CAGE - Centre for Arctic Gas Hydrate Environment and Climate Report Series, Volume 4 (2016)

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Modifications:
This version of the annual report has been modified from the original published in 2016.
Below is an overview of the changes made.

- Impact factor values have been removed from page 32 (Publications list)

UiT

THE ARCTIC
UNIVERSITY
OF NORWAY

Annual Report 2016

CAGE – Centre for Arctic Gas Hydrate, Environment and Climate

CAGE

Norwegian Centre of Excellence

UNIVERSITY OF TROMSØ

HIGHLIGHTS FROM THE FIRST FOUR YEARS:

2013–2017 from ambitions to breakthroughs

In this report, you will read of the leading scientific breakthroughs CAGE has achieved during its brief journey, setting the stage for our midway-evaluation. We are now at the forefront of cutting-edge gas hydrate related environment and climate research. The quality, quantity and breadth of our activities, results and outputs reflects not only the drive and excellence of the seven individual work package teams but, moreover, how they have effectively combined to provide a truly interdisciplinary framework fit to tackle major scientific questions of global relevance.

Leading the conversation

During its first four years, CAGE has firmly established itself as a world leader in gas hydrate research. In numbers, research from our scientific staff and PhD students has already produced over 170 publications in peer-reviewed journals (15 in Nature publications), over 400 conference presentations, and has been promoted internationally in more than 200 items – including features in the Washington Post, New Scientist, Daily Mail and Marine Technology Reports.

Furthermore, CAGE now plays a prominent role in the discourse of gas-hydrate research, hosting the international conferences Gas in Marine Sediments and Climate Time Series Analysis in 2016, as well as International Training School Bubbles in 2017. CAGE will be a major contributor to the 8th International Conference on Gas Hydrate (ICGH) in Denver in 2017.

Crossing boundaries

Scientific progress has been rapid, integrating research from the sub-seabed, through the water column, and all the way to the atmosphere. CAGE has completed 27 expeditions into the Arctic regions using UiT dedicated research vessel Helmer Hanssen. Since our inception in 2013, we have continuously strived to adopt novel technologies on our cruises as for example: remotely operated vehicles; a seabed ocean-observatory network; and high-resolution 4D seismic surveys. The precision of geophysical data we collect is vital for advancing insights into hydrate reservoir dynamics and their impacts.

> *"CAGE now plays a prominent role in the discourse of gas-hydrate research*

Pushing frontiers

At the smallest scale, we see that microorganisms thrive at methane seeps, and may even regulate gas emissions into and within the water column. An important avenue for future research at CAGE, is already in place to build a new and unique "Ice-Cold Microorganisms Laboratory" (ICOM). This will spearhead investigations of key geochemical feedbacks at the highest level of resolution possible: genomes.

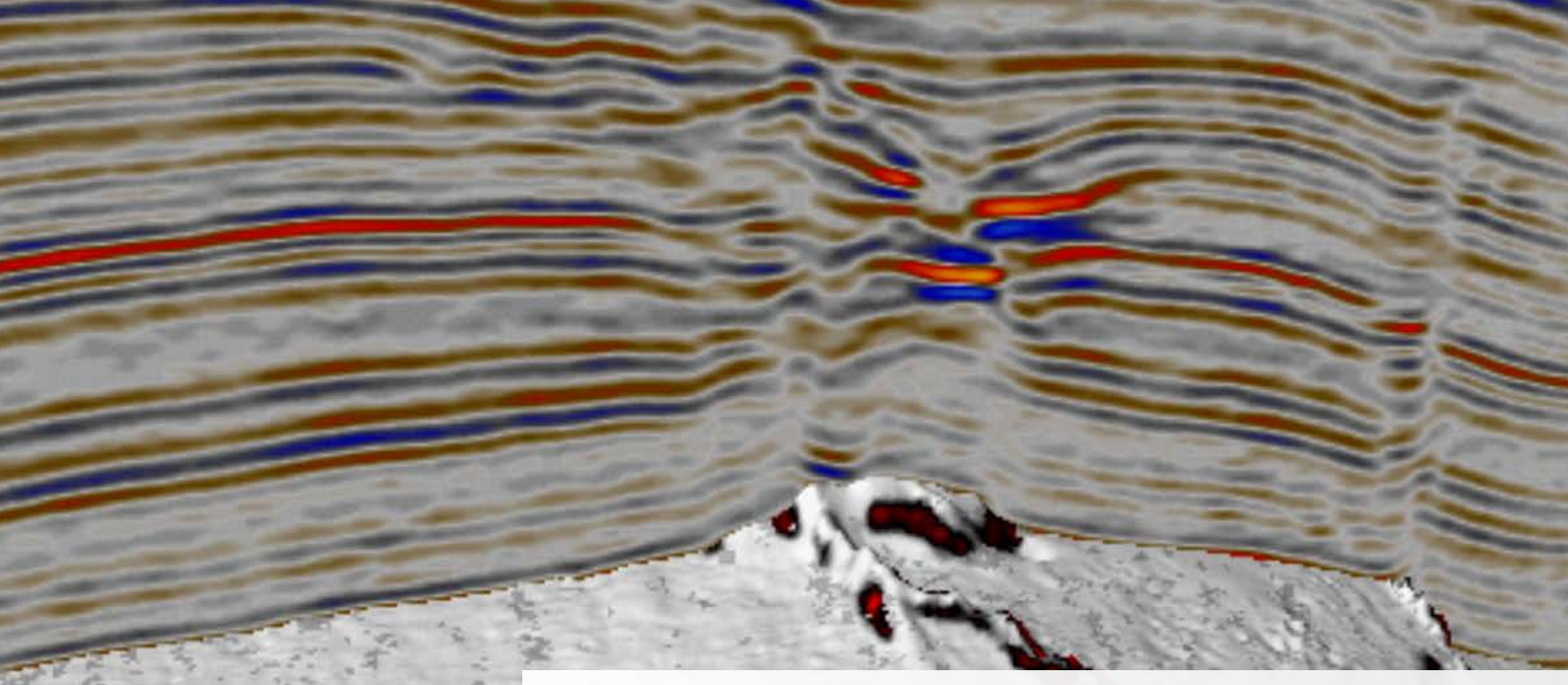
Getting breakthroughs

CAGE research is much more than empirically based. Our world-class modelling teams incorporate the interdisciplinary data we collect to upscale and examine problems across much broader timescales. These include the role repeated Arctic ice-sheet growth has played on cycles of methane release, quantifying volumes of potential Arctic hydrate reservoirs, and predicting atmospheric impacts from future methane release.

Looking ahead

The future of Arctic research is a strategic priority for UiT, with this position to be further secured with the arrival of the new ice-going Research Vessel Kronprins Haakon in 2017. We will continue to combine development of innovative technologies with strong scientific collaborations with international and industrial partners. This will expand the opportunities for pan-Arctic Research on gas hydrate, environment and climate beyond our original ambitions and remit. This allows us to provide world-class training to the next generation of leading scientists in our graduate school – AMGG.

Prof. Jürgen Mienert, *Centre Director*

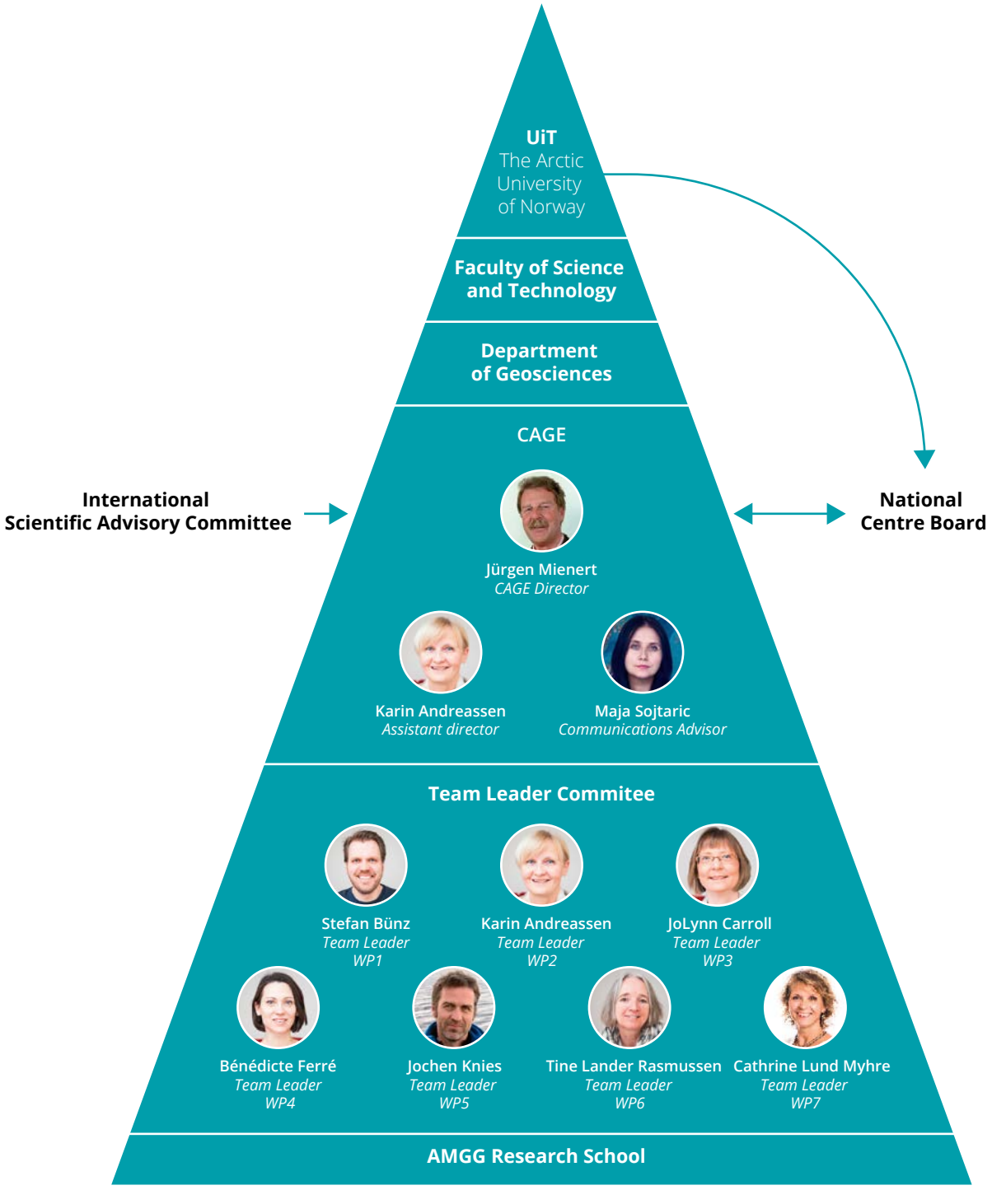


Contents

Front page photo: Deployment of ocean observatory, developed by CAGE and Kongsberg Maritime AS. Photo by R. Hymann. Photo page 2: Jürgen Mienert. Photo by Torger Grytå; Illustration page 3: Methane release associated faults fractures and acoustic anomalies in 3D seismic. Illustrated by A.P. Faverola, CAGE; Back page photo: Arctic sea ice. Photo by ESA.

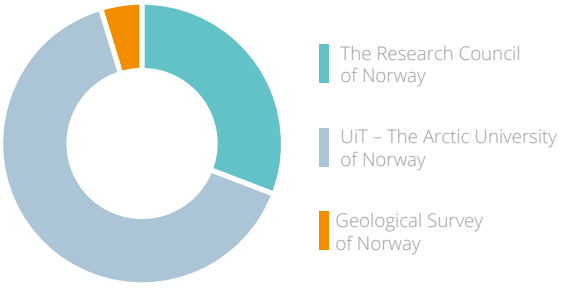
Editorial team: Maja Sojtaric & Jürgen Mienert. Design and layout by Torger Grytå, Department of Geosciences, UiT.

Organisation chart of the centre



Funding 2013-2016

Funding (1000NOK)	Amount	Percentage
The Research Council	54 916	31,1 %
UiT The Arctic University of Norway	113 837	64,4 %
Geological Survey of Norway	7 950	4,5 %
Total	**176 703**	**100 %**



The Centre Board

The centre board is responsible for overseeing the strategy for research, training, economy and patent developments at the center of excellence. The board also oversees operational aspects including the relationships to the University, institutes and industry. Director of CAGE, Professor Jürgen Mienert, reports to the centre board.

Kenneth Ruud
Chairman
Prof., Pro-Rector for Research and Development, UiT

Morten Hald
Prof., Dean NT-faculty, UiT

Nalan Koc
PhD, Research Director, Norwegian Polar Institute

Morten Smelror
PhD, Adm. Director, Norwegian Geological Survey

Ingrid Schjølberg
Prof., Director, Ocean Science Technology NTNU

Kristina Helland-Hansen
Head of Exploration Technology Statoil

Scientific Advisory Committee

CAGE has an international scientific advisory committee that gives advice on stratigic scientific issues and consists of distinguished experts in their fields.

Prof. Antje Boetius
Alfred-Wegener Institute for Polar Research, FRG

Prof. Georgy Cherkashov
Institute of Mineral resources of the Ocean, RUS

Dr. Carolyn Ruppel
United States Geological Survey, USA

Dr. Jerome Chappelaz
Research Director, CNRS, Grenoble, FR

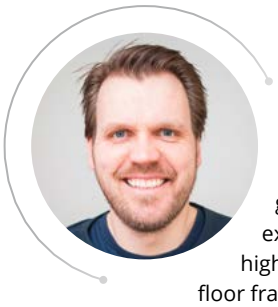
Prof. Doug Connelly
National Oceanography Centre, Southampton, UK

Research groups

WORK PACKAGE 1

Sub Seabed Reservoirs

Methane hydrate and free gas reservoirs



Stefan Bünz, *Team Leader*

Associate Professor Stefan Bünz has 15 years of experience in marine geology hydrate modeling and geophysics with specific research expertise in: gas hydrates, shallow gas anomalies and geohazards, high-resolution 4D seismics, CO_2-storage in petroleum provinces, sea-floor fracture and fluid release systems in sedimentary basins.

