









































Universities:

UiT The Arctic University of Norway (UiT) Norwegian University of Science and Technology (NTNU) The University Centre in Svalbard (UNIS) University of Bergen (UiB) University of Oslo (UiO) University of Stavanger (UiS)

Research institutes:

Akvaplan-niva AS (APN) International Research Institute of Stavanger AS (IRIS) Norges geologiske undersøkelse (NGU) Northern Research Institute AS (Norut)

Industry partners:

Statoil Petroleum AS Eni Norge AS Aker BP ASA Lundin Norway AS Tullow Oil Norge AS ENGIE E&P Norge AS AS Norske Shell DONG Energy E&P Norge AS

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WP3 - Adj. Prof. JoLynn Carroll, APN

WP4 - Prof. Tor Arne Johansen, UiB

WP5 - Prof. Jan Sverre Laberg and Assoc. Prof. Jasmine Nahrang, UiT

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Design and layout: Torger Grytå, Department of Geosciences, UiT. Main photos and illustrations: Cover and pages 12–13 Torger Grytå/IBCAO; Pages 22–23, 24–25, 30-31 and 32-33 Torger Grytå; Pages 8-9 and 16-17 NASA; Pages 10-11, 14-15, 20-21, 26-27 and 28-29 Sten Andreas Grundvåg; Pages 18-19 ESA.



ARCEx - the Research Centre for Arctic Petroleum Exploration - has since its start developed to become an important instrument for research, education and national coordination in the field of oil and gas activities in the high north. During times of low oil prices and reduced investments on the continental shelf, it is more than ever important to develop new knowledge and educate young people to take the oil and gas industry into a sustainable future.

og21 – Norway's oil and gas technology strategy for the 21st century was recently revised, including ARCEX' director as one of the og21 committee members. The strategy points to technology adoptions for new challenges in the Norwegian parts of the Barents Sea as an area of particular importance. This is also within the focus area of ARCEX.

The Norwegian Government recently (2017) launched an ocean strategy document "Ny vekst, stolt historie" The petroleum industry is the dominating ocean-related industry in Norway and contributes with 71% of the value creation and 46% of the employment. The ocean strategy points to further sustainable development of the petroleum technology,

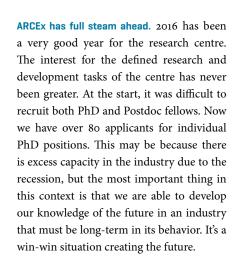
Foreword

but also to the possibilities for new petroleum-related industries such as handling of co₂ and offshore wind energy. The research and educations activities of ARCEX is directed to meet many of these challenges.

ARCEx is now running "in full speed" concerning its deliverables ...

ARCEX is now running "in full speed" concerning its deliverables such as publications, master and PhD education and out-reach activities within all its main topics (work packages). The collaboration between the academic partners, and between the industry partners and academic partners, appears dynamic and constructive. Thus based on the achievements so far, the centre is well prepared for the midway-evaluation that will take place during the fall of 2017.

Morten Hald Professor/Dean Faculty of Science and Technology Chair, ARCEX Consortium Board



Work packages are comprehensive and interesting and it will be important to have a good dialogue with industry partners to ensure implementation of the knowledge being developed in the packages. This is a mutual responsibility for both user partners and research partners in ARCEX.

The petroleum industry is going to be Norway's most important industry for years to come. ARCEX' way to where the centre is to-day, has been a continuous learning. As an



industry and as a nation, it is important that we build on this learning. We must dare to ask tough questions and to devote resources to respond by research. We must agree that developing the future is a common responsibility and that cooperation is the only way to get there

> Several people contribute daily their utmost to the centre's tasks and development

Several people contribute daily their utmost to the centre's tasks and development. On behalf of the industry, I want to thank you all for the work you do and wish you continued success with important tasks. And we do look forward to learn more together with you!

Terje Solheim Leader of Harstad office, Industry CoordinatorARCEX Director's Corner - 2016 in retrospect. When looking at our schedules and calendars for 2016, it is clear that this was a year with an insanely high level of activity. ARCEX was in a consolidation and production phase, and our main focus was to ensure maximum scientific output at the highest possible level.

Our busy schedule included hiring new people (Tyler Appleyard, PhD Fellow at UNIS, and Ingrid Wiedmann, postdoc at UiT), coordinating with the industry partners to ensure relevance, teaching and supervising students at all levels, submitting several new manuscripts to top ranking journals, organizing conferences, presenting at national and international conferences, organizing sessions at conferences, representing ARCEX in various boards and organizations, participating in science fairs and exhibitions, in addition to planning, organizing, and executing complex field work, research cruises, and expeditions.

The integration of industry and academia has been strengthened in 2016. Terje Solheim from Aker BP has been appointed industry coordinator to ensure a single pointof-contact between the ARCEX management and the industry partners. Through a strategy meeting and subsequent coordination meetings, we laid plans for the new ARCEX positions to be filled in 2017. The process culminated in a collection of work descriptions that ensures the highest possible relevance while simultaneously maintaining the highest possible academic standards. These new researchers will carry out their research at the University of Oslo, University of Bergen, University of Tromsø, and unis, and we will welcome them during the spring semester of 2017.

In October, we had the pleasure of welcoming representatives for all stakeholders to a site visit in Tromsø. We spent a day indulging in great popular presentations, orientations from the host institution, the head of the board, industry representatives, and the ARCEX management. Dr. Matthias Forwick, the Head of Dept. of Geosciencs gave us an enthusiastic guided tour of the labs, and he drew the longer lines showing connections between ARCEX and other field based research at the department.

ARCEX scientists have also taken a great responsibility to ensure that future generations will be around after ARCEX comes to an end. We therefore extend our heartfelt congratulations to Jasmine Nahrgang (UiT), Kim Senger (UNIS), Marcus Landschulze (UiB) and Iver Martens (UiT) with their newborns.

Alfred Hanssen Professor/ARCEX Director

The ARCEx Research Fellows



Tore Aadland PhD Fellow, UiB

Disentangling the time represented by siliciclastic sedimentary deposits





Babak Khodabandeloo

PhD Fellow, NTNU

Investigation of the effects of acoustic wave-field generated by marine seismic sources on marine mammals and methods to reduce the impact.

2015-2018



Willy Røed

Postdoc, UiS

Application of risk and uncertainty concepts, principles and methods

2015-2016



Ana Sofia Aniceto

PhD Fellow, Akvaplan-niva

Using Unmanned Aerial Vehicles for marine mammal surveys in Arctic and sub-Arctic regions

2014-2018



Jean-Baptiste Koehl PhD Fellow, UiT

Onshore-offshore fault correlation on the SW Barents Sea margin, Western Troms and Finnmark

2015-2018



Agnar Sivertsen

Research Fellow, Norut

New methods and technology to utilize UAS for environmental monitoring, such as detection and classification of ice icebergs

2014-2017



Tyler Appleyard

PhD Fellow, UNIS

Sequence stratigraphy of Upper Paleocene paralic wedges in the Central Basin of Spitsbergen

(2016-2018



Marcus Landschulze

Postdoc, UiB

Seismic on Ice using simulations and field data; processing of full wave field data

2015-2017



Terje Solbakk

PhD Fellow, NTNU

Geophysical imaging of prospects and reservoirs with chemical weathering porosity, based on data from field analogues on Svalbard and Greenland.

