CRYOSPHERE RESEARCH AT MANCHESTER

CRAM Workshop on

# Past, present and future glaciation extents in Greenland and their implications for sea level rise and carbon budgets

The Waterhead Hotel, Ambleside,

Lake District,

20th-21st May 2015

Sponsored by the University of Manchester Research Institute

## Contents

**Welcome to the Cryosphere Research At Manchester (CRAM) workshop on 'Past, present and future glaciation extents in Greenland and their implications for sea level rise and carbon budgets'. We hope that you enjoy the sessions and find some useful collaborations within CRAM.**

## List of Attendees

**Invited delegates:**

| | | |
|---|---|---|
| John Anderson | Loughborough University | N.J.Anderson@lboro.ac.uk |
| Karin Andreassen | Arctic University of Norway | karin.andreassen@uit.no |
| Liz Bagshaw | Cardiff University | BagshawE@cardiff.ac.uk |
| Rob Bingham | University of Edinburgh | r.bingham@ed.ac.uk |
| John Clayburn | Cairn Energy | John.Clayburn@cairnenergy.com |
| David Fink | Australian Nuclear Science and Technology Organisation | david.fink@ansto.gov.au |
| Andy Hein | University of Edinburgh | andy.hein@ed.ac.uk |
| Paul Knutz | GEUS | pkn@geus.dk |
| Gareth Phoenix | University of Sheffield | g.phoenix@sheffield.ac.uk |
| Brice Rea | University of Aberdeen | b.rea@abdn.ac.uk |
| Phil Wookey | Heriott Watt University | p.a.wookey@hw.ac.uk |

**CRAM members:**

UoM - University of Manchester, MMU - Manchester Metropolitan University

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|---|---|---|
| Kathryn Adamson | MMU | K.Adamson@mmu.ac.uk |
| Richard Bardgett | UoM | richard.bardgett@manchester.ac.uk |
| Roger Braithwaite | UoM | roger.braithwaite@manchester.ac.uk |
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| Simon Cook | MMU | S.J.Cook@mmu.ac.uk |
| Cathy Delaney | MMU | C.Delaney@mmu.ac.uk |
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| Robert Sparkes | UoM | robert.sparkes@manchester.ac.uk |
| Bart van Dongen | UoM | Bart.VanDongen@manchester.ac.uk |

# Workshop Programme

**Wednesday 20th May 2015**

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9:30-10:15 Coffee and registration

10:15-10:30 Welcome by Laura Edwards

10:30-12:15 **Terrestrial palaeoglaciology and contemporary glaciology theme**

- 10:30 Liz Bagshaw 'High resolution monitoring of hydrological processes on the Greenland ice sheet'
- 10:45 Rob Bingham 'Use of geophysical techniques to analyse subglacial environments'
- 11:00 David Fink 'Accelerator Mass Spectrometry and the technique of in-situ cosmogenic radionuclide exposure age dating'
- 11:15 Andy Hein 'Ice history from blue-ice areas of the southern Ellsworth Mountains, Antarctica'
- 11:30 CRAM talk 'Terrestrial palaeoglaciology and contemporary glaciology'
- 11:45 Discussion

12:15-13:30 Lunch

13:30-15:15 **Marine geophysics/palaeoglaciology theme**

- 13:30 Karin Andreassen 'Glaciations in the Barents Sea area and links with fluid flow from deeper hydrocarbon reservoirs'
- 13:45 Paul Knutz 'Architecture and depositional evolution of trough-mouth fans (TMF) on the Baffin Bay-West Greenland margin'
- 14:00 Brice Rea 'Greenland Ice Sheet outlet glaciers across four temporal orders of magnitude'
- 14:15 John Clayburn 'Cairn in Greenland'
- 14:30 CRAM talk 'Offshore Greenland Projects at Manchester'
- 14:45 Discussion

15:15-15:45 Coffee

15:45-17:15 **Carbon/glacial biosphere theme**

- 15:45 John Anderson 'Organic Carbon dynamics in SW Greenland Lakes: controls and regional significance'
- 16:00 and Gareth Phoenix 'Arctic ecosystems and carbon cycling: climate change responses scaling through simplification'

- 16:15 Phil Wookey ‘Cryosphere/biosphere interactions in the Arctic and the role of anthropogenic drivers of change’
- 16:30 CRAM talk ‘Carbon cycling in the Arctic; from molecular-level investigations to large scale observations’
- 16:45 Discussion

17:15-17:30 Summary and close of day one

19:00-20:00 Wine reception with canapés

20:00 Workshop dinner

**Thursday 21st May 2015**

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9:15-9:30 Day 2 introduction