Members:

Joel Johnson
Associate Professor (USA)

Peter Franek
Postdoctoral Researcher

Alexey Portnov
Postdoctoral Researcher

Sunil Vadakkepuliyambatta
Postdoctoral Researcher

Shyam Chand
Researcher

Andreia Plaza Faverola
Researcher

Sandra Hurter
PhD Candidate

Giacomo Osti
PhD Candidate

Sunny Singhroha
PhD Candidate

Alexandros Tasianas
PhD Candidate

Espen Valberg
PhD Candidate

Malin Waage
PhD Candidate

Kate Waghorn
PhD Candidate

About:

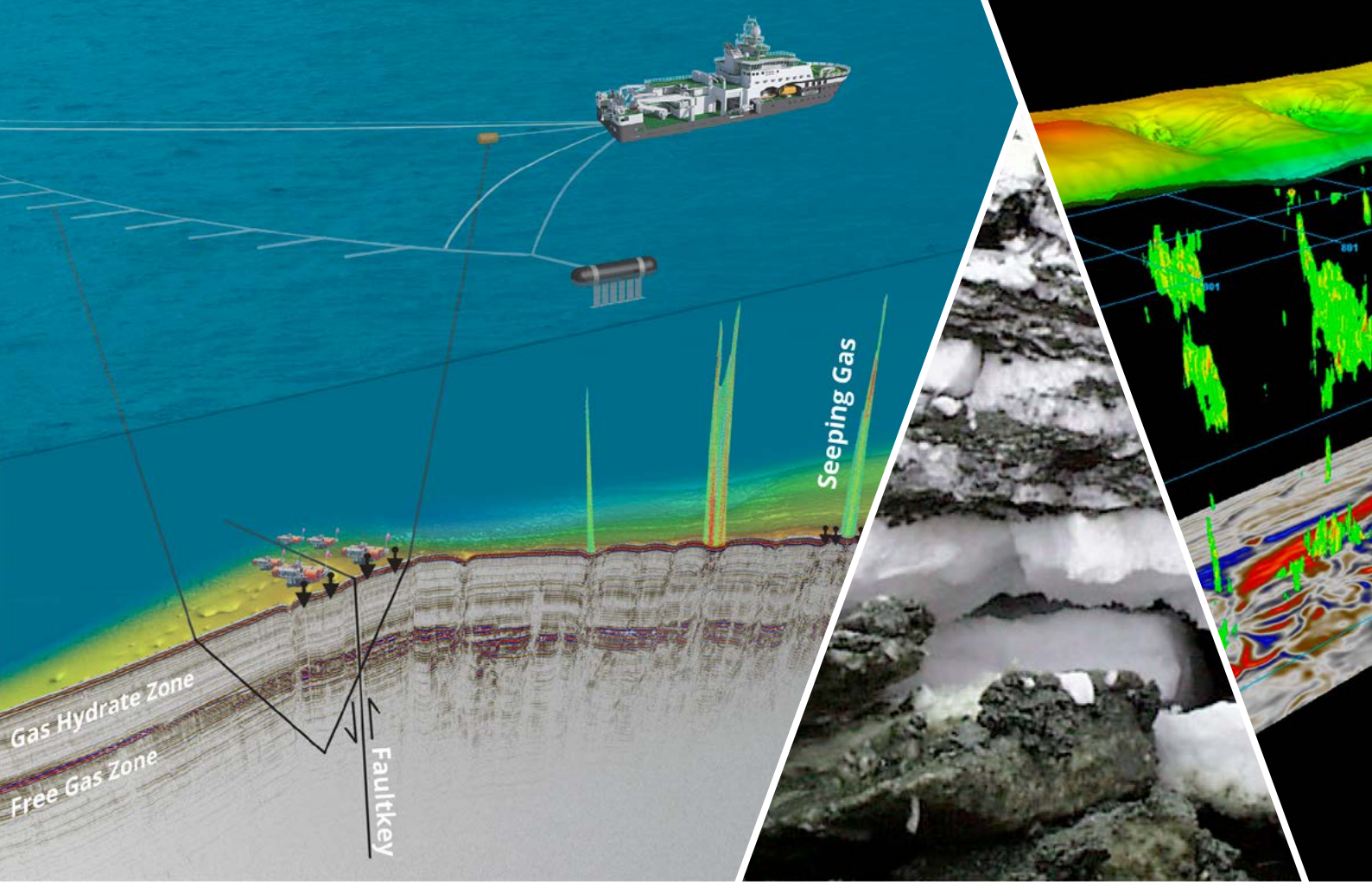
Among the greatest uncertainties in the Arctic marine gas hydrate system is the amount and stability of frozen methane in sub-seabed sediments. Evenly important is, how much of this methane is and will be released impacting ocean life and climate. In our work package we have developed innovative, high-resolution geophysical acquisition, processing and interpretation techniques that, when combined with inverse modelling, enable detection, imaging and assessment of marine methane hydrate reservoirs across the Arctic.

Main questions:

- How much carbon is stored in today's methane hydrate and free gas reservoirs in the Arctic and how much is susceptible to climate change?
- At what rates, by which means and under which circumstances is methane expelled from sub seabed reservoirs to the seabed?

Major aims:

- Develop technologies for direct detection of gas hydrate in glacial marine sediments.
- Determine gas hydrate dynamics and accumulations using high-resolution 4D seismic imaging, hydrate drilling and sampling as well as heat flow measurements and modelling.
- Acquire high-resolution 4D time-lapse data to quantify fluid flows through fractured systems.
- Develop basin-scale models to assess gas hydrate and shallow gas reservoir dynamics.
- Model the evolution of gas hydrate reservoirs under past and potential future climate scenarios.



We focused on investigating deep and shallow gas hydrate and methane release sub-seabed features in areas offshore of North West Svalbard and in the Barents and Kara Seas. Field campaigns with UiT's R/V Helmer Hanssen provided unique high-resolution 3D and 4D seismic data sets of gas hydrate systems spanning a range of environments from an Arctic shelf to a deep-water system.

Cooperation with the Norwegian Petroleum Directorate (NPD) and the wider hydrocarbon industry provides exclusive access to commercial geophysical data to investigate deeper sediment formations where thermogenic gas from petroleum reservoirs migrates upwards into the Gas Hydrate Stability Zone (GHSZ). Close collaboration with Russian colleague's facilitated further acquisition field-campaigns in the Kara Sea at a marine gas release site near Yamal peninsula. The Yamal peninsula has received worldwide attention due to the natural blowout craters in onshore permafrost.

Main Achievements 2013–2017

1. Developed an integrated gas-hydrate stability model coupled to glacial, isostatic and eustatic sea-level evolution to investigate the dynamics, processes and feedbacks of methane release in seepage systems on the western Barents-Svalbard continental margin.

2. Discovered a new and unique gas hydrate and free gas reservoir - fed by an abiogenic methane source – located on the western flank of the Knipovich Ridge, part of the Arctic Ocean spreading ridge system.

3. Conducted a suite of high-resolution 4D time-lapse seismic experiments utilizing UiT's P-Cable system to provide unprecedented insight into the temporal dynamics of fluid migration from deep reservoirs.

4. Successfully drilled a 62-m long borehole into submarine sediments on the Vestnesa Ridge, offshore NW Svalbard, which was unaffected by methane flow, and several more boreholes at a seabed pockmark actively releasing methane. Findings of thick authigenic carbonate crust and thinner carbonate crusts from various depths indicate sustained paleo-methane release events from the deep ocean.

5. Determined the periodicity and duration of gas release at this 1200 m deep, Vestnesa site, which have been ongoing for at least 2.7 Ma controlled by tectonic stress fields from ice loading and ocean-spreading ridge activity.

6. Estimated the seismic attenuation (Quality factor Q) in gas hydrate and free-gas-bearing sediments from high-resolution P-cable 3D seismic data. This enabled the development of a new technique to detect and directly image the distribution of gas hydrates within the pore space of sediments.

7. Modelled the evolution of gas hydrate build-up and decay at a climatically sensitive permafrost region across the West Yamal shelf. Results support the continuous release of formerly trapped gas, primarily methane, linked to the degradation of subsea permafrost.

8. Acquired, processed and analyzed continuous 24-month records of seismicity at several active gas seepage systems on the Barents-Svalbard margin. These data provide new insights as to the role of microseismicity in triggering gas leakage processes through time.

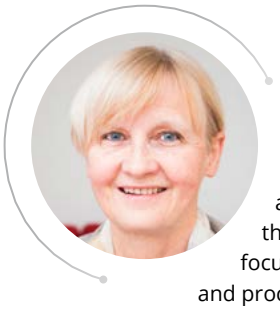
UiT's innovative P-cable system is capable of conducting 3D seismic explorations (see page 30); Gas hydrates layered in ocean sediments; Gas migration from deep reservoirs to sediment surface.

Illustrations: Torger Grytå and Stefan Bünz, CAGE.

WORK PACKAGE 2

Sub-seabed

The role of ice ages for fluid flow and methane hydrate



Karin Andreassen, *Team Leader*

Karin Andreassen is a professor in marine geology and geophysics at UiT. Her research career spans more than 20 years investigating the long-term development of the Barents Sea and the wider Arctic, focussing on ice sheet dynamics and subglacial landforms, sediments and processes, shallow gas and fluid flow from glacial to interglacial conditions.

Members:

Alun Hubbard
Professor

Chris Stokes
Visiting Professor (UK)

Leonid Polyak
Adjunct professor

Eythor Gudlaugsson
Postdoctoral Researcher

Henry Patton
Postdoctoral Researcher

Monica Winsborrow
Researcher

Nikolitsa Alexandropoulou
PhD Candidate

Emilia Daria Piasecka
PhD Candidate

Calvin Shackleton
PhD Candidate

Mariana da Silveira Ramos Esteves
PhD Candidate

About:

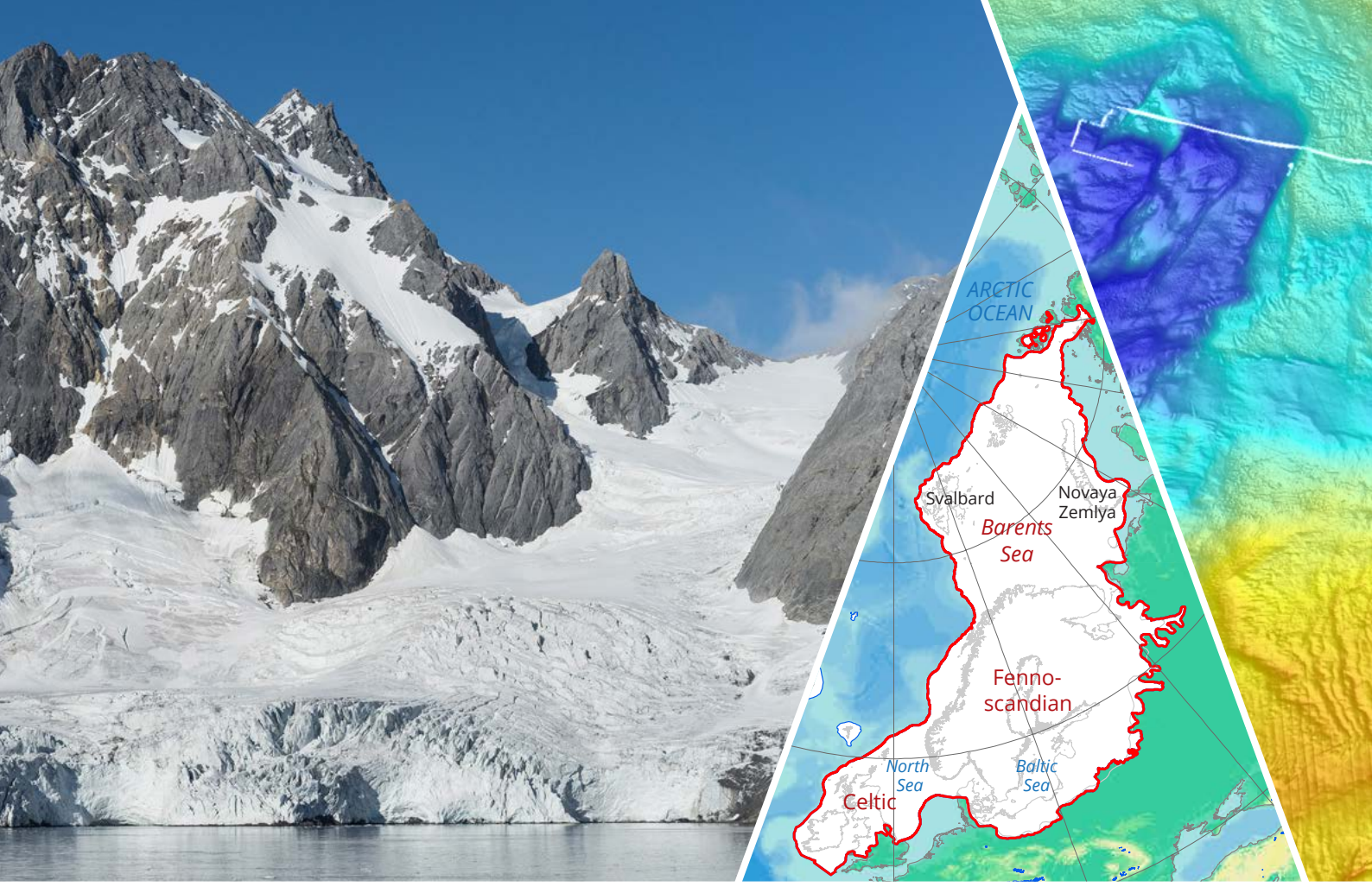
Today vast quantities of methane are sequestered as shallow gas hydrates across the Barents Sea shelf. Deep thermogenic sources continually feed these gas hydrate reservoirs, which exist within a narrow envelope of temperature and pressure conditions determined by the gas hydrate stability zone (GHSZ). We propose that these hydrate reservoirs were much thicker, more extensive and stable under the extreme conditions of past ice ages. As the massive ice sheet loaded the Barents seabed, it created persistently high pressure and low temperature subglacial regimes. We combine state-of-the-art marine geophysics with high-resolution ice sheet modeling. This provides us with extraordinary insights into the long-term variability of methane storage and release, forced by glacial advance and retreat over the past 2.7 Ma. Our new understanding is crucial to improve the prediction of present and future greenhouse gas release from today's Greenland and Antarctica ice sheets.

Main questions:

- How does the subglacial footprint of ice sheets impact on deep fluid flow and gas hydrate dynamics?
- How does the thickness, extent and volume of gas-hydrates change through the ice ages?

Major aims:

- Determine the key processes, interactions and fluxes between gas hydrates and ice sheets.
- Model the long-term impact of past glacial cycles on gas hydrate and hydrocarbon systems.
- Isolate critical subglacial controls on past ice sheet and ice stream behaviour and dynamics.
- Develop stratigraphic and environmental frameworks for key CAGE study areas with an extension into the Norwegian sector of the Arctic.



