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Reports on Polar and Marine Research

The Expedition PS115/1 of the Research Vessel POLARSTERN to Greenland Sea and Wandel Sea in 2018

Edited by

Volkmar Damm

with contributions of the participants

HELMHOLTZ
GEMEINSCHAFT

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Titel: Das 3.000 m lange seismische Streamerkabel wird zu Wasser gelassen (Foto: Dr. Thomas Funck/GEUS Kopenhagen)

Cover: Deploying the 3,000 m long seismic streamer cable (Photo: Dr. Thomas Funck/GEUS Copenhagen)

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Tromsø - Longyearbyen

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CONTENTS

Appendix

1. ÜBERBLICK UND FAHRTVERLAUF

Volkmar Damm BGR

Die Expedition PS115/1 startete am 5. August 2018 in Tromsø (Norwegen) und endete am 3. September 2018 in Longyearbyen (Spitzbergen; s. Abb. 1.1).

Mit dieser Reise von *Polarstern* wurden im Rahmen des BGR-Projekts GREENMATE multidisziplinäre geowissenschaftliche Forschungsarbeiten durchgeführt, die zu einem besseren Verständnis der geologischen Entwicklung des Europäischen Nordmeeres und der Schelfgebiete Nordost- und Nordgrönlands führen sollen. Den Schwerpunkt bildeten einerseits marine geophysikalische Untersuchungen mittels seismischer, magnetischer, gravimetrischer und geothermischer Verfahren und andererseits geologische Beprobungsarbeiten unter Einsatz von Schwerelot, Kastengreifer, Multicorer und Dredge. Die Arbeiten zur Beprobung mariner Schelfsedimente wurden in enger Abstimmung mit der Nebennutzergruppe des GEOMAR geplant und durchgeführt. Das Probenmaterial ist Grundlage für die geplanten Arbeiten zur Rekonstruktion der Paläoumwelt- und Paläoklimaentwicklung der jüngeren geologischen Geschichte im Rahmen des Projekts ECHONEG (s. Kapitel 6).

Unter Nutzung der bordeigenen Helikopter wurden die marinen Beprobungen durch geologische Probenahmen an einzelnen küstennahen Lokationen ergänzt.

Weitere wissenschaftliche Projektgruppen nutzten die Reise PS115/1 zur Erfassung mariner Säuger und Seevögel entlang der Fahrtstrecke, um zu Daten über deren statistische Verteilung im Fahrtgebiet als Teilbeitrag für ein langfristig angelegtes Beobachtungsprogramm (Projekt Birds & Mammals – Kapitel 8) zu gelangen, und im Rahmen eines weiteren Langzeitbeobachtungsprogramms zur Erhebung meteorologischer Daten mittels zusätzlicher Radiosondenaufstiege (Projekt YOPP – Kapitel 9) über den Zeitraum der Expedition.

Unerwartete und außergewöhnliche Eisverhältnisse vor der Nordküste Grönlands ermöglichten erstmals die Durchführung reflexionsseismischer Arbeiten mit 3 km langem Streamer bis nördlich von 84°N am Südrand des Morris Jesup Rise und damit in einen Bereich, der speziell für die Ziele des Projekts GREENMATE (Strukturanalyse und Kontinentrandentwicklung Nordgrönland) von besonderem Interesse ist. Die reflexionsseismischen Profile werden hier durch ein 100 km langes refraktionsseismisches Profil ergänzt.

Die weiteren Arbeiten im Expeditionsverlauf konzentrierten sich auf den nördöstlichen und östlichen Schelfbereich Grönlands zwischen 76° N und 82.5°N.

Im Fahrtverlauf wurden insgesamt 2.500 km reflexionsseismische Profile, davon 2.250 km mit 3 km Streamerauslage und 100 km Refraktionsseismik unter Einsatz von 9 Ozeanbodenseismometern erhoben. Begleitend hierzu wurden magnetische und gravimetrische Messdaten aufgezeichnet und an 7 Stationen Wärmestrommessungen vorgenommen.

Im Schelf- und Tiefseebereich wurden 21 geologische Beprobungen durchgeführt, davon am Ostgrönlandrücken an einer Lokation mit Dredge (ca. 200 kg Probenmaterial). Im übrigen Fahrtgebiet wurden an 16 Lokationen mit Schwerelot Sedimentkerne (mit insgesamt ca. 65 m Kernlänge) gewonnen, sowie 12 Sedimentbeprobungen mit Kastengreifer und 6 mit Multicorer vorgenommen. Das vorliegende marine Probenmaterial wird ergänzt durch Sedimentproben, die mit Hilfe der bordeigenen Hubschrauber an 11 Lokationen an Land entnommen wurden.

Zusätzlich konnten ca. 250 kg Festgesteinsproben an insgesamt 21 küstennahen geologischen Aufschlüssen für Altersbestimmungen gewonnen werden.

Alle Forschungsaktivitäten wurden unter Berücksichtigung hoher Umweltstandards zum Schutz mariner Säuger im Einklang mit den Vorgaben der Genehmigungsbehörde durchgeführt. Im Rahmen der Vorsorgemaßnahmen, speziell in Zusammenhang mit den seismischen Messungen, wurden neben externen Walbeobachtern passive hydroakustische Überwachungssysteme und das bordeigene Infrarotdetektionssystem AIMMMS des AWI zur Überwachung der Meeresumwelt eingesetzt.

Tabelle 1.1 gibt einen Überblick über sämtliche Forschungsaktivitäten während PS115/1.

SUMMARY AND ITINERARY

The expedition PS155/1 started on August 5, 2018 in Tromsø (Norway) and ended in Longyearbyen (Spitsbergen) on September 3, 2018 (Fig. 1.1).

In the course of BGR's GREENMATE project the geological development of the European North Atlantic and the northern and north eastern Greenland shelf was analyzed using various marine geophysical methods (seismics, magnetics, gravity, heatflow measurements) and geological sampling (gravity corer, box corer, multi-corer, dredge).

Sampling of marine Shelf sediments was undertaken in close correspondence with co-users from GEOMAR (add-on project ECHONEG – ref. Chapter 6), aiming to reconstruct Holocene paleo environmental and climatic evolution.

Using the ship's helicopters, marine sampling was complemented by onshore sampling operations to extract geological material at selected near coastal locations.

Other scientific project groups used expedition PS115/1 as an opportunity to quantify marine mammals and sea birds along the ship's track for getting data about their statistical distribution in the research area as part of the long-term project (add-on project Birds& Mammals – ref. Chapter 8), and to gather additional meteorological data via radiosondes (add-on Project YOPP - ref. Chapter 9).

Against all expectations, outstanding ice conditions along the northern coast of Greenland enabled us to carry out reflection seismic surveys north of 84°N at the southern tip of Morris Jesup Rise with a 3 km long streamer. Structural data of this particular region of North Greenland is of special importance for BGR's project GREENMATE for reconstructing the continental margin evolution. A 100 km long refraction seismic profile was measured to complement the reflection seismic data.

After completing this, scientific work was concentrated on the northeastern Greenland shelf area between 76°N and 82.5°N.

Over the time of the cruise a total of 2,500 km of reflection seismic profiles (2,250 km measured with 3 km streamer length) and 100 km of refraction seismic profile (using nine ocean bottom seismometers) were measured, accompanied by gravity and magnetic surveys and seven heat flow measurement stations. Along the shelf and deep-sea area 21 geological sampling sites were chosen, with all together one dredge (around 200 kg of sample), 16 gravity cores (total core length 65 m), 12 box corers and 6 multi-corer stations.

Onshore sediment sampling was done at 11 sampling sites. Beside sediment sampling hard rock from near coastal outcrops was collected in a total amount of 250 kg that will be used for age dating.

The entire science programme was carried out under consideration of the highest ecological standards to protect marine mammals and to meet all environmental requirements of the permitting authorities. In addition to external marine mammal observers (MMO) various acoustic monitoring systems and AWI's on board infrared detection system AIMMS monitored any activity of marine mammals in the ships perimeter, especially during seismic operations.

Table 1.1 provides an overview of all scientific activities during expedition PS115/1.

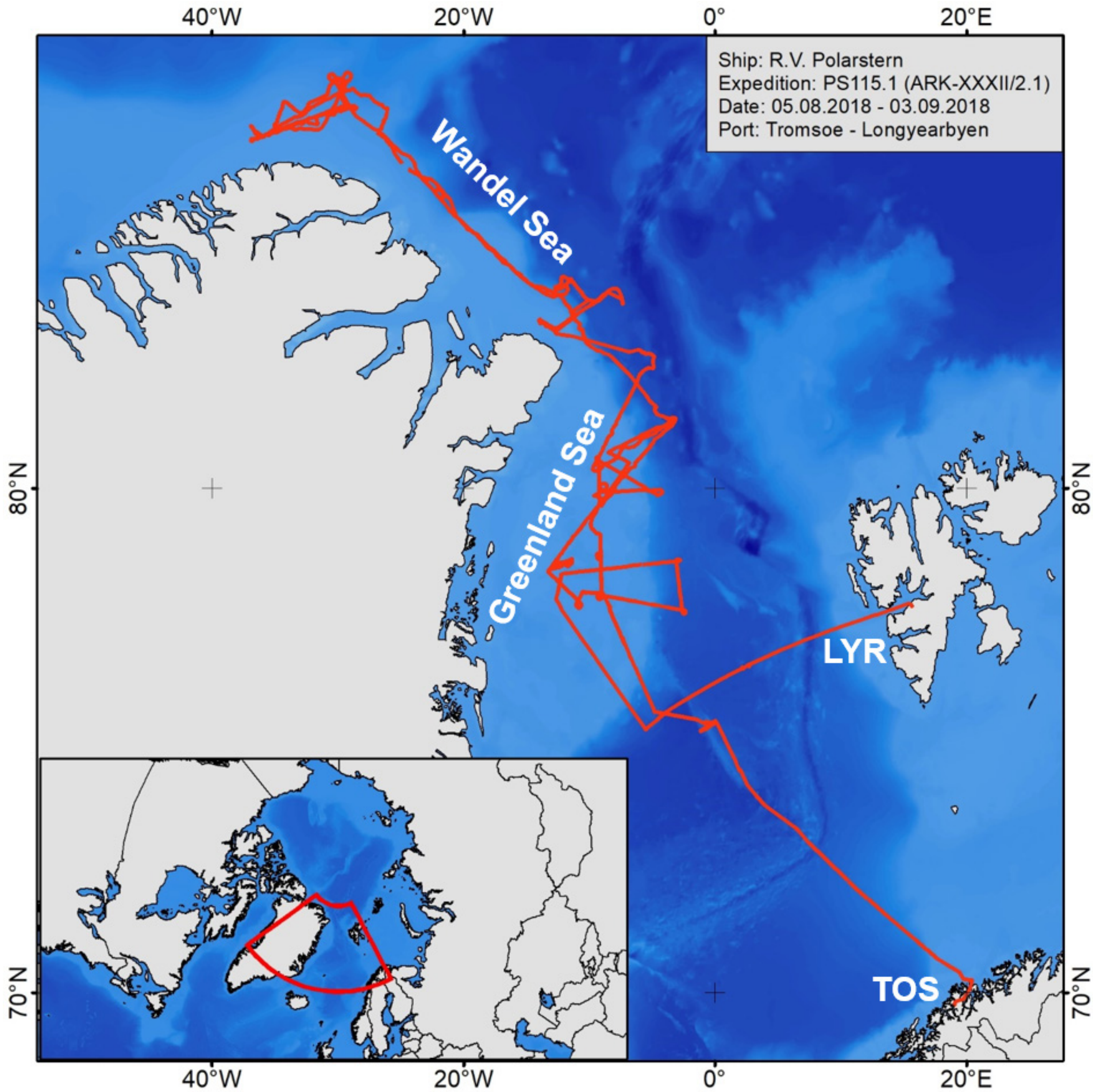

Abb. 1.1: Fahrtverlauf von Polarstern während der Expedition PS155/1 von Tromsø (TOS) nach Longyearbyen (LYR). Der untere Ausschnitt zeigt das Fahrtgebiet in der nördlichen Hemisphäre. Siehe https://doi.pangaea.de/10.1594/PANGAEA.895065 für eine Darstellung des master tracks in Verbindung mit der Stationsliste für PS115/1.

Fig. 1.1: Track of Polarstern during expedition PS115/1 from Tromsø (TOS) to Longyearbyen (LYR). The inlet box indicates the cruising sector in the northern hemisphere. See https://doi.pangaea.de/10.1594/PANGAEA.895065 to display the master track in conjunction with the list of stations for PS115/1.

Tab. 1.1: Itinerary of science activities

Day	Date (2018)	Board time UTC -2h	Station	Scientific activities and events	Weather sky cover, wind state, sea ice
So	05.08.	15:00		departure	cloudy, low winds, 0/1_10
Mo	06.08.			transit	cloudy, medium to strong winds, 0/1_10
Di	07.08.	11:00-13:30		sound velocity profile	cloudy, strong winds, rain, 0/1_10
		13:30-15:00	PS115/1_1-2	releaser test	
Mi	08.08	03:50-07:50	PS115/1_2-1	dregding	sunny, medium winds, 0/1_10
		08:50-09:10	PS115/1_3-1	airgun floatation test	
		14:40-17:20	PS115/1_4-1	heatflow measurement	
		17:40-19:40	PS115/1_4-2	coring with video multi corer	
		21:00-22:30	PS115/1_4-3	coring with gravity corer	
Do	09.08.	11:10-11:45	PS115/1_5-1	coring with gravity corer	partly cloudy, fog patches, low winds, 0/1_10
		11:50-12:20	PS115/1_5-2	coring with video multi corer	
		12:30-12:55	PS115/1_5-3	coring with video multi corer	
		15:05-15:35	PS115/1_6-1	coring with video multi corer	
		15:45-16:05	PS115/1_6-2	coring with gravity corer	
		19:25-19:55	PS115/1_7-1	coring with video multi corer	
		20:00-20:20	PS115/1_7-2	coring with gravity corer	
		21:00-00:00	PS115/1_8-1	deployment of 600m streamer followed by	
Fr	10.08.	00:00-03:40		streamer floatation test	sunny, thin fog, low winds, 2/1_10
		05:09		start of Rx-seismic profile 107.1	
		12:03		end of Rx-seismic profile 107.1	
		12:04		start of Rx-seismic profile 107	
		14:42		end of Rx-seismic profile 107	
		15:00-16:40		recovery of seismic equipment	
		20:35-21:05	PS115/1_9-1	coring with gravity corer	
		21:45-22:10	PS115/1_9-2	coring with gravity corer	
		22:50-23:10	PS115/1_9-3	coring with gravity corer	
		23:45-00:17	PS115/1_9-4	coring with box corer	
Sa	11.08.	00:20-06:35	PS115/1_10-1	hydrosweep mapping	sunny, thin fog, low to medium winds, 3/1_10
		06:35-06:55	PS115/1_11-1	coring with box corer	
		07:20-07:45	PS115/1_11-2	coring with gravity corer	
		07:55-08:15	PS115/1_11-3	coring with gravity corer	
		11:45-13:00	PS115/1_12-1	deployment of seismic equipment	
		12:57	PS115/1_12-1	start of Rx-seismics profile 107a (incl. magnetics)	

Day	Date (2018)	Board time UTC -2h	Station	Scientific activities and events	Weather sky cover, wind state, sea ice
So	12.08.	07:54		end of Rx-seismics profile 107a (incl. magnetics)	sunny, thin fog, low winds, 2/1_10
		08:10-11:55		extending streamer to 3600m	
		13:04	PS115/1_12-1	start of Rx-seismic profile 107b (incl. magnetics)	
Mo	13.08.	08:11		end of Rx-seismic profile 107b (incl. magnetics)	sunny, foggy, low winds, 6/1_10
		08:12	PS115/1_13-1	start of Rx-seismic profile 106.1 (incl. magnetics)	
Di	14.08.	00:44		end of Rx-seismic profile 106.1 (incl. magnetics)	cloudy, foggy, medium winds, 4/1_10
Di	14.08.	00:46	PS115/1_13-1	start of Rx-seismic profile 106 (incl. magnetics)	
		19:43		end of Rx-seismic profile 106 (incl. magnetics)	
		19:44	PS115/1_13-3	start of Rx-seismic profile 105 (incl. magnetics)	
Mi	15.08.	09:12		end of Rx-seismic profile 105 (incl. magnetics)	cloudy, low winds, 4/1_10
		09:13	PS115/1_13-3	start of Rx-seismic profile 104 (incl. magnetics)	
		18:30		end of Rx-seismic profile 104 (incl. magnetics)	
		18:40-21:10	PS115/1_13-4	recovery of seismic equipment	
Do	16.08.	00:55-02:35	PS115/1_14-1	heatflow measurement	partly cloudy, low to medium winds, 4/1_10
		03:35-06:35	PS115/1_15-1	heatflow measurement	
		07:45-10:30	PS115/1_16-1	heatflow measurement	
		10:55-12:30	PS115/1_16-2	coring with gravity corer	
		12:50-14:15	PS115/1_16-3	coring with box corer	
		14:40-16:10	PS115/1_16-4	coring with box corer	
		17:45-20:15	PS115/1_17-1	heatflow measurement	
		20:35-21:55	PS115/1_17-2	coring with box corer	
		22:50-23:20	PS115/1_18-1	coring with box corer	
		23:40-00:15	PS115/1_18-2	coring with gravity corer	
Fr	17.08.	01:55-02:15	PS115/1_19-1	coring with gravity corer	sunny, low to medium winds, 4/1_10
		02:40-03:00	PS115/1_19-2	coring with box corer	
		03:00-13:30	PS115/1_20-1	hydrosweep mapping	
		13:35-13:55	PS115/1_21-1	coring with box corer	
		14:20-14:45	PS115/1_21-2	coring with gravity corer	
				onshore geological sampling	
		19:20-22:35	PS115/1_22-1	coring with box corer	
		23:25-01:05	PS115/1_23-1	hydrosweep mapping	

Day	Date (2018)	Board time UTC -2h	Station	Scientific activities and events	Weather sky cover, wind state, sea ice
Sa	18.08.	01:50-03:10	PS115/1_24-1	magnetic calibration circle	cloudy, low winds, 6/1_10
		06:15-07:55	PS115/1_25-1	heatflow measurement	
		09:50-11:15	PS115/1_26-1	coring with box corer	
		11:50-13:25	PS115/1_26-2	coring with gravity corer	
		13:35-16:10	PS115/1_26-3	heatflow measurement	
		16:30-17:25	PS115/1_26-4	releaser test	
		17:30		transit towards Cape Morris Jesup	
So	19.08.	06:10-08:50	PS115/1_27-1	deployment of seismic equipment	sunny, fog banks, low winds, 2/1_10
		09:09	PS115/1_27-1	start of Rx-seismic profile 108 (incl. magnetics)	
				onshore geological sampling	
Mo	20.08.	06:33		end of Rx-seismic profile 108 (incl. magnetics)	cloudy, low winds, 2/1_10
		06:40-12:25		airgun maintanance	
		13:00	PS115/1_27-1	start of Rx-seismic profile 108b (incl. magnetics)	
				onshore geological sampling	
Di	21.08.	04:35		end of Rx-seismic profile 108b (incl. magnetics)	partly cloudy, fog, low winds, 6/1_10-2/1_10
		04:48	PS115/1_27-1	start of Rx-seismic profile 109 (incl. magnetics)	
		20:55		end of Rx-seismic profile 109 (incl. magnetics)	
Di	21.08.	21:00-23:00		recovery of seismic equipment	
				onshore geological sampling	
Mi	22.08.	00:20-08:05	PS115/1_28-1 - 36/1_1	deploying of 9 ocean bottom seismometers	cloudy, snow, strong winds, 2/1_10-6/1_10
		09:45	PS115/1_37-1	start of refraction seismic profile 1R1	
		21:00		end of refraction seismic profile 1R1	
		22:35-23:55	PS115/1_38-1 - 39/1_1	recovery of 2 ocean bottom seismometers	
Do	23.08.	01:10-11:55	PS115/1_40-1 - _46-1	recovery of 7 ocean bottom seismometers	cloudy, medium to strong winds, 6/1_10
		13:40-14:20	PS115/1_47-1	coring with box corer	
		14:25-15:00	PS115/1_47-2	coring with box corer	
		15:25-16:05	PS115/1_47-3	coring with gravity corer	
		16:25-17:05	PS115/1_47-4	coring with gravity corer	
		17:50-18:30	PS115/1_47-5	coring with gravity corer	
		18:30		heading towards Morris Jesup Rise	

Day	Date (2018)	Board time UTC -2h	Station	Scientific activities and events	Weather sky cover, wind state, sea ice
Fr	24.08.	11:25-11:50	PS115/1_48-1	coring with box corer	sunny, light to medium winds, 7/1_10
		11:50		transit towards Kronprins Christian Land	
				onshore geological sampling	
Sa	25.08.	14:05-17:40	PS115/1_50-1	heatflow measurement	partly cloudy and foggy, medium to strong winds, 3/1_10
		17:55-19:40	PS115/1_50-2	coring with box corer	
		20:15-21:55	PS115/1_50-3	coring with gravity corer	
So	26.08.	04:30-04:55	PS115/1_51-1	coring with gravity corer	cloudy, fog, low winds, 3/1_10
		05:10-05:30	PS115/1_51-2	coring with box corer	
		07:40-08:05	PS115/1_52-1	coring with box corer	
		08:10-08:45	PS115/1_52-2	coring with gravity corer	
		13:20-13:35	PS115/1_53-1	coring with gravity corer	
		13:40-14:10	PS115/1_53-2	coring with video multi corer	
		16:40-20:00	PS115/1_54-1	deploying Rx-seismic equipment	
		21:46	PS115/1_54-1	start of Rx-seismic profile 113a (incl. magnetics)	
Mo	27.08.	07:41		end of Rx-seismic profile 113a (incl. magnetics)	partly cloudy, fog, low to medium winds, 2/1_10
		07:42	PS115/1_54-1	start of Rx-seismic profile 114 (incl. magnetics)	
		19:48		end of Rx-seismic profile 114 (incl. magnetics)	
		20:56	PS115/1_54-1	start of Rx-seismic profile 115 (incl. magnetics)	
Di	28.08.	14:39		end of Rx-seismic profile 115 (incl. magnetics)	partly cloudy, low winds, 6/1_10
		18:20	PS115/1_54-1	start of Rx-seismic profile 115a (incl. magnetics)	
Mi	29.08.	01:16		end of Rx-seismic profile 115a (incl. magnetics)	partly cloudy, low to medium winds, 2/1_10-7/1_10
		02:41	PS115/1_54-1	start of Rx-seismic profile 116 (incl. magnetics)	
		19:55		end of Rx-seismic profile 116 (incl. magnetics)	
		21:11	PS115/1_54-1	start of Rx-seismic profile 117 (incl. magnetics)	

Day	Date (2018)	Board time UTC -2h	Station	Scientific activities and events	Weather sky cover, wind state, sea ice
Do	30.08.	06:57		end of Rx-seismic profile 117 (incl. magnetics)	partly cloudy, medium winds, 2/1_10-7/1_10
		08:30	PS115/1_54-1	start of Rx-seismic profile 118 (incl. magnetics)	
Fr	31.08.	04:30		end of Rx-seismic profile 118 (incl. magnetics)	cloudy, foggy, medium to strong winds, 3/1_10
		05:56	PS115/1_54-1	start of Rx-seismic profile 119 (incl. magnetics)	
		08:50		end of Rx-seismic profile 119 (incl. magnetics)	
		08:51	PS115/1_54-1	start of Rx-seismic profile 120 (incl. magnetics)	
Sa	01.09.	13:10		end of Rx-seismic profile 120 (incl. magnetics)	cloudy, foggy, strong winds, 0/1_10
		13:10-15:55	PS115/1_54-2	recovery of Rx-seismic equipment	
So	02.09.			transit to Longyearbyen	cloudy, rainy, strong wind, 0/1_10
Mo	03.09.	08:00		arrival	cloudy, rainy, strong wind, 0/1_10

2. WEATHER CONDITIONS

Christian Paulmann, Christian Rohleder DWD

- **Week 05.08.-12.08.18, Tromsø – Eastern Greenland**

On August 5 at 15:30 pm, the expedition PS115/1 began under low atmospheric pressure in Tromsø, accompanied by 16°C, a gentle variable breeze and cloudy skies.

Meteorological situation: Low centers northwest of the Siberian Ob river mouth Ob and over the White Sea stood opposite to an extended high pressure zone between the Eurasian Arctic and Greenland. On August 6 another central low developed over the Kara Sea.

While on transit towards the Greenland shelf area, *Polarstern* became rapidly influenced by the western flank of the above-mentioned lows, which were combined with a momentary freshening cold northeasterly airstream and waves up to 1.5 m. A very stable boundary layer built up, however with deteriorating visibility down to 5 km only during temporary light rain. The low across the Kara Sea was migrating northwest to the area east of Svalbard. For a while on August 7, that low became prevailing with a backing northwesterly airstream up to 6 Bft and crossed seas up to 2 m. From late August 7 on, wind was weakening and first deep inversion fog came up over the first target area near 75°N 02°E.

On August 8, a shallow and slowly eastward moving lee depression established northwest of *Polarstern* over coastal Greenland. The ground-based temperature inversion intensified up to 8 degrees due to widely descending air. The light to moderate northwesterly wind was turning to southwest and the inflowing dry air caused fog dissipation for 8 hours. During the following days, *Polarstern* slowly moved north towards 81°N to the research area offshore East Greenland (12°W - 00°E) and the vessel passed first ice fields on August 9. Pleasant, calm and frosty conditions set in, combined with inversion and radiation fog in the humid and stable boundary layer. The fog development process was very sensitive to little modifications regarding wind, temperature, humidity and ice conditions. From August 10 to 11 we crossed a high-pressure zone, which ranged from Svalbard to Jan Mayen. Meanwhile, the weak wind turned to southerly directions.

- **Week 13.08.-19.08.18, East Greenland – Wandel Sea - Cape Morris Jesup**

Meteorological situation: The weather situation over extended Arctic areas was changing: The high atmospheric pressure over the inner Arctic with only few blocking deep highs and lows over the outer Arctic changed to eastward propagating highs and lows. The predominant pressure system for our expedition area was the above-mentioned high, which shifted east from East Greenland to the East Siberian Sea. Additionally, for August 15 and 16, there was a weak lee depression across the Wandel Sea.

From August 14 to 15 during our approach towards Kronprins Christian Land (northeastern peninsula of Greenland), coastal effects brought the light southerly winds up to 5-6 Bft (wind induced seas up to 1 m). The inversion fog continued, light snowfall came up on August 15 and 16. On August 16, the lee depression filled up and the vessel became gradually influenced by the northern limb of a high-pressure belt, extending from the Barents Sea to Greenland. Again, regional coastal effects brought southerly winds up to 6 Bft (sea state momentary up to 1.5 m). In the course of August 16, forecasted lee-effects offshore Kronprins Christian Land caused fog dissipation, combined with warming up to +2°C on August 17. Subsequently, while sailing only a little distance to the east, we left the lee-effects and came back to fog and wind from SSE, 5 Bft with seas up to 1.5 m.

During August 18, the mentioned belt of high pressure passed north with calming winds and ongoing fog. On August 19, during the transit to the world's northernmost land area (Cape Morris Jesup, Kaffeklubben Island near 83°39'N), we came under the influence of the north westernmost limb of a Spitsbergen low. The wind shifted to north, for short time combined with good visibility due to uplifting air.

- **Week 20.08.-26.08.18, Lincoln Sea – Wandel Sea – Greenland Sea**

Meteorological situation: During that week, another changeover occurred in the weather situation. A cold and almost stationary central low around the North Pole developed, triggered by northeastward moving lows over the Norwegian Sea and the Barents Sea. The change took place stepwise until August 21.

During the beginning of the week *Polarstern* was operating offshore Cape Morris Jesup, between the Wandel and Lincoln Sea. Since this area is generally covered by thick multi-year ice all the year round, it is widely known as "region of the last ice in the Arctic". During August 20 and 21, we sailed mainly under the influence of the remaining belt of high pressure northwest of us, combined with mostly weak northeasterly to northwesterly wind conditions and with temporary inversion fog. The exception was a touching frontal trough in the afternoon of August 20.

On August 22, we experienced a weather break: We came under the influence of the southern flank of the North Pole low. Pressure differences were strongly increasing. Advection of cold and humid air at all tropospheric levels caused unsettled weather with light snowfall. We had misty conditions, however the tendency to fog reduced. The wind turned to WSW and increased up to 6 Bft. The wind-driven waves could only grow up to 1 m due to irregular ice fields. The light permanent frost continued, combined with a windchill factor to about -20°C. From August 22 to 23, two embedded small-scale off-ice eddies were passing *Polarstern* with backing winds and moderate snowfall. On August 24, we left the current research area due to a downgrading ice situation. *Polarstern* was sailing back eastward to Kronprins Christian Land and Greenland Sea. Surrounding an East Greenland high with lee effects offshore Peary Land we could enjoy a nice weather window with light and variable winds, but also with slowly growing risk of fog due to a stabilizing atmospheric stratification. In the second half of the day we experienced the same exception as a few days before: The southerly wind freshened up only close to the north easternmost tip of Greenland due to regional coastal effects (with seas temporary up to 1m). From August 25, *Polarstern* was operating off East Greenland under a weak extended zone of high pressure. The fog lifted only for short time in the surroundings of two small-scale and shallow off-ice eddies.

- **Week 27.08.-03.09.18, Greenland Sea – Fram Strait - Longyearbyen**

Meteorological situation: The high-pressure zone developed off East Greenland. It was intensifying and propagating eastward. It gradually overtook steering function over all the low-pressure areas, which moved from southern Greenland and the Norwegian Sea to the Inner Arctic. The meteorological situation "central low North Pole" continued until the weekend, but the storm track was shifting west to our cruising area. In the second half of the week three meteorological lows passed by.

Until the evening of August 28, the SSW wind freshened up for short periods. On August 29 and 30, two lows with ongoing thick fog, rain and warming up to +5°C from Jan Mayen passed *Polarstern* one after the other: the first filling low with cyclonic winds about 2 Bft during the night to August 29. The following second low arrived the cruising area on early August 30, in combination with an up-fill. An associated secondary low remained east of *Polarstern*, it developed into a storm low along its way to Svalbard. In front of that complex low system, the wind increased up to 6 Bft and backed to easterly directions. Significant waves exceeded 1.5 – 2 m close east of the ice edge. Later on August 30, at the backside of the low, the wind turned to WNW with 6-7 Bft. The low passed by during the night to August 31, followed by a northward shifting belt of high pressure with backing and abating winds. In the morning of August 31, offshore winds brought dry cold air from Greenland with lee effects, cloud dispersal and fog dissipation.

Simultaneously, a weakening storm 975 hPa was moving from southern Greenland heading to the Denmark Strait and subsequently to the west coast of Spitsbergen. During September 1, the last working day of the cruise, associated warm and cold fronts passed by with rain, poor visibility and fresh wind. The southerly airstream was increasing up to 5-6 Bft during the night to September 2, wind-sea and swell grew up to 3m. From September 2 to 3, a secondary depression over the Norwegian Sea was deepening into a severe storm low. In the afternoon of September 3, that storm entered the sea area between Svalbard and Bear Island. Early enough we arrived at Longyearbyen with moderate southeasterly winds and good visibility.

3. STRUCTURAL INVESTIGATIONS OFF NORTH EAST AND NORTH GREENLAND BASED ON GEOPHYSICAL DATA

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Objectives

The plate tectonic history of Greenland is very complex, especially in the transition from the Paloecene to the Eocene, when Greenland acted as independent lithospheric plate (Tessensohn and Piepjohn, 2000). In this time period Greenland compensated the seafloor-spreading in Labrador Sea and Baffin Bay until chron C24 and starting from chron C24 seafloor-spreading in the North-Atlantic (Jackson and Gunnarson, 1990; Tessensohn and Piepjohn 2000) most likely by an anti-clockwise rotation that caused a northward movement of Greenland with respect to Eurasia in the Palaeogene about 50 Mio years ago. The northward motion of Greenland resulted in compression affecting the region of northern Greenland and Svalbard. Later in the Oligocene, seafloor spreading in the Eurasia basin propagated southwards and initiated extension separating the Yermak Plateau and Moris Jesup Rise.

The questions arise (1) how far did the compression that originated by the northward movement of Greenland extended to the North and (2) did this process result in an overriding of the early oceanic crust in the Eurasian basin by the North Greenland continental margin.

We aim to characterize the style of deformation that affected the NE Greenland margin and to quantify compression versus extension, which is manifested in sedimentary basins in the region. This provides the basic facts to conclude whether Greenland act as an independent plate with predominantly N-S compression in the north during the Paleogene, or was it attached to North America and underwent an anti-clockwise rotation resulting in oblique compression with strike-slip in the north.

In the course of the project GREENMATE we acquired geophysical data that allows us to address certain topics in the evolution and plate tectonic reconstruction of the NE-Greenland margin.

- Multichannel seismic data will image the deformation of the sediments and the crystalline basement. The deformation gives evidence for the chronological and spatial displacement pattern along the NE Greenland margin.
- A wide angle and refraction seismic line will image the deeper crust and the crust mantle transition. The knowledge of the deeper crust and its seismic sound velocities will contribute to identify the actual Continent Ocean Boundary (COB) and the type of continental margin.

- Magnetic data acquisition along the planned profiles lines will help to identify the oldest magnetic seafloor spreading anomalies which mark the onset of the spreading between Yermak Plateau and Morris Jesup Plateau. This would give direct evidence of the continent ocean boundary and the age of the North Atlantic oceanic crust. Ideally, also the direction of the opening of the North Atlantic could be determined. Additionally, magnetic data are required to support an integrated interpretation of the continental margin structures. Other results will be structural information on the location of fault systems, the presence of volcanic intrusions, magmatic bodies and different types of basement in conjunction with seismic and gravity data.

- Gravity data will be used for quantitative statements of crustal thickness and lateral discrimination of crustal blocks. In particular, the interpretation will include forward modelling of gravity anomalies along a number of key profiles to develop sound density models.

- Heat flow density data will be used to estimate paleo-temperatures and geothermal gradients which affect the maturation of organic sequences. Basin modelling is based on sediment thicknesses and paleo-temperatures for assessment of the hydrocarbon potential of sedimentary basins. Heat flow data spread over the survey area may help to identify the areal extent of oceanic floor or stretched continental crust, type of extension and sea-floor spreading. As an additional tool, heat flow measurements might assist in restraining age estimates of the oceanic crust.

- All activities were carried out under high standard mitigation procedures and were accompanied by a contracted service company adopting marine mammal observation (MMO) and passive acoustic monitoring (PAM) tasks during the survey. Several precautionary measures were taken in advance not to harm the marine wildlife by seismic operations. By reducing the source level of the seismic sources prior the survey operations to the absolute minimum necessary to achieve the scientific goals, potential behavioral effects were minimized as much as possible. In the adoption of best practice to international standards, BGR generally implements a precautionary regime for seismic surveying identical to the UK JNCC (2017). Survey operations within Greenlandic waters followed procedures outlined and required in the granted Scientific Survey License No. VU-00135 issued by the Government of Greenland, Ministry of Industry and Energy, August 2, 2018.

- For more details on mitigation measures during survey operations please refer to Chapter 10.

3.1 Reflection seismic data acquisition

Work at sea

Seismic streamer cable

- For the multichannel seismic data (mcs) acquisition a 3,000 m active length solid state streamer was at our disposal. The streamer cable consisted out of 16 sections with 12 channels (group distance 12.5 m (Type SSAS from Sercel™) and 4 sections with 24 channels (group distance 6.25 m) (Type SSRD from Sercel™). The 6.25 m sections were placed at the rear part of the streamer, as these sections were dedicated to be used as a short streamer for heavy ice conditions. How the streamer winches were placed on the working deck is shown in Fig. 3.1. The two streamer setups are outlined in Fig. 3.2 and Fig. 3.3. In order to prevent collisions of floats of sea ice with the streamer cable, the lead-in cable was hold with a towing point (eye) about 1 m below sea level at the stern of the vessel. A steady cruise speed was possible; however, large floating ice sheets required deviations from the intended course. Despite the challenging sea ice coverage, most of the reflection seismic lines were acquired with 3,000 m streamer cable with 288 channels in total. Because of the sea ice conditions, it was not possible to do loops at all end-of-lines. We did usually simple turns and line change was carried out at the end of the turn. However, this means that the streamer cable was not straight behind the vessel at begin-of-line and end-of line.

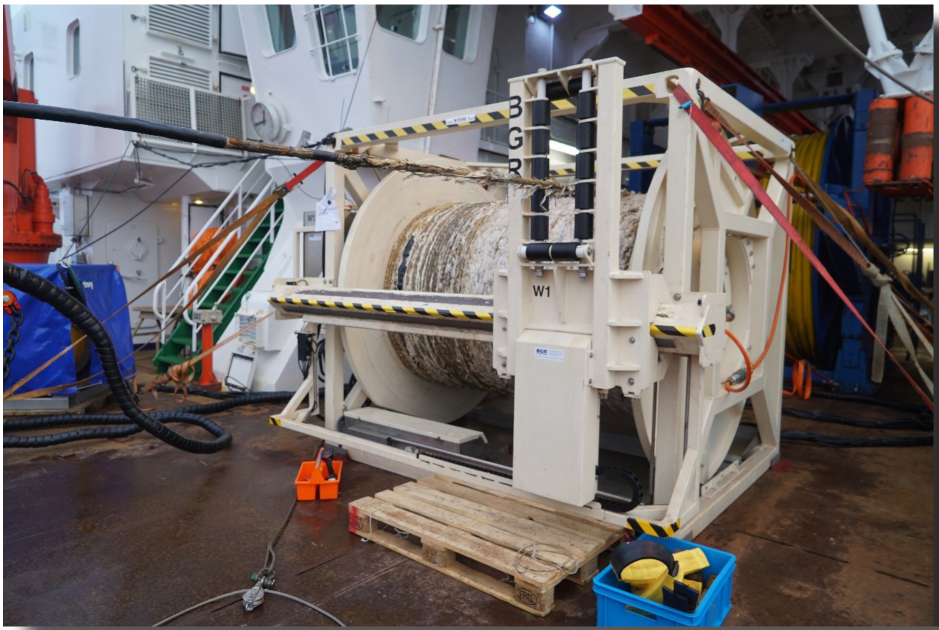


Fig. 3.1: Streamer winches on the working deck of Polarstern. White winch in the front holds the 4 SSRD streamer section of BGR with 24 channels per section. In the back of the white winch is the large blue AWI streamer winch, which holds 2,400 m of SSAS streamer cable with 12 channels per section.

