CAGE - Centre for Arctic Gas Hydrate Environment and Climate Report Series, Volume 7 (2019)

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Modifications:
This version of the annual report has been modified from the original published in 2019.
Below is an overview of the changes made.

- The URL links for the PhD dissertations have been changed to a permanent handle in page 21.
- Impact factor values have been removed from page 34-35 (Publications list)

Annual Report 2019

CAGE – Centre for Arctic Gas Hydrate, Environment and Climate

CAGE

Norwegian Centre of Excellence

The Arctic University of Norway · UiT ·

Words from the Director

CAGE investigates methane release, a greenhouse gas far stronger than CO_2, from the Arctic seafloor. Vast amounts of methane are trapped at shallow depths below the seafloor as gas hydrates, ice-like mixtures of gas and water. Current ocean warming makes these shallow greenhouse gas reservoirs particularly vulnerable to thawing. CAGE investigates the processes involved and implications to the Arctic climate and environment.

Scientific recognition

2019 has been a productive year for the centre. CAGE has now since we started in 2013 published over 330 peer-reviewed scientific publications, which have been cited over 3990 times and the centre has an H-index of 33. Our Scientific Advisory Committee visits us once a year, and concluded in their last report in November 2019 that "there has been an impressive amount of work completed, and the scientific outputs have been exceptional".

Scientific highlights

CAGE had an exciting year 2019. Our scientists led four scientific cruises to the Arctic Ocean, two of these with the new ice-going Research Vessel *Kronprins Haakon* (KPH), which will be changing our knowledge about the high Arctic. Information about our exciting visits to the Aurora Seamount hot vents on the Gakkel Ridge at 83°N, and to the Fram Strait Arctic-Atlantic Gateway, where over 300 m core material were sampled are given in pages 26-27. Still, Research Vessel Helmer Hanssen provides the possibility to visit important study sites that do not require the same ice-breaking force as KPH.

The Arctic Ocean is a harsh working environment. That is why many of the scientific expeditions are conducted in the summer and early autumn months when the weather and the waters are the calmest and most predictable of the year. Most extrapolations regarding the amounts of methane discharge from the ocean floor are thus based on observations from the warmer months. New results from CAGE work package 4 led by oceanographer Benedicte Ferré reveal that there is huge seasonal variability in bottom water temperatures, methane seeps and methane-consuming bacteria in the Arctic Ocean. These exciting results were accepted late 2019 for publication in Nature Geoscience. The next step will be to do more winter cruises to account for seasonal changes.

New projects

Nine new research projects which add on to the CAGE funding and activities started in 2019, allowing us to continue our exciting research on methane seeps from an increasingly warming Arctic Ocean. These new projects are presented on pages 28 and 29 in this report.

Awards

I am honoured to have received the UiT Gender Equality Award for 2019 on behalf of CAGE scientists and staff. The centre has had gender equality in all positions from its start in 2013. During this time we have published well over 300 scientific papers and welcomed 18 CAGE-babies to the world. Gender equality is rare in science, technology, engineering and mathematics (STEM) fields, with men dominating the scientific positions. For CAGE, a center where geology, geophysics, chemistry, biology, oceanography, and glaciology are fields of research, this has never been an issue.

I am also proud of our early career scientist, Andreia Plaza Faverola who received the Else-Ragnhild Neumann Award 2019 for Women in geosciences, awarded by the University of Oslo.

Education

Four CAGE PhD students defended their Theses (Calvin Shackleton, Sunny Singhroa, Malin Waage, Kate A. Waghorn), while three Master students received their degrees (F.A. Amdal, K.L. Bruvik, K.R. Samuelsen). The new research school for PhD students within the Department of Geosciences, including CAGE, "Geoscience Research Academy – GREAT" was launched at the end of 2019, and is a continuation of the previous trainee school in "Arctic Marine Geology and Geophysics – AMGG".

2019 was another successful year for CAGE. Our scientific results would not have been possible without the generous funding from RCN and the support from UiT, our NT faculty and the Department of Geosciences. We are further blessed by having access to two fantastic ice-going research vessels, RV *Helmer Hanssen* and the new RV *Kronprins Haakon*. Finally, our largest resource is the people working within CAGE; our PhD- and Master students, Postdoctoral fellows, Researchers, Professors, and the technical and administrative staff that support us. Thank you so much to you all!

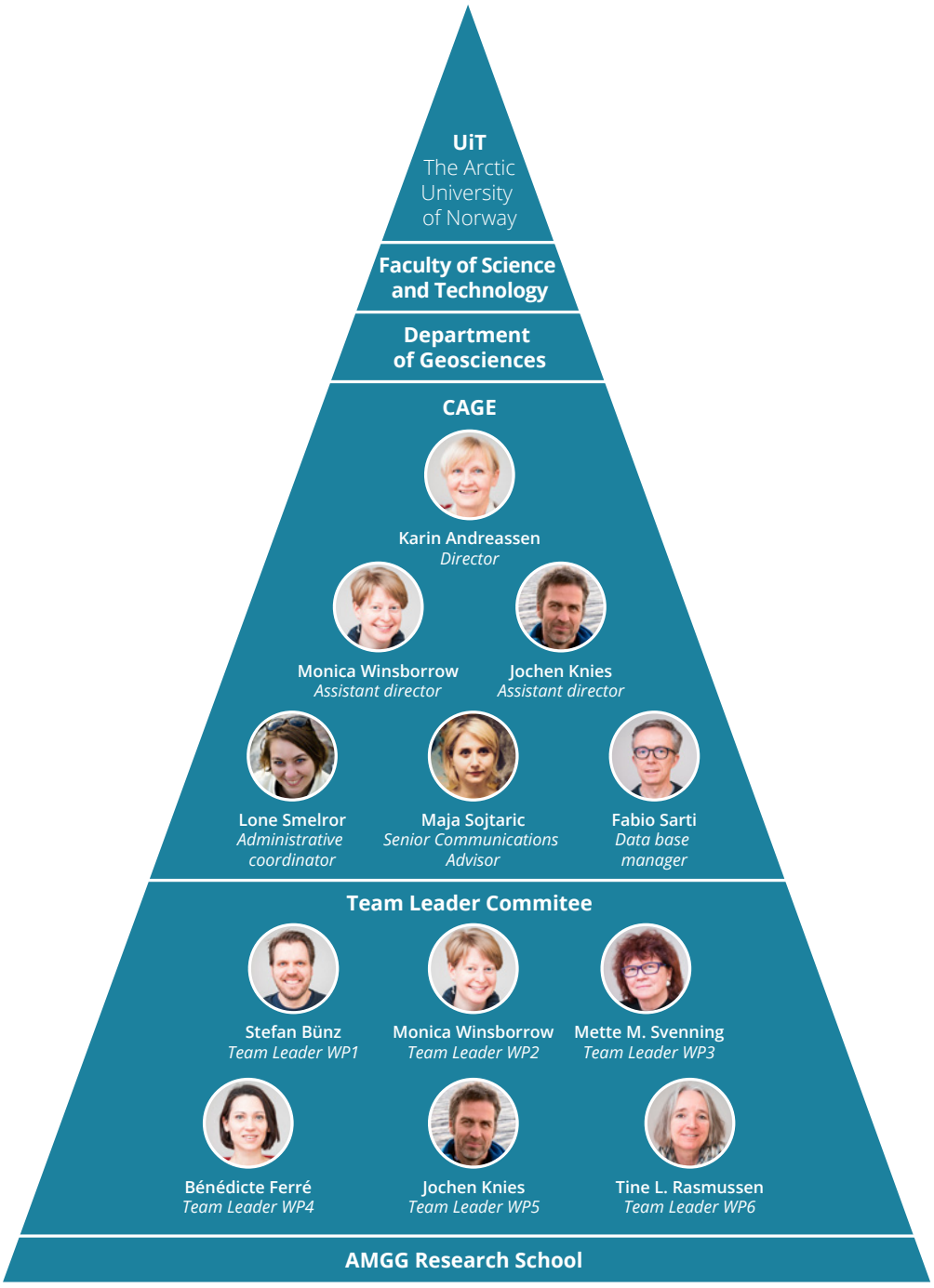
Prof. Karin Andreassen
Centre Director

Contents

Cover photo by Dimitri Kalenitchenko; Photo page 2: Karin Andreasesen; Photo page 3: Polar bear watch during a cruise to High Arctic. Photo by Robin Hjertenes

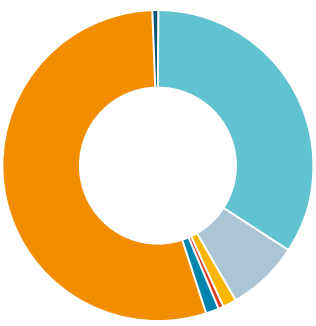
Editorial team: Maja Sojtaric & Karin Andreassen. Design and layout by Torger Grytå & Julian Høgset

Organisation chart of the centre



Funding 2019

Funding (1000NOK)	Amount	Percentage
The Research Council	25 029	34,3 %
Industry	5 449	7,5 %
EU	1 028	1,4 %
Other external funding (TFS, VISTA)	368	0,5 %
Norwegian Petroleum Directorate	1 000	1,4 %
UiT The Arctic University of Norway	39 841	54,5 %
Geological Survey of Norway	325	0,4 %
Total	**73 040**	**100 %**



The Research Council of Norway
Industry
EU
Other external funding (TFS, VISTA)
Norwegian Petroleum Directorate
UiT The Arctic University of Norway
Geological Survey of Norway

Centre Board

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

Kenneth Ruud
Chairman
Prof., Prorector for Research and Development, UiT

Arne Smalås
Prof., Dean NT-faculty, UiT

May Britt Myhr
Director of the Norwegian Geological Survey (NGU) Trondheim

Nalan Koc
Research Director of the Norwegian Polar Institute Tromsø

Ingrid Schjølberg
Prof., Director NTNU Ocean Science and Technology (NTNU Oceans)

Kristina Helland-Hansen
Vice President of International South Exploration at Equinor Bergen

The Scientific Advisory Committee

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

Prof. Doug Connelly
National Oceanography Centre, Southampton, UK

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

Dr. Carolyn Ruppel
United States Geological Survey, USA

Prof. Mads Huuse
University of Manchester, UK

Prof. Alexander Loy
University of Vienna, Austria

WORK PACKAGE 1

Gas hydrate and free gas reservoirs

Stefan Bünz, *Team Leader*

Professor Stefan Bünz has 20 years of experience in marine geology and geophysics with specific research expertise in: gas hydrates, fluid flow systems, shallow gas anomalies and geohazards, high-resolution 3D/4D and multi-component seismics, CO_2-storage in petroleum provinces, seafloor ecosystems, ultra-slow spreading ridges, and tectonic and non-tectonic faulting.

Members:

Jürgen Mienert
Professor Emeritus

Sunil Vadakkepuliyambatta
Researcher

Shyam Chand
Researcher

Andreia Plaza-Faverola
Researcher

Sunny Singhroha
PhD Candidate

Malin Waage
PhD Candidate

Kate Waghorn
PhD Candidate

Frances Ann Cooke
PhD Candidate

Przemyslaw Domel
PhD Candidate

Hariharan Ramachandran
Postdoctoral Researcher

Stefan Beaussier
Research assistant

Rémi Vachon
Postdocotoral Researcher

Jean-Baptiste Koehl
Research assistant

About:

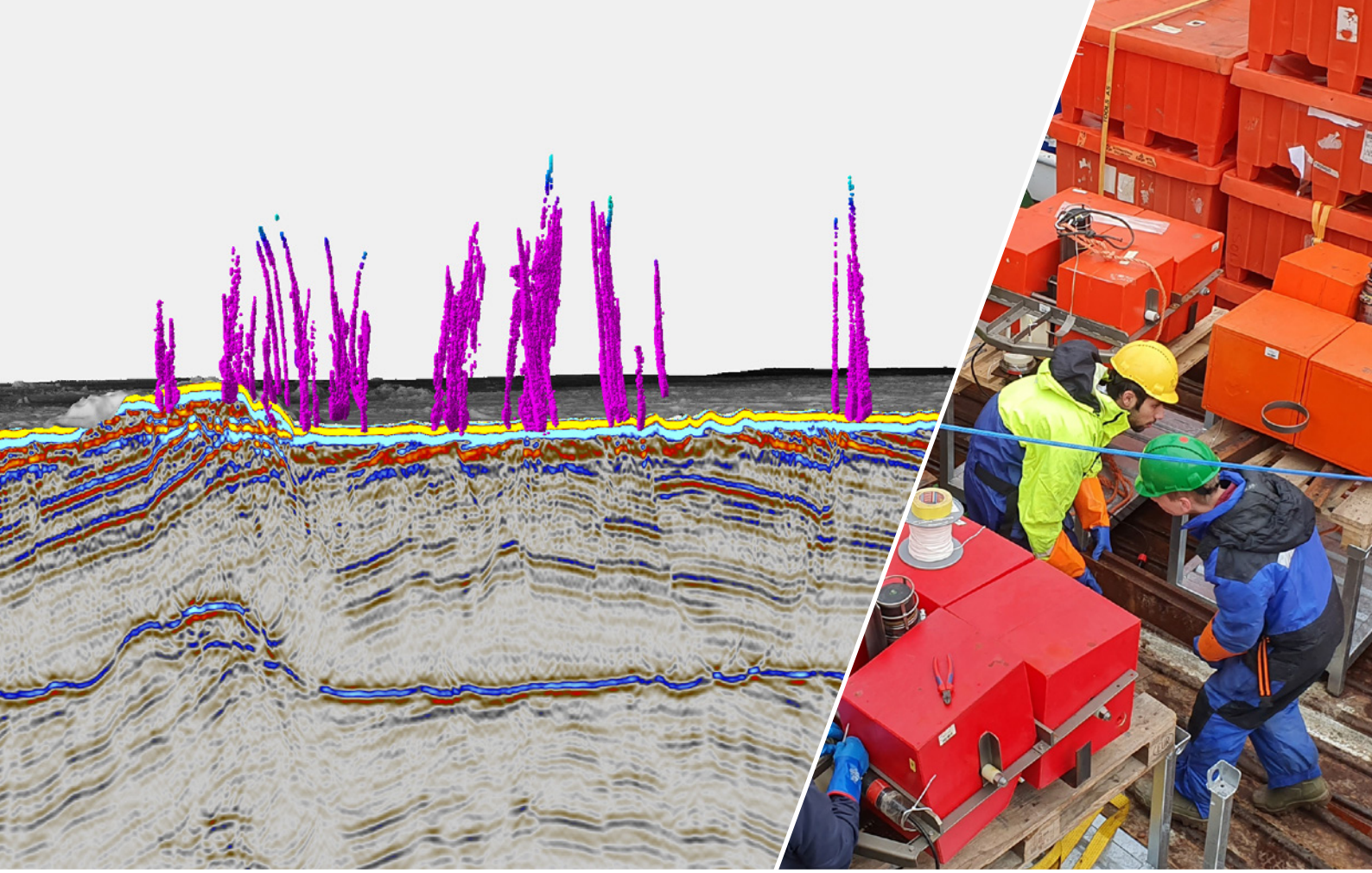
One of the greatest uncertainties regarding the Arctic marine methane supply is the amount of frozen methane that lays hidden beneath the seabed. Equally important are the quantities of methane that have been, or will be, released - potentially impacting ocean life and our global climate. In order to shed light on these mysteries, we rely heavily upon UiT's research infrastructure Geosystem 3D Seismic Imaging (G3), a national facility for the acquisition of high-resolution 3D seismic data based on the P-Cable 3D seismic system. It allows for imaging in unprecedented detail when investigating complex and dynamic geosystems of gas hydrates, geofluids and geohazards in marine environments from the shelf to the deep sea. This data enables us to perform excellent reservoir mapping while measuring the amounts of frozen methane and free gas waiting beneath the sediment, as well as identifying any leakage from within.