Accurate models and reconstructions of ice sheet behaviour over millennia require boundary constrains provided by high quality empirical data. We have unprecedented access to the best geophysical datasets across numerous key areas in the Norwegian-Barents Sea and Arctic.

This puts our work package in the world leading position to implement models of past glacial cycles and processes. We can assess their concomitant impact on subglacial gas hydrate dynamics at unprecedented accuracy and detail.

Main achievements 2013–2017

1. Developed an innovative, climatically coupled ice-sheet model simulation reconstructing the evolution of the Eurasian ice-sheet complex over the past 37,000 years, constrained by an established empirical framework detailing the timing and dynamics of glaciation.

2. Identified and assessed previously undocumented subglacial processes and associated landform assemblages that regulate ice-stream dynamics over sticky zones of gas hydrates.

3. Recorded a new 6-million-year stratigraphic framework for the Atlantic–Arctic Gateway.

4. Discovered and imaged a suite of giant seafloor craters and gas-hydrate pingos at a formerly glaciated site, and developed a novel model for their formation based on coupled ice sheet-gas hydrate modelling of the evolving hydrate stability zone.

5. Advanced understanding of the Barents Sea ice sheet deglaciation sequence from high-resolution marine geophysical datasets i.e. drivers and processes of ice-stream retreat, including complex flow switching dynamics and history of the Bjørnøyrenna ice stream inferred from buried landforms imaged within 3D seismic data

6. Implemented calibration and validation of the glacial-isostatic response history of the Barents Sea. This was achieved in collaboration with Durham University (UK) glacial isostatic adjustment modellers to fine tune modelled glacial/gas hydrate scenarios.

7. Instigated national and international collaborations for data access and research excellence. Partners include Norwegian petroleum Directorate, Universities of Durham and Manchester (UK), Byrd Polar and Climate Research Centre at Ohio State University (USA) and Bolin Centre for Climate Research at University of Stockholm (SWE).

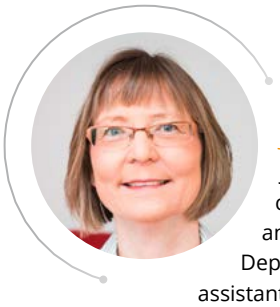
A carving outlet glacier at Svalbard; Eurasian ice sheet extent towards the Arctic during last glacial maximum; Sticky gas hydrate spots on ocean floor revealed by MAREANO data.

Photo/Illustrations: Torger Grytå; Henry Patton; CAGE and Karin Andreassen, CAGE/Mareno.

WORK PACKAGE 3

Modern Seabed Group

Methane release and benthic faunal response



JoLynn Carroll, *Team Leader*

JoLynn Carroll is a marine geochemist whose research interests combine the fields of marine geochemistry, benthic biology, and environmental pollution. She is an adjunct professor at the Department of Geosciences, UiT The Arctic University of Norway, and assistant director at Akvaplan-niva, a research-based company providing advisory services and research in aquaculture as well as marine and freshwater environments. Carroll holds a PhD in Marine Science from the University of South Carolina in Columbia, USA, and has also studied innovation leadership at the Norwegian Business School.

Members:

Mette Marie Svenning
Professor, Arctic Marine Biology, UiT

William G. Ambrose, Jr.
Visiting Professor (USA)

Helge Niemann
Assoc. Professor (20%)

Friederike Gründger
Postdoctoral Researcher

Wei-Li Hong
Postdoctoral Researcher

Arunima Sen
Postdoctoral Researcher

Michael Carroll
Researcher

Vincent Carrier
PhD Candidate

Pavel Serov
PhD Candidate

Emmelie Åström
PhD Candidate

About:

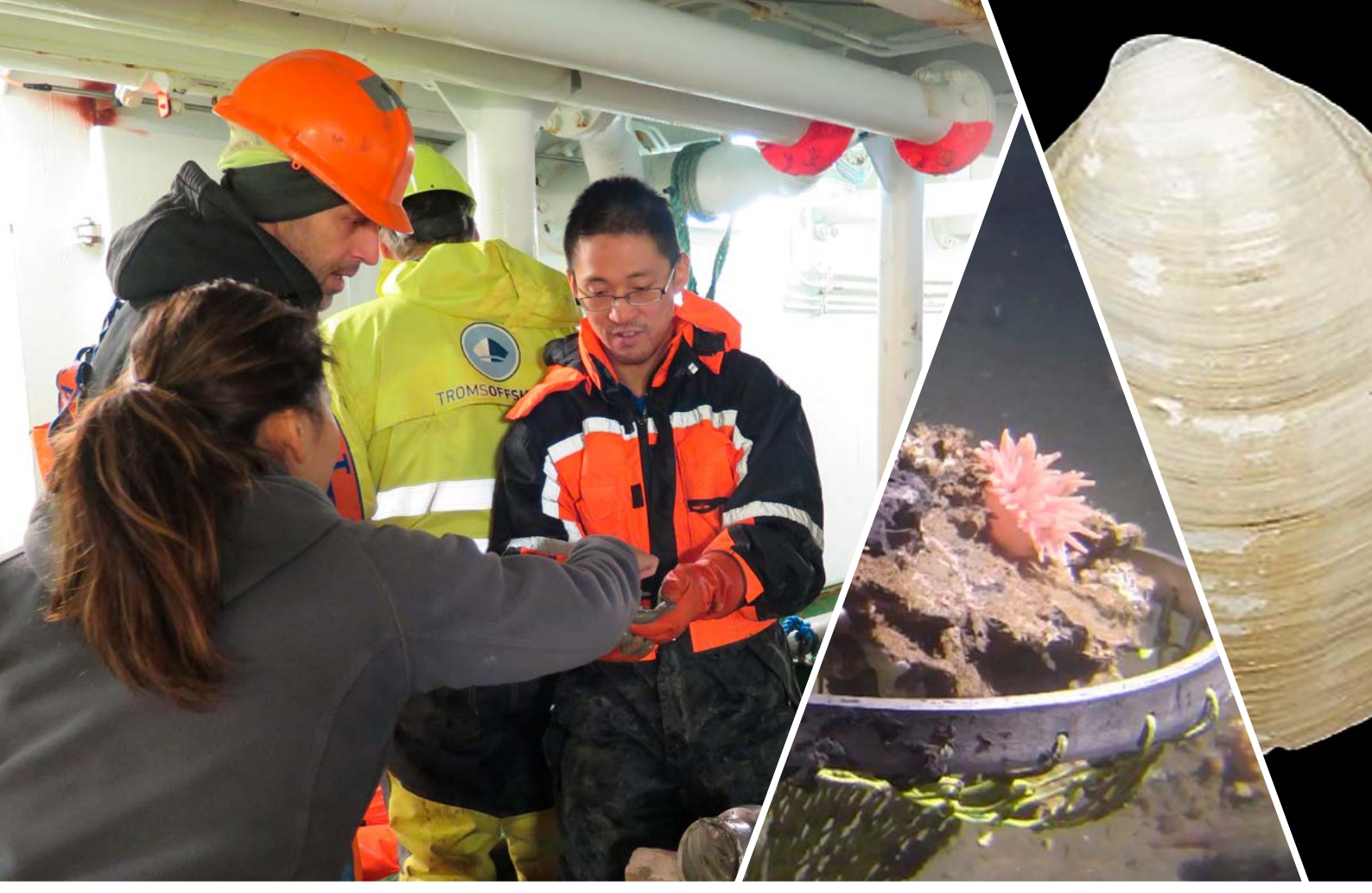
We study benthic organisms, communities, and food webs to understand the range of biological responses to varying intensities of natural hydrocarbon seeps from marine sediments. We focus on the the Svalbard/Barents Sea area studying seasonal and interannual changes from the microbial to the macrofauna scale. Future research strategy for our group will be the development of new and unique infrastructures, such as the Ice-Cold Microorganisms Laboratory: ICOM. This will help us decipher key controlling functions of microorganisms on methane release in the Arctic, as well as their influence on the macro communities on the ocean floor.

Main questions:

- How is life on the seabed affected by methane release from gas hydrate dissociation?
- What is the role of the seafloor biological communities in mediating the exchange of methane from seafloor sediments into the water column?

Major aims:

- Understand the sources of methane seepage, including geological, geochemical and microbiological factors.
- Examine biogeochemical cycles, including the dynamics and timing of fluid circulation in marine methane hydrate environments and impacts on macrobenthic and microbial communities.
- Understand habitat characteristics and locations of seep communities.
- Document the characteristics of microbial communities in sediments and the water column, including methanotrophic activity and community composition.
- Decipher life cycles of macrobenthic and microbial communities, along with the ecological structure and function of communities and food webs associated with seafloor methane emissions.



We have achieved the most comprehensive investigation of cold seep biological communities in the Arctic, spanning both shallow and deep-water areas. Our focus has been on optical seabed observations and determinations of the fauna at seafloor methane release sites.

We have also gathered sediment samples to determine physical and geochemical parameters for development of methane associated seafloor communities. This data is reinforced with quantitative assessments of microbial and macro fauna in order to determine species composition and community structure along a gradient of methane intensity.

Main Acievements 2013–2017

1. Proposed that the the seabed release of methane during the past 2000 years may not be a response to increasing ocean temperatures but to carbon cycling within the sulfate-methane transition zone.

2. Categorized cold seep communities in the High Arctic, and discovered that they consist of chemosymbiotic polychaetes and heterotrophic fauna. Locations of these highly specialized communities are limited to very close proximities around focused methane emissions. These cold seep communities differ markedly from communities in other seep-associated areas where large, distinctive seep fauna (vestimentiferan polychaetes, vesicomyid clams and mytilid mussels) are present.

3. Discovered a new genus and two new species of Thyasiridae bivalves at active methane seeps and pockmarks along the western and southern margins of the Svalbard shelf (75–79°N) and at 350 to 380 m depth.

4. Estimated that the Arctic biological filter removes ~50% of the methane coming out of the seafloor. Our calcuatlion of the methane sink is based on modeling of anaerobic oxidation of methane rates (AOM) . This is combined with estimates of the dissolved methane supply from the seabed to the water column based on acoustic data. Ex situ microbial AOM and methane oxidation data from sediment and water samples are now available. They are key for understanding primary mechanisms that control methane emissions from the seabed to the ocean. These data will contribute to improving our first estimates of microbial filter capacity in the Arctic Ocean.

5. Focused our strategy towards more intense investigation of methane associated micro-organisms. Microorganisms have a very short generation time, and are highly responsive to climate change compared to macro organisms, making them valuable environmental "watchdogs". A key future aim is to determine rapid versus slow feedback microbial responses at the highest level of resolution - genomes, gene expression and biochemistry. This new scientific direction is staked out in collaboration with the Arctic Marine Biology group at UiT and Professor Mette Svenning. She is an internationally recognized expert on methods for isolating and cultivating methane oxidizing bacteria, and will take the reins as leader of Work Package 3.

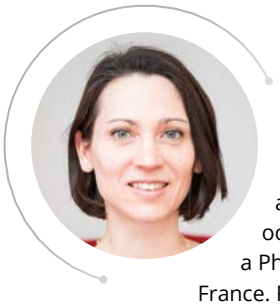
Cruise sampling, with WeiLi Hong, postdoc and Pär Jansson, PhD; Carbonate crust with associated fauna from joint ROV cruise with NTNU-AMOS; Clam shell from chemosynthetic environment.

Photo: CAGE, NTNU-AMOS; Will Ambrose; Emmelie Åström, CAGE

WORK PACKAGE 4

Water Column

Methane release and gas quantification



Bénédicte Ferré, *Team Leader*

Bénédicte Ferré is a physical oceanographer whose research activities span from sediment resuspension and transport to oceanographic data associated with methane release. She holds a PhD degree in Marine Science from the University of Perpignan, France. Ferré was a post-doctoral researcher at the United States Geological Survey in Woods Hole, USA, before joining the Department of Geosciences at UiT - The Arctic University of Norway as a researcher in 2008 and CAGE as a team leader in 2013.

Members:

Jens Greinert
Professor

Helge Niemann
Assoc. Professor (20%)

Anna Silyakova
Postdoctoral Researcher

Anoop Mohanan Nair
Engineer

Knut Ola Dølven
PhD Candidate

Pär Gunnar Jansson
PhD Candidate

Muhammed Fatih Sert
PhD Candidate

About:

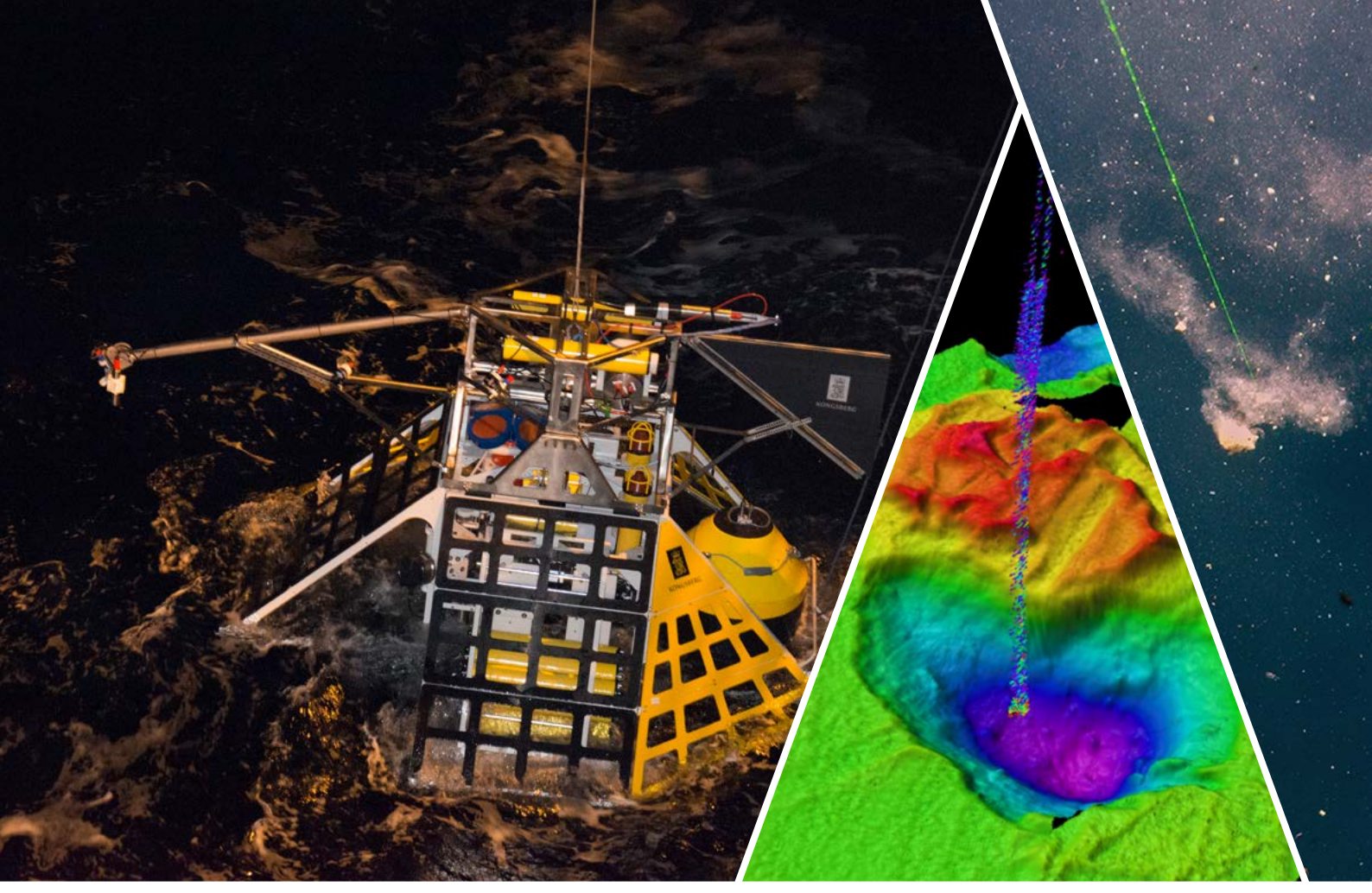
The effects on Arctic ocean life and climate from increases in sub-marine methane release, coupled with a reduced sea ice cover, is still largely unclear. Methane transport into Arctic water masses takes place via bubbles or in dissolved form from dissociating gas hydrate under the ocean floor. However, seasonally stratified water-columns can limit vertical methane diffusion. Our aim is to determine and understand the key transport processes of hydrocarbon gases from the seabed through to, potentially, the atmosphere. This is achieved primarily by deciphering long-term (multiyear) physical and chemical oceanographic measurements using state-of-the-art technology at key methane release sites, both in deep and shallow waters of the High Arctic, as well as through numerical modelling.

Main questions:

- How much of the released methane reaches the upper water column or lower atmosphere?
- Over what horizontal and vertical distances do ocean currents transport methane plumes?
- What are the interactions between the physical, chemical and biological processes in the ocean that affect methane transport?

Major aims:

- Observe and model the transport of methane plumes.
- Determine the amount of dissolved methane beneath the ocean bottom boundary layer.
- Determine and model methane fluxes from the seafloor to sea surface.
- Determine physical and chemical boundary conditions of the bottom water that modify methane seep activities.



We developed two ocean floor observatories together with Kongsberg Maritime in 2014–2015, that have allowed us to deploy multi-sensor technology at key Arctic sites over annual timeframes. With such advanced equipment it is possible to continuously measure environmental changes associated with methane release at remarkable resolutions.

The so-called K-Landers demonstrate a successful cooperation between maritime industry and research teams, thatis crucial in establishing pioneering, cross-disciplinary research for Arctic Ocean climate systems. While the ocean observatories monitor the seabed, a continuous recording system on-board our research vessel RV Helmer Hanssen (in co-operation with NILU, Norwegian Institute for Air Research) measures the release of methane into the atmosphere. This allows us to quantify local and regional atmospheric methane fluxes, as well as to investigate how changes in ocean stratification can regulate methane release through the water column into the atmosphere.

Main Achievements 2013–2017

1. Deployed two ocean observatories (K-Landers) in 2015 offshore Western Svalbard at 90 and 240m water depth, followed by their successful recovery with data retrieval. Analysis of multi-sensor data from the first K-Lander deployment shows coupling between oceanographic and methane release events.

2. Re-deployed the observatories in October 2016: one was deployed offshore Western Svalbard, while the other was placed in the central Barents Sea where our colleagues in WP2 are examining a crater and pingo field.

3. Conducted 3D oceanographic surveys in 2014, 2015 and 2016 on a 15 x 30 km grid at water depths of 70 and 200 m offshore Western Svalbard. The surveys show distinct oceanographic conditions that influence methane transport through the water column. The study have provided timeslices over a three year period from areas of active methane release.

4. Revealed that the uptake of atmospheric CO_2 was larger above this 15 x 30 km grid compared to the surrounding area. The work was done in collaboration with US Geological Survey (USGS), and Woods Hole Oceanographic Institution, and has led to a new hypothesis on seep fertilization, biological productivity and atmospheric uptake of CO_2.

5. Installed a methane sensor and sensors for measurements of conductivity, temperature, and depth (CTD) at the Arctic long-term deep sea observatory, Hausgarten, in the Fram Strait at 2500 m water depth. This will serve as a reference site for our work in the Barents Sea. (Part of the EC funded project FixO3).

6. Participated in N-ICE 2015 expedition, where the Norwegian Polar Institute's RV Lance was frozen into and drifted with the sea ice at 80°N for several months. This allowed us to measure methane in surface water under the young sea ice, as well as in and above the ice.

7. Tested a high-precision underwater laser spectrometer during one of our cruises to the Arctic Ocean. This was in collaboration with the developers of a new generation of dissolved gas sensors: French company Senow and CNRS (National Centre for Scientific Research, Grenoble, France). This led to a new hypothesis on freshwater intrusion into the ocean boundary layer from gas hydrate dissociation.

8. We have been awarded a collaborative new grant to develop and deploy cabled observatories (LoVe Lofoten-Vesterålen) led by the Institute for Marine Research, Bergen. CAGE is in charge of node 7 located on an active methane seep.

Redeployment of the K-Lander in 2016; Crater area methane flares; Gas hydrate dissolving in the water column.

Illustrations/Photo: Benedicte Ferré, CAGE; Alexey Portnov, CAGE; WHOI Tow Cam/CAGE.

WORK PACKAGE 5

Paleo-methane History

Pleistocene and Beyond

Jochen Knies, *Team Leader*

Jochen Knies is a senior researcher at the Geological Survey of Norway. His research expertise integrates marine geochemical and environmental investigations along formerly glaciated continental margins in the Arctic. Knies holds a PhD degree in Marine Geology from the University of Bremen. His broad professional experience includes, among others, a position as postdoctoral fellow at the Alfred Wegener Institute for Polar and Marine Research (AWI), Germany, and a visiting professor position at the University of Hawaii, USA.

Members:

Giuliana Panieri
Associate Professor

Antoine Cremiere
Postdoctoral Researcher

Karl Fabian
Researcher

Aivo Lepland
Researcher

Shyam Chand
Researcher

Soma Baranwal
Postdoctoral Researcher

Terje Thorsnes
Researcher

Deniz Koseoglu
PhD Candidate

Katarzyna Melaniuk
PhD Candidate

Simone Sauer
PhD Candidate

Andrea Schneider
PhD Candidate

Kärt Upraus
PhD Candidate

Haoyi Yao
PhD Candidate

About:

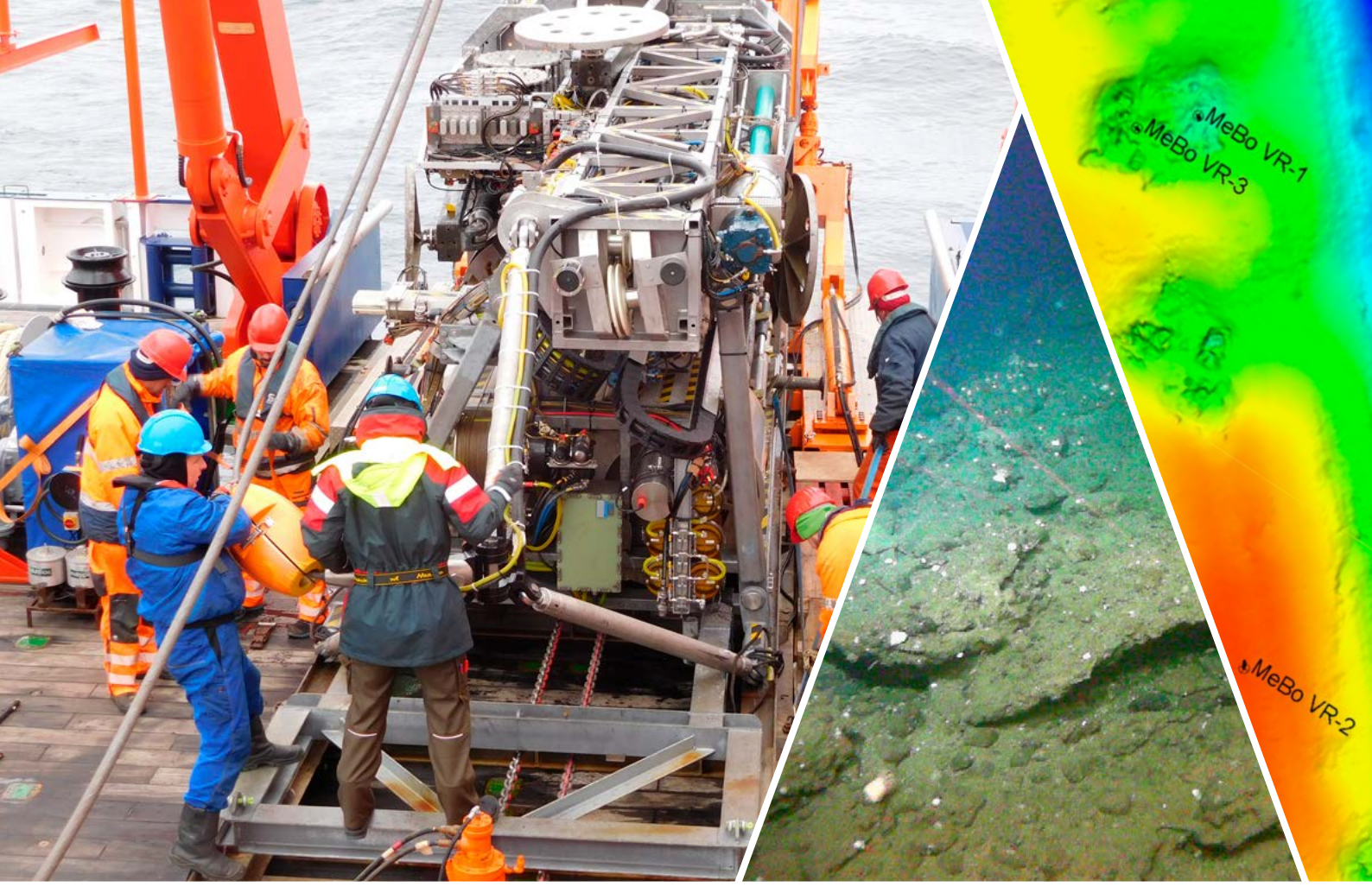
To learn about the timing of methane release in the Arctic, we have to understand the role that the ice has played in the area throughout the geological past. Understanding the history of ice sheet loading during the ice ages of the Pleistocene era can provide us with key answers to the ultimate timing of historic methane leaks from the Arctic Ocean floor. Within this context, authigenic carbonates and microfossils represent a key paleo record for our studies. Moreover, understanding the long-term development of the sea ice as a barrier for methane transport that can help us learn about past exchanges of methane between the ocean and atmosphere.

Main questions:

- What is the effect of glacial driven erosion and loading, and the postglacial uplift, on the gas release system in the Eurasian Arctic?
- Does the methane release system respond periodically and over millions of years to ice sheet loading and unloading? Or do these changes occur abruptly?
- How can we quantify hydrocarbon leakage from “fossil” seep sites and accurately determine the timing of leakage during the geological past?

Major aims:

- Establish geochemical markers and time constraints for ”abnormal” methane ocean – atmosphere conditions and links to climate scenarios during the geological past.
- Develop paleo-ice sheet climate models in cooperation with work packages 1 and 2 that can be used to determine and calibrate the ages and amounts of methane release associated with authigenic derived carbonates in the Arctic. From collaborations with the hydrocarbon industry, we will use borehole samples to establish long-term records of methane release.



Deciphering the impact of ice ages on fluid flow in the Norwegian-Arctic seabed depends on the quality and accessibility of seabed and sub-seabed samples. Direct information on the timing of past methane release events can be obtained through dating of methane-derived authigenic carbonate, as well as extensive studies of the microfossils found within the sediments.

In a unique cooperation with several hydrocarbon companies, we have gained access to authigenic carbonate crust samples and borehole information from the formerly glaciated Barents-Norwegian continental margins. In addition, a 2016 MEBO seafloor drilling campaign with MARUM (University of Bremen, FRG) retrieved authigenic carbonate crust from the 1200 meter deep-water site of Vestnesa Ridge (see also WP1 pp).

Main achievements 2013-2017

1. Identified new cold-methane seep sites off the coast of the Lofoten – Vesterålen islands that provide new insights into potential hydrocarbon migration pathways from the deep. This site will be one of the hotspots for the new Lofoten-Vesterålen Cabeled Ocean Observatory (LoVe) (see WP4 pp).

2. Found evidence for a much lower Arctic sea ice-extent in the Pliocene (between 4-5 Ma) than at present. The maximum winter-sea ice extent did not reach its current position until ~2.6 Ma.

3. Deduced that an ice-covered Arctic Ocean dominated the last 2.6 million years. This is an important analogue for the modeling of future greenhouse gas exchanges from an ice-free Arctic Ocean.

4. Determined that intensive post-glacial gas hydrate dissociation occurred due to the unloading effects of a retreating ice sheet in the Barents Sea. This is based on geochemical and geochronological analyses of methane-derived authigenic carbonate.

5. Performed a pioneering analysis on foraminiferal calcite tests from methane seepage sites. They revealed a close relationship between biogenic and authigenic carbonate. This challenges the findings from previous studies that infer that low $\delta^{13}C$ values recorded by foraminifera are caused only by the precipitation of authigenic carbonate.

6. Conducted isotopic measurements of both foraminifera and authigenic carbonate crusts from active and inactive pockmarks along the 1200 m deep Vestnesa Ridge. They provide an event history of methane emission for the last deglaciation.

7. Identified lipid biomarkers that enable us to decipher taxonomic composition of microbial communities from cold seepage environments.

8. Conducted novel experiments with foraminifera and methanotrophic bacteria collected from Arctic seep sites. Analyzing foraminifera growth and shell geochemistry will indicate whether foraminifera ate chemosynthetic bacteria and built carbonate shells in methane seeps. (in collaboration with Woods Hole Oceanographic Institution, USA.)