9:30-10:45 Breakout session

10:45-11:15 Coffee

11:15-12:15 Breakout session feedback

12:15-13:30 Lunch

13:30-14:45 Breakout session

14:45-15:15 Coffee

15:15-16:15 Breakout session feedback and close of meeting

16:15-17:15 Coffee

# Talk titles and abstracts

## *Research Theme 1 – Terrestrial palaeoglaciology and contemporary glaciology*

**Liz Bagshaw**

**High resolution monitoring of hydrological processes on the Greenland ice sheet**

Technological development has afforded a variety of new tools to assess processes occurring on, within and beneath the Greenland ice sheet. Wireless sensors can enable the collection and broadcast of data from the depths of crevasses, englacial passages, proglacial lakes and the ice sheet bed. Chemical sensors can deliver high resolution, continuous records of biogeochemical changes in meltwater on the ice sheet surface and emerging from the subglacial environment. These records may be used to interpret changes occurring in microbial populations throughout the melt season, and to understand how glacial microbial communities can impact global carbon and nutrient budgets via their influence on downstream ecosystems. This wide-ranging talk will introduce the innovative tools I use to monitor and interpret the glacial environment.

**Rob Bingham**

**Use of geophysical techniques to analyse subglacial environments**

Numerous studies show that conditions at the bed of ice sheets determine their ice dynamics, and in so doing mediate the response of the ice sheets to climate and oceanic perturbations. Because subglacial environments are (almost by definition) inaccessible, a range of geophysical techniques are commonly deployed to infer basal properties relevant to ice dynamics, most commonly bed forms, geology and presence/absence of water. Here I will present a selection of examples pertaining to geophysical recovery of basal conditions from West Antarctica, with the aim of initiating discussion on their potential transfer to studies of the Greenland Ice Sheet.

**David Fink**

**Accelerator Mass Spectrometry and the technique of in-situ cosmogenic radionuclide exposure age dating.**

Accelerator Mass Spectrometry is recognized as one of the most significant advances in analytical isotope research in the 20th century. Since the 1980's its impact in science and technology has been immeasurable. In all subjects related to the study of planet Earth, geologic and biologic, past and present, the outcomes facilitated by the unprecedented

sensitivity afforded by AMS have resulted in paradigm shifts of prevailing concepts and models. Measurement of miniscule concentrations of cosmogenic radioisotopes produced in the atmosphere or within the shallow lithosphere in a myriad of natural archives has given scientists a means to quantify the spatial and temporal scales of processes and interactions which shape our planet.

In addition to revolutionising the art of radiocarbon dating, the technique of cosmogenic radionuclide exposure dating has revolutionised glacial chronologies and landscape process research. In this talk, I will present a short summary of the basic principles of the method and technique.

**Andy Hein**

**Ice history from blue-ice areas of the southern Ellsworth Mountains, Antarctica**

Our understanding of the current behaviour of the Antarctic Ice Sheet, and our ability to model its future behaviour, is enhanced with quantitative information on longer-term trajectories of change. One area where such data can be obtained is from inland nunataks. Here, it is possible to constrain past changes in the thickness of the ice sheet by determining exposure ages for sediment deposited on the flanks of nunataks. By measuring the concentration of cosmogenic nuclides that accumulate in rock minerals exposed at the Earth's surface, the duration of exposure can be determined. This can be used to track the trajectory of ice sheet change through time. I will present geomorphic mapping and exposure age dating of blue-ice areas in the southern Heritage Range of the Ellsworth Mountains, Antarctica. We measured cosmogenic 10Be, 26Al and 21Ne in quartz-bearing lithologies exotic to the nunataks. The use of multiple isotopes can help us to investigate exposure histories. The geomorphic mapping and cosmogenic nuclide dating together help us to determine the upper limit of the ice sheet during the last glacial cycle and its trajectory of change. Our new data indicate an ice history extending back beyond 1.4 million years. I will discuss these new data and the insight they give on the behaviour of this part of the West Antarctic Ice Sheet.

