MagellanPlus workshop series program, UiT-Tromsø

Temporal evolution of Arctic gas hydrate and methane seepage systems

1. Acknowledgments

We are thankful to ECORD, ICDP and IODP for supporting organization of a MagellanPlus workshop at UiT- The Arctic University of Norway, Tromsø. Communication with Nadine Hallmann and Verena Heuer (who was the assigned watchdog but could unfortunately not join the workshop) was helpful. Special thanks to Patricia Maruejol for sending ECORD USB sticks as souvenirs for participants. The workshop was organized by Andreia Plaza-Faverola, Sunil Vadakkepuliyambatta, Jochen Knies and Stefan Bünz. Knut Ola Dølven, Margrethe Lindquist, Christina With, Cecilie Rikstad and Mariana Esteves helped with different practical aspects of the organization of the workshop. Torger Grytå provided beautiful "plastic free" nametags. Special thanks to all the participants for coming all the way up to the Arctic Circle, sharing your knowledge and experience, and expressing interest in cooperation.

2. Summary

2.1 Objectives

The main objective of the workshop was to gather scientists from around the world to discuss potential proposals for scientific drilling in the Fram Strait. A pre-proposal was submitted in April,2018 focusing on the reconstruction of methane release to the oceans over geological time and the interaction between regional processes and the near-surface Earth system. The workshop will be a platform to explore further scientific questions in the Fram Strait, create interest among young scientists, discuss ocean drilling strategies with experts as well as preparing an action plan to develop and submit a full proposal in October 2018.

2.2 Key aspects of the workshop

The workshop was hosted on the **4th and 5th of June 2018** at the Department of Geosciences, Faculty of Science and Technology, ***UiT-The Arctic University of Norway in Tromsø, Norway***. It was organized by CAGE- Center of Arctic gas hydrate, environment and climate at the department with financial support from ECORD. The workshop was attended by ***36 participants,*** of which 31 participants were officially registered and supported through the ECORD grant (annex 1). Since we ran the lectures in an open auditorium, we had 5 additional participants. The participants represented ***16 different national and international institutions***, including pioneering institutions in ocean drilling such as JAMSTEC in Japan and the US Geological Survey. A ***total of 7 early career scientists*** were actively involved in the workshop.

2.3 Program

The workshop consisted of three sessions with 18 speakers in topics that ranged from regional geological processes relevant to the Fram Strait to specialized ocean drilling techniques and methods for reconstructing paleo methane emissions (annex 2). A total of 7 hours of group discussions on specific aspects for finalizing an IODP full proposal were distributed through both days of workshop.

2.4 Scientific content of the workshop

In the first session, few key multi-disciplinary topics relevant to the Fram Strait were discussed after a general introduction to the Fram Strait methane seepage systems. (see program in annex 2 for details on talk titles and speakers):

1) Tectonics: New magnetic data and plate kinematic models in the region were presented (e.g., Gaina et al., 2017). In addition, studies about detachment fault morphology and models of burial, exposure and erosion of detachment blocks at slow spreading ridges were disused (e.g., Escartín et al.,). Key topics discussed include the origin (continental vs. oceanic) of the Hovgård Ridge in the Fram Strait; the controls on plate motion changes spatially and over geological time; Difference in fluid-rock interactions between an active detachment system at ultra-slow spreading ridges and an old, extinct system. Observations of detachment fault plane corrugations and its relation to crustal deformation processes like serpentinization.
2) Oceanography: An overview of what is known and what remains unknown about paleo oceanography in the Fram Strait was presented. Major unknowns were regarding the extent of a Miocene ice-sheet in the Barents Sea; the time of submergence of the Hovgård ridge; the faith of condensed depositional periods or hiatus during the Oligocene/Miocene in the Arctic, and the timing of isolation of the Arctic Ocean from the Atlantic . for a concurrent IODP drilling proposal focusing on areas on the East Greenland margin and the western flank of the Knipovich Ridge was also discussed for identifying potential overlapping themes with Fram Strait proposal.
3) Sedimentology: A summary of key aspects of sedimentation at formerly glaciated margins and extent towards the continental slopes was provided. Differences in the morphology of the shelf break at high latitudes compared to lower latitude were presented. The interaction between tectonism and sedimentation in the region was touched upon. For example, Early Cenozoic tectonic regimes were affected by glacial erosion and lithospheric adjustments. Main questions in this aspect are related to the timing of ocean circulation,onset of the deposition of large contourite drifts and the detailed age control on the oceanic circulation. In addition, a study form the Kveithola Trough area was presented to illustrate how the study of mineral transports (illite, kaolinite, chlorine, smectite) can help at reconstructing paleoenvironemnts. The Fram Strait is an extremely important region due to the climate sensitivity of the region and may hold records of unique climate events in the past. The timing of the onset of past glacial events are still unknown.
4) Crustal deformation, rock-water interactions: aspects like spreading symmetry and asymmetry, serpentinization at slow vs. ultra-slow spreading ridges were presented. The kind of fluids generated during serpentinization and potential minerals that could help to trace back the presence of serpentinization-related fluids were discussed. One of the main hypothesis for the proposed drilling is that shallow fluid flow systems and gas hydrates may be sustained also in regions that are not rich in organic matter, thanks to crustal deformation processes like serpentinization.
5) Deep biosphere: Main focus of this talk was a recently published study which presents evidence for deep (>1km) microbial activity based on IODP drilling data. Another key knowledge from the study was the ability of microbes to generate methane with a heavy carbon isotope (i.e., it appears as thermogenic), which can mislead isotope analysis for identifying the origin of methane.