Fahrt	PS115.1 Greenmate Polarstern													
										Lead In	SHS	Hau	HESE	HESA
Gesamtlänge (Heck - TAPU):3118,7m								) Ring		50 m	6m	0,3	50m	10m
	CB1R1				CB2		CB3R2			CB4		CB5R3		
QS	SSAS RD1	QS	SSAS RD2	QS	SSAS 3	SSAS 4	SSAS 5	LAUM	SSAS 6	SSAS 7	SSAS 8	SSAS 9	SSAS 10	LAUM
	1 - 12		13 - 24		25 - 36	37 - 48	49 - 60	1	61 - 72	73 - 84	85 - 96	97 - 108	109 - 120	2
	57538		57560		2363	2347	2354	6690349	2342	2311	2368	2356	2301	6690039
						AWI	BGR							
CB6		CB7R4		CB8			CB9			CB10	CB11			
SSAS 11	SSAS 12	SSAS 13	SSAS 14	SSAS 15	LAUM	SSAS 16	SSAS 17	SSAS 18	LAUM	SSAS 19	SSAS 20	TAPU		
121 - 132	133 - 144	145 - 156	157 - 168	169 - 180	3	181 - 192	193 - 216	217 - 240	4	241 - 264	267 - 288			
2350	2340	23261	2318	2371	6690079	2365	59304	59304	6685199	59298	59305	6681239		

Fig. 3.2: Streamer modules used for the 3,000 m streamer cable during the Greenmate project. SHS: Short Head Section; HAU: Head Acquisition Unit; HESE: Head Elastic Section; HESA Head Elastic Section Adapter; QS Quiet Sea module; SSAS Solid State Streamer Section; LAUM: Line Acquisition Unit module; CBx: Compass Bird; Rx Recovery module; TAPU Tail Acquisition unit

Polarstern - Greenmat 2016 version 2

	Ziehstrumpf auf 85m						CB1	
Slip Ring	Lead In 405m/85m	SNS 70/70	HAU 0,28m	SNS 70/70	RVIM	SNS 70/50	SSAS 1 1 - 24	QS 50 1
10.6.2 10	001	1045855129	5352069	1045855126	404006980	1043880154	59289	--

				CB2		
SSAS 2 25-48	QS 50 2	SSAS 3 49-72	QS 50 3	SSAS 4 73-96	QS 50 4	TAPU
59296	--	59304	--	59305	--	522

Fig. 3.3: Streamer modules used for dense ice conditions (600 m active sections). The SSAS sections have 24 channels each with a group distance of 6.25 m. Abbreviations in addition to Figure : SNS: Short Nautilus Section; RVIM: Stretch section.

Seismic Sources

We used an airgun array that was special designed for the application aboard *Polarstern* with eight 250 in³ G-Guns from Sercel™ (Fig. 3.4). The G-Gun hanger is subdivided into two sub-cluster. Each sub-cluster consists of two four-gun clusters that were mounted face to face. The volume of each gun was 250 in³ (4,1 l). The total volume of the array was 2000 in³ (32,8 l). The compressor was capable to produce 31 m³/min at 200 bar working pressure. The towing depth of the airgun array was 7 m troughout the survey. The center of the array was 14 m behind the stern of the vessel. Because of the shotpoint interval of 12-14 seconds the nominal working pressure of airgun array was reduced to 1.962 psi (135 bar). Triggering and synchronization was controlled by a shot-PC developed by BGR in combination with a Big-Shot from Real-Time Systems. The source for the seismic refraction data acquisition consisted out of 4 x 520 in³ G-Guns (Fig. 3.4b).

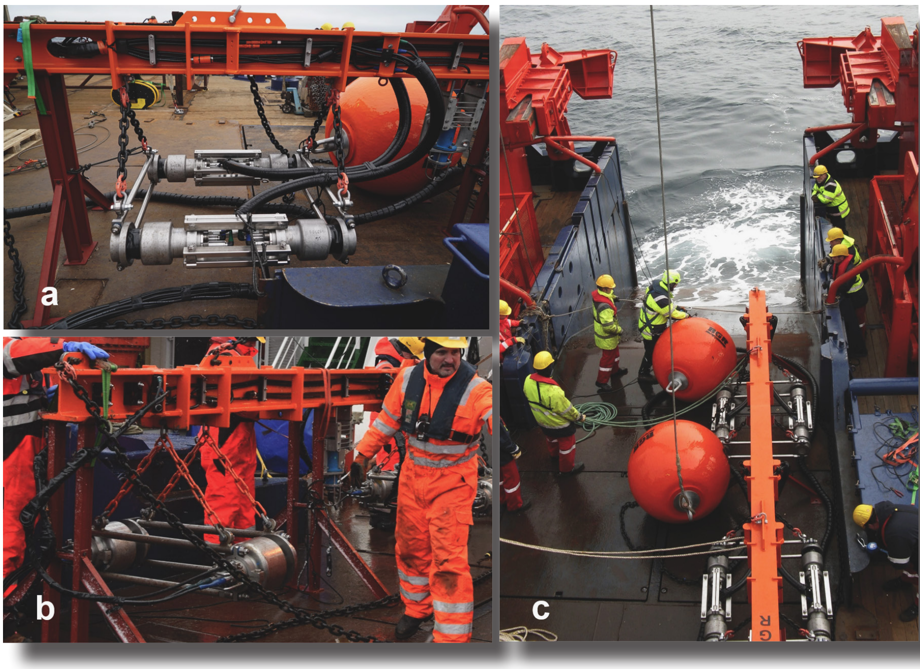


Fig. 3.4: Airgun configuration during the survey: a) face to face cluster of 4 x 250 in³ G-Guns 1 m below the airgun hanger. b) 2x2 520 in³ G-Gun cluster for OBS refraction seismic data acquisition. c) top view of the of the 2x4 250 in³ G-Gun cluster. The orange hanger is 6 m below the red floatation buoys (Fig. 3.4c).

Seismic data acquisition

The seismic data acquisition system on board consists out of four main units including the SEAL acquisition unit, the Shot Master-PC, the Digicourse Bird control system and the Big Shot gun trigger unit.

The **SEAL 428** is a marine seismic data acquisition system developed by SERCEL™, based on standard x86 computer systems running RedHat Linux and special hardware to synchronize all seismic channels with an accuracy of one microsecond. A high precision GPS clock (Meinberg LANTIME M300) provides the time base for the SEAL 428. The main function of the SEAL 428 is to synchronize the seismic channels, control the streamer power, retrieve the digitalized data from the streamer, convert and export the raw data to SEGD files. The recording is triggered by the Master PC 70 ms before the BigShot is triggered, as a consequence the trigger delay (70 ms) and the aim point delay (50 ms) the first break is recorded after 120 ms.

The SEAL428 provides a quality control system eSQCPro. The eSQC Pro is a software package from SERCEL running on x86 computer with RetHat Linux operating system. eSQC Pro was used to monitor all seismic channels on production.

A **Shot Master-PC** provides the trigger interval for the seismic sources for seismic reflection and refraction operations. It is a BGR in-house developed “Master” x86 PC equipped with a Meinberg GPS170PCI high precision satellite clock and a National Instruments NI PCI-6602 Timer/counter, running Microsoft Windows XP. For control, an in-house developed software based on National Instruments LabVIEW 2011 is used. The GPS clock captures the time, with an accuracy of one microsecond, of the seismic sources release.

The **DigiCOURSE System 3** is a system used to control the streamer depth and monitor the streamer direction. The system consists of a special on board hardware with a Microsoft Windows based graphical user interface (GUI) and compass birds units mounted on the streamer cable. The compass birds are equipped with fins to control the depth, a pressure sensor to measure the depth and a compass to measure the heading. The bird units comprise an online communication with the on board system over the streamer cable for real time depth control and monitoring.

The Real Time Systems BigShot system generates the timing, controls and monitor the seismic sources. After receiving a trigger signal from the Shot Master PC the BigShot system controls the seismic sources timing to the maximum power at the aiming point. The aiming point is 50ms after trigger. A clock time break (CTB) signal is send at the aiming point to the Master PC and captured by the Meinberg GPS clock.

After finishing a line, the captured shot-times are merged with the vessel’s navigation data to generate the shot positions.

Passive acoustic monitoring with QuietSea™:

QuietSea™ is a recently developed Marine Mammal Monitoring System designed by SERCEL to detect the presence of marine mammals during seismic operations without towing additional PAM equipment behind the vessel. This streamer integrated system is operated as a peripheral device to Sercel’s seismic data acquisition unit SEAL 428. QuietSea™ system (QS) uses two classes of data to cover a broadband frequency spectrum:

- the seismic data (using the SEAL interface) to detect vocalizations in the (low-frequency) seismic bandwidth from 10Hz to 200Hz with usual seismic sampling frequency of 2ms and

- high-frequency data, provided by additional QS streamer modules integrated within the Sercel seismic streamer (Sentinel SSAS, Sentinel SSRD and Sentinel MS) and other QS auxiliary modules to detect vocalizations in the bandwidth of 200Hz to 96kHz.

This potentially allows for marine mammal detection capabilities in a wide frequency listening range that covers a large variety of vocalizing cetacean species. Monitoring is conducted by automated detection and localization algorithms. During the 2D seismic operation for the high-frequency detections 3 to 4 QS streamer modules (Fig. 3.5A) plus 1 QS aux modules fixed to the airgun hanger (Fig. 3.5B) were employed. The QS streamer modules were integrated between the first 4 active sections of the streamer (Figs. 3.2 and 3.3), separated 150 m to each other, the QS aux modules were connected to the gun hanger (Fig. 3.4B).

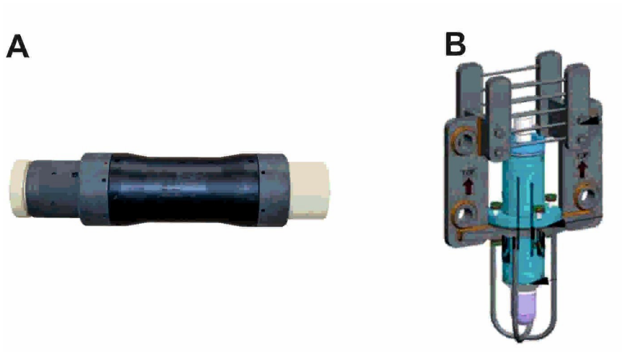


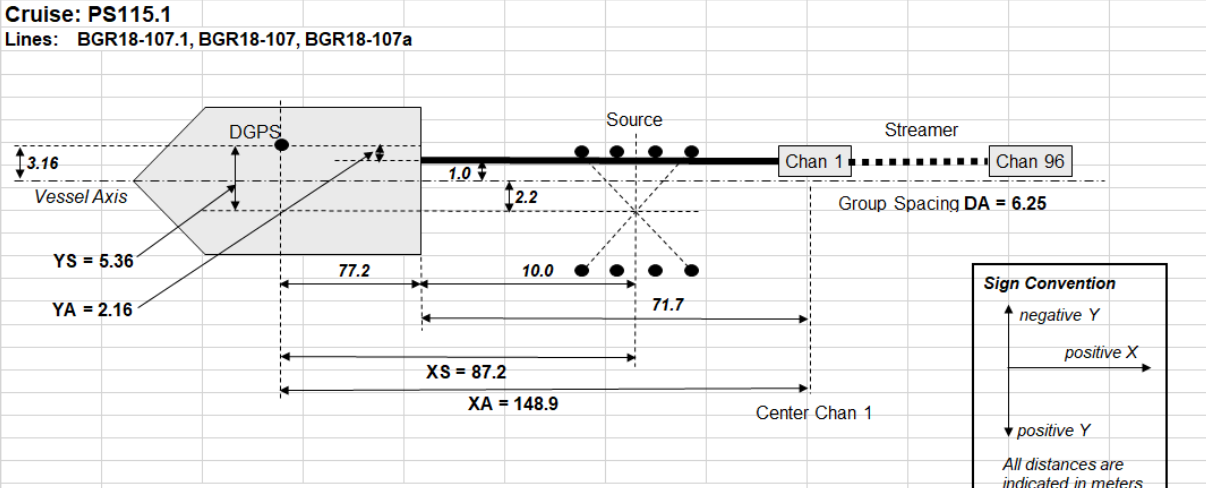
Fig. 3.5: QuietSea modules: A: Inline module assembled in between streamer sections. B: Aux module fixed at the airgun hanger.

During mcs operations with long streamer cable (Fig. 3.2) for low-frequency detection 48 channels of the streamer hydrophone groups were selected separated 50 m to each other with a nearest offset of 100m to the vessel and a farthest offset of 2,500m. In case of the short streamer cable (Fig. 3.3) the maximum offset was 650 m.

Each in-sea module integrates the QuietSea detection function and the results are sent to the QuietSea server. The signal processing algorithms use optimized parameters to obtain low false alarm rate and give assistance to the operator in decision making when a marine mammal has been detected by a sensor. QuietSea software allows to monitor acoustic events in the high- and low-frequency range separately. The several sources of anthropogenic impulsive sounds of the vessel (produced by the airguns and echosounders), can be filtered out. All acoustic events are logged in a protocol.

The QuietSea system claims to localize a marine mammal when a vocalization is detected by several sensors. The location of a marine mammal is determined based on the time difference of a sound arriving at two or more separated hydrophones. Localization results are displayed on the navigation screen. With 2D configuration localization results are mostly ambiguous, whereas with 3D configuration positions of acoustic signal sources can be defined unambiguously.

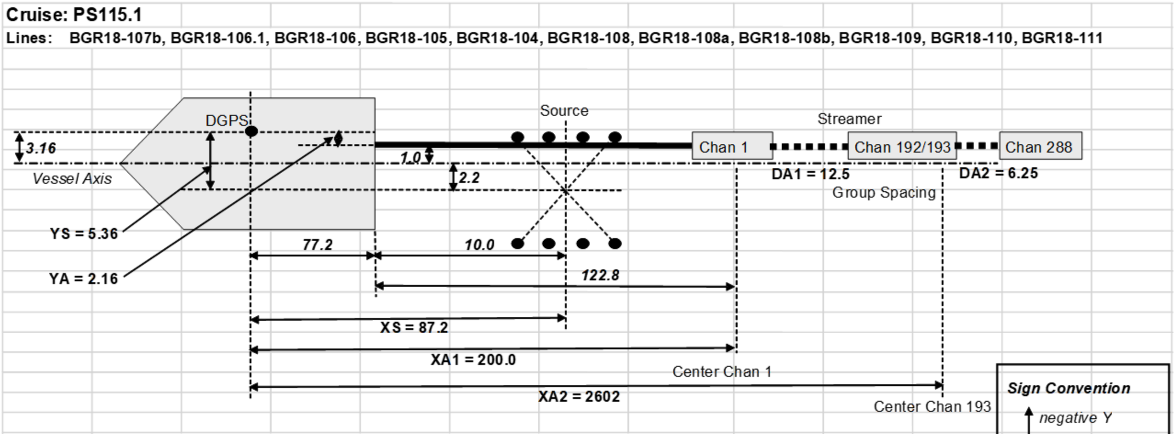
Detections were distinguished for the high-frequency range (toothed whale species) and low-frequency range (baleen whales). The option to analyse low frequency signals (provided by the streamer hydrophone) for acoustic detections of marine mammals is an unique feature of QuietSea compared with conventional PAM systems. Thus, the bandwidth of QuietSea can be extended to the very low frequency range to potentially be able to detect baleen whale vocalizations.



Patterns Spreadsheet for 2D Marine Geometry Assignment in ProMAX

Mark Block	Min Chan	Max Chan	Chan Inc	Src Pattern	Grp Int	X Offset	Y Offset	
1	A1 = 1	AN = 96	1		DA = 6.25	XA = 148.9	YA = 2.2	Streamer Pattern
						XS = 87.2	YS = 5.4	Source Pattern 1

Fig. 3.6: Acquisition geometry pattern of lines BGR18-107, -107.a and -107a



Patterns Spreadsheet for 2D Marine Geometry Assignment in ProMAX

Mark Block	Min Chan	Max Chan	Chan Inc	Src Pattern	Grp Int	X Offset	Y Offset	
	1	192	1		DA1 = 12.5	XA1 = 200.0	YA = 2.2	Streamer Pattern 1
	193	288	1		DA2 = 6.25	XA2 = 2602	YA = 2.2	Streamer Pattern 2
				1		XS = 87.2	YS = 5.4	Source Pattern 1

Fig. 3.7: Acquisition geometry pattern of lines BGR18-107b, -106 to -111

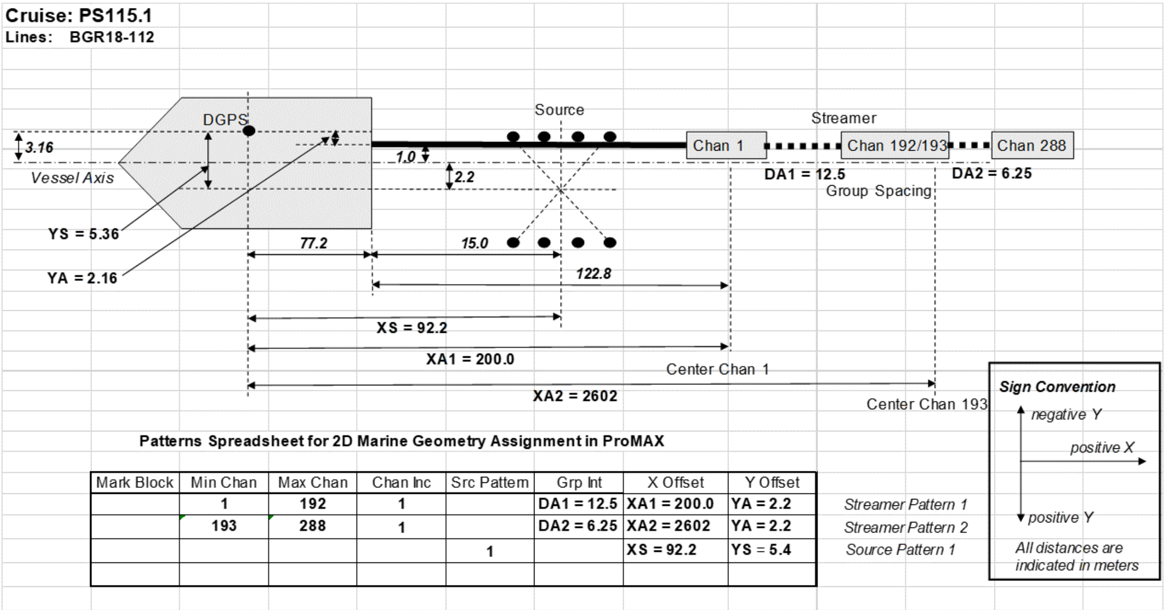


Fig. 3.8: Acquisition geometry pattern of lines BGR18-112

Data Processing

For QC purposes the mcs data were processed onboard the research vessel *Polarstern*. Processing was done with SeisSpace™ processing software including the following processing steps:

- Geometry and Navigation application
- Source-signal designature
- Bandpass filtering
- Noise removal
- SRME
- Tau-P predictive deconvolution
- Velocity Analysis
- Stacking
- Poststack Migration

As an example, the seismic line BGR18-110 is shown in Fig. 3.9. The data quality of the mcs data is overall good. The resolution and signal penetration are dependent on source, streamer cable, shot point interval and recording length. Unwanted energy like signal bubble and seafloor multiples could be widely removed by designature and SMRE/tau-P deconvolution processing. As for the mcs lines with 288 channels, the velocity analysis worked well and resulted in a reliable velocity depth function.

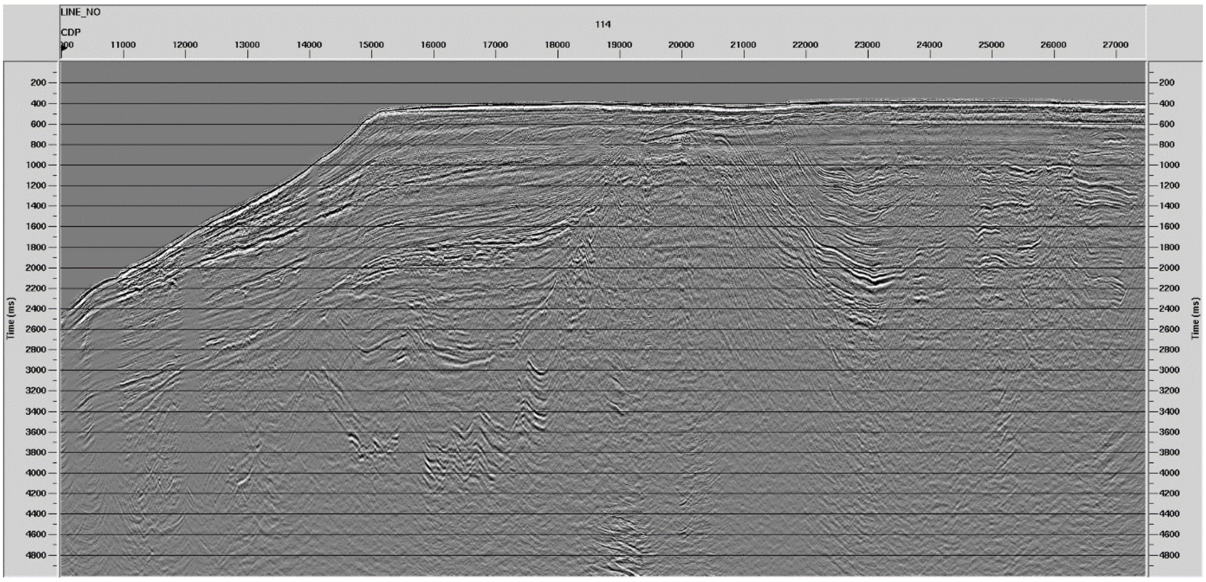


Fig. 3.9: Line BGR18-114 (location of profile in Fig. 3.10). This line was acquired with 3,000 m active streamer cable and 8 G-Guns. Preliminary processing is up to pre-stack time migration. Please note zones of low energy (e.g. CDP12000 and 14000) were the source signal was reduced to the smallest airgun due to mitigation phases for marine mammals.

Preliminary results

We acquired 2509 km of multichannel seismic data across the NE Greenland shelf its slope and into the adjacent deep-sea area (Fig. 3.10). Straight line acquisition was not always possible due to ice conditions. The example in Fig. 3.9 shows sediment thicknesses on the shelf of at least 2 s (TWT) and decreasing thicknesses in the deep sea of around 1 s (TWT).

Data management

Seismic reflection data will be stored in the marine seismic database and archived at BGR in raw and processed formats. It will be available to other scientists after a period of 4 years after the end of the cruise.

Tab. 3.1: Details of the mcs data of the Greenmate project

line number	shotpoint start/end	date	time	latitude	longitude	course	length (km)	number of channels	Source / Guns	Recording length (ms)	Shotpoint interval (s)
BGR18-107.1	1	10.08.2018	05:09:00	78° 23.854 N	11° 15.858 W			96	8 x 250	14000	15
BGR18-107.1	1656	10.08.2018	12:02:45	78° 46.602 N	13° 14.923 W	315°	61.15				
BGR18-107	1	10.08.2018	12:03:45	78° 46.669 N	13° 15.106 W			96	8 x 250	14000	15
BGR18-107	633	10.08.2018	14:41:45	78° 56.129 N	12° 41.050 W	35°	22.42				
BGR18-107a	1	11.08.2018	12:57:53	78° 56.368 N	12° 42.031 W			96	4 x 250	10000	11
BGR18-107a	6192	12.08.2018	07:53:11	80° 0.521 N	8° 2.423 W	36°	153.62				
BGR18-107b	1	12.08.2018	13:04:18	79° 47.136 N	9° 8.877 W			288	4 x 250	10000	11
BGR18-107b	6256	13.08.2018	08:11:09	80° 55.165 N	3° 8.578 W	39°	175.02				
BGR18-106.1	1	13.08.2018	08:12:04	80° 55.226 N	3° 8.823 W			288	4 x 250	10000	11
BGR18-106.1	5411	14.08.2018	00:44:00	80° 16.175 N	9° 44.094 W	242°	156.76				
BGR18-106	1	14.08.2018	00:46:12	80° 16.377 N	9° 43.502 W			288	4 x 250	10000	11
BGR18-106	6202	14.08.2018	19:43:03	81° 39.841 N	4° 51.306 W	26°	185.43				
BGR18-105	1	14.08.2018	19:44:42	81° 39.983 N	4° 51.442 W			288	4 x 250	10000	11
BGR18-105	4408	15.08.2018	09:12:45	81° 56.531 N	12° 41.921 W	288°	131.87				
BGR18-104	1	15.08.2018	09:13:51	81° 56.622 N	12° 42.033 W			288	4 x 250	10000	11
BGR18-104	3037	15.08.2018	18:30:27	82° 24.745 N	7° 58.704 W	52°	89.51				
BGR15-108	1	19.08.2018	09:09:38	83° 11.013 N	21° 5.050 W			288	6 x 250	10000	11
BGR15-108	823	19.08.2018	11:40:20	83° 20.876 N	22° 12.470 W	322°	23.49				
BGR15-108b	1	19.08.2018	14:01:19	83° 19.332 N	22° 0.952 W			288	6 x 250	10000	11
BGR15-108b	5410	20.08.2018	06:33:04	84° 18.727 N	30° 26.331 W	322°	153.62				
BGR18-109	1	20.08.2018	12:59:54	84° 22.403 N	29° 17.533 W			288	8 x 250	10000	11
BGR18-109	3682	21.08.2018	00:14:51	83° 55.418 N	34° 50.059 W	234°	104.05				
BGR18-110	1	21.08.2018	00:17:47	83° 55.411 N	34° 47.822 W			288	8 x 250	10000	11
BGR18-110	1468	21.08.2018	04:46:44	83° 55.112 N	31° 22.780 W	89°	40.97				
BGR18-111	1	21.08.2018	04:48:01	83° 55.180 N	31° 22.027 W			288	8 x 250	10000	11
BGR18-111	1850	21.08.2018	10:27:00	84° 18.399 N	29° 23.635 W	27°	51.55				
BGR18-112	1	21.08.2018	10:29:45	84° 18.245 N	29° 21.965 W			288	8 x 250	10000	11
BGR18-112	3394	21.08.2018	20:51:48	83° 50.917 N	35° 59.360 W	240°	95.89				
BGR18-1R1	1	22.08.2018	09:46:00	84° 6.361 N	28° 40.623 W				4 x 520	OBS	60
BGR18-1R1	675	22.08.2018	21:00:00	83° 49.097 N	36° 54.664 W	256°	102.82				
BGR18-113a	1	26.08.2018	21:54:08	79° 56.605 N	8° 39.906 W			288	8 x 250	12000	14
BGR18-113a	2517	27.08.2018	07:41:18	79° 55.599 N	4° 16.118 W	89°	91.18				
BGR18-114	1	27.08.2018	07:42:14	79° 55.540 N	4° 16.433 W			288	8 x 250	12000	14
BGR18-114	3112	27.08.2018	19:48:08	80° 23.038 N	9° 20.050 W	300°	111.76				
BGR18-115	1	27.08.2018	20:56:16	80° 23.083 N	9° 14.952 W			288	8 x 250	12000	14
BGR18-115	4556	28.08.2018	14:39:12	79° 0.240 N	9° 5.744 W	179°	165.61				
BGR18-115a	1	28.08.2018	18:23:26	78° 58.911 N	9° 4.893 W			288	8 x 250	12000	14
BGR18-115a	1765	29.08.2018	01:15:08	78° 22.798 N	9° 1.555 W	179°	67.14				
BGR18-116	1	29.08.2018	02:41:56	78° 23.686 N	9° 20.925 W			288	8 x 250	12000	14
BGR18-116	4425	29.08.2018	19:54:12	78° 9.843 N	2° 29.208 W	96°	158.31				
BGR18-117	1	29.08.2018	21:11:12	78° 7.683 N	2° 35.708 W			288	8 x 250	12000	14
BGR18-117	2515	30.08.2018	06:57:54	78° 57.014 N	3° 6.169 W	353°	92.08				
BGR18-118	1	30.08.2018	08:30:46	78° 56.315 N	3° 6.257 W			288	8 x 250	12000	14
BGR18-118	5138	31.08.2018	04:29:30	78° 44.102 N	12° 13.692 W	268°	198.31				
BGR18-119	1	31.08.2018	05:56:04	78° 36.582 N	12° 20.609 W			288	8 x 250	12000	14
BGR18-119	747	31.08.2018	08:50:08	78° 20.056 N	12° 37.019 W	191°	31.35				
BGR18-120	1	31.08.2018	08:51:18	78° 19.939 N	12° 36.941 W			288	8 x 250	12000	14
BGR18-120	7280	01.09.2018	13:09:50	76° 14.417 N	6° 4.280 W	142°	282.39				
							Summe:				
							2509.11				

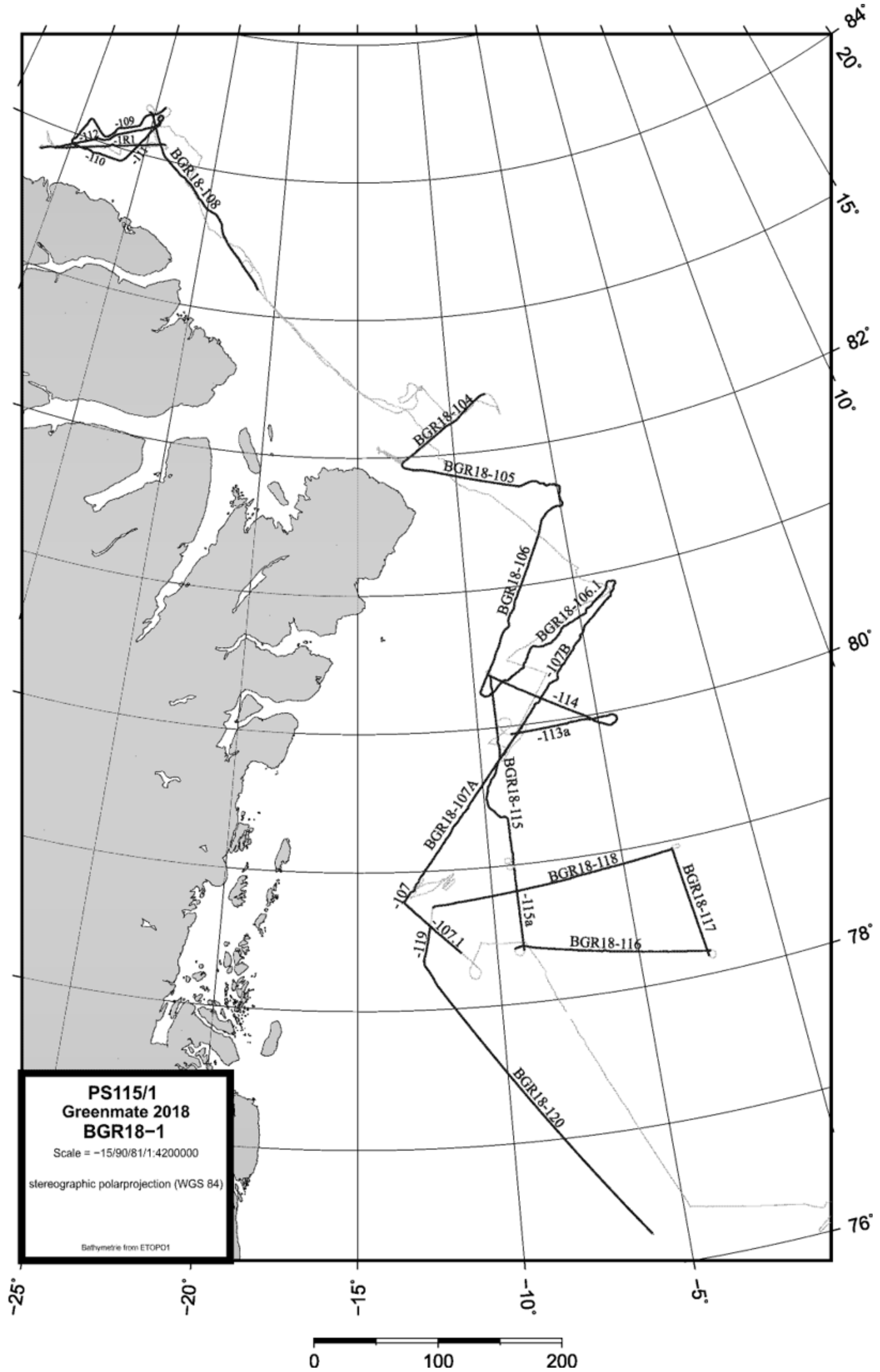


Fig. 3.10: Base map of the mcs lines during the Greenmate project

3.2 Wide angle seismic data using sonobuoys

Work at sea

27 sonobuoys were deployed along key seismic lines in order to derive a solid seismic velocity-depth function. Sonobuoys are disposable seismic devices that are deployed from the vessel and transmit the registered hydrophone signals by radio to the vessel. Sonobuoys were deployed at dedicated positions and signals were recorded up to 40 km distance. These far offset recordings enable a solid velocity function at this point.

The hydrophone of the sonobuoy is specially dedicated for seismic purposes with a maximum sensitivity at 4 Hz. Four depths below sea level were optional for each buoy (30 m, 66 m, 133 m, 330 m). The life time of each buoy could be chosen between 0.5 hour and 8 hours and 99 channels in the 100 MHz VHF band were available. Sonobuoys were purchased from Ultra Electronics™ (Fig. 3.11c). Radio signals were received by a tuned and stacked Yagi-Antenna array that was mounted at the backside of the funnel (Fig. 3.11b). In total three WIN-Radios were connected via an antenna distribution box and finally recorded by Send MBS recorders (Fig. 3.11a).

Three of 27 sonobuoys did not work, the position of deployment of the remaining 24 buoys is listed in Table 3.2 and marked in Fig. 3.12. A data example is given in Fig. 3.13. The antenna/receiver setup enabled recording distances of 35 km to 40 km between sonobuoy and vessel. This distance is good for wide angle seismic velocity analysis that supports the stacking velocity analysis of the mcs data.

Three sonobuoys were deployed along the refraction seismic line (see Table 3.2, Fig. 3.12) were the prevailing sea ice conditions did not allow the application of ocean bottom seismometers (OBS).

Preliminary results

We acquired wide-angle seismic data with 27 sonobuoys to derive P-wave velocity data of the sediments and uppermost crust. Out of these, 6 sonobyous were deployed at the Northeast Greenland shelf to get improved velocity information for mcs data processing. The majority (21 sonobuoys) were used to get far-offset for characterizing the nature of the North Greenland cotnintental margin in the transition to the Morris Jesup Rise.

Most sonobuoys enabled data transmission of up to 30 km.

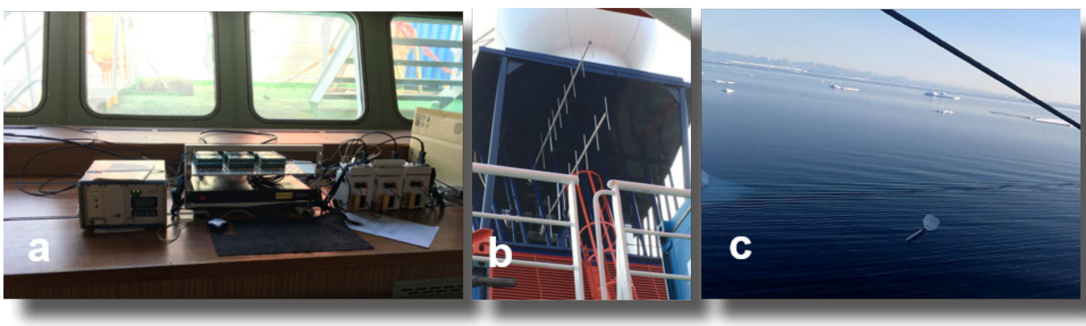


Fig. 3.11: a) Receiving equipment opposite the radio office of Polarstern with Meinberg clock (left side), rack with 3 win radios and antenna distribution unit (center), and 3 MBS recorders (right side); b) stacked and tuned Yagi-antennas at the back side of the funnel; c) sonobuoy deployed from the port side of the working deck.