**CRAM: Terrestrial palaeoglaciology and contemporary glaciology theme talk**

**Rocks, Ice, & Satellites**

Our research comprises a diverse range of glacial related topics and routes of investigation over Pleistocene to contemporary timescales. Our interest include: glacier controlled landscape scale dynamics and erosion over long (geomorphic) timescales (Brocklehurst, Dortch); glacial chronology, valley morphology, sediment production, and meltwater influenced sediment transport over the last several glacial cycles (Adamson, Cook, Delaney, Hughes); and contemporary ocean-ice dynamics, glacier modelling, surface mass, and energy balance (Braithwaite, Edwards). There is strong research overlap between us and we all contribute to more than one topic. The methods utilized by our group's ranges from:

thermochronologic and cosmogenic methods to obtain “dates & rates”; modelling on various timescales of glaciated landscapes, glacier dynamics, and proxies; mapping and field investigation, and a strong theme of GIS analysis of DEMs and imagery.

## *Research Theme 2 – Marine geophysics/palaeoglaciology*

**Karin Andreassen**

**Glaciations in the Barents Sea area and links with fluid flow from deeper hydrocarbon reservoirs**

The Barents Sea has been covered by grounded ice sheets reaching the continental shelf breaks numerous times over the last 1.5 million years. Large trough mouth fans (TMFs) at the mouth of troughs that extend to the shelf break contains up to 3-4 km of Plio-Pleistocene glacial sediments. Whereas as the Barents Sea margin TMFs are important sedimentary archives of glacial activity over 2.6 million years, landforms on the seafloor of the continental shelf are imprints from activity of the Barents Sea – Fennoscandian Ice Sheet (BSFIS) since LGM. The integration of 3D seismic geomorphology with stratigraphy documents the importance of glacial processes in the evolution of this area. Studies of the former BSFIS have relevance far beyond the regional scale, as they may serve as analogues for marine parts of contemporary ice sheets.

3D seismic and seafloor bathymetry data from the Barents Sea continental shelf and margin reveal spatial links between distribution of inferred glacitectonic geomorphic landforms, fluid flow from deeper hydrocarbon reservoirs, ice sheet retreat and gas expulsion into the ocean and atmosphere. Empirical data will be presented and processes involved discussed. The results have implications for potential gas expulsions from disintegrating polar ice sheets in a warming climate.

**Paul Knutz**

**Architecture and depositional evolution of trough-mouth fans (TMF) on the Baffin Bay-West Greenland margin**

Kilometre-thick prograding wedges that straddle the Greenland margins form the depositional product of paleo-icestreams and glacial margins that during cold stages advanced across the continental shelves. As such these sedimentary packages contain long-term records of Greenland Ice Sheet variability. On the west Greenland margin toward Baffin Bay the imprint of paleo-icestreams is seen by erosional troughs crossing a >250 km broad shelf that caps a series of Mesozoic-Tertiary sedimentary basins. This presentation provides an overview of the seismic stratigraphy, borehole tie and examples of seismic facies of the Melville Bay TMF based on a dense grid of 2D seismic data. The wider aim is to elucidate the external mechanisms for TMF evolution linked to climate and tectonics.

**Brice Rea**

**Greenland Ice Sheet outlet glaciers across four temporal orders of magnitude**

The marine terminating outlet glaciers from the GrIS are the major flux gateways routing ice from the inlandsis to the sea and many are grounded in troughs below sea level which extend some way inland of the present margin. The instrumental record is short and calving models are concomitantly poorly calibrated/validated over longer timescales. Outlet glacier retreat chronologies based on marine and terrestrial geomorphology and dated using 14C, cosmogenics and OSL, provide empirical data to contextualise the present retreat rates and also to calibrate and validate numerical models of outlet glacier dynamics. Details of deglacial, Holocene and millennial timescale projects from west (Uummannaq and Kangersuneq) and east Greenland (NEGIS) will be presented. Across the Pliocene and Quaternary the outlet glaciers have progressively incised the continental margins and shelves generating relief and transporting and delivering sediments to the shelf edge. This process of landscape evolution has implications for evolving ice dynamics and crustal loading/unloading. The shelf and slope glacial deposits contain many shallow clastic reservoirs which may become gas-charged impacting drilling and exploration. Improving our understanding of the longer term landscape evolution of Greenland offers the potential for collaboration across a range of disciplines generating outputs of both a scientific and applied nature.

**John Clayburn**

**Cairn in Greenland**

The talk will focus on the drilling and seismic activities of Cairn in Greenland since they acquired exploration acreage in Baffin Bay. It will tell a short story on what was done and what was necessary to be able to complete a complex and difficult operation

**CRAM: Marine geophysics/palaeoglaciology theme talk**

**Offshore Greenland Projects at Manchester**

Marine geology and geophysics in Manchester comprises principally work with geophysical data intended to recover the morphology of the modern seabed and subsurface strata ranging from the LGM to the Palaeozoic. These data are used in a variety of environments. In high-latitude margins and previously glaciated margins, our work has addressed structures left by ice flowage, subglacial water flow and glacial deposits including the North Sea, Irish Sea, Antarctica and Australia.