2015-2018



Ryan Dillon

PhD Fellow, Akvaplan-niva

Modelling the behavior and movements of marine mammals in the Lofoten-Barents Sea region.

2015-2017



Amando Lasabuda

PhD Fellow, UiT

Early - Mid Cenozoic evolution of the southwestern Barents Sea margin - paleoenviromental evolution and sediment yield.

2015-2018



Ronny Tømmerbakke

PhD Fellow, UiB

Sea ice & erosional uplift: impact on Arctic seismic exploration

2015-2018



Tectonic inversion in the SW Barents Sea



2015-2017



Nathalie Morata

Postdoc, Akvaplan-niva

Impact of changes in environmental conditions on benthic communities.

2015-2018



Ingrid Wiedmann

Postdoc, UiT

Arctic pelagic ecosystems and the vertical export of organic carbon and particles

2016-2019



2017-2019

Fredrik Wesenlund

PhD Fellow, UiT

2017-2020

The ARCEx Work Package Leaders and Management



Jan Inge Faleide Work Package leader WP1 Professor, UiO Adjunct Professor, UiT



Sten-Andreas Grundvåg Work Package leader WP2 Associate Professor, UiT

WP2

WP5



Kim Senger Work Package leader WP2 Associate Professor, UNIS

WP2



JoLynn Carroll Work Package leader WP3 Assistant Director, Akvaplan Niva Adjunct Professor, UiT

WP3

WP1



Tor Arne Johansen Work Package leader WP4 Professor, UiB Adjunct Professor, UNIS



Jan Sverre Laberg Work Package leader WP5 Professor, UiT



Jasmine Nahrgang Work Package leader WP5 Associate Professor, UiT

WP4



Alfred Hanssen ARCEx Director, Professor

Ellen Ingeborg Hætta Administrative leader

Iver Martens Advisor

Management

Management

Management



ARCEx - a multi-disciplinary research centre ARCEx consists of a complex research program covering complementary subject fields such as geology, environmental risk and technology. Education and training is an integrated part of ARCEx. ARCEx is sub-divided into five interconnected work packages addressing different research objectives. Basin analysis: to understand the regional geology and tectonic evolution in the Barents Sea region and to provide a better basis to assess the petroleum potential and reduce exploration risk in the north. Petroleum systems and play concepts: to provide detailed knowledge on basin characteristics, summarised in detailed paleogeography reconstructions to improve prediction of the resource potential of the Arctic Basins Environmental risk management: to develop new environmental risk management approaches tailored to the unique exploration and future operational challenges for Arctic areas. Technology for eco-safe exploration in the Arctic: to develop the best possible geophysical data acquisition strategies to use - both with respect to the environment and data quality Education and outreach: to offer international top-level petroleum geology, geophysics, biology and ecotoxicology education and to ensure that highly competent candidates will provide a pool of experts for the industry and academia.

Modeling and mitigation of ghost cavitation noise for seismic arrays

Ghost cavitation is a high-frequency noise signal that can be created by seismic source arrays. The noise is generated by collapsing vapor bubbles formed by the acoustic waves reflected from the sea surface. Through controlled experiments, we found that the distance between the source strings in a source array is a major factor that influences the amount and strength of the high-frequency signal. A significant finding is that ghost cavitation noise can be reduced by increasing the distance between the guns. A numerical model of cavitation noise has been developed and the simulated noise has been validated by comparing field data with simulations. The numerical model will be an important tool in order to design array layouts that minimizes unwanted ghost cavitation noise. (Landrø et al., 2016; Khodabandeloo et al., 2017.)

Risk identification in the Arctic

We have developed a risk identification method based on identification of system characteristics such as harsh weather, ice and darkness. The method stimulates the ability to be prepared for new hazards and accident scenarios in the arctic regions and takes advantage of experiences from developed areas. (Røed, W. (submitted 2017). Improved hazard identification in major accident prevention based on evaluation of system characteristics, in Knowledge in Risk Assessment and Management (Wiley Publishers).)

Selected scientific highlights

Uplift of the Loppa High

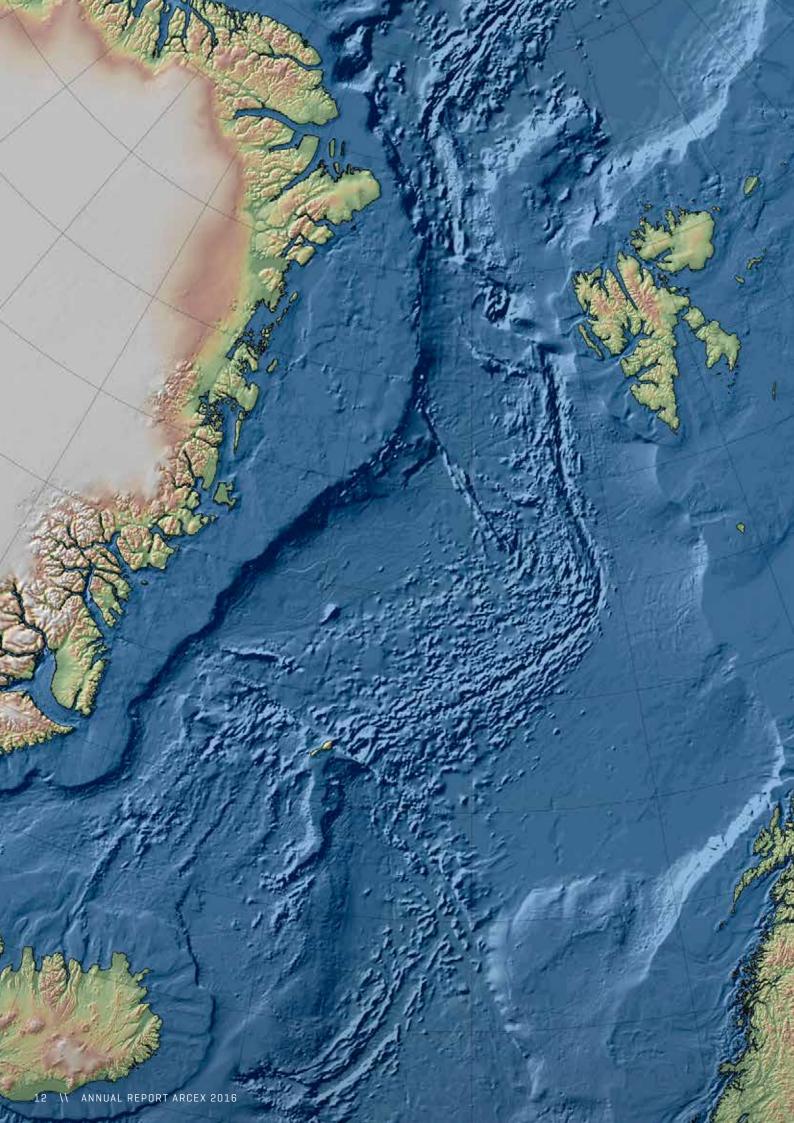
We have carried out research to understand the development of the Loppa High which has a key position in the sw Barents Sea. Many of the recent petroleum discoveries are located at or close to this high. Results published by Indrevær et al. (2016) focused on the timing and consequences of the uplift of the high, while we in a following-up paper focus more on the cause(s) of the uplift. Through numerical modeling, we study and quantify the effects of various geological processes that may have interacted in the geological evolution of the wider Loppa High area. Increased understanding of the driving forces is crucial to provide constraints for the structural evolution and associated temperature and vertical motion histories of the study area.