Tab. 3.2: Sonobuoy positions during project Greenmate. Three buoys that did not work are not listed

No	Lat deg	Lon deg	Profile	Buoy depth [m]
SB001	83.2825	-21.7657	108	66
SB002	83.5300	-23.5688	108	30
SB003	83.7143	-24.9871	108	30
SB004	83.9189	-27.1898	108	30
SB005	84.3363	-29.5926	109	30
SB006	84.1884	-30.0222	109	30
SB007	84.0669	-33.2676	109	30
SB008	84.0719	-34.5133	109	30
SB009	83.9205	-34.3866	110	30
SB010	83.9296	-31.2647	111	30
SB011	84.0892	-30.3873	111	30
SB012	84.2238	-29.6583	112	30
SB013	84.1845	-30.4217	112	30
SB014	84.1540	-31.0037	112	30
SB015	84.0196	-33.3225	112	30
SB019	84.1073	-28.9527	Refraction	66
SB020	84.0818	-29.8015	Refraction	66
SB021	84.0587	-30.5478	Refraction	66
SB022	80.3493	-9.2501	115	30
SB023	79.0747	-9.0830	115	30
SB024	77.9360	-11.3887	120	30
SB025	77.3084	-9.3665	120	30
SB026	76.7285	-7.5434	120	30
SB027	77.0078	-8.4031	120	30

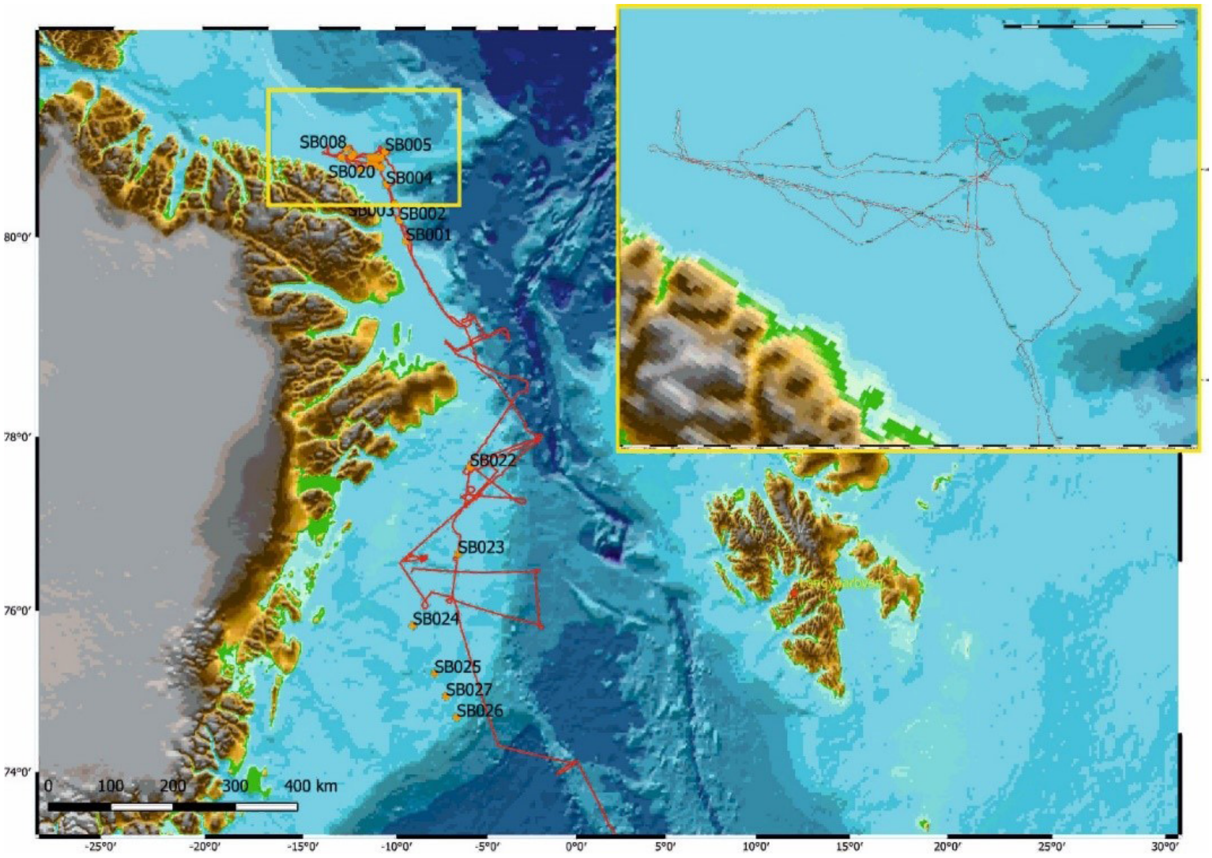


Fig. 3.12: Positions of the sonobuoys. Most of the sonobuoys were deployed in the area of the Morris Jesup Rise (see inlet)

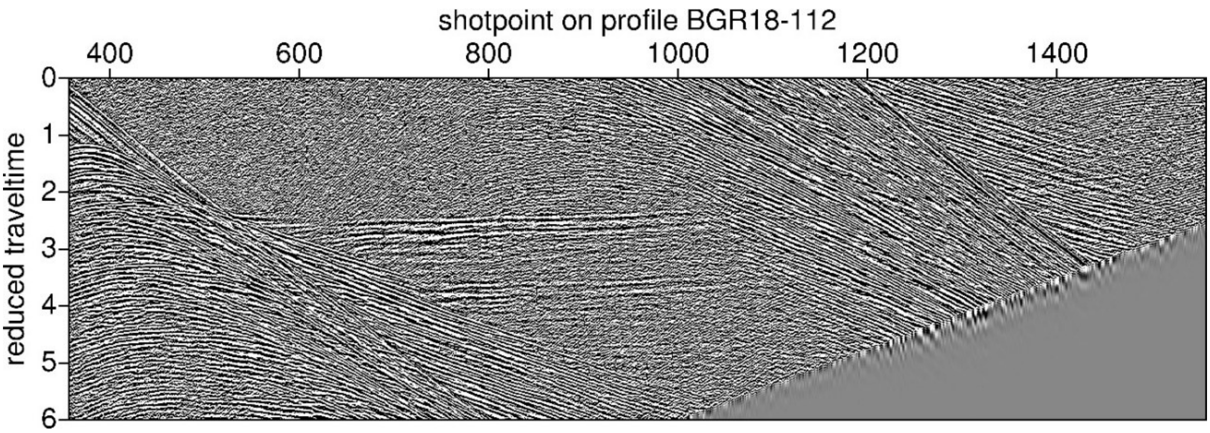


Fig. 3.13: Record section for sonobuoy 12 on line BGR18-112, covering 1200 shots. Traveltime reduction was applied to flatten the refracted arrival. Refracted energy was recorded for offsets up to approximately 30 km.

Data management

Wide angle seismic reflection data will be stored in the marine seismic database and archived at BGR in raw and processed formats. It will be available to other scientists after a period of 4 years after the end of the cruise.

3.3 Refraction seismic data (OBS)

Work at sea

The knowledge of the deeper crust and its seismic sound velocities will contribute to identify the actual continent-ocean boundary (COB) and the type of continental margin.

21 ocean bottom seismometers (OBS) were available on the cruise to cover the planned profile with a maximum station spacing of 10 km. However, the application of the OBS is strongly dependent on the prevailing sea ice conditions. In the case of inadequate ice conditions, the recovery of the OBS is not secured. In that case, sonobuoys were planned to be deployed for the acquisition of the seismic refraction data. The disadvantage of sonobuoys is, that no seismic signals can be recorded beyond the range of the data transmission via VHF radio (approx. 30 km). In addition, sonobuoys were planned to be deployed to complement the mcs data acquisition, in order to record long offset data at key positions for a solid control on the seismic velocities at deeper levels.

Due to permanent ice cover in the northeastern part of the study area and problems with the seismic sources at the beginning of the cruise we decided to cancel the originally planned refraction and wide-angle seismic profile. Later on, we had the opportunity to realize a short refraction profile across the shelf north of Greenland towards the southern Morris Jesup Rise. The profile was designed to cross several magnetic provinces as shown on the maps published by Jokat et al. (2016). The strong magnetic anomalies in the area of the Morris Jesup Rise and Morris Jesup Spur indicate the presence of magmatic rocks that might have been emplaced during the breakup of the southwestern part of the Eurasian Basin in the Oligocene, splitting the Morris Jesup Spur from the conjugate Yermak Plateau. An alternative interpretation is that the anomalies stem from volcanic rocks emplaced earlier in the Cretaceous during the formation of the High Arctic Large Igneous Province (HALIP). Due to sea ice approaching from the north, we finally decided to slightly rotate the profile closer towards the coastline, away from the planned profile paralle to seismic reflection line BGR18-112.

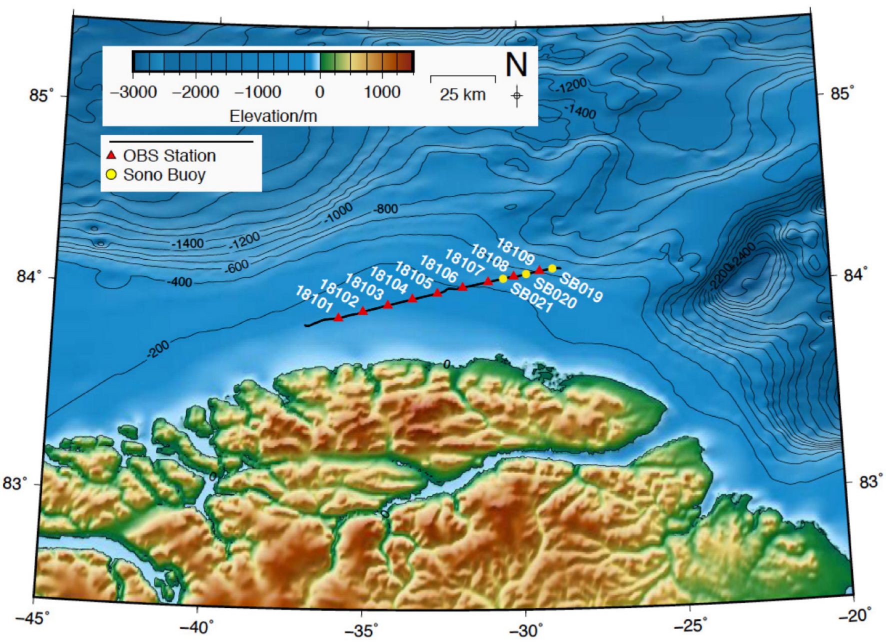


Fig. 3.14: Bathymetric map of the northern Greenland shelf (IBCAO version 3, Jakobsson, et al., 2012). Triangles show BBOBS stations, dots show sonobuoy stations. The black solid line marks the seismic refraction profiles.

Nine DEPAS standard broadband ocean-bottom seismometers (BBOBS) and three sonobuoys (see Chapter 3.2) were deployed along the 95-km-long profile (see Fig. 3.14). The station spacing between the BBOBS was 10 km. Unfortunately, the sea-ice conditions with a large moving ice floe did not allow expanding the profile farther towards the northeast. The southwestern end of the line was fixed by the limit of the 12 nm zone of Greenland and the denser sea ice towards the Lincoln Sea.

The BBOBS consist of an iron anchor and a titanium frame to which floatation units (made of syntactical foam) and several titanium pressure tubes are attached (Fig. 3.15). The cylinders contain the data logger with alkaline batteries, the seismometer and the release unit (KUM K/MT 562) that connects the frame to the anchor. Two VHF radio beacons (Novatec RF-700A and MMB7500) and a flag were mounted to the frame to aid the recovery of the instruments at the sea surface. The nominal maximum deployment depth of the BBOBS is 6,000 m.

The BBOBS were equipped with two sensors each, a hydrophone (HighTechInc HTI-04-PCA/ULF, 100 sec - 8 kHz) and a three-component broadband seismometer (Güralp CMG-40T, 60 s - 50 Hz). The seismometers are gimbal-mounted and were programmed to perform an automatic levelling procedure at the sea floor. The seismic signals were stored on the 20 GB hard disk of the data logger (Send Geolon mcs, 24 bit, 1-1,000 Hz) with a uniform sampling rate of 250 Hz. For the hydrophone data, a gain of 4 was used, the signals of the Güralp seismometer were recorded with a gain of 1. All data streams were written to the disk in continuous mode.

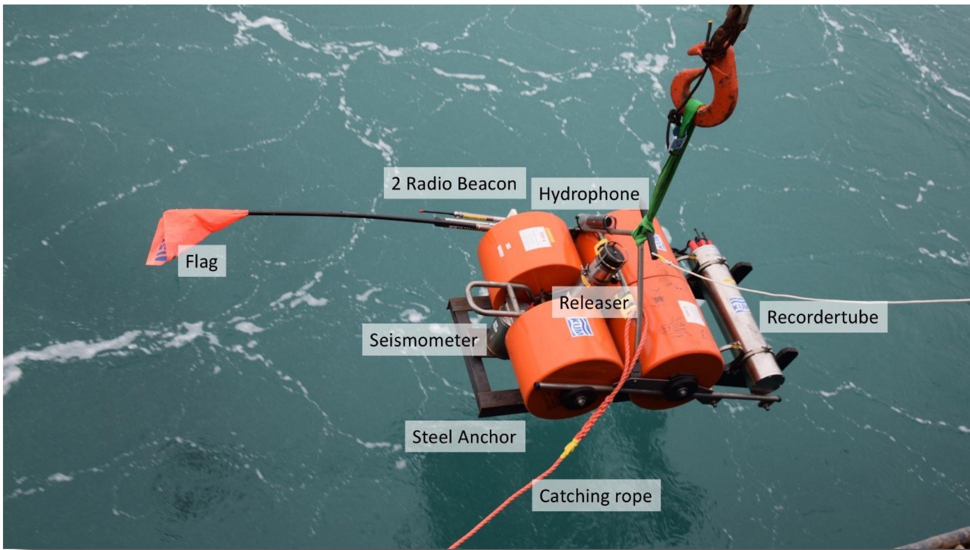


Fig. 3.15: Technical overview of the DEPAS ocean-bottom seismometer. (Photograph by V. Timkanicova)

A releaser test was conducted well before arriving in the survey area (August 7, 2018, 75° 14.7’ N 01° 55.2’ E) to have sufficient time for the preparation of the instruments before deployment. Baskets with 15 and 14 release units were lowered down to depths of approx. 2,000 m and 1,500 m, respectively. Then the testing sequence was run and the basket was heaved up again. For the acoustic communication with the releasers, a mobile on-board unit (KUM K/MT 8011M) with an external transducer was used. Almost all release units worked well and were available for the deployment. For the test at 2,000 m water depth, the answers from the release units could not be heard on deck, but all hooks turned twice or at least once. For the test at 1,500 m depth, most of the answers could be heard. In case of no answer, there was also a problem with the releaser. We also tested four release units that were planned to be deployed with long-term Ice-OBS during cruise PS115/2 at the Gakkel Ridge. Two of these units did not release properly. Therefore, we decided to exchange them and to conduct another releaser test later during the cruise (August 18, 2018, 82° 29.1' N 11° 27.0' W, 1,000 m water depth).

Finally, nine BBOBS were assembled and stored for deployment. The frames with the floatation units were connected to the anchor by the release units. Seismometers, hydrophones, radio beacons, flags and the pressure tubes containing batteries and the mcs data loggers were mounted on the frame. The clock timers of the releasers were set as fail-safe option and the recorders were programmed. The internal high-precision clocks of the mcs recorders were synchronized with an external GPS signal to set the exact time and the recording was started and verified. Right before the deployment, the radio beacons were switched on (Fig. 3.15), but the pressure and conductivity switches deactivated them after the OBS submerged a couple of meters into the water. The OBS were lowered on starboard side with a crane to the sea surface and slipped to descend freely to the seafloor.

We deployed all nine BBOBS on August 22, 2018 (Fig. 3.14, Table 3.3). Just after deployment of the last BBOBS, we went to the start of profile, turned and started the measurements (soft start at 9:25 UTC, full power at 9:46 UTC). Due to the ice conditions we had to skip the very first part of the profile in the northeast. Since there was a certain risk to lose instruments due to sea ice, we decided to deploy three additional sonobuoys (SB019 through SB021) along the line, which decreased the receiver spacing in the northeast and provided an additional receiver beyond the north easternmost BBOBS.

During data acquisition of the refraction OBS profiles, the BGR gun array with four 8.5 l G-guns from AWI was used in order to generate a low-frequency signal for deeper penetration and larger offsets. The G-gun array was deployed over the A frame and towed 15 m behind the ship's stern at a depth of 7.2 m. The shot interval was 60 s. The system was operated at a pressure of 150 to 170 bar and worked without problems and a total of 975 shots were fired. A Big Shot was used as gun controller. The end of line was reached on August 22, 2018 21:00 UTC.

Tab. 3.3: Deployment and recovery parameters of the OBS

STN	Deployment			
	Date Time UTC	**Latitude**	**Longitude**	**Depth**
18101	22.08.2018 00:20	83° 51.384‘ N	35° 50.950‘ W	201 m
18102	22.08.2018 01:15	83° 53.432‘ N	35° 04.066‘ W	(218 m)
18103	22.08.2018 02:19	83° 55.418‘ N	34° 16.061‘ W	204 m
18104	22.08.2018 03:20	83° 57.315‘ N	33° 28.592‘ W	193 m
18105	22.08.2018 04:18	83° 59.103‘ N	32° 40.447‘ W	166 m
18106	22.08.2018 05:14	84° 00.858‘ N	31° 51.481‘ W	159 m
18107	22.08.2018 06:13	84° 02.520‘ N	31° 02.105‘ W	390 m
18108	22.08.2018 07:00	84° 04.146‘ N	30° 12.570‘ W	725 m
18109	22.08.2018 08:03	84° 05.763‘ N	29° 22.336‘ W	825 m
	Recovery			
18101	22.08.2018 22:48	83° 51.327‘ N	35° 50.443‘ W	210 m
18102	22.08.2018 23:55	83° 53.402‘ N	35° 03.945‘ W	375 m
18103	23.08.2018 01:10	83° 55.340‘ N	34° 15.531‘ W	207 m
18104	23.08.2018 02:28	83° 57.280‘ N	33° 28.341‘ W	185 m
18105	23.08.2018 04:09	83° 59.009‘ N	32° 40.236‘ W	168 m
18106	23.08.2018 06:45	84° 00.788‘ N	31° 51.356‘ W	155 m
18107	23.08.2018 08:00	84° 02.452‘ N	31° 01.738‘ W	351 m
18108	23.08.2018 10:05	84° 04.085‘ N	30° 12.494‘ W	722 m
18109	23.08.2018 11:51	84° 05.846‘ N	29° 21.151‘ W	828 m

In the late evening of August 22, 2018, just after the end of the measurements, we started to recover the stations. All BBOBS released immediately after sending the acoustic release command and ascended to the surface. The anchors remain on the sea floor. Depending on water depth, the rising time ranged between three minutes (less than 200 m water depth) and about 15 minutes (water depth larger than 800 m). The instruments were located by visibly spotting the flags and by the bearing obtained from the radio signals of the VHF beacons that automatically turned on at the sea surface. For the bearings, the ship-borne cross bearing receiver was used. The OBS were caught from the working deck on starboard side by a grappling hook and lifted with the movebar on board.

The first four stations (18101, 18102, 18103, 18104) could be recovered without any problems, since the denser ice that was present during the deployment had moved away. The time between the first contact to the release units (enable and range) and the recovery on deck was only about twenty minutes in total (not including the parking of the vessel at the beginning).

However, the ice conditions had become worse at stations 18105 and 18106. At station 18105 the deployment position was located close to an open water pool between compact ice floes. We ranged the instrument several times from different positions and it became clear that the instrument was located close to or beneath the rim of one of the ice floes. We decided to wait until the expected position of surfacing became clear of ice due to the drift of the ice floes. About half an hour after the initial enable command was sent, we could release the OBS from the seafloor. It surfaced close to the rim of the ice floe and could be recovered on deck about 15 minutes later. Station 18106 was more problematic, since no obvious natural open water pool was existent at the deployment position. Therefore, the position had to be cleared of ice, which was achieved by breaking and crushing the smaller ice floes and preparing an artificial pool (Fig. 3.16, Fig. 3.17). The operation took about 30 minutes, before the OBS could be released from the seafloor. Finally, it surfaced in the centre between smaller pieces of ice and could be recovered 15 minutes later without problems.

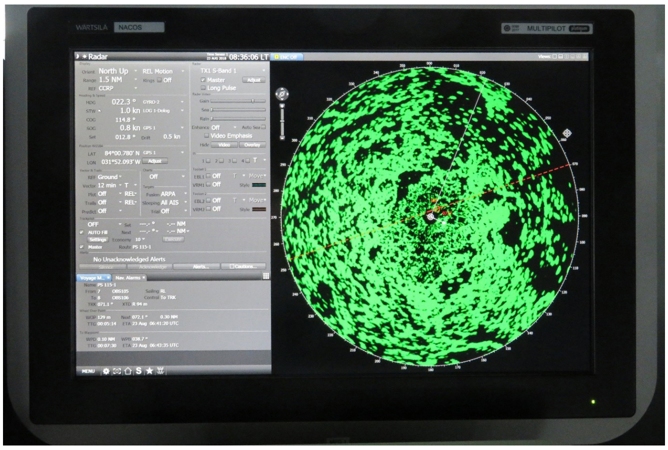


Fig. 3.16: X.3 Radar image at station site 18106 after breaking and crushing the ice floes (Photograph by T. Funck)

Recovery of stations 18107 and later also 18109 were again easier and faster due to almost open water with only minor and small ice rafts. Station 18108 was also located within a denser field of larger ice floes, which made an immediate release too risky, especially due to the larger water depth (725 m) and continuing ice drift. Therefore, the expected position of surfacing was again cleared of ice, mainly by pushing the smaller ice floes away. Then the OBS was released and recovered about 20 minutes later on deck.

No problems or damage occurred during the final recovery of the instruments from the sea surface due to good weather conditions and the experience of the crew. For all stations, the distances between deployment and recovery positions were less than 300 m (Table 3.3).

Fig. 3.17: Ice conditions at station site 18106 after breaking and crushing the ice floes. In the centre the surfaced BBOBS can be spotted. The dotted line outlines the cleared area. (Photograph by T. Funck)

Preliminary (expected) results

After stopping the recording, the internal clocks of the mcs data loggers were again synchronized with an external GPS signal to determine the clock drift, which will later be linearly corrected in the data. The data loggers of the stations worked very well with only minor clock drifts not exceeding 4 ms for the duration of the deployment (Table 3.4). All seismometers (channels XYZ) functioned properly, except for station 18107, where component X (channel 4) did not level (Table 3.4). There is noise on the seismometer channels at station 18101. Unfortunately, hydrophone channels experience spikes and jumps, but most of them can still be used for the analysis of the seismic refraction data.

A first data quality control shows that all OBS recorded the seismic signals, however, some seismograms are very noisy. This makes, in some cases, a phase identification difficult. The recorded maximum offsets range from about 40 to 70 km (see example in Fig. 3.18).

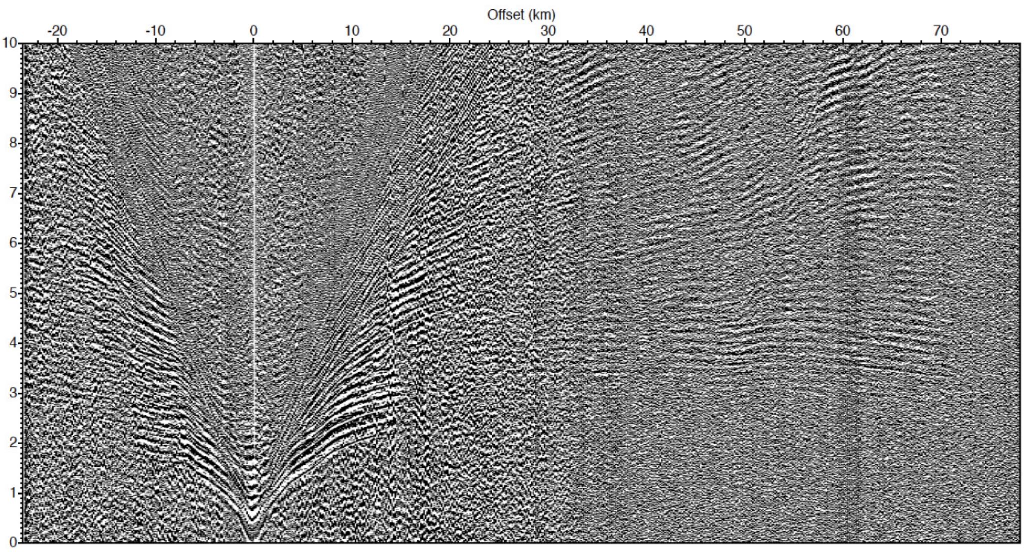


Fig. 3.18: Data example for OBS channels

Tab. 3.4: Recording parameters and quality control (QC) of the BBOBS data

STN	Recording				QC				Comments
	Start	Stop	Size [kb]	Skew [µs]	H [1]	X [4]	Y [3]	Z [2]	
18101	21.08.2018 23:53:27	22.08.2018 22:57:29	198.395	2406	(ok)	ok	ok	ok	H: “spikes” ZXY: temporary noise
18102	22.08.2018 00:35:41	23.08.2018 00:06:23	160.826	532	(ok)	ok	ok	ok	H: jumps
18103	22.08.2018 01:40:35	23.08.2018 01:16:13	233.433	3187	ok	ok	ok	ok	jump close to time when we passed the station
18104	22.08.2018 02:36:13	23.08.2018 02:32:50	156.793	62	ok	ok	ok	ok	
18105	22.08.2018 03:27:49	23:08:2018 04:17:12	176.068	1812	(ok)	ok	ok	ok	H: problems towards the end
18106	22.08.2018 04:34:06	23.08.2018 06:50:52	171.838	406	(ok)	ok	ok	ok	H: temporary jumps
18107	22.08.2018 05:21:26	23.08.2018 08:05:37	156.243	1437	ok	-	ok	ok	X (4): not levelled
18108	22.08.2018 06:18:24	23.08.2018 10:13:29	194.153	3625	ok	ok	ok	ok	
18109	22.08.2018 07:29:28	23.08.2018 12:00:25	181.855	4125	(ok)	ok	ok	ok	H: problems in second half

Data management

Refraction seismic refraction data will be archived at the geophysics section at AWI in raw and processed formats. It will be available to other scientists after a period of 4 years after the end of the cruise.

3.4 Magnetics

Work at sea

Two instrument setups were used during the cruise: a towed and an onboard magnetometer. Fig. 3.19 illustrates the location of both sensors plus all relevant coordinates. The positions of ship's reference point (MINS-1), gravity meter KSS32-M and onboard vector magnetometer, BGR GPS antenna, magnetometer winch and outrigger port are annotated. Magnetometer towfish distances from the ship's GPS position follow from the sketch, taking cable length on the winch, cable path along the outrigger, and GPS antenna position into account.

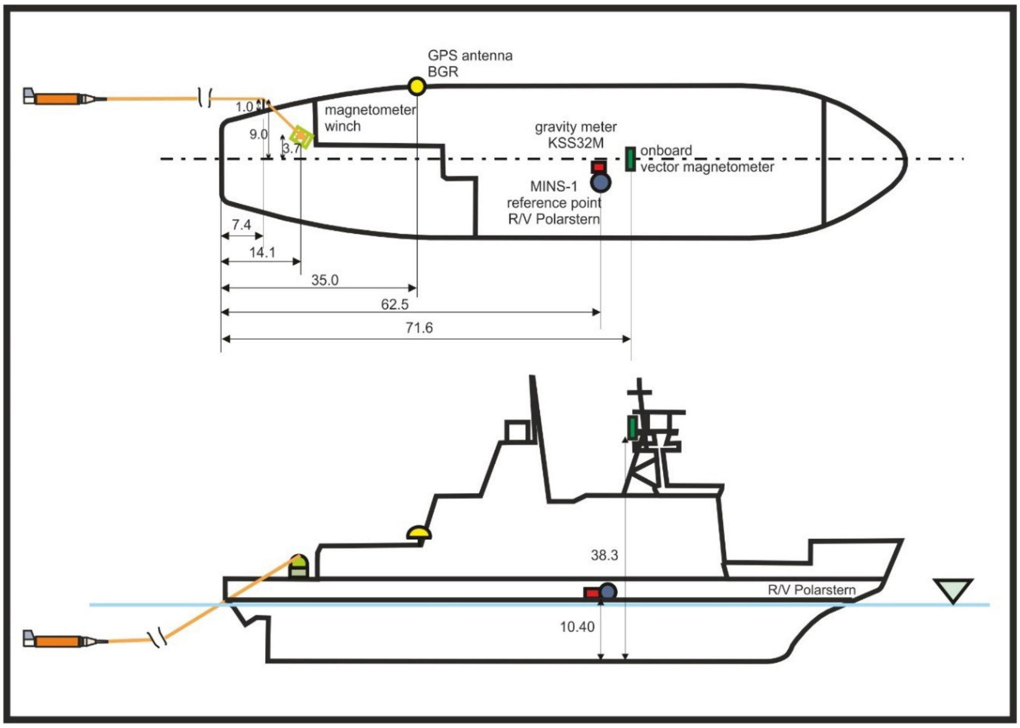


Fig. 3.19: Sketch of Polarstern with the locations of relevant equipment. (distances in metres)

3.4.1 Towed magnetometer system

The towed magnetometer system consists of two different types of sensors (Fig. 3.20). Overhauser sensors measure the scalar absolute value of the total magnetic field while fluxgate magnetometers measure the magnetic field vector in its three components.

The SeaSpy™ Marine Gradiometer System manufactured by Marine Magnetics Corp. consists of two proton precession magnetometers, enhanced with the Overhauser effect. Two exactly equivalent magnetometers are towed 150 meters apart as a longitudinal array about 600 metres astern of the ship (Fig. 3.20). Both sensors measure the total intensity of the magnetic field simultaneously. The difference between the two measurements is an approximation for the longitudinal gradient of the field in the direction of the profile line. Provided that the time variations are spatially homogeneous over the sensor spacing, the differences are free from temporal variations and their integration restores the variation-free total intensity or magnetic anomaly (apart from a constant value).

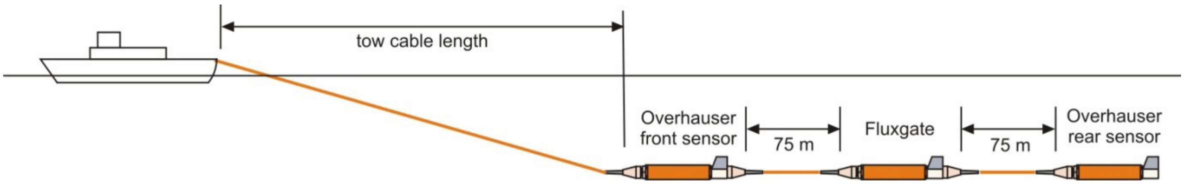


Fig. 3.20: Schematic sketch of the towed gradiometer system setup

A standard proton precession magnetometer uses a strong DC magnetic field to polarize itself before a reading can be taken. Overhauser sensors work similar to proton magnetometers with the exception that the excitement of the proton spin (polarization) is done by radio waves which excite the spin of the electrons in an organic fluid within the sensors. The electrons then transfer their spin to the protons in the fluid via a quantum mechanical process called Overhauser effect. Similar to every other proton magnetometer the relaxation frequency of the protons is a measure for the magnitude of the ambient magnetic field. The polarization power required is much smaller than that needed by normal proton magnetometer systems and the AC field may be left active while the sensor is producing a valid output signal. This allows the sensor to cycle much faster and to produce more precise results than a standard proton magnetometer. As configured for this survey, the Overhauser sensors had a cycle time of one second. The sensors are specified with a noise level of 0.01 nT/√Hz, a resolution of 0.001 nT, and an absolute accuracy of 0.2 nT.

The fluxgate tow fish was designed by the BGR marine geophysics group. The fluxgate magnetometer and the electronics were built by MAGSON GmbH in Berlin and are installed into a standard SeaSPY tow fish housing. The system (Fig. 3.21) consists of a digital tri-axial fluxgate magnetometer, two different dual-axial tilt-meters, a single axis accelerometer and sensors for temperature, pressure, and humidity. Fluxgate and inclinometers are mounted on a common platform.

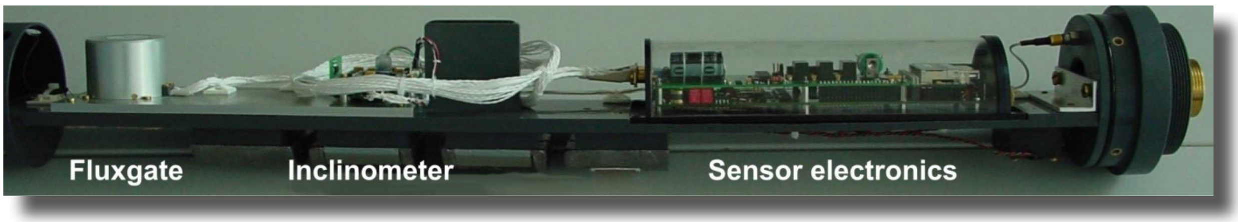


Fig. 3.21: Components inside the fluxgate magnetometer tow fish

The digital Magson fluxgate consists of two crossed ring-cores, three pick-up coils, and a tri-axial Helmholtz coil system for field feedback. The vector compensation reduces the cross field influence on the measurements. The internal feedback circuit, using digitally controlled DC-currents fed into the Helmholtz-coils maintains precise nulling of the field inside the ring-core. The second harmonic of the excitation frequency, which is digitized directly, is a measure of the absolute value of the magnetic vector component. Scale factor and non-orthogonality depend only on the stability of the feedback coil system and are estimated by a scalar fluxgate calibration. Fluxgate magnetometers with digitally compensated ring-core sensors maintain a considerably higher accuracy over non-compensated instruments and yield higher stability over time and temperature (24 ppm/°C thermal expansion coefficient of feedback coil system). The Magson fluxgate sensor is specified with a noise level of <0.02 nT/√Hz, a resolution of 0.008 nT and a long-term stability < 10 nT/year.

The fluxgate and the tilt sensors are mounted on a common aluminium plate. The first tilt sensor by ABJ measures pitch and roll angles by 3D-MEMS technology (VTI sensor chip). The angular range covers a span of ±30° with a resolution of 0.001°. The second tilt sensor is a dual-axial accelerometer by Analog Devices (ADXL203), measuring pitch and roll angles over a range of ±50° resolving 0.05° of arc (noise level 0.095°). A third accelerometer for the vertical axis (ADXL103) allows detection of unintended tow fish positions beyond the inclinometer range. The accuracy of the ABJ sensor is significantly higher than that of the Analog Devices sensor, but the calibration function is non-linear and temperature dependent. The Analog Devices sensor has a calibration function which is linear and almost temperature independent, but it suffers resolution and a higher noise level by an order of magnitude. Both tilt meters measure not only the static acceleration, which would provide the needed true roll and pitch angles, but by principle they also measure dynamic accelerations of the continuously moving tow fishes. This source of error can be reduced by filtering. An embedded microprocessor with a flash disc was used to store all fluxgate and tilt-meter readings. The storage capacity of 1 GB is sufficient to allow 11 days of continuous operation at the selected sampling rate of 10 Hz. High precision of the measured tilt angle is necessary to rotate the field components from the sensor's coordinate system of the moving fluxgate tow fish into the geomagnetic coordinate system.

During cruise PS115/1 the towed magnetic measurements were massively hampered by the ice conditions. It was not safe to deploy the sensors directly behind the stern as the distance to the airgun cluster towed there in the middle would have been too small. So, the sensors were deployed on portside (Fig. 3.22). With the given weight of the tow cable and the sensors and with the ship's speed during mcs operations, the cable entered the water about 40 to 50 metres behind the stern. Therefore, although the tow cable was pulled inwards and the navigation officers tried to avoid them, frequently ice floats were captured by the tow cable, so that the sensors were pulled subsequently across the ice floats. During the first mcs profiles no magnetics was deployed as there was hope that the ice conditions will improve. After two days, however, it became clear that the ice conditions will persist and that we would not get any towed magnetic data, if we take the risk to deploy the sensors also during the prevailng ice conditions. However, we deployed a maximum of 2 sensors, in order to get the instruments back on deck in shorter time, when the ice conditions worsen in a way that the instruments had to be recovered. The sensors were amazingly robust and delivered satisfying data for quite a long time. But after some days the mechanical stress on the electronics was too high and the sensors failed. The screw connections and the cable itself, however, never failed, so that no instrumentation was lost. Towards the end of the cruise just the fluxgate sensor tow fish could be deployed. The applied magnetometer configurations are listed in Table 3.5.

Tab. 3.5: Magnetometer configuration (sensors and cables) during cruise PS115/1

Profiles PS115/1 GREENMATE	**Main Cable**	**Front sensor Overhauser**	**Cable**	**Rear sensor Overhauser**
BGR18-107b	600-1	13545	150-4	13546
BGR18-106.1 – BGR18-108	600-1	13545	150-4	13809
BGR18-108b	600-1	13141	n/a	n/a
BGR18-109 – BGR18-1R1	600-1	13545	n/a	n/a
BGR18-113a – BGR18-116	650-1	13142 Magson	n/a	n/a

Fig. 3.22: Outrigger with block on starboard side (left) and frapped tow cable (right)

Data Processing

Available BGR programmes for magnetic data processing are either by Eilers et al. (1994) or by Engels et al. (2008). The Eilers code is processing SeaSpy gradiometer data and performed routinely during the cruise. The Engels code has been written for processing both, gradiometer and vector magnetometer data. It is using different filter and gradient reconstruction techniques than Eilers; processing details are well described in cruise report SO197 (2008). However, as mentioned above the data are often disturbed and require additional preprocessing. So, no gradiometer processing has been performed on board. Only the International Geomagnetic Reference Field IGRF-15 (Finlay et al., 2010) was removed.

Single sensor fluxgate data provide additional anomalies in all three components (e.g. Z-anomaly), which may contain an external variation contribution. Post processing vector data analysis provides additional interpretation tools (Engels et al., 2008): magnetic boundary strike ellipses in time-space domain locate magnetic contrasts, their direction and dimensionality; spectra analysis provides estimates of the depth of magnetic sources and their wavenumber range, detects distortions by external variations, and resolves magnetic strike directions even from single profiles. This vector data analysis is a part of post cruise processing as well.

3.4.2 Onboard vector magnetometer

The onboard vector magnetometer consists of two orthogonal three axis ring-core vector magnetometers systems installed in the ships crow nest towards the stern one over the other in the direction of the ship's yaw axis (Fig. 3.23). The system was built also by MAGSON GmbH and is permanently installed on *Polarstern*. The sensors have a dynamic range of +/- 100.000 nT and a long-term stability of <10 nT/year. The data are recorded in the DShip data acquisition and management system. The data set also contains navigation data from the MINS inertial platform (ship's roll, pitch and heading angles). Unfortunately the sampling rate of the data is set to 1 Hz and could not be changed. BGR installs routinely an equivalent system on research vessels and then a sampling rate of 10 Hz is used. Calibration loops in the shape of figure-of eights were performed on August, 18 and on September, 2. The diameter of the loops was 1 nm, the ship's speed about 5 kn. The evaluation of the calibration and the processing of the data will be performed after the cruise.

