaceous, resulting in the eventual separation of Greenland from the paleo-North American plate. Cretaceous rift phases were followed by oceanic crust formation and related tectonism starting in the Maastrichtian in the Labrador Sea and developing northward in the Paleocene before seafloor spreading ended in the late Paleogene. This tectonism led to the formation of several Mesozoic–Cenozoic sedimentary basins in the Labrador–Baffin Seaway and locally along onshore parts of the margin. The unique geology of the region has resulted in a seismically active area that contains significant mineral (iron, diamonds, zinc, lead, nickel, copper, platinum-group elements, uranium, thorium, gemstones, carving stone, and coal) and hydrocarbon (onshore and offshore) potential. Detailed papers in this Bulletin will serve as important source material for future work in this part of the Arctic.

ICAM9-TS3-2

Correlating the Nagssugtoqidian Orogen, West Greenland, across the Davis Straight and Labrador Sea

Timothy McIntyre*

tm3@ualberta.ca

The ~1860 to 1840 Ma Nagssugtoqidian Orogen (NO), West Greenland, comprises a portion of the North Atlantic Craton (NAC) and a more enigmatic crustal block, the Aasiaat Domain. Despite the NO being an important part of the framework of sutures that link the Archean cratonic cores of Laurentia, there is no consensus on how components of the NO relate to their counterparts that likely occur in either Baffin Island or Labrador. The majority of Archean crust in the NO consists of orthogneisses formed between 2870 and 2810 Ma with included minor orthogneisses dated to ~3180 Ma. Sm-Nd and Lu-Hf isotopic systematics suggest these gneisses have depleted mantle model ages younger than 3300 Ma, limiting the possible contribution of more ancient, recycled components to this crust. The Archean rocks throughout the NO record 2790 to 2720 Ma metamorphic reworking during an orogeny that marks the end of major Archean tectonic events. This record provides a geochronological fingerprint critical to regional correlations. In addition to Archean components, throughout the central NO a number of Paleoproterozoic supracrustal belts occur, e.g, the Nordre Strømfjord and Maligiaq supracrustal suites. The detrital zircon from these supracrustal belts typically record very few Archean ages and instead record ages that cluster at ~2050 Ma. Two major Paleoproterozoic calc-alkaline volcanic formations also occur in the central NO – the Artersoirfik Quartz Diorite (AQD) and Sisimuit Charnockite. The AQD comprises arc-related plutonic crust that formed between ~1920 and 1885 Ma and intrudes into the Nordre Strømfjord Supracrustal Suite. Based on chondritic Sm-Nd isotopic characteristics of the AQD and no Archean detrital zircon in the intruded supracrustal rocks, these crustal units have been interpreted to be a remnant oceanic arc. In contrast, the Sisimuit charnockite suite – magmatism between 1910 and 1870 Ma – intrudes Archean gneisses and has crustally contaminated Sm-Nd signatures, and as such, is interpreted as a remnant continental arc. The occurrence of convergent Paleoproterozoic lithostratigraphy, some of which being oceanic, implies the central NO is a suture between two crustal blocks, i.e, the NAC and Aasiaat domain. The geochronology of components across this suture is an important record with which to make regional comparisons. This most recent geochronological compilation of the NO components, along with their spatial relationships, will be compared with wider regional geology of the Labrador-Baffin Seaway providing new insights into how the NO fits within the crustal architecture of this region.

ICAM9-TS3-3

Geology of the Rinkian Orogen, central West Greenland

Pierpaolo Guarnieri*, Nigel Baker, Erik V. Sørensen, Diogo Rosa

pgua@geus.dk

New geological maps at 1:100000 scale in central West Greenland allowed to constrain the tectonostratigraphic evolution of the Paleoproterozoic Karrat Group and the polyphase deformation, magmatism and metamorphism in the Rinkian orogen. Geochronology, stratigraphy, geochemistry, structural geology and economic geology data, together with 3D-photogeology, improved the understanding of the structural evolution of the region. The Karrat Group (from c. 71°00′ to 73°00′ N) formed in an intra-cratonic sag basin after c. 2000 Ma with basal quartzites unconformably overlaying Archaean gneisses of the Rae Craton. From 1950 to 1900 Ma a carbonate platform developed toward the south, while rift related alkaline volcanic rocks and syn-rift siliciclastic/volcaniclastic sediments were deposited to the north. The rifting was then succeeded by a back-arc system with transitional and tholeiitic magmatism.

Arc-related granitoids intruded into and along the basal contact of the Karrat Group at c. 1900 Ma with major pulses at c. 1870 and c. 1850 Ma, concomitantly with the development of the back-arc system. During the collisional phase of the Rinkian orogen, the Karrat Group and the magmatic arc rocks underwent HT-metamorphism at c. 1830–1800 Ma. The metamorphic grade increases from greenschist facies in the south, to granulite facies in the north, where the metamorphism is associated to migmatization and emplacement of S-type leucogranites. Extensive thrust emplacement and folding characterize the Rinkian orogen south-east of the magmatic arc and its internal boundary to the west, is reworked along a top to ESE shear zone post-dating the HT-metamorphism. The ESE-ward emplacement of allochthonous thrust sheets during an early stage of thin-skinned tectonics is followed by NE-ward emplacement of basement nappes and finally by a NW-SE compression stage resulting in tectonic inversion of basin normal faults.

The back-arc extension and Cordilleran-type magmatism were driven by eastward subduction of oceanic crust during the Trans-Hudson orogeny resulting from the convergence of the Superior, Meta Incognita and Rae Archean cratons between 1900–1800 Ma. The Rinkian orogen represent an example of Cordilleran-type tectonics resulting from the deformation of the Rae continental margin intruded by magmatic arc granites during subduction, followed by HT-metamorphism in the upper plate and the structuring of a back-arc fold and thrust system antithetic to the subducting plate.

ICAM9-TS3-4

The Isortoq Nappe of Baffin Island, Canada: potential link to the Rinkian deformation of West Greenland

Stephen T. Johnston*, Benoit M. Saumur, Diane R. Skipton, Marc R. St-Onge

stjohnst@ualberta.ca

The Isortoq Shear Zone (ISZ), a 100km-scale structure in northern Baffin Island, was identified in the 1970s through the interpretation of regional geophysical surveys. However, the ISZ is cryptic in the field, and its origin and significance with respect to the regional structural framework of northern Baffin Island remained ambiguous. Recent mapping along the ISZ, as well as within the Archean Isortoq and Eqe Bay greenstone belts of central-west Baffin Island, provides new regional structural constraints. We show that the Isortoq and Eqe Bay belts form one continuous folded supracrustal package that was likely deformed by nappe tectonics during the early Paleoproterozoic Trans-Hudson orogeny. The northern NE-striking, moderately SE-dipping Isortoq belt is structurally thinned, metamorphosed, sheared (by the ISZ) and overturned, with strata younging down-section to the NW. In contrast, the southern ENE-striking, steeply dipping Eqe Bay belt is structurally thickened, comparatively less metamorphosed, exhibits weaker deformation, and stratigraphically youngs to the SE. New mapping and available geophysical data show that the two belts are folded around a hinge zone located offshore to the SW, within nearby Grant-Suttie Bay, and together form an asymmetric synformal anticline. Structural and stratigraphic relationships are consistent with the fold forming part of the lower limb of a map-scale southeast-verging nappe, with the ISZ representing a shear zone at the base of this nappe.

The Isortoq Nappe occurs along strike with S to SW-verging Rinkian nappes exposed >200 km to the NE, on Baffin Island and in Greenland. This implies that south-verging tectonics, opposed to and predating the dominant N-verging nappes of the Foxe Fold Belt, are more important in spatial extent than previously considered, and emphasizes the importance of horizontal transport via nappe tectonics during the construction of the Nuna supercontinent.

ICAM9-TS3-5

Mesoproterozoic bedrock and tectonostratigraphic history of northern Baffin Island and nearby areas

Elizabeth C. Turner*

gaynariver@gmail.com

The late Mesoproterozoic Borden basin (Baffin Island, NU) records a complex geodynamic history (Bylot Supergroup; ~6 km thick) that includes sag, rift, and foreland-basin-like depositional phases, as well as two dramatic internal unconformities. Rock units deposited during the initial sag phase consist of a thin, geographically limited, partly subaqueous, undated basal basalt possibly linked to the ~1270 Ma Mackenzie igneous event, overlain by a regionally distributed shallow-subaqueous quartzarenite. Transition to the rift phase is initially marked by upward-deepening siltstone and shale, followed by a rift-defined lacustrine carbonate-shale succession including fault-related deep-water carbonate seep mounds and high-TOC black shale. Thick overlying highly cyclic shallow-marine carbonate successions locally influenced by rift-defining faults are punctuated by two unconformities that record dramatic differential uplift, tilting, and hectometre-scale erosional relief, and subsequent re-flooding. A flysch-molasse-like marine siltstone-sandstone succession containing Grenville-aged detritus forms the third phase of basin-fill. Geochronological data indicate that most or all sedimentation took place ca. 1100-1050 Ma. One of the carbonate intervals is the host of numerous regional Zn-Pb±Cu showings, including the past-producing Nanisivik deposit. The Nanisivik ore-body formed penecontemporaneously with basin-filling from low-temperature fluids; its emplacement was strictly controlled by stratigraphic and structural factors. All of these events were approximately contemporaneous with Rodinia's amalgamation, indicating the importance of far-field stress on distant intracratonic basin evolution and crustal fluid migration.

ICAM9-TS3-6

Stratigraphy and geological evolution of the West Greenland margin

Ulrik Gregersen*, P.C. Knutz, G.K. Pedersen, H. Nøhr-Hansen, J.R. Ineson, L.M. Larsen, J.R. Hopper, J.A. Bojesen-Koefoed, G. Dam, T. Funck, J. Hovikoski

ug@geus.dk

The stratigraphy and the geological evolution of the West Greenland continental margin from the Labrador Sea to the Baffin Bay since the Archean are outlined. The summary is based on comprehensive regional studies of seismic stratigraphy combined with other offshore data in comparison to outcrop studies from the Nuussuaq and Thule basins. The timing of the stratigraphic units and key rifting events are well constrained by biostratigraphy and radiometric dating of rock samples. The database involved all deep offshore wells, several shallow wells and nearly all seismic 2D and 3D seismic surveys along the entire West Greenland margin. The geological evolution of the West Greenland continental margin is divided into six overall tectono-stratigraphic phases (I–VI), defined by eight seismic stratigraphic mega-units (A–H): (I) pre-rift and early extension (pre-Cretaceous), (II) early rift (Albian–Cenomanian), (III) subsidence and rifting (Cenomanian–Campanian), (IV) late rift (Campanian–Danian), (V) drift (mainly Paleocene–Eocene), and (VI) post-drift (Oligocene–Present). Proterozoic sedimentary rocks in NE Baffin Bay were recovered in cored boreholes and are correlated to the uppermost part of mega-unit H of which the lower part includes Archean basement bedrocks. In addition, Ordovician carbonates are known from seabed and onshore samples collected farther south. A succession including sandstones, locally conglomerates, and mudstones of Albian–Cenomanian age are widely documented (Kap York, Nuussuaq and Nuuk basins) and correlated to mega-unit G of the early rift phase. Mudstone dominated successions and local sandstones were deposited during subsidence and late rifting phases of mega-units F and E. Transtensional strike-slip related structures, inversion, pull-apart basins, and major volcanic eruptions including subaerial lava flows of the West Greenland Volcanic Province formed during the Paleocene to Eocene drift phase. This occurred when the Greenland plate moved towards northeast and then north as it separated from North America and oceanic crust formed in the Labrador Sea and in central Baffin Bay. Tectonic activity decreased during the late Cenozoic post-drift phase (mega-units A–D), where wide basins evolved, and deltas, mass-flows and contourite drift complexes also formed. Eventually, the glacially affected shelf-edge margins of mega-unit A evolved in W–SW directions with several pulses of ice-sheet advances/retreats and formation of trough-mouth fan systems. The geological evolution of the West Greenland margin is connected to the evolution of the conjugate Canadian margin.

ICAM9-TS3-7

On the Frobisher Bay Half-Graben: X-ray Diffraction Analysis of Fault Gouge Exposed in Iqaluit, Baffin Island, Nunavut

Farah Gagnier*, Benoit M. Saumur, Jean-Carlos Montero-Serrano, Christian Sasseville, Lorraine Lebeau, Tommy Tremblay

gagnier.farah@courrier.uqam.ca

The various Neoproterozoic to Eocene brittle extensional events that have occurred in the Canadian Arctic still give rise to many questions due to a lack of geochronological and structural data. The Frobisher Bay half-graben, which is partially exposed in the Iqaluit area, represents one of the many brittle extension systems found on the southeast Arctic Platform, and is likely associated with the opening of the Labrador-Baffin Seaway. Recent excavations in Iqaluit have revealed fresh outcrop exposing normal faults of the Frobisher Bay system. These outcrops are thus conducive to geochronological sampling for timing of fault movement, as well as the collection of structural data on the kinematics and geometry of the Frobisher Bay half-graben.

Regional NNW-trending lineaments associated with the half-graben control the topography and the geometry of local coastlines. A conjugate, NW-SE trending, normal-oblique fracture system is recorded from field measurements and is consistent with the regional geometry of the half-graben. A steeply plunging (~80°) σ_1, deduced from fracture populations identified in the field, is consistent with documented, dominantly normal-sense, fault kinematics. Samples carefully recovered from fault gouge were analyzed using X-ray diffraction (clay fraction, <2 μm) which revealed the presence of interstratified illite-smectite, smectite, vermiculite, chlorite and illite. The occurrence of chlorite together with mixed-layer illite-smectite suggests that propylitic alteration with a temperature interval between 220 and 350°C is associated with the regional hydrothermal processes linked to movements along Frobisher Bay faults.

The occurrence of significant amounts of illite and illite-smectite, which are both authigenic minerals, suggests that the gouge is prospective for highly specialized K-Ar clay mineral geochronology. Considering that the <2 μm fraction also contains diagenetic clay minerals, future work includes the identification of authigenic minerals through centrifugal separation of the <0.2 μm fraction and the analysis of this fraction via backscattered electron microscopy. Integrated with other previously established geological and geochronological constraints (e.g. fission track, detrital xenoliths from kimberlites), this work will contribute to a more accurate interpretation of Phanerozoic exhumation rates that occurred on southern Baffin Island, and specifically Hall Peninsula.

ICAM9-TS3-8

Mineral resources of Baffin Island – links to Greenland

Benoit M. Saumur*, J. Christopher Harrison, Diane R. Skipton, Jochen Kolb

saumur.benoit-michel@uqam.ca

As the world's fifth largest island, Baffin Island's sheer size rivals that of mineral endowed jurisdictions such as Manitoba and northern Ontario. The geology of Baffin Island is comparable to these as well, with a multitude of geological environments typical of base and precious metal deposits. Yet, like the rest of Canada's Arctic Archipelago, it remains relatively unexplored. Factors such as remoteness, a lack of infrastructure, complicated logistics, short field seasons and high operational costs have played a role in hindering exploration investment. Although a handful of significant discoveries have been made over the last half century, Baffin Island's mineral potential remains largely untapped.

Mineral resources of Baffin Island include high-grade, high-tonnage, banded iron formation hosted Fe deposit at Mary River, the northernmost active mine in Canada. The deposit is located within highly metamorphosed and deformed Neo-to Meso-Archean greenstone belts of the Mary River Group within the Rae Craton. Within Mesoproterozoic Bylot Group, carbonate-hosted zinc and lead was mined between 1976 and 2002 at the now closed Nanisivik camp. Also discovered on Baffin Island are diamonds, nickel, copper, platinum group elements, uranium, thorium, gemstones (sapphire, spinel, lapis lazuli), carving stone and coal.

Proposed correlations with well-endowed geological areas of Western Greenland highlight the potential lack of discoveries on the Canadian side of Baffin Bay. Greenlandic deposits of interest include Au and Fe deposits of the Rae Craton, IOCGs of the Inglefeld belt, and stratiform Zn-Pb deposits of the Proterozoic Karrat Group, for which Piling Group represents the Baffin equivalent. Notably, Baffin Island equivalents of the Maamorilik (Black Angel) metamorphosed Mississippi Valley Type Zn-Pb deposit were a focus of exploration efforts in the 1970s.

ICAM9-TS4-1

Zircon and monazite age correlations in the northern Rae domain: New data from NW Baffin Island, Nunavut

Lorraine E. Lebeau*, Jeffrey H. Marsh

lorraine.lebeau@nrcan-rncan.gc.ca

The Rae domain is a Meso-to Neoarchean granodioritic to tonalitic orthogneiss with komatiite bearing volcano-sedimentary greenstone belts that spans much of north-central Canada, into mainland Nunavut, Baffin Island, and western Greenland. This study presents a first account of zircon and monazite U-Pb ages of gneissic and plutonic rocks from northwestern Baffin Island, allowing for regional correlation among nearby regions in the northern Rae domain and the Superior Province.

Compiled zircon data across all samples reveal four main age populations of ~2730, 2715, 2700, and 2680 Ma, with a Mesoarchean muscovite gneiss sample yielding a 2900±1.6 Ma crystallization age. Neoarchean gneiss ages are between 2730±3 – 2716 ±2 Ma (with inheritance as old as ~3.2 Ga), moderately foliated granitic rocks are dated at ~2730 Ma; and a porphyritic monzogranite is dated at 2698±2 Ma. Most samples display decreasing Th/U with deceasing age, the ~2680 Ma populations commonly having Th/U<0.2. We interpret this ~2680 Ma timeframe to reflect variable subsolidus recrystallization and likely the initial phase of gneiss formation across the region. A number of samples have small zircon populations between 1.8-1.9 Ga, suggesting a late phase of zircon recrystallization. Monazite from three samples records multiple age populations, ranging from ~2640 to 2550 Ma, with corresponding compositional changes apparently recording metamorphic assemblage evolution.

