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R/V Kronprins Haakon

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Longyearbyen-Longyearbyen

CAGE21-5 Cruise Report

Test of offshore instrumentation for in-situ sediment pressure measurements, west-Svalbard continental margin

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2. Introduction and narrative

The SEAMSTRESS project is investigating how the stress generated by regional processes in Arctic margins (e.g., mid-ocean ridge spreading, glacial advance and retreat, tides, gravitational forcing) affect pore fluid pressure and seepage.

Cruise CAGE21-5 had as main objective to test the Marchetti dilatometer [*D Marchetti*, 2018; *S Marchetti*, 2015] for in-situ measurements of horizontal pressure at various sites along the continental margins, where methane seepage passes from being highly active to inactive. To push the dilatometer into the sediment we had Geomil's Manta-200 CPT (Cone Penetration Test) tool (https://www.geomil.com/products/manta-200) operated by Marine Sampling Holland (https://www.marinesamplingholland.nl/). We aimed at measuring in-situ sediment properties (e.g., horizontal pressure, shear strength, pore fluid pressure, temperature) that we are lacking to advance our understanding of the spatial and temporal evolution of seafloor seepage at continental margins.

We rented, through a tender, instrumentation from Marine Sampling Holland (MSH) and the Marchetti Lab for conducting such measurements. The instrumentation consisted of a Cone Penetration Test (CPT) tool and sensors (a dilatometer and a cone penetrometer). We used the Manta-200 CPT, a ca. 12 tones iron structure with a motor to push the instrument rods down to 20 m into the sediment. Information about the Manta200 was provided to the ship administration in advance. Due to the weight of the instrument it was assed that deployment could be done with one of the trawling winches.

The CPT work was planned for the day shift, and heat flow surveys together with acoustic surveys were planned for the night shift.

Deployment of the Manta200 was successfully tested in the fjord at 67 m water depth after the toolbox meeting with the ship crew, the operators of the instrumentation and the chief scientist. This test went well. The CPT penetrated 1.5 m of sediment and we collected everything back.

The same day in the evening, we sailed offshore towards the first site of investigation. We arrived on site by 3 am. We collected 2 chirp profiles and did one deployment of UiT's heat flow lances (the crew spent 1.5 hours fixing an issue with the winch wires). The measurement was aborted after 10 minutes because it was time to transit to the site for the first CPT (communication was a factor here, since we could have perfectly finished the measurement).

We arrived on site at 890 m water depth at ca. 8:30 am on Monday 25/10. We started the deployment of Manta200. Preparation went well and deployment started well until the operators of the tool reported a short circuit in the instrument. We started to bring the instrument back on board from ca. 700 m. At ca. 440 m we needed to stop the ascend of the instrument because we noticed that the winch wire was entangled with itself and with cables from the instrument. We spent the rest of the day trying to untangle the wire without success. One of the instrument cables was cut but it did not help. The crew tried separating wire segments from the entanglement, but it did not help sufficiently. We started sailing at 1-1.5 knots towards 430 m water depth to aim at placing Manta on the bottom, release some tension, and try again heaving the winches. This did not work either. We realized that the most likely scenario was that all the wires (2 winch wire segments, an umbilical cable and a dyneema rope) were all entangled and Manta was stocked. The decision was to cut all the wires and allow Manta to gently lay at the seafloor. This was done on the 27/10. In the evening of the 27 we conducted an acoustic survey (chirp and ADCP data) over the faulted structures north of the Knipovich Ridge northernmost corner. We stopped on the 28/10 at ca. 15:00 when the weather got rough and we decided to sail back to Longyearbyen.

Simultaneously, we spent the 26-29 contacting ship agencies to identify a ship that could help retrieving the instrumentation back. Such operation turns out to be extremely expensive and the cost of it is comparable to the cost of a new Manta200. After discussing the situation with Ægirs ROV pilot, the captain expressed that it would be feasible to retrieve the instrument with R/V KH having the ROV on board to assist on cutting wires and reducing the total weight of the item to be lifted back on deck. A retrieval operation may be coordinated following an ROV cruise in early December or in March 2022.

All the cruise participants left the ship on the 29/10. The cruise was terminated one week earlier than planned.