The Basin Studies and Petroleum Geoscience Group at Manchester has recently started projects in the Melville Bay and Scoresby Sund areas offshore NW and East Greenland. The projects, which are jointly funded by NERC and Cairn Energy, aim to unravel the continental margin development during environmental change from pre-glacial conditions to repeated

glaciation at the shelf edge in order to compare and contrast this evolution to the evolution of the mid Norwegian margin.

The datasets utilized include industrial 2D and 3D seismic data, multibeam bathymetry, seabed cores in NW Greenland, and 2D seismic and ODP borehole data in East Greenland. These databases are representative for the types and density of industry and DSDP/ODP/IODP data available along the Greenland margins and thus provide a good starting point for assessing the offshore element of source to sink and other onshore-offshore linked projects.

The strongly progradational margin architectures observed along the NW Greenland margin are strikingly similar to the mid Norwegian margin whereas the more aggradational Scoresby Sund margin suggests much greater subsidence rates, which may explain the apparent absence of grounding zone wedges in this area. Both margins present opportunities to constrain the onshore exhumation and glacial history, but further constraints are needed in order to date the deposits, both on multi-million year and thousand year timescales and high quality high-resolution seismic data and multi-beam bathymetry data are required to image deposition since the LGM.

## *Research Theme 3 – Carbon/glacial biosphere*

**John Anderson**

**Organic Carbon dynamics in SW Greenland Lakes: controls and regional significance**

Lakes are a key feature of arctic landscapes and can be an important component of regional organic carbon budgets. Although numerous, arctic lakes are comparatively under-studied and organic carbon burial rates are not well prescribed. Moreover, it has been proposed that regional warming will increase aquatic production but also result in deepening of the thaw layer in permafrost and hence lateral transfer of POC/DOC. Lake sediment records can be used to examine past changes in C burial rates and how they have responded to past warming (the Hypsithermal) and/or cooling, such as Neoglacial cooling. Analyses of ~15 $^{14}$C-dated Holocene records and 16 $^{210}$Pb-dated short cores along Søndre Strømfjord allows an assessment of the regional variability of carbon burial and associated catchment ecological changes/drivers at a range of spatial and temporal scales. The study lakes span a range of water chemistries (conductivity values range 25–3400 µS cm$^{-1}$), DOC concentrations (<5 - >80 mg C l$^{-1}$) lake areas (<4–77 ha), and maximum depths (range ~10–50 m). Analyses of Holocene C profiles show a clear interaction between catchment processes, notably soil instability associated with Neoglacial cooling. The average 20$^{th}$ century OC AR rate (derived from all lakes) corrected for sediment focussing (using the mean $^{210}$Pb flux method) is low (<3 g C m$^2$ yr$^{-1}$). The implications of these data for regional carbon sequestration by lakes, past and present, are discussed.

**Gareth Phoenix**

**Arctic ecosystems and carbon cycling: climate change responses and scaling through simplification**

Arctic ecosystems are experiencing greater climate change than most other regions of the world, with major consequences for both ecosystem change and carbon balance. Our research uses a combination of climate simulations and landscape gradient approaches to assess the impacts of a range of climate change driver on arctic terrestrial ecosystem. Our work includes assessment of trend changes such as warming, precipitation and snow regime change, and climatic events such as extreme winter warming. Our recent research on the latter has revealed the considerable damage to vegetation and reduced carbon sink capacity of arctic landscapes that results from these extreme winter events. This is in sharp contrast to the much studied "greening" of the Arctic arising from trend warming. Our landscape approaches allow us to study environmental and ecosystem controls on carbon balance. A theme in recent work is the elucidation of tight coupling between carbon sequestration, stocks and turnover, and readily and simply quantifiable parameters such as leaf area index (LAI). Since LAI can be remotely estimated at a range of scales using hand held, aircraft and satellite sensors, these relationships significantly simplify estimation of key components of the carbon cycling in the large, heterogeneous and remote landscapes of the Arctic.