Age data from this study is compared to that from nearby Melville Peninsula, north-central Baffin Island, and Greenland. Overall, the geologic history of northwestern Baffin Island encompasses Mesoarchean to Neoarchean crust (~2900 – 2750 Ma) that was intruded by ~2730-2715 granitic to tonalitic and ~2700 Ma porphyritic magmatic pulses. Metamorphic ages of zircon and monazite suggest a protracted gneissic forming event from ~2680-2550 Ma, with minor activity recorded in the timeframes of the MacQuoid (2.56-2.50 Ga), and/or Arrowsmith (2.50-2.3 Ga) orogenies; and the Trans-Hudson orogeny (~1.8 Ga). Comparison of the northwestern Baffin Island age spectra with that from the Superior Province (southeastern Canadian Shield) shows a remarkable correlation in apparent magmatic pulses between ~2730-2700 and the onset of tectonic reworking starting ~2690 Ma. The monazite age spectra from northwestern Baffin Island also correlate well with monazite and xenotime ages from the Superior Province, which commonly are associated with orogenic gold deposition.

ICAM9-TS4-2

Precambrian Turbidites of Eqe Bay, Baffin Island: Stratigraphic, Structural and Geochronological Constraints on the Evolution of Canada's Arctic Greenstone Belts

Carl-Philippe Folkesson, Benoit M. Saumur*, Joshua Davies, Jon Hey, Stephen T. Johnston

folkesson.carl-philippe@courrier.uqam.ca

The Archean greenstone belts of the Mary River Group (2865-2706 Ma), or MRG, occur in northern Baffin Island and remain poorly understood in terms of structure, stratigraphy and metallogeny. The Eqe Bay greenstone belt is the least deformed and metamorphosed exposure of the MRG, and is divisible into a stratigraphically lower metavolcanic sequence and an overlying metasedimentary sequence. The upper sequence of the Eqe Bay belt consists mainly of a large turbiditic formation that unconformably overlies the lower volcanic and volcaniclastic sequence. Two primary units make up the metasedimentary sequence: (U1) a jointed polygenic conglomerate with a variable thickness between 100 and 250 m, that stratigraphically overlies the lower volcanic domain along the main unconformity; and (U2) an turbiditic formation with a maximum thickness of 6.5 km consisting mainly of wackes and graywackes including siltstone, argillites and meter-scale beds of granular polygenic conglomerate interbedded with sandstone. Two subunits are recognized within the turbidite succession: (U2.1) a distinctive 5 to 10m thick quartzite layer located near the base of the U2 turbidite sequence layer located near the base of the U2 turbidite sequence; and (U2.2) a thin iron formation interbedded with phyllite and garnet-rich schist. The unconformity at the base of the metasedimentary sequence is coincident with a major NE-SW trending, mylonitic shear zone that extends along the length of the Eqe Bay belt.

We distinguish three deformation events affecting the metasedimentary belt: the first deformation is represented by a penetrative bedding-parallel foliation (S1) that is assumed to have developed during isoclinal folding. The second (S2) records is a penetrative fabric oblique to S1 associated with local F2 folds. The third event is recorded in localized strongly deformed zones that are characterized by a shallowly dipping crenulation cleavage (S3).

U-Pb geochronological work on magmatic and detrital zircons provides an update on the stratigraphy and formation age of the greenstone belt as well as for the entire MRG. Meta-rhyolite from the volcanic sequence were dated at 2865 Ma, now the oldest age reported for the MRG. The youngest fraction of detrital zircons from a sample of the quartzite subunit (U2.2) located near the stratigraphic base of the turbidite unit yield an age of 2213 Ma. CLimagery and U/Th ratios are inconsistent with a metamorphic origin for these grains; instead they indicating post-Archean deposition. The metasedimentary sequence was likely deposited during the Paleoproterozoic and represents part of the Piling group, thereby expanding the regional footprint of this proto-Trans-Hudson basin sedimentary succession. Our results suggest that significant revision of the stratigraphy of the MRG and coeval greenstone belts of the Rae Craton may be required.

ICAM9-TS4-3

Surface Histories Revealed by Apatite (U-Th)/He Thermochronology in the Canadian Arctic

Spencer D. Zeigler*, Rebecca M. Flowers, Graham D. Pearson, Bruce A. Kjarsgaard

spencer.zeigler@colorado.edu

How surface histories are linked with magmatic records, the composition and history of the lithospheric mantle, and deeper mantle processes are important questions. The Canadian Arctic Archipelago provides an unusual opportunity to study this problem. This region is characterized by a complex lithospheric architecture with heterogeneity in lithospheric age, thickness, and history, and was affected by several episodes of rifting, two major orogenic events, repeated kimberlite magmatism on the southern margin, and the aerially extensive Cretaceous High Arctic Large Igneous Province (HALIP). To the south, the Slave and Rae Cratons are the most stable and the thickest part of the lithosphere in the Canadian Arctic and were not significantly modified during the Phanerozoic. In contrast, to the north, the lithosphere undergoes ~150km of thinning over an ~800 km distance from Somerset Island to the Amerasian Basin (Dockman, 2018). The steepness of this thickness gradient had a profound impact on the geochemistry of HALIP and associated volcanics but the impact of this thickness gradient on the surface history across the region has not been as thoroughly investigated.

We are using apatite (U-Th)/He (AHe) thermochronology to constrain the magnitude, timing, and spatial variability in burial and erosion histories across this region, with a particular focus on the surface response to lithospheric thinning. Our strategy is to primarily focus on well-dated Phanerozoic intrusive units such as kimberlites, which facilitates tighter constraints on Phanerozoic thermal histories than AHe analysis of Precambrian basement. To the south, in the central Slave Craton, the Jericho kimberlite yields AHe dates that overlap with the emplacement age of 173.1 ± 1.3 Ma, indicating limited magnitudes of burial and erosion after its emplacement. In the northern Slave Craton, in the Coronation Gulf region, preliminary data from the Thrift (534.2 ± 2.8 Ma), Artemisia (616.3 ± 28.2 Ma), and Hydra (601.6 ± 18.8 Ma) kimberlites all have younger AHe dates that do not overlap with emplacement, indicating some amount of post-emplacement burial and erosion. Future work involves expanding the spatial extent of our dataset. Targets include samples from farther south and west on the Slave Craton, from farther north on Victoria Island and Somerset

Island, as well as across the steep lithospheric gradient by analysis of sills and volcanics from Bathurst Island, Ellesmere Island, Axel Heiberg Island, and the Sverdrup Basin.

ICAM9-TS4-4

Phanerozoic tectonics of northern Ellesmere Island: insights from $^{40}Ar/^{39}Ar$ and (U-Th)/He dating

Jeremy W. Powell*, David A. Schneider

jeremy.powell@nrcan-rncan.gc.ca

The northern margin of Ellesmere Island, Canada, has experienced a complex geological history throughout the Phanerozoic, including multiple episodes of orogenesis and first-order depositional cycles related to the Paleozoic accretion of the composite Pearya terrane, the Devonian-Carboniferous Ellesmerian orogeny, and Paleogene Eurekan deformation. However, supporting geochronological data are sparse resulting in poor temporal resolution on the timing of important Circum-Arctic geologic events. To constrain the age of these tectonic episodes, this study uses muscovite 40Ar/39Ar geochronology and zircon and apatite (U-Th)/He thermochronology to investigate the polydeformed fault zones that bisect the Pearya terrane and Franklinian Basin of northern Ellesmere Island. The muscovite 40Ar/39Ar geochronometer can provide an age record for a variety of geological processes, including post-metamorphic cooling and recrystallization during subsequent deformation. In comparison, apatite and zircon (U-Th)/He thermochronology (AHe; ZHe) quantifies the thermal history of rocks as they heat and cool through upper crustal temperature regimes. When rocks are rapidly cooled from high temperatures, AHe and ZHe dates correspond to the time at which the rock cooled through a nominal closure temperature (AHe ~70 °C; ZHe ~180 °C). Protracted thermal histories result in AHe and ZHe date dispersion, which can be interpreted using numerical modelling methods that account for the effects of grain size and radiation damage on the kinetics of helium diffusion. In anticipation of dispersed 40Ar/39Ar dates, total fusion 40Ar/39Ar dating was conducted on 165 single muscovite grains from 22 samples. Age dispersion was sample dependent, with some samples exhibiting robust Paleozoic ages corresponding to the assembly and accretion of the Pearya terrane. Other samples yielded intra-sample date dispersion that spanned the late Paleozoic and Mesozoic, suggestive of a previously unreported post-Ellesmerian and pre-Eurekan history. Zircon (U-Th)/He dates from 11 samples (n: 73) and apatite (U-Th)/He data from 6 samples (n: 21) are largely Eocene in age, with dominant populations of c. 48 Ma and c. 41 Ma, respectively. Inverse thermal history modelling of (U-Th)/He data indicates episodic Mesozoic burial and unroofing coinciding with changes in the regional stress regime, and rapid cooling during the nascent (>53 Ma) and initial (53 Ma to 47 Ma) phases of Eurekan deformation. These new data provide temporal constraints on the timing of deformation, structural reactivation, and the Phanerozoic burial and erosive history of northern Ellesmere Island, and facilitate correlations with offshore structural features and equivalent rocks and deformation events

across the Circum-Arctic.

ICAM9-TS4-5

Continental response to oceanic changes: Cenozoic exhumation & heat flow variations of the Arctic

Cornelia Spiegel*, Katrin Meier, Agnes Vamvaka, Mohammad Sohi, Paul O´Sullivan, Karsten Piepjohn, Solveig Estrada, Malte Jochmann, Antonia Ruppel, Kai Berglar, Frank Lisker

cornelia.spiegel@uni-bremen.de

The Cenozoic tectonic history of the Arctic is dominated by the opening of the Norwegian-Greenland Sea, Baffin Bay–Labrador Sea, and Eurasia Basin, and associated northwards movements of Greenland. The latter was related to convergence and crustal deformation in Ellesmere Island, Greenland and Svalbard (= Eurekan deformation), and it has been suggested, that Eurekan deformation also affected areas further north, across the pole. Here we present low-temperature thermochronology data from Ellesmere Island, western and eastern North Greenland, Svalbard, and the New Siberian Islands. Thermochronology data such as apatite fission track and (U-Th)/He analysis give evidence on temperature changes within the upper ~5 km of the Earth´s crust, which can be interpreted in terms of dynamic movements or variations of the geothermal heat flux. Our data from southern Ellesmere Island and northwest Greenland show heating during the latest Cretaceous to Paleocene, probably resulting from rifting and incipient spreading of the Baffin Bay-Labrador Sea, but very little exhumation in response to Eurekan deformation. The Pearya terrane of northern Ellesmere Island behaved completely different from the south, showing km-scale Cenozoic exhumation, with several episodes of enhanced movements during the Eocene and Oligocene. These movements correlate with changes of rates and direction of seafloor spreading in the Norwegian-Greenland Sea, suggesting that Pearya was coupled to the North Atlantic via the De Geer Fault Zone. The direct margins of the Norwegian-Greenland Sea, i.e., the Wandel Hav Mobile Belt in the west and Prins Karls Forland in the east, also experienced Eocene tectonic deformation and exhumation, but they were also strongly affected by heat flow variations, presumably in response to rifting and incipient continental breakup. Heating was particularly pronounced during the latest Cretaceous to Paleocene, when parts of eastern North Greenland were heated to temperatures >300°C, and West Spitsbergen also experienced enhanced heat flow. Prins Karls Forland only became exhumed to shallow crustal levels during the Oligocene to Miocene, i.e., later than other parts of Northeast Greenland or Svalbard, presumably due to transtensional movements preceding the opening of the Fram Strait. Finally, within the sensitivity limits of low-temperature thermochronology, we did not observe exhumation related to Eurekan tectonics along the New Siberian Islands. Here, the youngest exhumation period seems to be associated with the Cretaceous closure of the South Anyui Ocean.

ICAM9-TS4-6

A low-temperature thermochronology database for northern Canada

Jeremy W. Powell, Dawn A. Kellett, Fabian Kohlmann, Malcom McMillan

Jeremy.powell@nrcan-rncan.gc.ca

Low-temperature thermochronology (LTT) is a rapidly advancing sub-field of geochronology that aims to constrain the temperature-time history of geological processes that occur at upper crustal temperature regimes (< 200°C). LTT methods, including fission track and (U-Th)/He dating, have become increasingly popular over the last few decades and have been incorporated into diverse Canadian geoscience studies. Existing data are available across various publications, reports and graduate student theses. However, "available" is not the same as "publically accessible". Unlike most other geochronology data, which are more easily represented as point data on a map, the value of LTT data are obtained upon incorporation into thermal history numerical models, resulting in interpreted time-temperature histories for dated samples. Since these methods include complex metadata, often for multiple individually dated/analyzed crystals per sample, they are not appropriately captured by existing geochronology databases, such as the Geological Survey of Canada's (GSC) Canadian Geochronology Knowledgebase (CGKB). As part of the GSC's GEM-GeoNorth research program, and in partnership with Lithodat Pty Ltd., all published LTT data from northern Canada have been compiled and incorporated into a purpose-built relational database. This new database includes more than 1400 unique samples, with over 970 fission-track dates and 3230 (U-Th)/He single grain data entries, and incorporates metadata required for thermal history modelling, such as individual fission track lengths and individual grain mineral chemistry. Eventually, this database will be integrated within a modernized GSC information management system and contain all Canadian LTT data. In the meantime, the database will be freely available as a download through the GSC's GEOSCAN publication database (https://geoscan.nrcan.gc.ca/). An accessible, complete and functional LTT database will form the foundation for regional and national scale studies of upper crustal processes such as sedimentary basin evolution, brittle faulting, and tectonic- and climate-driven landscape evolution.

ICAM9-TS4-7

Towards a consistent model of burial and denudation along the North Atlantic margins

Cornelia Spiegel, Wolfgang Reiter, Alissa Bach, Katrin Meier, Kai Berglar, Volkmar Damm, Rüdiger Lutz, Karsten Piepjohn, Frank Lisker

cornelia.spiegel@uni-bremen.de

Low-temperature thermochronology data can be used for extracting thermal histories of the upper ~5 km of the Earth´s crust. Modelled histories can then be interpreted in terms of burial (= heating) or denudation (= cooling). However, depending on the constraints included in the models, more than one thermal history may be in agreement with the data observed. This non-uniqueness increases for protracted and complex thermal histories. The exposed structural levels along the present East Greenland and West Scandinavia margins have remained within the shallow crust for >100 Ma, and accordingly, their thermal histories were interpreted in different ways, either assuming largely continuous steady cooling, or alternatively, episodic cooling with intermittent periods of reburial. Both models have very different consequences regarding sediment production and movements: while continuous slow cooling produces little sediment, episodic cooling is associated with higher erosion rates and redistribution of sediment. The mixed application of both models, as it is currently the case in the literature, introduces artificial variations in denudation rates along the continental margins, which are not in agreement with the actual age data variation, making it hard for non-specialists to interpret thermochronology data of the North Atlantic realm in a comprehensive way.

For this project, we compiled literature data along the North Atlantic margins between Yermak Plateau / Morris Jesup Rise in the north and the Jan Mayen Fracture Zone in the south. All thermochronology data were reinterpreted by applying forward thermal history modelling using the same annealing and diffusion algorithms and the same constraints for the general cooling pattern, under the assumption of episodic cooling and reburial. From the models, we derived denudation and burial rates, using the same assumptions for the geothermal gradient and its variations for all data. Furthermore, we included seismic and, where available, bore hole data from the offshore sedimentary basins of the East Greenland and Barents Shelfs, and applied the same stratigraphic models and two-way-travel times for all sites. The resulting data was visualised in map form for various time slices from the end of the Caledonian Orogeny to the present day. The maps provide an internally consistent and comprehensive data basis for sediment production and deposition in response to post-

Caledonian tectonic processes. They furthermore illustrate periods of common or differential history of the two conjugated margins (e.g., during the late Cretaceous) and highlight areas with insufficient data coverage.

ICAM9-TS4-8

Paleozoic sedimentation and new Caledonian terrane architecture in NW Svalbard: Indications from U–Pb geochronology and structural analysis

Nikola Koglin, Andreas Läufer, Karsten Piepjohn, Axel Gerdes, Donald W. Davis, Ulf Linnemann, Solveig Estrada

nikola.koglin@bgr.de

Svalbard´s Northwestern Basement Province is traditionally divided into the Albert I Land and the Biscayarhalvøya terranes. New U-Pb age data on zircon and monazite, structural and geochemical data provide first evidence of early Palaeozoic deposits south of the Biscayarhalvøya Terrane indicating the possible existence of a third terrane: the Germaniahalvøya Terrane. This area is represented by a Cambro-Ordovician succession of mica schist and marble (Lernerøyane Group) with youngest detrital zircon ages between 571 and 492 Ma and its higher-grade metamorphic equivalent (Liefdefjorden Migmatite Complex) yielding youngest non-metamorphic detrital zircon ages between 579 and 511 Ma. Both successions were affected by migmatization during the Taconian phase at c. 469 Ma and metamorphic overprint up to anatexis during the Scandian phase (c. 422–415 Ma) of the Caledonian Orogeny.

New isotopic data from the eclogite-bearing Richarddalen Complex of the Biscayarhalvøya Terrane imply the formation as Ordovician–Silurian collision-related mélange dominantly composed of c. 730 to 600 Ma Timanian island-arc derived detritus and igneous rocks, partly eclogite-facies metamorphosed at c. 656 Ma, and Tonian meta-igneous rocks. After amphibolite-facies metamorphism of the mélange matrix at c. 423 Ma, the Richarddalen Complex and the Stenian–Tonian Biscayarfonna Group were juxtaposed and mylonitized by the dextral Biscayarhalvøya Deformation Zone.