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:

- Identify and quantify gas hydrate and free gas reservoirs in the Arctic.
- Develop technologies for direct detection of gas hydrate in marine sediments.
- Understand the spatial and temporal dynamics of gas hydrate reservoirs under changing environmental conditions using high-resolution 3D seismic imaging, sediment drilling and sampling, as well as heat-flow measurements and modelling.
- Understand the genesis, mechanisms and governing geological processes of fluid flow.
- Acquire high-resolution 4D time-lapse data to quantify fluid flow through fractured systems.



Methane seepage from faults. Deployment of ocean bottom seismometers. Illustration: Andreia Plaza Faverola. Photo: Stefan Bünz.

In 2019 we contributed prominently to a review paper on hydrate occurrence in Europe, where the Norwegian-Svalbard Margin constitutes the largest offshore area hosting gas hydrates. Three of our PhD students - Malin Waage, Kate Waghorn, and Sunny Singhroha - defended their theses. At the same time the SEAMSTRESS project lead by Andreia Plaza Faverola (see page 18-19), brought an influx of six new group members

A new research project funded by Aker BP started in June. In this project, work packages 1 and 5 will jointly continue investigations of the gas seepage field at the Leierdjupet fault complex in the South West Barents Sea. Two postdocs were employed within this project. They provided analysis of samples taken in 2018, which will be a backbone for a planned ROV cruise on RV *Kronprins Haakon* in May 2020.

In early fall, Stefan Bünz led an expedition with RV *Kronprins Haakon* deep into the Arctic Basin. The expedition was related to the HACON FRINATEK project investigating the Aurora hydrothermal vent field on the Gakkel Ridge. (See page 26-27)

Main achievements 2019

1. A 4D seismic processing procedure has been established based on data examples from 3 areas. It demonstrates the repeatability of P-Cable high-resolution 3D seismic data as a 4D time-lapse tool to investigate natural geological processes.
2. Analysis of multicomponent ocean-bottom seismic (OBS) data from the Vestnesa Ridge gives much better constraints on gas hydrate saturation, distribution and morphology from the eastern Vestnesa Ridge. Significant variation in gas hydrate and free gas saturation across faults suggests a structural control on the distribution of gas hydrate and free gas in the Vestnesa Ridge and indicates the presence of gas hydrates in faults and fractures.
3. Two important publications on the understanding of the hydrocarbon system of the Vestnesa pockmarks were published from samples taken during the MeBo seafloor drill expedition on RV Maria S. Marian in 2016. A combined analytical/modeling approach, including concentration and isotopic mass balances, reveals that pockmark sediments experience diffuse migration of thermogenic hydrocarbons. Uranium-thorium dating of seep carbonates reveal three methane emission episodes mainly forced by glacial tectonics induced by ice sheet fluctuations on Svalbard.
4. The gas hydrate pingos in the Storfjord Trough have been studied in detail using geological, geochemical and microbiological approaches. Our interpretation of 3D P-Cable seismic data acquired in 2016 revealed the subsurface structure of the pingos and their relation to the geological setting. Pingos occur on top of gas chimneys piercing a thin section of low-permeability glacial sediments. The chimneys connect to faults within the underlying tilted and folded fluid and gas-hydrate-bearing sedimentary rocks. Correlation of the P-Cable data with regional 2-D seismic surveys shows a spatial connection between the shallow subsurface fluid flow system and the deep-seated regional Hornsund fault zone.

WORK PACKAGE 2

The role of ice ages

Monica Winsborrow, *Team Leader from september 2019 due to maternity leave*

Monica Winsborrow is a Researcher at CAGE. Her research focuses on the reconstruction of past ice sheets, working to understand the processes and mechanisms that control their evolution and dynamics, and examining their environmental impacts. She holds a PhD in Physical Geography from the University of Sheffield, UK, and worked in both academia and industry before joining CAGE in 2014. She became Team Leader and assistant director of CAGE in August 2017.

Karin Andreassen, *Team Leader until September 2019*

Karin Andreassen is a Professor in marine geology and geophysics at UiT. Her research career spans more than 35 years investigating the long-term development of the Barents Sea and the wider Arctic, focusing on ice sheet dynamics and subglacial landforms, sediments and processes, shallow gas and fluid flow from glacial to interglacial conditions.

Members:

Alun Hubbard
Professor (50%)

Renata Lucchi
Adjunct Professor (20%)

Jemma Wadham
Adjunct Professor (20%)

Henry Patton
Researcher

Nikolitsa Alexandropoulou
PhD Candidate

Nils Brückner,
PhD Candidate
(Western Norway University of Applied Sciences)

Calvin Shackleton
PhD Candidate
(completed June 2019)

Pavel Serov
Postdoctoral Researcher

Mariana de Silveira Ramos Esteves
Research assistant

Craig Hammock
PhD Candidate
(University of Swansea/CAGE)

About:

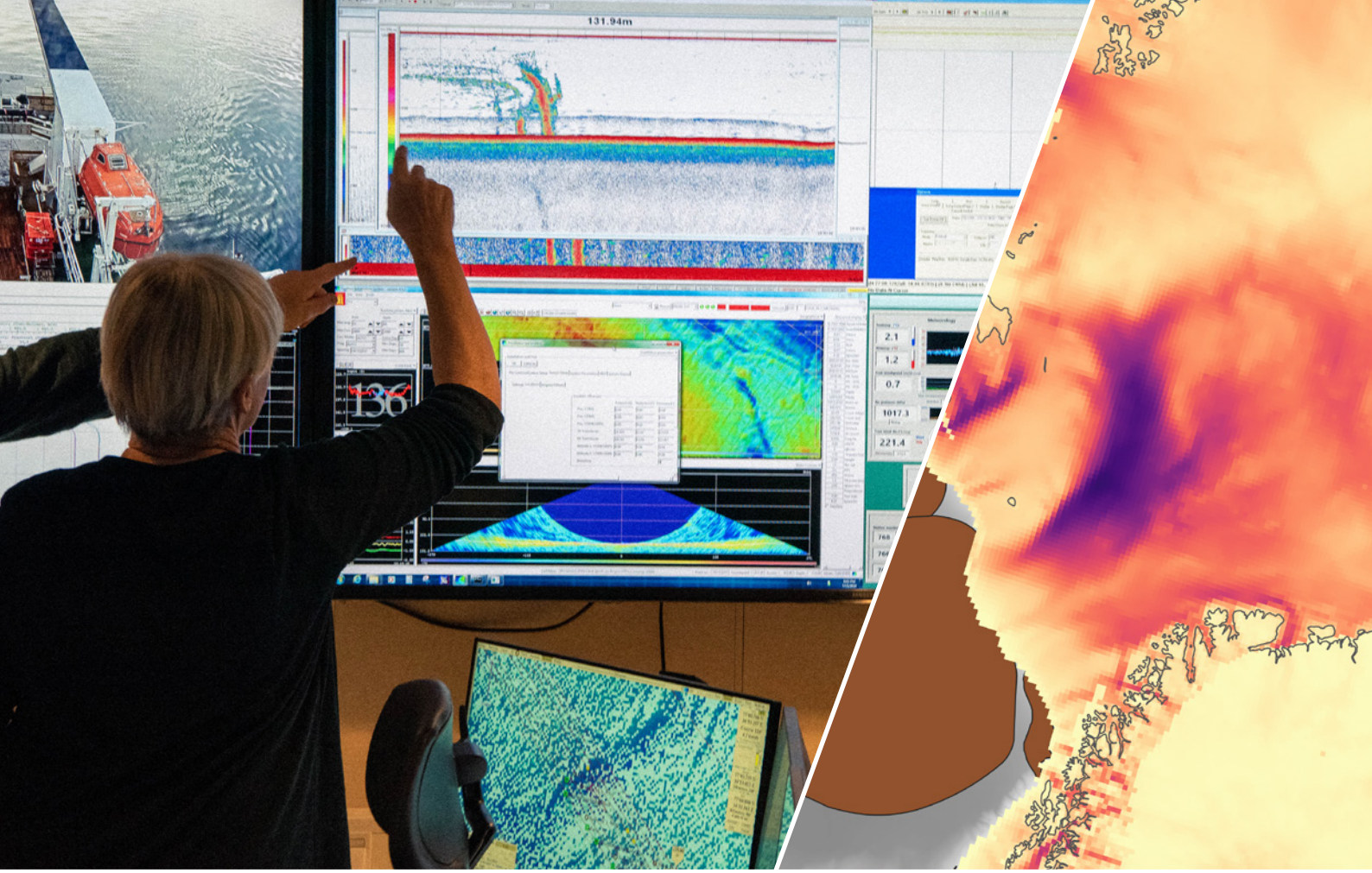
Today, vast quantities of methane are sequestered as shallow gas hydrates across the Barents Sea shelf, fed continuously by gas from deep thermogenic sources. We propose that these hydrate reservoirs were much thicker and more extensive under the extreme conditions of past ice ages, whereby high pressure and low temperature conditions beneath former ice sheets created an environment conducive for stable hydrate formation. We combine state-of-the-art marine geophysical data with high-resolution modelling to provide extraordinary insights into the long-term variability of methane storage and release forced by repeated 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 contemporary Greenland and Antarctic ice sheets.

Main questions:

- How do ice sheets affect fluid flow and gas hydrate systems?
- How does the thickness, extent and volume of gas hydrates change through the ice ages?
- What impact did glaciations have on the Arctic environment?

Major aims:

- Determine, through modelling and empirical observations, the key processes and feedbacks between gas hydrates, fluid flow and ice sheet glaciation.
- Model the long-term impact of past glacial cycles on the Eurasian Arctic, both within and beyond formerly ice-covered regions.
- Isolate critical subglacial controls on past ice sheet and ice stream behaviour and dynamics.
- Develop stratigraphic and environmental frameworks for key CAGE study areas.



Karin Andreassen in the instrument room on board RV Helmer Hansen during a cruise in 2019. Erosion intensity/erosive impact of the Eurasian ice sheet during the last glacial cycle. Photo: Torger Grytå. Illustration: Henry Patton.

Numerical models require accurate constraints provided by high quality empirical data. We continue to acquire state-of-the-art geophysical datasets from strategic field sites across the Norwegian-Barents Sea and Arctic.

Our work package is in a world-leading position to integrate high resolution empirical datasets and numerical models of past glacial cycles and processes to assess their concomitant impact on subglacial gas hydrate dynamics in unprecedented accuracy and detail.

Main achievements 2019

1. Start-up of a modelling collaboration with ARCEX, funded by Akademia-Agreement between UiT and Equinor, (Researcher Henry Patton) to examine the evolution of the Barents Sea basin through the Late Cenozoic Era.

2. Start-up of VISTA funded post-doctoral project (Pavel Serov) examining the effects of glacial "pumping" on fluid flow in the Barents Sea.

3. Early career scientist Mariana Esteves participated in IODP expedition 379 to the Amundsen Sea, West Antarctica.

4. Geophysical surveying of the Adventdalen pingo system, Svalbard, began, in collaboration with work package 3 microbiological investigations.

5. Setup a modelling collaboration, JointClimate, with the Department of Physics and Technology (IFT), and the Department of Mathematics and Statistics (IMS) at the Faculty of Science and Technology at UiT, within which the work package will focus on modelling palaeo ice-ocean interactions in the Arctic (Post Doctor Mauro Pau).

6. JointClimate was included in UiT´s Aurora Centre for Nonlinear Dynamics and Complex Systems Modelling (DYNAMO). This interdisciplinary centre with thematic focus on climate change, its impact on ecosystems received funding of 30 million NOK.

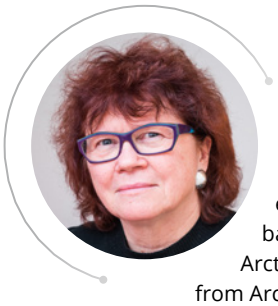
7. Successful integration of ice-sheet and climate reconstructions into a permafrost model (Uni. Oslo) to track the dynamic behaviour of frozen ground since the last glacial maximum through to the present day.

8. Developed an updated, high-resolution chronostratigraphic framework, with constrained sediment package volumes, of the Bjørnøyrenna trough mouth fan over the last 2.7 Ma.

9. The drivers and key constraints for long-term glacial erosion and landscape development across the Eurasian domain are modelled and validated against marine and terrestrial datasets.

WORK PACKAGE 3

Cold loving microbes in a warming Arctic



Mette Marianne Svenning, *Team Leader*

Professor Mette Marianne Svenning is an internationally recognized expert on methods for isolation and cultivation of methane oxidizing bacteria (MOB), and has a culture collection of representative MOB from Arctic and sub-Arctic regions. Svenning has extensive fieldwork experience from Arctic (Svalbard) and sub-Arctic regions. This includes leadership, management and coordination of fieldwork, methane emission measurements, vegetation analyses and sampling for microbial and molecular studies in the laboratory.

Members:

Helge Niemann
Adjunct Professor (20%)

Dimitri Kalenitchenko
Postdoctoral Researcher

Vincent Carrier
PhD Candidate

About:

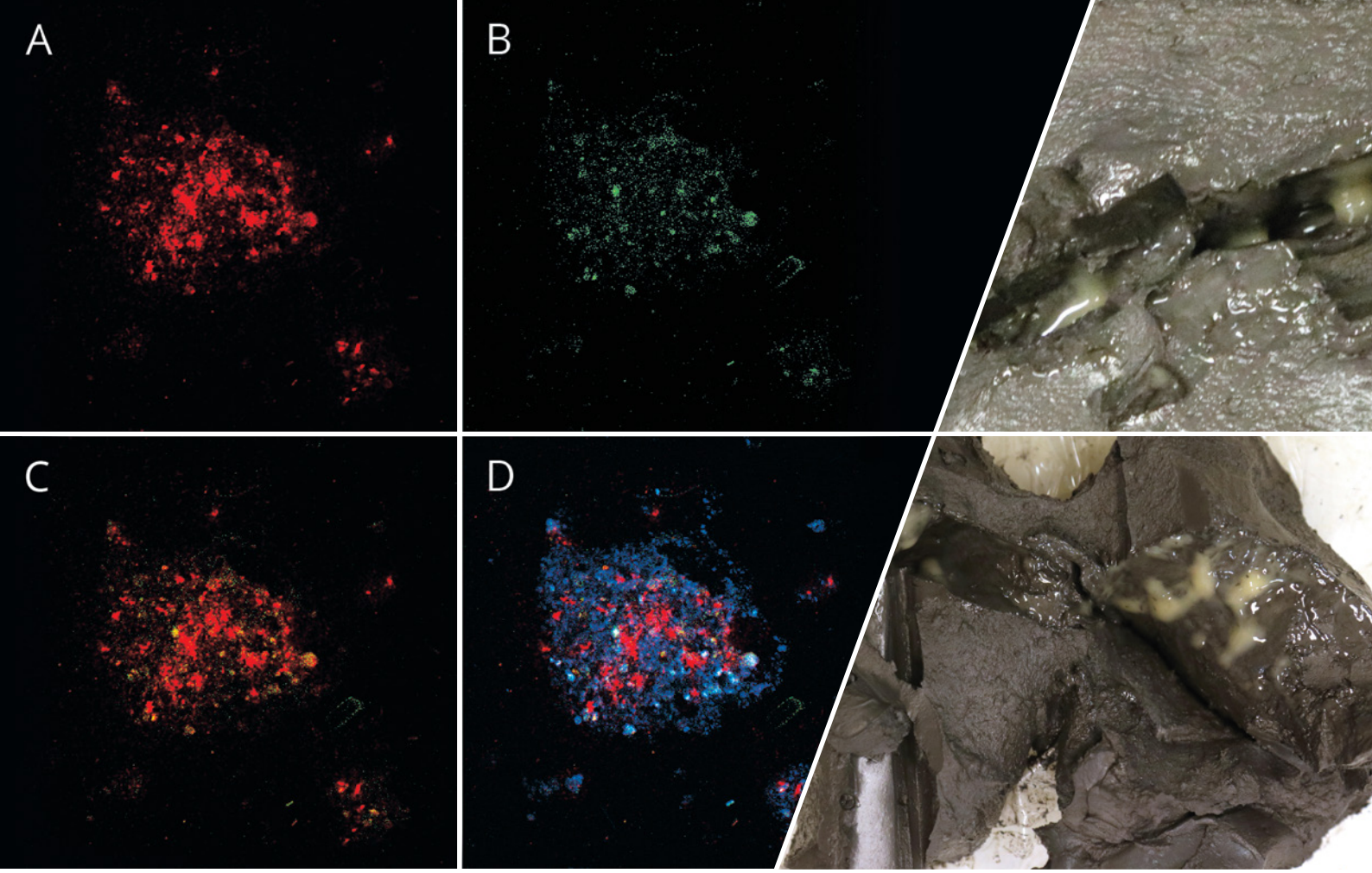
It is uncertain how, and to what extent, methane release from gas hydrates affects life on the seabed, such as benthic organisms, communities, microorganisms and food web structures. This research group has been established in order to dig further into this mystery. Our studies are linked to, and coordinated with, geochemical, sedimentological and water column studies of the CAGE team. In the coming years, WP3 will emphasize microbiology and the sensitivity of cold adapted microbial sub-seabed ecosystem's importance for methane emissions and do comparative studies in terrestrial ice pingo systems. A new and unique infrastructure, the Ice-Cold Microorganisms Laboratory (ICOM), will be a novel tool to address biodiversity, activity and evolution of cold loving microbes.