**Phil Wookey**

**Cryosphere/biosphere interactions in the Arctic and the role of anthropogenic drivers of change**

As a researcher new to CRAM this presentation will give a very brief overview of my track-record and interests, as well as indicating how my research might dovetail with CRAM planning for the future. Briefly, however, I started my research in the Arctic 22 years ago, with a focus on plant and ecosystem process responses to experimental manipulations of temperature, precipitation and nutrient availability. Since then I've become strongly involved in ITEX (the International Tundra Experiment), and have been involved in, or led, several research programmes, mainly with EU, Swedish Research Council (VR) and NERC support. Over time, my research has become more directly 'biogeochemical' in emphasis, addressing issues such as greenhouse gas fluxes and soil organic matter dynamics, and exploring the coupling between ecosystem processes and global change drivers. In the mix includes a recent emphasis on interactions between the biosphere and cryosphere (both seasonal snow cover and frozen ground, as well as permafrost).

During the CRAM workshop I would be very keen to take an 'Earth System Science' approach that would complement ongoing NERC Arctic Programme work where we are researching land-atmosphere and land-freshwater fluxes of carbon in rapidly-changing permafrost catchments (but not currently following this into deltaic/estuarine or marine systems). In the context of Greenland, I'm interested in the implications of landscape change through, for example, deglaciation and permafrost-driven processes (e.g.

thermokarst or thaw lake dynamics) for ecosystem processes in the terrestrial, freshwater and marine realms. The opportunities for work on chronosequences (with some scope for 'space-for-time' approaches) are obvious, as are the opportunities to cover a very broad spectrum of 'environmental space' from sub-arctic systems in the far south, to the high-Arctic barrens of Thule and Peary Land.

**CRAM: Carbon/glacial biosphere theme talk**

**Carbon cycling in the Arctic; from molecular-level investigations to large scale observations.**

Carbon cycling in Glacial/Arctic environments has been the focus of a range of research groups at the University of Manchester (UoM), varying from molecular-level investigations of the environmental processes involved to large scale observations using the FAAM aircraft. During this presentation the (unique) capability available in the UoM, both in the Faculty of Life Sciences and the School of Earth, Atmospheric and Environmental Sciences, related this theme will be presented, combined with highlights from recent (Arctic related) research projects.

## Attendee brief introduction paragraphs

### *Invited delegates:*

**John Anderson, Department of Geography, Loughborough University**

John's research interests initially focussed on the development of diatoms as quantitative biological and environmental indicators and the usefulness of quantitative palaeolimnology as a management tool, particularly in relation to disruption of biogeochemical cycles, i.e. lake eutrophication and acidification in the UK and Scandinavia. Today, his research is concerned with lake response to natural and anthropogenic environmental perturbations over a range of timescales and the importance of lake-catchment interactions, both in the Arctic and alpine catchments in SW China.

He has worked in South-West Greenland (Søndre Strømfjord; Kangerlussuaq) for the last ~20 years on a range of topics, including lake-climate interactions, palaeolimnological reconstructions of effective precipitation and timescales of Hg and Pb pollution. His present work in SW Greenland focuses on the role of lakes in carbon cycling (funded by NERC ARP), including carbon sequestration and carbon dioxide fluxes from lakes. A parallel, ongoing NERC funded project (joint with Prof. Graham Underwood at the University of Essex) is concerned with characterising the nature, quality and dynamics of DOC in the Kangerlussuaq lakes and its implications for C processing.

**Karin Andreassen, Arctic University of Norway, Tromso, Norway**

Karin has an MSc in Glacial geology and a PhD in Applied Geophysics. Her research interests include: Cenozoic development of the Barents Sea area; Glacial geomorphology, landforms, sediments and processes; Reconstructing former ice sheet- and ice stream dynamics; Links between glacial processes, gas hydrates and fluid flow from deeper hydrocarbon reservoirs; 4D seismic time lapse studies to understand the dynamics of gas leakage to the ocean and atmosphere.

Karin's current funded research projects include: Centre of Excellence in Arctic Gas Hydrate, Environment and Climate (CAGE; 2013-2023; Ass. Director and PI); Centre for Arctic Petroleum Exploration (ARCEx: 2013-2021; Director 2013-2015); Glaciations in the Barents Sea area (2011-2015; PI); Glaciated North Atlantic Margins (GLANAM; 2013-2016; PI).

Karin also has a number of PhD students working on topics related to her funded projects.

**Liz Bagshaw, School of Earth and Ocean Sciences, Cardiff University**

Liz is a glaciologist with particular interest in biogeochemical processes in the cryosphere, and in the development and testing of new technologies to monitor them. She has conducted over ten seasons of fieldwork in Antarctica and Greenland, monitoring the impact of physical processes on microbial communities through geochemical changes in meltwater. Current projects include: testing of new generation sensors for pH and H2S in glacial runoff; development of wireless sensors for measuring simple parameters in UK rivers and subglacial melt channels; microsensor monitoring of carbon exchange in glacier surface ecosystems.