Fig. 3.23: Onboard dual vector magnetometer installed in the ship's crows nest

Data Quality

The magnetic data observed during the cruise are in general of good quality. The Earth magnetic activity was generally low to moderate while magnetic measurements have been carried out with the towed magnetometer system. Fig. 3.24 shows the Earth magnetic activity represented by Kp values after Bartels (1957) for the time of May to September 2018. The time period of the onboard vector magnetometer recording is marked by the blue bar. Additional red lines indicate the times when the towed magnetometers were deployed. From August 25 to 28 the Earth magnetic activity was higher and we could expect disturbances in the vector magnetometer data. In order to estimate the magnetic daily variations, the observations from the nearest magnetic observatory in Hornsund on Spitsbergen (77°N, 15.55°E) will be considered. The observatory is run by the Institute of Geophysics of the Polish Academy of Sciences. The data could be accessed via the INTERMAGNET web page.

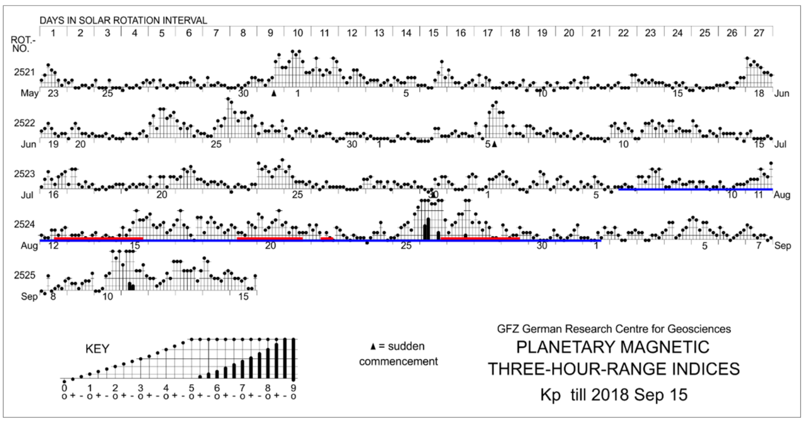


Fig. 3.24: Planetary magnetic three-hour-range indices for May to September 2018. Low indices indicate low Earth magnetic activity and thus little disturbance of magnetic measurements. The time period of magnetic measurements during cruise PS115/1 is shown by the blue bar. Additional red lines indicate the times when the towed magnetometers were deployed.

Preliminary results

Fig. 3.25 shows the magnetic data along the profiles that were acquired with the towed magnetometer system during PS115/1. The total length of the magnetic profiles is 1,582 km. Fig. 3.26 shows all magnetic data in a map display. Four profiles (BGR18-104, -106, -106.1 and -107B) run across the continental margin onto the oceanic crust. Magnetic sea floor spreading anomalies can be clearly identified on these profiles. However, a detailed interpretation with this data will become difficult because only a few wiggles (polarity intervals) are visible on the short oceanic parts of the profiles. The continent/ocean boundary shows no significant magnetic anomalies and is marked by slight negative anomalies only. The strongly positive gravity anomalies (see Fig. 3.31) at the shelf break, e.g. at 80°N / 7°W, are not accompanied by magnetic anomalies. Comparison with reflection seismic and gravity data will be performed to investigate the architecture of the continental margin.

On the continental shelf mostly negative anomalies are found. At around 80.3°N / 8°W a strong positive anomaly with a rather long wavelength character is evident. This indicates the presence of highly magnetized rocks of probably volcanic origin in this area. However, this anomaly does not correlate with a gravity maximum. Again, a combined interpretation with reflection seismic and gravity data will be necessary.

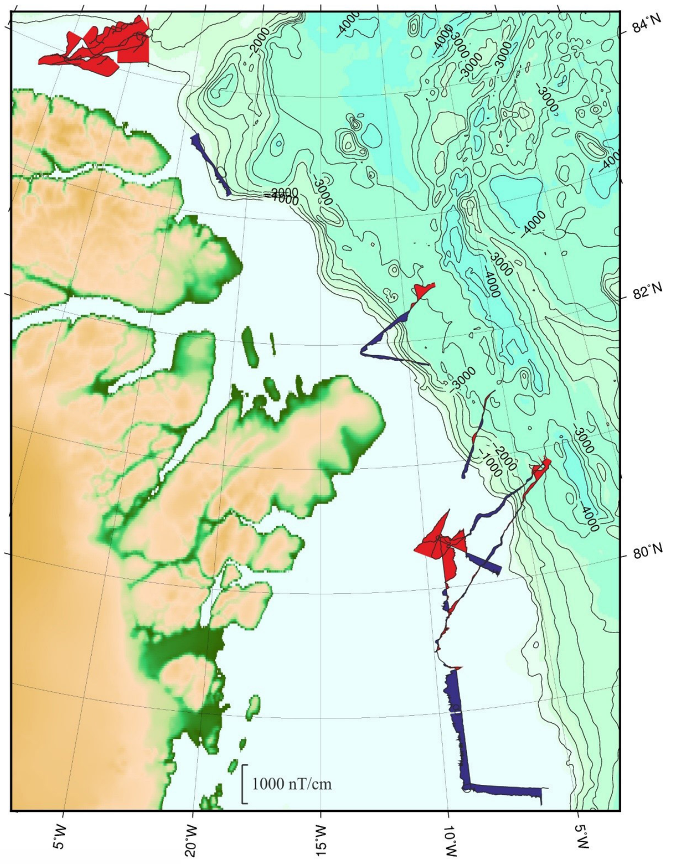


Fig. 3.25: Magnetic total field anomalies (red: positive; blue: negative) acquired with the towed magnetometer system during PS115/1.

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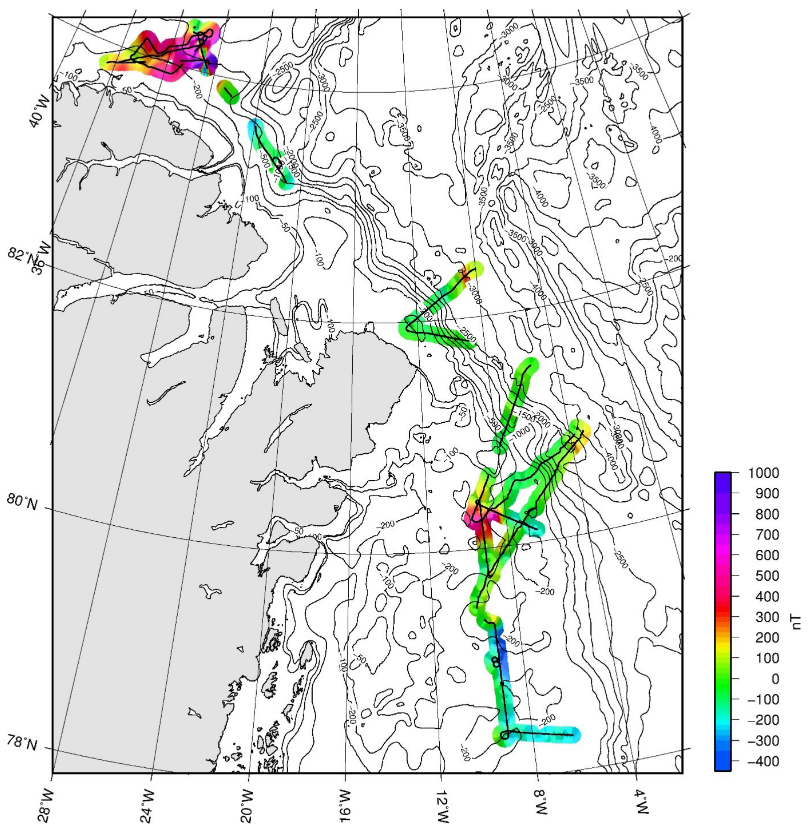


Fig. 3.26: Map of the total magnetic field anomalies in the survey area of cruise PS115/1. The map is drawn up to a distance of 8 kilometres from the tracks and is underlain by the bathymetry of Andersen et al. (2014).

Fig. 3.27 shows a detailed map of the magnetic anomalies in the area north of Cape Morris Jesup. Especially in the eastern part the anomalies show both short wavelength and long wavelength character at rather high (up to 1,000 nT) amplitudes. This indicates the incidence of shallow highly magnetized rocks of probably volcanic origin in a larger area. The anomalies decrease westward reflecting less volcanic material in this area. A detailed comparison with reflection and refraction seismic and gravity data will be necessary to decipher the structural elements of this area adjacent to the Morris Jesup Rise.

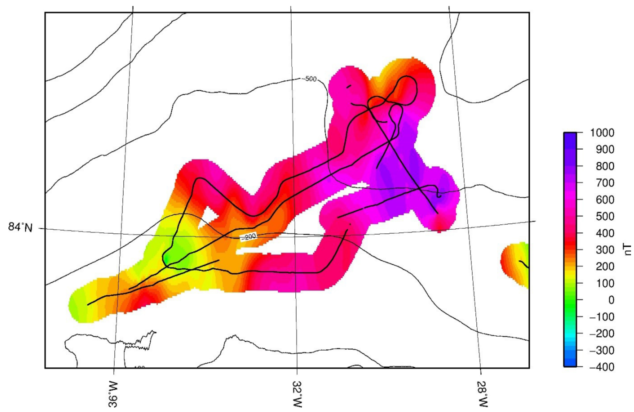


Fig. 3.27: Map of the total magnetic field anomalies in the area noth of Cape Morris Jesup. The map is drawn up to a distance of 5 kilometres from the tracks and is underlain by the bathymetry of Andersen et al. (2014).

Data management

Magnetic data will be stored in the marine magnetics database and archived at BGR in raw and processed formats. It will be available to other scientists after a period of 4 years after the end of the cruise.

3.5 Gravity

Work at sea

During cruise PS115/1 the sea gravimeter system KSS32-M, serial No. 25, was used. The system is permanently installed on *Polarstern* in the gravimeter room (F-632) one level below the main deck (Fig. 3.28). The sea gravimeter is located 11.26 m above the vessel's keel, 0.88 m to portside from the centerline, and 53.20 m forward of the stern (see Fig. 3.19).

Fig. 3.28: KSS32-M gravimeter system (platform with sensor and notebook) in the gravimeter room on Polarstern.

The gravimeter system KSS32-M is a high-performance instrument for marine gravity measurements, manufactured by the Bodenseewerk Geosystem GmbH (BGGS). The system is controlled by a notebook (HP ProBook 6550B). The main software to operate the KSS32-M is DACQS developed by BGGS. It allows to change a number of settings (for example: parameters of the Bessel Filter applied to the measured data) and provides detailed information about the status of the system. The data acquisition is also managed by DACQS, whereby a wide range of values, not only the gravity but also for example the attitude and horizontal accelerations of the platform, could be recorded.

The data are transmitted to the DSHIP system and online navigation data from this system are sent with a rate of 1 Hz to support the stabilizing platform.

Data processing

The raw gravity data from the DAVIS-SHIP (DSHIP) system are recorded and processed by the BGR data acquisition system installed in the dry lab no. 4.

Processing of the gravity data consists essentially of the following steps:

- a time shift of 76 seconds due to the overcritical damping of the sensor,
- conversion of the output from reading units (r.u.) to mGal by applying a conversion factor of 4.505 mGal/mV. On this cruise this was done in the system itself by software settings,
- connection of the harbour gravity value to the world gravity net IGSN 71,
- correction for the Eötvös effect using the navigation data,
- correction for the instrumental drift (not performed until completion of the cruise),
- subtraction of the normal gravity (GRS80),
- correction for the instrumental drift (performed after completion of the cruise).

As a result, we get the so-called free-air gravity anomaly (FAA) which is in case of marine gravity simply the Eötvös-corrected, observed absolute gravity minus the normal gravity. Gravity values were recorded with a data rate of 1 Hz. This data rate is kept during data processing. The KSS32-M anomalies show short-wavelength oscillations in the order of 1-2 mGal especially while cruising with higher ship velocities. Therefore a median filter with a length of 300 s was applied to the data. Infrequent outliers were removed manually in advance. Additionally, data recorded during sharp turns and rapid speed changes of the vessel show disturbed values and were removed also manually.

The gravity anomalies, which are provided directly by DAQS were additionally recorded. Free-air gravity anomalies are obtained when the KSS32-M is supplied with the necessary navigation data (geographical latitude and longitude, speed, course over ground and heading). However, the filtered free-air anomalies provided by the BGR processing described above were used for display and interpretation.

Gravity ties to land stations

To compare the results of different gravity surveys the measured data have to be tied to a world-wide accepted reference system. This system is represented by the International Gravity Standardization Net IGSN71 (Morelli, 1974). The IGSN71 was established in 1971 by the International Union of Geodesy and Geophysics (IUGG) as a set of world-wide distributed locations with known absolute gravity values better than a few tenths of mGal.

Therefore, gravity measurements on land have to be carried out to connect the gravity measurements at sea with the IGSN71. As the instrument was already heated and ready to use in Tromsø we used the AWI gravity meter (LCR G1031), which is permanently on *Polarstern*. In Bremerhaven also the LCR G1031 was used. The point descriptions and absolute gravity values of reference stations in Tromsø and Longyearbyen were kindly provided by NGU in Trondheim. In Tromsø two reference stations are located at the Tromsø University Museum (points **01**, **02**). In Longyearbyen there is a reference station at the airport. In Tromsø *Polarstern* moored at Breivika harbor about 80 m from the southwestern end of pier position No. 25 (Fig. 3.29). On August 4, tie measurements to point **A** on the pier opposite the gravimeter room have been made. The connection measurements resulted in an average absolute gravity value of 982,556.491 mGal (with water level –3.25 m, IGSN71) for point **A** at the water level. The ship's draught was 11 m and the gravity sensor is located 11.26 m above keel. So the absolute gravity value for the sensor location amounted to 982,556.424 mGal. The reading of the KSS32-M at the leaving time on August 5, 13:30 UTC with the same water level was 2364.75 mGal.

Tab. 3.6: Gravity tie measurements in Tromsø and Bremerhaven

Station	Observer	Instrument	Date	Time UTC	Reading units	Gravity value [mGal]
A	H	LCR-G1031	04.08.18	12:00	6085.62	6219.578
A	H	LCR-G1031	04.08.18	12:03	6085.62	6219.578
A	H	LCR-G1031	04.08.18	12:05	6085.63	6219.588
01	H	LCR-G1031	04.08.18	12:35	6081.48	6215.350
01	H	LCR-G1031	04.08.18	12:40	6081.51	6215.380
01	H	LCR-G1031	04.08.18	12:42	6081.51	6215.380
02	H	LCR-G1031	04.08.18	12:55	6082.22	6216.106
02	H	LCR-G1031	04.08.18	12:58	6082.23	6216.107
02	H	LCR-G1031	04.08.18	13:00	6082.23	6216.107
A	H	LCR-G1031	04.08.18	13:40	6085.63	6219.588
A	H	LCR-G1031	04.08.18	13:45	6085.63	6219.588
A	H	LCR-G1031	04.08.18	13:48	6085.64	6219.598
B	H	LCR-G1031	16.10.18	09:47	4913.74	5021.969
B	H	LCR-G1031	16.10.18	09:49	4913.74	5021.969
04	H	LCR-G1031	16.10.18	10:20	4913.70	5021.928

Station	Observer	Instrument	Date	Time UTC	Reading units	Gravity value [mGal]
04	H	LCR-G1031	16.10.18	10:25	4913.70	5021.928
B	H	LCR-G1031	16.10.18	11:12	4913.76	5021.990
B	H	LCR-G1031	16.10.18	11:14	4913.76	5021.990
Observer: H = Heyde Gravity in mGal was calculated using LCR-G1031 scaling tables.						

Reference Stations:

01: Tromsø, University Museum, Bolt Q, near entrance 982551.448 mGal (IGSN71)

02: Tromsø, University Museum, Bolt R, seismograph room, concrete pillar 982552.140 mGal (IGSN71)

03: Longyearbyen, 45 m from the southeastern end of the main Pier (from tie measurements in 2013) 982965.286 mGal (IGSN71)

04: Bremerhaven, AWI building Wegener-Haus, Room 0082 981356.720 mGal (IGSN71)

Gravity stations:

A: Tromsø, Breivika Harbor, pier No. 25

B: Bremerhaven harbour, Dalbenpier at Lloyd shipyard

Differences between reference and gravity stations:

01 – A = - 4.215 mGal

02 – A = - 3.484 mGal

01 – 02= - 0.727 mGal (-0.692 mGal according to IGSN71)

Difference to **02** is preferred as point **02** is perfectly located on a concrete pillar and shows no uncertainties concerning the elevation.

Absolute gravity at **A**: 982555.663 mGal from **01**

982555.624 mGal from **02**

Absolute gravity for **A** (reduced to sensor level –3 m) 982556.424 mGal (IGSN71 system) used for the gravity tie on 05.08.2018 (13:30 UTC).

Reading of sea gravimeter KSS32-M at that time: 2364.75 mGal.

Difference between reference and gravity station:

04 – B = -0.052 mGal

Absolute gravity at **B**: 981356.772 mGal

Absolute gravity for **B** (reduced to sensor level –0.84 m) 981356.995 mGal (IGSN71 system) used for the gravity tie on 16.10.2018 (11:15 UTC).

Reading of sea gravimeter KSS32-M at that time: 1159.44 mGal.

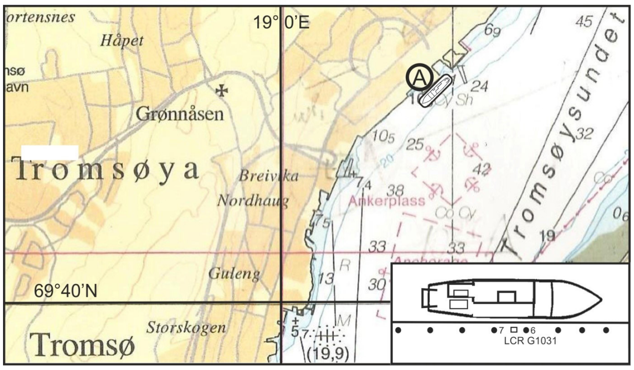


Fig. 3.29: Location of the mooring site of Polarstern at pier No. 25 in Breivika Harbor in Tromsø (A)

On September 3, *Polarstern* anchored in Adventfjorden about 1 km northeast of the main pier in Longyearbyen. Of course, no direct connection measurements could be carried out. However, tie measurements to the pier were done during the PANORAMA 1 cruise in 2013. The connection measurements resulted in an average absolute gravity value of 982,965.286 mGal (with water level –3.25 m, IGSN71) for point **03** at the water level. The sensor is located 0.26 m above the water level resulting in an absolute gravity value of 982,965.206 mGal. The reading of the KSS32-M on September 3, 07:30 UTC was 2775.22 mGal and a drift rate could be at least roughly estimated. The readings in Tromsø and Longyearbyen would imply an instrumental drift of +1.69 mGal in 28.75 days, which is a very reasonable value. However, the correct drift rate could be determined only when *Polarstern* moored at the pier in Bremerhaven after PS115/2.

At the end of the cruise *Polarstern* moored at the Dalbenpier at Lloyd shipyard in Bremerhaven near the second bollard 60 about 80 m from the southern end of the pier (Fig. 3.30). On October 16, tie measurements to point **B** on the pier opposite the gravimeter room on *Polarstern* were made. A reliable reference gravity station is located in the AWI Wegener-Haus, Room 0082 (**04**). Point **B** was 1.7 m above the water level with a ship's draught of 10.4 m. The connection measurements resulted in an average absolute gravity value of 981,357.21 mGal (reduced to sensor level –0.84 m, IGSN71) for point **B**. The reading of the KSS32-M at the same time (October 16, 2018, 11:15 UTC) was 1,159.44 mGal.

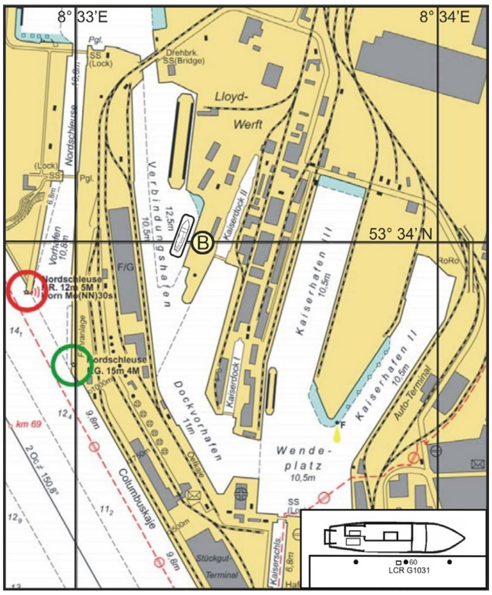


*Fig. 3.30: Location of the mooring site of Polarstern at the Dalbenpier at the Lloyd shipyard in Bremerhaven (**B**).*

The instrumental drift for the cruise can be derived from the readings in Tromsø and Bremerhaven to -5.88 mGal / 71.9 days or -0.082 mGal/day. This drift rate is rather large but lies within the normal drift range of marine gravity measurements with the KSS32-M. Besides the negative drift behavior contradicts the observations in Longyearbyen, which suggested a positive drift rate. Nevertheless it will be applied to the data. Marine gravity measurements were recorded from 06.08.18 (06:23 UTC) till 01.09.18 (13:16 UTC), i.e drift started with 0.058 mGal and ended with -2.208 mGal.

Preliminary results

Gravity measurements were carried out continuously during the cruise from Tromsø to Longyearbyen. However, the data were recorded only from August 6 (06:23 UTC) till September 1(13:16 UTC) along a total track length of 6,165 km. Thus, gravity data along all 24 profiles with a total length of 2,509 km were measured. In addition about 2,500 km of the acquired data along transits and curves were usable. The distribution of the survey profiles can be seen in the track chart in Fig. 1.1. Despite the coverage of the survey area is relatively sparse, a map of the free-air gravity anomalies was prepared. Fig. 3.31 shows the map based on a 1 x 1 (arc-)minutes grid together with the survey tracks. The map is drawn up to a distance of 10 km from the survey track.

Our dataset can serve as a reference for the comparison of two different satellite gravity data compilations. Global precise tracking coupled with dynamic orbit calculations provide an independent option to measure the height of the satellite above the ellipsoid. The difference between these two measurements is equal to the geoid height. So, in marine areas the free-air anomaly can be calculated from the slope of the geoid. Closely spaced satellite altimeter profiles collected during the GEOSAT Geodetic Mission (~ 6 km) and the ERS 1 Geodetic phase (~ 8 km) were used by different groups to calculate grids of the free-air gravity anomalies.

However, as the one from Sandwell and Smith (2005), version 24.1., is limited to a latitude of 80.738°N, it was not further considered. In contrast the second data set from the DTU Space Centre, Copenhagen (Andersen et al., 2014), version DTU13, covers the complete latitude range. Subtracting the 1 x 1 minute grid of the DTU13 data from the 1 x 1 minute grid of the shipboard data one obtains the maps of the differences shown in Fig. 3.32.

The differences of both datasets range between +40 and -35 mGal, but the differences are below ±10 mGal along most tracks. Higher positive differences are found in the northernmost area and above all north of Kronprins Christian Land in the transition area from the shelf to the ocean. Especially in this area also higher negative differences could be observed. South of 80°N the differences are generally smaller but amount nevertheless locally to values of more than 20 mGal. Satellite gravity anomalies along the complete track were additionally calculated with bicubic interpolation out of the 1 x 1 minute grids and subtracted from the shipboard data (Fig. 3.33). The mean difference is 0.29 mGal with a standard deviation of 7.47 mGal.

To illustrate the differences between the data sets in detail, Fig.s 3.34 and 3.35 show exemplary comparisons along profiles BGR18-112, -1R1 and -118. Regarding BGR18-118 the wavelength range of satellite and shipboard anomalies is comparable in case of water depths greater than 1000 m whereby the satellite data show oscillations with a wavelength of about 25 km and amplitudes of ±3 to 5 mGal which do not correlate with anomalies in the shipboard data. We consider these differences to represent the error in the satellite data. Moreover, close to the coast anomalies of short wavelength are not resolved in the satellite data. This reflects the limited resolution of these datasets. For the northern profiles the differences are so big that it could be stated that the satellite derived gravity and bathymetry data are obviously so incorrect that the data should not be used in this region.

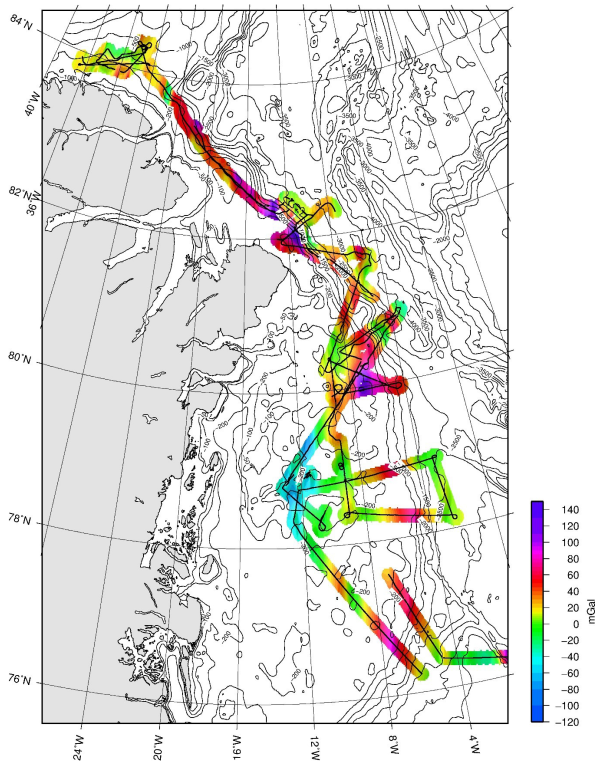


Fig. 3.31: Map of the free-air gravity anomalies in the survey area of cruise PS115/1. The map is drawn up to a distance of 10 km from the tracks

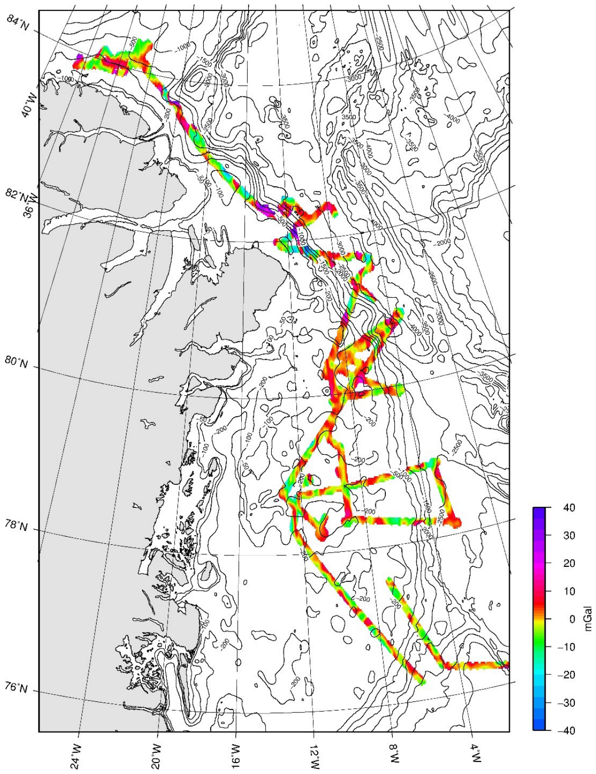


Fig. 3.32: Differences of the shipboard free-air gravity data and the gravity dataset DTU13 derived from satellite altimetry (Andersen et al., 2014). The maps are masked beyond a distance of 5 km from the PS115/1 profiles.

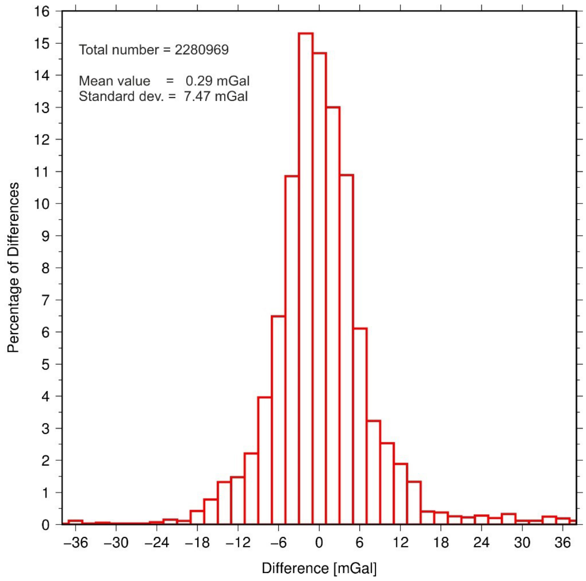


Fig. 3.33: Histogram of differences between shipboard KSS32-M free-air gravity anomalies and the corresponding DTU13 gravity data derived from satellite altimetry

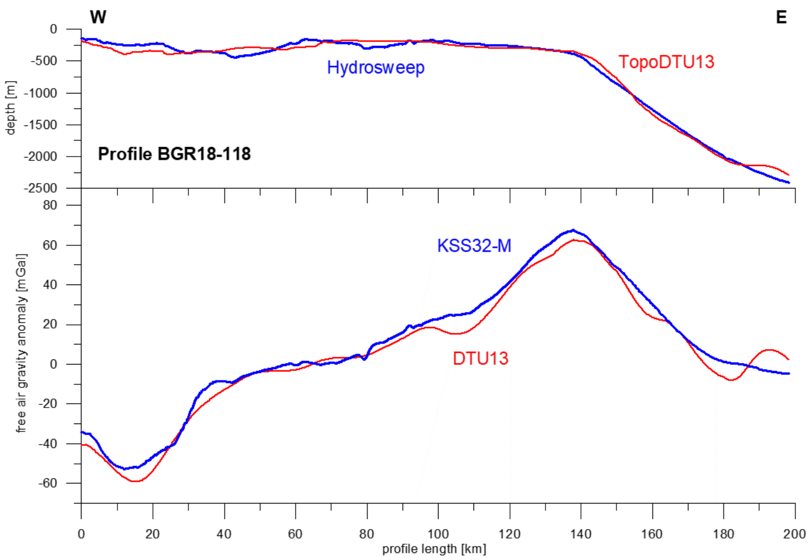


Fig. 3.34: Comparison of the ship-based KSS32-M with DTU13 satellite free-air gravity anomalies along profiles BGR18-118 together with the corresponding bathymetry measured with the Hydrosweep multibeam system and from the global bathymetry of Andersen et al. (2014)

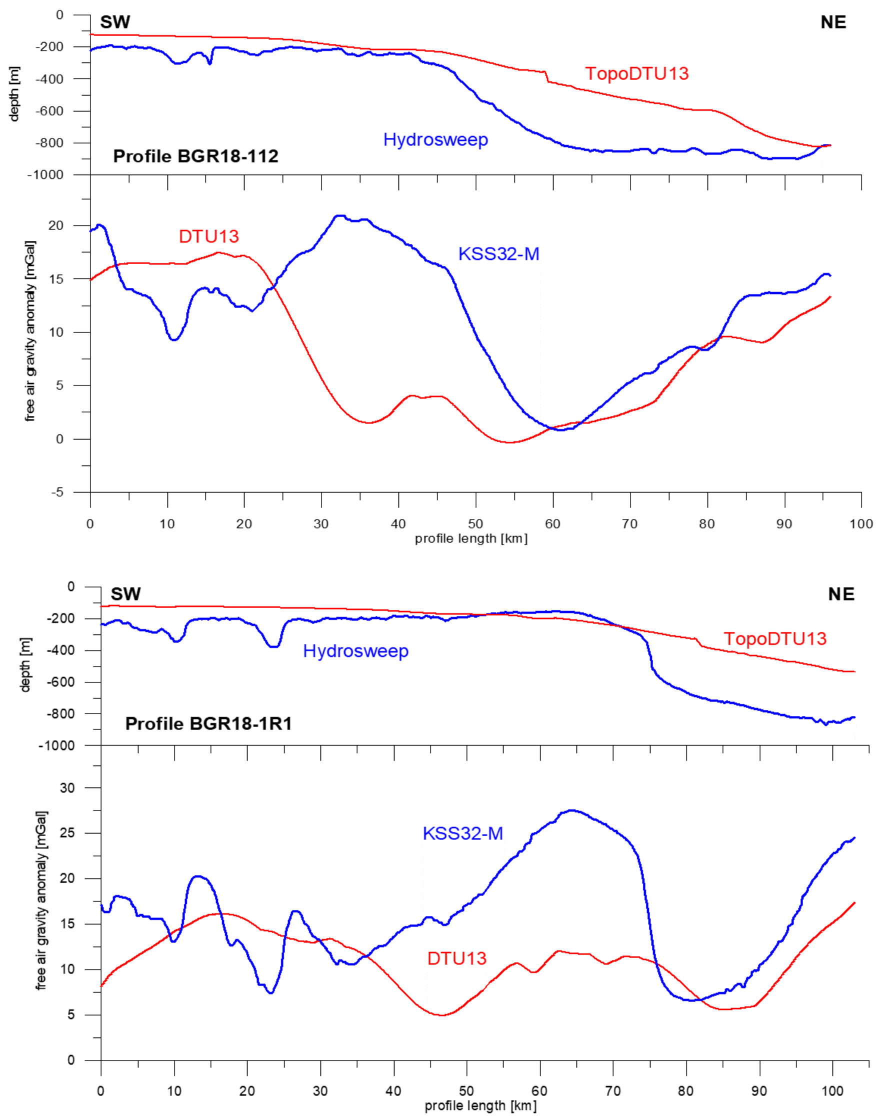
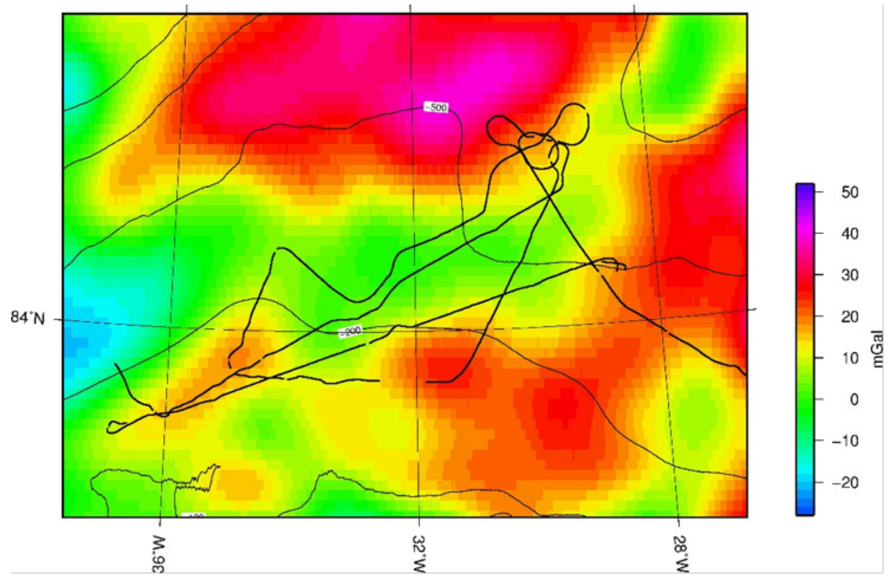


Fig. 3.35: Comparison of the ship-based KSS32-M with DTU13 satellite free-air gravity anomalies along profiles BGR18-112 (above) and BGR18-1R1 (below) together with the corresponding bathymetry measured with the Hydrosweep multibeam system and from the global bathymetry of Andersen et al. (2014).

One can conclude that the free-air gravity anomalies derived from satellite altimetry are of great importance to get an overview of the gravity field in an oceanic area. For areas north of about 82°N and for detailed investigations shipboard gravity measurements are indispensable. Fig. 3.36 shows the comparison of the free-air gravity anomaly maps for the survey area north of Cape Morris Jesup. Only the shipboard data should be used for further interpretation.



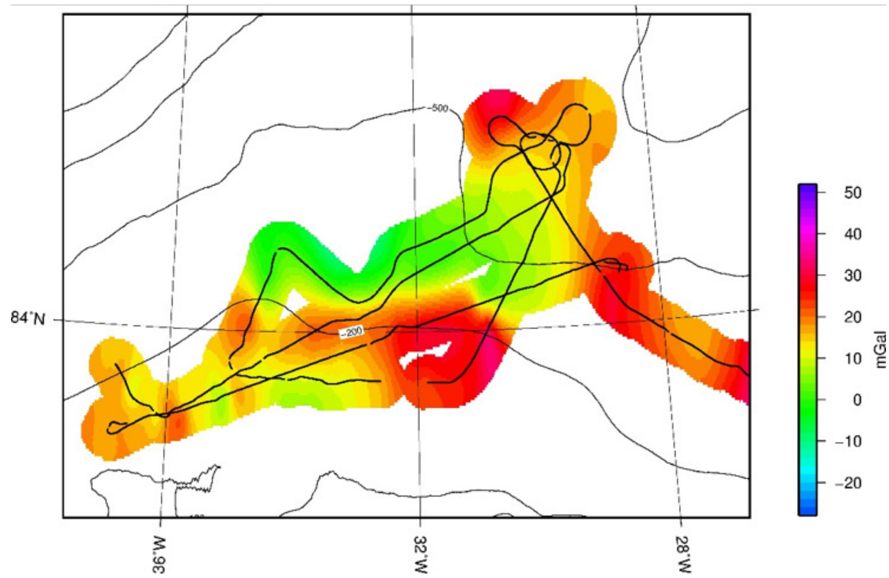


Fig. 3.36: Comparison of the DTU13 satellite (above) and the ship-based KSS32-M (below) free-air gravity anomaly maps in the area noth of Cape Morris Jesup. The maps are underlain with the global bathymetry of Andersen et al. (2014).