9. Succeeded with the applications for two research proposals funded by the Research Council of Norway (RCN) and various industry partners. "PACT", in collaboration with Indian partners, will allow us to study the "Pliocene Arctic Climate Teleconnections" between the Arctic Ocean and Indian monsoon. "NORCRUST – Norwegian Margin Fluid Systems and Methane-Derived Carbonate Crusts" will be one of the backbones of our research activity during the next four years.

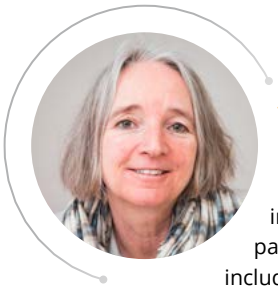
MeBO drilling for gas hydrates on Vestnesa Ridge; Authigenic carbonate crust on the seabed; Pockmarks targeted by MeBo drilling.

Photos/Illustration: Stefan Bünz, CAGE; WHOI Tow Cam/CAGE.

WORK PACKAGE 6

Pleistocene to Present

Methane, ocean acidification and CO_2



Tine Lander Rasmussen, *Team Leader*

Tine Rasmussen is a professor at the Department of Geosciences, UiT The Arctic University of Norway. Her research interests include paleoceanography, paleoclimate, paleoecology, micropaleontology, focused on abrupt climate and oceanographic changes including long paleo-time series from Arctic and sub-Arctic areas. She holds a PhD degree in marine science/micropaleontogy from Aarhus University in Denmark, and has professional experience from among others from Woods Hole Oceanographic Institution (USA), Lund University (SWE) and University of Copenhagen (DK).

Members:

Chiara Consolaro
Postdoctoral Researcher

Ulrike Hoff
Postdoctoral Researcher

Katarzyna Zamelczyk
Postdoctoral Researcher

Mohamed Ezat
PhD Candidate

Siri Ofstad
PhD Candidate

Kamila Sztybor
PhD Candidate

About:

We investigate methane seep areas by annual sampling in order to document changes in both methane release and related ocean acidification. Methane oxidizes to CO_2 and can potentially cause ocean acidification. Isotopic records from measurements of foraminiferal shells and quantitative fauna analyses are amongst our proxies for recording changes due to methane emissions. Studies of living and fossil foraminiferal distribution patterns, may indicate the degree of methane release through time. Also abundance of the benthic foraminiferal communities in methane seep areas, and geochemical analyses of stable isotopes and sediment chemistry contribute in that respect. We also investigate areas largely unaffected by methane as control areas.

Main questions:

- Can we quantify variations in past methane release in benthic and planktonic foraminifera?
- Is there a significant relation with climate (ocean temperature) variability and methane release or not?
- Does methane release contribute to ocean acidification?

Major aims:

- Investigate methane release in relation to past climate and ocean temperature changes.
- Apply multi-proxy techniques to reconstruct high-resolution climate and greenhouse gas records.
- Detect and quantify planktonic foraminiferal responses to changes in ocean chemistry due to methane release, increasing atmospheric CO_2 and ocean warming.
- Provide robust records of ongoing alterations in the Arctic Ocean to the modeling teams, which can improve forecasting of future changes.

Insights into past and present ocean conditions depend on improving existing standards and established methods. Our methods comprise: analysis of sediment and foraminiferal fauna/diatom flora (quantitative and qualitative); carbon-14 datings; isotope analyses (18-O, 13-C, 11-B); elemental analyses (Mg/Ca, B/Ca, Sr/Ca, Cd/Ca ratios a.o.); organic geochemistry hereunder the sea ice proxy IP25, and biomarkers from dinoflagellate and diatom productivity. This integration of methods allowed us to publish several benchmark papers in Nature Communications and Scientific Reports.

Main achievements 2013-2017

1. Reconstructed bottom water temperatures show gradual increase to up to 5.5°C during Henirich event H1 ca. 17,000-16,000 years ago at ca. 1200 m water depth in the Norwegian Sea. Bottom water warming constitutes a potential trigger for gas hydrate instability.

2. Dated increase in release of methane at Vestnesa Ridge to the last deglaciation, beginning during Heinrich event H1 at ca. 17,000-16,000 years. This correlated with bottom water warming.

3. Observed that methane release from Vestnesa Ridge culminated during the warm Bølling and Allerød interstadials 15,600-13,000 years ago. A smaller increase occurred during the initial early Holocene warming ca. 10,000 years ago.

4. Reconstructed sea ice of the Nordic Sea for the last 90,000 years that showed millennial scale fluctuations in sea ice with permanent to near-permanent sea ice cover during cold stadials and Heinrich events.

5. Analyzed CO_2 records for the the past 135,000 years, that show that the Nordic seas acted as a CO_2 source during the end of cold Heinrich events. This happened at the same time as the the permanent sea-ice cover disappeared and and bottom water temperatures reached their maximum.

6. Investigated for the first time methane seeps in the Barents Sea that indicate extreme productivity of non-calcareous planktic organisms, and poorer preservation of planktic foraminifera and pteropods. This has an impact on CO_2 uptake (see WP4).

7. Reconstructed surface water warmings during stadials and Heinrich events for the central north Atlantic, which showed that they were out of phase with Greenland climate and synchronous with Antarctic and Southern Ocean climate instead.

8. Bottom water warmings in the North Atlantic and Nordic seas are controlled by the northward flow of Atlantic water (Gulf Stream) which forms part of the bipolar seesaw.

Collecting samples from high productivity area using multi-plankton net; Examining a sediment core; Foraminifa and diatoms from area above methane seeps.

Photo: Katarzyna Zamelczyk (CAGE), Evelyn Pecori (CAGE).

WORK PACKAGE 7

Atmosphere

Methane emissions from the Arctic Ocean

Cathrine Lund Myhre, *Team Leader*

Cathrine Lund Myhre is a senior scientist at the Department of Atmospheric and Climate Research, at NILU- Norwegian Institute for Air Research. She studies natural and anthropogenic greenhouse gases and aerosols, including their sources, concentrations and long-term trends. Lund Myhre focus is on the Sub-Arctic and Arctic regions. She holds a PhD in Physical Chemistry from the University of Oslo, Norway. Lund Myhre coordinates the project MOCA (Methane Emissions from the Arctic OCean to the Atmosphere) at NILU, funded by the Norwegian Research Council, and connects the hydrate research done at CAGE with atmospheric science. The MOCA project is a collaboration between UiT/CAGE, NILU - Norwegian Institute for Air Research, and the Center for International Climate and Environmental Research – Oslo (CICERO).

Members:

Jürgen Mienert
Professor CAGE

Bénédicte Ferré
Team Leader, CAGE

Sunil Vadakkepuliyambatta
Postdoctoral Researcher, CAGE

Gunnar Myhre
Senior Researcher, CICERO

Ignacio Pisso
Senior Scientist, NILU

Stephen M. Platt
Scientist at NILU

Norbert Schmidbauer
Senior Scientist, NILU

Andreas Stohl
Senior Scientist, NILU

About:

The MOCA project investigates the release of methane from the ocean to atmosphere, and the potential effects this greenhouse gas may have on increased radiative forcing and subsequent global warming. The project combines state-of-the-art atmospheric and oceanographic measurements to investigate this powerful greenhouse gas. We also integrate this empirical data with atmospheric models, such as the FLEXPART Lagrangian transport model and OsloCAM3, to achieve impact scenarios for present and future climate change. MOCA contributes to understanding present atmospheric effects of methane released from Arctic seabed sediments.

Main questions:

- How much methane released from the seabed into the ocean reaches the atmosphere?
- What are the climatic implications of seabed methane seepage?

Major aims:

- Measure and estimate natural methane emissions from the Arctic Ocean floor to the atmosphere.
- Describe the climatic impact and radiative forcing (direct and indirect effects) from seabed methane emissions under present-day as well as future atmospheric compositions.

CAGE
Centre for
Arctic Gas Hydrate,
Environment and Climate

NILU
Norsk institutt for luftforskning
Norwegian Institute for Air Research

MOCA
Methane Emissions from Arctic OCean to the Atmosphere: Present and Future Climate Effects

The atmosphere group has focused on using observational data to constrain models in order to understand the processes influencing ocean-atmosphere exchange, and address the question of whether methane form the ocean is, or will become, an important issue for the future climate.

Main Achievements 2013–2017

1. Started the CAGE-MOCA collaboration on 1st October 2013 with the installment of an atmospheric lab on UiT's research vessel (RV) Helmer Hanssen.

2. Collected atmospheric gas measurements over a three-year period from across large areas of the Arctic Ocean and Barents Sea from the RV Helmer Hanssen. The continuous measurements include methane, CO_2, CO, in addition to offline bottle sampling for isotope analysis of trace gases ethane and propane.

3. Constrained the methane flux from shallow waters around Svalbard for 2014–2015 for use in FLEXPART atmospheric modelling. The model is constrained by comprehensive sets of atmospheric measurements from ocean (RV Helmer Hanssen), land (Zeppelin Mountain Observatory, Svalbard), and air (flight campaigns using FAAM aircraft)

4. Published a study showing that very small amount of methane, insignificant to the global annual atmospheric budget, leaves the ocean during the summer. Methane does not reach the atmosphere in significant quantities, despite the presence of active gas flares at the shallow water depths west of Prins Karls Foreland. Ocean stratification seems to mitigate the release of the gas to the atmosphere in the summer. However, the flux might vary throughout the year.

5. Modelled methane emissions from gas hydrates over the Arctic Ocean over the 21st century. The model indicates that methane emissions from hydrate dissociation may not be a major driver of global warming.

6. Discovered repeated instances of unexpectedly high methane concentrations along North Svalbard towards the Arctic Ocean. This region is characterized by active methane seeps and water mass stratification very close to the sea surface (<15m). Release of methane from the ocean to atmosphere may be higher in these less stratified water masses. Further work and collaboration between CAGE and NILU relies on new funding as the MOCA project will end in April 2017.

The FAAM BAE 146 aircraft from National Centre of Atmospheric Science (UK); Sensor measuring methane and other greenhouse gases on board RV Helmer Hanssen; Zeppelin atmospheric observatory, Svalbard.

Photo: Facility for Airborne Atmospheric Measurements (FAAM); CAGE; Ove Hermansen/NILU

Researcher training

ARCTIC MARINE GEOLOGY AND GEOPHYSICS RESEARCH SCHOOL (AMGG)

Giuliana Panieri, *AMGG Leader*

The research school is led by Associate Professor Giuliana Panieri from CAGE, with coursework developed in close collaboration with the Department of Geosciences.

Activities 2013–2016

The aim of AMGG is to understand the multiple facets of Arctic Ocean seabeds and also how methane release impacts the marine environment and climate system. To achieve this the Research School offers: scientific cruises to the Arctic; relevant seminars about climate and environmental change; field trips to fluid emission locations on land; specialized workshops with national and international participants; and courses through which it trains a new generation of scientists.

PhD students associated with our school update our website with new activities and relevant courses (amgg.uit.no).

Annual workshops and teaching cruises

The major event of the AMGG calendar is the annual meeting, where students discuss their work amongst themselves and distinguished academic visitors to develop ideas and receive crtical feedback.

Another important annual event is our AMGG cruise onboard UiT's R/V Helmer Hanssen. It brings PhD students and Master students together with leaders from CAGE and the Department of Geosciences for extended periods of marine studies and technology training. Target areas include, among others, the Fram Strait and the Barents Sea.

AMGG also offers cruise-associated workshops on relevant scientific disciplines. More than 25 hours of lectures and exercises are provided, focusing on theoretical and practical applications of geo-marine research from the sub-seafloor, the seabed, and the water column. Examples of the topics covered include: sedimentary processes and paleo environments on glaciated continental margins; fluid flow; ocean acidification, and anthropogenic impacts.

Transferrable skills for early career scientists

Through collaboration between AMGG and CAGE's communications advisor, we offer our PhD candidates several workshops in transferrable skills. Among the highlights are workshops in scientific presentations, poster design, visual aids for technical talks and pitching ideas for investors. Recognized experts such as Melissa Marshall, consultant and faculty member at the Department of Communication Arts & Sciences at Penn State University, USA have delivered such workshops.

Another highlight is a workshop on science, innovation, entrepreneurship and design. The workshop covers subjects such as academic entrepreneurship; how thinking like a designer can improve scientific ideas, and skills that PhDs have that business needs.

Fieldtrips to Northern Apennines and Sicily show Earth in action

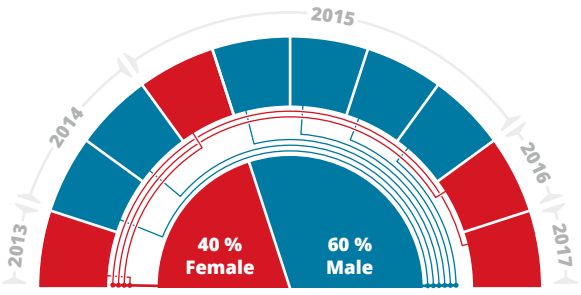
AMGG has organized several field trips to earthquake-prone Italy over the past two years to learn about active fluid flow systems. We have visited both the Northern Apennines and Sicily. One of the main objectives of this field trip is to get an impression of the timing of fluid flow processes in collision zones. The sedimentary archive in these areas provide excellent examples of methane-seepage related formations. Geochemical and biological processes connected to seepage systems, driven by tectonic events, are also widely evident. This makes it possible to visualise the imprint of tectonics on timescales of millions of years.

The students created an oral presentation and a blog to document and present the outcomes of the field course. (factsfromthefield.wordpress.com).

The research school is led by Associate Professor Giuliana Panieri from CAGE, with coursework developed in close collaboration with the Department of Geosciences.

AMGG partners: the Geological Survey of Norway, Norwegian Polar Institute and The University Centre of Svalbard (UNIS). AMGG collaborates with ResClim, the Norwegian Research School in Climate Dynamics and CHESS, the Norwegian Research School on Changing Climates in the Coupled Earth System http://www.uib.no/en/rs/chess.

The AMGG conducts its training through hands-on experience on cruises in the Arctic Ocean, and fieldwork in areas where fluid flow features are evident, such as Sicily. Photos: CAGE, Maja Sojtaric, Giuliana Panieri.



PHD TRAINING AND INTERNATIONAL COLLABORATION

PhD students at CAGE receive standardised training and diplomas from UiT The Arctic University of Norway. We also welcome PhD students from other institutions for training, through established exchange programmes and relevant scientific networks. Our PhD students and postdocs also participate in training programmes with colleagues at internationally acclaimed science institutions.