**Rob Bingham, School of Geosciences, University of Edinburgh**

Rob is a glaciologist with particular interests in using geophysical techniques to investigate the subglacial environment. He has an especial focus on Antarctica, though also work at times in the Arctic. He also works on landscape evolution, especially in the field of linking the modern subglacial environment beneath the contemporary ice sheets of Antarctica and Greenland to deglaciated landscapes left behind by the retreat of ice sheets across the Northern Hemisphere. Rob is actively involved in several NERC-funded projects in West Antarctica, including the NERC iSTAR programme on Pine Island Glacier, and projects on the Bellingshausen Sea coast and Weddell Sea area.

**John Clayburn, Cairn Energy**

John is currently Head of Exploration at Cairn Energy. He graduated from Oxford with a D.Phil in radiogenic isotope geochemistry and geochronology (in 1982). He has published his research on Crustal timing, origins and growth in Nature, The Royal Society and Earth and Planetary Science Letters. Since his PhD he has gained more than 30 years in the oil industry with Shell, Petronas, Repsol, and Cairn living in 10 different countries and working in more than 100. He has been involved in hydrocarbon discoveries of over 4 billion barrels of CR and reserves, including appraisal and developments of the equivalent. These account for some of the world's major finds including the recent SNE discovery in Senegal reported as the world's biggest in 2014.

Cairn are studying The Barents Sea region and are very active in Greenland and have supplied Greenland data to the University of Manchester. Cairn also sponsor Andrew Newton's PhD under Mads Huuse.

**David Fink, Australian Nuclear Science and Technology Organisation (ANSTO)**

David is a Senior Principle Research Scientist at ANSTO and an expert in Accelerator Mass Spectrometry (AMS). He is Group Leader at the ANTARES AMS Facility (a global leader in the field of AMS) and leader of the flagship project 'Cosmogenic Climate archives in the Southern Hemisphere'. He has been involved with the development and application of AMS in archaeology, paleoclimate change, landscape evolution, Antarctic glaciation, biomedical bomb-pulse radiocarbon tracing, and meteorites. His current research focuses on 1) comparing glacial chronologies of Tasmania and New Zealand with northern hemisphere records, 2) paleo-climate change in Antarctica, 3) assessing the interplay of tectonics and climate on the rate of bedrock landscape denudation, 4) using cosmogenic isotopes to study basin-wide erosion and sediment generation, and 5) using stable isotopes in fossil Pacific ocean coral records to determine if past ENSO cycles are different from today.

**Andy Hein, School of Geosciences, University of Edinburgh**

Andy is a glacial geomorphologist specialising in the application and development of the cosmogenic nuclide dating technique. His research concerns reconstructing the dimensions (thickness, extent) of ice sheets at different times in the past, and constraining the timing and trajectory of changes using cosmogenic nuclide dating of glacial erratics. In recent years his research has focused on understanding the evolution of the Antarctic and Patagonian Ice Sheets. He also manages the University of Edinburgh's Cosmogenic Nuclide Laboratory where they routinely measure rock sample cosmogenic Be-10, Al-26, Cl-36 and Ne-21 and have the capacity to support collaborative research projects.

**Paul Knutz, GEUS, Copenhagen**

Paul is a senior scientist at the Geological Survey of Denmark and Greenland. He has more than 15 years' experience as a marine geologist/geophysicist and project leader, primarily by working in a cross-disciplinary public sector research environment with strong links to the industry. He is interested in all aspects of continental margins (icesheet-climate history, tectonic and paleo-oceanographic evolution, sedimentary processes and economic relevance, e.g. hydrocarbon

resources) and has participated in several coring/drilling expeditions, mainly in the North Atlantic and Arctic region. His current research interest is in understanding the development of the Baffin Bay-West Greenland margin and its significance for Arctic gateways and Greenland Ice Sheet evolution.

**Gareth Phoenix, Department of Animal and Plant Sciences, University of Sheffield**

Gareth is a Reader in Plant Ecology at the Univerity of Sheffield. His core research interests are in arctic ecology and biogeochemistry. This includes the impacts of climate change (warming, extreme events, snow regime change, permafrost thaw, precipitation), UV-B radiation and pollution on high latitude ecosystem structure and function, biodiversity, and cycling of carbon, nitrogen and phosphorus. His work also seeks to understand how responses observed at the vegetation/ecosystem level are driven by individual plant, root and leaf responses.