Combined free-air gravity anomaly map

In order to get a more detailed idea of the gravity field in the survey area the DTU13 gravity data were included in areas with no shipboard data to get a complete overview of the gravity anomalies. The resulting free-air gravity anomaly map is shown in Fig. 3.37. The anomalies range from -130 mGal close to East Greenland to +150 mGal at the shelf edge offshore NE Greenland.

The oceanic crust in the North Atlantic and the Fram Strait is characterized by free-air gravity anomalies from about -40 and to +50 mGal. In this area water depths of more than 4,000 m are reached. Higher gravity values can be correlated partly with topographic highs on the oceanic crust. The spreading ridges (Gakkel Ridge, Lena Trough, Knipovich Ridge) are characterized by elongated gravity minima. Towards Greenland the gravity anomaly values increase considerably. The map reveals prominent positive anomalies parallel to the shelf break (up to +140 mGal. These anomalies are typical for rifted continental margins which are characterized by prominent free-air gravity anomalies elongated parallel to the ocean-continent transition. For example, these features could be observed along large portions of the Atlantic margins (Watts and Fairhead, 1999). Sleep and Fuyita (1997) demonstrated that a simplified ocean-continent transition (oceanic crust bordering directly on continental crust, both of uniform thickness and isostatically compensated) produces an asymmetric free-air anomaly located at this boundary with a high on the outer shelf and a low on the oceanic crustal edge.

Landward the gravity anomaly values decrease considerably. Prominent minima are reached in the Wandel Sea and near the coast both to the North and the South of the Danmarkshavn Peninsula. In the North the southeastern boundary of the Morris Jesup Rise is characterized by a strong elongated gravity gradient area with high values on the rise and low values on the oceanic crust. However, these gravity anomalies derived from satellite altimetry have to be regarded with suspicion as mentioned above.

Bouguer gravity anomaly map

The underlying grid of gravity was compiled by merging the shipboard gravity observations and DTU13 gravity data derived from satellite altimetry. The water depth values were taken from the ship's echo sounding system and from the DTU13 bathymetry data when no echo sounder data was available. The reduction density was 1.64 g/cm³ and an infinite horizontal slab was assumed. A topographic reduction was not performed.

Fig. 3.38 shows the map of the Bouguer gravity anomalies together with the bathymetry. On the oceanic crust the anomalies are positive (up to +320 mGal in the Fram Strait) with a clear N-S trending decrease of values towards the Lena Trough and the Boreas Basin. Landward the gravity values decrease rapidly with decreasing water depth. Low Bouguer gravity values (-80 mGal) were estimated for the area of the basins on the E Greenland continental shelf. The lowest values (-130 mGal) are found close to the E coast and the NE coast in the Wandel Sea area.

Data management

Gravity data will be stored in the marine geophysical database and archived at BGR in raw and processed formats. It will be available to other scientists after a period of 4 years after the end of the cruise.

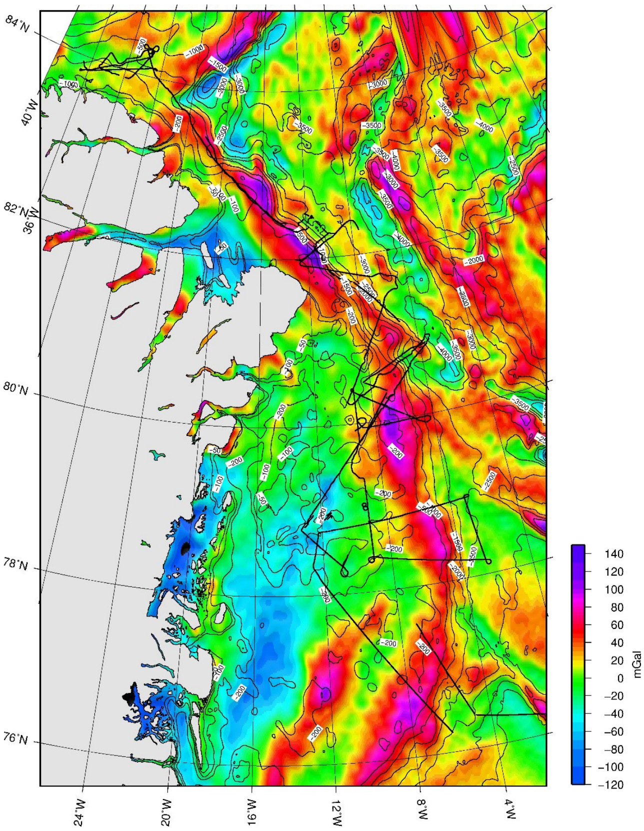


Fig. 3.37: Map of the free-air gravity anomalies. The underlying gravity grid was compiled by merging shipboard gravity observations and DTU13 gravity data derived from satellite altimetry. The map is based on a 1 x 1 (arc-) minutes grid and is underlain by the DTU13 bathymetry (Andersen et al., 2014).

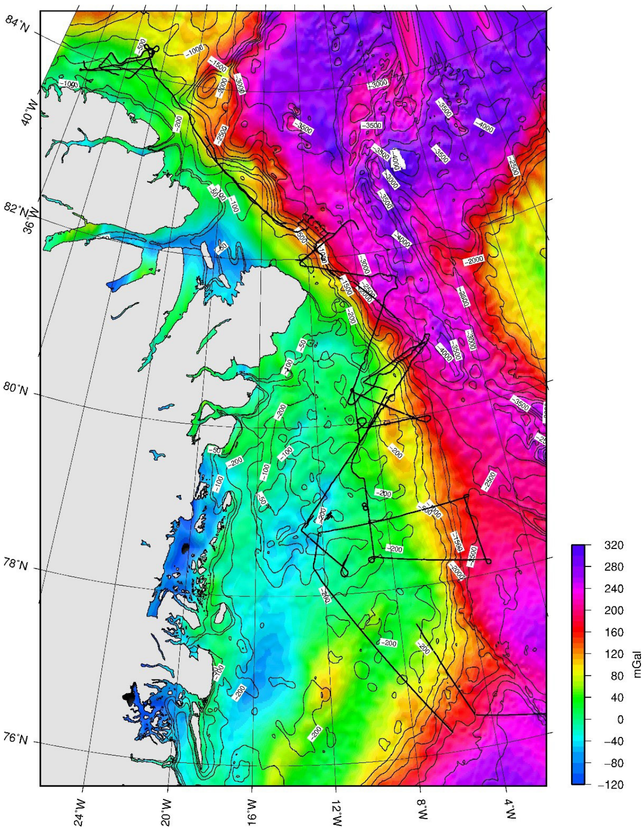


Fig. 3.38: Map of Bouguer gravity anomalies with no terrain corrections applied. The reduction density was 1.64 g/cm³. The map is underlain by the DTU13 bathymetry (Andersen et al., 2014).

3.6 Heatflow density measurements

Work at sea

BGR operates two different types of marine heat flow probes – a conventional probe, built after the so-called violin-bow concept and a second probe, specially designed for deployment in hard ground situations. It was assumed that in the survey area sediment strata are characterized by rather hard top sediments (drop-stones, relatively coarse, ice-rafted debris). For this reason BGR's "hard ground" heat flow probe (Fig. 3.39) was used during the cruise.

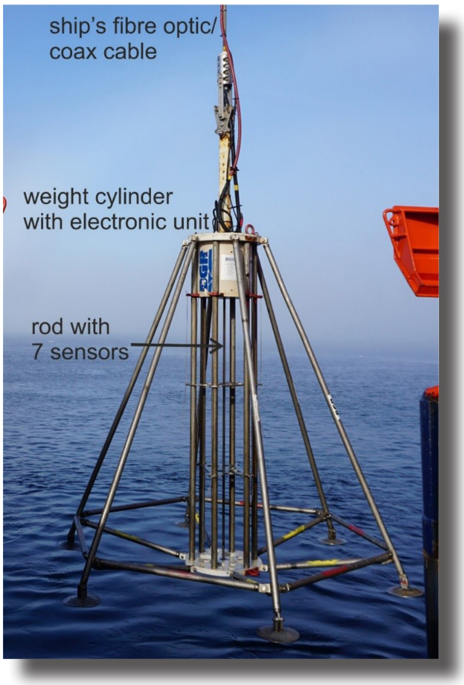


Fig. 3.39: BGR Hard ground heat flow probe prior to deployment from Polarstern.

The hard ground heat flow probe features a 2.2 m long sensor rod made of steel with a diameter of 2 cm mounted along the long axis of a cage and held in position by a special mechanism to prevent bending during penetration of hard ground sediments. It contains 7 thermistors with a spacing of 28 cm. The necessary force to press the sensor rod into the sediments is provided by a cylinder, which houses lead plates with a total weight of 600 kg and an electronic unit within a pressure vessel with a total weight of additional 144 kg. The purpose of the electronic unit housed in the pressure vessel is to control the data transfer and the measurements. All measured data are transferred via the coax part of the ship's combined fibre optic/coax cable in real time online to a laptop PC on board. All measured data are recorded, stored, digitized and monitored by the so-called "intelligent sensor modules" (ISM) installed in the pressure vessel. This technology relies on immediate digitization of measured values and their download in the memory and enables us to improve the accuracy of measurement to ~0.002 K. All recorded values are sent to an analogue-multiplexer and then to a 16-bit-A/D-converter. To further improve the accuracy of the measurements, an arithmetic mean of 20 consecutive measurements per sensor is calculated and then accepted as one single measured value. Unfortunately, the data of two sensors were not usable also when a different sensor rod was used. Thus the problem should be located within the electronics unit, but could unfortunately not be solved during the cruise.

Fig. 3.40 shows a typical heat flow measurement with the temperature graphs of five sensors from arriving at the seafloor until hoisting back through the water column. To achieve optimum thermistor calibration, the heat flow probe is stopped slightly above the seafloor during the lowering. A horizontal tilt meter (in the two perpendicular directions) in the electronic unit allows to record horizontal pendulum movements and verifying when the probe stopped swinging. After a time period of typically less than two minutes, thermal stabilization within ~0.002K is obtained at all thermistors. It is assumed that the thermistors measure identical seawater temperatures. Recalibration of all thermistors is achieved by using one thermistor as the master sensor, whose measured value is used to determine the offset measured by the other thermistors.

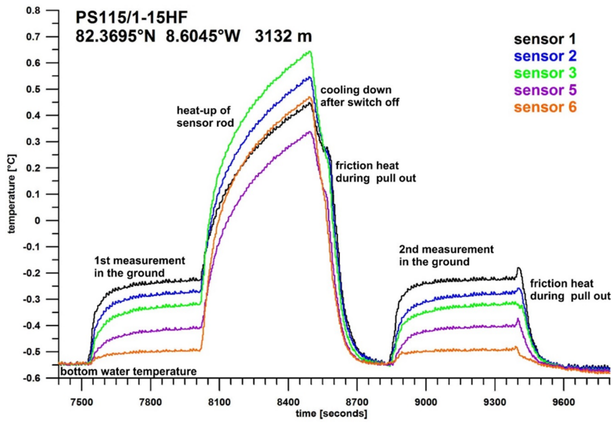


Fig. 3.40: Heat flow measurement PS115/1-15HF with the temperatures of five sensors from reaching the seafloor, penetration into the ground, heating, 2nd penetration and beginning heave up through the water column

Subsequently, the probe is lowered with a velocity of 0.1 m/s until penetration of the seafloor by the sensor rod is achieved. The tilt meter again gives information about the inclination of the probe. The thermal gradient in the sediments is measured continuously for a time period of 8 minutes. After this period, the frictional heat component, caused by the penetration of the rod into the sediments, has decayed to negligible values. Thereafter, a constant electric current of about 1 A (@ 10 V) is sent through the heating wire (about 2.2 m long) for 10 minutes for the determination of the *in-situ* thermal conductivity (λ). The temperature increase in the metallic rod is inversely proportional to the *in-situ* thermal conductivity of the adjacent sediments. The observed linear temperature increase after the initial heat-up phase at every thermistor is examined and afterwards λ can be determined from these values. Afterwards the probe is pulled out of the sediments until 10 m above ground. Then the probe is lowered again until penetration to conduct a second temperature gradient measurement for 8 minutes again.

It was planned to conduct the heat flow measurements at the same locations where the gravity cores and/or box or multi cores were sampled whenever the water depth was greater than 1,000 m. Experiences showed that measured temperature gradients in shallower areas are strongly disturbed by seasonal variations of the bottom water temperature.

After arrival in the southern survey area at the beginning of the cruise, one location was surveyed. One week later four measurements along a profile and at two locations a little northward were surveyed. At station 25-1HF the ice conditions made it necessary to shift the position to the slope and when the probe arrived at the bottom the inclination of the seafloor was higher than 8° and the probe was heaved again. On August 25 the final measurement was carried out in the largest water depth of 3,400 m.

Preliminary results

Altogether at 7 stations heat flow density measurements were conducted, whereby heat conductivities were determined at all stations. Fig. 3.41 shows the determined conductivities at the five thermistors at stations 14HF, 15HF, 16HF and 17 HF, together with the mean value for each location

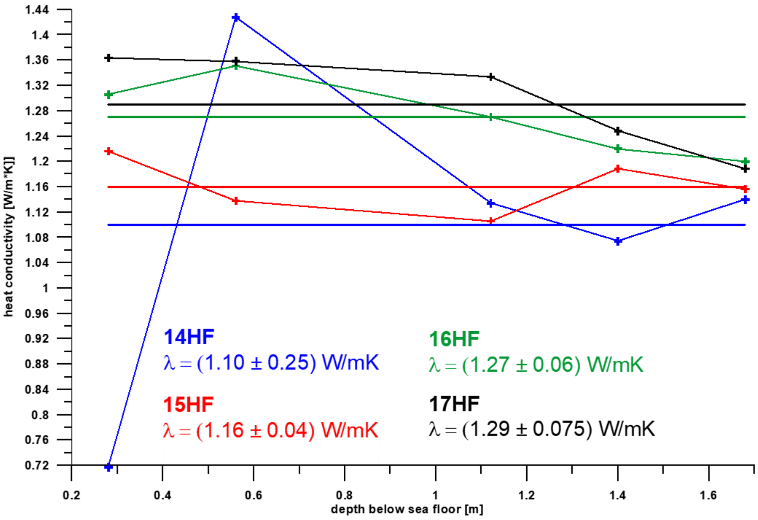


Fig. 3.41: Determined heat conductivities at stations PS115/1-14HF, 15HF, 16HF and 17HF. The mean values and the standard deviations are given

The mean values range from 1.10 to 1.29 W/mK, which could be expected for mid consolidated sediments. The values increase landward reflecting the increasing coarse grained composition of the sediments closer to the coast.

Figs. 3.42 to 3.48 show the measured subsurface temperatures, the fitted temperature gradients and the derived heat flow values considering the respective heat conductivities. The temperature gradients surveyed during the two measurements at each location differ from each other, which is a measure for the accuracy limits of heat flow measurements. It is obvious, that the temperature gradient within the first meters of the sea bottom differs considerably even over a distance of some meters only. For upcoming measurements, the hard ground probe will be complemented by an underwater lighting and camera system to enable the visual evaluation of every measurement location and to understand possible differences at nearly the same spot. Moreover, this will enable the visual detection of steep terrain and insufficient sediment coverage before lowering the probe.

The results for all heat flow density stations are given in Table 3.7. Figs. 3.49 and 3.50 show maps of the stations with the determined mean temperature gradients and heat flow densities. The mean values range from 123 to 226 mW/m², whereby the values increase generally towards the Lena Trough which represents the continuation of the Mid-Atlantic ridge system into the Arctic Ocean. The relatively low value of 82 mW/m² at station PS115/1-04HF reflects the location on older oceanic crust in greater distance to the Knipovich Ridge.

Aside from this point, seismic lines give us information on the sediment thickness and a rough estimate on sedimentation rates. In this way the true heat flow value, corrected for sedimentation effects will be determined. Detailed investigations to the influence of high sedimentation rates on the heat flow density will be carried out after the cruise.

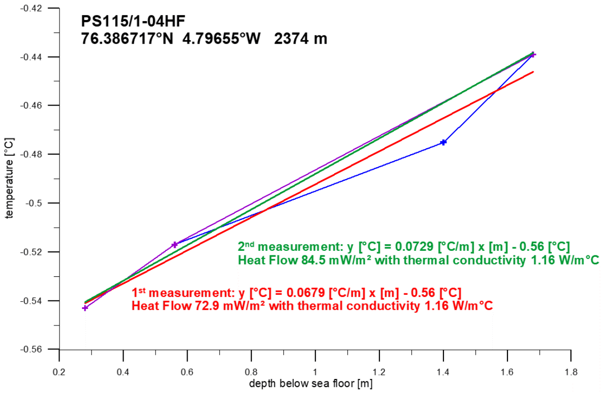


Fig. 3.42: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-04HF at nearly the same location

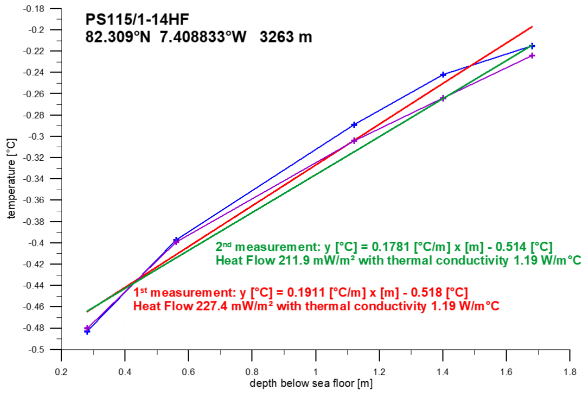


Fig. 3.43: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-14HF at nearly the same location

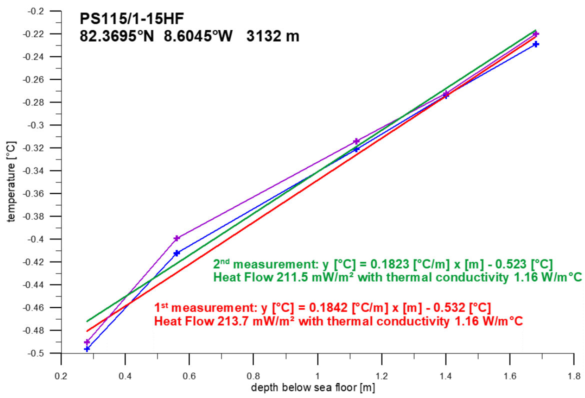


Fig. 3.44: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-15HF at nearly the same location

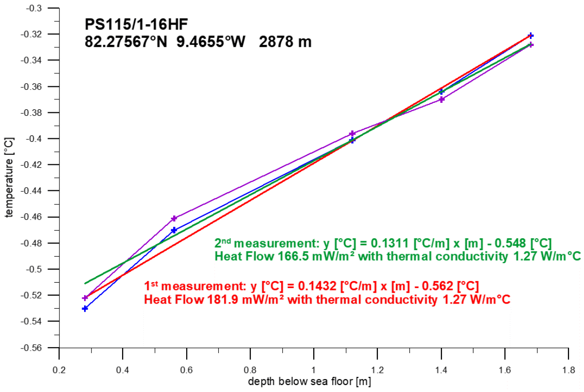


Fig. 3.45: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-16HF at nearly the same location

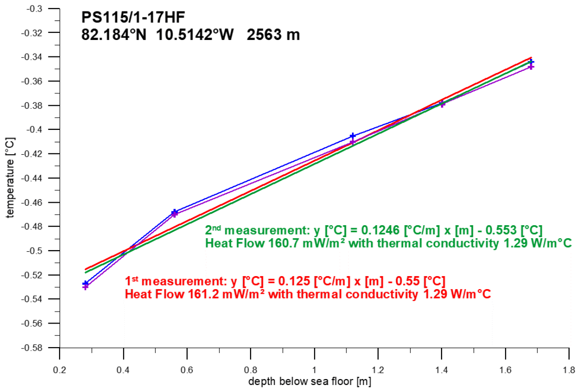


Fig. 3.46: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-17HF at nearly the same location

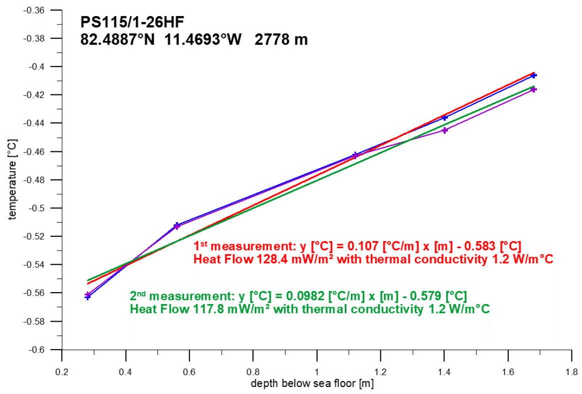


Fig. 3.47: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-26HF at nearly the same location

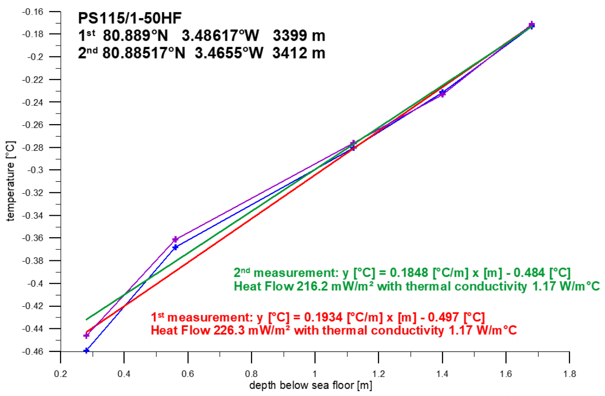


Fig. 3.48: Determination of the temperature gradient by linear regression for the two penetrations at station PS115/1-50HF at a distance of about 560 m

Tab. 3.7: List of heat flow stations with position, water depth, temperature gradient, heat flow value and heat conductivity

Station PS115/1_	**Date/Time**	**Latitude**	**Longitude**	**Depth [m]**	**Inclination X-/Y-Direction**	**Temp. Gradient [mK/m] Heatflow [mW/m²] λ [W/mK]**
04-1HF	08.08.18 14:40-17:02	76.38672°N	4.79655°W	2374	1.7° / 1.0° 2.2° / -0.7°	67.9 / 72.9 78.8 / 84.5 1.16
14-1HF	15.08.18 23:28-02:30	82.309°N	7.40883°W	3263	-0.5° / 0.5° 1.5° / 0.3°	191.1 / 178.1 227.4 / 211.9 1.19
15-1HF	16.08.18 03:36-06:34	82.3695°N	8.6045°W	3132	0.7° / 1.0° -1.6° / 4.2°	184.2 / 182.3 213.7 / 211.5 1.16
16-1HF	16.08.18 07:45-10:30	82.27567°N	9.4655°W	2878	0.1° / 1.7° 1.7 °/ -2.7°	143.2 / 131.1 181.9 / 166.5 1.27
17-1HF	16.08.18 17:45-20:15	82.184°N	10.5142°W	2563	0.8° / -3.0° 3.1° / -0.2°	125 / 124.6 161.2 / 160.7 1.29
25-1HF	18.08.18 06:16-07:55	82.40217°N	12.67533°W	1850	>8° / >8° too steep	measurement aborted
26-3HF	18.08.18 13:40-16:10	82.4887°N	11.4693°W	2778	0.9° / -0.3° 0.7° / -2.0°	107 / 98.2 128.4 / 117.8 1.20
50-1HF-1	25.08.18 14:05-15:55	80.889°N	7.48617°W	3399	-0.4° / 0.3°	193.4 226.3 1.17
50-1HF-2	25.08.18 15:55-17:45	80.88517°N	7.4655°W	3412	-1.4° / 3.7°	184.8 216.2 (1.17)

Heat conductivity measurements at gravity cores

Heat conductivity measurements were also carried out at all on board available archive halves of the gravity core stations as soon as possible after the opening of the sediment core liner normally about two to three days after the respective station. The archive halves were wrapped in transparent plastic sheets to minimise drying-out. The instrument used was a KD2Pro Thermal Properties Analyzer from Decagon Devices, Inc. The sensor was the SH-1 dual needle sensor with needle's length of 30 mm. The measuring time was set to the standard value of two minutes. Readings were taken usually every 20 cm starting at a depth of 10 cm and keeping a distance of at least 8 cm to the top and bottom of every core segment. The heat conductivities are quite variable both within a sediment core and from one core to the other. A summary of the determined values at the 10 gravity corer stations are given in Table 3.8. At first sight the conductivities from the cores at the heat flow density stations are in the same range as the in situ determined values. Detailed investigations and correlation to the in-situ measured conductivities will be conducted during the interpretation.

Data management

Heatflow data will be stored in the marine geophysical database and archived at BGR in raw and processed formats. It will be available to other scientists after a period of 4 years after the end of the cruise.

Tab. 3.8: List of gravity cores with position, water depth, core length which were examined on board with the KD2Pro to determine the heat conductivity

Station PS115/1_	Latitude	Longitude	Depth [m]	Core length [cm]	Number of measurements	Min/Max/Mean heat conductivity [W/mK]
04-3GC	76.38682°N	4.7958°W	2380	65	14	1.125 / 1.552 1.293
05-1GC	78.25117°N	8.4485°W	195	35 compacted	3	1.941 / 2.05 2.003
06-2GC	78.441°N	8.96°W	260	221	25	0.928 / 1.868 1.528
09-3GC	78.92973°N	11.768°W	377	475	28	0.855 / 1.689 1.146
16-2GC	82.27513°N	9.4652°W	2901	705	37	1.024 / 1.856 1.186
26-2GC	82.49867°N	11.48033°W	2788	909	54	0.996 / 1.608 1.179
47-3GC	84.2333°N	29.5833°W	882	504	25	1.22 / 2.016 1.533
50-3GC	80.889°N	3.48617°W	3394	627	32	0.931 / 1.791 1.088
51-1GC	80.48055°N	8.48633°W	291	281	14	0.91 / 1.345 1.054
52-1GC	80.34783°N	6.838917°W	254	312	18	1.145 / 1.81 1.568

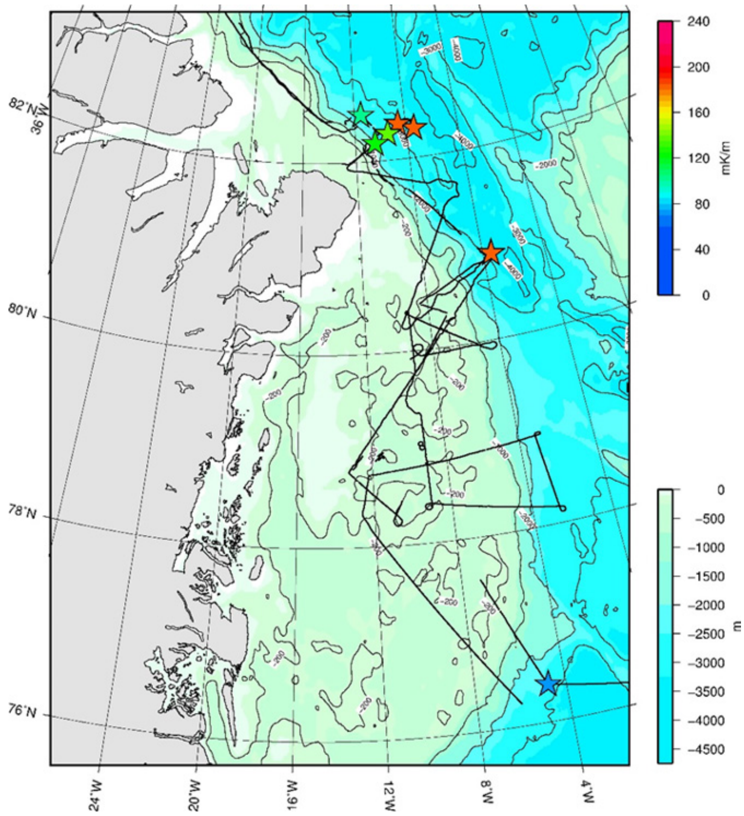


Fig. 3.49: Map of the stations with measured temperature gradients

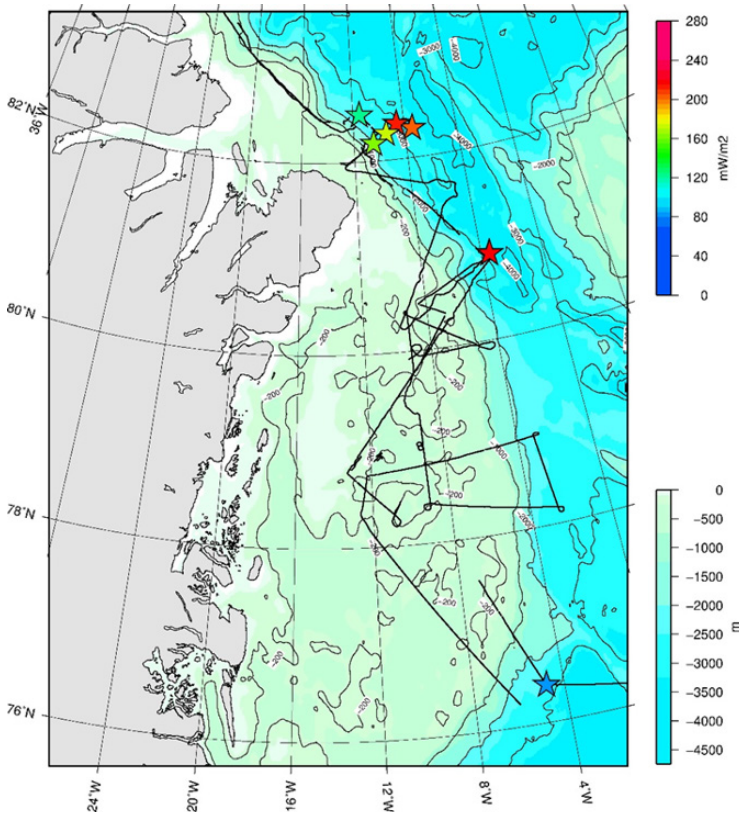


Fig. 3.50: Map of the stations with measured heat flow density values

References

Andersen OB, Knudsen P, Kenyon S & Holmes S (2014). Global and arctic marine gravity field from recent satellite altimetry (DTU13). In 76th European Association of Geoscientists and Engineers Conference and Exhibition 2014: Experience the Energy - Incorporating SPE EUROPEC 2014, 3049–3053.

Eilers G, Roeser HA & Kewitsch P (1994) Reduktion geomagnetischer Variationen durch ein Gradientenmagnetometer. BGR-Report, 110.615, 1-73.

Engels M, Barckhausen U & Gee JS (2008). A new towed vector magnetometer: Methods and results from a Central Pacific cruise. Geophys. J. Int., 172, 115-129.

Finlay CC, Maus S, Beggan C, Bondar T, Chambodut A, Chernova T, Chulliat A, Golovkov V, Hamilton B, Hamoudi M, Holme R, Hulot G, Kuang W, Langlais B, Lesur V, Lowes F, Lühr H, Macmillan S, Mandea M, McLean S, Manoj C, Menvielle M, Michaelis I, Olsen N, Rauberg J, Rothe M, Sabaka T, Tangborn A, Toffner-Clausen L, Thebault E, Thomson A, Wardinski I, Wei Z & Zvereva T (2010) International Geomagnetic Reference Field: the eleventh generation, Geophys. J. Int., Vol 183, Issue 3, pp 1216-1230, DOI: 10.1111/j.1365-246X.2010.04804.x.

Jackson HR & Gunnarsson K (1990) Reconstructions of the Arctic: Mesozoic to Present. Tectonophysics, 172, 303-322.

Jakobsson M, et al. (2012) The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0, Geophysical Research Letters, 39(12), L12609, doi:10.1029/2012GL052219.

JNCC (2017) JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys.- Joint Nature Conservation Committee, Inverdee House, Baxter Street, Aberdeen, AB11 9QA, United Kingdom, August 2017, 26 pp.

Jokat W, Lehmann P, Damaske D, & Bradley Nelson J (2016) Magnetic signature of North-East Greenland, the Morris Jesup Rise, the Yermak Plateau, the central Fram Strait: Constraints for the rift/drift history between Greenland and Svalbard since the Eocene. Tectonophysics, 691, Part A, 98-109, doi:http://dx.doi.org/10.1016/j.tecto.2015.12.002.

Sleep NH & Fuyita K (1997) Principles of Geophysics. Blackwell Science, Malden, Mass..

Tessensohn F & Piepjohn K (2000) Eocene Compressive Deformation in Arctic Canada, North Greenland and Svalbard and Its Plate Tectonic Causes. Polarforschung, 68, 121-124.

Watts AB & Fairhead JD (1999) A process-oriented approach to modelling the gravity signature of continental margins. Leading Edge, 17, 258-263.

4. GEOLOGICAL SAMPLING FOR THERMOCHRONOLOGICAL STUDIES

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Cornelia Spiegel[1] (not on board)

[1]UBremen

Grant-No. AWI_PS115/1_00

Objectives

The primary objectives of this part of the expedition are to obtain samples for petrographic and thermochronological analysis (mostly apatite fission track and (U-Th)/He analysis). These methods allow tracing geodynamic processes within the upper ca. 5 km of the earth´s crust. Furthermore, thermochronological age patterns contained in clastic sediments are indicative for certain source areas. Samples collected during PS115/1 will be used to address the following questions / topics:

(i) Erosion and exhumation history of the Northeast Greenland continental margin in response to Eocene collision of Greenland with the Barents Sea margin, and in response to subsequent extensional processes leading to the opening of the Fram Strait;

(ii) Movement history of the onshore Trolle Land Fault System and its potential offshore continuation, the Greenland Fracture Zone. The kinematics of the Harder Fjord Fault is also of importance as all these fault zones might have played a major role for both, Cenozoic compression and extension;

(iii) Provenance of the clastic infill of Wandel Sea and Danmarkshavn Basins. This question is important for deciphering erosion patterns of the source area at the time of deposition, but also gives evidence on reservoir characteristics of the basin deposits, and

(iv) Post-depositional thermal histories of the Wandel Sea and Danmarkshavn Basins. This question is relevant for understanding the regional tectonic history, but also for assessing the potential formation of hydrocarbon resources.

Another objective of this expedition is to reconstruct the deglaciation history of onshore areas of Northeast Greenland. This will be achieved through determination of the timing and rates of glacial retreat and thinning, using cosmogenic nuclide exposure dating (^{10}Be and ^{26}Al).

Work on land

For both thermochronological and cosmogenic nuclide dating analyses, the main priority was sampling along iso-altitude horizontal profiles, because it is possible to derive lateral glacial retreat rates from them, and they reveal information on fault movements, crustal tilting, and paleo-topography. For thermochronology, *in-situ* bedrock samples were collected (Fig. 4.1a). The applied thermochronological dating methods are based on the radioactive decay of U (and Th and Sm) in the mineral apatite; accordingly apatite bearing rocks were sampled, which involves essentially the same lithologies as required for surface exposure dating.

For surface exposure dating, sampling of erratic boulders was carried out (Fig. 4.1b). Because surface exposure dating relies on the accumulation of ^{10}Be in quartz, quartz-bearing lithologies such as granitoids, sandstones, and gneisses were collected. Most of ^{10}Be production occurs in the upper few cm of a rock and thus the surfaces of exposed rocks have been sampled. Since these are difficult to sample from unweathered, rounded bedrock or boulders, a rock saw was used to cut up to 5 cm deep grids into the rock´s surface, for samples which were too big to sample the entire erratic. After sawing, the samples were removed from the surface with a hammer and chisel. Where entire erratics were collected, the upper side of the sample was noted on the rock. At each location where samples were collected for cosmogenic analysis, shielding measurements were taken at 30° increments through 360°.

For structural geological research and thin section analysis, a few additional oriented *in-situ* bedrock samples were taken (Fig. 4.1a).

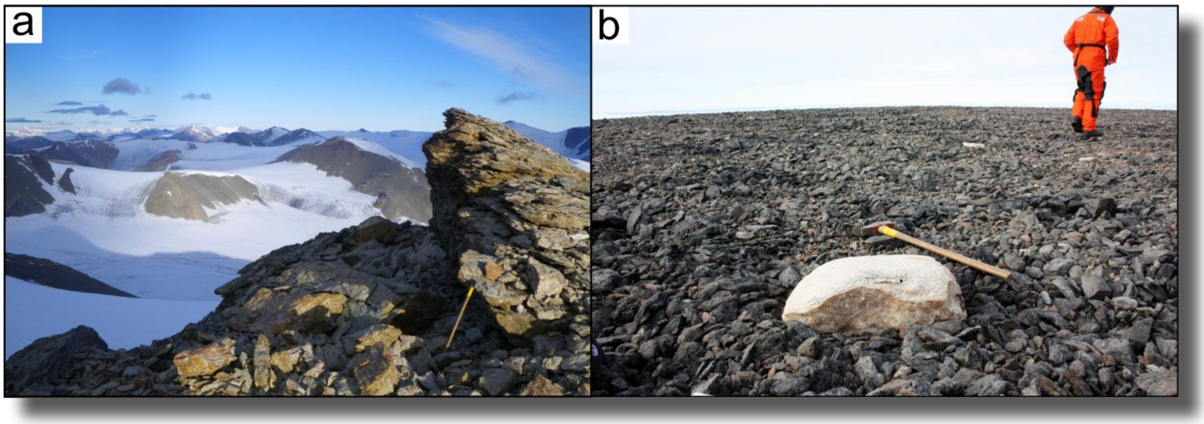

Fig. 4.1 a) A small N-S-trending ridge exposes meta-sandstones which were sampled for thermochronological and thin-section analyses. (Location of MZ18-54, Johannes V. Jensen Land, view to the N). b) Felsic erratic boulder is well visible on darker rocks which mostly reflect the local bedrock (Location of MZ18-47, Nakkehoved, view to N).