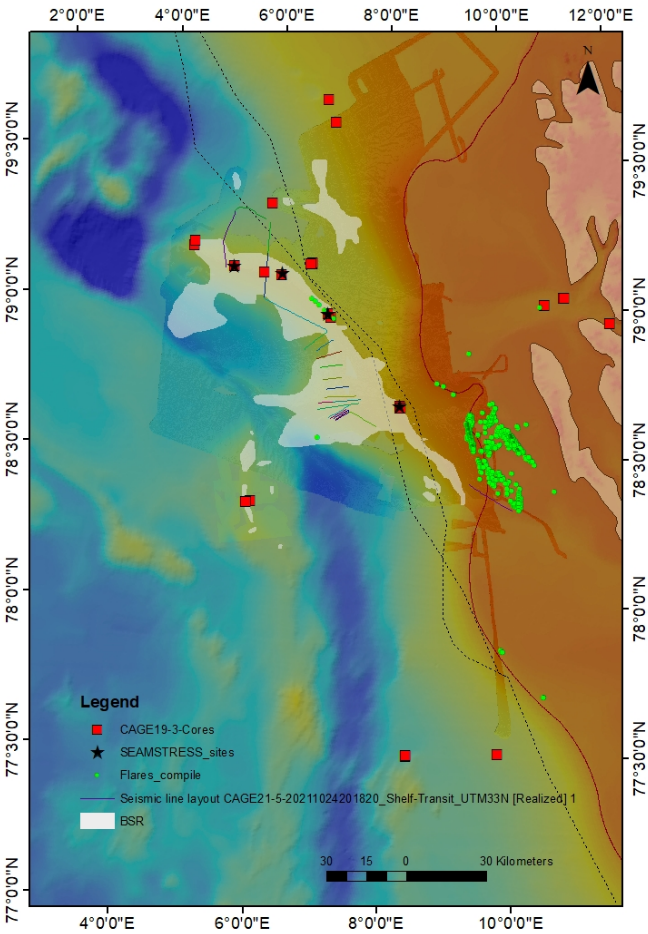

Figure 1: Study area with outline of chirp profiles collected during the cruise. The CPT lost occurred when attempting deployment at the easternmost SEAMSTRESS site, west of Prins Karl foreland's seepage area (easternmost black start in the map).

3. Equipment, challenges and data acquired

3.1Marchetti dilatometer

To measure in situ horizontal pressure we wanted to use the Marchetti dilatometer, one of the few if not the only dilatometer tested offshore [*D Marchetti*, 2018; *S Marchetti*, 2015]. This is a ca. 1.5 meter long metal bar with a flat tip and a membrane that inflates and deflates to measure the horizontal pressure of the sediment it penetrated. The pressure measurements are then translated into horizontal stress after processing.

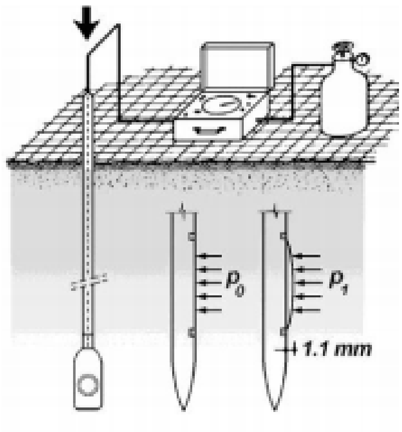

Figure 2: Cartoon of the Marchetti Dilatometer [*D Marchetti*, 2018]

3.2Cone Penetration Test tool

To push the dilatometer into the sediment we wanted to use the Manta-200 CPT, develop by Geomil and operated by Marine Sampling Holland (MSH). Manta-200 is a 11 tones rectangular frame with an hydraulic motor that can push cone penetration tool down to 20 meters into the sediment.