Main questions:

- How is life on the seabed affected by methane release from gas hydrate dissociation?
- How is microbial community structure and activity in marine seabed gas hydrate pingos as compared to terrestrial pingos?
- What is the role of the seafloor biological communities in mediating the exchange of methane from seafloor sediments into the water column?
- How do the sub-seabed microbial communites and networks respond to changes in temperature and substrate availability?
- How active is the methane oxidising filter in the water column?

Major aims:

- 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.
- Understand responses and evolution of cold seep biological communities.



A biofilm found hidden in the crevice of seafloor sediment, an unusual location. Biofilm samples found were shown to have a unique microbial composition. Photos: Friederike Gründiger.

We have documented a first case of biofilms found in the cracks of methane-rich sediment in Arctic waters. It could prove to be a common occurrence of which the scientific community was previously unaware.

Addressing adaptive mechanisms to Arctic ecosystems by molecular physiology by combining laboratory experiments with genomics is the current research platform for work package 3.

The platform is built upon Prof. Svenning expertise regarding methane oxidizing bacteria; biodiversity, and the activity of microbial communities; and their involvement in organic carbon degradation and CH_4 emission in Arctic and sub-Arctic regions. The strengthened cross-disciplinary collaboration with Svenning's home Faculty of Biosciences, Fisheries and Economics at UiT continues to be of great importance for work package 3.

Main acievements 2019

1. Described microbial community structure and composition in Arctic gas hydrates pingos.

2. Identified biofilms of anaerobic methane oxidation in sediment pockets closely associated with methane seeps.

3. Participated in the CLIMAGAS project (PI: Andrew Hodson, UNIS) to explore the diversity and function of the water and ice microbiome of terrestrial open system pingos. Part of this project CAGE's drone was used to map the site and 2D orthomosaic map was created using WP3 informatic resources allocation on the Norwegian e-infrastructure for research and education (SIGMA2/UNINETT).

4. Participated in the FRINATEK HACON project to study microbiology and methane oxidation at hydrothermal vents in the Arctic Ocean and their signature in the ice in collaboration with NASA. The aim is to use the knowledge of Earth's ice-covered oceans and transfer it to understand the ice-covered moons and planets in our solar system.

5. Identified frenulate species and how certain oceanographic processes may affect the distribution and speciation of cold seep frenulates at high latitudes.

6. Further developed the collaboration with The Faculty of Biosciences, Fisheries and Economics to strengthen the research and infrastructure platform of UiT The Arctic University of Norway.

7. Established parts of the Ice-Cold Microorganisms Laboratory (ICOM) in collaboration with Dr. Alexander T. Tveit, for conducting experiments and gaining new insights into how microbial communities work in ice-cold environments.

Gas in the water column

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. She is involved in many projects related to ocean observatories and is, among other tasks, responsible for the development, acquisition and analysis of data related to the seafloor observatory K-lander.

Members:

Anna Silyakova
Researcher

Helge Niemann
Adjunct Professor (20%)

Pär Gunnar Jansson
Researcher

Knut Ola Dølven
PhD Candidate

Manuel Moser
PhD Candidate

Muhammed Fatih Sert
PhD Candidate

About:

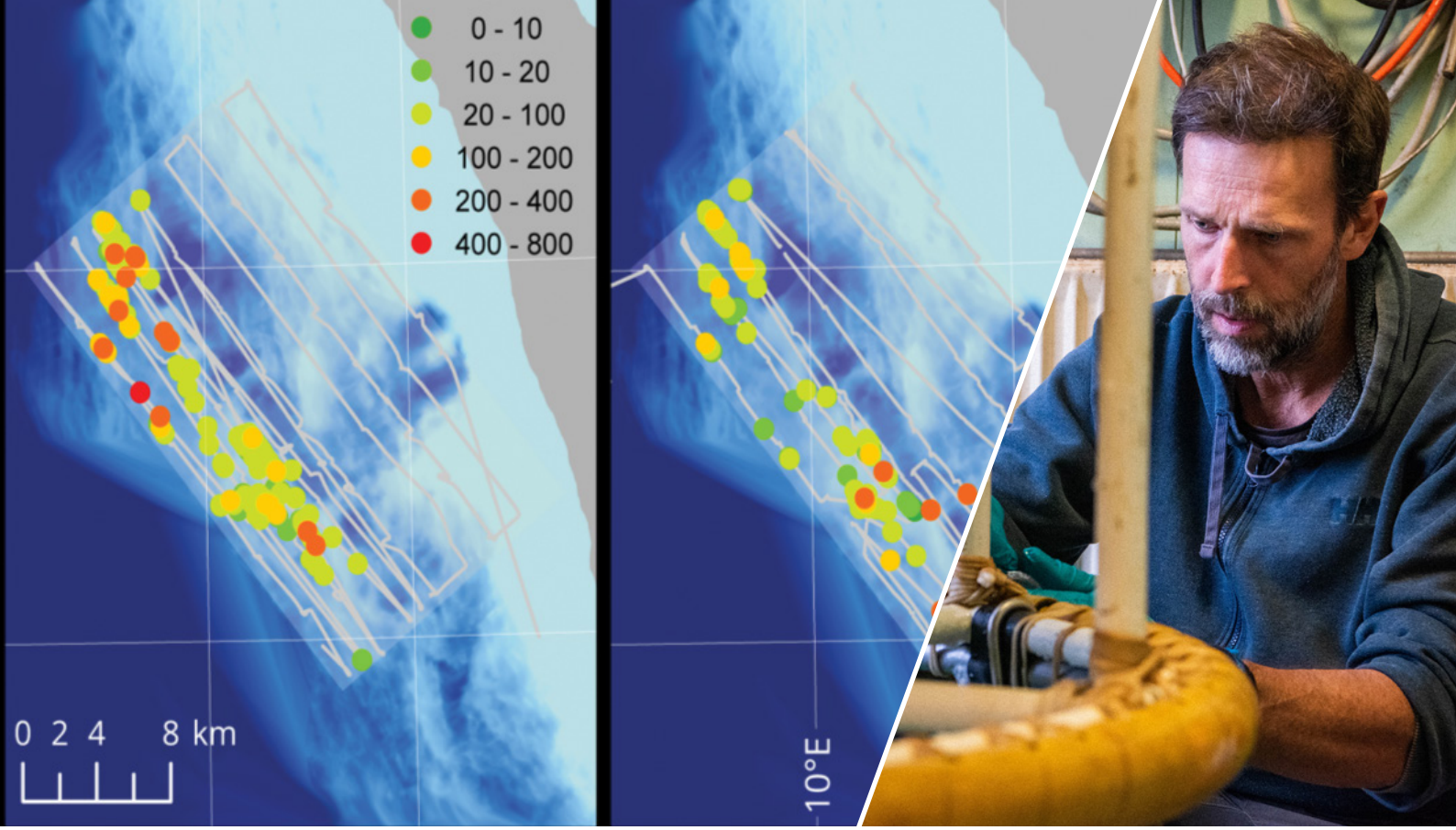
The effects of methane release on underwater ecosystems and our global climate are still unclear. Methane transport in Arctic oceans takes place via bubbles or in dissolved form beneath the seabed and travel vertically towards the ocean surface. However, continuously shifting water dynamics due to changing seasons and other factors can limit vertical methane migration. By understanding the constant evolution of the ocean and the related variability of methane release on a time scale that ranges from hours to years, we can quantify local and regional methane leakages as well as methane transport in the water column over time. This ultimately helps us to determine what effect, if any, this methane has on underwater ecosystems and climate change.

Main questions:

- How much of the methane released from the seafloor reaches the upper water column and the atmosphere?
- Over what horizontal and vertical distances do ocean currents transport methane plumes?
- What is the variability of the methane release and what are the processes involved?
- What are the interactions between the physical, chemical and biological processes that affect methane transport?
- What is the effect of methane seeps on the Arctic Ocean biogeochemistry?

Major aims:

- Observe and model the transport of methane plumes.
- Determine and model methane fluxes from the seafloor to the sea surface.
- Determine physical and chemical boundary conditions of the bottom water that modify methane seep activities.
- Investigate and compare water column biogeochemistry at and around active methane flares



Methane flow rate comparison from three different years offshore Svalbard ~90m depth. From Silyakova et.al (2019). Pär Jansson checking the CTD instruments for a cruise in 2019, during which the CAGE observatory was deployed once again. Photo: Torger Grytå.

The team focuses on physical and chemical data collected in the water column and near the seafloor, to understand the link between oceanic settings and methane release and transport. We therefore rely on data collected during experiments at sea, as well as from the K-landers observatories.

The K-Landers represent a successful cooperation between the maritime industry (Kongsberg Maritime) and academia that is essential for future climate research. This advanced equipment makes it possible to continuously measure environmental changes associated with methane release at remarkable resolutions, and acquire data to tune and force models. Modeling is also one of the main focuses in order to understand the fate of methane and other gases in the ocean.

The main activities of WP4 during 2019 consisted in ongoing (Lofoten Vesterålen - LoVe; Svalbard Integrated Arctic Earth Observing System - SIOS; Environmental Research Infrastructures - ENVRIplus; and Hot vents in an ice-covered ocean: the role of the Arctic as a connectivity pathway between ocean basins - HACON) as well as new projects (Norwegian node for the European Multidisciplinary Seafloor and water column Observatory - NOREMSO).

Main achievements 2019

1. We have collected two years of data from the K-lander offshore Svalbard, and two publications are expected in 2020. One K-lander was deployed for the third time at the same site offshore Svalbard, and the deployment was financed by SIOS. Recovery expected in June 2020.

2. Developed a new tool for predicting the fate of seafloor-emitted methane using a two-phase gas model in one dimension. The new model has proven most accurate in predicting the upward progression of gasses in aquatic methane seepage systems thus far. (Jansson et al., 2019a).

3. It demonstrates major technological advances in water column measurements. A new study published in Ocean Science details its first use at a site with vigorous methane release.

4. Published a paper on high resolution ocean laser spectrometer in collaboration with a team at Institute for Geosciences and Environmental research (Grenoble, France). The paper is based on an experiment with a high-precision underwater laser spectrometer during a CAGE cruise in 2015 (Jansson et al., 2019b).

5. Participated to the HACON cruise in November 2019. HACON is a FRINATECH initiative funded by NFR and led by NIVA. Our role is to study the physical characteristics of a water column in a hydrothermal vent in the Gakkel Ridge.

6. Continuous data collection at LoVe node 7, deployed on a known methane seepage area. The lander is working well, and the physical data can be compared with other data collected from other nodes along the connected cable.

7. Awarded the new INFRASTRUKTUR project NOREMSO co-led with UiB, where moorings, landers and gliders will be deployed in the North Sea in order to study the physical oceanography and Ocean Acidification. In particular, one mooring will be equipped with chemical sensors for CO_2 and CH_4 monitoring. (see page 28-29)

Methane seepage history

Jochen Knies, *Team Leader*

Jochen Knies is a senior researcher at the Geological Survey of Norway. He holds a 20% position at CAGE, where he is currently one of the two Vice-Directors. 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:

Aivo Lepland
Researcher

Giuliana Panieri
Professor

Karl Fabian
Researcher

Shyam Chand
Researcher

Terje Thorsnes
Researcher

Soma Baranwal
Postdoctoral Researcher (contract ended August 2019)

Wei Li Hong
Postdocotoral Researcher

Tobias Himmler
Postdoctoral Researcher

Pierre Antoine Dessandier
Postdoctoral Researcher

Simone Sauer
Postdocotoral Researcher (IFREMER)

Christiane Schmidt
Postdocotoral Researcher (Anger University)

Haoyi Yao
PhD Candidate

Katarzyna Melaniuk
PhD Candidate

About:

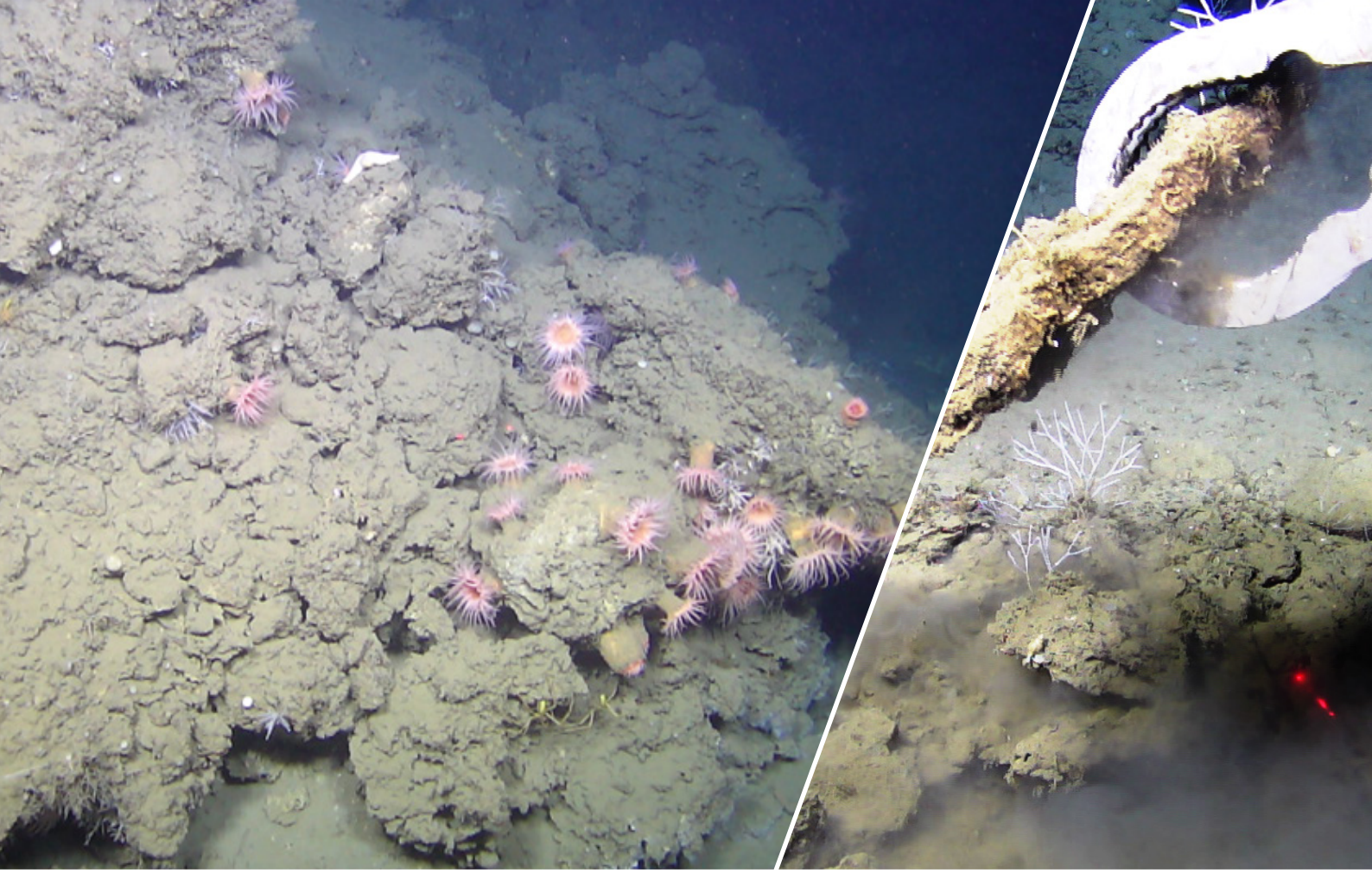
To understand the environmental factors that drive methane seepage we need to better constrain the timing of methane release throughout the geological past. To do this we use authigenic carbonates and microfossils to develop records of palaeo-methane seepage for sites around the Arctic. We then assess the influence of various environmental conditions, for example sea ice extent and glacial isostatic adjustment, on methane seepage history.