Work at sea

Marine-deposited clastic sediments derived from the onshore study areas supplemented our sample set for thermochronology. Therefore, the coarse-grained detrital fraction of ocean sediment was collected. This was recovered using box-corer, multi corer, and gravity corer from the sediment geology group (see Chapter 6). Dating of this ice-rafted debris yields averaged age patterns that reflect the cooling and exhumation history integrated over the whole source area. The main priority was to target coring sites that can be related to well-defined glacial catchments.

Dredging of bedrock from the East-Greenland Ridge (EGR) was also carried out. The better lithological and thermochronological understanding of the EGR may help to reconstruct the upper crustal evolution of the Northeast Greenland-North Atlantic region during the Cenozoic.

Preliminary results

Onshore samples

A variety of locations on land were sampled on the Northeast Greenland margin in Kronprins Christian Land and in Peary Land (Fig. 4.2): In Kronprins Christian Land, samples were taken from Nakkehoved and Kap Prins Knud. In Peary Land, Herluf Trolle Land, Hans Egede Land and the eastern portions of Johannes V. Jensen Land were sampled.

At all locations, the priority for sampling was the collection of *in-situ* bedrock samples for thermochronological analysis and quartz-rich erratics (granites, sandstones, gneisses) for cosmogenic exposure dating. Apart from sample collection, observations on structural evolution, tectonic activity and glacial geomorphology were included in the fieldwork. Table 4.1 provides information on all samples collected at each location.

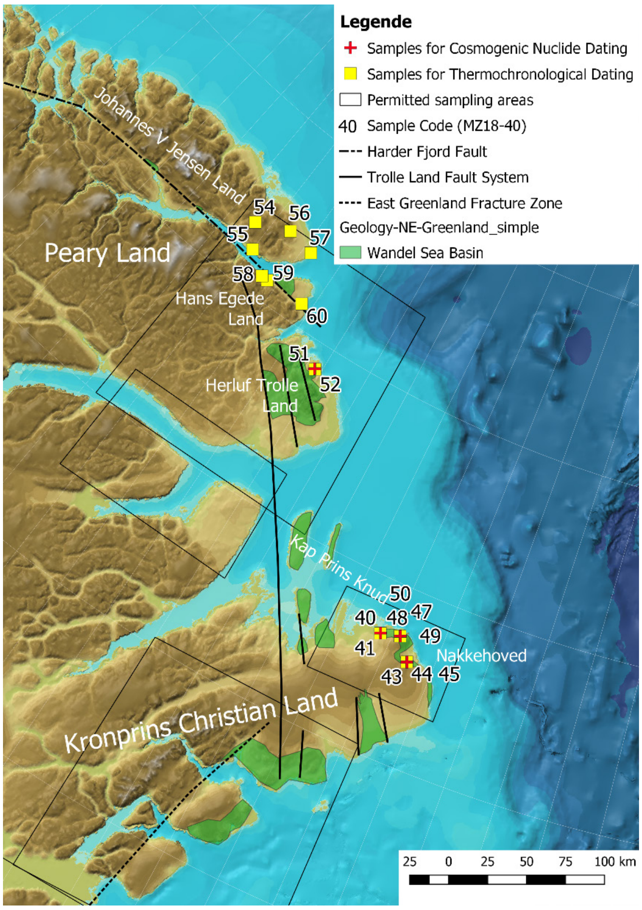

Fig. 4.2: Topographic and bathymetric map of Northeast Greenland shows major fault zones and the distribution of Upper Paleozoic-Paleogene rocks of the Wandel Sea Basin (Paech & Estrada, in press). Also shown are the individual sampling areas and the samples taken from onshore localities for thermochronology and cosmogenic exposure dating. Map based on IBCAO (Jakobsen et al., 2012).

Kronprins Christian Land

Five samples around Kap Prins Knud and Nakkehoved on the northern and northeastern coast of Kronprins Christian Land were taken for thermochronology and thin-section analysis. Samples were taken from relatively low elevations, at Kap Prins Knud ca. 50 m, at Nakkehoved at 380–470 m (Table 4.1). Bedrock of the sampled area comprises fine to medium-grained sandstones, deposited in the Wandel Sea Basin during the Cretaceous (e.g. Håkansson and Pedersen, 2015, Fig. 4.2). At the visited locations, these sandstones were often fractured and showed discontinuous foliation planes, mostly subparallel to a shallowly N- to NE-dipping bedding. Steeply dipping joints coated with Fe-oxides were also encountered. White quartz veins of cm to dm thickness, concordant and discordant to bedding and foliation, were frequently observed. Especially at Kap Prins Knud the veins are very prominent, and boulders indicate vein thicknesses of several dm. Thermochronological analyses based on the samples from Kap Prins Knud will constrain the post-depositional evolution of the Wandel Sea Basin and may thus provide information about the opening of the Fram Strait.

For cosmogenic nuclide dating, six erratic block samples were taken from the locations at Kap Prins Knud and Nakkehoved (Fig. 4.2, Table 4.1). Kap Prins Knud is characterized by a relatively flat landscape with an extensive cover of glacial moraine deposits with only small areas of outcropping bedrock. As part of this extensive glacial deposit, a pale erratic boulder of massive vein quartz was sampled. Dating of this boulder may give information about the retreat of the local glacial which current front was encountered ca. 50 m further to the south of the sampling location. At Nakkehoved, erratic boulders were sampled from flat-lying plateaus which were covered by cobbles and boulders, forming a glacial moraine deposit. Identified erratic boulders of this deposit were sampled.

Tab. 4.1: Samples collected for cosmogenic nuclide dating, thermochronological and thin section analyses

Seq. No.	Sample Code	Purpose	Latitude	Longitude	Eleva-tion in m	Region	Location	Lithology	Sampled material in kg
1	MZ18-40	C	81.6890	-14.4687	46	KCL	Kap Prins Knud	vein quartz	3
2	MZ18-41	T	81.6880	-14.4718	50	KCL	Kap Prins Knud	sandstone	12
3	MZ18-42	TS	81.6890	-14.4687	46	KCL	Kap Prins Knud	vein quartz	3
4	MZ18-43	T	81.5976	-13.0576	456	KCL	Nakkehoved	sandstone	15
5	MZ18-44	C	81.5963	-13.0599	465	KCL	Nakkehoved	sandstone	12
6	MZ18-45	C	81.5966	-13.0516	460	KCL	Nakkehoved	sandstone	15
7	MZ18-46	TS	81.5966	-13.0516	460	KCL	Nakkehoved	vein quartz	1
8	MZ18-47	C	81.7189	-13.6980	399	KCL	Nakkehoved	gneiss	4
9	MZ18-48	C	81.7191	-13.7005	403	KCL	Nakkehoved	sandstone	12
10	MZ18-49	T	81.7192	-13.7085	382	KCL	Nakkehoved	sandstone	16
11	MZ18-50	C	81.7192	-13.6993	407	KCL	Nakkehoved	gneiss	12
12	MZ18-51	C	82.8528	-22.3218	820	PEA	Herluf Trolle Land	sandstone	5
13	MZ18-52	T	82.8522	-22.2907	850	PEA	Herluf Trolle Land	sandstone	15
14	MZ18-53	TS	82.8528	-22.3218	820	PEA	Herluf Trolle Land	volcanic rock	4
15	MZ18-54	T	83.3422	-28.7105	1214	PEA	Johannes V. Jensen Land	(meta)sandstone	20
16	MZ18-55	T	83.2107	-27.9822	10	PEA	Johannes V. Jensen Land	(meta)sandstone	14
17	MZ18-56	T	83.4267	-27.0508	1322	PEA	Johannes V. Jensen Land	(meta)sandstone	20
18	MZ18-57	T	83.3952	-25.5792	10	PEA	Johannes V. Jensen Land	(meta)sandstone	10
19	MZ18-58	T	83.1205	-26.5151	20	PEA	Hans Egede Land	mylonitic schist	22
20	MZ18-59	T	83.1223	-26.8435	3	PEA	Hans Egede Land	coarse-grained sand	8
21	MZ18-60	T	83.1246	-24.5088	30	PEA	Hans Egede Land	schist/marble	18

C-Cosmogenic nuclide dating; PEA-Peary Land; T-Thermochronological analysis; TS-Thin-section analysis; KCL-Kronprins Christian Land; Sampling dates: MZ18-40 to -50 (17.08.18), MZ18-51 to-53 (19.08.18), MZ18-54 to -55 (20.08.18), MZ18-56 to -57 (21.08.18), MZ18-58 to -60 (24.08.18).

Peary Land

In Peary Land, nine samples for thermochronology and thin-section analysis were taken from elevations between sea-level and ca. 1,300 m. In Johannes V. Jensen Land, medium to coarse-grained grey to greenish meta-sandstones with a gneissic foliation were sampled from *in-situ* bedrock. Protoliths of these rocks were supposedly part of a sequence of Cambro-Ordovician sediments, deposited at the northern passive continental margin of Laurentia in the Franklinian Basin (Escher and Pulvertaft, 1995). The foliation was shallowly to moderately dipping either towards the ENE or towards the SW. In Hans Egede Land, grey fine to medium-grained schists with occasionally interlayered pale marbles were sampled. Protoliths of this assemblage probably represented Silurian sequences of the Franklinian Basin (Escher and Pulvertaft, 1995). Samples from both the Johannes V. Jensen Land and Hans Egede Land may allow to constrain activity of regional tectonic structures, e.g. Trolle Land Fault System and the Harder Fjord Fault (see Fig. 4.2).

In Herluf Trolle Land, one bedrock sample was taken from the Paleoproterozoic Independence Fjord Formation in the area of the Clarence Wyckoff Bjerg (Escher and Pulvertaft, 1995). The sample comprise a coarse-grained to conglomeratic reddish sandstone. At the same location, a sample for cosmogenic nuclide dating was collected from a moraine deposit, filling a small U-shaped valley. At all other locations in Peary Land no samples for cosmogenic nuclide dating were sampled because such material was not available, or there was insufficient time for sampling.

Offshore samples

Altogether, ten detrital samples from six box corer and four gravity corer sites were taken from the Lincoln, Wandel and Greenland Sea (Fig. 4.3, Tab. 4.2). Additionally, a few lithic clasts were gained from 2 multi corer sites in the Greenland Sea. In general, coarse grained layers (sandy and gravelly layers) and lithic clasts were sampled. Samples from gravity cores were taken from existing coarse-grained and clast-bearing layers. Samples from box corer were mostly bulked from the entire box. Two box corer samples were sieved at 1.5 cm an d 2.0 cm, respectively. Most of the samples were, however, not investigated on board. Sampled lithic clast which were already washed and examined on board comprised quite a mixture of different lithologies. However, silt-/sandstones were relatively frequent, while crustal crystalline rocks (gneisses, plutonic rocks) were relatively rare. This could reflect a higher abundance of silt-/sandstones in the source areas.

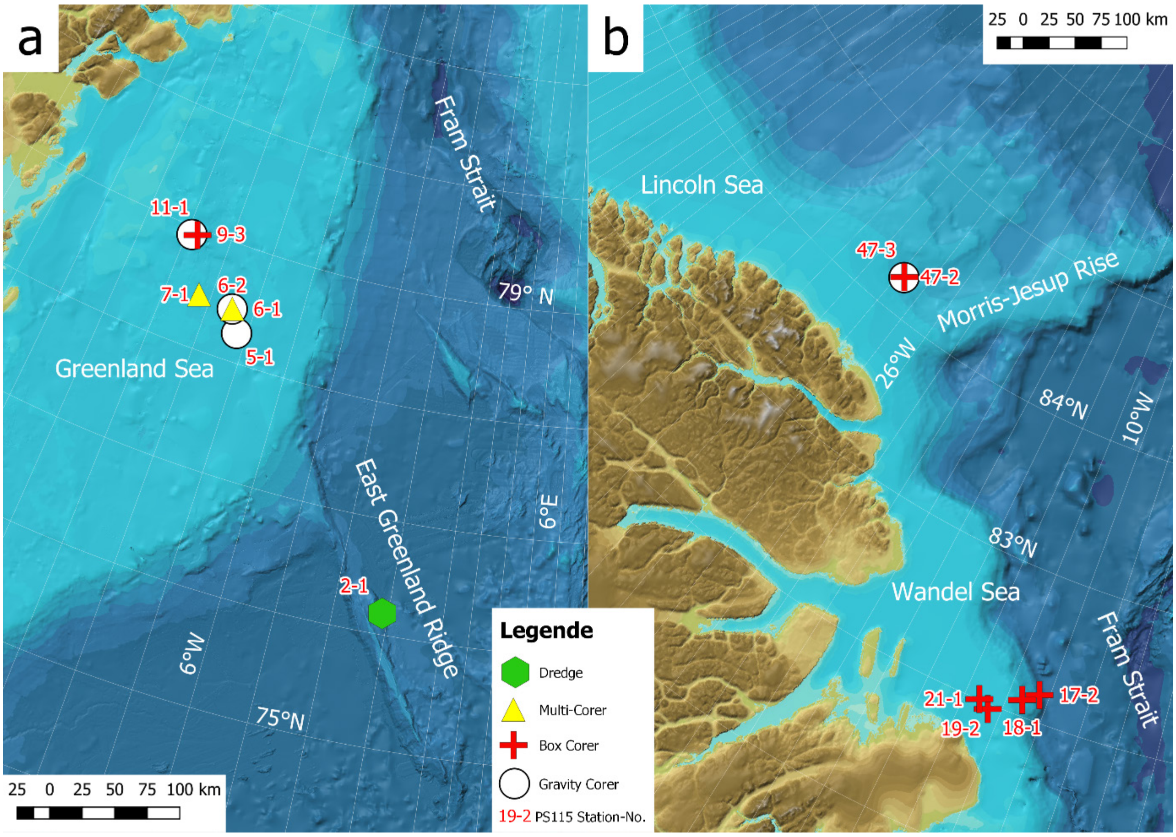

Fig. 4.3: Bathymetric maps (a and b) show the working area offshore Northeast Greenland and the samples taken from offshore localities. Maps based on IBCAO (Jakobsen et al., 2012).

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Tab. 4.2: Collected detrital samples

Seq. No.	Sample Code	Device	Latitude	Longitude	Depth m (b.s.l.)	Region	Sampled material
1	PS115/2-1	Dredge	76.1862	-0.2169	1877	East Greenland Ridge	several clasts
2	PS115/5-1	Gravity Corer	78.2513	-8.4482	195	NE-Greenland shelf	coarse-grained material
3	PS115/6-1	Multi Corer	78.4417	-8.9592	260	NE-Greenland shelf	lithic clasts
4	PS115/6-2	Gravity Corer	78.4411	-8.9606	261	NE-Greenland shelf	coarse-grained material
5	PS115/7-1	Multi Corer	78.4625	-10.5240	263	NE-Greenland shelf	lithic clasts
6	PS115/9-3	Gravity Corer	78.9294	-11.7701	376	NE-Greenland shelf	coarse-grained material
7	PS115/11-1	Box Corer	78.9420	-11.5315	209	NE-Greenland shelf	coarse-grained material
8	PS115/17-2	Box Corer	82.1839	-10.5151	2568	Wandel Sea slope	coarse-grained material
9	PS115/18-1	Box Corer	82.1101	-11.2386	654	Wandel Sea slope	coarse-grained material
10	PS115/19-2	Box Corer	81.9632	-12.6528	239	Wandel Sea shelf	coarse-grained material
11	PS115/21-1	Box Corer	82.0037	-13.2294	197	Wandel Sea shelf	coarse-grained material
12	PS115/47-2	Box Corer	84.2420	-29.5965	878	N-Greenland shelf - Morris-Jesup Rise	coarse-grained material
13	PS115/47-3	Gravity Corer	84.2380	-29.5926	879	N-Greenland shelf - Morris-Jesup Rise	coarse-grained material

At the EGR, a dredge was deployed for recovering *in-situ* rocks (Fig. 4.3a). The dredge was deployed at ca. 2,900 m water depth at a steep north-eastern flank of the EGR and was hoisted up-slope (Tab. 4.3). Rope tension during dredging mostly ranged between 40 and 50 kN (Fig. 4.4). Several clasts were successfully dredged, they were estimated to weigh around 400 kg in total. The clasts mainly comprised altered and fresh basaltic rocks (ca. 30 volume-%) and ice transported boulders. The latter comprised gneisses, granites-gabbros, conglomerates, limestones and sandstones. In addition, a few rounded, less consolidated mudstones were among the clasts. Dredged rocks are generally intended be analyzed by petrographic and thermochronological analyses. However, basaltic clasts which commonly do not contain apatite, are planned to be analyzed by Ar-Ar-dating techniques.

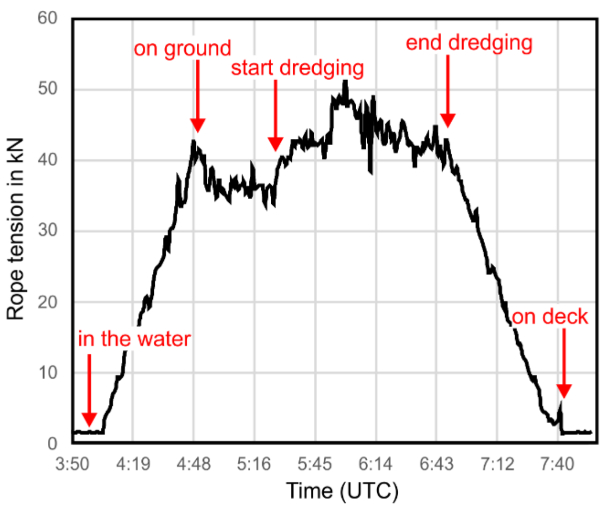

Fig. 4.4: Diagram shows the rope tension during dredging operations at the East-Greenland Ridge (Station PS115/2). For details about the individual dredging steps see Table 4.3.

Tab. 4.3: Protocol during dredge operations at station PS115/2

No.	Time (UTC)	Latitude	Longitude	Depth in m	Action/Comment
1	03:58:28	76.1862	-0.2169	1877	in the water
2	04:50:09	76.1866	-0.2171	2950	on ground, profile start, rope length 3016m
3	05:27:18	76.1859	-0.2601	2577	profile end, rope length 3896m
4	06:49:24	76.1858	-0.2602	2588.9	hoisting, dredging
5	07:42:27	76.1859	-0.2613	2578.8	on deck

Data management

All data and associated metadata will be stored in the Data Publisher for Earth & Environmental Science PANGAEA (www.pangaea.de).

References

Escher JC & Pulvertaft TCR (1995) Geological map of Greenland, 1:2500000. Copenhagen: Geological Survey of Greenland.

Håkansson E & Pedersen SAS (2015) A healed strike-slip plate boundary in North Greenland indicated through associated pull-apart basins. In: Gibson GM, Roure F, Manatschal G (eds) Sedimentary basins and crustal processes at continental margins: from modern hyper-extended margins to deformed ancient analogues. Geological Society of London, Special Publications, 413, 143-169. doi:10.1144/SP413.10.

Jakobsson M, et al. (2012) The International Bathymetric Chart of the Arctic Ocean (IBCAO) Version 3.0. Geophysical Research Letters 39(12),1-6.

Paech HJ & Estrada S (in press) Coal rank data and tectonic structure of Mesozoic and Paleogene sediments in North Greenland. GSA books.

5. MICROBIOLOGICAL AND GEOCHEMICAL INVESTIGATIONS TO UNDERSTAND GASES AND MICROBIAL PROCESSES IN ARCTIC SEAFLOOR SEDIMENTS

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5.1 Geomicrobiology

Objectives

Both, the structural and the tectonic evolution of the Wandel Sea Basin and adjacent areas are poorly explored and remain a matter of an ongoing debate. Geophysical testing of the contrasting tectonic models is expected to shed light on the geometric and thermal evolution of this basin. To better understand the basin evolution and its effect on petroleum generation and migration, we intend to study the quantity, the chemical and the isotopic compositions of gases adsorbed by surface sediments in the study area. These compositional data shall be interpreted in the context of the measured basin geometry and heat flow to be integrated into a model of hydrocarbon generation and migration.

Besides its structure and tectonic evolution, also the geological and biogeochemical characteristics of the NE Greenland and the adjacent continental shelf and margin areas are largely unknown. Our aim is to study the geochemistry and geomicrobiology in Arctic sediments, and to quantify and identify the *prokaryotes*, which drive major elemental cycles of e. g. N, C, S in respective ecosystems. Another objective is the oil biodegradation potential of the indigenous microbiota for a potential oil spill under polar *in-situ* conditions. A third objective is the microbial degradation and production of the greenhouse gas methane by sedimentary microbial communities. Sediments, water and ice samples were collected (1) using coring instruments at the seafloor, and (2) directly at the coastline using small push cores. These samples were sealed (partly frozen) after extraction and transported to the BGRs laboratories for geochemical, micro- and molecular biological analyses.

Work at sea

Along several transects sediment echosounder surveying was conducted parallel to seismic profiles to determine sites, with maximum sediment thickness to allow for sufficient core material retrieval. In general, site selection was done in collaboration with other working groups on board (see Chapter 7). Sampling material was obtained out of long sediment cores (extracted by gravity corer - GC) and short sediment cores (extracted by multi-corer – MUC and box corer - BC). Short cores were used to ensure the availability of sediments from the sediment-water interface. Longer gravity cores (up to 15 m) were employed to collect deep (gas) geochemical and microbiological profiles. Locations of all offshore sediment samples extracted during PS115/1 are shown in Fig. 5.1 and Table 5.1.

Retrieval, handling and sampling of obtained sediment cores were performed at sea in collaboration with other working groups. Cores were described and photographed on board. Measurements on unopened cores and continuous sampling of opened cores (subcores and/or work halves) were performed at sea in various ways and for various purposes.

Sediment and porewater samples (see Chapter 5.2) for geochemical analyses were taken in short intervals along the cores onboard. These were then prepared and fixed for subsequent determination of total organic carbon, elemental (especially Fe-, Mn-species) composition, stable C and H-isotopes, microbial substrates, sulfate/sulfide concentration, and profiles of methane and CO_2. Representative samples were frozen immediately for later laboratory analysis of adsorbed hydrocarbons (methane and higher hydrocarbons).

In addition to the offshore sampling activities, several helicopter operations were used to collect further sediment samples at selected near coastal locations ashore (Fig. 5.2, Table 5.2).

At both onshore and offshore stations, sediment was also sampled for micro- and molecular biological analyses roughly at the same sediment depths as the geochemistry samples. Sediment microcosms were set-up onboard to measure rates of important microbial processes, i.e. sulfate reduction, methane and carbon dioxide formation and consumption, as well as the degradation of different higher hydrocarbons. These incubations will be continued in the home laboratories using gas chromatography and photometric analyses for monitoring.

Samples for molecular biological studies of the quantitative and qualitative microbial community composition were collected, and immediately stored frozen for further onshore analyses.

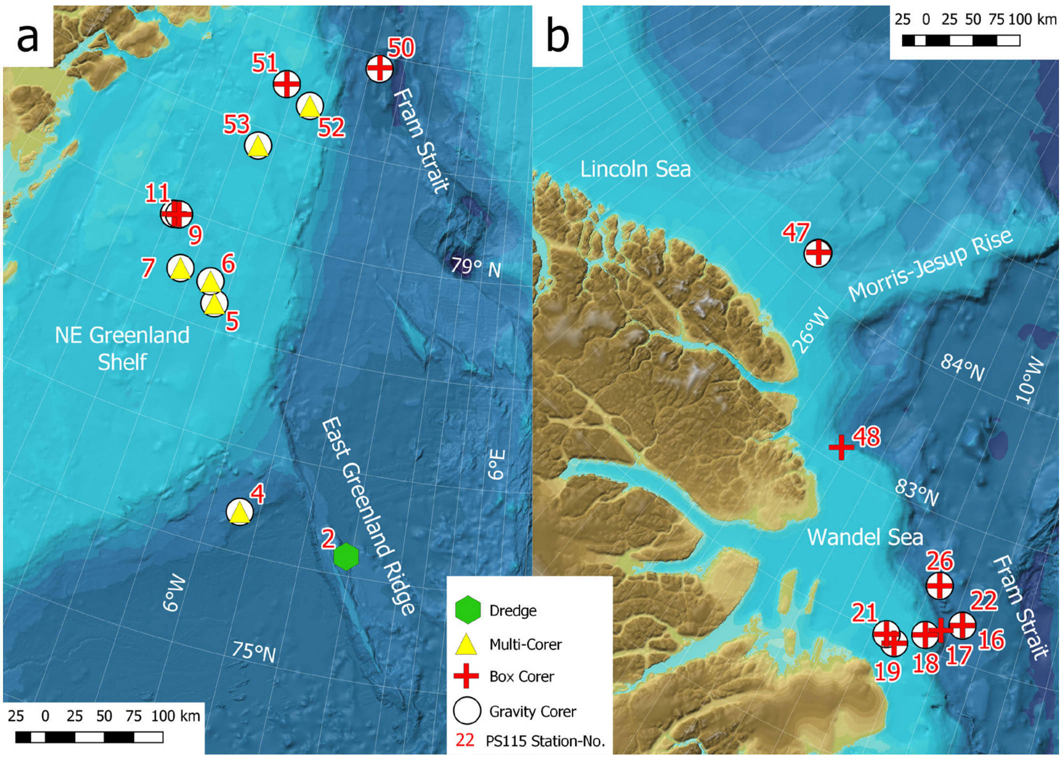

Fig. 5.1: Map showing the location of the offshore sampling stations for geomicrobiology

Tab. 5.1: Overview on offshore geological sampling stations

Station-No.	Date	Longitude	Latitude	Gear	Recovery (cm)
PS115/1_4-2	08.08.2018	76°23.188N	04°47.822W	TV-MUC	50
PS115/1_4-3	08.08.2018	76°23.209N	04°47.748W	GC	65
PS115/1_5-1	09.08.2018	78°15.07N	08°26.91W	GC	35
PS115/1_5-2	09.08.2018	78°15.09N	08°26.88W	TV-MUC	no recovery
PS115/1_5-3	09.08.2018	78°15.08N	08°26.9W	TV-MUC	25
PS115/1_6-1	09.08.2018	78°26.5N	08°57.5W	TV-MUC	70
PS115/1_6-2	09.08.2018	78°26.461N	08°57.603W	GC	221
PS115/1_7-1	09.08.2018	78°27.7N	10°31.2W	TV-MUC	50
PS115/1_7-2	09.08.2018	78°27.789N	10°31.605W	GC	20
PS115/1_9-1	10.08.2018	78°55.749N	11°46.410W	GC	478
PS115/1_9-2	10.08.2018	78°55.745N	11°46.410W	GC	568
PS115/1_9-3	10.08.2018	78°55.784N	11°46.083W	GC	486
PS115/1_9-4	10.08.2018	78°55.775N	11°45.808W	BC	40
PS115/1_11-1	11.08.2018	78°56.518N	11°31.899W	BC	30
PS115/1_11-2	11.08.2018	78°56.52N	11°31.497W	GC	no recovery
PS115/1_11-3	11.08.2018	78°56.527`N	11°31.925`W	GC	60
PS115/1_16-2	16.08.2018	82°16.508`N	9°27.912`W	GC	701
PS115/1_16-3	16.08.2018	82°16.537`N	9°27.925`W	BC	no recovery
PS115/1_16-4	16.08.2018	82°16.547`N	9°28.001`W	BC	no recovery
PS115/1_17-2	16.08.2018	82°11.033`N	10°30.889`W	BC	35
PS115/1_18-1	16.08.2018	82°06.599`N	11°14.328`W	BC	40
PS115/1_18-2	16.08.2018	82°06.596`N	11°14.309`W	GC	129
PS115/1_19-1	17.08.2018	81°57.794`N	12°39.132`W	GC	no recovery
PS115/1_19-2	17.08.2018	81°57.794`N	12°39.175`W	BC	30
PS115/1_21-1	17.08.2018	82°00.219`N	13°13.768`W	BC	35
PS115/1_21-2	17.08.2018	82°00.208`N	13°13.808`W	GC	no recovery
PS115/1_22-1	17.08.2018	82°16.545`N	09°27.973`W	BC	no recovery
PS115/1_22-2	17.08.2018	82°16.545`N	09°27.960`W	BC	45
PS115/1_26-1	18.08.2018	82°29.999`N	11°29.162`W	BC	40
PS115/1_26-2	18.08.2018	82°29.92`N	11°28.82`W	GC	909
PS115/1_47-1	23.08.2018	84°14.568'N	29°35.740'W	BC	no recovery
PS115/1_47-2	23.08.2018	84°14.49'N	29°35.675'W	BC	35
PS115/1_47-3	23.08.2018	84°14.257'N	29°35.531'W	GC	504
PS115/1_47-4	23.08.2018	84°13.966'N	29°35.043'W	GC	577
PS115/1_47-5	23.08.2018	84°14.706'N	29°35.825'W	GC	544
PS115/1_48-2	24.08.2018	83°7.307'N	20°32.232'W	BC	35
PS115/1_50-2	25.08.2018	80°53.60'N	03°25.84'W	BC	40
PS115/1_50-3	25.08.2018	80°51.992'N	3°26.736'W	GC	642
PS115/1_51-1	26.08.2018	80°28.833'N	8°29.182'W	GC	281
PS115/1_51-2	26.08.2018	80°28.846'N	8°29.146'W	BC	25
PS115/1_52-1	26.08.2018	80°20.87'N	6°50.335'W	GC	328
PS115/1_52-2	26.08.2018	80°20.876'N	6°50.382'W	TV-MUC	30
PS115/1_53-1	26.08.2018	79°49.858'N	8°54428'W	TV-MUC	no recovery
PS115/1_53-2	26.08.2018	79°49.861'N	8°54.764'W	GC	no recovery

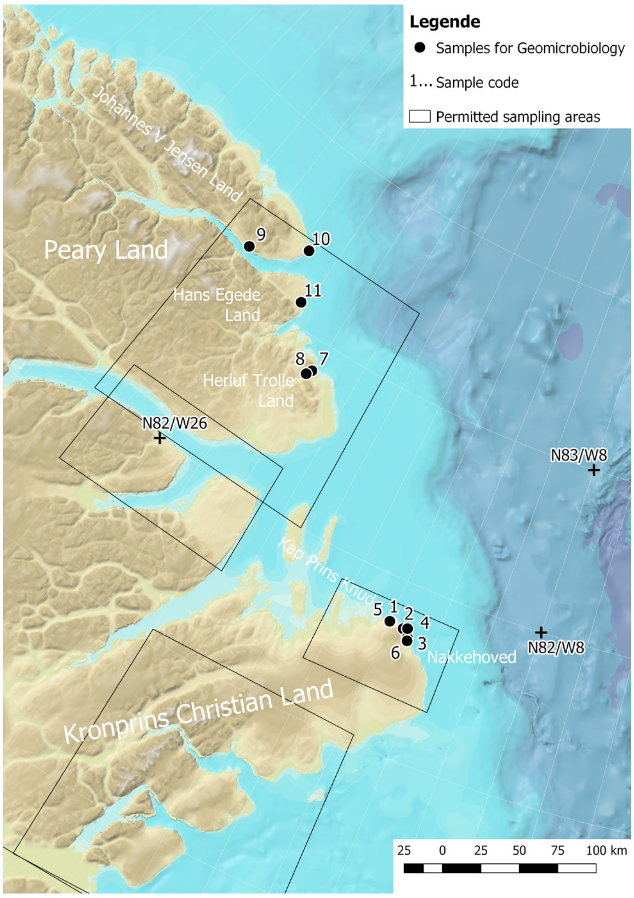

Fig. 5.2: Map showing the location of the onshore sampling stations for geomicrobiology

Table 5.2: Greenland onshore samples for geomicrobiology

Nr	Longitude	Latitude	Location	Sample amount (g)
1	N81°44,7`	W13°56,85`	Kronsprins Christian Land	1500
2	N81°44,1`	W13°22,98`	Kronsprins Christian Land	2000
3	N81°41,81`	W13°04,86`	Kronsprins Christian Land	3000
4	N81°40,71`	W13°02,54`	Kronsprins Christian Land	3000
5	N81°44,6`	W13°59,84`	Kronsprins Christian Land	3200
6	N81°44,71`	W13°13,06`	Kronsprins Christian Land	1400
7	N82°49,53`	W22°05,91`	Herluf Trolle Land	1600
8	N82°47,56`	W22°14,93`	Herluf Trolle Land	1800
9	N83°23.94´	W27°58.937`	Johannes V Jensen Land	1200
10	N83°23.94´	W25°27.149`	Johannes V Jensen Land	4000
11	N83°7,549`	W24°18,823`	Hans Egede Land	7000

5.2 Sediment and pore water geochemistry

Objectives

The main objective of the AWI Geochemistry Group during PS 115/1 was to acquire high-resolution profiles of pore water and sediment geochemistry to investigate metal- and sulfur-based biogeochemical processes:

1. To address the reliability of iron and manganese minerals as diagnostic recorders of geochemical and biogeochemical processes in marine sediments.
2. To better understand the biogeochemical cycling of trace metals and their isotopic signatures as these metals are subjected to continual burial, diagenesis, and varying redox biogeochemistry.
3. To integrate organic and inorganic geochemical studies to address the potential role of dissolved organic chemicals as mediators of abiotic or biotic iron reduction in deep marine sediments.
4. To determine the spatial variability of organic matter reactivity and how it is controlled by the regional sedimentary processes.
5. To widen our knowledge about the early diagenetic redistribution of phosphorus in iron-rich sediments and the precipitation of vivianite and other authigenic phosphate minerals.

Work at sea

Porewater and sediment sampling
The gravity cores (GC) were cut into 1 m segments on deck. To prevent warming of the sediments on board the cores were transferred into a cooling room immediately after recovery and maintained at a temperature of about 4°C. On the working halves pH and Eh were determined and pore water sampling was carried out using Rhizons, while the cores remained as whole rounds. Solid phase samples and pore water samples were taken in intervals of 20 to 30 cm. High resolution sampling for methane was carried out within a few hours to a few days after recovery. The retrieved multi corer MUC cores were processed directly after recovery in the wet lab. During cruise PS 115/1 pore water was extracted from 10 GCs and 2 MUCs (Table 5.3). Depending on the quantity of the extracted pore water different splits were separated. Additionally, sediment samples were taken at all GCs where porewater was collected. In a total of 519 pore water splits and 155 sediment samples were extracted.

Onboard analysis
Alkalinity was determined on a 1 mL aliquot of sample by titration with 10, 50 or 100 mM HCl. pH measurements were performed using a Hamilton micro-electrode. The samples were titrated with a digital burette to a pH below 3.9 and both titration volume and final pH were recorded. The alkalinity was calculated using a modified equation from Grasshoff et al. (1999). Dissolved iron (Fe^{2+}) was detected photometrically (CECIL 2021 photometer) at 565 nm. 1 mL of sample was added to 50 µL of Ferrospectral solution to complex the Fe^{2+} for colorimetric measurement. Samples with high concentrations of iron (> 1mg L-1) were pretreated with 10 µL ascorbic acid and diluted with oxygen-free artificial sea-water (1:2 or 1:5) prior to complexation.

Tab. 5.3: Overview of sampled GCs and MUCs with exact location, water depth and device used

Station	Area	Latitude	Longitude	Water depth [m]	Device
PS 115/1_4-2	North Greenland Basin	76° 23.19' N	4° 47.82' W	2379	GC
PS 115/1_5-1	Northeast Greenland Shelf	78° 15.07' N	8°26.91' W	197	GC
PS 115/1_6-2	Northeast Greenland Shelf	78° 26.46' N	8° 57.60' W	261	GC
PS 115/1_7-1	Northeast Greenland Shelf	78° 15.07' N	8°26.91' W	197	MUC
PS 115/1_7-2	Northeast Greenland Shelf	78° 15.07' N	8°26.91' W	197	GC
PS 115/1_9-3	Northeast Greenland Shelf	78° 55.78' N	11° 46.08' W	377	GC
PS 115/1_16-2	Wandel Sea	82° 16.51' N	9° 27.91' W	2901	GC
PS 115/1_26-2	Wandel Sea	82° 04.32' N	13° 58.54' W	2788	GC
PS 115/1_47-3	Morris Jesup Rise	84° 14.49' N	29° 35.68' W	882	GC
PS 115/1_50-3	Fram Strait	80° 53.60' N	3° 25.84' W	3394	GC
PS 115/1_52-2	Northeast Greenland Shelf	80° 20.87' N	6° 50.34' W	255	MUC
PS 115/1_52-1	Northeast Greenland Shelf	80° 28.83' N	8° 29.18' W	254	GC

Analysis in the home laboratories (planned)
Ammonium (NH_4^+) and Phosphate (PO_4^{3-}) will be analyzed in the home-lab of the Alfred Wegner Institute (AWI). 1 mL sub-samples were taken and stored frozen at –20°C.
For dissolved pore-water sulfur species porewater subsamples were immediately fixed using a 2.5 % zinc-acetate solution to preserve the sulfate and sulfide. When available additional 4 – 6 mL of pore water were also fixed with a 2.5 % zinc-acetate solution for shore-based analysis of stable sulfur and oxygen isotope composition of sulfate and sulfide.
Organic/inorganic carbon/solid-phase sulfur and phosphorus species samples were collected from gravity cores and multicores for the shore-based analysis, including concentration and stable isotope composition of total organic, inorganic carbon and solid-phase sulfur and phosphorus species. Samples were collected with cut-off 10 mL syringes. The sediment remained in the syringes, which were sealed properly in Argon flushed plastic/aluminium bags. Samples were then frozen at -20°C.
Pore water cations and trace metals (e.g. Al, Ba, Ca, Mg, Mn, Fe, Si, P, and S) will be analyzed in our home-laboratory at the AWI with ICP-OES and ICPMS, respectively.