6) Gas hydrate and methane seepage related geomorphology: A model was presented for explaining formation of seabed morphologies known as pockmarks, related to dynamics in the gas hydrate and fluid flow systems. The novelty of the model is the concept of hydrate dissolution as opposed to hydrate dissociation to explain extensive cavities (up 500-800 m in diameter) formed in fine-grained sediments in margins like offshore Nigeria and the Fram Strait. One key issue raised was the awareness of that a 500 m diameter pockmarks in these settings is highly heterogeneous in space and time. Having boreholes separated a few tens of meters inside one pockmarks will provide large variability in the results and measurements of the physical properties of the sediments. To fully understand the evolution of a single pockmark, many nearby boreholes might be necessary. Key state of the art technology (CPTu piezocone) to investigate the geomechanical properties of "deep" sediments were discussed. Is it possible to track back in time morphological/mineralogical footprints of such dynamic systems since their onset?

A second set of talks was dedicated to discussing drilling challenges in shallow gas and hydrate systems:

1) We heard recommendations and shared experience from experts in drilling through so called gas chimneys, bottom simulating reflections, and gas hydrate systems. Hydrates are only part of a large and complex system that must be understood and investigated in terms of the physical/geological mechanisms in place. We received positive feedback on the pre-proposal, particularly on the amount and quality of data available as site surveys to build on a drilling plan. However, detailed analysis of safe drilling sites is a requirement. Selection of as many alternate sites as possible is key to avoid risks of drilling through shallow gas. The full-proposal must focus on designing alternate drilling sites where key hypotheses can be tested. In addition, the importance of LWD while drilling through gassy sediments was discussed.
2) Insights from the recently concluded IODP drilling of gas hydrates offshore New Zealand (Ex.372) was presented, which includedchallenges and benefits of different sampling/coring techniques for sampling gas and dealing with hydrates in the sediments. The success rate of pressure-coring tools onboard JR was about 60 %. There are also challenges involved in keeping the original pressure in the pressure core sample. This leads to unreliable measurements of gas hydrate volumes. Contamination of pore-fluid samples by hydrate dissociation is another major challenge. The pressure coring equipment onboard JR is useful for estimating the volume of gas within sediments/hydrates but can't be used for any other analyses. The PCATS system by GeoTek could be worth considering. Analysis of noble gases could provide clues to the origin of the gases trapped in hydrates.
3) Geomechanical properties of gas hydrate bearing sediment and how can these be investigated in borehole and deep samples were briefly discussed (radial shear strength vs. tri-axial tests in the labs). One of the main messages was that the effect of hydrates on the shear strength of sediments has been done only in the lab using artificial hydrate in porous sediments. Investigating such an effect on fine-grained fracture sediments remains less investigated.

The second day we had a final session with talks focused on proxies for reconstructing paleo fluid emissions (mainly methane):

1) Dating methane-derived authigenic carbonates (MDAC): advanced methods for cleaning and selecting ideal samples for dating of carbonate crusts were presented. A line fitting approach for dealing with uncertainties and randomness in the age of samples was discussed. U-Th dating is an efficient method but challenges exist related to disturbances in the corrections due to the presence of pyrite, hematite. Fluctuations in the methane flux can be reconstructed by looking at the chemistry and age of MDAC samples.
2) Salinity and pore-water geochemistry is a powerful tool to trace spatial and temporal variations in the methane-sulfate transition zone, which can provide clues to the intensity of methane flux. Chlorinity of pore-water samples can provide information about hydrate dissociation in the past.
3) Dating of sediments can be challenging if no conventional proxies like foraminifera are available in the sediment sample. Dating of MDAC does not necessarily provide the age of the stratigraphic horizon they are located on. Abnormal negative excursions in d13C of microbial (foraminifera tests) and MDAC carbonates can be used for inferring paleo SMTZ, that can be often linked to seepage events. The main challenge is that the forams also get authigenic carbonate in their skeleton compromising the dates of the original time period they lived in. It was suggested to focus the drilling in only one pockmark to aim at testing difference hypotheses related to the formation of such features.