Physiological effects of oil on Arctic key species

We have made an assessment of the potential long-term physiological effects on polar cod (Boreogadus saida), an Arctic key species, from short term acute exposures to environmentally realistic concentrations dispersed oil and burned oil residue. These exposures resulted in no long-term effects in polar cod. (Bender ML, Frantzen M, Nahrgang J, LeFloch S, Palerud J, Camus L (submitted 2017) Long-term resilience in polar cod exposed to dispersed oil and burned oil residue. Environmental Science & Technology.)

Global mass extinctions and accumulations of organic rich sediments Throughout the geological history, short periods with extremely low oxygen levels in the oceans have resulted in global mass extinctions and accumulations of organic rich sediments, which now form important source rocks in many hydrocarbon provinces, including the Barents Sea. Our geochemical studies of Permian sediments in Svalbard shows that the global mass extinction at the Permian-Triassic boundary also heavily affected the Arctic regions (Uchman et al., 2016). However, the question whether the Permian sediments have a source potential remains unanswered. The geochemical signature of an Aptian shale unit in the Lower Cretaceous of Svalbard shows that it have local source potential (Abay et al., 2017) and may correlate to a global event with dramatic drops in oxygen levels (Midtkandal et al., 2016). Sedimentation and fluid migration in deep marine rift The gravity-driven emplacement of sand and gravel in tectonically active, deep marine rift basins may result in the formation of good reservoirs. Sedimentological studies of an exhumed deep marine rift basin in NE Greenland have improved our gen-

eral understanding of the processes that form such deposits, and particularly how flows transform from being gravel-rich to more sand-dominated as they travel across the deep ocean floor (Henstra et al., 2016). Our structural investigation of the fault that border the rift basin indicates a close relationship between fault damage and chemical alteration, hence shedding a new light on fluid migration in deep marine rift basins (Kristensen et al., 2016).



WP1: Basin Analysis

The research activity in WP1 is being carried out with high intensity by our two PhD fellows Tore Aadland at the University of Bergen, and Amando Lasabuda at the University of Tromsø, and postdoc Kjetil Indrevær at the University of Oslo.

Together with their academic supervisors, national and international collaborators, and industry partners, this core team has investigated several aspects of basin formation. The work package is led by professor Jan Inge Faleide at the University of Oslo. Through prof. Faleide, ARCEX is also connected to the Centre of Excellence CEED (Centre for Earth Evolution and Dynamics) at the University of Oslo.

Topicwise, Tore Aadland focuses his work on source-to-sink, regional depositional systems, and post-depositional processes. Aadland is now in the final year of his PhD-work, and we are looking forward to see him succeed as the first PhD carrying the ARCEX logo on his dissertation. Amando Lasabuda focuses on erosion and mass balance estimates, glacial history, and pre-glacial uplift and erosion. Dr. Kjetil Indrevær focuses his research on the detailed understanding of tectonic phases and the structural analysis of basin architecture.

A brief exposition of two important results from Indrevær's recent research can be stated as follows:

For the last year, Indrevær and his co-workers have focused on identifying, documenting and characterising early Cretaceous tectonic inversion structures within the sw Barents Sea. A paper on the topic, linking tectonic inversion to vertical movement(s) of the Loppa High in the early Cretaceous is published by Journal of the Geological Society of London. After having documented effects of uplift, we have now changed focus to understanding the cause(s) of the uplift through crustal scale numerical modeling. We have tested the concept whether metamorphic phase changes at the base of the Loppa High could cause subsidence and uplift at the surface, and whether or not such a mechanism could reproduce the present day complex geometry of the Loppa High as we observe on seismic data. The results are promising and a manuscript on the subject is currently being finalized for submission.

A parallel project focusing on folds and minor thrusts affecting early Permian bioherms present on the eastern flank of the Selis Ridge suggest that the area was affected by syn-rift event(s) of minor west-vergent shortening. Such shortening may potentially be linked to late stages of uplift and tilting of the Selis Ridge, far-field stress originating in the east or salt tectonics. Lundin Norway has been involved in the project and a manuscript is being prepared on the subject.



Prof. Jan Inge Faleide Work Package Leader, Professor, UiO, Adjunct Professor, UiT

Team: Kjetil Indrevær

Postdoctoral Researcher, UiO

Amando Lasabuda PhD Fellow, UiT

Tore Aadland PhD Fellow, UiB

Jan Sverre Laberg *Professor, UiT*

Per Terje Osmundsen Researcher, NGU

William Helland-Hansen *Professor, UiB*

Alvar BraathenProfessor, UiO/UNIS

Roy Helge Gabrielsen Professor, UiO

Sebastian Gac Researcher, UiO

Stig-Morten KnutsenAdjunct Associate Professor, UiT
Assistant Director Exploration, NPD



WP2: Petroleum Systems and Play Concepts

The ongoing research activity in WP2 reflects a diverse and multidisciplinary research group.

Some topics covered by our publications in 2016 include:

- Migrated petroleum in the Mesozoic of Svalbard
- Depositional processes in deep-marine rift basins
- Flow properties of border faults
- Organic carbon-isotope stratigraphy of the Upper Jurassic source rock in
- Sedimentological and geochemical characterization of the Upper Permian to lowermost Triassic of central Spitsbergen.

Our activity also demonstrates the importance of Svalbard as a field laboratory.

In the start of 2016, Jean Baptiste Koehl (UiT) was our only fully ARCEX-financed PhD candidate. Jean Baptiste has investigated rift systems onshore Spitsbergen and Bjørnøya, but his main focus was on brittle faults and half grabens in Finnmark, and how these compare to rift basins in the sw Barents Sea. He presented his main findings at amongst others the EGU general assembly in Vienna, Austria in 2016. Tyler Appleyard (UNIS) started his PhD in early 2016. In his first field season, he investigated an ancient tidal delta in Svalbard, which shows many similarities to parts of the reservoir in the Goliat Field, sw Barents Sea. Tyler presented his first results at our ARCEX workshop in Tromsø in October. We

look forward to hear more from these two young scientists.

Towards the end of the year, Prof. Snorre Olaussen (UNIS), aged by many cold winters in Svalbard, decided to pass on his role as a co-leader of wp2 to Assoc. Prof. Kim Senger (UNIS). Kim's interest field covers fractured reservoirs, intrusions and their influence on petroleum systems, as well as seismic and EM modelling of outcrops. His diverse explorationist background is already seen to be a great asset to WP2.