Differences in structural development indicate that the Germaniahalvøya and Biscayarhalvøya terranes were independent tectonic units the Taconian phase of the Caledonian Orogeny. The Scandian phase is the first phase that evidently affected both terranes: the Germaniahalvøya Terrane by migmatization and the subsequent intrusion of late Caledonian granites and leucogranites and the Biscayarhalvøya Terrane by amphibolite-facies metamorphic overprint. The events were followed by the formation of the Biscayarhalvøya and Lerner deformation zones in the Biscayarhalvøya Terrane and the Germaniahalvøya Terrane, respectively. Intense ductile shearing and similar orientation of lineations suggest that they belong to the same stage of late Caledonian shearing. This is confirmed by the age data of 422–415 Ma (Lerner Deformation Zone) and c. 423 Ma (Biscayarhalvøya Deformation Zone). Along these deformation zones, the Biscayarhalvøya and Germaniahalvøya terranes had been (?) juxtaposed during late Caledonian ductile shearing.

ICAM9-TS5-1

Svalbox 2.0 – a networking project to facilitate the use of already collected HALIP samples from Svalbard and beyond

Kim Senger*, Owen Anfinson, Lars Eivind Augland, Christoph Beier, Peter Betlem, Simon Buckley, Bernie Coakley, Nikita Demidov, Graeme Eagles, Victoria Ershova, Carmen Gaina, Olivier Galland, Wolfram Geissler, Rafael Kenji Horota, Monika Kusiak, Karolina Kosminska, Harmon Maher, Jaroslaw Majka, Krzysztof Michalski, Kei Ogata, Nil Rodes, Anna Sartell, Benoit Saumur, Grace Shephard, Włodzimierz Sielski, Aleksandra Smyrak-Sikora, Cornelia Spiegel-Behnke, Christian Tegner

kim.senger@unis.no

Svalbard is a true playground for geoscientists, with excellent exposures of Pre-Cambrian to Paleogene rocks. The Diabasodden Suite encompasses Early Cretaceous igneous rocks in Svalbard, i.e. Svalbard's portion of the High Arctic Large Igneous Province (HALIP). While Svalbard is relatively easy to access compared to the other circum-Arctic HALIP locations, it is still a remote area. Any field undertaking is an expedition. As such, access to the field sites is hampered by high costs and restricted by a short field season and logistical challenges (poor weather, wildlife etc.). From 2017, the University Centre in Svalbard (UNIS) has been developing the Svalbox geoscientific portal to facilitate the integration and use of geoscientific data from Svalbard. Svalbox is an open-access data portal (www.svalbox.no) where anyone can access a growing number of 3D digital models of drill cores (DCMs), rock samples (DSMs), and full digital outcrop models (DOMs) given regional context by 360° imagery. These are all presented in Svalbard-wide geospatial layers (e.g., geological and topographic maps, satellite imagery, overview of seismic and borehole coverage). Svalbox has, since its onset, been heavily used in education, research and outreach at UNIS.

Svalbox 2.0 is a 2-year network project (2021-2023) that brings together a circum-Arctic partnership. One of the sub-objectives of Svalbox 2.0 to establish a data-driven pilot project on the HALIP, by using the Svalbox platform to harvest already collected samples and jointly analyse them geochronologically and geochemically. Where adequate data are available we aim to directly link collected samples (which are also digitized as digital sample models) with the digital outcrop models of the individual intrusions. A geo-referenced sample database linked to the Svalbox portal will be used to highlight the collected samples from the various past field expeditions spanning the majority of the Svalbard archipelago.

In this contribution, we firstly present and demonstrate the functionality and data coverage of the Svalbox portal. Secondly, we outline the ongoing HALIP sample harvesting and integration within Svalbox. Finally, we showcase examples of utilizing the Svalbox platform to bring Svalbard's excellent HALIP outcrops closer to geoscientists elsewhere by using virtual field trips and fully downloadable digital outcrop models.

ICAM9-TS5-2

Remote Predictive Mapping of Gossans on Baffin Island, Nunavut – Spectral Signatures

Éloïse Brassard*, Erin M. Bethell, Marie-Claude Williamson, Myriam Lemelin

eloise.brassard@usherbrooke.ca

Gossans are rust-coloured surficial deposits that are the product of surface weathering of sulphide and oxide minerals in host rocks. Most gossans are small (a few tens of meters to less than 1 or 2 km in length) and they are usually demarcated by a single point on geological maps. Over the past decade, the Geological Survey of Canada carried out field and laboratory studies of gossans located in the Canadian Arctic Islands. To determine how many gossans were mapped in areas of continuous permafrost in the Canadian Arctic, we compiled all known occurrences from geological maps, open file reports and journal articles. The resulting geospatial database includes hundreds of gossans located mostly in Nunavut. This study was carried out in parallel with an investigation of the geomorphic attributes of ~ 300 gossans mapped on Baffin Island, Nunavut. The objectives are (1) to refine remote predictive mapping techniques to accommodate small targets such as gossans and (2) to evaluate the potential of hyperspectral satellite images for mineral mapping. Satellite hyperspectral imaging is a spectroscopic technique that allows remote identification of mineralogy and mineral chemistry on a variety of rock surfaces. The use of satellite images for remote geological studies has several advantages, including their large spatial coverage that allows for geological investigations on a regional scale. Furthermore, it offers the possibility to study several targets spread over a large area with less investment in resources and time than field mapping. Using spectrally-rich PRISMA images (spatial resolution of 30 m per pixel) of gossans on Baffin Island, we captured subtle differences in VNIR and SWIR bands. When combined with other information such as geomorphic attributes (e.g. size, shape, and contact relationships with the host bedrock), these spectral signatures uniquely characterize the gossans. Mapping of gossans can be achieved using hyperspectral satellite imagery thus enabling a better understanding of their mineralogy, geochemistry, and ultimately, potential value as economic indicators.

ICAM9-TS5-3

Remote predictive mapping of volcanic terrain in the High Arctic Large Igneous Province, Nunavut, Canada

Stephanie Lachance*, Marie-Claude Williamson, Myriam Lemelin

stephanie.lachance6@usherbrooke.ca

Thematic geological maps of bedrock exposed in sparsely vegetated areas are produced using geospatial data in a process referred to as remote predictive mapping (RPM). RPM is a tool that helps geologists identify regions of interest for fieldwork and serves to fill knowledge gaps in frontier regions. Remote predictive maps are usually derived from supervised classifications performed on multispectral satellite images acquired in the visible, near infrared and shortwave infrared. However, the best available spectral resolution (such as provided by PRISMA images) enables the user to highlight the absorption and emission peaks that are characteristic of different mineral and rock types. Moreover, the use of a supervised classification requires a priori knowledge of bedrock geology thus contradicting the underlying objective of predictive mapping. A case in point is the use of RPM in the Geological Survey of Canada's northern mapping projects such as the generation of 1:50 000 scale bedrock maps of the Minto Inlier, Victoria Island, Northwest Territories. Building on these results, the objectives of our research project are to (1) generate a geological map at 1:10 000 scale for our region using emerging satellite imagery and classification methods (i.e., PRISMA hyperspectral satellite images and the self-organizing maps method); and (2) compare our results with those obtained using traditional remote sensing approaches (e.g., multispectral imagery and Random Forest). The study area for this project is located in the Sverdrup Basin, at the head of Expedition Fiord, on central Axel Heiberg Island, Nunavut. This region is characterized by volcanic and intrusive rocks of the High Arctic Large Igneous Province (HALIP). A preliminary validation of the classifications using the available 1:100 000 scale bedrock geology map has been completed with the objective of ground truthing the results during fieldwork planned for July 2022. Portable field instruments will be used to validate the RPM approach for mapping at a 1:10 000 scale with the goal of providing a higher resolution of geological units in the vicinity of the McGill Arctic Research Station. In this presentation, we introduce the methods, geological context and preliminary results associated with the two classification methods, and showcase the remote predictive geological map.

ICAM9-TS5-4

Remote Predictive Mapping of Gossans on Baffin Island, Nunavut – Geomorphic Attributes

Erin M. Bethell*, Éloïse Brassard, Marie-Claude Williamson, Myriam Lemelin

ebethel2@uottawa.ca

Boots-on-the-ground geological mapping in sparsely vegetated regions of the Canadian Arctic is challenging because of the remoteness of the study areas, complex logistics and high costs of transporting field crews, equipment and supplies. However, the degree of bedrock exposure is often exceptional, leading to a better understanding of large-scale lithological domains, structural features and tectonic boundaries. As a result, northern mapping projects include the analysis of satellite imagery and the compilation of existing data in advance of fieldwork. In this study, we investigate gossans that were previously mapped in central and southeast Baffin Island at scales ranging from 1:100 000 to 1:250 000. Gossans are surficial cap deposits that are the product of weathering of sulphide and oxide minerals in the host bedrock. Most gossans are small (a few tens of meters to less than 1 to 2 km in length) and they are routinely represented as a single point on geological maps. The distinctive colours of the oxide cap of gossans render them easily recognizable on satellite imagery in the visible-near-infrared (VNIR) and short-wave infrared (SWIR) portions of the electromagnetic spectrum. The objective of the project was to employ a remote predictive mapping (RPM) approach to revisit each of the 300 localities where mapped gossans occur and compare their host rocks and geomorphic attributes; the rationale being that, in some important cases, gossans are associated with an ore deposit. Once the host lithology was recorded, we targeted a subgroup of 24 gossans associated with igneous rocks. Overall, a large proportion (approximately 40%) of the gossans in the study area are hosted in igneous rocks of intermediate to felsic composition. Using Esri World Imagery (spatial resolution of ~ 1 m per pixel), we identified 17 gossans with lengths ranging from 100 meters to 2-3 kilometers. In the process of identifying the mapped gossans on Esri World Imagery, we discovered new occurrences associated with large-scale lineaments. The ability to differentiate and map new gossans using high-resolution satellite imagery is the first step in further characterizing gossans in terms of their mineralogy and geochemistry. Remote predictive mapping of gossans on Baffin Island allows a comparison of the dimensions, structural setting and host lithologies, and as such, provides a new exploration tool in the search for new mineral deposits.

ICAM9-TS5-5

Helicopter-borne hyperspectral imaging, a valuable approach for mineral mapping in areas with difficult accessibility

Sara Salehi*

ssal@geus.dk

Remote-sensing techniques play an important role in the geological surveys for mapping and mineral prospecting and are particularly well adapted for the investigation of remote and inaccessible areas, either for preparing field work or for supporting thematic mapping in the field.

Satellite images allow for the discrimination of rock units in the broader region and help in effectively defining the best initial targets for regional exploration. Unmanned aerial systems (UAS) are particularly attractive to investigate potential deposits in difficult or environmentally sensitive areas but are limited to small-to-medium-sized survey areas, i.e. tens of square kilometers. Using a fixed-wing aircraft or helicopter, aerial surveys can provide information in a rapid, non-invasive manner on areas conducive to mineralization that may be otherwise difficult to access from the ground. Fixed-wing aircrafts are useful for large-scale and/or lower-resolution surveys, while helicopter surveys are excellent for defining smaller to medium sized targets at higher resolution and can be flown at both lower ground clearance and speed in terrains that would be impossible to follow in a fixed-wing aircraft.

To address scaling issues and the accessibility in the field, and to provide low altitude data from targets identified using space-borne dataset a helicopter has been utilized as a versatile means of acquiring remote sensing data emphasizing both spatial and spectral information domains using a novel sensors system setup. The focus lies hereby on the integration of digital photogrammetry with helicopter-borne hyperspectral imaging to gather high-resolution geometric data as well as quantitative information about mineral variations in the outcrop. The method is tested in North-East Greenland, where stereo images and hyperspectral data cubes have been collected simultaneously and from both nadir and off-nadir viewing angles.

The highly variable terrain leads to strong illumination and atmospheric absorption variations which must be accounted for in the hyperspectral data processing. A precondition for such correction is an accurate geo-rectification which is done by the PARGE® software. Retrieving the unbiased ground reflectance is solved by a physical based atmospheric correction with the DROACOR® model. The study demonstrates the potential of using helicopters to help understanding the geology in poorly accessible areas and to provide information that may help in the future exploration and geological mapping activities.

ICAM9-TS6-2

Gateway to the Arctic: Defining the eastern portion of Bering Strait

Mark Zimmermann, Rebecca A. Woodgate, Megan M. Prescott

mark.zimmermann@noaa.gov

The Bering Strait, divided at the Diomede Islands into a Russian western side and a US eastern side, is the sole gateway for Pacific waters to flow into the Arctic Ocean. The strait is an oceanographic bottleneck that influences Arctic ice, birds, mammals, and fish populations, prompting a great deal of US research between Little Diomede Island and Cape Prince of Wales. Understanding where the shallowest cross-sectional opening is located within the heavily studied eastern side of the strait would allow for better oceanographic models and an increased understanding about how the northward water flow impacts physical and biological processes. Until recently, the depth and morphology of this important passage have been defined only by low resolution hydrographic surveys from the 1950s, but nearly the entire width and about 26 km across the north/south axis of the strait was mapped with multibeam sonars in 2010 (Fairweather, NOAA's National Ocean Service) and 2015 (Terrasond, various vessels) for charting purposes. We used these public bathymetry data to define the location and size of the narrowest cross-sectional part of the Bering Strait. The multibeam data also confirmed the existence of a previously undescribed, narrow, 3 to 4 meter deep, linear channel, extending northward at least 70 km from the passage. Comparison of newer multibeam depths to the older 1950s surveys showed clear patterns of seafloor erosion and deposition during the six decades between the surveys. The majority of the depth comparisons showed an erosional regime, which may have facilitated increased northward flow of warmer, fresher Pacific waters into the Arctic over time. This compilation and comparison of bathymetric data in the Bering Strait region is part of an ongoing effort to make precise and accurate maps of the Alaska seafloor. In this way, data collected for one purpose can be used many times; as in this case to identify geological features, to derive landscape metrics, and to utilize this improved knowledge of the seafloor to model the habitat of federally managed species.

ICAM9-TS6-3

New Insight into Seismic Reflection Data across the Northern Chukchi Borderland

Wisnu S. Priyanto, Bernard J. Coakley*

wspriyanto@alaska.edu

We present the newly acquired eismic reflection data from the northern Chukchi borderland and the adjacent Canada Basin. These data were collected during August and September 2021 from the R/V Sikuliaq. We utilized a dual G-gun source (1040 cu inches total volume) for the MCS acquisition. The streamer was 200 meters long with 32 channels. So far, data processing has been focused on effectively stacking the data and suppressing the multiples. Within the Borderland, our seismic data image horst with grabens bounded by faults of variable dips and wedge-shaped sediment infill.

The Chukchi Borderland is a continental block that was extended prior to the opening of the Canada Basin sometime in the Mesozoic. The Chukchi Borderland has been dissected by normal faults, which created interior basins between the Chukchi Cap and Northwind ridge. The elevation of the Chukchi Borderland indicates it is underlain by continental crust, but the internal structure is poorly understood. This study will constrain the structures and features of the Northern Chukchi Borderland. This information complemented with previous data study allow us to reconstruct the tectonic history of the basin and develop constraints on the enigmatic Canada Basin.

ICAM9-TS6-4

Arctic Gravity Project grid version 3.0 - progress and plans

James R. Beale*, Howard J. Small, Bernard J. Coakley, and Rene Forsberg

james.r.beale@nga.mil

The Arctic Gravity Project (AGP), which was begun at ICAM III in Celle, Germany in 1998, was the first collective effort to develop a coherent gravity grid and map of the Arctic Ocean and adjacent continents. Intended to compliment the concurrent development of the International Bathymetric Chart of the Arctic Ocean (IBCAO; initial release 2001) and earlier release of a magnetic anomaly map and grid by the Geological Survey of Canada, the gravity grid completed a set of maps revealing gravity and magnetic anomalies and bathymetry/topography of the Arctic North of 64˚ N. These grids have made it possible to study the unique features of the Arctic Region and develop hypotheses about the origin and development of the Arctic Ocean itself.

A new version of the AGP grid (version 3.0) has been under development for some time. This new grid, substantially augmented by new satellite gravity and airborne gravity datasets, particularly GRAV-D, which covers all of Alaska with a uniform airborne gravity anomaly data set, reveal the basin and adjacent continents as never before. Also the explosion of gravity anomaly data collected for establishment of the Extended Continental Shelves of the circum-Arctic states under Article 76 of the United Nations Convention on the Law of the Sea has improved resolution of the map, particularly in regions with steep gradients.

The talk will focus on assembly of the 3 minute release grid and evaluation of the resulting representation of the anomalous gravity field North of 60˚ N, an expansion of the previous grids. We anticipate release of the grid in netcdf format and as a pdf-format map to the community by sometime in the late Summer of 2022.

ICAM9-TS6-5

Periglacial Features Mapped on the Chukchi Borderland: Constraints on Ice Extent and Motion

Bradley S. Keith*, Owen A. Anfinson, Bernard J. Coakley

keithb@sonoma.edu

Here we present newly acquired bathymetric data from the Chukchi Borderland region of the Amerasian Basin, Arctic Ocean. Data was acquired aboard the research vessel Sikuliaq from August 1st to September 30, 2021. The Sikuliaq is equipped with a hull mounted Kongsberg EM302 and EM710 multibeam echosounder and a Kongsberg TOPAS PS18 sub bottom profiler. Previous expeditions in the region observed iceberg plow marks and mega scale glacial lineations (MSGL). The primary goal of this research is to determine the extent and orientation of both the plow marks and MSGL throughout the region.