We had a final talk by a representative of IODP who is the expedition project manager for JR. An overview of the tools and technical possibilities onboard JR was presented. Similarly, the process of IODP proposal review and evaluation was discussed. Regarding the timeline of the drilling project, although it is common to go for a full 8 weeks project plan, it is not a requirement and it is better to ensure that enough time is dedicated to achieve the objectives of a focused plan than trying to fit an extensive plan and end up with insufficient time to achieve good results. Our proposal idea will most likely go through an additional evaluation phase by the EPSP (Environmental Protection and Safety Panel) for reviewing the safety issues.

2.5 Outcomes from the discussion session

The discussion session was done in three groups (annex 3). Each group had a specific topic assigned. About 10 participants per group (distributed based on their background and interests) were elaborating on key tasks they were assigned. The outcome of each discussion group was presented to all participants and the combined discussions continued until the conclusion of the workshop. Main conclusions drawn from the discussions are:

- The main cross disciplinary questions in the current (submitted pre-proposal) proposal will be kept. Key questions/objectives will be improved by inputs from experts across various disciplines. The following experts offered to join in developing the full proposal.
    - Fumio Inagaki , Helge Niemann (not in the workshop for involved in the proposal), Stephan Ker (?), will contribute to the deep biosphere part.
    - Jochen Knies, Tine Rasmussen, and Renata Lucchi will contribute to the paleo climate component;
    - Javier Escartin, Carmen Gaina, and Joel Johnson will contribute to the tectonic and crustal processes component.

- The selection of alternative sites (as many as possible) will be done carefully using high-resolution 3D seismic data with strong focus on cross-disciplinary questions.
- From the technical point of view, the general agreement was that this has the potential to be considered an expensive but exciting and highly relevant scientific project by the evaluation panel. When writing the full proposal, the general agreement is to focus on the science (including all the technology needed despite the cost and potential technical obstacles). Main technical aspects that remain to be decided based on final objectives are:

  * Use of LWD vs. WLT: **LWD expensive but necessary** considering safety issues in drilling through gassy sediments (no blind-science!) and for investigation of mechanical properties of the sediments and the near-surface systems (stress field, fractures, P and shear wave velocities). Multiple holes would be necessary at a single site for separate logging and sampling campaigns. This is in fact less time consuming than re-entering a drilled hole. LWD can include caliper, gamma-ray, acoustic, density, pressure, and temperature logging tools. A major disadvantage is the cost of LWD and the logging and sampling are generally done in two closely spaced (15-20 m apart) holes. This implies that the logs may not be entirely representative of the sampled sediments in such a dynamic system. **WLT can be useful for magnetic** susceptibility measurements, sonic, vertical seismic profiling (VSP) (for getting accurate time-depth relationship for integrating with seismic data). There is possibility to do walk-away VSP, but this could be time consuming and would require another vessel. Drilling through the BSR is generally not a problem if the free gas trapped under the BSR is not structurally trapped. Selecting an alternate sites on an inactive chimney can avoid the risk factor of drilling through an active one.*Use of pressure coring tools (PCS): Absolutely necessary for quantification of gas trapped in hydrates, understanding the methane solubility profile, and safe sampling of gassy sediments. It is also important for other measurements like chlorinity, salinity, resistivity, as these parameters will be altered if hydrates dissociate. The use of the pressure core system onboard JR may be good enough for the purpose of this proposal, because the main objective is not to investigate/quantify gas hydrates.
  *Use of PCTB: There is possibility to use advanced pressure-coring tools such as PCTB developed by JAMSTEC for IODP expeditions and PCATS lab by GeoTek A combination of PCTB and PCATS is useful for conducting measurements and sampling such as XR, velocity, degassing at in-situ conditions. GeoTek also offers transportation facility for pressure cores. However, this is very expensive service and external funding have to be secured to implement this program.
  *Selection of coring tools: JR generally uses Advanced Piston Corer (APC) for sampling the first few hundred meters. However, this might be difficult in sediments with carbonate accretions and an early switch to Extended Coring Barrel (XCB) might be required at the planned sites on the Vestnesa and Svyatogor ridges. In addition, in sediments with gas hydrates and dissolved gas, XCB might be a safer option. Continuous temperature measurement tools such as APCT3 (can used with APC) and SET-SETP (separate from the XCB bottom hole assembly) is also an important requirement while drilling.
  *Safety and environment: While selecting drilling sites avoid structurally isolated shallow gas accumulations. Carbonate accretion can create problems for APC. Shallow sediments at methane vents generally contain toxic H2S gas which can be a hazard once cores are taken onboard. Other safety aspects that need consideration are sea-ice conditions, weather patterns, bottom currents and the seasonal window for safe expedition. From