Preliminary (expected) results

The marine geochemical and microbiological work during expedition PS115/1 will broaden the basis of available knowledge on Arctic sediments by adding data from a number of new transects across the NE Greenland shelf and continental margin. New sediment cores from suitable sites were obtained and will be analysed using a diverse and comprehensive set of inorganic and organic geochemical as well as micro- and molecular biological techniques. Results of these oboard and laboratory investigations will improve our understanding of the geochemistry and geomicrobiology in Arctic sediments, and help to quantify and identify the prokaryotes, which drive major elemental cycles in this sensitive and unique geosystem.

Data management

All data obtained from geochemical and microbiological analyses of sediment cores at sea and in the home laboratories will be stored in BGR/AWI/UFZ data repositories and will be published in scientific journals.

References

Arnold GL, Weyer S & Anbar AD (2004) Fe isotope variations in natural materials measured using high mass resolution multiple collector ICPMS. Analytical Chemistry. 76(2), 322-327.

Cline JD (1969) Spectrophotometric determination of hydrogen sulfide in natural waters. Limnol. Oceanogr., 14, 454-458.

Cowie GL & Hedges JI (1992) Sources and reactivities of amino acids in a coastal marine environment Limnol. Oceanogr., 37(4), 703-724.

Grasshoff K, Kremling K, Ehrhardt M (eds), (1999) Methods of seawater analysis, 3rd ed. Wiley-VCH, Weinheim, New York

Haeckel M, Suess E, Wallman K & Rickert D (2004) Rising methane gas bubbles form massive hydrate layers at the seafloor. Geochimica et Cosmochimica Acta, 68, 4335-4345.

Hall POJ & Aller RC (1992) Rapid, small-volume flow injection analysis for ∑CO2 and NH4+ in marine and freshwaters. Limnology and Oceanography, 37(5),1113-1119

Hensen C, Zabel M, Pfeifer K, Schwenk T, Kasten S, Riedinger N, Schulz HD & Boetius A (2003) Control of sulfate pore-water profiles by sedimentary events and the significance of anaerobic oxidation of methane for the burial of sulfur in marine sediments. Geochimica et Cosmochimica Acta, 67,2631-2647.

Jørgensen BB (1978) A comparison of methods for the quantification of bacterial sulfate reduction in coastal marine sediments, I, Measurement with radiotracer techniques. Geomicrobiol. J, 1, 29-47.

Kallmeyer J, Ferdelman TG, Weber A, Fossing H & Jørgensen BB (2004) A cold chromium distillation procedure for radiolabeled sulfide applied to sulfate reduction measurements. Limnol. OceanogR Methods, 2, 171-180.

Kamyshny Jr A, Borkenstein C & Ferdelmar TG (2009) Protocol for Quantitative Detection of Elemental Sulfur and Polysulfide Zero-Valent Sulfur Distribution in Natural Aquatic Samples. Geostand. Geoanalyt. Res., DOI: 10.1111/J 1751-908X.2009.00907.x

Riedinger N, Pfeifer K, Kasten S, Garming JFL,Vogt C & Hensen C (2005) Diagenetic alteration of magnetic signals by anaerobic oxidation of methane related to a change in sedimentation rate. Geochimica et Cosmochimica Acta, 69, 4117-4126.

Schubert CJ, Ferdelman TG & Strotmann B (2000) Organic matter composition and sulfate reduction rates in sediments off Chile. Org. Geochem., 31, 351-361.

Seeberg-Elverfeldt J, Schlüter M, Feseker T & Kölling M (2005) Rhizon sampling of porewaters near the sediment-water interface of aquatic systems. Limnology and Oceanography: Methods, 3: 361-371.

Torres ME, Wallman K, Tréhu AM, Bohrmann G, Borowski WS & Tomaru H (2004) Gas hydrate growth, methane transport, and chloride enrichment at the southern summit of Hydrate Ridgem Cascadia margin off Oregon. Earth and Planetary Science Letters, 226, 225-241.

Ussler III W & Paull C (2001) Ion exclusion associated with marine gas hydrate deposits, in Paull C, and Dillon WP (eds.), Natural gas hydrates-occurrence, distribution, and detection. Geophysical Monograph, 124, Washington, AGU, pP 41-51.

6. SEDIMENT CORING FOR RECONSTRUCTION OF THE ENVIRONMENTAL AND CLIMATE HISTORY OFF NE GREENLAND (ECHONEG)

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Grant-No. AWI_PS115/1_00

Objectives

Currently our knowledge of the glacial, deglacial and Holocene history of NE Greenland and the adjacent continental shelf and margin areas is rather limited. In particular, this accounts for the continental ice extent, sea-level rise, water mass distributions, ice coverage and fresh water export from the Arctic Ocean. During expedition PS115/1 it was intended to strongly improve this knowledge by obtaining sediment cores from the NE Greenland shelf and continental margin and by the establishment of paleoclimate proxy records on sediment cores from selected sites in the work area. Proxies to be used include grain sizes, microfossil associations, the geochemical and isotopic composition of calcareous microfossils, organic sediment components (e.g., biomarkers), ice-rafted detritus, X-ray fluorescence variability, and others. These records will complement the currently available basis for a synoptic analysis of the natural variability of the Arctic atmosphere-ice-ocean system, including leads and lags of individual parameters in this system, and for a realistic modelling effort that couples the North Atlantic and Arctic oceans. The work programme of the ECHONEG group during expedition PS115/1 had three major goals which can be achieved by obtaining long and short sediment cores.

Goal I was to extend the available core data base from the NE Greenland continental margin and shelf to the area north of 81°N and to nearshore areas not sampled during expedition PS93 in 2015 (which concentrated on the continental margin, except at 80.5°N). By investigating these cores the ECHONEG group wants to distinguish IRD from different sources in NE Greenland and reconstruct the glacial history of the hinterland in a more comprehensive way than what is possible with the PS93 cores alone. The reconstruction will be done by comparing IRD in time-equivalent layers in cores from PS115/1 and from PS93.

Goal II was to obtain large-volume cores from suitable sites on the shelf, in particular small morphological basins south of 80.5°N. Here, the youngest Holocene history of Atlantic Water advection on the outer NE Greenland shelf and continental margin is recorded in multidecadal resolution.

Goal III was to obtain additional sediment cores from small morphological basins and from moraine ridges on the outer and middle shelf to reconstruct and date glacial events and the onset of marine conditions on the shelf immediately postdating the deglaciation.

Work at sea

To identify suitable sites for sediment coring, the PARASOUND system of *Polarstern* was essential. Along several transects PARASOUND sediment echosounder surveys were conducted parallel to seismic surveys. The PARASOUND system usually had a penetration of 20-70 m in hemipelagic Arctic sediments, in particular along the northern and northeastern Greenland continental margin. This was sufficient for tracing key reflectors and determining those water depths and sites on the profile which showed a maximum thickness of the uppermost layers (supposed to be of Late Quaternary age). On the NE Greenland continental shelf, penetration was usually weak. The high number of incisions into the seabed suggested that the area had been heavily ploughed by deep-keel icebergs originating from Greenland and the Arctic Ocean. Weak penetration may thus be due to overconsolidation of shelf sediments from the pressure of iceberg keels and/or from the load of continental ice during times of an extended Greenland ice sheet. Sediment coring in heavily ploughed areas yielded only very short cores. In a number of attempts, the gravity corer fell over and contained no or very little sediment. However, in local morphologic depressions, layered sediment sequences of several meters thickness could be identified in the PARASOUND records and were later cored successfully.

At sites selected from PARASOUND records, long and short sediment cores were obtained. Short cores (giant box cores and/or multicores) ensured the availability of sediments from the sediment-water interface which ideally reflect the modern environment at the site. The box corer (manufactured by Fa. Wuttke, Henstedt-Ulzburg, Germany) has a total weight of ca. 500 kg and a maximum sample volume of 0.15 m^3 (box measures: 50*50*60 cm). It was successfully deployed at 12 stations. Recovery (sediment depth) varied between 18 and 47 cm. To obtain long sedimentary records a gravity corer (12 cm in diameter, up to 15 m long, weight 1 t) was used. Recovery was also variable (see Table 5.1, Figure 5.1); the longest core measured 909 cm in length. At several sites, up to three gravity cores were taken to ensure the availability of sufficient sediment volume for a large number of investigations,

Retrieval, handling and sampling of obtained sediment cores was performed at sea in collaboration with other working groups. All box cores were visually described, photographed and sampled on board for various onshore investigations by the ECHONEG group (see below). Further sampling occurred for microbiological investigations (see Chapter 5). From sites sampled with the gravity corer, one core was opened and handled in an equal way. Subcores from box cores were taken as archive boxes (50x15x8 cm) pressed horizontally into the opened box core. These archive boxes and the work and archive halves of the gravity cores were stored cool or frozen and were transported to the AWI and GEOMAR core repositories. Further analyses on samples obtained for the ECHONEG group will be performed in the home laboratories in Bremerhaven, Kiel, and Tromsø. This work will comprise a huge set of analyses and proxy investigations like, e.g., X-ray photography of thin sediment slabs, XRF-scanning, wet and bulk density, grain sizes, biomarkers, ice-rafted debris, stable carbon and oxygen isotopes of foraminifers, microfossil associations, Mg/Ca ratios of carbonate microfossils, clay and bulk mineralogy, etc.

Preliminary results

According to the environmental and depositional settings, the sites successfully sampled for paleoenvironmental investigations can be grouped as follows:

- (North)East Greenland continental margin
- Northeast Greenland continental shelf

- North Greenland (Wandel Sea) continental shelf
- North Greenland (Wandel Sea) continental margin
- Southern Morris Jesup Rise
- Western Fram Strait

Based on the visual core descriptions and preliminary grain size determinations ("tooth test"), a preliminary characterization of the sediments can be performed. While more detailed investigations are needed to establish data-based paleoenvironmental reconstructions and, in particular, reliable age models, in cases some very preliminary conclusions may be drawn from the results presented here, sorted by geographical areas.

• *(North)East Greenland continental margin*

Only one short gravity corer could be obtained from the continental margin just west of the Greenland Fracture zone. The sediments consisted of grayish olive and grayish brown sandy silty clays, likely deposited from both icebergs and sea ice. Since earlier coring operations recovered considerably longer sequences, it remains unclear why only 65 cm could be recovered at site PS115/1_4.

• *Northeast Greenland continental shelf*

At stations PS115/1_5, /1_6, /1_9, /1_11, /1_51, and /1_52 the near-surface sediments mostly consisted of sandy silty clays. The sediment surface was usually free of coarse rock particles, implying only a very minor role for modern iceberg transport. The shallower sites (water depth around 200 m) did not allow to obtain long sediment cores. The short sequences recovered by box cores and gravity cores often contained dropstones (from iceberg transport) of various size below a thin drape of finer sediments. These deposits may reflect an ice-marginal or sub-ice environment, likely related to an expansion of the Greenland ice sheet during the last (and previous) glaciation(s). In morphological depressions and channels (water depths >250 m), sequences of up to 4.5 m of dark grayish sediments could be recovered at sites PS115/1_6, /1_/9, /1_51, and /1_52. The cores from sites PS115/1_6 and /1_52 contained coarse sediments with abundant gravel, associating the deposition with glacier ice transport. The cores from the other two sites are more fine-grained in nature which suggests a dominant role of sea ice and/or bottom currents for the particle transport, which likely occured after the last glaciation.

• *North Greenland (Wandel Sea) continental shelf*

Despite the proximity to North Greenland fjords and glaciers, the surfaces of box cores obtained from the Wandel Sea continental shelf consisted of surprisingly fine-grained sediments with comparatively rich benthic life and no dropstones. The box cores obtained from this area held brownish sandy silty clays in the uppermost 10-25 cm, typically underlain by dark grayish deposits which are often coarser-grained and contain some dropstones. Very likely our cores did not penetrate through the Holocene and deglacial sediment cover.

• *North Greenland (Wandel Sea) continental margin*

Two long sediment cores could be obtained from the lower continental margin of the Wandel Sea (sites PS115/1_16 and /1_26; water depth 2,800-2,900 m). They mostly consist of silty clays of brownish, olive and gray colors. Some layers have a remarkable reddish brown color which is largely unknown from deep-sea Arctic Ocean sediments of other areas. One may speculate that the reddish color is related to red clastic rocks ("redbeds") in the North Greenland hinterland and that the deep-sea deposits hold important information on the glacial and erosion history in North Greenland. Since no age information is available yet, it remains speculative as to which time interval is covered by the cores. However, the relatively fine-grained nature of most of the layers and the variable colors point to an equally variable oceanic history off North Greenland in the course of the (late?) Quaternary.

• *Southern Morris Jesup Rise*

One site (PS115/1_47, water depth 880 m) could be sampled on the upper slope of the transition from the North Greenland shelf to the Morris Jesup Rise. In contrast to the often fine-grained brownish and grayish colors of deposits from the Wandel Sea continental margin, the sediments on the southern Morris Jesup Rise are significantly more coarse-grained throughout the recovered 500 cm of the core and contain high numbers of dropstones. Although no age estimate can be given yet, the lower amount of fine-grained particles points to lower sedimentation rates than at the neighboring, deeper sites. Very likely bottom currents over the Morris Jesup Rise swept away much of the fine-grained material originating from Greenland fjords which may then have been deposited elsewhere in the deep-sea. Nevertheless, the rich dropstone content in the core will allow to reconstruct the ice-rafting history north of Greenland in unprecedented resolution.

• *Western Fram Strait*

At site PS115/1_50 a 6.27 m long gravity core and an associated box core were retrieved from ca. 3,400 m water depth in the western Fram Strait. In terms of sediment color and dominant grain sizes the recovered sequence very much resembles the deposits from the Wandel Sea continental margin. Some dark gray, coarser layers may reflect dominant deposition from icebergs during major circum-Arctic glaciations. If reliable age models can be established for the cores retrieved from off North Greenland during PS115/1, the array of sedimentary cores will allow the reconstruct the paleoenvironmental history of the are in unprecedented areal and temporal resolution

Data management

All data obtained from sediment core analyses at sea and in the home laboratories will be stored at the PANGAEA data repository and will be made public at PANGAEA after publication. Metadata will be freely available at PANGAEA.

7. BATHYMETRIC MAPPING AND SUB-BOTTOM PROFILING

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Grant-No. AWI_PS115/1_00

7.1 Bathymetric mapping

Objectives

To understand processes in a marine environment such as geological and tectonic processes, accurate knowledge of the seabed topography is of major importance. While world bathymetric maps give the impression of detailed seafloor knowledge, most of the world's ocean floor has been modelled through satellite altimetry yielding low horizontal and vertical resolution. Only a fraction of world's ocean floor has been mapped with hydroacoustic systems of adequate resolution necessary to resolve small- to meso-scale geomorphological features (e.g. sediment waves, glaciogenic features and small seamounts).

To acquire first bathymetric data around the Arctic seas, the main task of the hydroacoustic group was to operate the multibeam echosounder Atlas Hydrosweep DS3, including calibration and correction of the data for environmental circumstances (sound velocity, systematic errors in bottom detection, etc.), the post processing and cleaning of the data, as well as data management for on-site map creation. The multibeam system ran constantly throughout the cruise for underway surveying.

Work at sea

During the PS115/1 cruise, the bathymetric surveys were conducted with the hull-mounted multibeam echosounder (MBES) Atlas Hydrosweep DS3. The Hydrosweep is a deep-water system for continuous mapping with the full swath potential. It operates on a frequency of ~15 kHz ranging from 14.2 to 16.1 kHz within the three different transmit sectors. On RV *Polarstern*, the MBES transducer arrays are arranged in a Mills cross configuration of 3 m (transmit unit) by 3 m (receive unit). The combined motion, position (Trimble GNSS), and time data comes from an iXBlue Hydrins system and the signal goes directly into the Processing Unit (PU) of the MBES to do real-time motion compensation in Pitch, Roll and Yaw. With a combination of phase and amplitude detection algorithms the PU computes the water depth from the returning backscatter signal. The system can cover a sector of up to 140° with each 70° per side and was operated in equidistant spacing mode.

Data acquisition and processing

Data acquisition was carried out throughout the entire cruise starting August 6, 2018 at 05:55 UTC after leavng the territorial waters of Norway and ending September 2, at 11:01 UTC. Due to heavy ice conditions, the vessel had to enter the territorial waters of Greenland the 24th of August between 04:26 UTC and 05:11 UTC. Following the Greenlandic research permission all hydroacoustic system recording was switched off for this period.

Where possible, cruise tracks were planned parallel to existing bathymetric data to extend already mapped regions. The mean survey speed between sampling stations was around 11 knots during transit, however due to ice conditions the velocity had to be often reduced to 5-7 knots. During seismic surveying the normal speed was 5 knots.

The aperture angle was generally kept between 120° and 130° and the pulse type was set to Continuous Wave and Single Swath mode most of the time as this setting appeared to be more stable than Frequency Modulated (Chirp) and Dual Swath mode.

The MBES was operated with Atlas Hydromap Control and for online data visualization Teledyne PDS was used. The collected bathymetry was stored in ASD and S7K raw files.

Subsequent data processing was performed using Caris HIPS and SIPS. For generating maps, the data were exported to Quantum GIS in the GeoTIFF raster format.

Sound velocity profiles

To determine accurate depths with multibeam echosounders, it is of major importance to know the changes of sound velocity in the water column. The speed of sound in water is influenced by density and compressibility, both depending on pressure, temperature and salinity. An acoustic wave propagating through different layers in the water column will progressively refract at layers with different acoustic impedances and thus change its initial direction. To reconstruct the acoustic path, thus avoiding refraction errors, 14 sound velocity profiles were acquired throughout the cruise of which 11 were sampled by a sound velocity profiler (SVP) and 3 acquired from World Ocean Atlas 2015 data (see Fig. 7.1).

The sampled sound velocities were measured by the SVP Valeport MIDAS. The system measures the time of between a pre-defined distance while it is lowered to the seafloor. From these parameters, the velocity is calculated. All sound velocity profiles obtained by the SVP were immediately processed and applied within the MBES for correct beamforming during the survey.

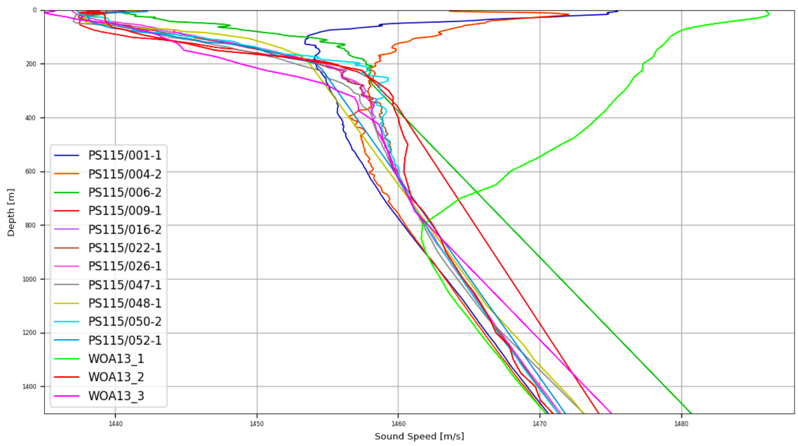

Fig. 7.1: Velocity Profiles used during PS115/1 (all profiles are extended with World Ocean Atlas 2013 data and virtually extrapolated to 12,000 m water depth)

Preliminary results

Throughout the cruise a continuous recording of data was achieved, except for small data gaps due to unexpected system/software errors and shutdowns. During 28 days of survey, a track length of 3,959 nm (7,333 km) was surveyed by the swath bathymetry system. The raw data volume of the Hydrosweep is 422 GB. The water depth ranges between 50 m on the East Greenland shelf to 3,820 m in the deep sea of the Fram Strait.

In the following, two preliminary results are presented. The first result shows the swath bathymetry data of the prior unsurveyed area of the Morris Jesup Rise, which due to fortunate ice conditions was accessible. Simultaneous to seismic profiling, bathymetric mapping was carried out. To prevent data repetition, track lines were planned parallel to seismic lines whenever possible (see Fig. 7.2).

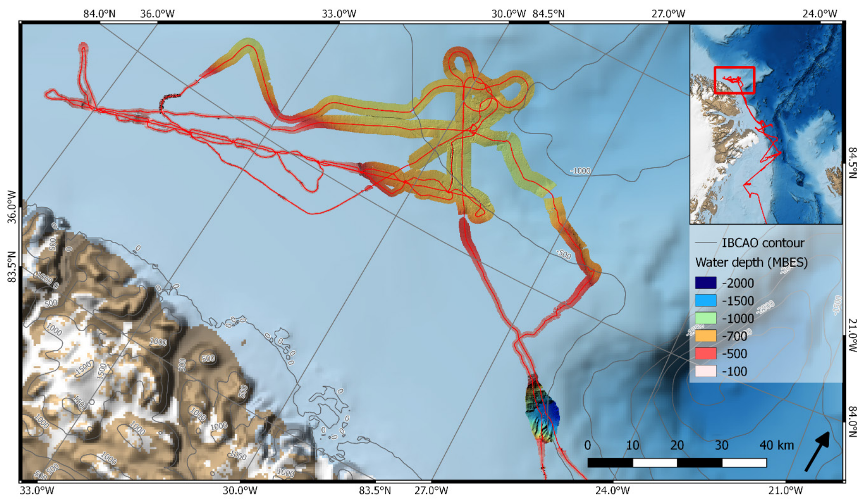

Fig.7.2: Swath bathymetry at Morris Jesup Rise

The second result abolishes the presence of two seamounts in Wandel Sea depicted in the IBCAO and GEBCO datasets. The 1,000 m tall seamounts were found to be only minor structures with a height of about 100 m (see Fig. 7.3). GEBCO data could be corrected by the acquired bathymetric data.

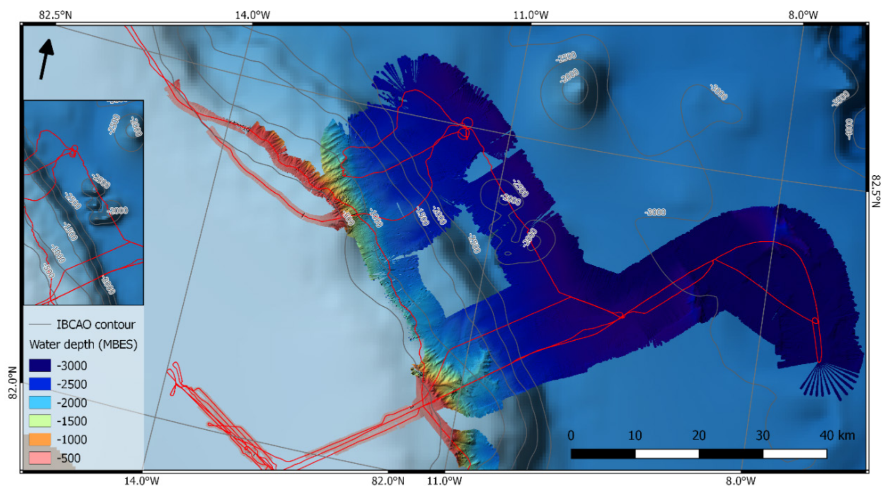

Fig. 7.3: Swath bathymetry in Wandel SeaRise

Data management

The collection of underway data during PS115/1 will contribute to the bathymetry data archive at the AWI and additionally contribute to bathymetric world datasets like GEBCO (General Bathymetric Chart of the Oceans). The raw datasets will be delivered to the long-term scientific database PANGAEA.

7.2 Sub-bottom profiling

Objectives

Supplementing the bathymetric data, high-resolution sub-bottom profiler data were recorded during the cruise. Sub-bottom reflection patterns characterize the uppermost sediments in terms of their acoustic behaviour of the top 10s of meters below the seabed and provide information on the lateral extension of sediment succession. The general objective was to select coring stations based on the acoustic pattern and reflection amplitude during the cruise.

Work at sea

The PARASOUND System DS3 (P70) is a hull-mounted parametric echo sounder developed by TELEDYNE ATLAS HYDROGRAPHIC GmbH. The transducer transmits signals with 70 kW transmission power to enable a maximum penetration depth of about 200 m in soft sediments. The system uses the parametric effect that occurs when very high (finite) amplitude sound waves are generated. If two waves of similar frequencies are generated simultaneously, the sum and the difference of the two primary frequencies are also emitted.

For the PARASOUND System on *Polarstern*, the first Primary High Frequency is 18 kHz which is distributed within a beam of ~4.5°. The second Primary High Frequency amounts to 22 kHz resulting in a Secondary Low Frequency (SLF) of 4 kHz and a Secondary High Frequency of 40 kHz. The SLF signal travels within the narrow 18 kHz beam, which is much narrower than e.g. the 30° beam of a 4 kHz signal when emitted directly from the same transducer. Therefore, a higher lateral resolution can be achieved, and imaging of small-scale structures on the seafloor is superior to conventional systems.

Data acquisition

The PARASOUND System was almost continuously running from August 6, 2018, 07:26 UTC to September 1, 2018, 10:43 UTC. However, several software failures required a software restart and in rare cases a full system restart. Additionally, the PARASOUND was switched to standby when entering the territorial waters of Greenland the 24th of August between 04:26 UTC and 05:11 UTC.

The PARASOUND system supports three different pinging modes – quasi-equidistant, pulse train, and single pulse mode. The system was mostly operated in single pulse and continuous wave mode. Both SLF and PHF were stored as ASD files, and additionally in PS3 and SEG-Y format. The PHF signal was only used for seafloor detection.

Preliminary results

SLF and PHF data (4 kHz) were acquired during the entire cruise and stored in ASD, PS3 and SEG-Y format. During 27 days of survey, the raw data volume of Parasound amounts to 311 GB.

In the following data examples of surveyed environments such as the East Greenland continental shelf (approx. 200 m) and the deep-sea environment (approx. 2,500 m) are presented.

The East Greenland continental shelf displayed a widely similar acoustic signature, dominated by a single strong seabed reflection (PHF, SLF) and scarce deeper reflections (SLF) implying the presence of a dense top most layer.

Further, the seabed morphology shows numerous incisions to the first 5 m of the sea bed (ploughmarks) by ground ice, only occasionally covered with draping sediment layers (see Fig. 7.4). So-called ploughmarks originated during the last glacial activity, hence their poor coverage insinuates a low sedimentation rate for large areas of the east Greenland shelf.

Pockets of sediment were detected in size varying depressions and targeted as sampling locations.

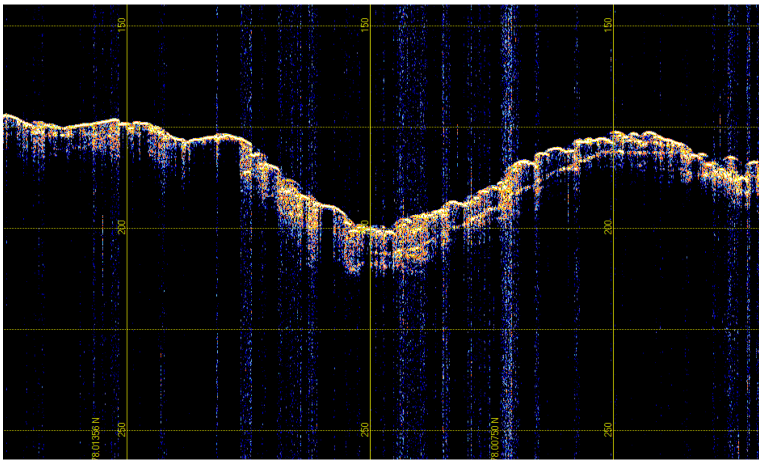

Fig. 7.4: Parasound example from the East Greenland continental shelf recorded during expedition PS115/1

In the deep-sea environment just east of the continental shelf, where deep signal penetration could be achieved, the strata display thick packages of widely undisturbed layering. Occasionally, slides are detected along the shelf break as seen in Fig. 7.5.

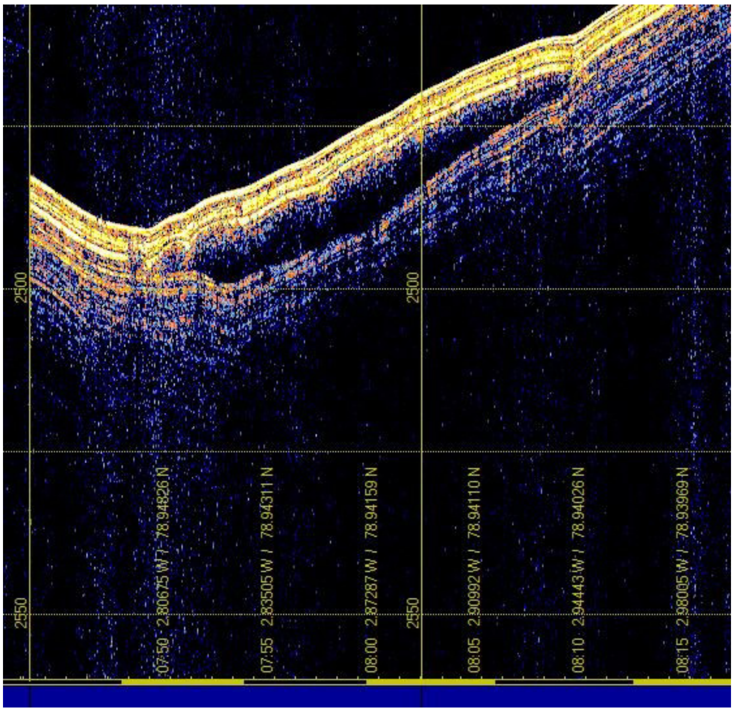

Fig. 7.5: Parasound data from the deep-sea seafloor of the Fram Strait showing thick sediment packages and a homogeneous slide structure recorded during the expedition PS115/1

Data Management

All acquired hydroacoustic data will be archived in the scientific database PANGAEA at AWI.

8. AT SEA DISTRIBUTION OF SEA BIRDS AND MARINE MAMMALS

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Grant-No. AWI_PS115/1_00

Objectives

The main objectives of PolE long-term studies are, on one hand, to contribute to a better understanding of the mechanisms influencing the quantitative at sea distribution of seabirds and marine mammals in polar marine ecosystems (water masses, fronts, pack ice, ice edge and eddies) and, on the other hand, to detect spatial and temporal evolutions in these distributions with special attention to possible consequences of anthropogenic activity and global climatic changes. As seabirds and marine mammals constitute the upper trophic levels in the food chain, their distribution reflects the abundance of prey, like zooplankton, krill, nekton and small fish, and is thereby an indicator for the ecology and biological production of the whole water column.

Improved knowledge of this distribution patterns is therefore of high relevance and interest to identify and localize areas of high biological productivity, and to observe temporal changes due to anthropogenic influences and global change.

Of several abiotic environmental factors, salinity and water temperature were identified as the most influential for bird distribution. Through monitoring across latitudes areas of strong variations called transition zones were identified. These zones potentially correspond to borders between water systems or fronts indicating ecological discontinuities, (Longhurst, 2007). Based on these fronts, the transects, conducted during PS115/1 between Norway and the northernmost visited point (84° N, north of Greenland) can be divided into 3 main zones (sub-Arctic; Arctic and polar).

The birds' spatial distributions will be compared to Longhurst's bio-geographical marine provinces (Longhurst, 2007) (Fig. 8.1). Here the oceans are divided into 4 biomes, which are divided into provinces, based on physical forcing. It is important to note that the boundaries of these provinces are not fixed in space or time, and evolve seasonally and inter-annually due to physical variations.

Further research should indicate if there are clear correlations with oceanographic and biological parameters, such as water quality parameters, seafloor topography, plankton blooms or crustaceans or fish concentrations. This knowledge can then be used for the mapping of ecologically important or vulnerable areas.

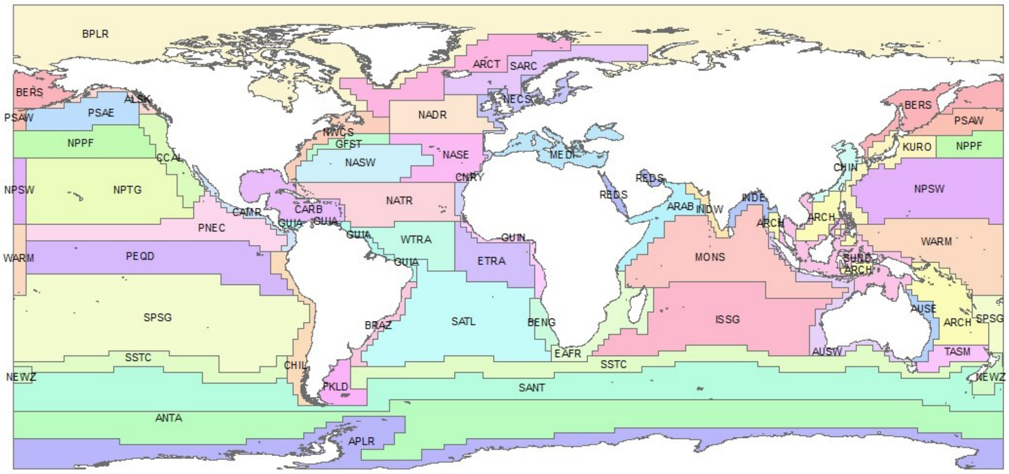

Fig. 8.1: Longhurst's bio-geographical provinces

Work at sea

Birds and mammals were recorded by transect counts from the bridge, 18 meters above sea level, without width limitation. Animals were detected with bare eyes, identification being confirmed and detailed with binocular (2x Leica Ultravid 10x42), telescope (Optolyth TBS 80 w/30x wide-angle lens) and/or cameras (Nikon D800 w/300 mm lens and D300 w/70-300 mm zoom lens). The total transit time between stations was monitored and divided into 30 minutes counts. These counts are performed from the ship's bridge where visibility reached at least an angle of 120°. Counting was done on a continuous basis during all movements of the ship (standard counts between stations and non-standard counts during seismic activities or other slow displacements of the ship), where the visibility was at least ≥500 m and a vessel velocity ≥ 7 kn (except during seismic activity).

A total of 323 counts was conducted during this cruise (excluding the final transect to Longyearbyen). Two helicopter flights were dedicated to the detection of marine mammals, when weather conditions allowed it, and one observer had the opportunity join an ice-reconnaissance flight for marine mammal detection outside the observable track of *Polarstern*.

Preliminary results

During all ship transects (excluding the ones during seismic activities), a total of 7,234 observations were made. 24 sea birds species were identified. The three most numerous species observed were the Puffin (*Fratercula arctica*), with 3,043 individuals observed during 18 counts mostly in the vicinity of the Norwegian coast (representing 43 % of the total of birds counted), 1,204 Herring Gull (*Larus argentatus*) were counted (17 % of the total of birds observed during only 8 counts), and the Little Auk (*Alle alle*), with 688 individuals (9,7 % of the total of birds) were observed during 57 counts.

As for the marine mammals: 12 different species were identified during our counts from the vessel and during successful helicopter flights. Polar Bear (*Ursus maritimus*) was the most commonly observed/identified marine mammal during this leg with 20 individuals detected from *Polarstern* and from the helicopter. Orcas (*Orcinus orca*) were detected twice (2 distinct pods) with a total of 9 individuals. Fin Whale (*Balaenoptera physalus*) was observed eight times, Sperm Whale (*Physeter macrocephalus*) was observed on seven occasions and 7

Minke Whale (*Balaenoptera acutorostrata*) were observed near Norway and in the Fram Strait. Smaller cetaceans were also detected, including harbour porpoise (*Phocoena phocoena*), monitored 5 times, as well as one species of unidentified *Lagenorhynchus* dolphin observed on our second day of transit to Greenland. A mother and a calve Blue Whale (*Balaenoptera musculus*) were detected from close distance near the continental slope of Fram Strait, east Greenland at the end of the cruise.

Four species of seals were observed: Harp Seal (*Pagophilus groenlandicus*), Hooded Seal (*Cystophora cristata*), Ringed Seal (*Pusa hispida*) and Bearded Seal (*Erignathus barbatus*). Despite our efforts, no Walruses (*Odobenus rosmarus*) could be detected during this leg, most likely due to the ship's constant distance to the coast and walruses foraging areas.

For practical reasons, data presented in this cruise report do not include the data collected during the ultimate transect of the ship (between the eastern coast of Greenland to the cruise's final destination: Longyearbyen, Svalbard).

Tables 8.1 and 8.2. list the species detected within the three bio-geographical provinces crossed during PS115/1 with the basic statistics based on our observations.