The bathymetric data confirm the widespread occurrence of both MGSL and iceberg scours across the relatively shallow water on Northwind Ridge and the Chukchi Plateau. This sculpting of the seafloor likely occurred sometime during the last glacial maximum. During this period, sea level was estimated to be approximately 125 meters lower than present day. In these data several large sets of parallel grooves were identified. Overprinting of MSGL indicates relative ages of sets of these lineations, which were associated with drumlins. Drumlins were recognized as streamlined positive features on the seafloor, perpendicular to bathymetric contours and parallel to MSGL. Terminal moraines were also observed in the vicinity of MSGL. The presence of MSGL, drumlins and moraines indicate the direction of ice flow, which averages 40 degrees NNW. The direction of flow for iceberg plow marks was apparently random, thousands of troughs cross each other at different angles at depths less than 400 meters below sea level along the Chukchi Plateau. The interpretation of these data will allow for a more detailed map of glacial movement within the region, which may provide further insight into the Arctic climate during the last Glacial Maximum.

An additional finding was a high concentration of pockmarks on Northwind Ridge. While not fully understood, it is hypothesized that these pockmarks are methanogenic in origin as evidence has suggested in several other locations around the world, most notably the North Sea. These pockmarks are generally 100 - 150 meters wide and 5 to 10 meters deep, while some larger craters can reach widths of 1 kilometer and depths of nearly 70 meters.

ICAM9-TS6-6

Mapping surficial geology in the Arctic Ocean

Kai Boggild*, David C. Mosher, Catalina Gebhardt, Kimberly E. Baldwin, Jolien van der Krogt

kai.boggild@nrcan-rncan.gc.ca

International research from icebreakers in the Arctic Ocean over the past two decades has led to a multi-fold increase in the quantity of subbottom profiler data in the region. Additionally, improvements in technologies, and acquisition and processing techniques have led to a marked increase in quality of these data. Compilation of these data with multibeam bathymetry and seafloor sample data provides an opportunity to produce a comprehensive map layer of surficial geology for the Arctic Ocean. Acoustic facies mapped from subbottom profiler data reveal the distribution of sedimentary processes that have shaped the seafloor in the high Arctic throughout the Quaternary. Results include turbidite beds that correlate over long distances and deep sea channels apparent in the basins; sediment drifts and bedforms of a variety scales occur in the basins and along the continental margins; mass failure and glacigenic debris flow deposits lie seaward of river and ice margin inputs; and, till and ice-margin wedges lie on the extensively ice-scoured shelves. Other morphologic features, such as Alpha Ridge and Mendeleev Rise host hemipelagic deposits, but even some of these areas show evidence of sediment mass failure and glacial overprint. The newly expanded map permits comparative study of the recent evolution of different physiographic areas within the Arctic basin. The map layer is presented as a queryable database that includes acoustic and process interpretations that can be groundtruthed by information from sediment cores where available. Ongoing development of this surficial geology layer will complement bathymetry of the International Bathymetric Chart of the Arctic Ocean (IBCAO) by providing surface and subsurface information that will support continuing geologic and oceanographic investigation of the circum-Arctic region.

ICAM9-TS7-1

The crustal transition from the northern Canada Basin to the southern Alpha Ridge, Arctic Ocean

H. Ruth Jackson*, Deping Chian, John Shimeld

ruth.jackson@nrcan-rncan.gc.ca

Regionally extensive magmatism constructed the Alpha Ridge during the Cretaceous and, in doing so, it obscured the nature of the crust beneath the ridge. We use six transects comprised of seismic wide-angle reflection/refraction, seismic reflection and potential field data to investigate variable lower to upper crustal features in the region between the northern Canada Basin and southern Alpha Ridge. Crustal P-wave velocities from forward modelling of expendable sonobouy records data recorded information from the seabed to the lower crust. The velocities are grouped by numerical range. For example, a deep crustal layer with a velocity 6.8-7.5 km/s in the northern Canada Basin is revealed along the southernmost periphery of the Alpha Ridge. Oceanic plateaus typically have lower-crust velocities of 6.9-7.5 km/s, consistent with an ultramafic layer. Velocity beneath the central Alpha Ridge reaches 7.2 km/s at a depth of about 28 km; in contrast, within the region of the High Arctic Magnetic High (HAMH) magnetic anomaly, high-velocity lower-crust exists at a depth as shallow as 13 km. These high lower-crust velocities are spatially associated with high-amplitude magnetic anomalies within the HAMH along the bathymetric edge of the ridge. 2D gravity modelling constrained with the measured crustal velocities demonstrates the first-order topography of the Moho in the study region. It shallows along previously identified northeast-trending non-transform faults in the northern Canada Basin, and deepens towards the Alpha Ridge, in a pattern that is generally compatible with published 3D gravity models. The inferred Moho depths also compared with those from published Rayleigh-wave group velocity analyses. Continental fragments including the Lomonosov Ridge, Marvin Spur and Chukchi Borderland flank the Alpha Ridge, and S-wave velocities from the published Rayleigh-wave results suggest that the Alpha Ridge region nearest to the Canadian polar margin is comprised of intermediate crust, not oceanic crust. We envision the ridge forming as part of the High Arctic Large Igneous Province during large-scale tectonic translation, with fragments of continent moving into the oceanic domain of the Canada Basin.

ICAM9-TS7-2

Seafloor spreading in Canada Basin: seismic imaging of an extinct spreading ridge of the Arctic

David C. Mosher, Bernard J. Coakley*

david.mosher@nrcan-rncan.gc.ca

Tectonic reconstruction of the Canada Basin of the Arctic Ocean is difficult due to lack of direct evidence of seafloor spreading and absence of clear conjugate margin pairs. The basin is shallow compared to other oceanic basins, which draws into question its crustal composition; yet, a central low gravity anomaly has long been suggested to represented an extinct spreading ridge. New seismic data acquisition over the past two decades has provided a window into the geologic history of the region.

Mapping these data has shown that basement generally dips toward the south and east. More than >15 km of sediment overlies basement to the south in the Mackenzie-Beaufort region. This sedimentary sequence thins to the north and west. This study employs a technique to remove the sediment column from the seismic data and isostatically compensate basement elevation (assuming Airy isostasy) to restore the surface to its “unloaded” position. This restored basement surface shows: 1) in central Canada Basin, basement is near horizontal and lies at full ocean depth (~6000 m), thus is oceanic; and 2) a ridge and valley system corresponds precisely with a central basin gravity low. Assuming half-space cooling for the ridge system, the depth of the ridge system can be restored to approximate its bathymetry at the time of formation. The depth of the ridge's axial valley suggests a slow-to-intermediate spreading rate. Interpretation of en echelon faults and integration of seismic and gravity anomaly data further indicate that seafloor spreading was likely contemporaneous with strike-slip tectonic motions oblique to the spreading axis. Canada Basin, therefore, presumably formed via seafloor spreading and production of oceanic crust as well as with significant transform tectonics.

ICAM9-TS7-3

Exploring the history of extension across the Chukchi Borderland and Canada Basin

Bernard J. Coakley* and the science party of RV Sikuliaq cruise SKQ202113S

bjcoakley@alaska.edu

The history of the Arctic Ocean is largely unwritten, but can be glimpsed through the fragments of what we know. Now that we know enough to articulate hypotheses about the origin and development of the Amerasia Basin, we can collect dedicated data sets to test hypotheses about the features in the basin and their relationships.

This past summer, I sailed on the RV Sikuliaq, UAF's research vessel, to the Central Arctic Ocean to explore the seafloor and sediments beneath it by collecting multibeam bathymetry, sub-bottom profiler, MCS reflection and OBS and sonobuoy refraction data. This cruise focussed on the linked extensional history of the Borderland and adjacent Canada Basin.

To make this cruise happen, it was necessary to work around a variety of COVID-related obstacles. It was something of a miracle that we left the pier at all. Once we were in the North, we encountered heavy ice conditions that dictated continuous revision to our science plan. We managed to collect good data over the Chukchi Borderland and the Canada Basin, which will define some of the ocean's unknown history.

This cruise had four basic objectives; 1) collect site survey MCS on Northwind Ridge crossing Langseth MCS lines from 2011 in support of an IODP proposal, 2) characterize the structure of the Northern Borderland, 3) collect OBS data to test the proposed division of Canada Basin into oceanic and hyper-extended continental crust, and 4) to image the extinct mid-ocean ridge axis in Canada Basin.

Processing of these data is underway. During this presentation, I will review what we accomplished and present some tentative conclusions based on our observations.

ICAM9-TS7-4

Displacement history along the Porcupine Shear Zone and its role in the opening of the Canada Basin

Karol Faehnrich*, William C. McClelland, Laura Webb, Troy Rasbury, Maurice Colpron, Justin V. Strauss

karol.faehnrich.gr@dartmouth.edu

Despite identification of numerous significant Paleozoic–Cenozoic strike-slip faults along the northern margin of North America, their role in the opening of the Amerasian Basin remains ambiguous. The Porcupine Shear Zone (PSZ) of northern Yukon and Alaska marks the southern boundary of the Arctic Alaska terrane with the autochthonous Laurentian margin, and as such, provides an opportunity to test the role of translation in the opening of the Canada Basin. Here we present results of our work along the PSZ that combine detailed field observations, U-Pb zircon geochronology, 40Ar/39Ar thermochronology, and U-Pb dating of calcite veins.

The PSZ forms a greater than 10 km wide zone of distributed shear that records polyphase deformation related to sinistral and dextral displacement. Within the shear zone, Tonian rocks of the Ch'oodeenjik succession are intruded by ca. 380 Ma dikes that are most likely connected to plutonic rocks of the Late Devonian Old Crow plutonic suite. The presence of ca. 780-820 Ma and ca. 1570 Ma detrital zircon grains in these strata, as well as their absence in coeval rocks south of the PSZ, suggest deposition of these units away from the autochthonous Laurentian margin (i.e., Yukon Block). Instead, the presence of Late Devonian intrusive rocks provides ties with the Arctic Alaska terrane and positions this crustal fragment to the east along the Canadian Arctic margin in the Late Devonian.

Muscovite from two phyllite samples collected north of the PSZ record plateau or plateau-like segments at ca. 342–367 Ma with younger steps at ca. 105 Ma, consistent with cooling after emplacement of the Late Devonian Old Crow plutonic suite and subsequent late Early Cretaceous or younger resetting. In contrast, samples collected within the PSZ do not record a thermal event related to pluton emplacement and instead yield complex spectra with single steps as old as ca. 1779 Ma. These data reflect contrasting thermal histories across the PSZ and partial resetting during or after the late Early Cretaceous. Coarse-grained calcite veins associated with fault breccias and vein arrays within the PSZ produced U-Pb ages of ca. 110–120 Ma. We associate the late Early Cretaceous calcite vein formation and 40Ar/39Ar partial resetting to strike-slip displacement within the PSZ. As such, the PSZ may have accommodated translation of Arctic Alaska during the opening of the Canada Basin.

ICAM9-TS7-5

Geology, Tectonic Origin, and Petroleum Potential of the North Chukchi Basin

David W. Houseknecht*, Christopher D. Connors, Bernard J. Coakley

dhouse@usgs.gov

The North Chukchi Basin (NCB) straddles U.S., Russian, and international waters beneath the outer shelves of the Chukchi and East Siberian Seas, and extends westward >950 km from the North Chukchi High (US Chukchi shelf) to the De Long High (Russia East Siberia shelf). The basin ranges in width from 150 km in the east to 450 km in the west and occupies more than 300,000 km^2 in area. Multi-channel seismic (MCS) data indicate that maximum basin fill exceeds ~20 km, comprising mainly Cretaceous–Cenozoic Brookian strata with sediment derived from the Chukotka and Brooks Range orogens. Sediment dispersal was generally northward and the basin was filled transversely by progradation of clinoform depositional systems. These strata onlap the low-accommodation Chukchi Borderland to the northeast and downlap the Chukchi Abyssal Plain to the northwest.

Inferred NCB stratigraphy includes: (1) Thin pre-Brookian basinal deposits; (2) Lower to mid-Cretaceous clinothems in the east, deformed by Late Cretaceous–Paleocene contraction, and thinning westward into undeformed basinal deposits; (3) Lower Paleogene clinothems in the west, thinning eastward by onlap onto the deformed Cretaceous strata; (4) Upper Paleogene–Lower Neogene succession comprising a single, giant clinothem; and (5) Upper Neogene and Quaternary strata comprising thin glacio-marine deposits.

We interpret the NCB as a rift basin that likely opened during Jurassic to Hauterivian, approximately coeval with rifting that led to opening of the Canada Basin. MCS observations and published gravity models are consistent with the floor of the NCB being either oceanic crust or exhumed mantle. West of ~170°W, seismic evidence suggests the southern and northern basin margins are analogous to published examples elsewhere in the world of magma-poor (absence of seaward-dipping reflectors, SDRs) and magma-rich margins (presence of SDRs), respectively. In contrast, east of ~170°W seismic evidence suggests less extension and either incipient or no mantle exhumation.

The tremendous depth of the NCB is a main control on petroleum potential. Geo-modeling indicates likely source rocks are over-mature except on basin margins. Oil vs gas risk includes interpretation of vertical and up-dip migration as deeply buried source rocks passed through the oil window. Regardless, optimum oil potential lies in Eocene to Miocene strata in the giant clinothem, where source-rocks likely exist in a basal condensed section still in the oil

window and reservoir-trap potential exists in overlying basin-floor fan, slope channel and lobe, and shoreface to deltaic deposits.

ICAM9-TS7-6

Crustal structure of the Morris Jesup Spur and the northern continental margin of Greenland

Thomas Funck*, Andreas Brotzer, Wolfram H. Geissler, Karsten Piepjohn, Ingo Heyde, Kai Berglar

tf@geus.dk

During expedition PS115/1 of the German research vessel Polarstern, geophysical data were acquired across the northern continental margin of Greenland and up to the Morris Jesup Spur. It was the first time that this otherwise ice-infested area was accessible by ship, which was facilitated by unusual wind conditions that created a coastal polynya. The data set comprises a 102-km-long seismic refraction line along which nine ocean bottom seismometers and three sonobuoys were deployed, seismic reflection data subparallel to the refraction line, as well as gravimetric and magnetic data. The location of the refraction line was determined by the location of the polynya and extends from the narrow shelf north of Greenland to the southwestern limit of the Morris Jesup Spur. A P-wave velocity model for the line was developed by forward modelling of travel times with gravity data providing additional constraints in areas that are poorly resolved by the seismic data. Beneath an up to 2-km-thick sedimentary cover with velocities of 1.8 to 3.4 km/s, a 1-km-thick layer with velocities around 4.3 km/s is encountered, which is interpreted to consist of volcanic rocks relating to either the volcanics of the Kap Washington Group known onshore or to magmatic activity on the Morris Jesup Spur. Farther below, velocities between 4.4 and 5.4 km/s are encountered in a 3 to 7-km-thick layer and interpreted as metasedimentary rocks associated with the deformed units of the northern Franklinian Basin as described onshore in northern Peary Land. Velocities in the 4 to 8-km-thick upper crust show pronounced lateral variations. There are three zones with velocities of 6.3 km/s separated by areas with velocities of 6.0 km/s. The zones with increased velocities are interpreted as magmatic intrusions. Velocities in the up to 8-km-thick lower crustal layer exceed 7.2 km/s and relate to either magmatic underplating or lower crustal sill intrusions, thereby indicating a magmatic overprint of the margin at all crustal levels. Moho depth is around 24 km but shallows to 20 km beneath the edge of the Morris Jesup Spur. The velocity model and the nearby seismic reflection data indicate the presence of a NW-SE striking fault zone between northern Greenland and the spur.

ICAM9-TS7-7

Seismic reflection surveys on the Lomonosov Ridge in regard to IODP Leg 377

Estella Weigelt*, Catalina Gebhardt, R. Stein

estella.weigelt@awi.de

We present a regional seismic data set across the southeastern Lomonosov Ridge (LR) serving as pre-site survey for the upcoming drilling project IODP-377 (Arctic Ocean Paleoceanography - ArcOP). The overall goal of this drilling campaign is to recover a complete stratigraphic sedimentary record of the southern ridge to meet the highest priority paleoceanographic objective, the continuous long-term Cenozoic climate history of the central Arctic Ocean Ocean (details see ArcOP Scientific Prospectus: https://doi.org/10.14379/iodp.sp.377.2021).

The seismic surveys provide basic information for the drilling, as the identification of undisturbed strata, location of slumps or hiatuses, depth-calculations of target reflectors, age estimations, and suggestions on the type of sedimentary rocks inferred from interval velocities of seismic units. On the LR the seismic lines confirm the presence of 1600 m thick, undisturbed, parallel sedimentary layers. 10 drilling locations can be proposed to recover the entire Miocene sedimentary sequence or even down to sediments of Lower Eocene age at about 900 mbsf.

A prominent high-amplitude-reflector sequence (HARS) within the strata can be used to directly correlate to previous seismostratigraphic models for the eastern Arctic Ocean. Four major seismic units were identified which provide constraints on the coupled evolution of tectonic processes, palaeoceanography, and glaciation history of the Arctic Ocean. First, Mesozoic strata on the LR, its faulted flanks and the initial Amundsen Basin were covered with syn-rift sediments of Paleocene to early Eocene age. Numerous vertical faults indicate differential compaction of possibly anoxic sediments deposited in the young, still isolated Eurasian Basin. The second stage, as indicated by the prominent HARS covering the ridge, was a time of widespread changes in deposition conditions, likely controlled by the ongoing subsidence of the LR and gradual opening of the Fram Strait. Episodic incursions of water masses from the North Atlantic probably were the consequences and led to the deposition of thin sedimentary layers of different lithology. The third stage is marked by continuous deposition since the early Miocene. At that time, the ridge no longer posed an obstacle between the Amerasia and Eurasia Basins and pelagic sedimentation was established. Drift bodies, sediment waves, and erosional structures indicate the onset of circulation. Lastly, a sequence of high-amplitude reflectors marks the transition to the early Pliocene large-scale

Northern Hemisphere glaciations.

In a future step, the link of drilling data to the seismic net via synthetic seismograms shall enable a spatial extrapolation of findings, and serve to improve the seismostratigraphic models.