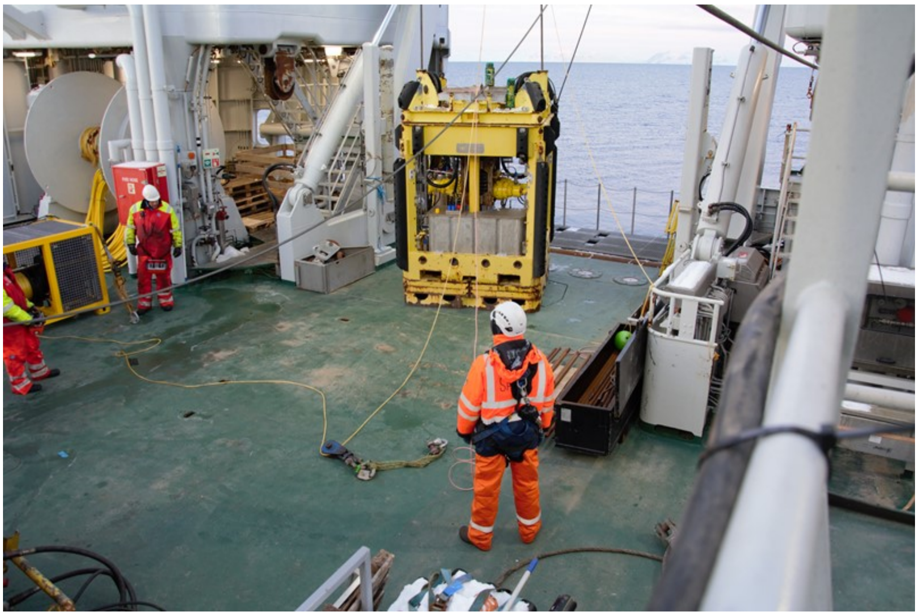

Figure 3: Manta-200 on deck on R/V Kronprins Haakon in preparation for deployment offshore.

3.3Manta-200 deployment technicalities

The Manta-200 has deployed using trawling winch 20 from the A-Frame. The end of the wire was fixed to the A-frame. The wire continued into the Manta frame towards a second block at the A-Frame and back to the winch on deck.

Why the wire got entangled with the rope that kept tension into the rods is still uncertain. It is also not clear whether all the wires and cables were part of the entanglement.

A few observations may help understanding what caused the problem.

1- Before deployment, the crew remade the braiding of the wire end that was fixed at the a-frame. Is there some twisting effect on the wire that may have trigger entanglement during heaving?
2- The currents in the Fram Strait are complex. Can strong currents favor rotation of the entire Manta and entanglement of all the cables?
3- The short circuit that appeared at 700 m indicate that the umbilical cable had problems. Is this an indication that all the cables and wires where part of the entanglement?
4- Can tear and wear on the wire lead to damaging of wire threats and further entanglement?

Comments from Manta200 operators: the wire experienced twisting and shortening due to having a fixed point at the A-frame. This behavior of the wire resulted into loops that got entangled.

Comments from the ship crew: too much lag in the umbilical cables lead to loops that entangled themselves with the winch wire.

3.4Kongsberg SBP300 Sub-bottom profiler

The data were recorded using the hull-mounted Kongsberg SBP300 MK2 and software system version 1.6.6. The maximum depth of penetration is 100ms TWT (approximately 30 metres) over contourite drifts (Figure 3). The chirp pulse form is 'linear chirp up' with 30ms sweep length and frequencies between 2.5 and 7 kHz. The transmit power starts with a soft setting -30dB and gradually increases (over 2.5 minutes) to -5dB. The ping rate and bottom tracking is externally controlled by the EM302 multibeam system, and varies with depth. Typically at water depth of 1000m a ping interval of 4 seconds is suitable. Sample interval is 48 kHz with an acquisition time window of 500 ms. The vessel velocity is 5-6 knots while surveying and during transits 8 knots. The average trace (along track) interval for a 5 knot survey (ship speed we used) is approximately 10m.

The sweep function from the signal is removed using a matched filter based on autocorrelation of the Klauder wavelet. Gain correction is applied, which corrects for spherical loss of the acoustic pressure wave in the water column. Time variable gain is also applied prior to the logging of the processed sequence. The vertical resolution is 0.15m, using a sound velocity of 1500 m/s, typical of sea water and shallow sediments. The acquisition processing applies the envelope function to the data (instantaneous amplitude) which improves the signal-to-noise ratio. The signal phase of the data is removed and displays positive amplitudes only. This is the standard for interpretation of chirp data. The segy data, output from the Kongsberg acquisition system is in data format 4 byte IEEE float. The same file format is used while processing in Seismic Unix (SU). Files with the suffix '_UTMXXN' are files output from SU. The XY coordinates are stored in byte positions 73 and 77 and copied to 81 and 85. The data are projected to Universal Transverse Mercator zones (UTM), for which, 31N is the zone used for the data acquired in this survey. The UTM zone number can also be found in byte position 21 (CDP). The data are logged with varying delay recording time (delrt) to reduce file size in acquisition. When required, the data are shifted back to a constant delay recording time in SU. The range of the minimum and maximum time values are expanded, when final processing reveals a partial display of data, with data muted outside of the 500ms acquisition time window.