Highlights: Alexey Portnov, post.doc

Portnov will be a part of a project entitled "Genesis of Methane Hydrate in Coarse-Grained Systems: Northern Gulf of Mexico Slope" at Ohio State University in Columbus, USA. He will be a part of a planned scientific drilling campaign with an extensive research network between CAGE amongst others Ohio State University, University of Texas, Lamont-Doherty Observatory. His tasks will include 3D seismic interpretation, working on the drill ship with sediment cores and coring tools, and working on land with hydrate modelling. The team will explore whether the hydrate-forming methane is generated in situ within the hydrate stability zone by microbial processes or whether microbial or thermogenic methane is transported upward from deeper hydrocarbon sources. This has relevance for our work in the Barents Sea.

Calvin Shackleton, PhD

Shackleton is joining a glaciology team at Lamont Doherty-Observatory in Palisades, New York for a year. He will work with professor Robin Bell primarily on the subject of subglacial hydrology of the Barents Sea/Eurasian ice sheet. He will examine the prediction of potential subglacial lake locations and meltwater drainage routes using ice sheet model output by Henry Patton, CAGE.

Katarzyna Melaniuk, PhD

Melaniuk is co-supervised by Dr. Joan Bernhard at Woods Hole Oceanographic Institution (WHOI) on Cape Cod, USA. She has been trained at Dr. Bernhard's lab to investigate whether certain species of a single celled marine organism foraminifera can live in chemosynthetic habitats such as methane seeps.

RV Joides Resolution, will drill through gas hydrates in the Gulf of Mexico; Plough-marks left by the ice stream in Storfjordrenna; Katarzyna Melaniuk in a WHOI lab, examining cultures of single celled foraminifera.

Photos: joidesresolution.org/MAREANO/Tom Kleindinst, WHOI

List of PhD dissertations

2013

Safronova, P.
Distribution, depositional environment and post-depositional deformation of Cenozoic gravity-induced deposits along the western Barents Sea continental margin.
Supervisor: Andreassen, K.

2014

Faust, J.C.
Environmental response to past and recent climate variability in the Trondheimsfjord region, central Norway - A multiproxy geochemical approach
Supervisor: Knies, J.

Vadakkepuliyambatta, S.
Sub-seabed fluid-flow systems and gas hydrates of the SW Barents Sea and North Sea margins
Supervisor: Bünz, S.

2015

Chauhan, T.
Late Quaternary paleoceanography of the northern continental margin of Svalbard
Supervisor: Rasmussen, T.L., Noormets, R.

Ezat, M.
North Atlantic–Norwegian Sea exchanges during the past 135,000 years: Evidence from foraminiferal Δ14C, d11B, d18O, d13C, Mg/Ca and Cd/Ca
Supervisor: Rasmussen, T.L., Groeneveld, J.

Gudlaugsson, E.
Modelling the subglacial hydrology of the former Barents Sea Ice Sheet
Supervisor: Andreassen, K., Humbert, A.

Jessen, S.P.
Ice rafting, Ocean circulation and Glacial activity on the western Svalbard margin 0–74,000 years BP
Supervisor: Rasmussen, T.L.

Portnov, A.D.
Role of subsea permafrost and gas hydrate in postglacial Arctic methane releases
Supervisor: Mienert, J., Cherckashov, G.

2016

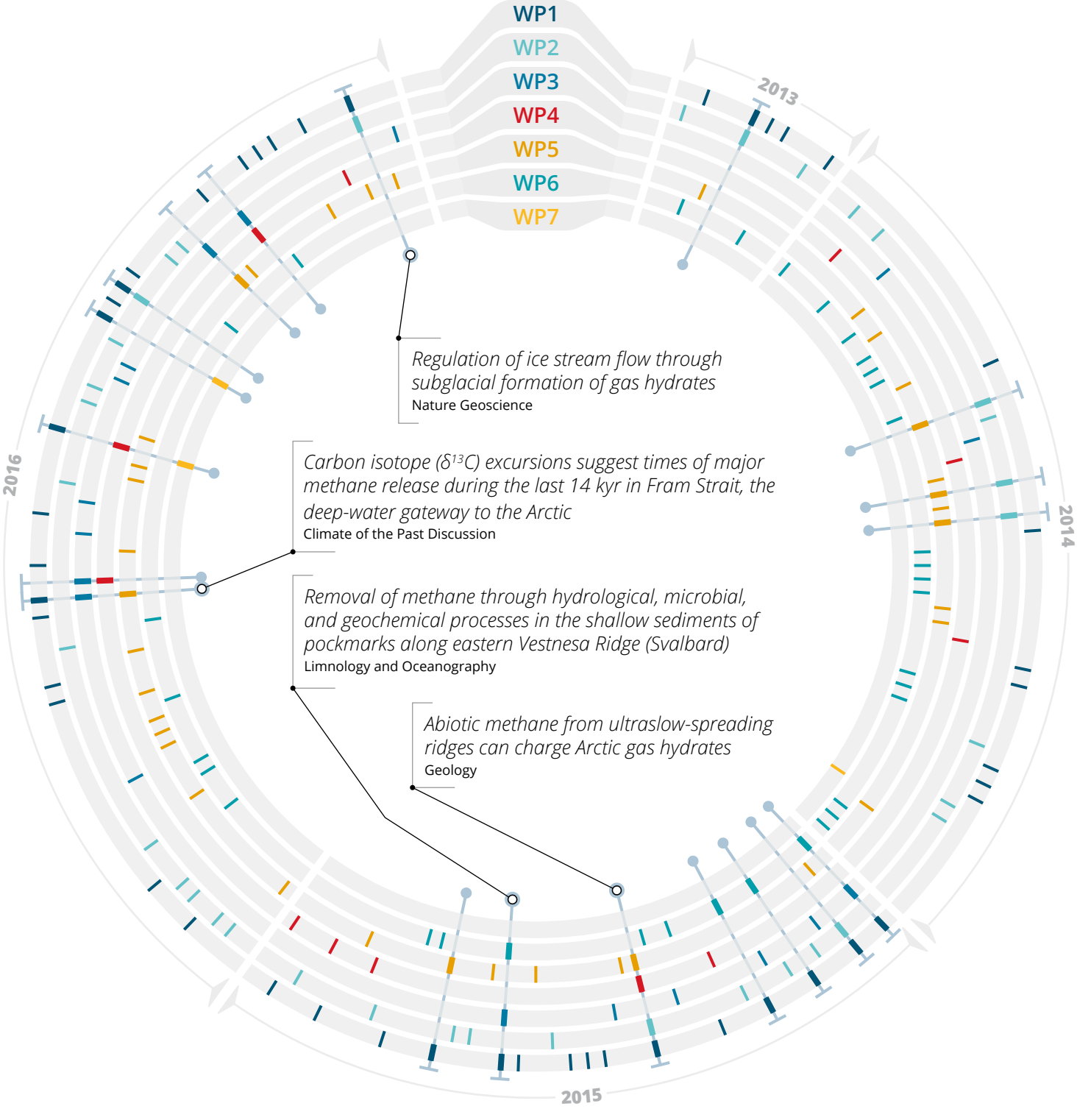
Sauer, S.
Past and present natural methane seepage on the northern Norwegian continental shelf
Supervisor: Knies, J., Mienert, J.

2017

Sztybor, K.
Late glacial and deglacial paleoceanographic and environmental changes at Vestnesa Ridge, Fram Strait: challenges in reading methane-influenced sedimentary records
Supervisor: Rasmussen, T.L.

Research collaboration across research groups in the centre

We are the only institution in the world that looks at methane release from the hydrates in the ocean floor through the entire chain: from the gas hydrate formation below the ocean floor to the atmospheric signals of methane gas. We look into the past; we contribute to future modelling. The task is challenging, and is best solved by interdisciplinary cooperation between our work packages.



2013
10 Articles Published
1 Collaboration Article

2014
47 Articles Published
3 Collaboration Articles

2015
40 Articles Published
7 Collaboration Articles

2016
63 Articles Published
8 Collaboration Articles

Article
Collaboration Article

Meetings and Conferences – Highlights

CAGE has hosted and contributed to several conferences and scientific meetings already, and plans to continue its efforst in the future.

GIMS13

Gas in Marine Sediments is a interdisciplinary conference – held every second year. It focuses on the gas and gas hydrates in the world's active and passive margins including the Arctic and Antarctic. CAGE was the host of the 13th GIMS conference in September 2016 in Tromsø.

Time Series Analysis in Environmental Science and Applications to Climate Change

CAGE was the host of the a conference and workshop on observations of environmental changes due to climate change.

The purpose of this event was to provide a discussion forum in the field of time series analysis and forecasting, as well as update the participants on the state of the current in situ measurement networks. The conference is based in the EU project FIXO3.

Gordon Conference on Gas Hydrates

Gordon Research Conferences are a group of prestigious international scientific conferences covering frontier research in a range of topics. CAGE was one of the contributors and sponsors for the 2016 conference on natural gas hydrate systems that was held in Galveston, Texas in March 2016.

9th International Conference on Gas Hydrates (ICGH) :

The conference aims to bring together the entire Gas Hydrates community, to review developments over the previous three years, and to attempt to extrapolate for the near-term future. CAGE is one of the sponsors and contributors to the conference that will be held in Denver (USA) in June 2017.

Bubbles 2017:

CAGE and the Research School AMGG, will host the international training school BUBBLES in 2017. The main aim is to provide a thorough and interdisciplinary introduction to the role of methane in marine and terrestrial environments (e.g. permafrost), from generation, migration, consumption and impact on the seafloor, water column and finally into the atmosphere. The school will also cover the planet's methane inventory and the impact of methane on the climate.

First hand exploration of the Arctic

We have completed 27 expeditions on research vessels to Arctic regions since 2013. They encompassed technologies such as remotely operated vehicles, seabed photography and seabed drilling campaigns. This extraordinary access to data gives us insights into gas hydrate reservoir dynamics from the Kara Sea in Russia, via the Barents Sea and into the Arctic Ocean. In the future the new RV Kronprins Haakon will be able to take us further into the ice opening new perspectives and frontiers for science.

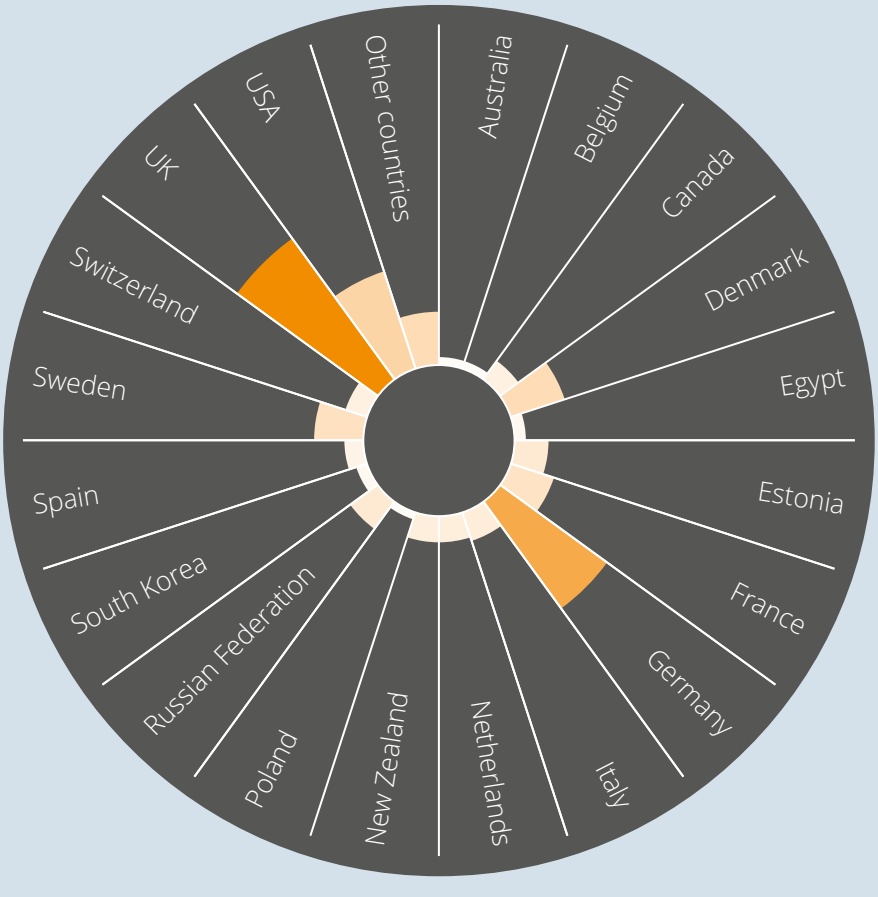
| RV Krinprins Haakon. Illustration Rolls Royce. | Fulmar. Photo: Johan Faust. | Helge Niemann. Photo: Johan Faust. | A view from the bridge of RV Helmer Hanssen. Photo: CAGE. | Sampling of plankton from the water column. Photo: Kasia Zamelczyk. | The new RV Kronprins Haakon. Photo: Øystein Mikkelborg, NPI. | ROV from AMOS, NTNU. Photo: Johan Faust. | Friederike Gründger taking samples for microbiology Photo: Randall Hyman. |

International Collaboration

Our research is connected with international scientific communities that are outlined as important collaborators by Norwegian Research Council and Norwegian Ministry of Foreign Affairs. We participate in several EU projects and actions such as: STEM CCS on carbon capture; COST MIGRATE on hydrate quantification; and FIXO3 on environmental observations and technologies. We also lead the PACT project funded by NRCs INDINOR program. It examines how Arctic Ocean warming affected monsoons in the past, in collaboration with Indian institutions NCAOR and Birbal Sahni Institute of Paleobotany. In addition to that we collaborate on papers with relevant colleagues from all over the world.

International collaborations on publications
(2013 to present)

Source: Scopus | Illustration:Torger Grytå



International collab

Illustration: Colourbox.com.