Main question:

- What caused the evolution of submarine Arctic gas hydrate systems and methane leakage events in the geological past?

Major aims:

- Establish geochemical markers and time constraints for "abnormal" methane release from seabed to ocean.
- Determine paleo conditions of ocean life and links to climate change during the geological past.



A seep carbonate sample from a drill core drawn from about 10 m below the seabed. July 2016: sampling seep carbonates from the seabed at 1200 m water depth, off western Svalbard using the ROV Ægir. Photos: NORCRUST.

Technology intensive explorations over the past couple of years, payed off for work package 5 during 2019: Unique material from the canyons on the ocean floor offshore Lofoten and Vesterålen Islands was collected using ROV Ægir and RV G.O.Sars. The same infrastructure, plus Marum´s RV Maria S. Merian and MeBo drill, were employed to collect carbonate samples offshore Svalbard. The expeditions resulted in two major discoveries published in 2019.

The alliance with world-class laboratories, and academic and industry partners, allowed the application of cutting-edge technologies that resulted in a deeper understanding of methane dynamics and interrelated processes. It gave us a broader international audience with publications in Science Advances, Geophysical Research Letters, Frontiers and Scientific Reports.

Main achievements 2019

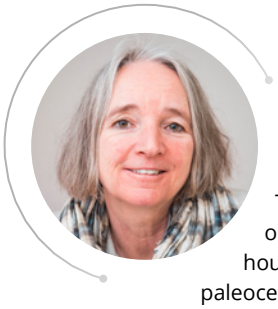
1. We discovered that fresh water was leaking from the seabed along Lofoten/Vesterålen continental margin. Freshwater seepage was documented at 800-meter water depth and has been occurring over the last 20.000 years. Its presence is likely the result of meltwater discharge from the collapsing ice sheet at the end of the last glacial period. The thick ice caps that enveloped Norway, pushed down on the crust of the Earth with tremendous force, squeezing large amounts of meltwater down through cracks in the seabed. This freshwater seepage sustains an oasis of chemosynthethic benthic community, which has existed since the last ice age. This community is responsible for the formation of a large pool of biologically derived methane gas.

2. Ice sheet dynamics of the past, likely induced fault movements in the Earth's crust, thereby facilitating seabed methane release in ~1200 m water depth offshore Svalbard throughout the past 16.000 years. Our study provides direct evidence for seabed methane emissions during the penultimate glaciation which shows that periodic changes in ice volume of the Eurasian ice sheets have a significant impact on Arctic methane release during the entire Pleistocene.

3. A step forward has been made in understanding how microorganisms (foraminifera) inhabiting methane seeps use the chemical energy from methane and microbes. Experiments are underway and study on living species show that seep sites are hostile for some common Arctic species.

WORK PACKAGE 6

Methane, CO_2 and ocean acidification



Tine Lander Rasmussen, *Team Leader*

Tine Rasmussen is a professor at the Department of Geosciences, UiT The Arctic University of Norway. Her research interests are focused on abrupt climate and oceanographic changes and changes in greenhouse gases in Arctic to sub-Arctic areas. She is educated in the fields of paleoceanography, paleoclimate, biology, micropaleontology, ecology and paleoecology. She holds a PhD degree in marine science/paleoecology and micropaleontology from Aarhus University in Denmark, and has professional experience most notably from Woods Hole Oceanographic Institution (USA), Lund University (SWE) and Copenhagen University (DK).

Members:

Tine L. Rasmussen
Professor

Katarzyna Zamelczyk
Researcher

Mohamed Ezat
Researcher

Siri Ofstad
PhD Candidate

Naima El Bani Altuna
PhD Candidate

Griselda Anglada-Ortiz
PhD Candidate
(Nansen Legacy project)

About:

To understand the impact of methane release on past and present environments and climate, WP6 studies both modern environments by sampling living planktic and benthic foraminiferal faunas and past environments by examining the fossilized remains of once-living faunas, mostly from the seep sites around Svalbard. To better understand the processes and changes seen at methane release areas, WP6 also reconstructs the general paleoceanography by the study of cores from sites from the Svalbard margin, the Barents Sea, the Nordic seas and Arctic Ocean not influenced by methane.

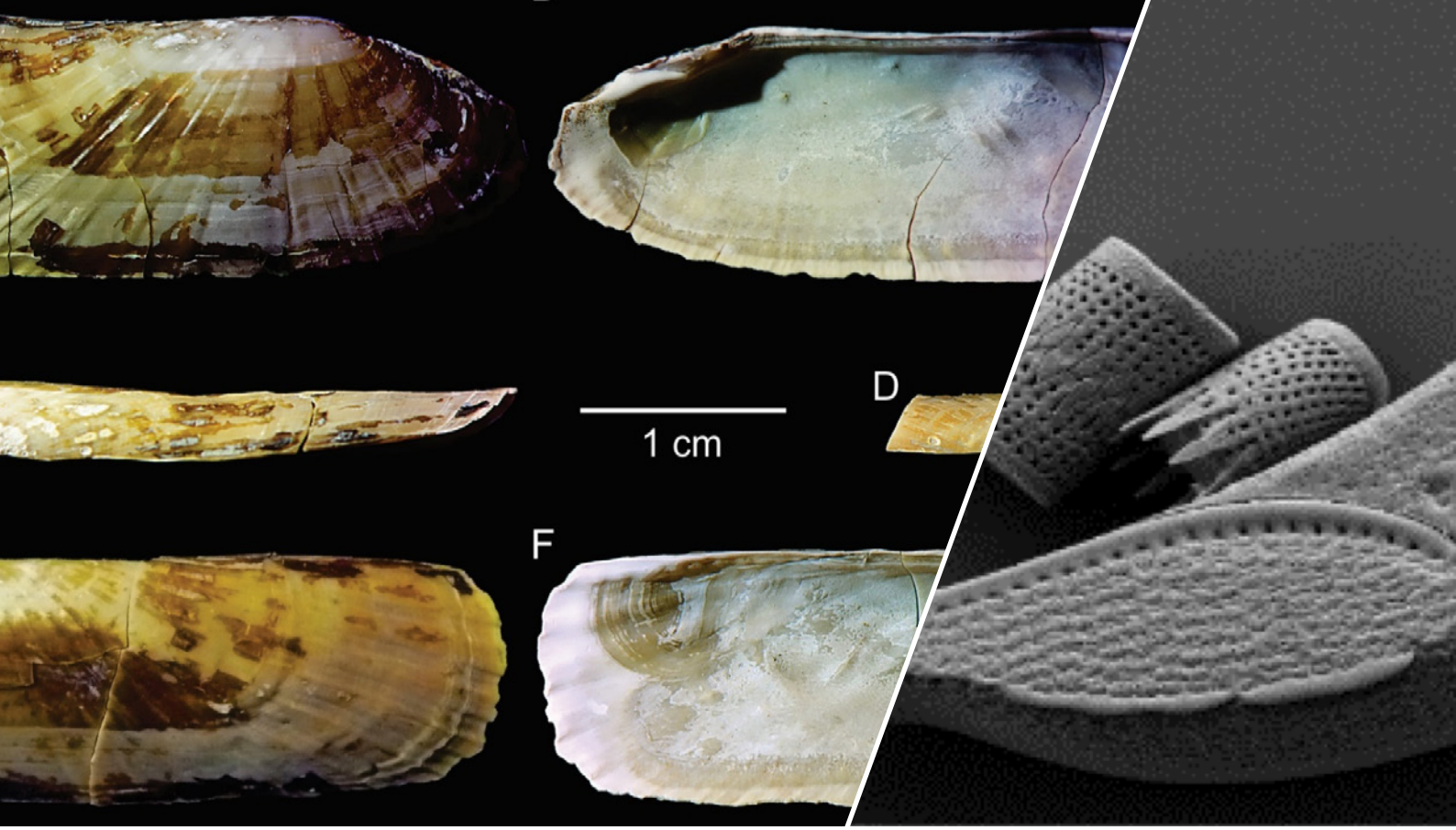
In addition, WP6 investigates methane seep areas by annual and/or seasonal sampling in order to document changes in planktic foraminifera in relation to ocean chemistry changes over time. Methane released from the seabed rapidly oxidizes to CO2, which change the carbonate chemistry of the ambient water. This can potentially increase ocean acidification, which can have detrimental effects on the delicate ecosystem of underwater life. In addition, WP6 monitors the planktic foraminiferal and pteropod response to ocean acidification by studying physical properties of their shells in the past and present.

Main questions:

- What is the impact of increased methane release on marine micro- and macrofaunas?
- Is there a relationship between this release and climate (ocean bottom water temperature) variability?
- Does methane release contribute to ocean acidification?

Major aims:

- Investigate methane release and its impact 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 planktic foraminiferal and pteropod responses to changes in ocean chemistry due to methane release, increasing atmospheric CO2 and ocean warming.
- Provide robust quantitative records useful for modelling and forecasting future changes as a result of ongoing changes in the polar ocean.



Bivalves found deep in the sediment in Vestnesa. Scanning Electron Microscope image of diatoms. Photos: J. Hansen & Ulrike Hoff.

We work to improve existing standards and intergrate established methods with groundbreaking technologies to estimate past CO2 concentrations, bottom water temperatures, and ventilation rates of the ocean and sea-ice cover.

Our work package also identifies general ocean circulation patterns of the past in relation to ice sheet advances/retreats and meltwater flows. With this information at hand, variations in methane release from the seafloor, and its impact on the environment and micro- and macro-faunas over time. can be compared to palaeoceanographic and climatic developments in order to obtain a better understanding of controlling factors.

Main achievements 2019

1. Diatom floras were quantified to reconstruct surface-ocean changes in the southern Norwegian Sea for the last ~130,000 years. The diatoms indicated earlier warmings and later coolings at the surface than the foraminifera, revealing a stratified water column at the beginning and end of interglacials and large interstadials.

2. A new Late Pleistocene solemyid species of Acharax from Arctic methane seeps off Svalbard were discovered, described and named A. svalbardensis. The genus is found in warm water conditions both past and present indicating that warm bottom water reached Vestnesa Ridge 17,000 years ago during the early deglaciation.

3. Deep ocean 14C ventilation age reconstructions from the Arctic Ocean have been critically assessed and the hypothesis of an isolated deep Arctic during the last glacial can be rejected. Instead, there was a persistent exchange between the Arctic Ocean, the Nordic Seas and the North Atlantic Ocean during the last glacial. Storage and release of CO2 and heat from the deep Arctic Ocean contributed significantly to the abrupt changes in atmospheric CO2 and regional climate during the last glacial.

4. The Svalbard-Barents Sea Ice Sheet reacted on millennial timescale to the abrupt warmings of the Greenland interstadials by sending out high amounts of coarse, local ice rafted material (IRD) through the last 70,000 years. During cold stadials and glacial maxima the IRD came from elsewhere.

5. The cold-seep fossil macrofaunal assemblages from Vestnesa Ridge, eastern Fram Strait during the past 45,000 years showed showed increased density and diversity compared to non-seep areas – seepage thus generated oases for macrofaunas in the past as it does today.

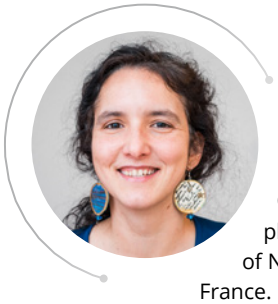
6. Investigation of seasonal distribution of planktic foraminiferal faunas and pteropods over seep sites in the crater area in the Barents Sea revealed no relation between faunal composition, concentration and preservation states in relation to seasonal water chemistry changes, but a potential productivity effect.

7. Changes in ocean circulation, surface productivity and properties of surface water masses correlated closely to the major climate anomalies of the past two millennia southwest of Svalbard.

8. The history of the Greenland Ice Sheet and its relation to both the East Greenland Current and the sedimentary processes of the Scoresby Sund/north-east Greenland shelf areas were studied based on a combination of marine sediment cores, shallow seismic and seabed morphology.

RESEARCH PROJECT

SEAMSTRESS



Andreia Plaza-Faverola, *Researcher*

Andreia Plaza-Faverola is researcher within WP1 Gas Hydrates and Free Gas Reservoirs'at CAGE. She holds a PhD degree (2010) in marine geophysics from the Department of Geosciences at UiT The Arctic University of Norway and a MSc degree in petroleum geology from the IFP School in France. Her PhD was centered on the integration of seismic methods for the study of shallow gas distribution and gas hydrate systems on the passive Norwegian continental margin. She went to New Zealand for a two years post-doctoral fellowship at GNS Science in Wellington, where she investigated fluid flow and gas hydrates systems in active subduction margin settings.

Members:

Hariharan Ramachandran
Postdoctoral Researcher

Remi Vachon
Postdoctoral Researcher

Frances Ann Cooke
PhD Candidate

Przemyslaw Domel
PhD Candidate

Stefan Beaussier
Research assistant

Jean-Baptiste Koehl
Research assistant

About the project:

The SEAMSTRESS project aims at quantifying the effect of tectonic forcing on the release of greenhouse gasses from the ocean floor in the Arctic. SEAMSTRESS is supported by the Tromsø Research Foundation (TFS) and the Research Council of Norway (RCN-Frinatek) through two starting grants awarded to Andreia Plaza-Faverola. In addition, the Faculty of Science and Technology, the Department of Geosciences at UiT, and the Center for Arctic gas hydrate, environment and climate (CAGE) provide significant support to the project.