3.4.1 – Sub-Bottom profile survey and data example

We collected chirp data across faults outcropping north of the Knipovich Ridge northern termination to study the most recent activity in the faults. We observe indications for recent faulting in particular in blocks that may indicate gravitational collapse (figure 3).

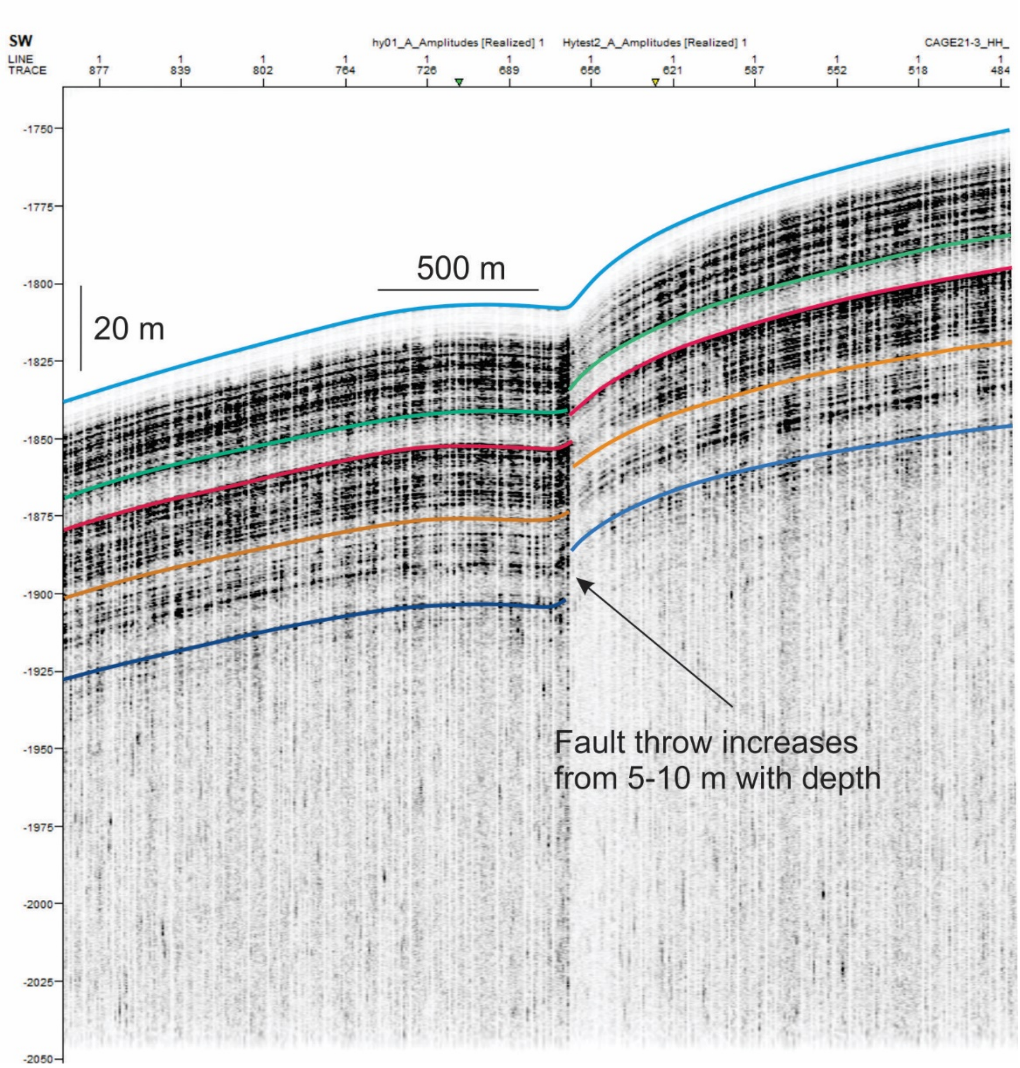

Figure 2: Chirp profile across one of the outcropping faults north of the Knipovich Ridge northern termination.