AARHUS UNIVERSITY · ANI · PRIFYSGOL BANGOR UNIVERSITY · BGR · BGS · NERC Isotope Geosciences Laboratory · British Antarctic Survey · BYRD POLAR AND CLIMATE RESEARCH CENTER · Durham University · MOSCOW STATE UNIVERSITY · National Oceanography Centre · NENUN · OCEAN.RU · OGS · OSU Oregon State · RWE The energy to lead · SMU · Stockholm University · Swansea Prifysgol

Highlighted publications

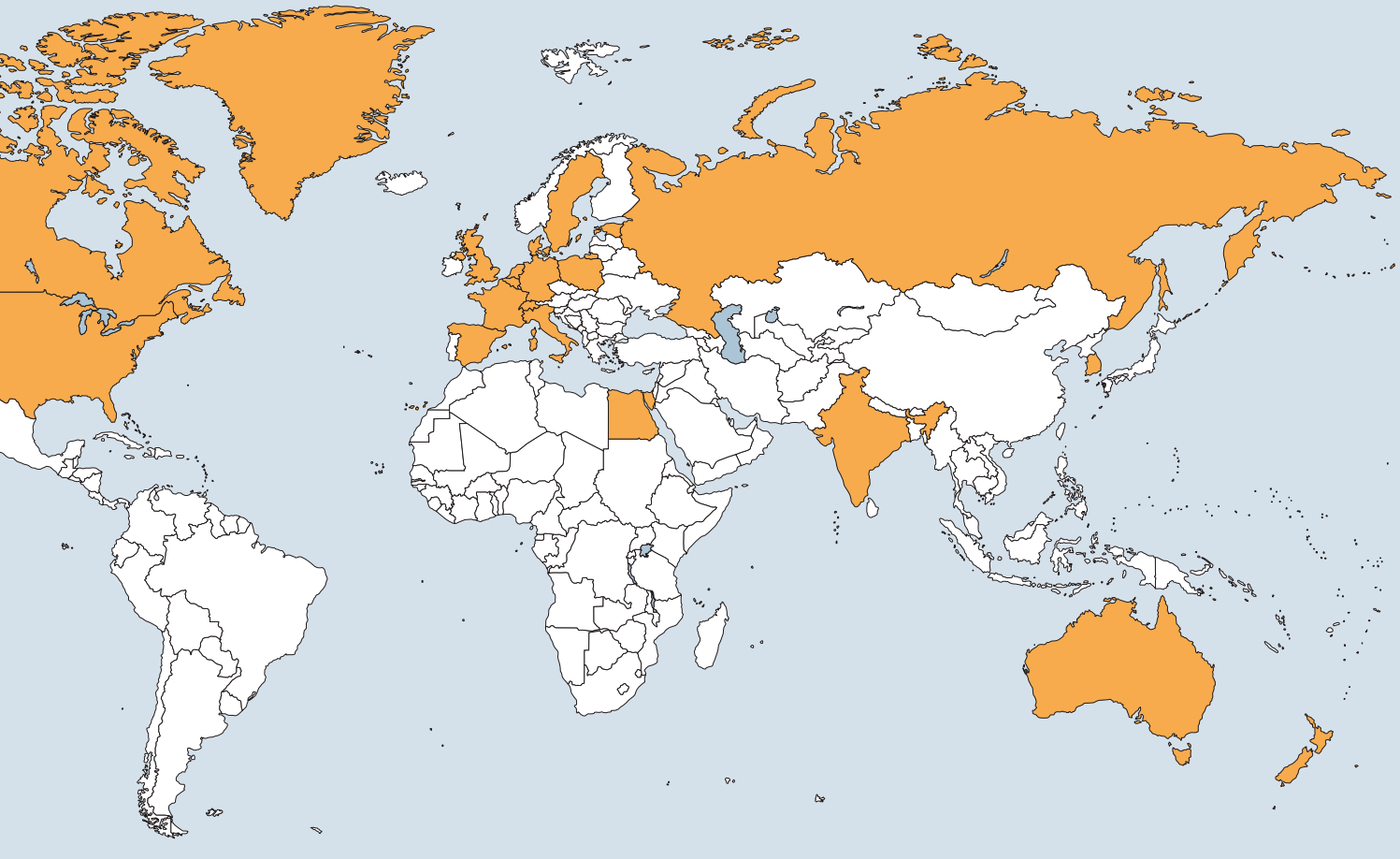
Ezat et al. *Episodic release of CO_2 from the high latitude North Atlantic OCean during the last 135 kyr*. Nature Communications 2017. **Collaboration with:** Beni-Suef University, Egypt; Lamont-Doherty Earth Observatory of Columbia University, USA. Institute of Marine Environmental Sciences (MARUM); University of Bremen, Germany

Johnson, J.E., et.al. *Abiotic methane from ultraslow-spreading ridges can charge Arctic gas hydrates,* Geology, 2015. **Collaboration with:** University of New Hampshire, USA.

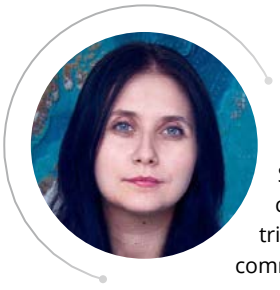
Myhre C.L.,et.al. *Extensive release of methane from Arctic seabed west of Svalbard during summer 2014 does not influence the atmosphere,* Geophysical Research Letters 2015. **Collaboration with:** Centre for Atmospheric Science, School of Earth, Atmospheric and Environmental Science, University of Manchester, UK; National Centre for Atmospheric Science, Department of Chemistry, University of Cambridge, UK;Department of Earth Sciences, Royal Holloway, University of London, UK.

Steinle, L., et.al., *Water column methanotrophy controlled by a rapid oceanographic switch.* Nature Geoscience, 2015. **Collaboration with:** Department of Environmental Sciences, University of Basel, Switzerland; Ocean and Earth Science, National Oceanography Centre Southampton, UK; GEOMAR, Helmholtz Centre for Ocean Research, Germany

oration (contries)




WASHINGTON POST
Remember those weird Siberian craters? Scientists say they may have an underwater version
New Scientist
New Arctic life on barren seabed thrives on methane jets
NRK
Overraskende klimafunn ved Svalbard
WELT
Schatz aus der Tiefsee



Maja Sojtaric, *Communications Advisor*
She writes our press releases, manages media contact and maintains our social media distribution, as well as arranging workshops in communication.

DISSEMINATION AND COMMUNICATION :

From blank slate to worldwide reputation

CAGE started off as a blank slate in 2013. Today the name resonates through many channels, both in scientific and non- scientific circles.

Even though many of our scientist have an established reputation, CAGE itself has to establish an identity of its own. Our focus on narrating our excellent results to general public, industry, stake holders, and media plays an important part in our overall strategy for the centre.

Some 240 reports on our research have been published by media outlets online and in the press. We have reached both traditional media, such as radio and television and made an impact through social media, such as YouTube. And we wish to do more.

Factual scientific knowledge in a post-truth world

Never has it been more important for scientists to bring their findings and methods to the public in an understandable and relatable way. This is the reason why we have prioritized outreach. We need to provide expert voices in the general discourse on climate change and natural world, a voice that needs to connect to a much larger audience than our scientific community.

From East to West

Not only does our research span from East to West, so does our outreach impact. Our studies have been spotlighted by such diverse outlets as Siberian Times; Washington Post; New Scientist; Smithsonian Magazine; Sydney Morning Herald; Gazeta.ru; Daily Mail and Die Welt.

We aim for high exposure of our results by distributing them through press releases aimed at the public. Our scientists meet willingly with the public, through science fairs and popular lectures. They also participate in press conferences and other outreach events organised by scientific assemblies such as EGU. They are encouraged to use social media, such as Twitter, Instagram, Facebook, YouTube.

> *Never has it been more important for scientists to bring their findings and methods to the public in an understandable and relatable way*

We reach a very diverse audience. This does expose our scientist to a media world that is becoming very harsh indeed, and can even appear intimidating.

Preparing for a new media world

We provide workshops, together with our research school AMGG, through which our early career scientist can learn presentation and writing techniques that empower them in their communication.

They learn how to navigate and use social media, through for instance our blogging platform factsfromthefield.wordpress.org.

We also provide workshops in data visualisation and information design, skills useful for communicating results both through scientific and non-scientific publication platforms.

Stay connected

The world of science communication is moving very fast away from the written content and towards the visual. By 2019, global Internet video traffic will account for 80 percent of all Internet traffic. Facebook alone generates 8 billion video views daily.

To adapt to this, we are launching and participating in several visualisation projects in the coming years: ICEMAP, funded by Norwegian Research Council, will visualize development of the Eurasian ice sheet during the last ice age. The project is a collaboration with the Nordnorsk vitensenter engaging school children of all ages. The results will spearhead several interactive visualisations and will engage general public with interactive visualisations both at the museum and online.

PACT is a project funded through Research Councils INDINOR programme, and will look at how Arctic Sea Ice in the past influenced Indian monsoon. Cold episodes in the Arctic may link to a weakened Asian monsoon. A change in the monsoon arrival or intensity can have a strong impact on the Asian economy. New finding from this research will be told in stories throughout the project on UiT's new intergrated storytelling platform Living Science, which will use video, podcast, text and illustration.

All of our communications and outreach work is facilitated and organized by our senior advisor Maja Sojtaric, who also develops strategies for our outreach. She has worked for a decade as a science journalist and editor, before joining CAGE as a fulltime advisor.

Photo/Illustration: Colourbox.com & Torger Grytå

4D seismic using P-Cable

CAGE uses UiT's national infrastructure G3 (Geosystems 3D seismic imaging), which was developed by CAGE members. The design stems from the P-cable concept (http://pcable.com/).

The high-resolution P-cable 3D seismic system differs from low-resolution conventional 3D seismic systems by having a cable-towed perpendicular to the steam direction of the research vessel. Up to 24 streamers, each only 25 meters long connect to the towed cable. The streamers are much shorter than in conventional 3D seismic systems where they usually measure several kilometers. The series of streamers collect data from 24 seismic lines simultaneously. Hence, they cover an approximately 240 meter wide area with ultra-high resolution in a cost effective manner.

Study of gas hydrate and gas in marine sediments is one of the main targets of our system. By deploying the system in the same area over time, using the same configuration of the P-Cable, we are developing a time series observations. These add to our understanding on how a gas hydrate system behaves over time.

Societal impact, innovation and industrial impact

A recent study in Nature shows that the amount of methane released from natural sources to the atmosphere is much greater than previously known. The study collates known knowledge of the subject, but focusses solely on terrestrial sources. The complex marine environment, retreating Arctic ice, melting permafrost in the ocean floor, and ocean-atmosphere interactions are still not taken into the account.

The IPCC in its 5th assessments has also not yet taken ocean bound methane into the account as a driver of future climate change because we are still far away from understanding it. Neither is there a comprehensive understanding of the impact of the microbial communities in the ocean on the containment of methane released from the sub-seabed. We also need to learn more about ocean acidification in the Arctic.

Our work is thus uniquely qualified to have a major implication for the understanding of Arctic environment and our planet's future. We have made more precise calculations and observations than ever before, and will continue to do so for the next five years. This gives our research economic, social, and environmental impact on a global scale.

Contributions to scientific and industrial innovation

Methane stored beneath the Arctic Ocean is both a powerful greenhouse gas and a potential source for unconventional energy. Throughout the world, from Asia to North America, scientists are attempting to quantify gas hydrates and associated hydrocarbon reservoirs.

In 2015 European Concerted Research Action (COST) designated to marine gas hydrates was established. Stefan Bünz, associate professor at CAGE, was elected the Vice Chair of the action. Marine gas hydrate – an indigenous resource of natural gas for Europe (MIGRATE) will examine the potential of gas hydrates as an economically feasible and environmentally sound energy resource.

Carbon capture in the ocean floor

Understanding the complexity of gas hydrate reservoirs; their stability under the ocean floor, and the effect methane release has on Arctic Ocean life, will be of major significance for the society facing an obviously rapid climate change in the Arctic. As a byproduct we are able to assist hydrocarbon industry in the assessment of leaks from Arctic hydrocarbon reservoirs where shallow gas hydrate caps have been melting.

CAGE is participating in a carbon capture project that will conduct a first of a kind, deep-water experiment on controlled release of CO_2 from a submerged carbon dioxide storage reservoir. Strategies for Environmental Monitoring of Marine Carbon Capture and Storage (STEMM CCS) is funded by Horizon 2020 programme. It will take place in 2018 as a part of a €16M collaborative project led by the National Oceanography Centre (NOC) in Southampton, UK.

> *"CAGE is participating in a carbon capture project that will conduct a first of a kind*

Geohazards

Knowledge about the existence of gas hydrates and shallow gas is crucial for the offshore industry that is interested in avoiding regions with potential gas blow outs. CAGE research provides insights into areas of the seabed where installations in the future may encounter such hazards.

Contributions to scientific and industrial innovation

A new generation of ocean observatories (K-Landers) from Kongsberg Maritime were delevoped in collaboration with CAGE. First deployments started offshore Svalbard in summer 2015, and successfully recovered and redeployed them in 2016. We retrieved a year of unprecedented multi-sensor data on Arctic methane release and ocean physical as well as chemical conditions. Data will provide insights in ocean acidification processes and trends. Based on the success of the first mission and fostered by a close collaboration between CAGE and Kongsberg Maritime, the K-Lander technology has been successfully placed in scientific and industrial monitoring campaigns in Far East.

2G Cryogenic Magnetometer

CAGE partner, Norwegian Geological Survey (NGU), has installed a 2 G Cryogenic Magnetometer at their facilities in Trondheim. It analyses magnetic iron minerals for dating, among others, samples from marine sediment cores. Analyzing magnetic remains in marine sediments can help detect changes in the polarity, intensity and direction of Earth's magnetic field through millions of years. Hence it enables us to develop a precise chronology for the climate of the past.

Collaboration between centres of excellence

The research vessel Helmer Hanssen spent 3-weeks in 2016 on an expedition to seabed methane seeps in the Arctic Ocean around Svalbard. On-board the ship was a remotely operated vehicle (ROV) that is under development by another centre of excellence AMOS at NTNU, Trondheim. An ROV is an exploration system that can be deployed into the depths of the ocean while operated by scientists aboard the ship to collect desired images and samples.

The results of the engineering research at NTNU AMOS improved scientific data collection, at the same time the collaboration with CAGE led to further improvement of their own systems.

Advanced isotopic measurements

CAGE has established at the Department of Geosciences a Stable Isotope Laboratory equipped with MAT 253 Isotope Ratio Mass Spectrometer. The laboratory is an integral part of paleo climatic, oceanographic, geobiological and carbon cycling research. It is one of the few laboratories in the world with this capacity. It is a part of the national infrastructure FARLAB.

The lab will eventually become one of the few places in the world where scientists can analyze clumped isotopes. The ground-breaking method allows for more precise reconstruction of past climate on Earth.

P-Cable technology development and deployment from RV Helmer Hanssen; Drilling for authigenic carbonate crust.

Photos/Illustrations: CAGE; A.P.Faverola; A. Lepland.