the ecological point of view, sites with seabed chemosynthetic communities should be avoided.
-Proxies and approaches: A table was provided (annex 4) with key proxies discussed and applications. Special equipment has to be carefully prepared to work onboard with biological samples. The importance of measuring bicarbonates and hydrogen in addition to methane for understanding the carbon cycle was pointed out. Radioactive tracers are highly important (?).

2.5 Action plan

- Once the feedback for the pre-proposal is received, a meeting will be organized between main proponents to discuss the comments from the Science Evaluation Panel and finalize key objectives as well as selection of alternative sites.
- Propose a meeting with LWD experts; including representative from the service companies providing the tools (Schlumberger, GeoTek?) to gain a clear and realistic view of the possibilities.
- Work on a detailed spreadsheet with the indication of intervals where pressure or piston cores will be collected (if they will be).
- Work on annexes with information about technical challenges like climate conditions in the area (ice, weather, seabed ecology, mammals, etc).
- Use key IODP successful proposals as guidance (e.g., Cascadia margin, New Zealand, etc.)

3. Budget

We received 14.900 euros from ECORD for conducting the workshop. The grant was used to cover:

1- Flights (and additional travel expenses like taxis) for 12 participants including 2 traveling from the USA. Only 8 have requested reimbursement to this date (04.07.18). The flight tickets for the two USA participants were more expensive than expected since there were issues with connections (we are discussing with the agency to compensate for some extra charges). We think that tickets would have been cheaper if booked more in advance. This includes 2 early career scientist.
2- 3-nights hotel with Wi-Fi and breakfast for 18 participants. This includes early career scientists and some non-speaker participants.
3- Lunch, 2 coffee breaks, fruits and snacks twice a day for the two days of workshop (for all the participants)
4- A workshop dinner with most of the participants (ca. 33) at Bardus Bistrau.

To date the expenses add to a total of ca. 14153 euros. We still need to receive the reimbursement request of 3 participants. We would like to point out that in the possible (but unlikely) scenario in which the total expenses extend slightly above the 14.900 euros received by ECORD we will pay the difference from an internal project at UiT.

Magellan Workshop 2018			
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Beskrivelse	**Beløp (NOK)**	**Cost (Euros) ***	**comment**
Flight J. Johnson	17188,2	1820,057032	booked by us to avoid them refunding problems
Flight Tim Collett	19472,6	2061,951954	booked by us to avoid them refunding problems
Lunsj og kaffe 4/6	6 659,00	705,1209422	
Lunsj og kaffe 5/6	9 041,00	957,350719	
Hotellopphold 3.-6. juni, Skansen hotell	31 550,00	3340,82681	hottel provided for 20 participants
Reiseutgifter Javier Escartin	5 341,62	565,6236863	
Reiseutgifter Renata Lucchi	6 248,71	661,6753691	
Reiseutgifter Mark Zindorf	5 979,21	633,138037	early career who got full cover of travel expenses
Reiseutgifter Wei-Li Hong	3 800,20	402,4028539	early career who got full cover of travel expenses (speaker)
Reiseutgifter Fumio	7 742,00	819,7997198	Includes flight ticket Aberden-tromsø-helsinski and taxis in tromsø.
Reiseutgifter Katja Heeschen	3 439,52	364,2104795	Tim payed an aditional ticket; missed connecton (egency mistake)
Refusjon flybillett Tim Collett OSL-TOS	2 644,60	280,0364685	
Workssho dinner Bardus Bistrau	14 555,00	1541,227709	
Totale kostnader pr 26.06.2018	**133 661,66**	14153,42178	

Figure 1: Budget as it is until the 04.07.18. The budget is also provided as excel file.