3.5 Echosounder data

To monitor flares we had the single beam echosounder data on. The ship has an EK80 system. A flare was spotted on one of the pockmarks (believed to be extinct) located north of the Knipovich ridge (e.g., Johnson et al., 2015). See figure 3 for an example of the type of flares identified. This is a very important observation because this area was expected to be inactive in terms of gas release from the seafloor. The release of gas at present day may be a direct indicator of fault reactivation. Seismic signals from the ocean bottom seismometers collected in the summer (SEAMSTRESS cruise CAGE21-3) must be carefully analyzed for the occurrence of micro seismicity and short duration events possibly associated with seafloor gas release.

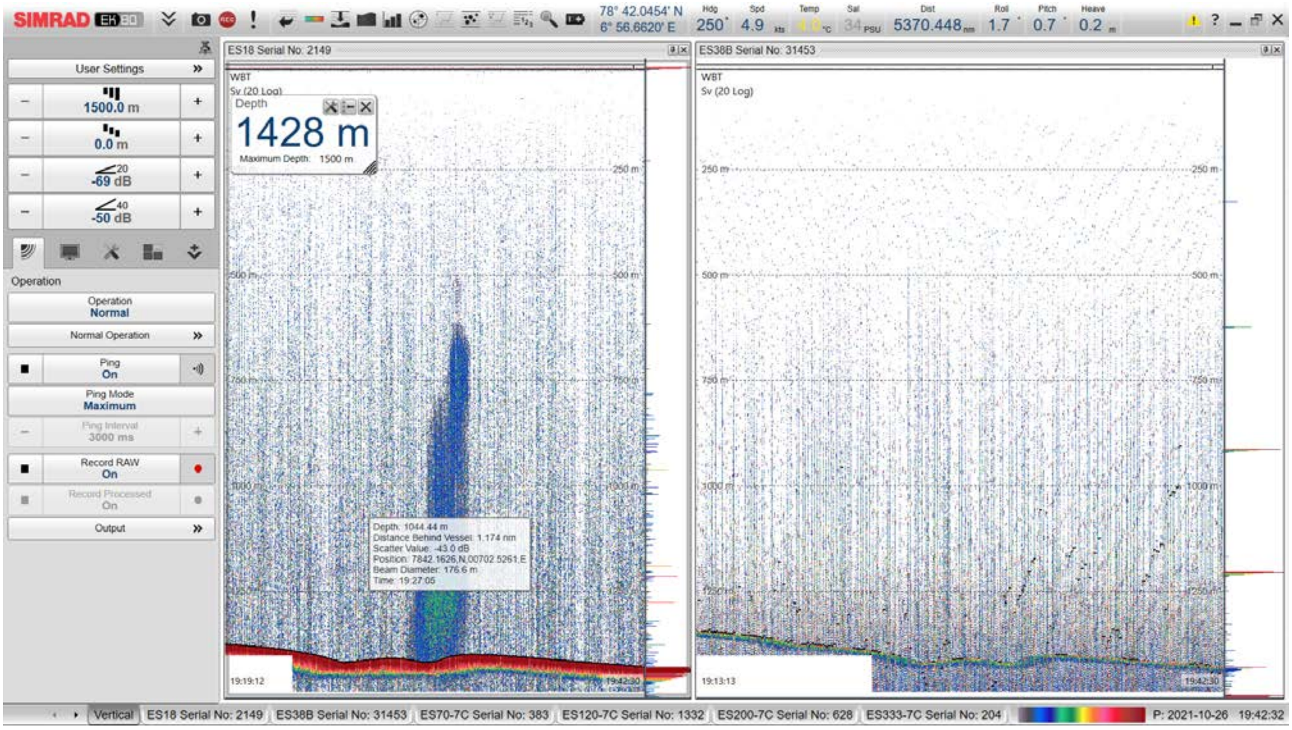

Figure 3: Snap shot from a screen during acquiring of water column acoustic data (from EK80) over the pockmarks north of the Knipovich ridge.

3.6 Current meter

To investigate whether there are distinct patterns of changes in the characteristics of the bottom currents north of the Knipovich ridge area, we recorded ADCP data (we used the 38Khz and the 150Khz frequency ranges). These data needs to be processed.