Ocean bottom seismometers are currently on the seafloor surrounding an area of active methane release offshore west-Svalbard. Photo: Stefan Bünz

Long calypso sediment cores were collected all over the Fram Strait during a cruise with RV Kronprins Haakon in 2019. Photo: Stefan Bünz.

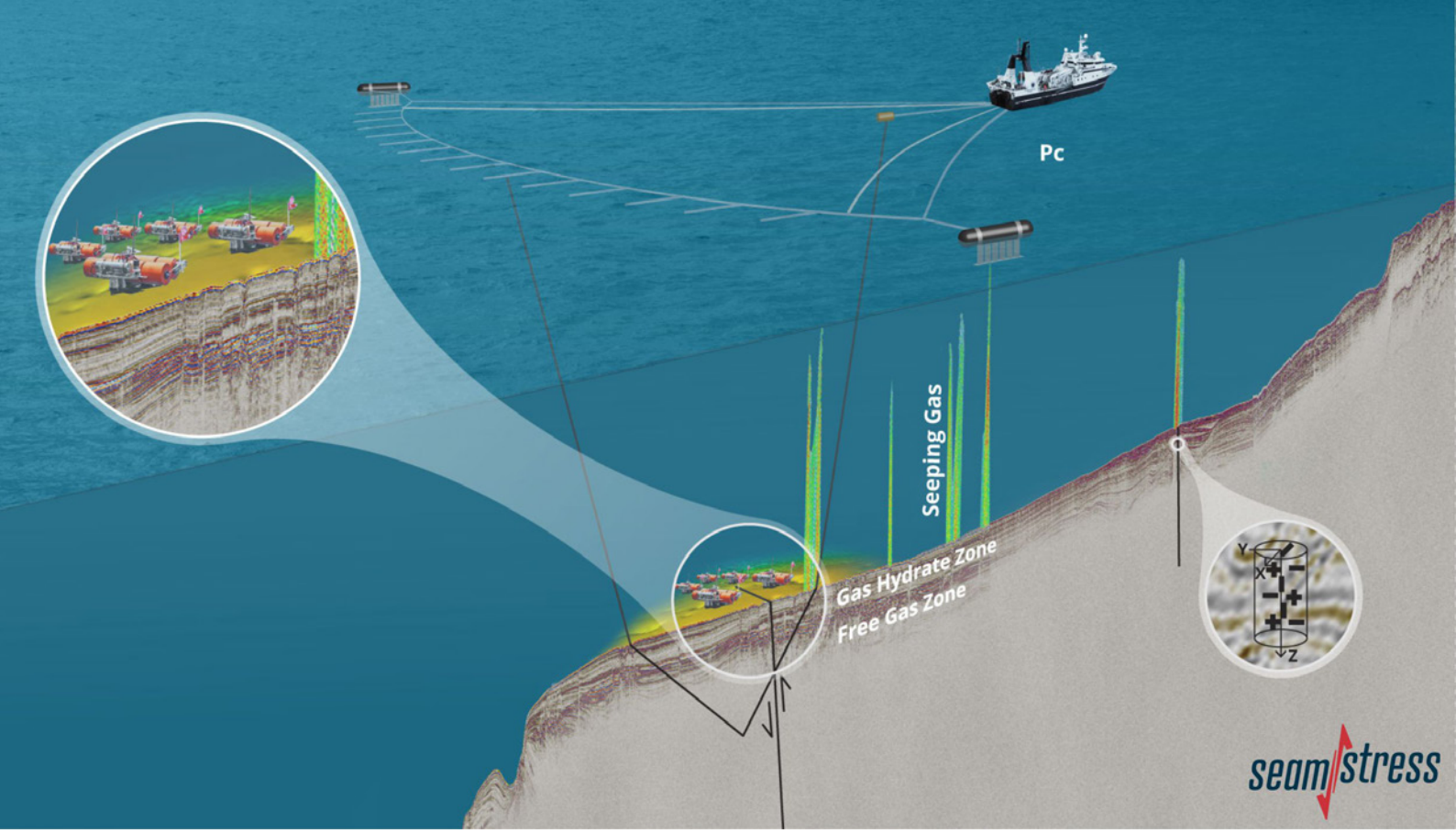


Illustration: Torger Grytå.

The release of large amounts of greenhouse gasses from the ocean floor not only effects seabed ecology and the stability of underwater landmasses; it can also influence our global climate. While we know that this is a widespread phenomenon, we still do not understand the mechanisms controlling the timing and quantities of this release. SEAMSTRESS puts forward a working hypothesis for the Arctic, this is that methane release is closely related to regional physical processes such as the separation of tectonic plates at mid-ocean ridges and the crushing weight of solid ice-masses.

To test this hypothesis the project integrates seismological, seismic, petrophysical and geomechanical data with numerical models of the stress regime and simulations of fluid migration in response to regional stress.

The project counts on a strong support from CAGE and the Institute for Geosciences at UiT to conduct highly technical and cross disciplinary sea expeditions.

The first expedition took place in the summer of 2019 on board RV *Helmer Hanssen* and the main outcome will be the recording of earthquakes and micro-earthquakes in ocean bottom seismometers that are currently on the seafloor surrounding an area of active methane release offshore west-Svalbard. The seismological data collected during the project will be analyzed as part of a PhD project that aims at constraining the prevalent stress regime along the continental margin.

The second expedition was conducted in autumn 2019 on board RV *Kronprins Haakon*. This expedition was a joined effort between SEAMSTRESS and CAGE groups to collect for the first time > 15 m long calypso sediment cores all over the Fram Strait. From 19 stations four were dedicated to collect sediment cores for geotechnical analyses at the Norwegian Geothecnical Institute (NGI). In these four stations in-situ pressure and temperature data were collected using Ifremer's piezometer instrumentation. Material from the 19 stations will be the target of cross disciplinary studies lead by various researchers within CAGE, NGU, UiT and collaborating institutions.

A large amount of 2D and 3D seismic data is already available and more will be acquired in the coming years as part of a second PhD project, to provide a detailed study of the faults and fractures that are channeling the release of gas to the ocean.

Preliminary models from the region offshore west-Svalbard show that most of the gas release in the region occurs where tectonic stress from mid-ocean ridges favors the opening of cracks in the sediment that allow the gasses to escape. In areas where tectonic forces are compressive, the cracks remain tight and the gas stays trapped within the sediment. During periods of maximum ice mass thickness on Svalbard the outgassing may have been more abundant than at present day, due to additional opening of cracks in the sediment by glacial stress.

Final numerical models by one post doc in the project and collaborators, will tell us what regional mechanism has the strongest influence on the deformation of the sediments and associated gas release. On-site measurements of sediment properties and tectonic forces will validate numerical models explaining the timing and quantities of historical gas release.

The concepts and approaches developed by SEAMSTRESS for Arctic sites will be relevant for other regions, e.g., along the Atlantic Ocean, where estimating what causes the release of methane from the ocean floor is crucial to determining its effect on Earth's hydrological and atmospheric processes.

The AMGG teaching cruise in 2019 went to Yermak Plateau, North West Svalbard. Photo: Rowan Romeyn.

From AMGG to GReAT: transitioning to a new decade

GReAT (Geoscience Research Academy of Tromsø) is a new research school launched at the end of 2019 for PhD students at the geoscience department at UiT. The school is a continuation of the Trainee School in Arctic Marine Geology and Geophysics (AMGG) established in 2005 at the University of Tromsø.

The training in GREAT focuses on methods related to studies of Arctic continental shelves and margins, including topics such as glacial processes and products, fluid emissions and gas hydrates, paleoclimate, oceanography, bedrock geology, energy and environment and geo-hazards.

The PhD trainee school offers scientific expeditions and excursions to the Arctic and to geologically interesting localities all around the globe, as well as relevant seminars about various aspects of terrestrial and marine geology, climate and environmental change.

The school also organizes specialized workshops with national and international participants, and soft-skill training courses in collaboration with the Faculty. From 2020, following the guidelines from the Faculty of Science and Technology at UiT, the PhD students enrolled in GREAT will have a midway evaluation. All the students will be evaluated by scientists outside the supervisor team, halfway in the course of their PhD program. This is an opportunity to obtain feedback on the PhD work that has been carried out, and receive advice for the work ahead.

GREAT has PhD students from about 20 different counties. During the organized activities, there are not only scientific and educational exchanges, but also cultural exchange between the participants. This promotes the creation of new academic culture, similar to the new concept of the 'world-class' university as was done so far by AMGG. The students can acquire various transferable skills, create their own professional network and go "across boundaries" of their own research fields.

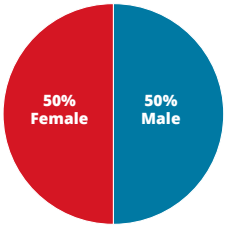
Giuliana Panieri, *GReAT Leader*

Professor Giuliana Panieri, is the leader of the PhD trainee school GREAT and project leader of a new educational project, Advancing Knowledge of Methane in the Arctic (AKMA)

Annual meeting, teaching cruise and the Sedimentary Gas Hydrate Workshop

The 2019 AMGG annual meeting was particularly exciting because of the shift to GREAT. During the annual meeting students presented their work, and were given an opportunity to network and receive critical feedback on their work from colleagues and invited academic experts. Another annual event was the AMGG teaching cruise to the Arctic aboard UiT's RV Helmer Hanssen, led by scientists from CAGE and the Department of Geosciences. This cruise allows PhD and Master students to gain valuable experience in the acquisition and interpretation of state-of-the-art marine datasets. Target area this year was NW Svalbard continental margin, and the southern part of the Yermak Plateau.

In 2019, AMGG together with the Petroleum Research School of Norway (NFiP) and the University of Bergen (UiB) organized "The Sedimentary Gas Hydrate Workshop", with 24 participants. Presentations were given by both expert researchers in gas hydrates as well as PhD students just beginning their careers. We were especially excited to welcome distinguished expert William Waite from the U.S. Geological Survey.



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 $\Delta^{14}C$, $d^{11}B$, $d^{18}O$, $d^{13}C$, 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.

Tasianas, A.
Fluid flow at the Snøhvit field, SW Barents Sea: processes, driving mechanisms and multi-phase modelling
Supervisor: Bünz, S.

2018

Esteves, M.d.S.R.
Doctoral dissertation. "Collapse of a marine-based ice sheet". (2018).
Supervised by: Winsborrow, M.

Jansson, P.
Doctoral dissertation. "Methane bubbles in the Arctic Ocean - Quantification, variability analysis and modelling of free and dissolved methane from the seafloor to the atmosphere". (2018).
Supervised by: Ferre, B.

Paiste, K.
Doctoral dissertation. "Reconstructing the Paleoproterozoic sulfur cycle: Insights from the multiple sulfur isotope record of the Zaonega Formation, Karelia, Russia". (2018).
Supervised by: Panieri, G., Lepland A.

Schneider, A.
Doctoral dissertation. "Diagenetically altered benthic foraminifera reveal paleo-methane seepage". (2018).
Supervised by: Panieri, G., Knies, J., Lepland, A.

Serov, P.
Doctoral dissertation. "Cryosphere-controlled methane release throughout the last glacial cycle". (2018).
Supervised by: Andreassen, K.

Åström, E.
Doctoral dissertation. "Benthic communities at high-Arctic cold seeps: Faunal response to methane seepage in Svalbard". (2018).
Supervised by: Carroll, J.

2019

Shackleton, C.
Doctoral dissertation "Subglacial hydrology of the Fennoscandian and Barents Sea ice sheets". (2019).
Supervised by: Winsborrow, M., Andreassen, K., Bjarnadóttir, L. R., Patton, H. 79 pages. https://hdl.handle.net/10037/15815

Singhroha, S.
Doctoral dissertation "Distribution and quantification of gas hydrates and free gas in marine sediments of Vestnesa Ridge, offshore W-Svalbard". (2019).
Supervised by: Bünz, S.,Plaza-Faverola, A., Chand, S. 127 pages.
https://hdl.handle.net/10037/15824

Waage, M.
Doctoral dissertation "3D and 4D seismic investigations of fluid flow and gas hydrate systems - at sites across the Barents Sea and NW Svalbard margin". (2019).
Supervised by: Bünz, S., Mienert, J., Andreassen, K. 48 pages.
https://hdl.handle.net/10037/15078

Waghorn, K.A.
Doctoral dissertation "Scales of tectonic processes controlling fluid flow systems on the Svyatogor Ridge, Fram Strait". (2019).
Supervised by: Bünz, S., Plaza-Faverola, A. 90 pages. https://hdl.handle.net/10037/15813

Masters theses 2019

Amdal, F. A.
Master thesis. "Cross-disciplinary investigation of gas seepage at Storbanken high and the Olga basin, The northern Barents Sea". (2019). Supervised by: Plaza-Faverola, A.; Mattingsdal, R. 160 pages. https://hdl.handle.net/10037/15460

Bruvik, K. L.
Master thesis. "How is the carbon and oxygen isotope composition of foraminiferal tests influenced by methane seepage?". (2019).
Supervised by: Panieri, G., Borrelli, C. 65 pages. https://hdl.handle.net/10037/15576

Samuelsen, K. R.
Master thesis. "Climatic variations and sediment provenance during the last 16 000 years in the North Hinlopen". (2019).
Supervised by: Rasmussen, T. L., El Bani Altuna, N. In press

With participation of scientists from
UiT The Arctic University of Norway and
the Norwegian Institute for Air Research (NILU)

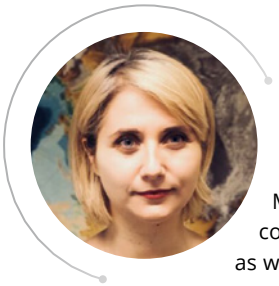
PRODUCED AND NARRATED BY LEONARDO DiCAPRIO

ICE ON FIRE

HBO DOCUMENTARY FILMS PRESENTS A TREE MEDIA APPIAN WAY PRODUCTION "ICE ON FIRE" NARRATED BY LEONARDO DiCAPRIO ORIGINAL MUSIC COMPOSED BY JEREMY SOULE JONAH JOHNSON CINEMATOGRAPHY BY HARUN MEHMEDINOVIC
CO-EXECUTIVE PRODUCER FOR APPIAN WAY PHILLIP WATSON EXECUTIVE PRODUCER JENNIFER DAVISSON EXECUTIVE PRODUCERS FOR HBO NANCY ABRAHAM LISA HELLER EXECUTIVE PRODUCERS GEORGE DiCAPRIO ROEE SHARON PELED PRODUCER MATHEW SCHMID PRODUCER LEONARDO DiCAPRIO PRODUCED AND DIRECTED BY LEILA CONNERS

PREMIERES TUES JUNE 11, 8PM

HBO®



Maja Sojtaric, *Senior Communications Advisor*

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

Public engagement on a global stage

In 2019 CAGE outreach efforts lead to red carpet appearances at Cannes Film Festival and Hollywood, as well as a bit less glamorous but equally important events closer to home.

One of CAGE top priorities throughout the center's lifetime has been an open-minded approach to dialogue, communication and outreach to an audience outside of scientific realm. Our scientists have actively and optimistically joined, contributed to and established projects that place us within the global as well as regional conversation on climate and enviromental issues in the Arctic. 2019 has been no exception in that respect.

Ice on Fire

Oscar®- winner Leonardo DiCaprio produced and narrated *Ice on Fire*, which highlights cutting-edge research driving today's climate science. Scientists from CAGE appear in the HBO documentary, which premiered to a standing ovation at Cannes Film Festival in 2019. It's focus on climate change, greenhouse gas release, and the newly developed technologies that could reverse global warming also received a standing ovation at the Hollywood premiere.