WP2 cooperates with both national and international groups, including the Lower Cretaceous basin studies in the Arctic (LoCrA) project at unis/UiS and other industry-funded projects like TELMA (Tectonosedimentary Evolution of the Lofoten Margin) and WEBMAR (Tectonosedimentary Evolution of the Western Barents Sea Margin) led by Prof. Atle Rotevatn (UiB). As a continuation of our ongoing work in Svalbard, we recently joined a project initiated by the University of Utrecht whose objective is to investigate the reservoir properties of ancient turbidite deposits in Svalbard. These type of deposits, emplaced by gravity flows, form reservoirs in many prolific sedimentary basins worldwide. A field trip in 2017 are currently being planned involving personnel from ARCEX and the University of Utrecht.



Sten-Andreas Grundvåg Work Package Leader, Associate Professor, UiT



Kim Senger Work Package Leader, Associate Professor, UNIS

Jean-Baptiste Koehl PhD Fellow, UiT

Tyler Appleyard PhD Fellow, UNIS

Malte Jochmann Associate PhD Fellow, UNIS

Steffen Bergh Professor, UiT

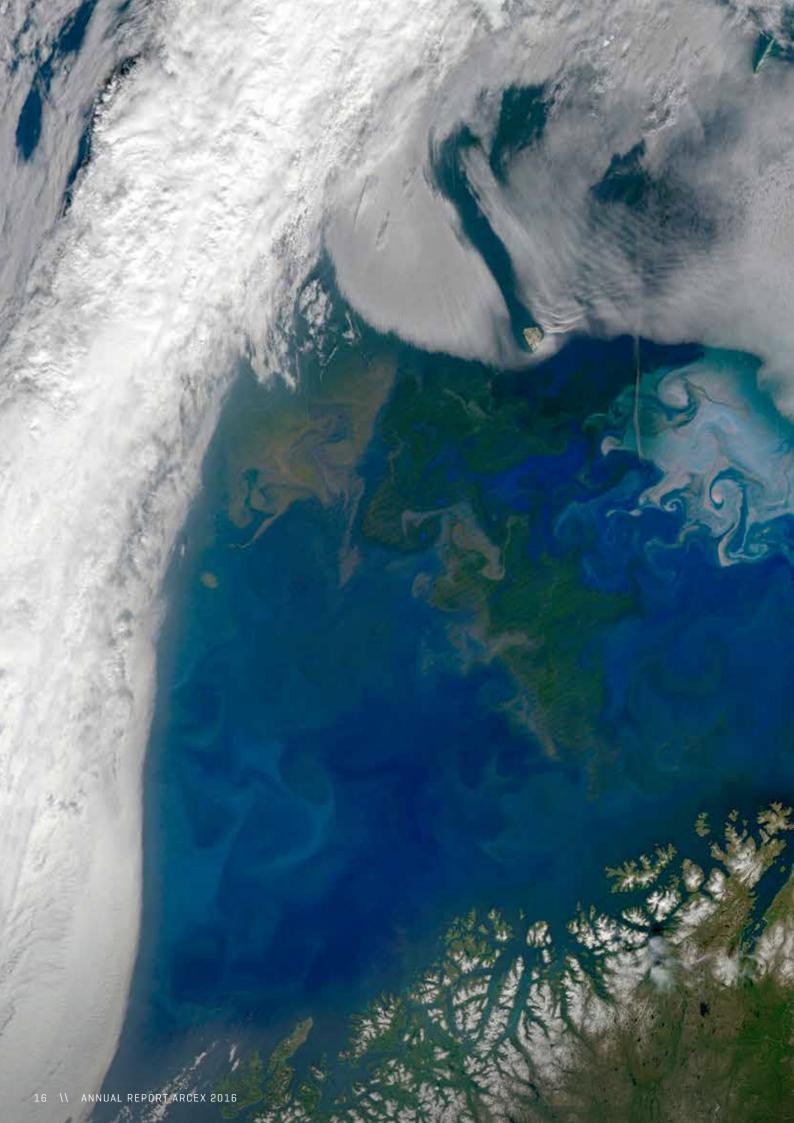
Researcher, NGII William Helland-Hansen Professor, UiB

Per Terje Osmundsen

Atle Rotevatn Professor, UiB

Snorre Olaussen Professor, UNIS

Spring semester of 2017, we are hiring two PhD fellows and a PostDoc, and the process of suggesting relevant topics for these positions was done in close dialogue with our industry partners in 2016. These upcoming recruitments will certainly strengthen our activity in 2017.



WP3: Environment Risk Management

We are acquiring new knowledge of northern ecosystems and applying this knowledge toward development of improved methodologies for eco-safe exploration in the high north.

We focus on characterizing the linkages and behaviors of species that comprise northern ecosystems, and the responses of Arctic organisms to petroleum compounds. These results are being linked to the development of improved environmental risk analysis methods tailored to the unique operational challenges associated with the exploration and development of petroleum resources in the Arctic.

The research performed in WP3 is led by Professor JoLynn Carroll at Akvaplan-niva As. We currently have four early career scientists who are working to improve our understanding of the environmental challenges and potential solutions to minimize the potential impacts and risks of industry operations in the Arctic. These are PhD students Ana Sofia Aniceto and Ryan Dillon (APN), and Postdoctoral researchers Nathalie Morata (APN) and Ingrid Wiedmann (UiT). These dynamic early career sci-

entists are all actively engaged in cooperation with national and international partners. In Spring 2016, the team carried out a coordinated field investigation of benthic and pelagic ecosystems in the Marginal Ice Zone in the central Barents Sea and several Svalbard fjords. During the investigation, surveys were also performed to test the performance and capabilities of Unmanned Aerial Vehicles to detect and monitor marine mammals. Ecotoxicology specialists in wp3 also established a new laboratory protocol to perform coordinated ecotoxicology experiments on different Arctic species. Also in 2016, Willy Røed (UiS) completed his Postdoctoral research on safety and environmental risk analyses. He has achieved several noteworthy advancements in safety and environmental risk analyses. Based on his examination of historical data from the Norwegian continental shelf he has identified some of the root causes of accidental leaks.