3.7 Heat flow Probe

To measure the in situ subsurface thermal regime and thermal conductivities of sediments, the FIELAX deep-sea heat flow probe is employed (Figure 6). The probe consists of a series of 22 thermistors and heating elements placed within a sensor string ~6.05 m long. The thermistors are places 0.26 cm apart and is designed for a temperature range of -2 to 60 ^{0}C with a resolution of 1 mK and accuracy of 2 mK after calibration. The sensor string is attached to a strength member, which bears the load while penetrating the sediments. The head section of the heat flow probe consists of data acquisition and power supply units. The whole probe weighs ~1100 kg and is rated for operation up to 6000 meters water depth.

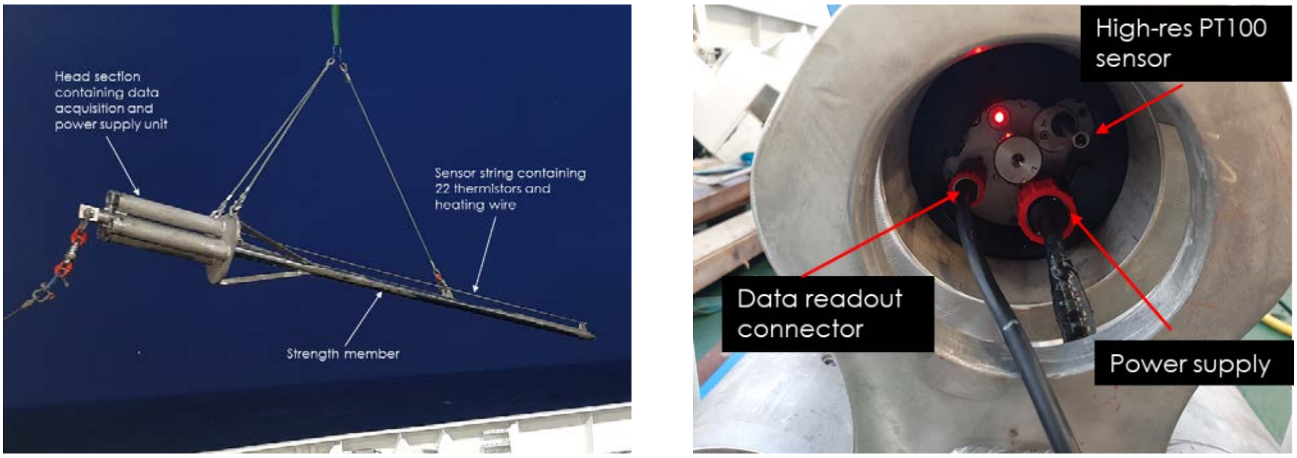

Figure 1: UiT's heat flow probe being deployed from the starboard side of RV Kronprins Haakon (left).Data acquisition unit housed in the head-section of the heat-flow probe(right). Red LED indicates that the acquisition unit is switched on. A blinking LED suggests that the system is recording data.

During CAGE21-5, we were unfortunately not able of conducting the planned survey. We inserted the probe in only one site and recorded for only 10 minutes. Time, complications with the CPT instrumentation and bad weather did not make the planned survey possible.

Acknowledgments

CAGE21-5 cruise on board R/V Kronprins Haakon was part of the SEAMSTRESS project – Tectonic stress effects on Arctic methane seepage (2019-2023). The project and therefor the cruise is primarily funded by the Tromsø Research Foundation (TFS) and the Research Council of Norway (RCN project number 287865) through their starting grant schemes. The project and cruises are also supported by the Department of Geosciences and the Center for Arctic gas hydrates, environment and climate at UiT – The Arctic University of Norway.

The cruise entailed conduction of a high-risk high gain experiment, which was not possible to realize due to technical challenges. However, there was significant effort and hard work invested in the preparation for such expedition. We are grateful to the Kronprins Haakon cruise committee, the department of Geosciences and the Faculty of Science and Technology at UiT for supporting our project and assigning us cruise time for the expedition. Equipment for the experiment was provided by Marine Sampling Holland (MSH) thanks to a timely tender process by UiT's administration. Special thanks to Tom Lune (NGI) for given expert advice on the design of the CPT-Dilatometer experiment and for pointing out critical aspects of the interpretation of dilatometer data. The preliminary sites for penetration of the CPT and dilatometer were chosen based on penetration and recovery of: 1- calypso cores and piezometer data during CAGE-Seamstress cruise CAGE19-3; 2- penetration of the heat flow lance during SEAMSTRESS cruise CAGE20-6. The scientific objectives builds up from seismic and bathymetry data collected during cage cruises CAGE13-7, CAGE14-5, CAGE15-6, CAGE17-

5, CAGE20-5. Seafloor imagery by the AKMA project (grant number 287869) from nearby areas to the SEAMSTRESS sites were helpful, when available, for inferring the type of seafloor to be penetrated. Special thanks to the Captain Johnny Peder Hansen and his crew for their time invested in attempting this technically challenging experiment in the Arctic.