ICAM9-TS7-8

The critical role of sea level and Bering Strait on Arctic Ocean dynamics as shown from Holocene records

Anne de Vernal*, Claude Hillaire-Marcel, Tengfei Song, Yanguang Liu, Jade Falardeau

devernal.anne@uqam.ca

The shallow (~ 50 m deep) Bering Strait, which is the unique gateway linking the Pacific Ocean to the Arctic Ocean, deserves special attention as sea-level changes modify considerably the exchanges between the two oceans. Under high sea level, poleward heat transfer and freshwater fluxes from the Pacific impact the Arctic freshwater budget and sea ice distribution. Furthermore, sea-level determines the status of the Arctic shelves, submerged or not, which plays a role in sea-ice production, as well as in the latent heat from Atlantic waters flowing northward through Fram Strait and the Barents Sea. Hence, high sea levels result in the connection of the Arctic basin with the Pacific, which modifies the Arctic freshwater and heat budgets and leads to the submergence of shelves, thus the potential development of sea-ice factories. The impacts of sea-level on the Arctic Ocean and subarctic seas are not easily reconstructed from sedimentary records, but radiocarbon-based chronologies and proxy-data covering the present interglacial provide useful information. For example, micropaleontological and geochemical records from the Chukchi Sea show progressive warming in surface water accompanying the increase of Pacific flux during the Holocene, until sea-level reached its present-day limit at ~ 4 ka BP. This contrasts with a trend towards perennial sea-ice cover in the southeastern Arctic and with changes at the eastern gateway of the Fram Strait, where cooling is recorded from early to late Holocene. Hence, we hypothesize that increased freshwater inflow from the Pacific into the Arctic together with enhanced sea-ice formation rates, both linked to sea-level rise, have played a role in the general cooling trend culminating during the late Holocene.

ICAM9-TS7-9

Paleogeographic and tectonic implications derived from early Late Triassic strata, NE Sverdrup Basin

Ashton F. Embry*

ashtonfoxembry@gmail.com

It is accepted that the Amerasia Basin did not start to open by rifting and eventual sea floor spreading before latest Triassic (Rhaetian). Thus, one important test for the viability of any proposed tectonic model for the opening of Amerasia Basin is that the pre-opening reconstruction must result in an acceptable Late Triassic paleogeography. Two key components for constructing a Late Triassic paleogeographic map of the Arctic are 1) the mapped sedimentary facies and associated land areas and 2) the detrital zircon populations found in the various areas surrounding the Amerasia Basin.

The Sverdrup Basin of Arctic Canada was a major Triassic depocentre with thicknesses of Triassic strata exceeding 5000 meters. Late Triassic shoreline-nearshore sandstones, deposited on the NE margin of Sverdrup Basin, are present on northern Axel Heiberg Island. These strata were derived from the north in the area now occupied by the Amerasia Basin. Thus, in any tectonic restoration that closes the Amerasia Basin, an extensive land area must lie to the north of Sverdrup Basin.

The second constraint for tectonic models for opening the Amerasia Basin is provided by the zircon population of Carnian (early Late Triassic) strata of northern Axel Heiberg Island. This population contains abundant Carboniferous, Permian, and Triassic-aged zircons, with the youngest zircons being of syn-sedimentary age. The only reasonable source area known to supply such a diverse, Carboniferous to Late Triassic zircon population is the Taimyr area at the Arctic end of the Ural Mountains. Similar zircon populations, which were undoubtedly derived from that area, have been identified in Carnian strata of the Barents Sea area. Thus, an acceptable pre-Amerasia Basin tectonic reconstruction must also allow for a Late Triassic river system, which has headwaters in the Taimyr area, and which reaches the northeastern shoreline of Sverdrup Basin.

The only published, tectonic model for the opening of Amerasia Basin, which is compatible with these two Late Triassic paleogeographic constraints, is the counterclockwise rotation of the Arctic Alaska-Chukotka microplate away from the Canadian Arctic Islands.

ICAM9-TS7-10

Integration of Interhemispheric Miocene – Pliocene Records to reveal ice-ocean interactions under warming climate: IMPRINT

Lara F. Pérez*, Katrine J. Andresen, Fernando Bohoyo, Florence Colleoni, Laura De Santis, Carlota Escutia, Wolfram Geissler, Karsten Gohl, F. Javier Hernández-Molina, Kelly Hogan, Paul Knutz, Robert D. Larter, Richard Levy, Renata Lucchi, Robert M. McKay, Timothy Naish, Michele Rebesco, Louise Sime, Gabriele Uenzelmann-Neben

lfp@geus.dk

Future changes in polar environmental conditions under different global warming scenarios are highly debated. An ice-free Arctic Ocean, increased melting of the Greenland Ice Sheet and retreat of sectors of the Antarctic ice sheets are anticipated consequences of ongoing global climate change. Accelerating ice sheet retreat is increasing the rate of sea level rise that among other effects will compromise the sustainability of about 1 billion of the World's coastal population. However, the extent of the effects of future climate change are still uncertain, largely due to insufficient model constraints. Key uncertainties are related to the lack of understanding of the past behavior of ice sheets, and the feedback effects of oceanography and climate.

The evolution of the Antarctic and Greenland ice sheets is a significant factor in global climate. Major advances of the ice sheets over the continental shelves are associated with displacement of the polar frontal systems towards low latitudes, leading to expansion of the polar oceans, further growth of ice sheets at high latitudes of both hemispheres and enhancement of cold deep-water mass outflows. During past warm periods, however, the polar fronts migrated towards high latitudes as the ice sheets retreated. The discharge of meltwater from the ice sheets resulted in weak deep-water formation. The latitudinal temperature gradient weakens during warm climates due to the so-called 'polar amplification'. The sedimentary sequences preserved on polar margins have recorded the changes in the ice sheets and polar fronts in thousand-to-million-year time scales.

The main aims of the proposal IMPRINT are to examine the record of ice sheet evolution, as well as the changes in oceanic circulation and associated migrations of the polar frontal systems in selected areas of Greenland and Antarctica. Detailed understanding of the role and behavior of the ice sheets and oceanic flows during the cold-warm climate transition between ~8 Ma and ~3.5 Ma will provide a measure of the magnitude of changes that can be expected in terms of cryospheric and oceanographic configurations in the future. This will contribute to understand the interhemispheric links between the position of polar frontal systems and ice sheet growth and decay. Thus, by improving knowledge of past ice sheet configurations, deep oceanic flows and polar frontal systems and relating this to projections of future climate scenarios, IMPRINT will improve understanding of the societal implications of future global warming and related sea-level rise.

ICAM9-TS7-11

Reflection seismic imaging of the continental crust between North Greenland and Morris Jesup Spur

Martin Engels, Peter Klitzke, Axel Ehrhardt, Rüdiger Lutz, Antonia Ruppel, Michael Schnabel

martin.engels@bgr.de

The North Greenland continental margin is characterized by tectonic events like phases of compression and extension, the transform motion along the De Geer fracture zone, and the opening of the Eurasian Basin among others.

During expedition PS115/1 of the German research vessel Polarstern, a coastal polynya allowed for the first shipborne geophysical survey in the Wandel Sea north of Greenland. We acquired in total five seismic reflection profiles with a three-kilometer long streamer cable, one seismic refraction line consisting of nine ocean bottom seismometers along with towed magnetometer and onboard gravity measurements. An interpretation of the refraction profile is presented at this ICAM by Thomas Funck and coauthors and can be compared with the surrounding reflection lines. They cover the continental margin between Kap Washington and Morris Jesup Spur. We assess the crustal structure of North Greenland based on a combined interpretation of multi-channel seismic and magnetic data.

Owing to the lack of wells, the age assignment of individual seismic reflectors in multi-channel seismic data is tentative. A regional prominent, unregular high amplitude reflector is interpreted as top of a volcanic sequence. It extends from the deep into the shallow continental shelf towards Greenland. This volcanic sequence can be correlated with the Kap Washington Group exposed along the coast of North Greenland. The Kap Washington Group was erupted in late Cretaceous-Paleocene times (71-61 Ma). The interpreted volcanic sequence is evident across wide parts of the study area and coincides with a positive magnetic anomaly. The volcanic sequence onlaps in the east on the Morris Jesup Spur.

Westward-dipping parallel reflections of a tilted and uplifted continental fragment indicate that the Morris Jesup Spur comprises pre-volcanic sediments. Shallow seismic data by Kristoffersen (2021) on the northern extent of the Morris Jesup Spur indicate a similar structural pattern. Outcrops onshore North Greenland encompass pre-Caledonian sediments (Franklinian Basin) as well as post-Caledonian Devonian to Cretaceous sediments (Wandel Sea Basin). Similar sediments are expected offshore below the volcanic sequence but the limited subvolcanic seismic resolution hampers further interpretation. Post-volcanic sediments are only mildly deformed.

ICAM9-TS8-1

Compatibility of HALIP development with opening Amerasia Basin by the counterclockwise rotation of the AACM

Ashton F. Embry

ashtonfoxembry@gmail.com

The High Arctic Large Igneous Province (HALIP) in the Amerasia Basin is outlined by magnetic data. It is centred on the Alpha-Mendeleev Ridge Complex (AMRC) and extends southward to about latitude 80 and northward to the base of the Lomonosov Ridge. Age dates of HALIP rocks indicate it began as early as Hauterivian, climaxed in latest Barremian, and lasted until early Late Cretaceous.

The most widely accepted model for the opening of the Amerasia Basin involves the counterclockwise rotation of the Arctic Alaska-Chukotka microplate (AACM) away from the Canadian Arctic, with a pivot in the Mackenzie Delta region and a rotational transform fault near the base of Lomonosov Ridge. An important question is whether this model is compatible with the current data on the development of the HALIP.

A seafloor spreading centre, emanating from the rotational pivot area, has been identified in the southern portion of the Amerasia Basin. The potential for identifying a continuation of the spreading centre northward is eliminated by the overwhelming strength of the magnetic field of HALIP. The interpreted Early Cretaceous age for the spreading fits well with the age of the main development of HALIP.

The extent of the HALIP in Amerasia Basin is supportive of the rotation of the AACM. Magnetic and seismic data demonstrate that HALIP extends northward to the base of the Lomonosov Ridge and includes the Makarov and Podvodnikov basins. Seismic data reveal no change in crustal velocities between the AMRC and these basins, indicating that basins developed coevally with the AMRC. The only significant tectonic boundary occurs at the base of the Lomonosov Ridge. Seismic data are compatible with this break being a transcurrent fault zone.

Notably, the extent of the HALIP in the Amerasia Basin matches its extent in the adjacent Sverdrup Basin, with a correspondence between the southern limits, as well as the locations of maximum volcanism. This correspondence indicates there was very little strike slip faulting along the Canadian margin of the Amerasia Basin from earliest Cretaceous onward. This fits well with a rift origin for the Canadian margin and the AACM rotation model.

The crest of the HALIP (AMRC) broadly follows a small circle related to rotation of AACM and may have been the site of a leaky transform during the seafloor spreading stage of basin opening. In summary, HALIP data are compatible with the AACM rotation model for opening the Amerasia Basin.

ICAM9-TS8-2

Geochemical systematics of Canadian High Arctic Large Igneous Province igneous rocks

Jean H. Bédard*, Valentin R. Troll, Frances M. Deegan, Benoit-Michel Saumur, Christian Tegner, Stephen E. Grasby, Keith Dewing, Carol A. Evenchick

jeanh.bedard@nrcan-rncan.ca

Cretaceous High Arctic Large Igneous Province (HALIP) magmatic rocks in Canada include evolved tholeiitic basalts and alkaline rocks. HALIP Continental Flood Basalt (CFB) eruption episodes (135-120 Ma, Isachsen Fm.; 105-90 Ma, Strand Fiord Fm.) and associated sills and dykes were classified into Types and Series using Ce vs Sm/YbNMORB distributions. Comparison with model melting curves imply higher-Sm/Yb HALIP tholeiites separated from deep garnet-bearing mantle sources; whereas voluminous low-intermediate- Sm/Yb HALIP tholeiites separated from the mantle at shallower levels. Progressive increases in incompatible elements are coupled with clockwise rotation of incompatible trace element profiles, requiring progressive and ubiquitous incorporation of a continental crustal component; inconsistent with models involving addition of voluminous sediment to the mantle source. Interaction with Sverdrup Basin sedimentary rocks cannot explain strong Ba-enrichment in the absence of concomitant K-Rb-Th-U-enrichment. Ba enrichment could reflect either a Ba-rich mantle component, or fluid-mediated transfers from Ba-rich host rocks.

The alkaline rocks scatter around major fault and basement structures. The newly-defined Fulmar Suite alkaline basalts (~96 Ma) are represented by dykes and sills, but also include Hassel Fm. volcanics. The younger group (Wootton Intrusive Complex, WIC, 92.2-92.7 Ma; Audhild Bay Suite, ABS, 83-73 Ma) were emplaced near the northern coast of Ellesmere Island. The Fulmar Suite resembles EM-type ocean island basalts (OIB) and generally show limited crustal contamination. They show increases of P2O5 at near-constant Ba-K-Zr-Ti that are nearly orthogonal to predicted fractionation- or melting-related variations; which we interpret as the result of melting composite mantle sources containing a regionally widespread apatite-bearing enriched component (P1). Low-P2O5 Fulmar Suite variants overlap compositionally with enriched HALIP tholeiites and fall on common garnet lherzolite trace element melting trajectories, suggesting derivation from similar sources. High-P2O5 Hassel Formation basalts are unique in being strongly contaminated with depleted cratonic lower crust; and because they also involve a high-P2O5-Ba-Eu mantle component (P2), similar to that seen in alkali basalts from Greenland. P2 may have contained Ba-Eu-rich hawthorneite and carbonate minerals as well as apatite, and may typify the Greenlandic sub-continental lithospheric mantle (SCLM) which extends beneath Ellesmere Island. The strongly alkaline ABS

and WIC rocks resemble HIMU ocean island basalts (high-Nb, low-Zr/Nb and low 87Sr/ 86Sri) and cannot share the Fulmar Suite's source. Normalized HREE profiles of ABS and WIC rocks range from flat to steep, indicating a range of melting pressures. Some contain the same P1 and P2 components identified in Fulmar-Hassel rocks, whereas other samples trend towards possible High-P2O5+Zr (PZr) and High-P2O5+K2O (PK) components. We propose that the strongly alkaline magmas sampled mineralogically heterogeneous veins or metasomes in Greenlandic-type SCLM at a variety of depths. The geographically widespread apatite-bearing component (P1) could have formed part of a heterogeneous plume or upwelling mantle current that also generated HALIP tholeiites when melted more extensively, but may also have resided in the SCLM. The scarcity of potassic alkaline HALIP facies and trace element and isotopic signatures provide no support for an ubiquitous fossil sedimentary subduction zone component in the HALIP mantle source.

ICAM9-TS8-3

Palynology refines age control of extrusive HALIP magmatism and reveals impacts on Arctic forests

Jennifer M. Galloway*, Robert A. Fensome, Graeme T. Swindles, Thomas Hadlari, Jared Fath, Claudia Schröder-Adams, Jens O. Herrle, Adam Pugh

jennifer.galloway@nrcan-rncan.gc.ca

The Hauterivian–Aptian aged Isachsen Formation at Glacier Fiord, Axel Heiberg Island, in the Sverdrup Basin of the Canadian Arctic Archipelago was deposited contemporaneous with initiation of the High Arctic Large Igneous Province (HALIP). Four terrestrial palynofloral zones are defined and used to reconstruct vegetation change over the Isachsen Formation's ca. 17 million year history, explore the role of the HALIP in these changes, and refine the understanding of the age of extrusive magmatism. Climate warming during the Hauterivian promoted expansion of a hinterland community dominated by members of the Pinaceae. By the middle Barremian, this community was replaced by mixed heathland and mire, represented by up to 70% fern spores in the uppermost Paterson Island Member, which may be, in part, in response to environmental disturbance associated with volcanic flows of the HALIP. Above the fern spore spike, dinoflagellate cyst assemblages indicate an early Aptian age and a marine setting for mudstones of the Rondon Member in which Ocean Anoxic Event 1a is recorded. An interval of floral instability is recorded in the overlying Aptian-aged Walker Island Member, characterized by fluctuations in Pinaceae and Cupressaceae pollen and fern

spores, possibly as a result of post-OAE 1a temperature variability and landscape disturbance associated with lava flows of the HALIP that were repeatedly extruded onto the subsiding delta plain during deposition of the member. This analysis of the quantitative palynological signature of the Isachsen Formation exposed in the eastern Sverdrup Basin at Glacier Fiord refines the understanding of drivers of Arctic climate change during Hauterivian to Aptian time by illustrating the effects of the HALIP on at least regional climate and habitat that, in turn, affected Arctic forest composition. Improved age control for the Rondon Member, below and above which extrusive magmatism of the HALIP is documented, in turn refines knowledge of the age of these flows.