JoLynn Carroll Work Package Leader,

Work Package Leader, Assistant Director, Akvaplan Niva Adjunct Professor, UiT

Team:

Ana Sofia Aniceto

PhD Fellow, Akvaplan-niva

Ryan Dillon

PhD Fellow, Akvapla-niva

Willy Røed

Postdoctoral Researcher, UiS

Nathalie Morata

Postdoctoral Researcher, Akvaplan-niva

Ingrid Wiedmann

Postdoctoral Researcher, Akvaplan-niva

Anita Evenseth

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Jasmine Nahrgang

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Marianne Frantzen

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Martin Biuw

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Jonas Juselius

Researcher, Akvaplan-niva

Roger Flage

Associate Professor, UiS

Terje Aven

Professor, UiS

Thierry Baussant

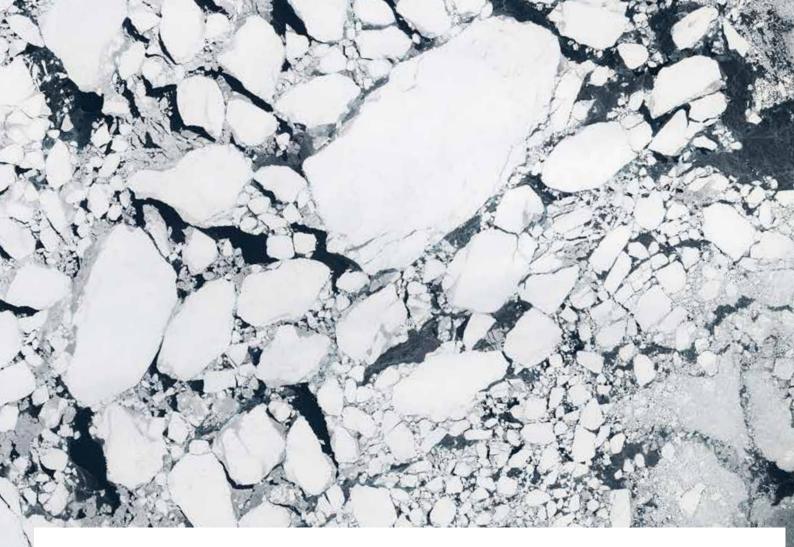
Researcher, IRIS

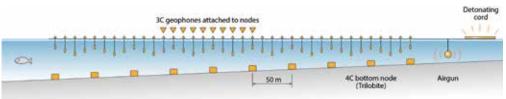
Paul Renaud

Researcher, Akvaplan-niva

Starrlight Augustine

Researcher, Akvaplan-niva





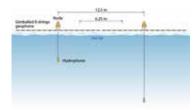


Figure 1a. Set up for seismic experiments performed spring 2016.

Figure 1b: Close up of figure 1a.

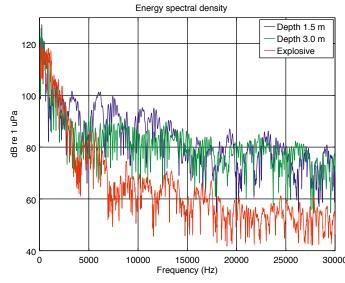


Figure 2. Energy spectra of an air gun (0.5 liter) fired at various depths and of 5 (200 g) m of detonating cord fired at the ice surface.

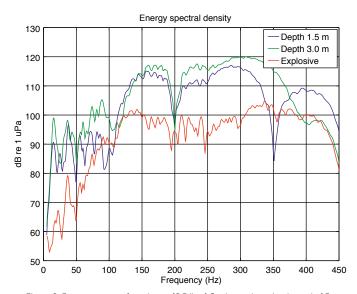


Figure 3. Energy spectra of an air gun [0.5] liter] fired at various depths and of 5 m [200] of detonating cord fired at the ice surface.

WP4: Technology for eco-safe exploration in the Arctic

In 2016 ARCEx in collaboration with University of Bergen and UNIS established a large scale geophysical laboratory for studying seismic wave propagation in sea ice and on frozen surfaces in the inner part of the Van Mijenfjord at Svalbard.

A wide range of seismic recording equipment including various kinds of geophones, hydrophones, four component ocean bottom nodes and seismic sources (airguns and detonating cord) are now stored in Svea. This provides ARCEX with a unique facility in order to conduct experiments important for wp4. The three main objectives of this laboratory are to i) do experiments on seismic imaging on sea ice, glaciers and frozen tundra, ii) perform controlled experiments to study environmental impacts of seismic sources close to the ice, and iii) gain experience on the performance of various types of geophysical equipment for operation in Arctic.

During March 2016 the first experiments were carried out along a 500 m long profile on the ice in Sveabukta. Along the profile, various types of geophones were mounted on top of the ice, hydrophones at various depths below the ice and four component nodes at the sea bottom, as illustrated in Figure 1. One focus of these experiments was to compare sound profiles and noise levels at different depths below the ice, caused by using explosives on top of the ice and an airgun below. Since sea mammals breed in this area, such data are of crucial importance for the further experimental work. Figures 2 and 3 show comparisons of energy density spectra measured by hydrophones at 3 m depth below the sea ice and at various distances from the source. In Figure 2 a hydrophone in the hearing range up to 500 Hz was used, while in Figure 3 the hearing range is up to 100 kHz. Both figures illustrate that air guns in general generate energy over a broader frequency range than explosives detonated on the ice surface. This is surprising since this is opposite to what we see when explosives are fired in water. For seismic imaging of deeper structures, 1 km and more, the most important part of the energy spectrum of the source is 50 Hz and below. From the spectra in Figure 2, we see that the air gun is the most effective source to use in this respect. However, an unwanted effect is that also higher frequencies are generated, which cause disturbances for sea mammals. However, from Figure 2 we see that for our data, the energy level at frequencies above 3 kHz is more than 20 dB lower than that of the peak frequencies at around 0.3 kHz. Although air guns produce considerable amounts of high frequency waves, these waves are not strong enough to generate physcial damage to fish or mammals at these distances (50 m).

ARCEX continues to contribute to the understanding and development of environmentally friendly exploration techniques. Research activities led by Prof. Martin Landrø at NTNU has led to new numerical models of high-frequency noise called ghost cavitation that is



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Researcher, Norut

Kamaldeen O. Omosanya Associate Postdoctoral Researcher,

Bent Ole Ruud Engineer, UiB

associated with seismic source arrays. PhD student Babak Khodanbandeloo at NTNU has developed simulation tools to model and understand the cavitation noise, and the model has been validated through comparison with real field data. The computational model will be further refined, and we aim to use the theoretical understanding to experimental design that minimizes the unwanted noise components.



WP5: Education and Outreach

We have had a strong focus on the record high number of master's students at the Department of Geosciences at the University of Tromsø.

This has included offering a number of new master's project, mobilizing internal and external supervisors, implementing the new master's courses established by ARCEX personnel for the students specializing in Petroleum Geosciences, as well as reviewing and optimizing the already existing course portfolio at the University of Tromsø. In addition, ARCEX personnel have been involved in teaching at master's and bachelor level at the Department of Geosciences and at the Faculty for Biology, Fisheries, and Economy in Tromsø.

ARCEX staff from several mainland universities are engaged in teaching at UNIS. Several of our students at all levels spend part of their time at Svalbard to attend courses that are not offered in mainland Norway. Several of these courses are highly relevant to the research activities in ARCEX.

ARCEX was present at the Northern Norwegian collaborative Explore Arctic stand at the ONS Exhibition and Conference in Stavanger, and we made our presence during the Science Week (Forskningsdagene) in Tromsø. We have had several popular presentations at various events and venues, and we have participated in panel discussions with non-governmental organizations (NGO's) and in public sessions at conferences where research based opinions are welcome.