**Brice Rea, School of Geosciences, University of Aberdeen**

Brice's main research focus is glaciers and glaciation, both process and palaeo and includes: glacial geology, geomorphology and sedimentology; glacier-climate interactions and glacier dynamics; physical processes in ice with a focus on basal ice rheology, chemistry, sliding friction, erosion and subglacial sediment deformation. He is also interested in permafrost slope movements (solifluction), and in glacier/permafrost interactions and cold-climate weathering processes and remnants. These areas of research are all integrated through work on long-term landscape evolution in mid- and high-latitudes where the role of glacial, periglacial and paraglacial processes are of prime importance. His approach to research utilises a combination of field-based data collection in both contemporary and formerly glaciated landscapes with numerical and physical modelling.

**Phil Wookey, School of Life Sciences, Heriott Watt University**

Phil is a biogeochemist/ecosystems ecologist with an emphasis on global change science and a formal training in both biology and geography. He has a keen interest in placing ecological processes into their temporal and spatial contexts within the Earth System. Essentially he wants to understand how ecosystems work, how they respond to the environment (and environmental change) and how they, in their turn, influence the Earth System (i.e. the carbon cycle and climate system). Since the early 1990s much of his work has been conducted in the Arctic, and he is particularly interested in cryosphere/biosphere interactions, and how these are coupled with the atmosphere and climate system. Research highlights include publications in Ecological Monographs, PNAS, Ecology Letters, Nature Climate Change and Nature.

Current and recent funded research projects include: Permafrost catchments in transition: hydrological controls on carbon cycling and greenhouse gas budgets (NERC ARP 2012-2016, PI Phil Wookey); Determining the role of permafrost thaw in controlling rates of methane release from terrestrial high-latitude ecosystems (DECC-funded supplement to NERC ARP 2014-2015); Global Change, Arctic Hydrology and Earth System Processes (ARCHES) (International Arctic Science Committee (IASC)-funded, 2013-2014, PI Phil Wookey); Thermal Acclimation of Soil Microbial Respiration (NERC 2010-2013).

## *CRAM delegates:*

(UoM - University of Manchester, MMU - Manchester Metropolitan University)

**Kathryn Adamson (MMU)**

Kathryn's research is focused on Quaternary meltwater systems and ice cap dynamics, at field sites in the Mediterranean and the Arctic. She uses a range of techniques including geomorphology, sedimentology, micromorphology, Uranium-series and surface exposure dating.

**Richard Bardgett (UoM)**

Richard's research is broadly concerned with understanding the role of interactions between plant and soil communities in regulating the structure and function of terrestrial ecosystems, and their response to global change. This work is done in a range of ecosystems, including glacial forelands, alpine grasslands, and arctic ecosystems.

**Roger Braithwaite (UoM)**

Roger's long-term work is focussed on glacier mass balance. Recent work includes (1) an appreciation of the pioneering glacier-climate research of Herfried Hoinkes (1916-1976); (2) verification of the Kurowski (1891) method to estimate the balanced budget ELA of a glacier; (3) evaluation of recent changes in glacier mass balance.

**Simon Brocklehurst (UoM)**

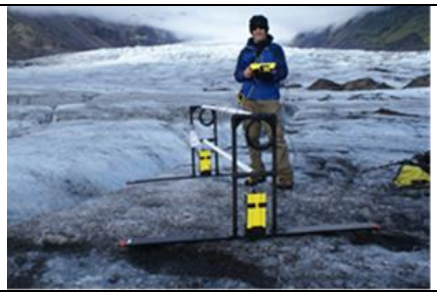
Simon's research in geomorphology concerns landscape evolution on timescales up to the duration of the Quaternary, to investigate how mountain ranges respond to climate change (glaciation) and active tectonics. The techniques he uses include field and remote mapping, digital topographic analysis, numerical modelling and Quaternary dating.

**Emma Chown (UoM)**

Emma is the research assistant for the CRAM group. She completed an MSc in Geographical Information Science in 2014, for which her dissertation project was titled 'Controls on the ice front positions of eastern outlet glaciers on the Greenland Ice Sheet from 2009-2013'.

**Simon Cook (MMU)**

Simon is a geoscientist with interests in glaciology and alpine geomorphology. He has particular interests in glacial erosion and sediment transfer, the generation of large-scale glacial landforms, glacial and post-glacial landscape evolution, glacial lake outburst floods, and the geomicrobiology of basal ice.



**Cathy Delaney (MMU)**

Cathy's research is focused on palaeoglaciological reconstruction using sedimentology and geomorphology, focusing on meltwater routing and fluxes. She uses Lidar to identify low-amplitude landforms (e.g. crevasse squeeze ridges) within deglacial landsystems; and investigating the use of varved glaciolacustrine sediments in reconstructing deglacial dynamics.