ICAM9-TS8-4

Early Cretaceous magmatism in central Spitsbergen: stratigraphic and spatial extent

Kim Senger, Olivier Galland

kim.senger@unis.no

Rapid extensive magmatism may have a profound effect on global climate by liberating and releasing greenhouse gases to the atmosphere because of contact metamorphism. For intrusive complexes, volume of emplaced magma, its timing, intrusion geometry, emplacement depth and composition of host rocks determine the overall climatic effect of igneous activity. The high Arctic archipelago of Svalbard offers relatively accessible and superbly exposed outcrops testifying to Early Cretaceous magmatism associated with the High Arctic Large Igneous Province (HALIP). In this contribution, we investigate the intrusive complex of central Spitsbergen, the most "data-rich" part of Svalbard due to past petroleum exploration and research drilling. We have integrated all available data to quantify the spatial and stratigraphic extent of Early Cretaceous igneous intrusions. In this area, the predominantly doleritic intrusions of the so-called Diabasodden Suite are emplaced in a range of host rocks ranging from Permian carbonate-dominated successions to organic-rich shale-dominated successions of Middle Triassic and Late Jurassic-Early Cretaceous age. Most intrusions occur in organic-rich mudstones (of Middle Triassic and Late Jurassic age) and in Permian spiculites. 265 individual igneous intrusions, cumulatively covering 72 km2, are exposed onshore in the study area. In addition, subsurface characterization using borehole, seismic and magnetic data indicates that an area of additional ca. 3000 km2 is affected by magmatism. Five petroleum exploration boreholes in the study area penetrate igneous intrusions. Previously unpublished geochemical data from drilled intrusions in Colesbukta and Vassdalen indicate that these have the same basaltic composition as exposed Diabasodden

Suite dolerites. Wireline logs in boreholes characterize both intrusions and associated contact metamorphic aureoles, with very low resistivity in aureoles affecting organic-rich shales suggesting past fluid circulation and de-gassing. Ship-based magnetic data provide a direct link from the onshore outcrops. A 10 m dyke exposed on the beach can be followed for > 15 km beneath Isfjorden as a high magnetic anomaly. This study forms the foundation for quantifying HALIP-related magmatism in the data-poorer parts of Svalbard, and within other circum-Arctic basins. We review the remaining knowledge gaps and suggest avenues for further research on Svalbard's excellent and easily accessible HALIP exposures.

ICAM9-TS8-5

Exploring potential lower mantle structures and interactions for the origins of HALIP

Grace E. Shephard*, Carmen Gaina, Björn Heyn, Clinton P. Conrad, Owen Anfinson, Andrew Schaeffer, Kim Senger

grace.shephard@geo.uio.no

Large-scale volcanism includes widespread intrusive (magmatic) and extrusive (volcanic) events, often referred to as Large Igneous Provinces (LIPs). Many are thought to be caused by deep-seated mantle plumes, which is supported by the distribution of hotspots, reconstructed LIP eruption sites, kimberlites, geochemical signatures, and large low shear wave velocity provinces (LLSVP) geometries. The Arctic offers a unique window into slab-plume generation and interactions because it is located just beyond LLSVP edges, is sandwiched between the two antipodal LLSVPs (under Africa and the Pacific), and has seen a long history of both subduction and volcanism. Circum-Arctic targets for major volcanic 420-0 Ma events include the Iceland Plume, North Atlantic Igneous Province, High Arctic LIP (HALIP), Siberian Traps, and Vilyui LIP. Several of these volcanic events present extra geodynamic interest due to their protracted ages, apparent pulsations, widespread erupted area and subsequently dispersed locations, and/or apparent (non)correlation with mantle plumes.

One such example is the HALIP, which is a centre-piece of the Arctic geographically, and has been attributed to a wide range of Cretaceous aged rocks, currently distributed onshore and offshore around the Arctic. Mantle plume origin(s) are suggested based on numerous dykes, a pre-breakup radiating pattern, and thermal doming associated with a major shift in sedimentary deposition in the Barents Shelf. Nonetheless, the contribution of sub-continental

lithospheric mantle, metasomatic mantle, and crustal contamination must be considered. The apparent multiple pulses of HALIP (during ~131-85 Ma, with a potential peak phase around 125 Ma) pose a particular challenge because most traditionally-defined LIPs are erupted in a relatively short amount of time (1-5 Myrs for >75% of the volume). Some key questions arise: If continuous, what process(es) could explain ca. 40 Myrs of magmatism; a 'fixed' and large-scale lower mantle thermal source, an upper mantle edge-driven convective source, or a combination of both? Alternatively, if pulsating, what are the dynamics causing this? Are plume and rifting-related magmatism origins overprinting each other? A deep mantle connection will enable the exploration of a deep plume-origin hypothesis for HALIP, and could determine whether a deep-seated, long-lived source can explain part or all of the protracted magmatism. The recently funded POLARIS project aims to explore some of these elements – including via numerical models of mantle convection, geodynamic relationships and seismic tomography. Preliminary results and related discussions will be presented at ICAM9.

ICAM9-TS8-8

Emplacement of HALIP dolerites in Ekmanfjorden, Svalbard: geometry, geochemistry, and geochronology

Anna M. R. Sartell*, Kim Senger, Ulf Söderlund, Peter Betlem, Christoph Beier, Olivier Galland, Grace Shephard, Rafael Horota

anna.sartell@helsinki.fi

Large Igneous Provinces are widespread in the geological record and can have a significant impact on the global climate. The High Arctic Large Igneous Province (HALIP) was emplaced during the late Mesozoic, and remnants of this large-scale magmatism can be found across the circum-Arctic. More geochronological data combined with petrological and geochemical studies are needed to understand the evolution of the HALIP. On Svalbard, the HALIP is represented by the Diabasodden Suite intrusions, which are still mostly unexplored despite the relative accessibility of outcrops. To bridge some of the knowledge gaps present on Svalbard, a field study in northern Isfjorden was done in 2020. Understanding the magma evolution and emplacement mechanisms at a single locality is key to understanding the same on a circum-Arctic scale. This project aimed to answer two questions: (1) do the intrusions of Ekmanfjorden share the same magma source, and (2) have they been emplaced in a single pulse or do they represent multiple phases?

The landmasses around Ekmanfjorden are a prime locality to study the igneous intrusions on Svalbard, with several pristine outcrops of sills and dykes emplaced in Triassic shales and Permian carbonate-dominated successions. Here, we present the results from the 2020 field campaign. Geo-referenced digital outcrop models were created from drone-based photographs to map the intrusive plumbing complex in three-dimensions within the stratigraphy. Whole-rock geochemical analyses and petrological observations of 24 samples were used to understand the chemical relationship between the different outcrops sampled and to correlate the intrusions in Ekmanfjorden with the HALIP in the circum-Arctic.

Outcrop models imply that the Ekmanfjorden intrusions could represent the erosional remnants of a single large sill. However, trace element data indicate at least two pulses with different sources. The order of emplacement cannot be constrained based on stratigraphy alone, and high-precision geochronology is needed. One pulse records low degree melting in the garnet stability field, combined with later, shallower melting in the spinel lherzolite field. The other pulse records only deeper melting from a garnet-bearing source. The geochemical signature of the Ekmanfjorden intrusions correlates well with the 120-126 Ma tholeiitic pulse found across the Arctic. An updated geochronological review shows that there are only 3 U-Pb ages from Svalbard to date, and 22 U-Pb ages of the HALIP in total. U-Pb baddeleyite ages from Ekmanfjorden will be obtained during spring 2022 as part of a recently started PhD project on the HALIP in Svalbard.

ICAM9-TS8-9

High seismic velocities within the Olga Basin: indications for extensive igneous intrusions?

Michael Schnabel, Axel Ehrhardt, Martin Engels

michael.schnabel@bgr.de

Igneous intrusions are a widespread phenomenon within the northern Barents Sea. These structures are easily accessible within outcrops in the onshore domain. Offshore, the identification is more complicated. One of the most promising method of mapping is the analysis of seismic velocities within the subsurface. Igneous material mostly show seismic velocities above 6.0 km/s, while the velocities within consolidated sediments rarely exceed values of 5.8 km/s. Up to now, published refraction seismic measurements have shown several high velocity patches (6.0 to 6.4 km/s) within the north-western Barents Sea (at the Sentralbanken High, the Sørkapp Depression and the western edge of the Gardarbanken High). Within the literature, these patches are generally interpreted as intrusive bodies.

We present a seismic velocity model covering the Olga Basin as well as the adjacent Storbanken High. The profile was acquired during cruise PANORAMA-2 conducted by the Federal Institute for Geosciences and Natural Resources (BGR). The seismic data was recorded with 18 free-floating sonobuoys with a mean distance of 10 km between single stations. The record sections show clear signals for offsets up to 25 km. Forward modelling in combination with raytracing allowed us to constrain velocities down to a depth of about 4 km below seafloor. Below the Olga Basin, our refraction seismic data show a layer with velocities around 6.2 km/s within a depth of 3.7 to 4.2 km. The lateral extend of this high-velocity area is about 80 km along the profile. Based on the interpretation of colocated reflection seismic data acquired during the same cruise this layer most probably is situated within lower Permian strata.

Existing refraction seismic data in the southern Olga Basin has shown that the Permian strata within the Olga Basin has seismic velocities around 5.8 km/s. Within our presentation, we discuss our hypothesis that the here reported high-velocity layer could be caused by igneous material, most probably related to the High Arctic Large Igneous Province (HALIP).

ICAM9-TS8-10

Geochemical and isotopic constraints on the origin of Aptian basalts from Axel Heiberg Island, Canadian HALIP

Frances M. Deegan, Victoria Pease, Ines G. Nobre Silva, Jean H. Bédard, George Morris

frances.deegan@geo.uu.se

Mafic volcanic and intrusive rocks associated with the Cretaceous High Arctic Large Igneous Province (HALIP) are recognized across the Canadian Arctic Islands, northern Greenland, Svalbard, Franz Josef Land, and the Chukchi Borderland. Two magmatic suites are recognized amongst HALIP rocks: an older, tholeiitic suite (135 – 90 Ma) and a younger, alkalic suite (95 – 73 Ma). We present new major and trace element data, 40Ar/39Ar ages, and Sr-Nd-Pb isotopic compositions for Cretaceous dykes, sills, and lava flows from Bukken Fiord, NW Axel Heiberg Island, Arctic Canada. The samples are evolved (3 to 7 wt% MgO) plagioclase + clinopyroxene-phyric tholeiitic basalts, with major and trace element compositions similar to typical HALIP tholeiites. The best constrained 40Ar/39Ar plagioclase ages combine to yield a weighted average age of 123 ± 4 (95%) Ma, which overlaps with established ages for

Isachsen Formation extrusive basalts on Axel Heiberg Island. Trace element ratios indicate derivation of the Bukken Fiord basalts from an enriched mantle source, and according to the genetic groupings defined by Bédard et al. (2021) the samples have intermediate to high Sm/Yb NMORB ratios, indicating extensive spinel-field mantle melting along with contributions from deeper-sourced garnet-field melt increments. The Axel Heiberg samples were acid leached prior to isotopic analysis and yielded εNd(t) and 87Sr/86Sr(t) compositions ranging from +2.5 to +8.5 and 0.70362 – 0.70778, respectively. These Nd-Sr isotopic ratios are similar to the published HALIP data and support a model involving assimilation of Sverdrup Basin sedimentary rocks by enriched, mantle-derived melts. We also present 206/204Pb, 207Pb/204Pb, and 208/204Pb ratios, among the first reported Pb isotope analyses for the HALIP. We argue that our new Pb isotope data provide further support and insight into a genetic model for HALIP tholeiites involving widespread magma-sediment interaction within the crustal dyke-sill network characterizing the HALIP plumbing system.

ICAM9-TS8-11

Structure and Petrology of Intrusive Systems of the HALIP: Case Studies from western Axel Heiberg Island

Benoit M. Saumur, Marie-Claude Williamson, Ashley Abraham, Eve Gosselin, Carol A. Evenchick, Keith Dewing

saumur.benoit-michel@uqam.ca

Several orientations, geometries and generations of diabasic to gabbroic dykes and sills of the HALIP crop out in Canada's Arctic Archipelago. Regional-scale mapping conducted by the Geological Survey of Canada has led to the documentation of saucer-shaped sills on Ellef Ringnes Island, and analysis of drilling and seismic data indicates their widespread occurrence in offshore Cretaceous strata of the Sverdrup Basin. HALIP intrusions are particularly common on Axel Heiberg Island. Saucer shaped sills and irregular intrusions associated with subvolcanic systems extend eastwards, at least to western Axel Heiberg Island, and possibly occur throughout the basin.
The ~20 km2 Middle Fiord intrusive complex exhibits a high density of gabbroic sills and dykes and forms part of the feeder system for HALIP flood basalts. Whole rock geochemical data on a suite of 50 samples suggest the presence of mafic and ultramafic rocks associated with rare intermediate and felsic rocks. Chondrite-normalized rare earth patterns show progressive differentiation of the rock suite, suggesting that the samples are cogenetic. A geometric dichotomy is observed among the Middle Fiord intrusions: those hosted in

sandstones are tabular and concordant, whereas those hosted in shales are subcordant to discordant, and exhibit anastamosing to irregular geometries along strike. Saucer-shaped sills of western Axel Heiberg Island tend to occur in the shale-rich strata. These observations suggest the nature and strength of the wall rock strongly controlled emplacement mechanisms. Well-consolidated sandstones largely restricted magma flow to conformable planar anisotropies and bedding planes, whereas relatively weak shales were locally thermo-mechanically eroded, promoting stoping, upward migration and the formation of discordant intrusive bodies.

Workers have proposed the occurrence of a 1000-km scale, giant circumferential dyke swarm associated with the HALIP, with corresponding dykes located, among other worldwide localities, in western Axel Heiberg Island. Here, these dykes are historically known as the Surprise Fiord dyke swarm, a series of ENE-WSW trending dykes exhibiting 10 km-scale strike lengths and thicknesses under 10 m. Originally identified through airphoto interpretation of regional lineaments, fieldwork confirms that most of the ENE-WSW lineaments are indeed discordant dykes. However, several intrusions, specifically N-S to NE-SW trending ones, are reinterpreted as sills based on observed conformable contacts and bridge structures. Brittle faulting contributed to the emplacement of magmas at Surprise Fiord, with alkaline magmas, attributed to the late (80 Ma) HALIP magma pulse, occurring in intrusions located near faults that were active during dyke emplacement. Away from these faults dykes are tholeiitic, implying that the initial emplacement of circumferential dykes is associated with the earlier tholeiitic magmatic pulses of the HALIP (130–90 Ma).

ICAM9-TS9-1

Sedimentary Successions of the Arctic Region and their Hydrocarbon Prospectivity

Sergey S. Drachev, Harald Brekke, Erik Henriksen*, and Thomas E. Moore

sdrachev@arcgeolink.com

The Arctic Ocean and surrounding continental shelves host sedimentary successions of tremendous size and volume that preserve the geological record of past 1.6 Ga of the Earth history. The total area of sedimentary accumulations is c. 15,310,000 sq.km, which is ~57 % of the entire Arctic north of 64°. These accumulations bear potentially huge hydrocarbon resources, including biogenic methane and gas hydrates. Combined with the rapidly degrading permafrost they represent significant sources of greenhouse gases.

The Geological Society of London M57 volume is an unparalleled summary of data on geology and hydrocarbon potential of all Arctic sedimentary successions containing sixty-nine scientific papers in total covering all Arctic areas. It is rooted in a map of sedimentary successions of the Arctic Region by Grantz et al. (2011). Two main goals have been designated: (i) to provide, based on the present-day knowledge and data, a characterization of all Arctic sedimentary successions, and (ii) to supply a snapshot of hydrocarbon-related exploration in the Arctic at the end of the second decade of this millennium. To achieve these goals, we define sedimentary successions as consisting of one or several "Tectono-Sedimentary Elements" - a first-order undeformed or moderately deformed, unconformity-bounded sedimentary succession that shares common lithostratigraphy and, therefore, geological history and confined to accommodation space that formed in a particular tectonic regime. This concept allows delineation, mapping, and characterization of nine categories of TSEs based of main tectonic regimes that formed accommodation space.

The majority of Arctic sedimentary successions have evolved through multiple tectonic regimes and, therefore, consist of more than one TSE. We combined some individual TSEs into larger sedimentary bodies, "Composite Tectono-Sedimentary Elements". Areal and stratigraphic extents of resulting CTSEs correspond to the sedimentary successions mapped by Grantz et al. (2011) with some modifications.

A TSE characterization template has been developed as an efficient method of organising and presenting the most important information about stratigraphy, structure, and petroleum geology of a TSE, including most significant exploration facts. This organizational architecture is the backbone of the volume and is a key feature that distinguishes it from other similar works about the sedimentary basins.

ICAM9-TS9-2

Evolution of the NE Greenland offshore basins and assessment of their petroleum potential

Rüdiger Lutz*, Peter Klitzke, Martin Blumenberg, Philipp Weniger, Dieter Franke, Lutz Reinhardt, Kai Berglar

ruediger.lutz@bgr.de

We assessed the petroleum potential of the NE Greenland margin based on vintage seismic data and new seismic data acquired in 2017 and 2018. The study area encompasses two large offshore basins, the Danmarkshavn Basin and the Thetis Basin, separated by the Danmarkshavn Ridge. Despite the lack of direct age control from wells, published information from outcrops onshore East Greenland and information from cored shallow boreholes, indicate a complete post-Caledonian sedimentary inventory in the offshore basins. Mobilized salt in the northern Danmarkshavn Basin documents the Pennsylvanian to early Permian early subsidence evolution by analogy to the Gipsdalen Group of the conjugate Norwegian Barents Sea. Overlying Permian to Jurassic strata are characterized by remarkably uniform thicknesses of ~1 s TWT. Polyphase latest Jurassic to early Eocene rifting enabled deposition of km-thick sediments. During this time interval, the Danmarkshavn Ridge evolved as a rift shoulder with fault throws locally exceeding 2 s TWT. Rifting shifted through time from the Danmarkshavn Basin eastward to the Thetis Basin and may have culminated in magma-rich continental breakup.

Four W-E seismic composite profiles capture the structural configuration of the East Greenland margin and serve as structural input for basin and petroleum systems modelling. The models include an optimistic and a pessimistic scenario. The optimistic scenario includes six potential source rocks ranging in age from Carboniferous to Cretaceous, while the pessimistic scenario incorporates only the Upper Jurassic source rock, equivalent to the Draupne Formation and Hekkingen Formation of the North Sea and Norwegian Barents Sea, respectively. We further applied two heat flow scenarios, which differ in the consideration of an additional heat flow peak during early Eocene volcanic continental breakup. The influence of volcanism decreases from south to north. The seismic profiles show several episodes of erosion during the geological history of the basins. We included two erosional phases attributing the Pliocene-Pleistocene glacial erosion and the major angular unconformity at the base Cenozoic.