ARCEX staff has served as faculty advisors and connections for the Society of Petroleum Engineers (SPE) and their student chapter at UiT The Arctic University of Norway. We are also present in the board of the Norwegian Petroleum Society, Tromsø branch, and we help to create a meeting arena where petroleum related topics are discussed on a regular basis across disciplines.



Jan Sverre Laberg Work Package Leader, Professor, UiT



Jasmine Nahrgang Work Package Leader, Associate Professor, UiT

Team: Stig-Morten Knutsen Assistant Director Exploration, NPD, Adjunct Associate Professor, UiT

Iver Martens Advisor, UiT



ARCEx Early Career Forum 3.0: Svalbard

The third ARCEx Early Career Forum (ECF) of ARCEx researchers had a great turnout among our PostDoc and PhD candidates. Gathering in the High Arctic of Svalbard at 78 degrees North September 14th-16th, the forum was slightly longer than earlier ECF's.

Text: Tyler Appleyard

We had three productive Open Session workshops. The first included working on communicative skills with a focus on building conference posters and presenting research to an audience of mixed levels and backgrounds, while the second workshop was a brief geological history of Svalbard and some of the recent outcrop modelling techniques used at UNIS. The final session prior to departure was a discussion on future oil development and the intricacies of the Svalbard Treaty.

A one-day field excursion was planned to Deltaneset where the Mesozoic succession can be observed and represents a direct analogue to the Barents Shelf petroleum system. However there were two polar bears present in this area, so we had to adjust our schedule slightly. Instead, we stayed within the Longyear-byen area and visited several unique localities. One stop along the trip high-



Photo: Tyler Appleyard

lighted the recent uplift of the archipelago, where whale bones and mummified clams (dated at 10 ka) rest in situ at 60 meters above sea level. The next locality was an old Store Norske well bore had been leaking small amounts gas for several decades and which is now sealed with a valve. Our field trip ended with a tour through Mine 3, where the group seemed to have gained a new apprecia-

tion for the physical labor from an earlier era of coal mining.

Overall, the group discussions and constructive collaborations across work packages during this ECF 3.0 strengthened our group and the ARCEX identity as a whole. The next ECF location and topic was discussed over dinner, and is surely one that is not to be missed.



ARCEx Research Cruise to the Marginal Ice Zone

Dressed in warm clothes, working gloves and a hard hat, I had been working with the crew of RV "Helmer Hanssen" the whole afternoon.

Text by Ingrid Wiedmann

We were loading 27 pallets with scientific equipment and distributing them on different decks, but now, everything was prepared. Tomorrow, on 17 May 2016, we would depart from Longyearbyen and head to van Mijenfjorden and Hornsund at the western coast of Svalbard, to Storfjorden, and to the western Barents Sea. During the 12-day cruise, we would collect field samples for Nathalie Morata (working on ecosystems connected to the benthos), myself (working on pelagic ecosystems and vertical export), and Ana Sofia Aniceto (using Unmanned Aerial Vehicles for marine mammals in the Arctic) to study central ecological aspects of the ARCEX work packages we are working in.

Do three female scientists need 27 pallets of equipment? Definitely, no, but Nathalie, Ana Sofia and I did not travel alone. We were joined by colleagues from UiT The Arctic University of Norway, the Institute for Marine Research, the Norwegian Polar Institute, the University of Bremen (Germany), the Polish Academy of Science, the King Abdullah University of Science and Technology (Saudi Arabia), and the University of South Alabama (USA) and together we wanted to

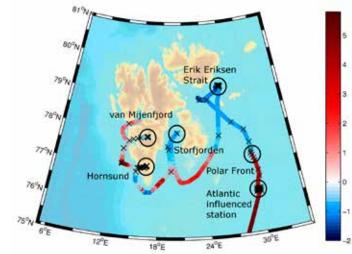


Illustration: Ingrid Wiedmann

improve the understanding of marginal ice zone ecosystems through synergetic effect of our findings.

Soon after we finished loading, Professor Paul Wassmann, the designated cruise leader called me. He was to attend the cruise too, and he asked if I could be the cruise leader because of an urgent situation that had appeared. This made me speechless for a moment, but, yes, I could.

Thus, I was thrown into cold water, and was for the first time the leader of a larger research cruise. Thanks to the pre-cruise planning with Paul and the

support by colleagues and crew, I had a steep learning curve and the ARCEX cruise was a success for all participants.

Analyses of the samples are currently ongoing, but on a personal level, my main finding of the ARCEX cruise is very clear. We observed very little sea ice in the fjords and we could not find any icefloe, which was large enough to work on - and this during May, when everyone would expect abundant sea ice in the area. This scares me, because it means that the major sea ice decline is not only a result of some models, but it is actually taking place out there.



Willy Røed – off to new adventures in accident prevention

For the past two years, Willy Røed has worked as a PostDoc at ARCEx at University of Stavanger. His main research topic has been accident prevention as part of the Environment risk management work package.

Accident prevention

No activities are completely risk free: If you walk your child to kindergarten, there may be an accident on the way, and if a company chooses to explore oil and gas there will be an inherent major accident potential. However, the good news is that risk can be managed by thinking through potential scenarios in advance and by implementing mitigating actions. The Norwegian oil and gas industry has a good record of accomplishment when it comes to accident prevention compared to other regions in the world and compared to other industries in Norway: Despite almost 50 years of oil and gas exploration and production, these activities have never caused oil pollution on any shoreline in Norway. This is a result of hard work and a dedicated focus on accident prevention in the industry through decades. However, we can never relax based on historical achievements; we will never know exactly what challenges we will meet around the next corner. Then, to be prepared, research activities such as the ones performed in the ARCEX project, are of major importance.

Motivation

"I have always been fascinated by risk", Willy says. "In the late 90s, after finishing my bachelor degree in fire safety engineering, I worked as a fire safety engineer in a fire brigade. Later I finished a master degree within offshore safety. Then, I was fascinated by the major

accident potential and the substantial focus on accident prevention in the oil and gas industry compared to other industries. When I was working on my PhD project, I realized that the offshore industry was the main catalyst for research on accident prevention in

Norway. In many other countries, much of the safety related research has traditionally been within nuclear, aviation and space industries. Then, after 10 years working in Proactima as a consultant, I wanted to spend more time on research, and the ARCEX PostDoc position popped up as the perfect alternative".

Research activities

As an initial activity, Willy was part of a team investigating the root causes to hydrocarbon leaks in the Norwegian oil and gas industry. This work provided knowledge to be used in the design and implementation of mitigating actions in the future. Later on, as part of the development of a risk-uncertainty framework for the arctic, Willy has developed a hazard identification method, based on identification of system characteristics such as harsh weather, ice and darkness. The method stimulates the ability to be prepared for new hazards and accident scenarios in the arctic regions, but also, to be able to take advantage of knowledge



that has been achieved in developed areas. Willy has also provided theoretical arguments that improved planning can reduce risk related to major accidents and save money at the same time. This came as a result of sharing the office with a colleague from Texas A&M University with expert competence on planning and project management. It is an example that research activities are closely related to creativity, and creative aspects are not always easy to plan in advance.