The director Leila Conners visited Tromsø with her crew in 2017 to document the research on methane in Arctic environments. What followed was a long and interesting two-year process, throughout which CAGE scientists and our senior communications advisor Maja Sojtaric engaged with the development of the film, contributing material and input.

The film has since its premiere been used by CAGE to further engage with the public. During the annual Science Festival (Forskningsdagene), CAGE arranged a free screening in Tromsø's venerable Verdensteateret Cinema together with Arctic Centre for Sustainable Energy (ARC). It was followed by a panel discussion, where scientists from both centers appeared and discussed the most pressing issues about carbon in the Arctic and the viability of mitigation scenarios outlined in the documentary. The event was sold-out and a huge success.

New permanent exhibition at The Arctic University Museum of Norway

Pioneering research conducted at CAGE plays a prominent role in the new permanent geology exhibition at The Arctic University Museum of Norway. This too is a result of a long-term commitment to a project, as the exhibition has been under development for several years.

There are two explainer videos in the exhibition summarizing the risks and scale of methane as a greenhouse gas; a video featuring remotely operated vehicle (ROV) footage from a research expedition to the Barents Sea, and 10 additional videos of CAGE scientists explaining various elements of this important research. Also, in place is an unusually well-preserved methane chimney carefully collected during one of the AMGG field works in the Apennines and delivered to the museum from Italy.

National Geographic joined a cruise to the High Arctic

A nerve-wracking scientific expedition to furthest realms of the Arctic Ocean, The Gakkel Ridge, was led by CAGE professor Stefan Bünz. (see page 26-27). The goal of the expedition: to see what creatures live in this remote region. Are these Arctic animals linked to animals in other regions of the planet? Nadia Drake, a writer for National Geographic and Luis Lamar director of photography for Avatar Alliance Foundation (funded by the director James Cameron) were in for the entirety of the expedition, spending a month on the ship getting in and out of sea ice. This resulted in a long form feature article in the prestigious magazine called: If alien life exists in our solar system, it may look like this.

The Conquerors of the Poles

Professor Giuliana Panieri contributed to a new documentary on France 5 which highlights scientists who do research in some of the most extreme environments on the planet: Arctic and Antarctica.

"I mostly spoke about methane emissions in the Arctic, and how they can be investigated in the fossil record, using the forams. Short for foraminifera, they are microscopic organisms with shells. The miniscule shells are however wonderful records of the environment in the ocean, both while the organisms are living, but also in their fossil state when they become part of the sediments of the ocean floor." says Panieri.

TEDed

Early career scientist Jean-Baptiste Koehl, associated with the SEAMSTRESS project, created together with TEDed an original animated educational video: Why are earthquakes so hard to predict? TED-Ed Originals are short, award-winning animated videos about ideas and research. Every TED-Ed Original represents a creative collaboration between experts in their field such as designers, animators, screenwriters, directors, academic researchers, science writers, historians, journalists and editors. Jean-Baptiste Koehl's contribution has been viewed over 420,000 times so far via TEDed's Youtube channel alone, which has over 1,7 million subscribers.

Greenland: A View From the Ice

Professor Alun Hubbard contributed audio diaries from his research expedition to Greenland, where he was measuring the ice sheet. The series of five episodes were published on BBC Radio 4, with short and exciting entries on impacts of global warming on the Greenland's ice sheets. They gave a very informative insight into a scientifically important research with high societal impact. The episodes are also very entertaining, especially the entry from inside an enormous chasm in the ice sheet.

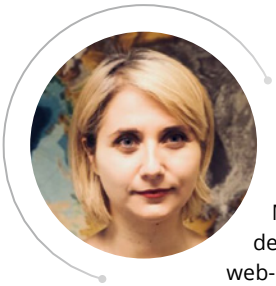
cage.uit.no

CAGE

Centre for Arctic Gas Hydrate, Environment and Climate

Reference:
Ferré, B. et. al: Reduced methane seepage from Arctic sediments during cold bottom-water conditions, Nature Geoscience. January 13, 2020

Climate gas budgets highly overestimate methane discharge from Arctic Ocean



Maja Sojtaric, *Senior Communications Advisor*

Maja was the project manager for re-design and development of new CAGE web-page.

Fabio Sarti, *Data base manager (50%)*

Fabio is the centre's data manager and is responsible for data storage, reporting of scientific results, and statistics.

Redesigned CAGE website plays important role in data management and open access strategy

CAGE is working on several levels to ensure that our data and results are as widely accessible as possible. The new and improved website acts as a portal to our publications and data repositories.

We redesigned our website to highlight the achievements of CAGE via press releases, facilitate the sharing and visibility of publications, and serve as a repository for cruise information in form of cruise logs, blogs and data.

Press releases are a point of entry for non-scientists and scientists alike to access our results in the more general sense. We curate a few publications each month to be translated into such stories with compelling visual content. They serve as a low threshold entry point for our publications.

Highlighting CAGE publications

The publications themselves feature more prominently on the site and are consistently updated through an application developed by website developers gnist. The application seamlessly corresponds with our entries in the national publications database Cristin, ensuring the latest. This database includes references to more than 330 titles that comprise our academic research portfolio since CAGE inception in 2013.

CAGE strives to comply to open access guidelines from The Research Council of Norway and is self-archiving most of our publications into the UiT's open research repository Munin. (munin.uit.no)

Towards more data sharing

In 2016, we decided to start a pilot project in developing software that would allow easy access to our raw research data. This mostly includes data from Arctic cruise expeditions, such as samples of the seafloor sediments and water, seismic survey data, observatory data, bathymetry mapping data, and image/video data. Fabio Sarti, our data manager, teamed up with the IT department at UiT and Avinet, a consultancy company specializing in map and database solutions.

To create a user-friendly experience, we decided to develop a new map-based interface for data that is now embedded in our web page.

The site is easily navigable and allows access to all the information on each cruise, including cruise tracks and sampling locations. There are good, prominent and cross-referenced links to publications from CAGE from the individual cruise pages and map interface, and most of these are self-archived. CAGE is committed to open access, driven in part by national policies and the business deals the Norwegian research organisations have made with most of the prominent scientific publishers.

All the raw data from CAGE is in UiT storage facility run by the IT department, ensuring data integrity. Data that comes as the result of laboratory analyses are not in the database, whilst this a plan in the future.

Photo/illustration: Bongkarn Thanyakij & Julian Høgset.

Louis Lamar of Avatar Foundation and Natural Geographic Magazine diving in the Arctic Ocean during the HACON cruise on board RV Kronprins Haakon. Photo: Robin Hjertenes.

Heading ever further North into the Arctic Ocean

Four CAGE-led expeditions were conducted in 2019, reaching realms of the Arctic Ocean that have scarcely been examined before. CAGE has now completed 41 research cruises into Arctic waters since 2013.

Two of the four 2019 research cruises were conducted using the new ice breaker RV *Kronprins Haakon*. Still, the good old RV *Helmer Hanssen* provided an opportunity to conduct teaching cruises and visit important study sites for CAGE that do not require full force of an ice breaking vessel.

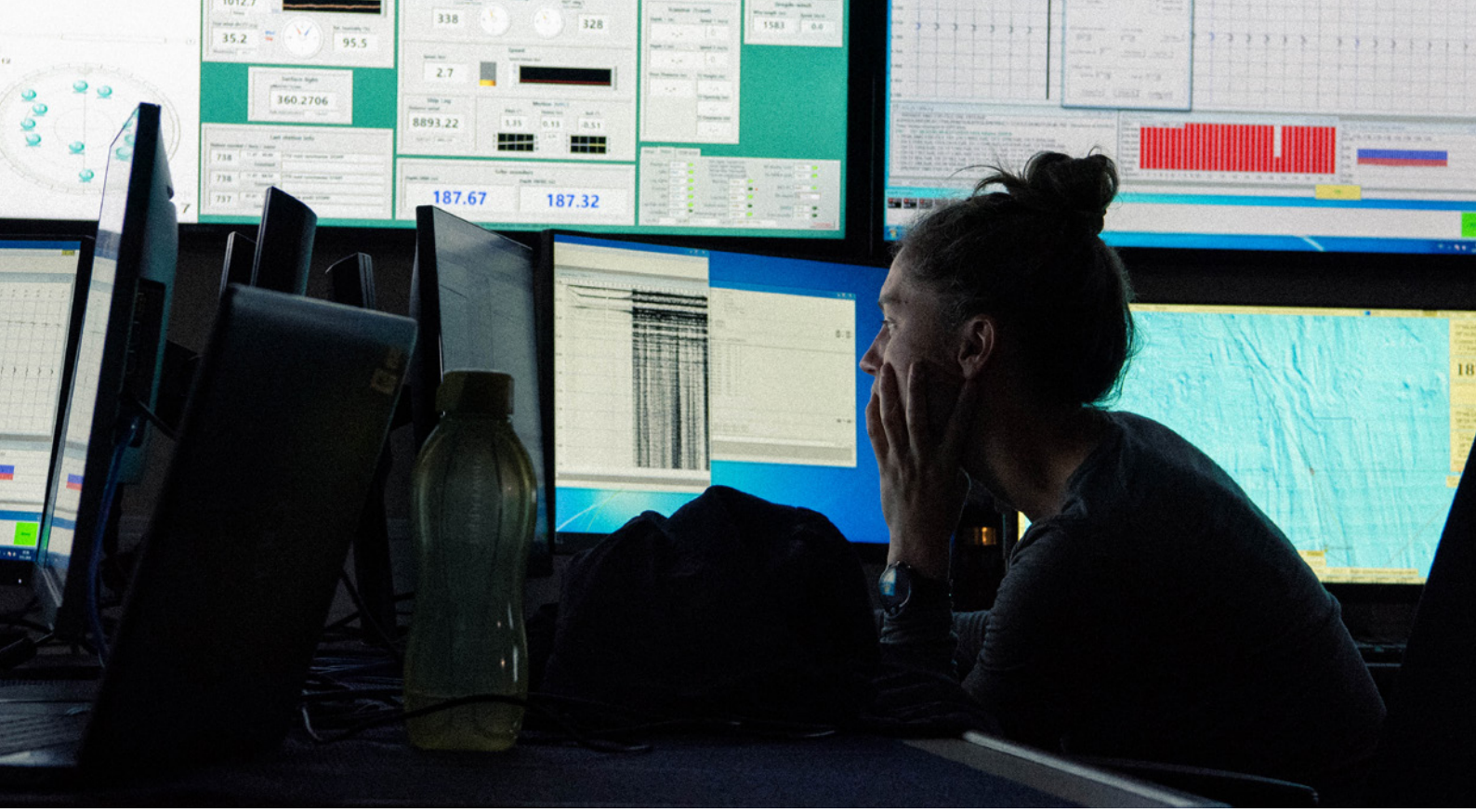
Searching for Aurora Seamount at 83°N

Aurora is a seamount on the ocean floor, a volcanic structure containing hydrothermal vents. It can be found on the 83°N on the Gakkel Ridge, which forms a tectonic plate boundary between the North American Plate and the Eurasian Plate. In September 2019 the new research vessel *Kronprins Haakon* reached the seamount in an expedition lead by CAGE professor Stefan Bünz. The Aurora Seamount is four kilometers below the surface of the ocean, and it is permanently covered by sea-ice. The air temperature in the area was as low as -20°C in September-October.

The expedition was part of the *Hot Vents in an Ice-Covered Ocean* (HACON) project, led by Norwegian institute for water research (NIVA). Six CAGE scientists from four work packages participate in the project

The chemicals in the fluids emanating from hydrothermal vents, such as hydrogen sulphide or methane, are used as source of energy by micro-organisms in this pitch-dark world, to produce organic matter. The vents sustain the exotic animals which then probably are distributed throughout the Atlantic and Pacific Oceans.

Vent related microbiology and chemical components in the sea ice is a very exciting field of research, which is also of interest for astrobiologists from NASA's Jet Propulsion Laboratory who joined the expedition. They are developing programs to look for life on the frozen oceans of moons like Enceladus or Europa. The microbiologist



Frances Cooke in the instrument room on board RV Helmer Hanssen. Photos: Torger Grytå.

from CAGE, Dimitri Kalenitchenko contributed to the experiments they conducted on the sea ice above the vents.

Taking the New Ice Breaker to the Arctic-Atlantic Gateway

RV *Kronprins Haakon* was also deployed to the Arctic – Atlantic Gateway in 2019, to collect data on methane release from the ocean floor. Along for the ride was coring equipment that can, for the first time, acquire up to 25-meter-long sediment samples in the study area.

The Arctic-Atlantic Gateway is the area between Svalbard and Greenland where the 150 km wide Fram Strait provides the only deep-water connection between the Arctic and the world oceans. It is essential for the thermohaline `engine' of the North Atlantic circulation system. It is also an area where CAGE has mapped and studied massive methane seeps on so called ultra-slow ridges – pieces of the oceanic crust that are spreading apart extremely slowly.

The cruise to the Arctic-Atlantic Gateway was conceived as a cross-disciplinary cruise with the aim of collecting deep sediment samples for the SEAMSTRESS project, (see page 18-19) CAGE and other groups from the Institute of Geosciences at UiT, as well as other collaborators. It was led by CAGE assistant director Jochen Knies from Geological Survey of Norway, NGU. The scientists collected 16-meter-long sediment cores on Vestnesa Ridge, by using the Calypso corer.

The expedition resulted in retrieval of 20 Calypso cores and recovered more than 300 m of unique material between Svalbard and Greenland.

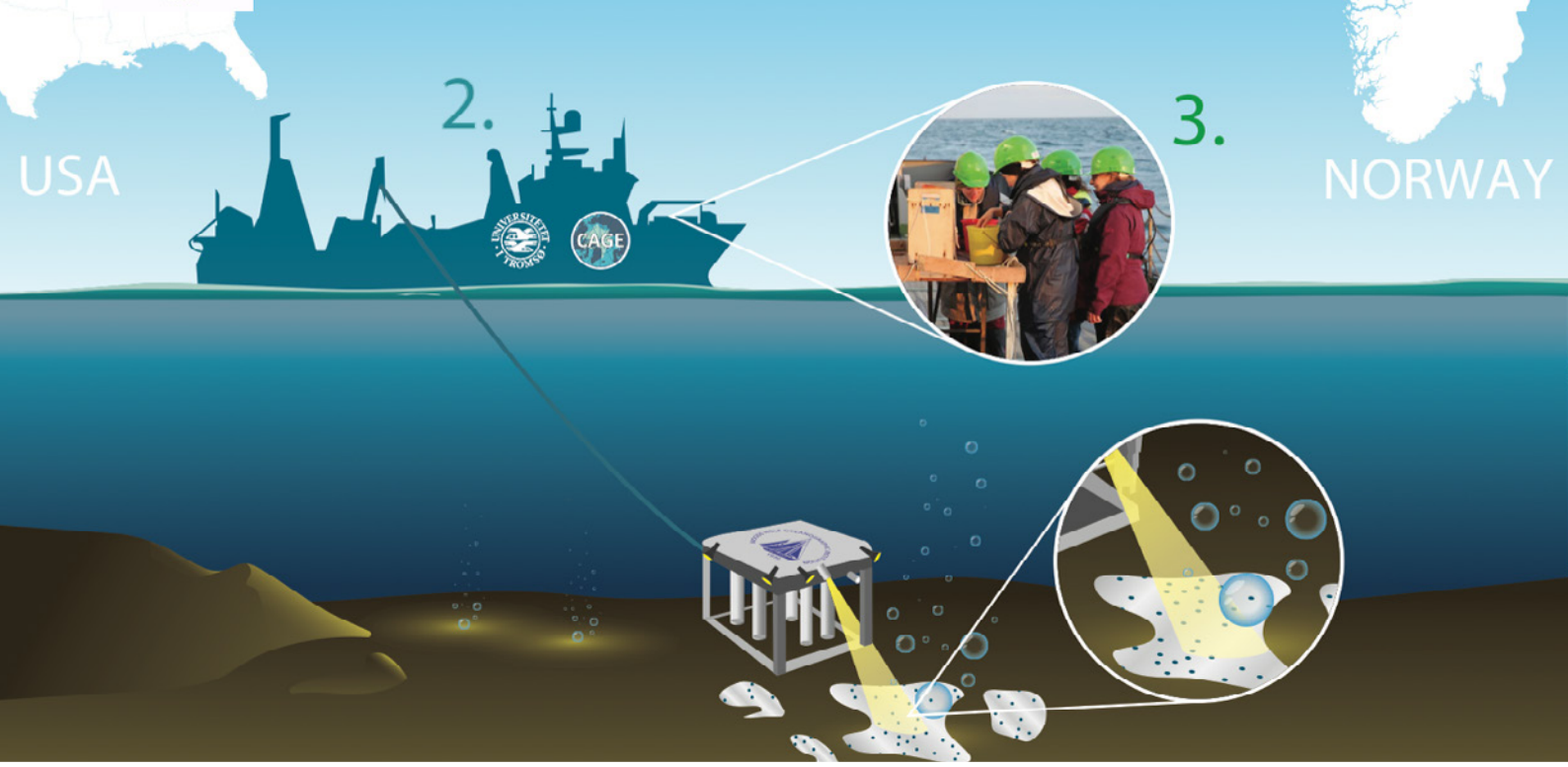
The expedition was also the first time CAGE scientists contributed a cruise blog to our newly refurbished webpage cage.uit.no. (see page 24-25).