We calculated the minimum and maximum petroleum generation for each structural element in the 2D model. The range of petroleum generation was used for a subsequent Monte Carlo simulation to calculate the probability density function of petroleum generation and trapping for the whole study area. We calculated trapped petroleum resources (p50) of 1.45 bcm oe,

which is around half of the value (p50, recoverable resources) calculated by the USGS in their CARA study and ~50% higher than the mean value of the GEUS/NUNAOIL study.

ICAM9-TS9-3

Geological evolution of the West Greenland Rifted Margin Composite Tectono-Sedimentary Element

Ulrich Gregersen*, P.C. Knutz, John R. Hopper

ug@geus.dk

The West Greenland Rifted Margin Composite Tectono-Sedimentary Element is composed of two distinct sedimentary accumulations: (1) pre-rift (pre-Cretaceous) and (2) syn-rift (Early Cretaceous–Danian), which represent individual tectono-sedimentary elements. The pre-rift tectono-sedimentary element includes the oldest and most poorly known offshore sedimentary basins, which mainly evolved in a cratonic platform setting with initial rifting phases. Orogenic phases with folded, rifted and metamorphosed rock successions are well documented onshore but less known in the offshore. Samples of gneiss, supracrustal rocks and some sedimentary rocks have been reported from offshore wells, shallow boreholes and/or seabed samples and tectonism is inferred by fault blocks in basement and pre-Cretaceous successions. These successions include Proterozoic rocks of the Thule Supergroup in NE Baffin Bay and the Thule Basin further north. Paleozoic carbonates are also indicated farther south. In contrast, Cretaceous–lower Paleocene sedimentary basins of the syn-rift tectono-sedimentary element are known from several wells, shallow boreholes and seabed samples, and basins are mapped in most parts of the margin. This element is composed of tectono-stratigraphic mega-units, formed during the early-rift, subsidence and late-rift phases. This element is known to have resource potential, in particular from well documented studies onshore from the Nuussuaq Basin including hydrocarbon seeps and other mineral resources. Large Cretaceous and Paleogene structures are buried below thick mudstone seal units and Paleogene volcanic successions, which are known from outcrops in central West Greenland and wells on the West Greenland continental margin. The geological evolution of the West Greenland margin is connected to the evolution of the conjugate Canadian margin, where similar rocks occur at some locations. The work presented here includes a contribution to the new GSL Memoir 57 on sedimentary successions in the Arctic region.

ICAM9-TS9-4

Petroleum seepage in Greenland

Flemming G. Christiansen*, Jørgen A. Bojesen-Koefoed

flemminggc@hotmail.com

Greenland is the World's largest island with a coastline of ~44 000 km within a coastal margin zone of a length of >7000 km. Along almost half of this zone, outcrops of Proterozoic to Recent sediments can be studied in great detail along coasts, fiords, on islands and in nearby valleys and mountains. Most of the Palaeozoic and Mesozoic basins in Greenland host evidence of petroleum seepage, especially as solid macroscopic bitumen, oil-stained sandstones, carbonates and volcanics but also with examples of conventional oil and gas seepage and gas-rich springs. Recently, a new web-based inventory of all onshore petroleum seeps and stains in Greenland was released by the Geological Survey of Denmark and Greenland (Christiansen & Bojesen-Koefoed 2021). So far, the inventory includes approximately 130 locations with detailed descriptions of features, geology, stratigraphy, analyses, reports, and publications. Although data span more than four decades with significant development in analytical methods and quality, everything is summarized within a modern mineral or a petroleum systems context with focus on correlation to known or inferred source rocks. Many more localities are expected to be discovered during future systematic mapping programs, especially in East and North Greenland with the use of satellite and airborne hyperspectral tools. Historically, information has primarily been of importance for traditional prospecting and exploration for minerals and petroleum with focus on distribution and thermal maturity of source rocks and later history of migrating, trapping and degradation. With rapidly increasing permafrost thawing, knowledge on distribution and geochemistry of gas seeps and gas-rich springs is important for predicting when and where greenhouse emissions will take place, and the expected composition of associated gases.

ICAM9-TS9-5

End of Petroleum Exploration in Greenland? – Perspectives for research and other activities in the future

Flemming G. Christiansen*

flemminggc@hotmail.com

In the summer of 2021, the newly elected Greenland Government cancelled future petroleum licensing. Although a surprise for most observers and taken without discussions in the Parliament, this decision was politically inconsequential as Greenland had already seen a dramatic decline in industry interest and activity from being one of the hottest regions for investments to virtually no activities at all. Activities in West Greenland and Baffin Bay culminated in the period 2010−2015 with large seismic programs, eight exploration wells and lots of relevant science based on large field campaigns and drilling of cored boreholes. This provided a well-documented knowledge on all petroleum systems elements and has created background for modern resources evaluations. Offshore North-East Greenland never quite reached the same high level of industry activities whereas the onshore research was significant, with a series of large field campaigns and a number of important cored boreholes drilled to test critical stratigraphic intervals, documenting the presence of good source and reservoir rocks.

For various reasons such as temporary falls in oil prices and consequently in exploration budgets, high exploration costs and technical challenges due to harsh climate conditions and sensitive environment, numerous unexpected changes towards more rigid regulations by the authorities, all petroleum licenses operated by supermajors and majors were relinquished in a remarkable short period of time (see discussion in Christiansen 2021). Of all non-producing countries in the World, Greenland probably has the best modern seismic coverage. Despite interesting structures suggesting a high potential, and comprehensive research background with dozens of new publications documenting key parameters, it is not likely that the western industry will return, even if a new government coalition changes its stance. Data, knowledge, and ideas will, however, be of great importance for future scientific drilling with focus on climate change and tectonic models; such drilling could not have been planned safely without good data coverage. Data are also important for continuing mapping and evaluation of mineral resources on the seabed, as background for tectonic models submitted to the Commission on the Limits of the Continental Shelf, and in a period of green transition with global need for evaluation of the potential for storage of CO_2 and energy.

ICAM9-TS9-6

Sedimentary succession of the Barents Sea Region: Finnmark Platform Composite Tectono-Sedimentary Element, an example area

Erik Henriksen*, Dimitrios Ktenas and Jesper K. Nielsen

erik.henriksen@uit.no

The Barents Sea region has been subdivided into eleven areas which are characterized in separate papers as Tectono-Sedimentary Elements (TSE) or Composite Tectono-Sedimentary Elements (CTSE) based on the age of known tectonic and depositional events. Petroleum has been discovered in many sedimentary intervals from Early Paleozoic to Eocene.

The Finnmark Platform CTSE, located in the southern Barents Sea, is a northward-dipping monoclinal structural domain. It covers most of the southern Norwegian Barents Sea where it borders the Norwegian mainland extending eastwards into the Kola Monocline on the Russian part of the Barents Sea. The general water depth varies between 200 and 350 m, and the sea bottom is influenced by Plio-Pleistocene glaciations that produced scour marks and deposition of moraine materials. Successively older strata sub-crop below the Upper Regional Unconformity (URU), which was formed by several glacial periods in the Pleistocene. Basement rocks of Neoproterozoic age were heavily affected by the Caledonian orogeny, and previously by the Timanide contraction in the easternmost part of the Finnmark Platform CTSE. Depth to crystalline basement varies between 4–5 to 10 km. Following the Caledonian orogenesis, the Finnmark Platform was affected by Lower–Middle Carboniferous rifting, sediment input from the Uralian Orogen in the east, the Upper Jurassic– Lower Cretaceous rift phase and the Late Plio-Pleistocene isostatic uplift.

A total of eight exploration wells drilled different targets on the platform. Two minor discoveries have been made proving the presence of both oil and gas, and sandstone reservoirs of good quality identified in the Visean, Induan, Anisian and Carnian intervals. In addition, thick sequences of Permo-Carboniferous carbonates and spiculitic chert are proven in the eastern Platform area. The deep reservoirs are believed to be charged from Paleozoic rocks. Well documented Domanik source rocks in the Timan–Pechora Basin may extend towards the eastern part of the Finnmark Platform. In the westernmost part, charge from juxtaposed downfaulted basins Jurassic - Cretaceous age may be possible.

In a time of transition from fossil to renewable energy, developing gas resources followed by CO2 capture and storage may be an important alternative to meet the increasing energy demand worldwide.

ICAM9-TS9-7

The North Barents Composite Tectono-Sedimentary Element – development and hydrocarbon potential

Bjørn Anders Lundschien*, Rune Mattingsdal, Sondre Krogh Johansen, Stig-Morten Knutsen

bjorn.lundschien@npd.no

The North Barents Composite Tectono-Sedimentary Element is a potential petroleum province in the Arctic. It is composed of several basins, platforms, and highs. The sedimentary succession is continuous from the Late Paleozoic throughout most of the Mesozoic. Terrestrial sediments of the Billefjorden Group (Early Carboniferous) are likely present and overlain by evaporites and carbonates of the Gipsdalen Group (Late Carboniferous - Early Permian). Most of the Triassic was dominated by a huge prograding deltaic system building out from the south, southeast and east, becoming successively younger towards northwest. The system was primarily sourced from the Urals, but also partly from mainland Norway and likely also from Taimyr. The progradation started in the Late Permian and reached Svalbard in the Early Carnian. The entire delta system was flooded during the regional Early Norian transgression, resulting in deposition of marine shales of the Flatsalen Formation in Svalbard and the time equivalent Akkar Member of the Fruholmen Formation in the Barents Sea. Seismic interpretation indicates a roughly 250 m thick Late Triassic to Middle Jurassic succession, correlative to the Wilhelmøya Subgroup in Svalbard and the Realgrunnen Subgroup in the southern Barents Sea. The Cretaceous and the Paleogene are comprehensively and completely, respectively, eroded in the area. Hydrocarbon source rocks occur at several stratigraphic levels, of which the most important is the Lower – Middle Triassic Steinkobbe / Botneheia Formation. The Upper Jurassic Hekkingen Formation, where present, is likely immature in the entire area. Potential reservoir rocks are Late Paleozoic carbonate rocks and Mesozoic sandstones. Structural traps dominate, but stratigraphic traps may also occur. Sealing capacity of caprocks is generally regarded as good. However, uplift and erosion in the Paleogene have impacted retention of hydrocarbons in traps and this relationship is important to consider in risk assessments.

ICAM9-TS9-8

Widespread natural hydrocarbon seepage in the Barents Sea and the relationship to the subsurface petroleum systems

Rune Mattingsdal*, Pavel Serov, Jochen Knies, Monica Winsborrow, Andé Jensen

rune.mattingsdal@npd.no

During the last couple of years several types of data, including water column data acquired with multibeam echosounder, radar satellite mapping, and seafloor investigations with ROV have revealed a widespread ongoing seepage of hydrocarbons in the Barents Sea, both of oil and gas. So far, thousands of gas seeps have been documented and many potential oil seeps have been discovered. The gas seeping out from the seafloor has been documented as gas flares in the water column and often shows a clear thermogenic signature when sampled by ROV. Some of the oil seeps have also been confirmed visually, both as large oil slicks on the sea surface and as oil droplets seeping out from the seafloor. Some of the perennial oil slicks mapped on satellite data can be more than 10 km long and several hundred meters wide. Sampling and analysis of the oil and gas have revealed important information about the subsurface petroleum systems. The seepage shows a very high correlation with the sub-surface geology, and are controlled by the presence of faults, geological structures and/or sub-cropping reservoirs. The most significant observed clusters of seeps are located on the large geological structures in the northern Barents Sea, often in areas where erosion has exposed Triassic rocks at the seafloor. In the southern Barents Sea, many natural gas seeps have been mapped over known hydrocarbon discoveries. Most knowledge is so far from mapping in areas of the central and eastern parts of the Norwegian Barents Sea. In these areas, the regional distribution of seeps seems in large parts to follow the areas of known or suspected Triassic source rocks.

ICAM9-TS9-10

Petroleum Potential of the Canadian High Arctic Basins

Keith Dewing*, Christopher Lister, Elizabeth Atkinson, Heather King, Lindsay Kung, Thomas Hadlari

keith.dewing@nrcan-rncan.gc.ca

Six distinct geological provinces, each with its own geological history and resource potential, underlie Canadian waters in the Arctic Ocean north and west of Ellesmere Island and the northeastern Canadian Arctic Islands: NE Sverdrup Basin, Deformed Lower Paleozoic basins, Lincoln Sea Basin, Lomonosov Ridge, Alpha Ridge, and NW Canada Arctic Margin. There is very limited geological information in the area, no offshore wells and very limited reflection seismic data, but there are published potential field and refraction seismic datasets. A hydrocarbon resource assessment of these areas was undertaken as part of Canada's ongoing Marine Protected Areas strategy that aims to protect 30% of Canada's offshore areas by 2030.

Quantitative resource estimates were made using Monte Carlo simulations based on parameters derived from local geological information and from similar, hydrocarbon-producing sedimentary basins elsewhere in the world. Risks for each petroleum system element at the play and prospect level were estimated for these areas based on expertise at the Geological Survey of Canada. The estimates of recoverable hydrocarbon for each area are expressed as a range from most likely (P90), to P50 (median estimate), and least likely (P10). No economic cut off was applied, but fields smaller than 1 million barrels of oil equivalent (MMBOE) are not considered.

The highest potential for petroleum resources is in the thick, relatively undeformed sedimentary sequences of the Lincoln Sea Basin and the NW Canada Arctic Margin. The Deformed Lower Paleozoic, Alpha Ridge, and Lomonosov Ridge assessment areas have very low potential due to thin sedimentary cover or complex deformation that would have destroyed any hydrocarbon accumulations. Risked recoverable hydrocarbons expressed as million barrels of oil equivalent are:

Assessment Area	P90 MMBOE	P50 median MMBOE	Mean MMBOE	P10 MMBOE
HAB1_NESverdrup_HALIPinfluenced	**0**	**773**	**1876**	**5261**
HAB2_Deformed_LPaleozoic_Strata	Play COS justifies zero resources			
HAB3_LincolnSea_CanadianWaters	**0**	**224**	**546**	**1601**
HAB4_LomonosovRidge	**0**	**0**	**103**	**107**
HAB5_AlphaRidge-HALIP	Play COS justifies zero resources			
HAB6_NWCanadaArcticMargin	**0**	**1256**	**2563**	**6448**

The large range in the petroleum resource estimate reflects the limited information about the geological elements necessary to generate and trap petroleum.

ICAM9-TS10-1

The first-order crustal structure of the northeastern Canadian Arctic Ocean margin

Randell Stephenson*, Goodluck Anudu, Ashton Embry, Brian Ricketts

r.stephenson@abdn.ac.uk

The Canadian Arctic Ocean margin between the continental Sever Spur and the magmatic Alpha Ridge and continental Lomonosov Ridge is a critical segment for understanding circum-Arctic tectonic evolution and reconstruction because it represents an important link between the formation of Canada Basin, Lincoln Sea and contiguous Eurasia Basin. Available information on the structure of the crust in this area is based on several seismic refraction profiles and potential field analyses, namely gravity inversion and 2-D forward modelling constrained by seismic profiles and spatial interpretation of aeromagnetic data. The seismic profiles mostly cover the shelf and intra-island area, with one profile imaging the crust underlying the Alpha Ridge. Some information from passive seismology receiver functions is available from Ellesmere Island. The maps are extrapolated southwest to the Beaufort Sea benefitting from additional deep seismic reflection and refraction profiling in this area. Using these data, depth to crystalline basement and Moho maps have been constructed (as well as the "isopach" of crystalline crustal thickness by subtracting the former from the latter). The results cannot be interpreted definitively but suggest that Sever Spur represents the continental margin of the main oceanic domain lying within Canada Basin. The main sedimentary depocentre along the northeastern Canadian Arctic oceanic margin (i.e., excluding the Beaufort Sea) is confined to the region adjacent to Ellef Ringnes and Axel Heiberg islands on the continental side and to Stefansson Basin on the oceanic side. The basement and Moho depth maps both suggest a possible link to the Sverdrup Basin (though this may be a superposition effect of more than one independent tectonic basin forming event). There appears to be a narrow, confined sedimentary basin between Ellesmere Island and the contiguous Alpha Ridge and Lomonosov Ridge basement highs. The Moho in this area, however, at least at the at the resolution of the maps, does not display any shallowing beneath the basin but decreases somewhat uniformly ~40 km to ~30 km from the Ellesmere coastline to the parallel Alpha-Lomonosov margin some 100-150 km offshore.

ICAM9-TS10-2

Tectonic Inheritance of the Continental Margin Adjacent to the Canadian Arctic Archipelago

Ashton Embry*, Randell Stephenson

ashtonfoxembry@gmail.com

The continental margin adjacent to the Canadian Arctic Archipelago runs 2000 km from Amundsen Gulf in the southwest to Nares Strait in the northeast. The margin formed with the opening of Amerasia Basin in Jurassic and Early Cretaceous. It is generally interpreted as a rifted margin that developed as the Arctic Alaska-Chukotka microplate rotated counterclockwise away from northern Laurentia.

The margin can be divided into three structural domains along strike. These are defined primarily on the varying depths to Moho and are also reflected in the changing orientation of both the continental margin and the Polar Shelf Magnetic Anomaly. The Southern Domain extends from Amundsen Gulf to northern Prince Patrick Island. It has a general N-S orientation and the depth to Moho contours parallel the shelf edge. This segment of the margin developed at the N-S trending juncture between highly folded basinal strata of the Franklinian Basin in the west (Ellesmerian orogeny) and the mildly to undeformed Franklinian shelfal units to the east.