4. Final remarks

We are satisfied with the outcome of the workshop. Keeping the time schedule right as planned was challenging because all the speakers had significant content to share. In addition, large number of questions by the audience to the speakers resulted in longer sessions that panned. Nevertheless, we completed the full program. One of the speakers, Michael Riedel, got stocked at Hamburg airport and decided to cancel the whole trip to Tromsø. He sent his presentation and Tim Collette presented key points during the discussion session to a few of us. The input from the participants was substantial and will hopefully open doors of cooperation beyond the writing of the IODP proposal. We are grateful with ECORD for supporting and having this initiative of encouraging organization of this series of international workshops.

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Temporal evolution of Arctic gas hydrate and methane seepage systems

Day 1 04/06/18			
Welcoming and introduction			
09:00-09:20	Karin Andreassen	Welcoming by CAGE	CAGE, UiT
09:20-09:40	Andreia Plaza-Faverola	Workshop motivation - seepage systems off west-Svalbard	CAGE, UiT
Cross-disciplinary perspective - Earth systems in the Fram Strait			
09:40-10:00	Carmen Gaina	A plate kinematic model for the opening of the Fram Strait: Constraints and consequences	CEED, UiO
10:00-10:20	Javier Escartín	Faulting at ultra-slow spreading ridges	IPGP
Coffee break			
10:40-11:00	Jochen Knies	Paleo-oceanography/climate history	NGU, CAGE
11:00-11:20	Jan Sverre Laberg	Sedimentation at formerly glaciated margins and beyond	UiT
11:20-11:40	Renata Lucchi	Sedimentological reconstruction on climatically dominated sedimentary processes offshore west-Svalbard	OGS
Lunch			
13:00-13:20	Joel Johnson	Water-Rock Reactions: Tracking Serpentinization at Mid-Ocean Ridges	University of New Hampshire
13:20-13:40	Fumio Inagaki	Deep-biosphere methane production stimulated by geosphere-biosphere interactions	Jamstec
13:40-14:00	Nabil Sultan	Gas-hydrate pockmark formation and evolution: insights from deep water Nigeria	Ifremer
14:00-15:00	**Plenary: key cross-disciplinary questions/key sites**		
Coffee break			
Strategies for drilling into hydrates and shallow gas			
15:20-15:40	Tim Collett	Integration of scientific drilling technologies and operational considerations associated with drilling chimney related features	USGS
15:40-16:00	Katja Heeschen	Gas hydrate imprints/Pressure coring for gas hydrates	Potsdam Uni.
16:00-16:20	Michael Riedel	Gas hydrates in fractures – working with fracture data	Geomar
Dinner at Bardus Bistro (18:00)			
Day2 05/06/18			
Proxies for methane seepage reconstruction			
09:00-09:20	Diana Sahy	Review of methods for geochronology	BGS
09:20-09:40	Wei-Li Hong	Using porewater geochemistry to indicate fluid sources and sediment processes	NGU
09:40-10:00	Aivo Lepland	Methane derived authigenic carbonates	NGU, CAGE

10:00-10:20	Giuliana Panieri	Benefit and limitation of using foraminifera to track past methane emissions in the Arctic	CAGE, UiT
Coffee break			
11:00-11:20	Leah Levay	Downhole tools and shipboard lab capabilities	Texas A&M University
11:20-12:00	**Group discussion – objectives, approaches, challenges**		
Lunch			
13:00-15:00	**Group discussion – continuation**		
Coffee break			
15:20-16:30	**Summary and conclusions**		

Guidance for the discussion:

Day 1 (14:00-15:00) *Plenary about current/additional hypotheses*

- Are the hypotheses inline with the challenges outlined in "The International Ocean Discovery Program Science Plan for 2013-2023"?
- What are additional key questions to accomplish a fully comprehensive scientific drilling proposal?
- How does this proposal relates to other ODP/IODP proposals?

Day 2 (11:20-15:20) *Group discussion about objectives, approaches, challenges (three thematic groups)*

Group 1: Cross-disciplinary strategy

- Identification of regional processes/scientific questions to be addressed in this region
- New potential sites (keeping in mind the availability of side surveys)
- Drilling/Sampling strategy

Group 2: Objective, risks and challenges in drilling through shallow gas and hydrates

- Safety requirements (need for LWD?)
- Types of logs
- Pressure coring (feasible?)
- Drilling/Sampling strategy

Group 3: Proxies

- Proxies for reconstructing methane emissions
- Proxies for reconstructing paleo oceanography/paleo climate
- Dating
- Drilling/Sampling strategy

The idea is that each group chooses one or two leaders to expose key points to everybody at the end on the session. To make the exercise realistic every group will get the IODP spreading sheet to estimate time for the proposed drilling plan.