Also, on the webpage you can find all of the CAGE cruise logs since the center's inception in 2013. The following selection are available cruise logs from 2019 expeditions:

Bünz et al. "Hacon 19: Hacon FRINATEK cruise aboard RV *Kronprins Haakon*." (2019) 74 pages. https://cage.uit.no/wp-content/uploads/2019/10/cruise-report-hacon19.pdf

Andreassen, K., Patton, H., Mattingsdal, R., Moser, M., Cooke, F. A., Jansson, P., Argentino, C. Cruise report. "CAGE19-2 Cruise Report: Hunting gas flares and launching seafloor observatory". (2019). 47 pages. https://cage.uit.no/wp-content/uploads/2019/10/cage_19-2-cruise-report_reduced.pdf

Knies, J., Vadakkepuliyambatta, S., CAGE 19_3 Team. Cruise report. "19-3 CAGE Cruise report. Calypso giant piston coring in the Atlantic-Arctic gateway – Investigation of continental margin development and effect of tectonic stress on methane release". (2019). 127 pages. https://cage.uit.no/wp-content/uploads/2019/10/cruise_report_version_final.pdf


USA
2.
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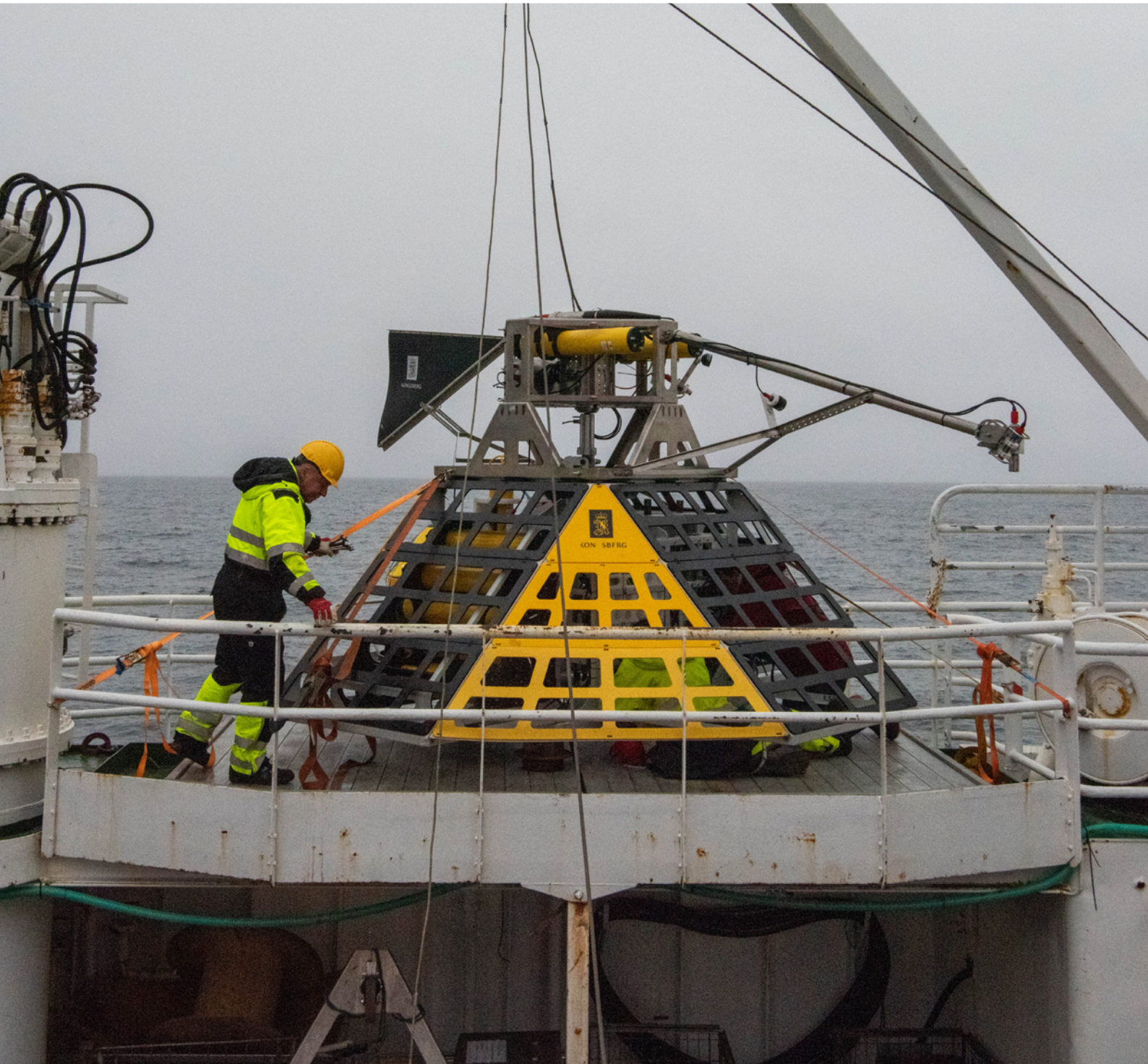
CAGE



New projects seek to improve infrastructure, increase collaboration and facilitate education

We are constantly seeking funding opportunities to increase our scientific footprint. External funding will be even more important in the years to come, as we are reaching the final three years of CAGE activity. Throughout the CAGE lifetime, our scientists have been ambitiously and successfully applying for external funding. In 2019 seven externally funded projects had a kick-off.

CAGE co-leads new Norwegian deep-ocean observation system

NOREMSO – a new ocean observation system in the Nordic Seas – has received 60 million Norwegian kroner from the Research Council of Norway (RCN). This will fill a huge gap in the European ocean monitoring network.

Close observations of world's oceans are crucial for our understanding of the immense power they have to store and distribute heat and greenhouse gases. The European network EMSO ERIC is a system of ocean observatories placed in key sites around Europe – from the Atlantic, through the Mediterranean, to the Black Sea. The observatories are platforms equipped with multiple sensors, placed along the water column and on the seafloor. They constantly measure different biogeochemical and physical parameters, to monitor processes pertaining to natural hazards, climate change and marine ecosystems.

Nordic Seas are very important for understanding many of these processes, but are not included in this large European network. Until now, that is.

NOREMSO will provide high-quality, open-access, long-term and consistent observations of essential ocean and carbon parameters. The observatory network in the Nordic Seas will comprise of three main components: moored observatories, gliders, and one seafloor observatory. The NOREMSO project has a duration of five years and is funded through RCN's INFRASTRUKTUR program. The project is led by Ilker Fer at University of Bergen with Benedicte Ferré as co-leader.

New collaboration strengthens methane research and education in US and Norway

The project, called INTPART AKMA (Advancing Knowledge on Methane in the Arctic), is shared between the Centre for Arctic Gas Hydrate, Environment and Climate in Tromsø Norway and Woods Hole Oceanographic Institution (WHOI) in Massachusetts USA.

AKMA aims to advance the collective knowledge surrounding methane activity in the ocean in Arctic regions. These regions are particularly vulnerable to the effects of climate change, and methane has the potential to drastically accelerate those effects if left unchecked.

The primary objectives of AKMA are to develop a long term, multidisciplinary education and research collaboration focused on Arctic methane sources, processes, ecosystems and geological history to provide exceptional training to become the next generation of experts in Arctic Marine sciences and greenhouse gas phenomena.

AKMA offers scientific and technical exchanges between partners and students, as well as dedicated research expeditions on the RV *Kronprins Haakon* focusing on student training in methods, data acquisition and analysis. There will also be intensive courses in Arctic cold microbe biogeochemistry and webinars/seminars pertaining to the scientific topics.

Project manager for AKMA is professor Giuliana Panieri. Project duration is three years, and funding is provided by The Research Council of Norway, to the amount of 6,3 million Norwegian Kroner.

OTHER PROJECTS KICKING OFF IN 2019

SEAMSTRESS – Tectonic stress effects on Arctic methane seepage

Project leader: Andreia Plaza-Faverola
Project duration: 2019–2023
Funding: NOK 26 million

See page 18-19.

SIOS-InfraNor

Project leader: Andreia Plaza-Faverola
Project duration: 2019–2022
Total funding: NOK 72 million

It will enable a coordinated and state-of-the-art observation network for marine, terrestrial and atmospheric research to be implemented and operated around Svalbard.

Akademiaavtale

Project leader: Karin Andreassen
Project duration: 2019–2022
Funding: NOK 9.3 million

Reconstructing the evolution of the Barents Sea basin over the last 3 million years. This project will bring together modelling and empirical-based expertise within CAGE, ARCEX and Equinor.

VISTA – The glacial hydrocarbon pump

Project leader: Pavel Serov & Karin Andreassen
Project duration: 2019–2023
Funding: NOK 1.8 million

The project investigates sub seabed and seabed hydrocarbon leakage and gas hydrate dynamics in response to multiple glaciations of the Barents Sea shelf.

Illustration: Arthur Peter Bjørkli, UiT.
Photo: Torger Grytå.

2019 in short

Photo: Torger Grytå.

Professor Jürgen Mienert, former director of CAGE, retires

Professor Mienert has dedicated his scientific pursuits to the response of polar continental margins to climate change, becoming a leading expert in the field. He retired in September 2019. Jürgen Mienert has served at countless boards and committees, at local, national and international levels. He was Head of the Department of Geology at UiT from 2009 until 2014. Professor Mienert is the founder of CAGE and developed the centre during the first five years of its lifetime, resulting in an exceptionally good mid-term evaluation. He published more than 120 peer-reviewed scientific papers that are frequently cited, some even more than 10 years after their publication, e.g. the COSTA special issue where he was editor. This volume was published in 2004 and it has been one of the two best-cited special issues in Marine Geology in 2016-2017 and 2017-2018.

Photo: Maja Sojtaric.

CAGE wins gender equality award at UiT the Arctic University of Norway

Gender equality is rare in science, technology, engineering and mathematics (STEM) fields, with men dominating the scientific positions. However, for CAGE achieving gender equality has never been a problem. The center of excellence has had gender equality in all positions from its start in 2013. The center has consistently had 50 percent female scientific staff – from PhDs to professors. The leadership group consists of 75 percent women. CAGE will use the award money, 100.000 Norwegian Kroner, to raise awareness about women in STEM.

CAGE researcher Andreia Paza-Faverola wins award for Women in Geosciences

Also CAGE early career scientist Andreia Plaza Faverola was honored by an award of her own: Else-Ragnhild Neumann Award for Women in Geosciences at University of Oslo. It is awarded to women who, through PhD or postdoctoral work, have made a significant contribution to research in the field.

Photo: Torger Grytå.

Professor Giuliana Panieri was elected General Secretary of the European Geosciences Union

The European Geosciences Union (EGU) is the leading organization for Earth, planetary and space science research in Europe. It is a non-profit international union of scientists with about 20,000 members from all over the world. The EGU has 22 scientific divisions that reflect the interdisciplinary nature of the organization The union publishes a number of diverse scientific journals, organises meetings, and education and outreach activities. The annual EGU General Assembly is the largest and most prominent European geosciences event, attracting over 16,000 scientists from all over the world.

Professor Panieri was elected by the members of the Union to act as its General Secretary, making her a part of the Executive Board. The Board oversees, and provides strategic guidance to, all activities of the Union. She will serve for two years starting in May 2020.

Photo: Mariana Esteves.

Mariana Esteves joined IODP expedition to West Antarctica

CAGE fellow Mariana Esteves joined International Ocean Discovery Program expedition 379 to Amundsen Sea, West Antarctica in 2019. The expedition was conducted with JOIDES Resolution, a scientific drill ship. During the cruise long drill cores of sedimentary records were collected from the continental shelf and rise of the Amundsen Sea. These cores will be examined to determine past changes in the ice cover of the area.

Esteves recently completed her PhD in marine geology at CAGE focusing on reconstruction of a large ice sheet that covered Barents Sea some 20.000 years ago. She hopes to combine this research with new findings from her trip to West Antarctica.

Three PhD defenses in the space of seven spring days

Sunny Singroha, Kate Waghorn and Calvin Shakleton defended their theses within hectic seven days in June 2019. First upwas Shakleton, who defended his thesis on reconstruction of past ice sheet drainage and meltwater processes on June 11. He was followed by Kate Waghorn who defended her theses on the creation of gas hydrate systems of non-biological origin, June 13. Lastly, Sunny Singroha defended his thesis on distribution and quantification of gas hydrates and free gas on Vestnesa ridge, June 18.

In total there were four PhD defences at CAGE in 2019, with Malin Waage defending her thesis in February. (see page 21)

Photo: Robin Hjertenes.

CAGE postdoc Dimitri Kalenitchenko joined NASA research, looking for life on frozen moons

Several experiments were conducted by NASA during the HACON cruise to the Gakkel Ridge aboard RV *Kronprins Haakon*. (see page 26-27) The group of scientists from NASA's Jet Propulsion Laboratory were joined by CAGE microbiologist Dimitri Kalenitchenko, looking closer into the sea ice chemistry and biology. The aim is to use the knowledge of Earth's ice-covered oceans, and transfer it to understand the ice-covered moons and planets in our solar system, particularly frozen oceans moons of Saturn and Jupiter, Enceladus and Europa.

Two papers made it to top 50 list of most read Nature Communications articles

Two articles in Nature Communications, co-authored by CAGE professor Alun Hubbard, made it to the Top 50: Earth and Planetary Sciences list compiled by the journal. The list is comprised of the 50 most read articles published in the open access journal in 2018.

«Dark zone of the Greenland Ice Sheet controlled by distributed biologically-active impurities» was 17th most read article, while "Cascading lake drainage on the Greenland Ice Sheet triggered by tensile shock and fracture» was 21st on the list.

Photo: Torger Grytå.

Naima El Bani Altuna visits Dr. Ezat at state-of the- art facilities at University of Cambridge

Early career scientists at CAGE have many exciting opportunities to do science at the most prestigious institutions in the world. During 2019 Phd student NaimaEl Bani Altuna got the chance to work closely with her supervisor Mohamed Ezat at the Department of Earth Sciences, University of Cambridge. Her guest stay at the university was used to carry out an essential part of her project: measuring the trace elements on foraminifera shells. She aims to understand the role of bottom water temperature in methane seepage during the time of past abrupt climate changes in the Arctic.