ARCEx

"I've had a great time being part of the ARCEX team", Willy says. "I hope my contributions will be used by the industrial partners and that my work can be used as a platform for future ARCEX activities. There may be a chance that I will show up on this year's ARCEX conference even though I am not a formal part of the project any more". And ARCEX welcomes Willy to join our events in the future, and wishes him good luck in his next adventure!



Bjørnøya – a peephole into the subsurface

For most sailers and fishermen, Bjørnøya is nothing more than a safe haven on their voyages across the vast Barents Sea. For many geologists, Bjørnøya is the ultimate dream and a once-in-a-life time experience. The many stories told by veteran Svalbard geologists had for many years fueled my passion for visiting this mysterious island located in the middle of the Barents Sea, and in September 2016, my dream-trip finally became a reality.

Text by Sten-Andreas Grundvåg

Bjørnøya is a small (178 km²) offshore island located 400 km north of Nordkapp, mainland Norway, and it is the southernmost island of the Svalbard archipelago. The island is located very close to the western margin of the Barents Shelf, and represent an uplifted and exposed part of the subsurface Stappen High. Because of this, Bjørnøya offers a unique opportunity to explore the petroleum geology and the tectono-sedimentary evolution of the western margin and the north-central parts of the Barents Shelf.

In September 2016, we arranged a field trip to Bjørnøya in close cooperation with our partners in NGU and Statoil. From UiT – the Arctic University of Norway, Jean Baptiste Koehl and Sten-Andreas Grundvåg participated. From NGU, Jomar Gellein and Marco Brönner participated, whereas from Statoil's Harstad office, Olaf Thiessen and Tore Forthun participated. In addition, Erik P. Johannessen, Gunnar Knag and Tormod Henningsen, all geologically-active Statoil retirees, joined in.

We had three main scopes for the trip: 1) collect high-resolution gravimetric and magnetic data across the island, 2) map faults and collect fault gouge in order to more accurately date fault activity, and 3) collect samples from potential organic-rich strata that may serve as alternative source rocks in the northernmost licenses of the Barents Sea. The field trip was in many ways a great success. As an example, the NGU-team managed to collect more than 220 km lines of gravimetry and magnetometry data.

What determines whether a field campaign is a success or not? In my opinion, the success of some trips cannot be measured in the amount of samples collected and goals achieved. The comradeship, knowledge sharing, and the possibility for us young researchers to work with more experienced personnel is invaluable.



Map: Norwegian Polar Institute



Photo: Sten-Andreas Grundvåg



ARCEx Uplift and Erosion Workshop



One of the major scientific aims of ARCEX relates to the response of the Barents Sea shelf to: 1) the glacial erosion of this area during repeated glaciations of the last 2 - 3 million years, and 2) the opening and development of the Norwegian - Greenland Sea from c. 55 million years ago. To discuss these questions a thematic 1-day workshop was arranged in Tromsø on October 26th. The workshop included participants from both academia and our industry partners and included 12 presentations, 3 of which were given by ARCEX PhD students. The workshop had several aims; 1) to be an arena for presenting and discussing a specific scientific topic, 2) to be an academic - industry arena for scientific discussions, and 3) to introduce and expose our early career scientists to the expertise of our industry partners. Together, the presentations gave a state-of-the-art overview of the latest results and the various methods used to address the complex issue of shelf erosion, its distribution, magnitude and consequences. Gaps in our approach were also identified. The workshop was ended by a summary of the results presented. Following the workshop, feedback on this format for discussing scientific topics of interest to ARCEX has been very positive. More workshops addressing other topics are in the pipeline.

Nathalie Morata, Akvaplan-niva

37 years old MSc in Marine Science, University of Marseille, France (2002) PhD in Oceanography, University of Connecticut, USA [2008] Supervisor: Paul E. Renaud, Akvaplan-niva

Nathalie Morata is a Postdoctoral fellow in marine ecology at Akvaplan-niva. Her research interests include the use of field observation and manipulative experiment to address issues related to carbon cycling and organic matter fluxes to the seafloor. She is particularly interested in understanding the impact of climate change and anthropic disturbances on seafloor benthic ecosystems. Climate change is enhanced in the Arctic and these changes are expected to have repercussions for ecosystems functioning all the way to the seafloor. Nathalie's Post-Doc aims therefore at studying the link between environmental conditions (sea ice cover, water masses), carbon supply to the seafloor, and response of the benthos to these inputs. For doing so, she participated in field work (ARCEX cruise, and invitation in the Transitions in the Arctic Seasonal Sea Ice Zone (Transsiz) and GreenEdge projects) in contrasted areas in terms of environmental and biological conditions: Svalbard fjords, Barents Sea (influenced by warm Atlantic waters), Baffin Bay (influenced by cold Arctic waters, with a strong seasonal ice cover). This study will permit to better understand the functioning of the Arctic benthic ecosystems in the context of climate change. These results are needed to



better assess the potential impact of future industry operation in Arctic areas.

While Nathalie Morata has mainly conducted basic research in academia in the past, her participation in ARCEX is for her a unique opportunity to interact with the industry partners and apply her research to important exploration activities. She strongly believes in the complementarity of academic and industry partners, and she will try to continue working on this path as long as possible.

International collaboration

The research activities in ARCEx involve collaboration with several international universities, research institutions and companies. Our international network is large and comprehensive, and it is very important for our early career scientists and seasoned professors alike. The international collaborators contribute with their knowledge and competence to scientific publications and presentations, they provide access to advanced laboratory facilities, and they serve as hosts for ARCEx research personnel. The list of collaborators is dynamic, but in the following we present a list of our most important international collaborating institutions.



United States of America

Bates College, Maine Colorado State University Oregon State University Stanford University, California

Texas A&M University University of California at Berkeley

University of Nebraska at Omaha

University of Southern California (UCSD), San

Iceland

University of Iceland

Netherlands

Utrecht University

United Kingdom

Sea Mammal Research Unit (SMRU), University of St. Andrews

Whale and Dolphin Conservation Society, Chippenham

France

IRIT-CNRS University of Toulouse UMR SEBIO University of Rennes

Denmark

Copenhagen University Geological Survey of Denmark and Greenland [GEUS]