**Jason Dortch (UoM)**

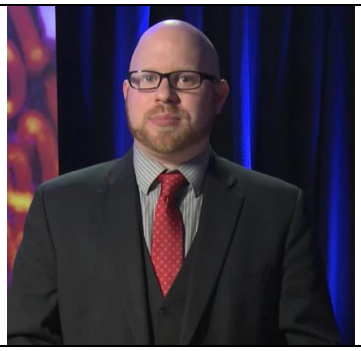
Jason has undertaken several studies using terrestrial cosmogenic nuclide (TCN) methods to understand the nature, timing, and climatic correlation of past glaciation. He also employs catchment-wide erosion rates to elucidate how erosional processes shape high-mountain landscapes.

**Laura Edwards (UoM) – Head of CRAM**

Laura's research focuses mainly on contemporary changes in the ice sheets, as well as glaciers in Iceland and Bolivia (however some of her previous research has focused on $CO_2$ flux in polar regions and ocean acidification). Laura's work involves satellite remote sensing (SAR interferometry and altimetry), ice modelling, and fieldwork in Greenland, Iceland, the Canadian Arctic and Bolivia.

**Jonathan Fairman (UoM)**

Jonathan's cryospheric research has been on glacial environments and glaciers themselves using atmospheric models as well as mass-energy balance and ice flow models respectively.



**Phil Hughes (UoM)**

Phil has extensive experience investigating the glacial history of Mediterranean mountains. He is also interested in the Quaternary glacial history of the British Isles especially Wales and neighbouring areas, and theoretical advances in glacier-climate reconstruction, geomorphology, and stratigraphy in Quaternary Science.

**Mads Huuse (UoM)**

Mads is interested in the glaciogenic processes and the record of formerly glaciated areas ranging from the Palaeozoic to the late Pleistocene. His main research tool is reflection seismic data which allow whole margin- and basin-scale architectures and sediment budgets to be resolved whilst also imaging details of iceberg and ice stream scour, tunnel valleys and glacial tectonics.

**Neil Mitchell (UoM)**

Neil is a submarine geomorphologist who is interested in seabed features produced by erosion by ice or deposits left by ice. These studies, in collaboration with now finished PhD students and researchers in the BAS and University College Cork, have involved work with multibeam sonar and other geophysical data.

**Andrew Newton (UoM)**

Andrew is a PhD student using stratigraphical techniques to image and reconstruct glacigenic landforms and sediments from 3D and 2D seismic reflection data for the mid-Norwegian shelf, its conjugate margin off East Greenland, and also Baffin Bay off West Greenland. The project will provide a better understanding of shelf edge glaciations and their dynamics.

**Robert Sparkes (UoM)**

Robert is a Post-Doctoral researcher working to understand and quantify the transfer of organic matter from terrestrial to marine systems. He studied organic carbon transport and deposition processes in Taiwan, Spain and Italy before working in the Arctic to investigate the effects of climate change on Siberian permafrost.

**Bart van Dongen (UoM)**

Bart is particularly interested in improving our understanding of the fate of the terrestrial carbon currently liberated from the Russian Arctic tundra/taiga areas, and transported to Arctic shelf regions by the Russian Arctic rivers and through coastal including the effects of climate warming on the remobilization and degradation on the Arctic shelf.

# CRAM member list

**University of Manchester**

School of Environment, Education and Devlopment:

- Roger Brathwaite
- Emma Chown
- Jason Dortch
- Laura Edwards – Head of CRAM
- Phil Hughes
- Wilfred Theakstone
- Jamie Woodward

School of Earth, Atmospheric and Environmental Sciences

- Grant Allen
- Simon Brocklehurst
- Richard Dixon
- Jonathan Fairman
- Martin Gallagher
- Mads Huuse
- Rachel Lamb*
- Neil Mitchell
- Andrew Newton*
- Carl Percival
- Jonathan Redfern
- Clare Robinson
- David Schultz
- Robert Sparkes
- Bart Van dongen

School of Mathematics:

- David Abrahams
- Geoff Evatt
- Nico Gray
- Matthias Heil

Faculty of Life Sciences:

- Richard Bardgett

**Manchester Metropolitan University**

- Kathryn Adamson
- Mike Bennett
- Simon Cook
- Cathy Delaney

- David Elliott
- Robin Sen
- Graham Smith
- Mario Toubes*

**University of Salford**

- David Collins
- Marc Matterson*

* denotes PhD student