Dr. Mohamed Ezat started as a PhD Candidate at CAGE in 2011 and took a postdoctoral position at the center in 2015. This has given him an opportunity to apply and receive FRIPRO mobility grant by The Research Council of Norway, awarded for groundbreaking research. He is using the substantial funding to utilise the state-of-the-art analytical facilities at University of Cambridge over a 3-year period. Dr. Ezat will be returning to CAGE in 2020.


Kronprins Haakon

The CAGE Toolbox: From birds-eye view to deep sediment imaging

Our success builds upon the integration of world-class empirical and numerical methods. These methods require development and clever implementation of innovative technologies - from drones to ice breakers.

The CAGE toolbox is used to find the controlling mechanisms for build-up and release of submarine gas hydrate systems in the Arctic and provide answers to what extent methane escape from sub-seafloor reservoirs has influenced Arctic and global climate perturbations. With access to the new icebreaker RV Kronprins Haakon, this toolbox has already been applied in permanently ice-covered regions. We are steadily approaching new discoveries on potential amplifiers for global change, including melting of submarine gas hydrate systems in the Arctic and accumulation of free methane gas below the ice-covered ocean.

Birds-eye view using drones

In 2019 CAGE purchased Mavic 2 pro DJI drone (RO1 pilot License) equipped with a Sentera near - infrared (NIR) sensor. It is used by our postdoc Dimitri Kalenitchenko to map sea ice and terrestrial methane seeps. One goal of this effort is to examine whether the red and NIR band can prove useful for mapping variations in ocean cover: from open water, to grease ice – thin,soupy layer of ice which makes the ocean surface resemble an oil slick; as well as from grey young ice to first and multi-year ice. Kalenitchenko also uses the drone to examine the terrestrial gas seep sites that we are exploring on Svalbard.

Streamer birds and heat probes

We successfully secured faculty funding for two new and important additions to the equipment pool for upcoming expeditions: 1) a streamer-steering system, so-called streamer birds, will provide depth control for the 2D seismic streamer and allow us to extend streamer length resulting in bandwidth stability and higher fold improving S/N-ratio. 2) a heat flow probe that measures the geothermal gradient and thermal conductivity of the sediments, will add significant value to our understanding of hydrate and fluid flow systems, and provide valuable constraints for the modelling.

Ocean observatories

The ocean observatories (K-Landers) developed in a collaboration between Kongsberg Maritime and CAGE were deployed and recovered five times offshore Svalbard and in the Barents Sea, providing unprecedented multi-sensor data on Arctic methane seepage and the physical and chemical properties of the ocean. These give us insights into the frequency of methane release and how this is influenced by ocean conditions, as well as on ocean acidification processes and trends.

CAGE video-camera system

In 2015 CAGE collaborated with WHOI (Woods Hole Oceanographic Institution) to develop a towed video-camera system. This digital imaging equipment provides real-time HD video and images of the seafloor, real-time digital depth and altitude, and allows visually guided water column (Niskin bottles) and sediment (multicores) sampling. In addition to dedicated digital imaging campaigns, the CAGE video-camera system plays a vital role in planning ROV operations. The system has been deployed at several methane sites in the Barents Sea in 2017.

4D seismic using P-cable

CAGE uses UiT's national infrastructure P-cable seismic system, which CAGE members have been involved in developing. Studies of gas hydrates, shallow gas and geological structures in sediments near the seafloor are ideal targets of our P-cable seismic system. By collecting P-cable data at the same study area over multiple years we are able to monitor spatial and temporal variations (4D) in the movement of fluids in the sediments. The unprecedented resolution of the P-cable seismic provides CAGE with a unique opportunity to investigate the processes and drivers that regulate past and present gas hydrate and fluid flow systems.

National facility for stable isotope analyses

CAGE has established a stable isotope laboratory, equipped with a MAT 253 Isotope Ratio Mass Spectrometer, at the Department of Geosciences, UiT. The laboratory is an integral part of our palaeoclimatic, oceanographic, geobiological and carbon cycling research, and is a part of the national infrastructure FARLAB (Norway's national facility for advanced isotopic research).

Fully automated palaeomagnetic laboratory

CAGE partner, the Norwegian Geological Survey (NGU), has installed a fully automated 2 G Cryogenic Magnetometer at their facilities in Trondheim. This equipment gives us the ability to analyze changes in the polarity, intensity and direction of the geomagnetic field of the Earth over the past millions of years. It, furthermore, provides a powerful means to trace variations in methane seepage in the sub-seafloor sediments over timescale of millions of years.

Numerical ice sheet modelling

Numerical modelling is a valuable tool that can be used to explore the role ice sheets have played in shaping and driving changes in the Arctic environment. At CAGE we have developed a high-resolution, 3D reconstruction of the last 120.000 years of glacial cycles to have affected the Eurasian continent, constrained and tested against a variety of up-to-date empirical datasets. Data-rich outputs derived from these modelling experiments inform us how the ice sheet developed and impacted with its surroundings through time, including the evolving pattern of crustal warping, hydrological routing and storage, broad-scale climate distributions, and subglacial temperature-pressure conditions.

RV Kronprins Haakon

The ice-going research vessel, Kronprins Haakon, is outfitted with state-of-the-art scientific instrumentation. It is capable of year-round operation in ice-covered waters, where it will monitor the environmental state and the climate state of both the Arctic and the Antarctic. It is equipped with a moonpool, and is capable of ROV, AUV and helicopter operations. The vessel is based in Tromsø, and is officially owned by the Norwegian Polar Institute, run and maintained by the Institute of Marine Research, and largely used by UiT. CAGE has already led several cruises using the vessel, and more are planned for the coming years.

ROV ÆGIR 6000 -

The ÆGIR 6000 is a remotely operated vehicle (ROV). It is a national facility that is operated by the Norwegian Marine Robotics Laboratory (NORMAR) at the University of Bergen (UiB). An ROV is an unmanned submersible tethered to the ship through the moon pool. ÆGIR 6000 can cary coring devices, a gas sampler to catch gas bubbles, a water sampler to collect water, geochemical and oceanographic sensors or a multibeam system for cm-scale imaging of the ocean floor. CAGE use of Ægir 6000 has resulted in many interesting publications, this year in particular. (see page 14-15)

Photo: Screenshot of drone footage of RV Kronprins Haakon. Dimitri Kalenitchenko & Luis Lamar.

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Subject area, publications

Source: Scopus

- 95% Earth and Planetary Sciences
- 31% Biological Sciences
- 24% Environmental Science
- 10% Social Sciences
- 7% Chemistry
- 7% Molecular Biology
- 7% Multidisciplinary
- 4% Engineering
- 2% Microbiology
- 2% Energy

Publications

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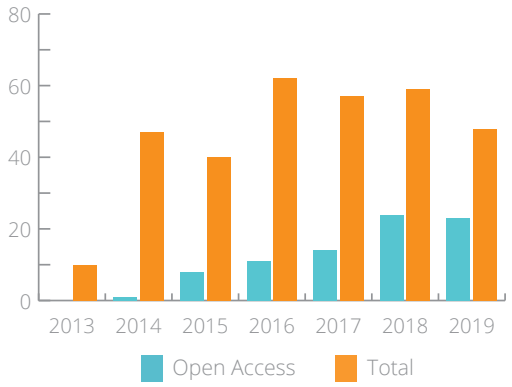

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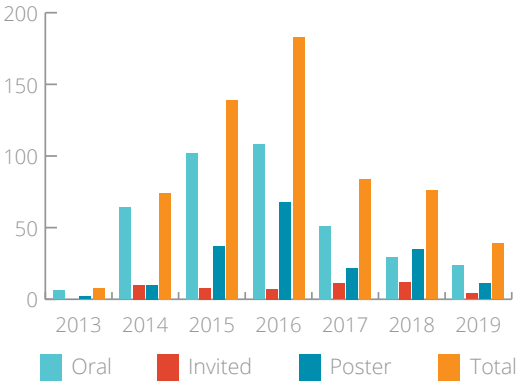

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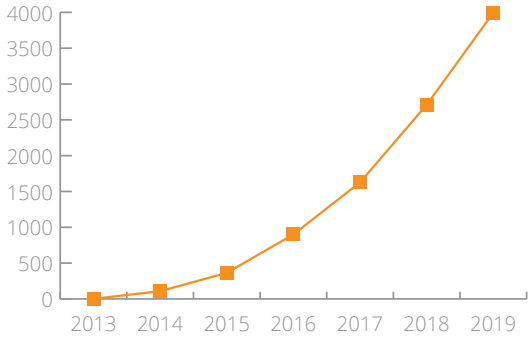

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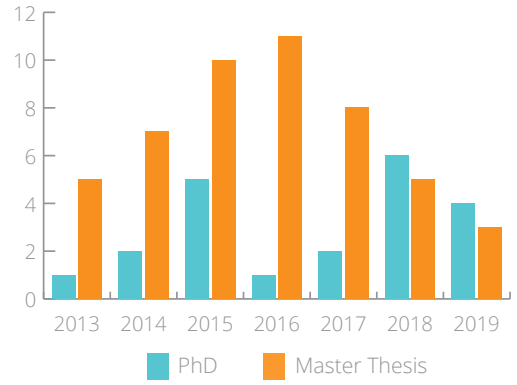

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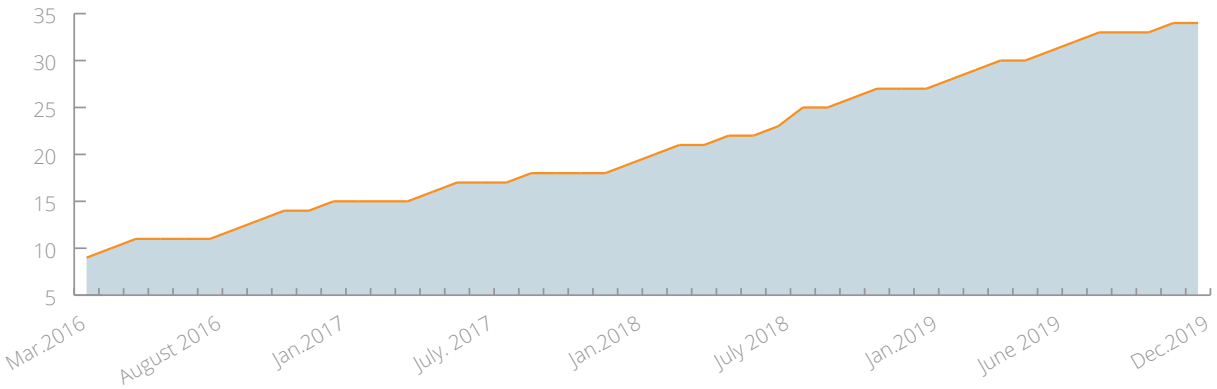
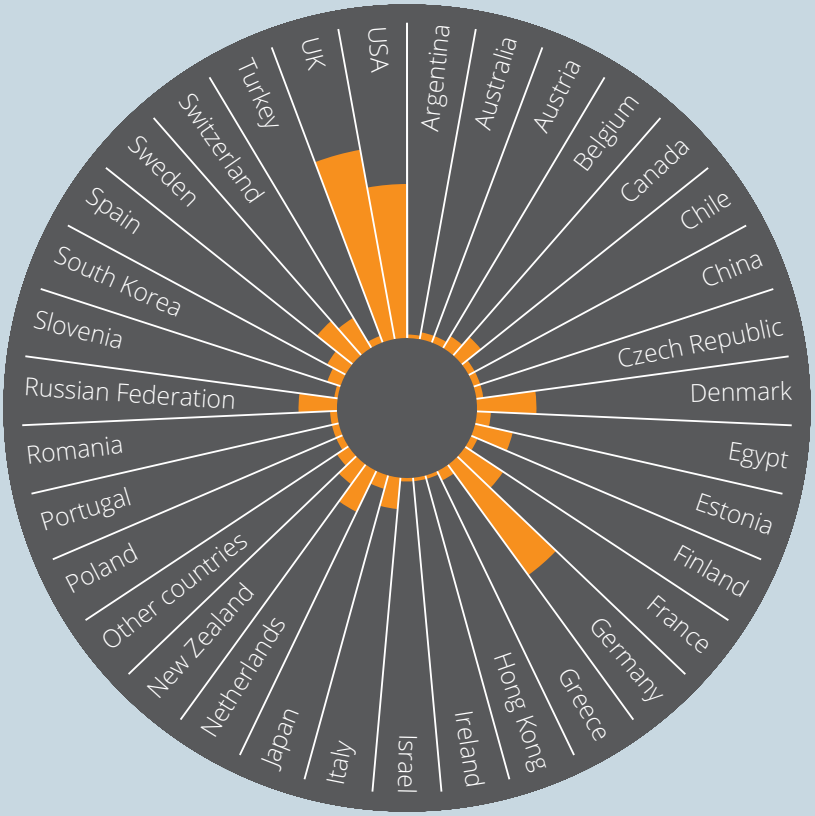


International collaboration 2013–2019

Our projects are connected with international scientific communities that are outlined as important collaborators by RCN and Norwegian Ministry of Foreign Affairs. We participate in EU projects and actions, as well as collaborate with institutions on other continents such as Woods Hole Oceanographic Institution in USA and NCAOR in India. 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

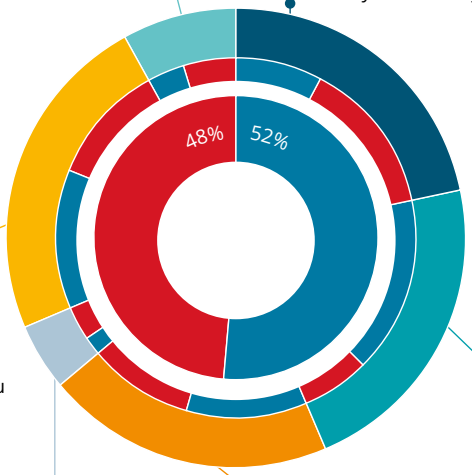


Full list of personnel at the centre

We consistently work towards gender equality in our staff. Not only is the centre director a woman, 4 of the 6 work package leaders are women, and 3 of the 5 administrative/ technical staff members are women. Our overall staff numbers also show that we place importance on this subject, with 48% women and 52% men working for CAGE in 2019. This is 30% above the average for women in STEM fields in OECD countries, and 35% above the average in Norway. We also support young researchers – more than 43 % of our staff are PhD Candidates and early career scientists.

Adminstrative and technical staff:
Jessica Green, Communications advisor (temporary)
Matteus Lindgren, Manager, Mass Spectrometer Laboratory
Fabio Sarti, Data manager
Lone Smelror, Administrative coordinator
Maja Sojtaric, Communications advisor

Senior scientific staff:
Karin Andreassen, Director, Temp Leader WP2, Professor
Stefan Bünz, Temp Assist. Director, Leader WP1/Professor
Bénédicte Ferré, Leader WP4, Researcher
Alun Hubbard, Professor
Jochen Knies, Assist. Director, Leader WP5, Researcher
Renata Lucchi, Adjunct Professor
Jürgen Mienert, Professor
Helge Niemann, Adjunct Professor
Giuliana Panieri, Research School Leader, Adjunct Professor
Tine L. Rasmussen, Leader WP6, Professor
Mette Marianne Svenning, Leader WP3, Professor
Jemma Wadham, Professor
Monica Winsborrow, Assist. Director, Leader WP2, Researcher
Katarzyna Zamelczyk, Co-leader WP6, Researcher



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