Natural History Museum of Denmark

Switzerland

University of Lausanne

Italy

University of Parma

Germany

Alfred Wegener Institute GEOMAR, Kiel Helmholz-Zentrum GFZ Potsdam

Poland

University of Warsaw Polish Academy of Sciences

Finland

University of Jyväskylä University of Eastern Finland, Joensuu

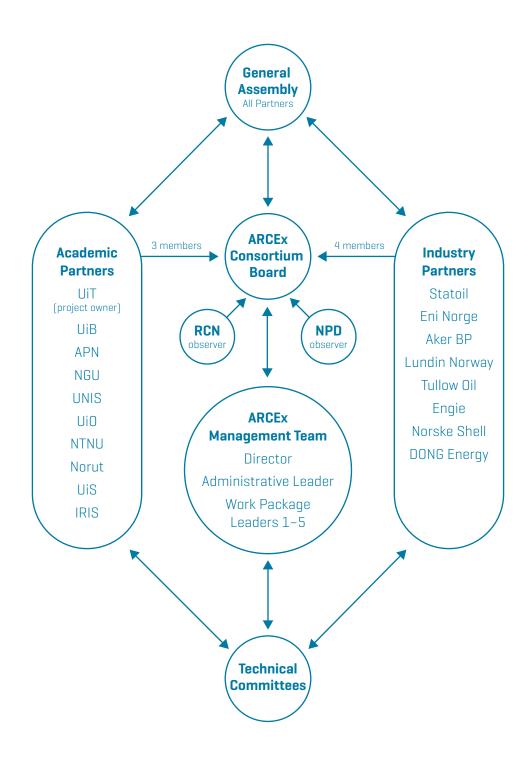
Russia

Gubkin University Lomonosov Moscow State University

Russian Academy of Science

VNIIOkeangeologia VSEGEI

Organisation



Accounts

(all figures in NOK 1 000)

Funding source	2016	
The Research Council	11,390	
The Host Institution (UiT)	5,350	
Research partners	4,948	
Industry partners	8,473	
Other public funding	3,279	
Total	33,440	

Costs per activity	2016
Management	1,999
WP1 Basin analysis	5,990
WP2 Petroleum systems and play concepts	5,917
WP3 Environmental risk management	9,406
WP4 Technology for eco-safe exploration in the Arctic	8,817
WP5 Education and outreach	1,311
Total	33,440

Costs per partner	2016	
UiT/NT	9,231	
APN	5,329	
UiB	4,204	
NTNU	2,792	
UNIS	2,539	
UiT/BFE	2,511	
Ui0	2,424	
NORUT	1,743	
UiS	1,646	
NGU	616	
IRIS	405	
Total	33,440	

¹ UiB, UiO, NTNU, UiS, UNIS, APN, IRIS, NGU, Norut

² Statoil Petroleum AS, Eni Norge AS, Aker BP, Lundin Norway AS, Tullow Oil Norge AS, ENGIE E&P Norge AS, AS Norske Shell, DONG Energy E&P Norge AS

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- Hanssen, A. (2016): The ARCEx project, Presentation for delegation from Univ. of Saskatchewan, Canada, 01.07.2016
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- Indrevær, K. (2016) Uten Platetektonikk ville Norge vært helt Danmark. Foredrag på UngForsk, UiO
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- Martens, I. (2016): *Geophysics and ARCEx.* EKM studiesamling, 29th September 2016, Vannøya, Tromsø, Norway, Oral presentation.
- Martens, I. (2016): Studieløpene i Energi, klima og miljø ved IG, Presentations for EKM students, UiT, 16th October 2016, Tromsø, Norway, Oral presentation.
- Martens, I., Hætta, E.I., Hanssen, A., Wassmann, P., Wiedmann, I., Aniceto, A.S. (2016): Stands, lectures, "Bestill en forsker", Science for schools in connection with Forskningsdagene 2016, 20.9-2.10.2016.
- Morata N. (2016) Impact of changes in ice cover on pelagic benthic coupling and ecosystem functioning on Arctic shelves. Climate Change, Resource exploitation and the diversity and functioning of Arctic benthic ecosystems, September 2016, Aberdeen, UK.
- Olaussen, S. (2016): New discoveries in the western Margin of the Barents Sea and R&D activities in Svalbard are the oil resource estimates in the Arctic Norwegian Continental Shelf too pessimistic. Presented in: NCS Prospects Stavanger 1.-2. november Geonova/Rystad Energy http://ncs-prospects.no/programme/wednesday/?scroll=1
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- Røed, W. (2016): Improved hazard identification in major accident prevention based on evaluation of system characteristics. ARCEx Conference 2016, 15-16 March 2016, Tromsø.
- Røed, W. (2016): Reflections on historical events, unforeseen events and major accident risk. Society for Risk Analysis (SRA) Annual Meeting 2016, 11-15 December 2016, San Diego, California, USA
- Rydningen, T.A., Laberg, J.S., Forwick, M., Safronova, P.A. (2016): On the evolution of glaciated continental margins. Glaciated Margins: The Sedimentary & Geophysical Archive. The Geological Society of London, London, 2 3 June 2016. Talk.
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- Solbakk, T., Airpuza, S., Johansen, S.E., Svånå, T. (2016): Pitfalls when interpreting karst from seismic images. Examples from the Norwegian shelf. 24th International Karstological School "Classical Karst" - Paleokarst. Postojna, 13th-17th June, Slovenia. Oral presentation
- Tømmerbakke, R., Johansen, T.A. (2016): Seismic AVO depth trends, well calibration – Hoop Area, Barents Sea. ARCEx Conference 2016, 15-16 March 2016, Tromsø.
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- Wiedmann, I., Morata, N., Wassmann, P., Renaud, P. (2016): ARCEx cruise 2016 – plans and expected outcomes. ARCEx Conference 2016, 15-16 March 2016, Tromsø.
- Wiedmann, I., Tremblay, J.-É., Sundfjord, A., Reigstad, M. (2016) Upward Nitrate Flux and Downward Particulate Organic Carbon (POC) Flux along a Gradient of Stratification and Turbulent Mixing in an Arctic Shelf Sea (Barents Sea). Ocean Science Meeting, 21-26 February 2016, New Orleans, Louisiana USA.

Master's theses

- Bergø, E. (2016): Analyses of Paleozoic and Mesozoic brittle fractures in West-Finnmark. Geometry, kinematics and relations to structures on the Finnmark Platform in the southwestern Barents Sea. UiT the Arctic University of Norway.
- Grimstad, S. (2016): Salt structures and salt tectonics in the Central and NE segments of the Nordkapp Basin, Barents Sea. University of Oslo.
- Hagset, A. (2016): Seismic attributes, well correlation and geostatistical analysis for sequence variability prediction in the Sleipner area. UiT the Arctic University of Norway
- Høgseth, G. (2016): The Cenozoic pre-glacial sedimentary environment of the SW Barents Sea continental margin – Lofoten Basin. UiT the Arctic University of Norway.
- **Jensen, K.** (2016): Modelling and Processing of flexural wave noise in sea ice. University of Bergen.

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- Karlsen, K.M. (2016): Evolution of an Eocene prograding system in the Tromsø Basin, southwestern Barents Sea. University of Oslo.
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- Lea, H. (2016): Analysis of Late Paleozoic-Mesozoic brittle faults and fractures in West-Finnmark: geometry, kinematics, fault rocks and the relationship to offshore structures on the Finnmark Platform in the SW Barents Sea. UiT the Arctic University of Norway.
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- central Spitsbergen. University of Bergen, The University Centre in Svalbard.
- Prytz, A.(2016): The Use of Seismic Attributes and Well Data for Prediction of Reservoir Sand Definition in the Vøring Basin, Norwegian Sea. UiT the Arctic University of Norway.
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