Publications List – Selected

CAGE scientists have published 172 papers, 15 of them in Nature publications, from 2013 to early 2017. We have also cotributed 383 oral and postr presentations at national and international conferences and seminars.

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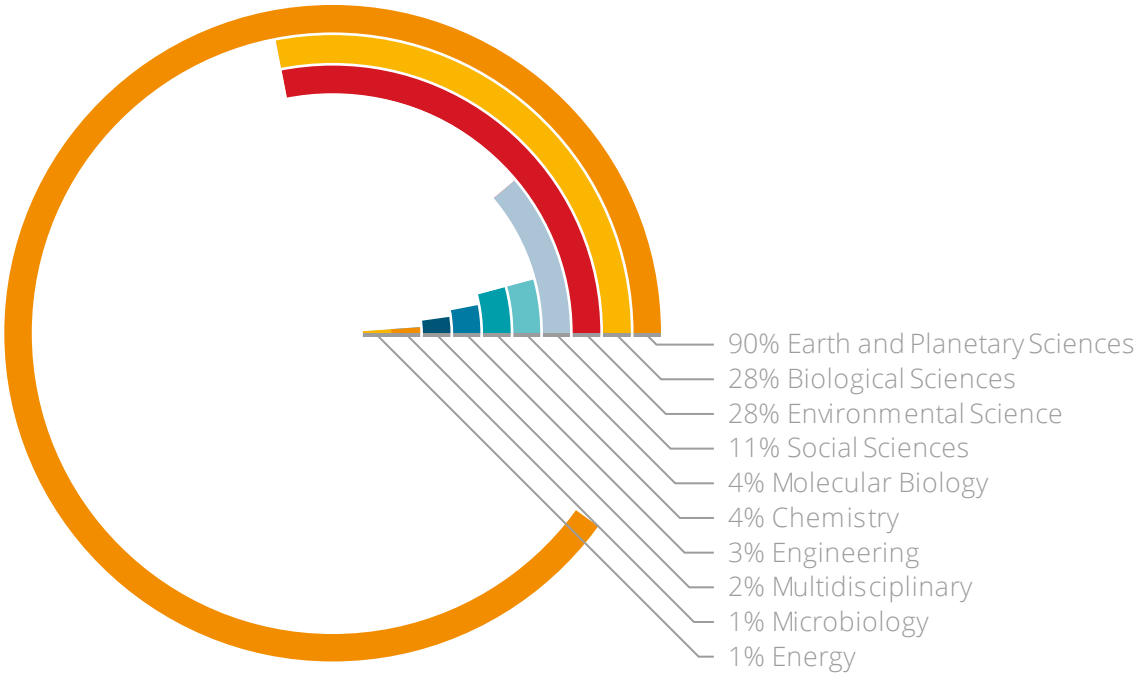
Subject area, publications

Source: Scopus



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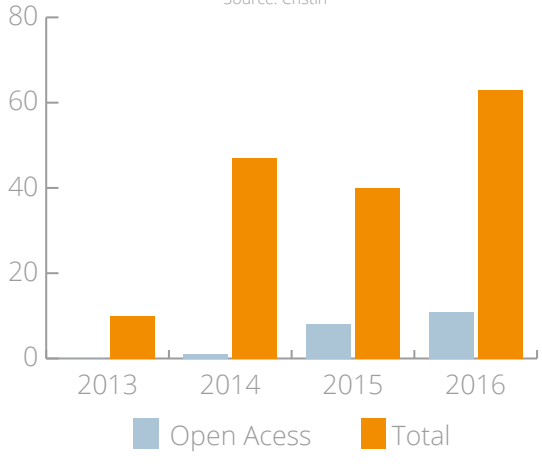

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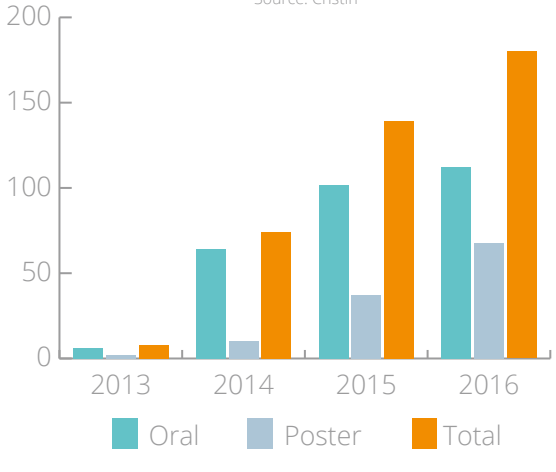

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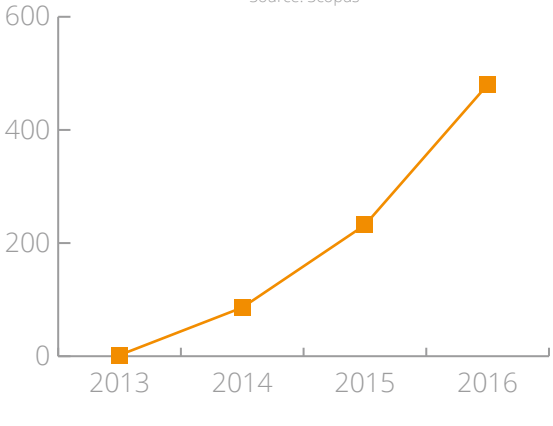

PhD and Master thesis

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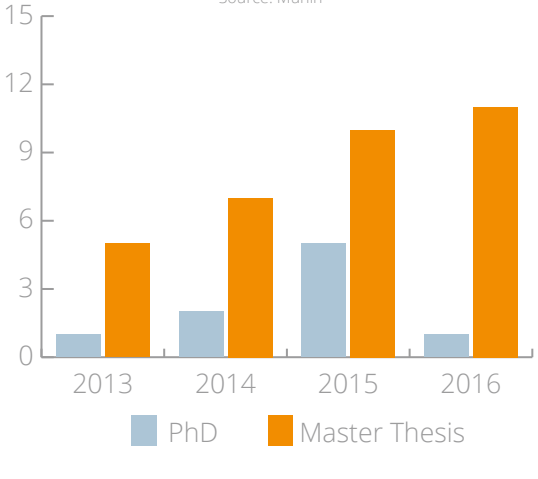
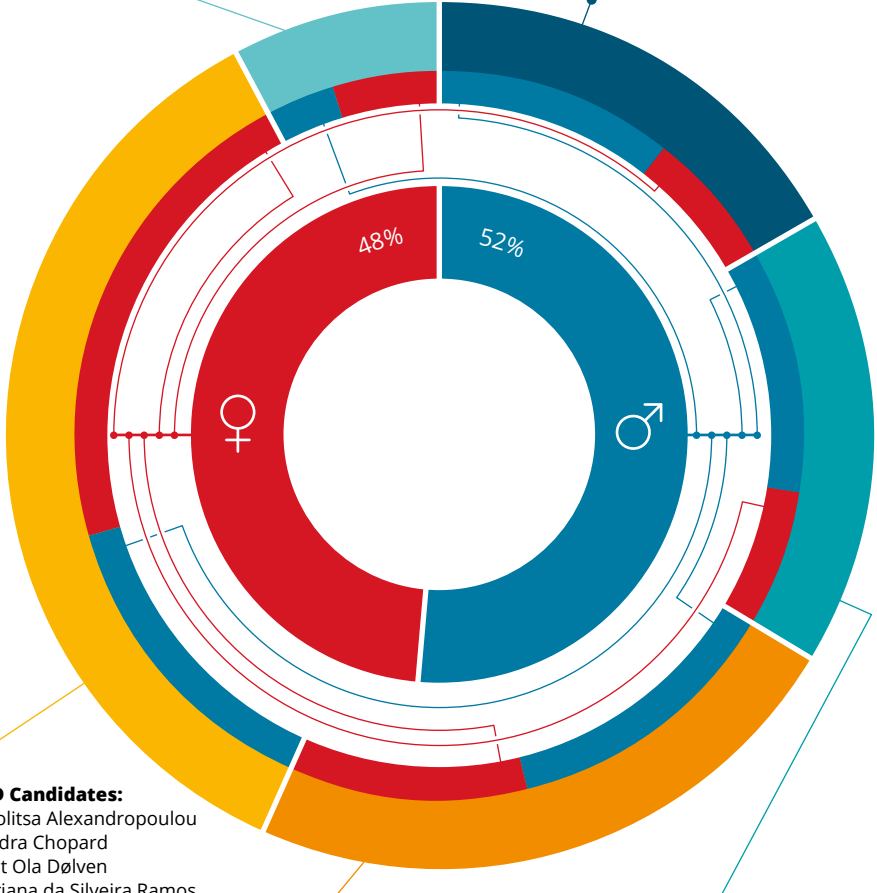


Full list of personnel at the centre

We have achieved gender equality for our scientific staff in 2016. 5 out of 7 of our work package leaders are in addition women. This is way above the average of 21 percent women in STEM fields in OECD countries, and significantly above the average of 16 percent in Norway. More than 60 percent of our staff are PhD students and early-career scientists.

Adminstrative and technical staff:
Lill-Iren Gabrielsen Mikalsen, Executive Officer
Matteus Lindgren, Engineer
Fabio Sarti, Data Manager
Maja Sojtaric, Communications Coordinator
Tonje Merete Moe Winther, Executive Officer

Senior scientific staff:
Jürgen Mienert, Professor
Karin Andreassen, Professor
Tine L. Rasmussen, Professor
Alun Hubbard, Professor
Stefan Bünz, Associate Professor
Giuliana Panieri, Associate Professor
JoLynn Carroll, Adjunct Professor
Leonid Polyak, Adjunct Professor (USA)
William Ambrose, Visiting Professor (USA)
Jens Greinert, Professor
Joel Johnson, Associate Professor
Helge Niemann, Visiting Professor (UK)
Chris Stokes, Visiting Professor (UK)



PhD Candidates:
Nikolitsa Alexandropoulou
Sandra Chopard
Knut Ola Dølven
Mariana da Silveira Ramos Esteves
Pär Gunnar Jansson
Deniz Koseoglu
Katarzyna Melaniuk
Siri Ofstad
Giacomo Osti
Emilia Daria Piasecka
Simone Sauer
Andrea Schneider
Pavel Serov
Calvin Shackleton
Sunny Singhroha
Kamila Sztybor
Alexandros Tasianas
Kärt Üpraus
Espen Valberg
Malin Waage
Kate Waghorn
Haoyi Yao
Emmelie Åström

Postdoctoral Researchers:
Soma Baranwal
Chiara Consolaro
Antoine Cremiere
Mohamed Ezat
Peter Franek
Friederike Gründger
Eythor Gudlaugsson
Ulrike Hoff
Wei li Hong
Henry Patton
Alexey Portnov
Arunima Sen
Anna Silyakova
Sunil Vadakkepuliyambatta
Katarzyna Zamelczyk

Researchers:
Michael Carroll
Shyam Chand
Karl Fabian
Bénédicte Ferré
Jochen Knies
Aivo Lepland
Cathrine Lund Myre
Andreia Plaza Faverola
Andreas Stohl
Terje Thorsnes
Monica Winsborrow


Nikolitsa Alexandropoulou
PhD Candidate


Karin Andreassen
Assistant director
Team Leader WP2


Chiara Consolaro
Postdoctoral Researcher


Antoine Cremiere
Postdoctoral Researcher

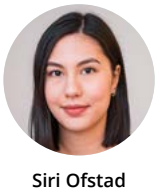

Jens Greinert
Professor


Friederike Gründger
Postdoctoral Researcher


Deniz Koseoglu
PhD Candidate

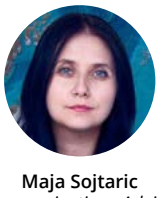

Aivo Lepland
Researcher


Helge Niemann
Assoc. Professor (20%)


Siri Ofstad
PhD Candidate


Fabio Sarti
Engineer


Simone Sauer
PhD Candidate


Maja Sojtaric
Communications Advisor


Andreas Stohl
Researcher, NILU


Espen Valberg
PhD Candidate


Kate Waghorn
PhD Candidate

William G. Ambrose, Jr.
Visiting Professor

Soma Baranwal
Postdoctoral Researcher

Stefan Bünz
Team Leader WP1

JoLynn Carroll
Team Leader WP3

Vincent Carrier
PhD Candidate

Michael Carroll
Researcher

Shyam Chand
Researcher

Knut Ola Dølven
PhD Candidate

Mariana da Silveira Ramos Esteves
PhD Candidate

Mohamed Ezat
PhD Candidate

Karl Fabian
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Andreia Plaza Faverola
Researcher

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Eythor Gudlaugsson
Postdoctoral Researcher

Ulrike Hoff
Postdoctoral Researcher

Wei-Li Hong
Postdoctoral Researcher

Alun Hubbard
Professor

Pär Gunnar Jansson
PhD Candidate

Jochen Knies
Team Leader WP5

Joel Johnson
Associate Professor

Matteus Lindgren
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Katarzyna Melaniuk
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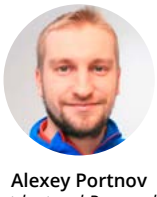
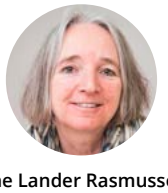
Emilia Daria Piasecka
PhD Candidate

Leonid Polyak
Adjunct professor



Alexey Portnov
Postdoctoral Researcher



Tine Lander Rasmussen
Team Leader WP6

Andrea Schneider
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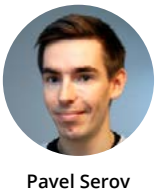
Calvin Shackleton
PhD Candidate

Arunima Sen
Postdoctoral Researcher



Pavel Serov
PhD Candidate

Sunny Singhroha
PhD Candidate

Muhammed Fatih Sert
PhD Candidate

Anna Silyakova
Postdoctoral Researcher

Chris Stokes
Visiting Professor

Mette Marie Svenning
Professor
Arctic Marine Biology, UiT

Kamila Sztybor
PhD Candidate

Alexandros Tasianas
PhD Candidate

Terje Thorsnes
Researcher

Kärt Upraus
PhD Candidate

Sunil Vadakkepuliyambatta
Postdoctoral Researcher

Monica Winsborrow
Researcher

Malin Waage
PhD Candidate

Haoyi Yao
PhD Candidate

Katarzyna Zamelczyk
Postdoctoral Researcher

Emmelie Åström
PhD Candidate

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CAGE

Norwegian Centre of Excellence

GEOLOGICAL SURVEY OF NORWAY - NGU -

UNIVERSITY OF TROMSØ