Appendix - Cruise logs

Table A1 – Stations

Location	Line ID	Date	Time (UTC) START	Lat. [N] Long. [E] START	Time (UTC) STOP	Lat. [N] Long. [E] STOP	Pulse mode	Shot Rate (HZ)	Ship Speed (kn)	Comments
Vestnesa Ridge	CAGE21-5-KH-SBP1-CHIRP	25.10	00:37	78400°66.000' 7209°18.000'	01:04	78385°13.000' 7097°32.000'				
Vestnesa Ridge	CAGE21-5-KH-SBP2-CHIRP	25.10	01:10	78387°92.000' 7094°29.000'	01:38:49	78403°85.000' 7209°62.000'				
Vestnesa Ridge	CAGE21-5-KH-SBP3-CHIRP	26.10	13:30	78°40.426' 07°19.027'	14:02	78°38.660' 07°05.775'				MB stopped after this line, running chirp only
Vestnesa Ridge	CAGE21-5-KH-SBP4-CHIRP	26.10	14:16	78°38.790' 07°03.389'	14:59	78°41.086' 07°21.668'				
Vestnesa Ridge	CAGE21-5-KH-SBP5-CHIRP	26.10	15:10	78°38.957' 07°10.854'	16:03	78°39.924' 07°29.473'				
Vestnesa Ridge	CAGE21-5-KH-SBP6-CHIRP	26.10	16:24	78°40.608' 06°51.670'	17:50	78°42.072' 07°32.690'				
Vestnesa Ridge	CAGE21-5-KH-SBP7-CHIRP	26.10	18:04	78°42.800' 07°33.658'	19:58	78°41.933' 06°50.030'				Flare sighted
Vestnesa Ridge	CAGE21-5-KH-SBP8-CHIRP	26.10	20:26	78°43.139' 07°00.860'	21:36	78°43.904' 07°31.027'				
Vestnesa Ridge	CAGE21-5-KH-SBP9-CHIRP	26.10	22:23	78°45.350' 07°19.212'	23:13	78°44.761' 06°58.301'				

Vestnesa Ridge	CAGE21-5-KH-SBP10-CHIRP	26.10	23:40	78°46.660' 06°55.586'	00:25 +1 day	78°47.354' 07°15.885'
Vestnesa Ridge	CAGE21-5-KH-SBP11-CHIRP	27.10	00:58	78°49.756' 07°13.521'	01:53	78°49.030' 06°51.808'
Vestnesa Ridge	CAGE21-5-KH-SBP12-CHIRP	27.10	02:24	78°50.782' 06°47.741'	03:18	78°52.584' 07°12.732'
Vestnesa Ridge	CAGE21-5-KH-SBP13-CHIRP	27.10	03:51	78°54.611' 07°03.599'	04:36	78°52.314' 06°46.171'
Vestnesa Ridge	CAGE21-5-KH-SBP14-CHIRP	27.10	05:08	78°52.637' 06°34.538'	06:15	78°56.232' 06°56.785'
Vestnesa Ridge	CAGE21-5-KH-SBP15-CHIRP	27.10	09:07	79°02.676' 05°49.400'	11:54	79°17.825' 05°51.846'
Vestnesa Ridge	CAGE21-5-KH-SBP16-CHIRP	27.10	13:00	79°19.116' 05°12.709'	13:56	79°14.171' 05°04.131'

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Marchetti, D. (2018), Dilatometer and Seismic Dilatometer Testing Offshore: Available Experience and New Developments, *Geotechnical Testing Journal*, *41*(5), 967-977.

Marchetti, S. (2015), Flat dilatometer (DMT). Applications and recent developments, paper presented at Proceedings of the Indian Geotechnical Conference, Pune, India.