The Central Domain runs from offshore northern Prince Patrick Island to offshore Ellef Ringnes Island and is characterized by a basinward bulge of the depth to Moho contours (Sever Spur). This domain coincides with the zone of E-W trending Ellesmerian structures in Franklinian basinal strata, as well as by the overlying E-W trending Sverdrup Basin.

The Northern Domain lies offshore of Ellef Ringnes, Axel Heiberg and Ellesmere islands and again has depth to Moho contours that parallel the shelf edge. The exception to this occurs in the area where the margin abuts the crest of the Alpha-Mendeleev Ridge Complex where depth to Moho values greatly increase. The southern extent of the domain corresponds closely with the southern extent of the Alpha-Mendeleev Large Igneous Province in Canada Basin. This segment of the rifted margin developed over the suture zone between Laurentia and the exotic Pearya terrane. It also coincides with the northern margin of Sverdrup Basin.

The notable tectonic inheritances that are associated with the Canadian Arctic margin can be linked to the geometry of the rifted margins of the Franklinian Basin which were established in the Neoproterozoic when the Siberian plate separated from northern Laurentia. The shape of this margin significantly influenced the sinuous trend of the Devonian Ellesmerian orogeny which in turn provided the variable structural trends exploited by the subsequent opening of the Amerasia Basin in the Mesozoic.

ICAM9-TS10-3

The myth of the De Geer Zone

Jean-Baptiste P. Koehl*

jeanbaptiste.koehl@gmail.com

The De Geer Zone is a major, thousands of kilometers long transform fault zone along the western Barents Sea–Svalbard margin that is thought to have accommodated c. 400 km of right-lateral movement in the Cenozoic during the opening of the North Atlantic and Arctic oceans and of the Fram Strait. The fault was first inferred from the physiographic morphology of the conjugate western Barents Sea–Svalbard and northern Greenland margins by du Toit in 1937. Despite numerous references to this major transform zone in subsequent studies, hard evidences of its existence and location remain scarce. Notably, seismic imaging of the De Geer Zone and its main segment off the coast of western Spitsbergen, the Hornsund Fault Complex, is challenging. Thus far, most seismic studies were unable to document the strike-slip character of the De Geer Zone and its main fault segments. New interpretation of high-resolution reflection seismic data northwest of Spitsbergen show that the faults in the area display low to moderate dip, bound (half) graben basins, and accommodated mostly vertical displacement. Since there are neither any evidence of lateral movement, nor any fault and basin geometries typical of strike-slip regime, it is proposed that the De Geer Zone does not exist. Instead, the opening of the Fram Strait and associated 400 km displacement of Svalbard towards the south in the Cenozoic are thought to have been facilitated by (1) lateral displacement along two major, 200 km long transform faults, the Molloy and Spitsbergen fracture zones, in the late Cenozoic, and by (2) contractional reactivation and overprinting (including folding) of newly evidenced, thousands of kilometers long, several to tens of kilometers thick, basement-seated, WNW–ESE-striking Timanian (ca. 600 million years old) thrust systems in Svalbard and the Barents Sea, which may have accommodated N–S-oriented shortening in the order of hundreds of kilometers in the early Cenozoic.

ICAM9-TS10-4

Extensional Tectonic Geomorphology on the NE Atlantic Margin? Investigating Three Half-Graben Basins

Linda C. Haaland*, Per Terje Osmundsen, Tim F. Redfield, Katia Svendby, Kim Senger

lin.haaland@gmail.com

This study investigates landscape evolution along passive continental margins on long timescales.

Recent work from onshore parts of the northeast Atlantic margin suggests that some present-day landforms are inherited from rifting and opening of the North Atlantic Ocean in late Paleozoic, Mesozoic and early Cenozoic times. These relict landscapes are difficult to recognize, as much of the topography is reworked by post-rift Cenozoic uplift and erosion, as well as by repeated glaciations during the Quaternary. For that reason, interpretations of these landscapes vary considerably. However, some of the rift features are demonstrably preserved in the form of half-graben sedimentary basins.

This work uses three half-grabens as study areas to assess possible landscape inheritance from rifting and margin formation. Two of the field sites are located on the Mid-Norwegian mainland. These are the late Jurassic Sortlandsundet half-graben in Vesterålen and the Beitstadfjorden half-graben in Trøndelag. Both half-graben basins are submerged in fjords and have no post-rift cover preserved. The third study area is the late Carboniferous Billefjorden Trough on Svalbard, which in contrast has post-rift cover preserved in both the footwall and hanging wall of the basin-controlling fault, and additionally exposes the entire basin stratigraphy onshore. Thus, the Billefjorden half-graben is an excellent example of how an ancient half-graben basin and its surroundings undergoes erosional disintegration under Arctic climatic conditions.

Preliminary results show that certain landscape features appear to be directly associated with rift-related faulting and/or post-rift fault reactivation, as all three half-grabens are characterized by marked topographical escarpments that run parallel to the basin-bounding normal faults. The formation of these escarpments was likely assisted by erosion into fault cores and damage zones containing fault-rock assemblages. Additionally, all three study areas have very distinct landscape signatures. For example, the Beitstadfjorden landscape appears to be strongly influenced by inherited ductile structures and transposed lithological boundaries. In Sortlandsundet, however, the topography resembles that in actively extending regions. This may indicate that Sortlandsundet experienced later reactivation of the basin's controlling structures. We therefore also conclude that present-day landscape components strongly reflect the pre-, syn- and post-rift history of the region. Important factors include erosional exploitation of pre-rift structures, syn-rift displacement of pre-rift surfaces, possible late-Cretaceous or younger reactivation of basin-bounding normal faults, and variable fluvial and glacial incision.

ICAM9-TS10-5

Stranding of continental crustal fragments during continental break-up: mantle suture reactivation in the Nain province of Eastern Canada

Philip J. Heron*, A.L. Peace, K.J.W. McCaffrey, and R.N. Pysklywec

philip.heron@utoronto.ca

The Earth's continental crust has evolved via a series of supercontinent cycles that have resulted in patchworks of Archaean cores surrounded by terranes, fragments and slivers of Proterozoic (and younger) crustal additions. However, the dispersal and/or stranding of continental fragments during break-up is not well understood. Inherited structures from previous tectonic activity can offer an explanation for the generation of continental terranes through controlling first-order deformation during rifting.

In this submission, we explore the influence of lithospheric deformation related to ancient orogenesis, focusing on the influence of the Torngat Orogen in the origin of the Nain Province continental fragment in Eastern Canada. Using the open-source community code ASPECT, we present 3-D continental extension numerical models in the presence of an inherited lithospheric structure. The results show that a narrow continental terrane could be localized by deep lithospheric scarring.

Our analysis estimates that continental terranes formed by this method would only have a width of 100 – 150 km, limited by subduction conditions during continental suturing. The findings here have broad implications, in particular for the breakup of Arctic continental margins, and demonstrate an original theory on the fundamental geological problem of terrane generation and continental breakup.

ICAM9-TS10-6

Caledonian influence on Mesozoic basin formation, East Greenland

P. Klitzke*, L. Reinhardt, N. Koglin, D. Franke, R. Lutz, K. Piepjohn

peter.klitzke@bgr.de

We examine the late and early post-Caledonian kinematics and their influence on the subsequent rift evolution for the Norway-Greenland region based on a compilation of geochronological data and recently acquired multi-channel seismic reflection data. The geochronological data highlights a late to early post-Caledonian three-stage evolution from late Silurian to early Carboniferous times. Dated eclogites from Greenland (Germania Land Region, Liverpool Land) and Norway (the Western Gneiss Region, Lofoten) document final Caledonian continent-collision between Laurentia and Baltica at around 400 Ma. P-T diagrams show that HP metamorphism occurred in a cold subduction environment except for the eclogites from Germania Land. Despite a similar timing of peak HP metamorphism at 400 Ma, P-T diagrams show that eclogites from Germania Land evolved in a setting of overthickened crust. Following the final collisional episode, a divergent phase involved the collapse of the Caledonian orogenic pile of nappes, the exhumation of deep crustal material and basin formation particularly well studied in the Western Gneiss Region. With termination of metamorphic core complex formation in the Western Gneiss Region at around 375 Ma, significant strike slip tectonics commenced along the Storstrømmen shear zone and the Germania Land Deformation zone onshore East Greenland at 370 Ma and lasting until 340 Ma. UHP metamorphism at 360 Ma within the Germania Land region underlines a significant transpressional stress regime that must have included eastward subduction. Interestingly, published plate tectonic models do not resolve major lateral movements between Greenland and Norway. Alternatively, the significant strike-slip deformation across the Germania Land Region may be the result of lateral extrusion of continental slivers along subvertical lithospheric fault zones, analogue to tectonic processes in Indochina related to the Himalaya-Tibet orogeny. The strike-slip system coincides spatially with the extent of a prominent horst system on the modern Greenland, as well as on the Norwegian margin (i.e. the Danmarkshavn and the Lofoten Ridges). These horst structures are bounded by high angle faults with fault throws of up to 3 s TWT. Late Devonian to Early Carboniferous strike-slip tectonics appear to have formed a N-S oriented template that played a crucial role during Mesozoic and Cenozoic episodes of rifting.

ICAM9-TS11-1

Characterization of Neoproterozoic metasedimentary rocks in the enigmatic Nome Complex, Alaska

Elizabeth L. Miller*, Travis Hudson, Jeffrey M. Amato

elmiller@stanford.edu

Seward Peninsula, adjacent to Bering Strait in western Alaska, lies within a broad zone of Jurassic and earliest Cretaceous convergent margin deformation that extends from the Brooks Range west to the Russian Far East. The region was subsequently intruded by syn-extensional plutons and rising sillimanite gneiss domes in the mid-Cretaceous, overprinting most rocks with a high-strain gently dipping foliation and N-S lineation. This intense deformation coupled with several metamorphic events has made it hard to determine the protoliths, age and origin of strata in the Nome Complex.

U-Pb zircon data now confirm that several areas of exposure of alternating marble, calc-schists, quartz mica schist and orthoquartzite, interpreted as a platformal sequence, is late Precambrian not Paleozoic in age and host to dated 600-700 Ma granitic orthogneiss bodies and minor (undated) mafic intrusive rocks. We informally call this sequence the Mt. Distin assemblage. It is in sharp, pre-metamorphic fault contact with the Casadepaga Schist that yields Neoproterozoic zircon populations ca. 550-750 Ma and older.

Three new U-Pb dated detrital zircon (DZ) populations together with previously reported data from the Mount Distin assemblage have a few 0.9-1 Ga, many 1-1.5 Ga, lesser 1.5-2 Ga, and 1-2 ~2.3 Ga zircons. Three out of four new samples of felsic orthogneiss within this sequence yield (inherited) DZ populations like their host rocks; a fourth sample yielded a more homogeneous zircon population with ca. 660Ma ages and lesser inheritance.

The DZ populations of the Mount Distin assemblage (and inheritance in orthogneiss) are similar to zircon inheritance in a 703 ± 5 Ma pluton on Wrangel Island. They are also similar to DZs of carbonate-bearing sequences in the Central and Schist Belts of the southern Brooks Range, units mapped in Pearya, Arctic Canada, as Group A of Succession II of the Milne Fiord region and the Malochernoretskaya Fm. of Timan.

The discovery and dating of the Neoproterozoic Mount Distin assemblage provides new ability to compare highly deformed rock sequences in Alaska and the Arctic. Their history should help better understand the Neoproterozoic and younger lithospheric evolution of the Arctic.

ICAM9-TS11-2

Timanian fold and thrust system and Caledonian overprint in the Loppa High, Norwegian Barents Sea

Jean-Baptiste P. Koehl*, Israel Polonio, Luis Rojo

jeanbaptiste.koehl@gmail.com

The western Norwegian Barents Sea is located between northern Norway in the south and the Svalbard Archipelago in the north, and consists of a series of late Paleozoic–Cenozoic basins and highs formed on top of Precambrian–lower Paleozoic basement rocks. Among these, the Loppa High is an elongated, N–S-trending structural element partly bounded by post-Caledonian brittle faults. The Loppa High is cored by basement rocks forming a N–S-trending ridge. The late Paleozoic–Cenozoic tectonic history of the Loppa High is relatively well studied and is recorded by thick, overlying and adjacent sedimentary successions deposited during various episodes of post-Caledonian subsidence and tectonic extension. The earlier history of the high is much less understood, mostly because seismic data resolution does not allow accurate mapping of intra-basement reflections and because of the scarcity of exploration wells penetrating basement rocks. A new 3D seismic attribute analysis and spectral decomposition have proven to be an excellent tool for basement characterization, helping to identify and delineate intra-basement geometries. The study reveals the presence of a 40–50 km wide system of E–W folds and thrusts, including a major, 4–5 km thick, top-southwest shear zone. These structures are reworked (folded) by a system of less developed N–S folds and thrusts with top-west vergence, which parallel inferred Caledonian trends in the Barents Sea and adjacent onshore area like Bjørnøya. Since the E–W-trending system of folds and thrusts is orthogonal to and is reworked by Caledonian structures, we propose that it formed earlier, most likely in the latest Neoproterozoic during the Timanian orogeny. In addition, post-Caledonian brittle faults appear to localize along and merge with inherited Timanian structures at depth, thus suggesting repeated partial reactivation/overprint of Timanian structures in the Phanerozoic and a strong influence of these on subsequent faults and basins. Other major implications of this work include (1) the accretion of the Loppa High and the western Barents Sea to northern Baltica (at least) in the latest Neoproterozoic, (2) the location of the Caledonian suture west of the Loppa High, (3) the location of the Timanian suture south of or on the southern edge of the Loppa High.

ICAM9-TS11-3

Detrital zircon signatures of the south-central Brooks Range, Arctic Alaska

Jason W. Craig, Elizabeth L. Miller*

elmiller@stanford.edu

The Brooks Range of Arctic Alaska is a fold-thrust belt related to the closure of the Angayucham ocean, which lay to the south in present day coordinates, and emplacement of a Jurassic arc onto the passive Arctic continental margin during Late Jurassic-Earliest Cretaceous Brookian orogenesis. Several deformational events related to contraction and subsequent extension produced blueschist to greenschist facies mineral assemblages in the Central Belt and Schist Belt in the metamorphic core of the range. Synthesis of existing data in combination with new mapping and U-Pb detrital zircon (DZ) geochronology of pre-Mississippian units (basement to the Brookian passive margin) in the John River drainage (Wiseman quad) were used to identify five DZ signatures that represent unique depositional environments, provenance and/or protoliths of metasedimentary units. Preliminary results, from north to south, indicate that rocks mapped as Hunt Fork Shale in the upper John River include mid-late Devonian "Ambler-age magmatism" signatures with maximum depositional ages (MDAs) between ~380-360 Ma. Middle Devonian-Ordovician signatures comprise an inferred rift basin sequence of metasedimentary strata that includes the mapped Beaucoup Formation, which structurally underlies the Hunt Fork Shale. The Beaucoup Formation overlies a north-dipping shear zone, named the Tangleblue fault, and the underlying package of higher-grade marbles, metasandstone, and schists also yield Ambler-age signatures. To the south, Neoproterozoic-Mesoproterozoic age rocks underlie a broad region along the Central Belt and Schist Belt boundary (MDAs between 1000-600 Ma) and are intruded by leucogranite along Sixty Mile Creek dated as 642 ± 2 Ma. The southern part of the Schist Belt and fault-bound Phyllite Belt to the south contains Hunt Fork Shale-aged and younger(?) protolith equivalents with MDAs ranging from 364-334 Ma. Definition of these DZ spectra that are linked to distinct stratigraphic packages allow initial mapping of units in the metamorphic core of the Brooks Range. In addition, Mesoproterozoic and Neoproterozoic strata yield DZ signatures that link them to similar rock packages that likely underlie a significant portion of the Central and Schist belts in the Brooks Range and Seward Peninsula; collectively they display a strong Baltica provenance signature.

ICAM9-TS11-4

Manifestations of Timanian rock fragments and structures along the northwestern arctic margin

Nikola Koglin, Peter Klitzke*, Solveig Estrada, Karsten Piepjohn

nikola.koglin@bgr.de

The Timanian orogeny affected the northeastern margin of Baltica in late Cryogenian to early Cambrian times. Rocks with Timanian radiometric ages can be found today along the circum-arctic continental margins. Their distribution provides important information for the post-Rodinia palaeogeographic reconstruction of the Arctic. Here we present examples from northwestern Svalbard, North Greenland and the Pearya terrane (northern Ellesmere Island, Canadian Arctic).

The Richarddalen Complex in northwestern Svalbard, now interpreted as Caledonian mélange, comprises to a large extent felsic and mafic meta-igneous rocks with U–Pb zircon ages of 687 and 670 Ma, respectively, partly eclogite-facies metamorphosed at c. 656 Ma, as well as metasedimentary rocks with a dominant detrital zircon population of 730–600 Ma related to a Timanian orogenic event.

Further west, the Midtkap igneous suite in northernmost Greenland forms isolated outcrops in early Palaeozoic deep-water sediments of the Franklinian Basin. The suite of supra-subduction zone origin is composed of intermediate and felsic intrusive rocks, serpentinite, and heterogeneous volcanic breccia (mélange). Intermediate intrusive rocks have Timanian zircon ages of 650–570 Ma and biotite from granite yielded an Ar–Ar age of 535 Ma.

In the composite Pearya terrane, late Cambrian–early Ordovician volcaniclastic sediments of Succession 3 are almost completely sourced from a Timanian volcanic arc as evidenced by detrital zircon ages of 590–560 Ma, peaking at around 570 Ma. The volcaniclastic sediments of Succession 3 rest probably on Timanian arc basement.

Seismic data from the northern Norwegian Barents Sea have revealed Timanian E-W striking structures and suggest the existence of a pre-Caledonian crustal block in the central Barents Sea. During the Caledonian orogeny, fragments of a long-lasting Timanian volcanic-arc system were possibly split off from the block and displaced northwestwards by large-scale sinistral strike-slip movements.