Tab. 8.1: Bird species observed during cruise PS115/1

English name	Latin name	Total No. of Individuals observed	No. of counts where present	Remark
Arctic skua	*Stercorarius parasiticus*	20	10	Occasional observations of single individuals
Arctic Tern	*Sterna paradisaea*	35	11	Sporadic observations of small groups
Brünnich's Guillemot	*Uria lomvia*	11	7	Occasional observations
Common Guillemot	*Uria aalge*	48	13	Common along Norwegian coasts
Common eider	*Somateria mollissima*	5	1	Few specimens observed near Norway
Common Gull	*Larus canus*	61	6	Common along Norwegian coasts and in fjords
Common Tern	*Sterna hirundo*	18	3	Common along Norwegian coasts and in fjords
Fulmar	*Fulmarus glacialis*	697	213	Most commonly observed species all along PS115-1
Gannet	*Morus bassanus*	6	4	Few specimens observed near Norway
Glaucous Gull	*Larus hyperboreus*	11	7	Occasional observations of single individuals
Great Black-backed Gull	*Larus marinus*	643	9	Common along Norwegian coasts and in fjords
Herrinng Gull	*Larus argentatus*	1204	8	Common along Norwegian coasts and in fjords. Sometimes in very large groups
Ivory Gull	*Pagophila eburnea*	345	114	Commonly observed in the polar region, mostly associated with ice floes
Kittiwake	*Rissa tridactyla*	196	55	Occasional observations. Present in most area visited.
Lesser Black-backed Gull	*Larus fuscus*	2	2	2 specimens observed in Norwegian fjord
Little Auk	*Alle alle*	688	57	Widespread between Svalbard and Greenland. Commonly observed.
Long-tailed Skua	*Stercorarius longicaudus*	11	11	Few individuals observed mostly near north coast of Greenland
Pomarine Skua	*Stercorarius pomarinus*	4	4	Few individuals observed mostly near east coast of Greenland
Puffin	*Fratercula arctica*	3043	18	Common along Norwegian coasts and in fjords
Razorbill	*Alca torda*	3	2	Few specimens observed near exit of Norwegian fjord
Red-trhoated Loon	*Gavia stellata*	1	1	1 specimens observed in Norwegian fjord
Ruddy Turnstone	*Arenaria interpres*	2*	2	2 individuals observed near north-eastern coast of Greenland
Sabine's Gull	*Xema sabini*	2	2	2 individuals observed near north-eastern coast of Greenland
Sanderling	*Calidris alba*	4*	1	Small flock observed near east coast of Greenland
		* Observed during seismic activity		

Tab. 8.2: Marine mammals observed during cruise PS115/1

English name	Latin name	Total No. of Individuals observed	No. of counts where present	Remark
Bearded Seal	*Erignathus barbatus*	7	7	Sporadic observations of single individual on ice floes
Blue Whale	*Balaenoptera musculus*	2*	1	2 specimen observed on the continental slope, east Greenland
Bowhead Whale	*Balaena mysticetus*	1*	1	1 specimen observed near north-eastern coast of Greenland (82°N)
Dolphin sp.	*Lagenorhynchus* sp.	6	1	One group of unidentified dolphins near coast of Norway
Fin Whale	*Balaenoptera physalus*	3 (+5*)	3	Single observations in Fram strait and on the continental slope, east Greenland
Harbor Porpoise	*Phocoena phocoena*	5	3	3 specimens observed in Norwegian fjord
Harp Seal	*Pagophilus groenlandicus*	10*	10	Sporadic observations of single individual on ice floes
Hooded Seal	*Cystophora cristata*	15	11	Sporadic observations of single individual (sometimes in pair) on ice floes
Minke Whale	*Balaenoptera acutorostrata*	7	5	Few specimens observed near exit of Norwegian fjord and Fram Strait
Orca	*Orcinus orca*	9	2	2 pods observed near Norwegian coast
Polar Bear	*Ursus maritimus*	9 (+11*)	7	Several observations of single individual (except one pair) on ice floes
Ringed Seal	*Pusa hispida*	14	11	Several observations of single individual swimming or on ice floes
Seal sp.		72	42	Several observations of single individual swimming or on ice floes
Sperm Whale	*Physeter microcephalus*	7	4	Few specimens observed near continental slope of Norwegian and Fram Strait
Whale sp.		9	8	Few blows observed at great distance in Fram Strait

* Observed during seismic activity

Conclusions and recommendations

Collaboration between the Marine Mammal Observer (MMO; 2 pers.), PolE (3 pers.) and the Infra-red team (3 pers.) has been very successful on this cruise. We can therefore only encourage chief scientists of future cruise using seismic equipment to strongly consider and rebuild such a team scheme that allows joined detection capacity. Only this complementarity appears to be efficient and can help reduce to a minimum the negative impact of seismic activity on the wildlife encountered.

All along seismic operation, the JNCC regulations were closely followed to keep the possibly negative environmental impact of the seismic operations as low as possible. The JNCC regulations only consider marine mammals as highly impacted by seismic activities. Diving birds, so far, have not been considered in these terms. We do consider this fact as a weakness in this protocol. Through the results of our observations during this cruise, we would like to emphasize investigations of the influence of seismic operations on behaviour and general health of (diving) seabirds. Very often diving birds were observed along the ship´s track (e.g. Little Auk (*Alle alle*), Black Guillemot (*Cepphus grylle*) and Brunnich's Guillemot (*Uria lomvia*)), either flying away or diving as *Polarstern* approached. These birds were not considered for mitigation although seismic activity conducted at full power are most likely to affect them as much as any other animal.

Regardless of their size, abundance or IUCN status of conservation, all vertebrate organisms should be considered equal on front of anthropogenic pressure and activity.

Data management

All results will be included in the PolE database and will be made accessible to anyone interested in collaboration (contact: crjoiris@gmail.com). After analysis and publication of our results, data will be made open access on the www.biodiversity.aq data portal.

Reference

Longhurst A (2007) Ecological Geography of the Sea. 2nd ed. Academic Press, San Diego, U.S.

9. THE "YEAR OF POLAR PREDICTION" (YOPP): ADDITIONAL RADIO-SOUNDINGS DURING THE SPECIAL OBSERVING PERIOD

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[2] AWI

Grant-No. AWI_PS115/1_00

Objectives

The „Year of Polar Prediction" (YOPP) is one of the key elements of the Polar Prediction Project (PPP, www.polarprediction.net). Its mission is to enable a significant improvement in environmental prediction capabilities for the polar regions and beyond, by coordinating a period of intensive observing, modelling, verification, user-engagement and education activities.

Within YOPP there are three "Special Observing Periods" (SOPs) defined:

SOP-NH1:	1 Feb. 2018 – 31 Mar. 2018 in the Arctic
SOP-NH2:	01 Jul. 2018 – 30 Sep. 2018 in the Arctic
SOP-SH:	16 Nov 2018 –15 Feb 2019 in the Antarctic

To contribute to the special observing efforts of YOPP the radio-sounding activity on board *Polarstern* is increased to 4 soundings per day. This follows the internationally compiled science plan of PPP[1] and the recommendations in the implementation plan of the project (WWRP 2016).

Work at sea

Whenever *Polarstern* was north of 60°N, the routinely launched daily radio-sounding is extended by another 3 soundings per day. Together, the soundings cover all synoptic main hours, namely 00, 06, 12 and 18 UTC.

Preliminary (expected) results

Radiosonde measurements are known to be one of the highest impact global observation systems for operational weather prediction analysis ("analysis" is the best guess of the status of the atmosphere at a certain point in time). Temporarily intensified soundings, together with modelling studies, are capable to quantify the impact on operational analysis products. During YOPP it is expected that the impact of polar radio-sounding activities on weather prediction capabilities can be estimated. This will give important reasoning for the optimisation of the polar meteorological observation network, which is one distinct goal of YOPP.

Data management

Data management is identical to the routinely performed radio-soundings. Data on board was made available through the DWD staff to any interested scientist. Data will be stored and made open access by the PANGAEA data archive at AWI after the cruise. Any scientific publication shall use the data from PANGAEA.

References

World Weather Research Programme (2013) WWRP Polar Prediction Project Science Plan. WWRP/PPP No. 1. World Meteorological Organization, Geneva. http://www.polarprediction.net/fileadmin/user_upload/www.polarprediction.net/Home/Documents/Final_WWRP_PPP_Science_Plan.pdf

World Weather Research Programme (2016) WWRP Polar Prediction Project Implementation Plan for the Year of Polar Prediction (YOPP), Version 2.0. WWRP/PPP No. 4. World Meteorological Organization, Geneva. http://www.polarprediction.net/fileadmin/user_upload/www.polarprediction.net/Home/YOPP/YOPP_Documents/FINAL_WWRP_PPP_YOPP_Plan_28_July_2016_web-1.pdf

10. MITIGATION MEASURES DURING SEISMIC OPERATIONS

Volkmar Damm[1] [1]BGR

Grant-No. AWI_PS115/1_00

All offshore projects conducted by BGR consider possible environmental effects of the planned survey operations to guarantee the lowest possible environmental impact during all marine research activities. In the adoption of best practice to international standards, BGR generally implemented a MMO regime for seismic surveying identical to the long-established UK JNCC (August, 2013).

After carefully re-evaluating our original research plan for the cruise PS115/1 we modified and adjusted our survey plan in a way to not touch any area of concern for protected wildlife and to not interfere with national parks. All seismic operations were located outside these sensitive zones. Moreover, we decided to reduce the total volume of our airguns from 3,120 in³ (51.1 liters) to 2,000 in³ (32.7 liters), which is 30 % less compared to what we had planned before. This still allowed us to achieve our scientific goals, but reduced the bandwidth and acoustic impact. For detail please see the Environmental Mitigation Assessment (BGR, 2018) which was elaborated during the application process for the Greenlandic research permission well in advance of the scientific operations.

Conducting the seismic survey, we followed the Guidelines to Best Environmental Practices by the Greenland authorities (Offshore Seismic Surveys in Greenland) which are almost identical to the JNCC rules and met all pre-conditions set by the research license issued by governmental authorities of Greenland.

The guidance for mitigation action was distributed to the seismic crew at the start of the survey, to ensure that everyone is aware of the requirements. As there were two dedicated joint MMO/PAM operators plus three bird watchers (due to the polar ecologic program – see extended non-technical summary) on board the vessel, almost continuous marine faunal watches was maintained during this survey and regardless of source activity. The two certified, professional MMO/PAM operators were in charge of coordinating all mitigation activities and MMSO service. They were assisted by the seabird observers and additional scientific personnel holding JNCC licenses.

In addition to standard visual observations two PAM systems plus a highly innovative infrared detection system will be used on the vessel during the cruise, primarily for marine mammal mitigation, and additionally for comparison purposes of the systems. For passive acoustic monitoring and infrared detection the following systems were employed:

1. Standard PAM system with 4-element towed array and acoustic processing system like Seiche Measurement Limited's (SML) (http://www.seiche.com/topics/73-towed-pam-system) using the PAMGuard analysis software (http://www.pamguard.org/), set up and operated by the PAM operator (The specific PAM system will be provided by the contracted MMO service company. The above system was used during previous cruises).The four-channel 250 m array cable is towed from the source vessel and consists of two (H1 and H2) identical, spherical broadband hydrophones (200 Hz to 200 kHz, - 3 dB points); two (H3 and H4) identical spherical hydrophones (2 kHz

to 200 kHz), and a depth gauge (10 Bar sensor). Channel sensitivity at the output from the pre-amplifier is -166 dB re: 1 V/µPa for the broadband channel and -157 dB re 1V/µPa for the low frequency channel. Marine mammal vocalisation signals are detected acoustically using a headset (Sennheiser HD280 pro) and the PAMGuard PC. The location of detected marine mammals are resolved by calculating the bearing and range of the received signals from pairs of grouped hydrophones (LF: H1 & H2, HF: H3 & H4) using a combination of automated detectors and manual localisation techniques. The bearings of detected vocalisations may be displayed on a map and the animal's location is resolved using Target Motion Analysis (TMA), where successive bearings begin to converge as the vessel advances along a track.

2. Sercel's QuietSea™ system (http://www.sercel.com/products/Pages/QuietSea.aspx) which processes and analyses sound from both the seismic streamers and additional high frequency hydrophones in the streamer and on the gun arrays. QuietSea™ is a recently developed Marine Mammal Monitoring System designed by Sercel to detect the presence of marine mammals during seismic operations without towing additional PAM equipment behind the vessel. This streamer integrated system is operated as a peripheral device to Sercel's seismic data acquisition unit SEAL 428. QuietSea™ uses two classes of data to cover a broadband frequency spectrum:

   (I) the seismic data (using the SEAL interface) to detect vocalizations in the (low-frequency) seismic bandwidth from 10Hz to 200Hz with usual seismic sampling frequency of 2ms and
   (II) (high-frequency) data, provided by additional QS streamer modules integrated within the Sercel seismic streamer and other QS auxiliary modules to detect vocalizations in the bandwidth of 200Hz to 96kHz.
   This potentially allows for enhanced marine mammal detection capabilities in a wide frequency listening range that covers a large variety of vocalizing cetacean species, i.e. Whistles - 200Hz-96kHz Auxiliaries module detection bandwidth, and Click trains - 10Hz to 200Hz; Seismic Bandwidth sampling. Monitoring is conducted automatically using localization algorithms. All acoustic events are logged in a protocol and stored in a database.

3. Automatic infrared-based marine mammal mitigation system AIMMMS AIMMMS provides a thermal image of the surrounding sea at a rate of 5 frames per second from the horizon to about 100 m from the sensor. Distances between sensor and auto-detected objects are automatically calculated using the object's angle under the horizon. The software analyses the data stream in real time for the occurrence of whale blows. It displays the 360° image at full resolution.

The synchronous operation of three systems, both of the PAM systems and the AIMMMS, provides an opportunity to compare the results and provides a database for further improving the QS and AIMMMS hard- and software components.

10.1 Standard MMO and PAM operations and service provided by SML

Stephanie Barnicoat[1], Eva Kvalheim[1]   [1]Seiche

Objectives

The research programme for the PS115/1 cruise involved seismic operations in Greenlandic waters and the Arctic ocean. The Government of Greenland Environmental Agency for Mineral Resource Activities (EAMRA) has set out guidelines for seismic activities pursuant to the Mineral Resources Act section 3c, sub section 3. According to these guidelines, "EAMRA decides, based on a preliminary scope (draft scope) of the seismic activities, whether an Environmental Impact Assessment (EIA) or an Environmental Mitigation Assessment (EMA) must be prepared". In accordance with the United Nations Convention for the Laws of the Sea articles 56, 1, a, article 240 c) and d) as well as article 246 paragraph 8, EAMRA has assessed measures necessary to mitigate impacts of the activity based on scientific recommendations. Consequently, according to the assessment of EAMRA and recommendations of GINR and DCE special mitigation measures were required for all seismic activities carried out in Greenland waters.

Two trained and skilled MMBO's (marine mammal and seabird observers) had to take part in the operation with a special focus on observations of walruses, narwhals and bowhead whales.

Marine mammal observations within Greenlandic waters followed procedures outlined in the Manual for Seabird and Marine Mammal Survey on Seismic Vessels in Greenland (4th revised edition, March 2015) to ensure that data fit into the databases of MMSO observations kept by the Greenland authorities. The specific role of the MMO/PAM operator during the survey was to focus on marine mammal monitoring and mitigation which correspond closely to the Joint Nature Conservation Committee (JNCC) standards, described in the guidelines to EIA/EMA of seismic surveys in Greenland waters. These data are recorded and reported to EAMRA and their scientific advisors (DCE and GINR) on JNCC Marine Mammal Recording forms which were downloaded from the JNCC website (http://jncc.defra.gov.uk/page-1534).

In addition to marine mammal visual observations, the MMO's were also tasked with operating the Passive Acoustic Monitoring (PAM) system on board the seismic vessel. This required that both MMO's are also certified and experienced PAM-operators.

Seiche Ltd (UK) provided Marine Mammal Observers (MMOs) and a Passive Acoustic Monitoring System (PAMS) to record the presence of marine mammals during the project.

A team of two MMOs conducted visual observations for marine mammals during daylight hours, while PAM using a towed hydrophone array was primary monitoring tool during the hours of darkness or poor visibility. In addition, there were three Marine Mammal Sea Bird observers (MMSO), provided from PoIE (see Chapter 8), who were on constant watch for marine mammals and sea birds. The MMO on duty was in charge of all mitigation actions during seismic operations and authorized to advice commence and interruptions of seismic survey activities.

Work at Sea

Marine Mammals in the Survey Area

The project includes survey locations around Yermak Plateau, Wandel Sea and the Danmarkshavn Basin. Collectively, these regions constitute an important area of the Arctic Ocean for marine life. Marine productivity around North East Greenland is limited by the persistent cover of sea ice which inhibits the growth of plankton and other small marine organisms. However, marine productivity can be found in places where the pack ice has fractured to expose large areas of open water (polynyas) which offer a winter refuge for marine mammals and seabirds.

While many species of cetaceans occur seasonally within Arctic waters, typically during summer months, there are several species which are native to the Arctic and occur year-round. In the North East Greenland area, three species have been identified by the EAMRA as species of concern in relation to the cumulative impacts of seismic activities since 2011. These include narwhal, walrus, and the critically endangered bowhead whale.

Bowhead whales (*Balaena mysticetus*) are circumpolar in Arctic pack ice and around polynyas and spend their entire life in Arctic waters, making seasonal movements into higher latitudes in the spring and summer as the ice recedes. They are sexually mature at about 20 years of age and females give birth to one calf every 3-4 years. The bowhead whale stocks in the survey area are assessed as critically endangered by the International Nature Conservation Organisation (IUCN). Small populations of narwhals (*Monodon monoceros*) occur in the Greenland Sea, aggregating in coastal areas when the ice breaks up in spring, and moving further offshore when the sea freezes in winter. In summer months, they can form herds of hundreds of animals which are segregated by age and sex. Walruses (*Odobenus rosmarus)* are distributed in pack ice and coastal waters of Greenland, are gregarious and haul out in great numbers on beaches and ice flows around openings in the sea ice. Females mature sexually at 4-8 years of age and breed in spring between April and May, delivering a single calf after one-year gestation.

Pinniped species which include the bearded seal, harp seal hooded seal and the ringed seal occur year-round throughout the Arctic Ocean, making seasonal movements further north in response to receding ice cover, while polar bears (*Ursus maritimus*) occur circumpolar on the Arctic Ocean sea ice and adjacent land masses.

Other marine mammals may occur seasonally over the survey area include rorquals (fin whale, blue whale, sei whale and minke whale) and humpback whales which are attracted by the triggering of the early blooming of phytoplankton and zooplankton to undertake a northerly migration to their summer feeding grounds in the cooler, high latitude waters of the Arctic where they feed for 3-4 months on the rich supply of krill and other food. After this they will migrate south to tropical breeding and calving waters. Several species of odontocetes (dolphins, beaked whales, and sperm whales) occur in the Greenland Sea. Sperm whales and beaked whales occur in the Southern Greenland Sea, primarily found over continental slopes, deep canyons and edges of ocean banks. Oceanic dolphins are resident all year round and can be observed both in the Greenland Sea as far north as the pack ice. In the winter months, they are found further offshore away from the ice. A list of all species found in the survey areas are listed in Table 10.1.

Tab. 10.1: Marine mammals in survey area

Species common name	Species Latin name	Distribution
Bowhead whale	*Balaena mysticetus*	Resident, Greenland Sea, Arctic Ocean
Humpback whale	*Megaptera novaeangliae*	Migration, Greenland Sea
Blue whale	*Balaenoptera musculus*	Migration, Greenland Sea
Fin whale	*Balaenoptera physalus*	Migration, Greenland Sea
Sei whale	*Balaenoptera borealis*	Migration, Greenland Sea
Northern Minke whale	*Balaenoptera acutorostrata*	Migration, Greenland Sea
Sperm whale	*Physeter macrocephalus*	Migration, Greenland Sea
Narwhal	*Mondon monoceros*	Resident, Greenland Sea, Arctic Ocean
Northern Bottlenose whale	*Hyperoodon ampullatus*	Resident, Greenland Sea
Orca/Killer whale	*Orcinus orca*	Resident, Greenland Sea
Long-fined Pilot whale	*Globicephala meals*	Resident, Greenland Sea
White-beaked dolphin	*Lagenorhynchus albirostris*	Resident, Greenland Sea
Walrus	*Odobenus rosmarus*	Resident, Greenland Sea, Arctic Ocean
Ringed seal	*Pusa hispida*	Resident, Greenland Sea, Arctic Ocean
Bearded seal	*Eringathus barbatus*	Resident, Greenland Sea, Arctic Ocean
Hooded seal	*Cystophora cristata*	Resident, Greenland Sea, Arctic Ocean
Harp seal	*Pagophilus groenlandicus*	Resident, Greenland Sea, Arctic Ocean
Polar bear	*Ursus maritimus*	Resident, Greenland Sea, Arctic Ocean

Greenlandic guidelines for seismic surveys have designated areas where seismic surveys are either prohibited in certain periods or can be regulated to reduce impacts on marine mammals (Fig. 10.1). The survey area is within designated areas of concern for narwhal and bowhead whale, and close to a designated closed area for walrus (area closed 1st June to 30st September). The MMO's/PAM operator along with the MMBO had not only to concentrate in the 500 m Exclusion Zone (EZ) for marine mammals but also concentrate their efforts to actively search for bowhead whales within 2 km of the airgun array, to shut down the array, move 50 km away before a new ramp up is commenced and the survey line continued. The vessel was not permitted to return to the sighting location until 24 hours after the whales were observed.

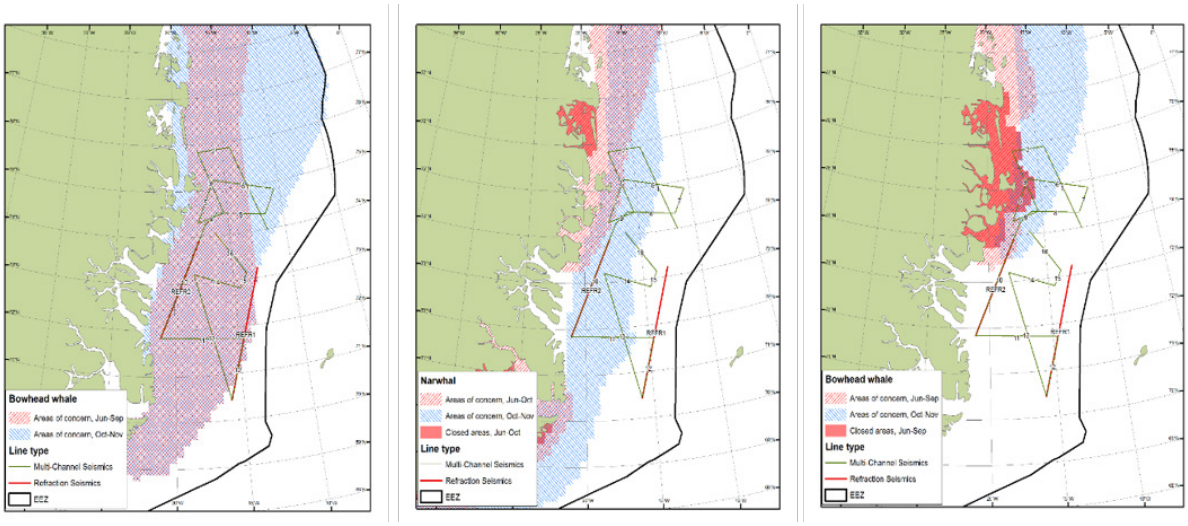

Fig. 10.1: Maps showing designated area of concern for bowhead whales (a), narwhals (b), and designated closed area for walruses (c)

Mitigation procedures

An **exclusion zone** of 500 m radius from the centre of the seismic source was adopted, as per the JNCC (2017) Guidelines. In Greenlandic waters, a 2,000 m exclusion zone during seismic operations was requested for bowhead whales.

During daylight hours, a JNCC-qualified MMO or MMSO conducted a visual **pre-shoot search** of the 500 m exclusion zone for at least 30 min or 60 min prior to every airgun use (depending on water depth). As well as visual watch, the pre-shoot watch was carried out acoustically by a dedicated PAM operator.

The **soft start** consisted of gradually increasing the volume of the airgun array, in uniform stages, from a low energy start-up, by increasing the number of airguns starting with the smallest airgun in the array over a period of around 20 minutes.

If marine mammals were detected within the exclusion zone at any point during the pre-shoot watch, then the sources had to **shutdown**, the soft-start was to be delayed for 20 min from the animals exiting from, or last observed within the mitigation zone. The MMSO would notify the MMO/PAM Operator who would then notify the seismic crew of the need to delay soft start and then again when they had the all clear to commence soft start. All marine mammals are covered in this including marine mammals on ice, including polar bears.

During operations, if a marine mammal was observed in the mitigation zone (including animals on ice), the source would be **powered down** to the mitigation gun with a source volume of 250 cubic inches. However, if a **bowhead whale** was observed within 2,000 m of the source, the source would be shutdown to inactive, and the vessel would move 50 km away from the animal in a different direction before resuming operations. The vessel would not return to the location of the sighting for a minimum of 24-hours.

During **unintentional operational breaks** in source activity the following shall be observed: If the break is shorter than 5 minutes the array can be re-initiated at full power without further actions. If the shut-down is between 5 and 10 minutes, a visual scan shall be performed. If no marine mammals are detected within the 500 m exclusion zone the array can be restarted at full output. If marine mammals are present in the exclusion zone the operator must wait until 20 minutes after the animal has left the zone before commencing with ramp-up. If the source output stops for more than 10 min, a full pre-shoot search and soft-start is required.

If **line changes** are expected to take longer than 40 minutes, airgun firing is to be terminated at the end of the survey line. A pre-shooting search is to be undertaken during the scheduled line. If line changes are expected to take less than 40 minutes airgun firing can continue during the line change only if power is reduced to 180 cubic inches (or as close as is practically feasible) at standard pressure. Airgun volumes of less than 180 cubic inches can continue to fire with an increased SPI. In the Greenland Sea, if the line changes are expected to be less than 1 hour, the airgun firing must be reduced to the mitigation gun, and the MMO/PAM remain on watch. Full power can commence on the next line without a soft-start. If the line is longer than 1 hour, airing gun firing shall be terminated at the end of the line and the next line must be preceded with a pre-watch and soft-start procedure.

A flow diagram of mitigation measures is given in Fig. 10.2.

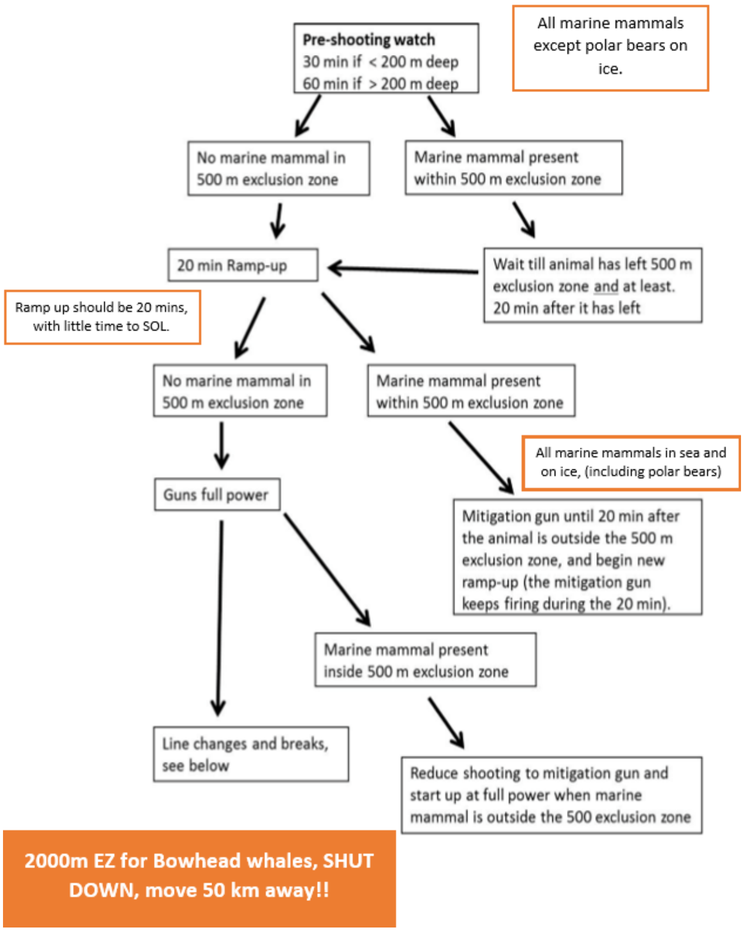

Fig. 10.2: Modified JNCC mitigation flow diagram showing protocol for marine mammal mitigation in Greenland waters

Detailed marine mammal mitigation procedures for operations within Greenland waters are summarised in Table 10.2. The guidance for all mitigation procedures (Figs. 10.2 to 10.4) was distributed to the seismic crew and the chief scientist at the start of the survey, to ensure that everyone was aware of the requirements. As there were two dedicated joint MMO/PAM operators and three MMBO's on board the vessel, continuous marine faunal watches were maintained during this survey and regardless of source activity.

Tab. 10.2: Mitigation procedures summary

Source mitigation zone	500 m for marine mammals in water and on ice, 2,000 m for bow head whales during operations
Pre-watch period	30 minutes (depth < 200 m), 60 minutes (depth > 200 m)
Soft start length	> 20 minutes, < 40 minutes
Soft-start delays	Yes
Shut-down during production	Yes, if a marine mammal enters mitigation zone, airguns reduced to mitigation output until marine mammal has left the area and MMO/PAM instructs to resume at full operating power
Species covered	Marine mammals in water and on ice including Polar bears
Special requirements	2000 m mitigation zone for bowhead whales. If seen within 2,000 m, shut down operations, move 50 km away before resuming seismic operations and do not return to sighting location for 24 hours. Passive acoustic monitoring (PAM) during darkness & reduced visibility

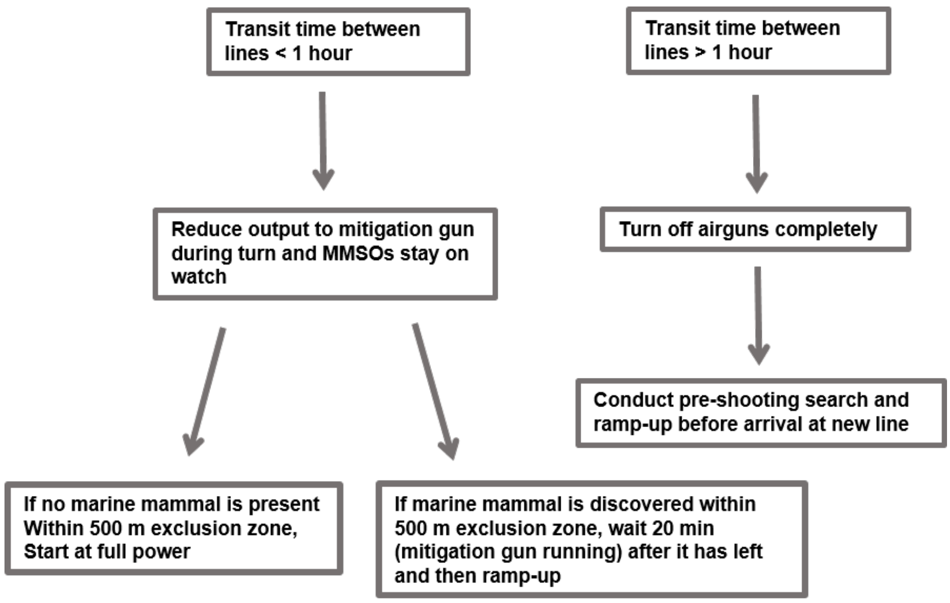

Fig. 10.3: Modified JNCC mitigation flow diagram showing protocol for marine mammal mitigation in Greenland waters during line change

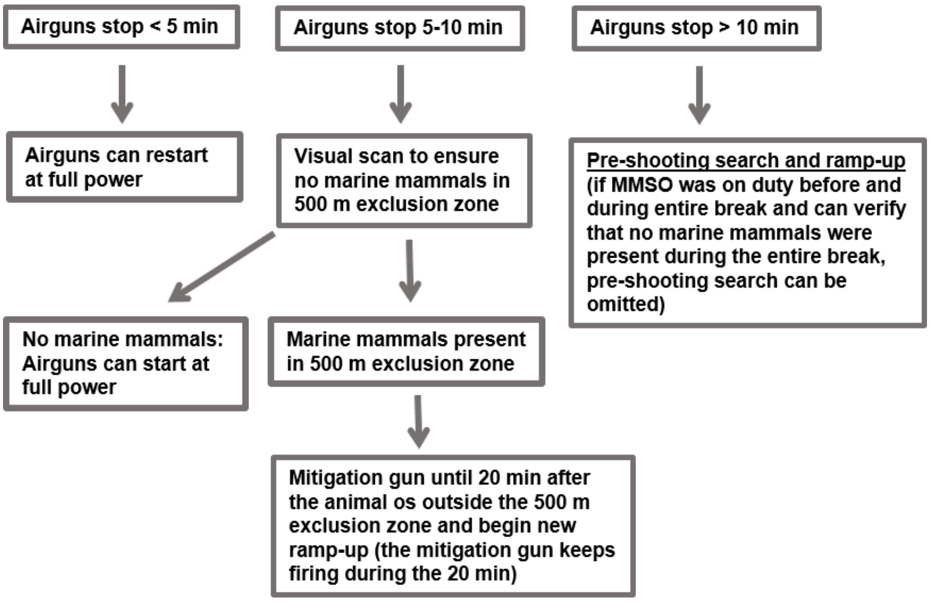

Fig. 10.4: Modified JNCC mitigation flow diagram showing protocol for marine mammal mitigation in Greenland waters during unplanned breaks in firing

Marine Mammal Survey methods

Dedicated visual observations were carried out during hours of daylight and when weather conditions permitted. Observer effort was recorded with environmental data. Wind speed was classified to the Beaufort wind scale. Other classifications for sea state, swell, visibility and glare followed the JNCC recording forms (Appendix 6). A new record was entered every time environmental conditions or the source status changed, or at least every hour.

Observations were carried out from the observation deck above the bridge (21 m) and on the bridge (19 m). The MMOs scanned the sea with the naked eye, using 7x50 binoculars to closer investigate any visual cues seen, such as circling seabirds, dark shapes, splashes or blows. If marine mammals were observed, the distance to the sighting was estimated, using reticules from binoculars. The time, location and other data required for the completion of the JNCC sightings forms were also recorded, as well as the behaviour of the animals in relation to the survey vessel.

Photographs of marine mammals were taken whenever possible to document the species identification (also sometimes providing information on group sizes and behaviour). Photography is a useful tool in freezing the motion of fast-moving species such as delphinids, allowing later examination of their flank markings and facilitating identification. It also permits independent verification of sighting data. During this survey, the MMOs used a range of photographic equipment; Canon DSLR cameras 70 x 300 zoom lens.

Passive Acoustic Monitoring (PAM) was used to monitor underwater sounds during the hours of darkness and periods of poor visibility and in conjunction with the MMSO observer. A four-channel 250 m towed array cable consisted of two (H1 and H2) identical, spherical broadband hydrophones (200 Hz to 200 kHz, - 3 dB points); two (H3 and H4) identical spherical hydrophones (2 kHz to 200 kHz), and a depth gauge (2 Bar sensor). Channel sensitivity at the output from the pre-amplifier was -166 dB re: 1 V/μPa for the broadband channel and -157 dB re 1V/μPa for the low frequency channel.

The 250 m array cable was deployed from a winch to the starboard side stern. The cable was deployed and retrieved using the starboard winch and the cables reel. The array cable was connected to a PAM base station via a 100 m deck cable. The PAM Base was contained in a 19-inch rack housing and consisted of a buffer box with an internal card (NI DAQ USB-6251) for sampling high frequency (HF) sound (H3 and H4, 500 ks/s), an external sound card (Fireface 800) for digitally sampling Low Frequency (LF) sound (H1 and H2, 48 ks/s), a rack mounted PC ("PAMGuard PC") running PAMGuard64 version 1.15.11 CORE, Java (update 8 version 131), NI Device Monitor (version 17) and the Fireface 800 controller software.

Odontocetes (e.g. toothed whales and dolphins) emit echolocation clicks to navigate and find prey. Individual click energy broadly varies between species but generally, peak frequency may range from 4 kHz to 200 kHz and are emitted in rapid sequences or trains. Mysticetes (e.g. baleen whales) and many odontocetes also emit frequency modulated (FM) tonal signals and pulsed calls that are used for communication. Marine mammal vocalisation signals were detected acoustically using a headset (Sennheiser HD280 pro) and the PAMGuard PC. Raw FFT data acquired by the LF sound card was displayed in real-time on spectrograms. A mid-frequency (MF) spectrogram displayed signals with a frequency range of 0 Hz to 24 kHz and was suitable for the detection of frequency modulated (FM) tonal signals (e.g. whistles, peak frequency 4 kHz to 24 kHz) and pulsed calls (e.g. buzz, squawk, bark, etc.) produced by odontocetes (e.g. dolphins, narwhals etc.) A low-frequency (LF) spectrogram displayed signals with a frequency range of 0 Hz to 3 kHz and was used to detect LF tonal signals (e.g. songs, moans, grunts, shrieks, pulses) produced by mysticetes (e.g. humpback whales, bowhead whales, etc.). A very low-frequency (VLF) spectrogram displayed signals with a frequency range of 0 Hz to 480 Hz for closer inspection of VLF tonal vocalisations (e.g. calls, pulses, moans, etc.) produced by large mysticetes (e.g. blue whales, fin whales, sei whales, etc.).

Data from the LF sound card were processed using a LF click detector (frequency range of 0 Hz to 24 kHz, trigger high pass 4 kHz, order 4) to identify echolocation click trains of dolphin species and sperm whales. Candidate clicks were verified by inspection of click waveform and spectrum characteristics. Sperm whales produce powerful broadband echolocation clicks with a peak energy (160 to 180 dB re 1 μPa @ 1m) at approximately 0.1 kHz to 30 kHz. Many odontocetes (e.g. dolphins, beaked whales, *Kogia*, etc.) produce clicks with energy exceeding the human hearing range (e.g. > 20 kHz). High frequency echolocation clicks were processed using an HF click detector (frequency range 0 Hz to 250 kHz, trigger band pass 15 kHz to 160 kHz, order 6) and classified by frequency sweep as MF Pulse (e.g. test band 20 kHz to 50 kHz, click length 0.04 to 1 ms), HF Pulse (e.g. test band 50 kHz to 100 kHz, click length 0.04 to 1 ms) and Narrow Band HF (e.g. test band 120 kHz to 150 kHz, click length 0.03 to 0.12 ms) to facilitate detection of target frequency bands (e.g. beaked whale clicks have a peak frequency of 30 kHz to 60 kHz). The vessels position was provided by the on-board GPS navigation system (NMEA GGA string, BAUD 4800) and displayed in PAMGuard on a map along with hydrophone positions, 500m exclusion zone, vessel heading, track and local bathymetry data.

The location of detected marine mammals are resolved by calculating the bearing and range of the received signals from pairs of grouped hydrophones (LF: H1 & H2, HF: H3 & H4) using a combination of automated detectors and manual localisation techniques. The bearing of the target signal is calculated using a time of arrival difference (TOAD) cross-correlation function, which calculates the difference in the arrival times of the same signal when detected on two or more hydrophones of known separation distance (e.g. H1 and H2 have a separation of 2m, H3 and H4 have a separation of 0.25m) and the speed of sound in water (e.g. 1500 m/s). The bearings of detected vocalisations may be displayed on a map and the animal's location is resolved using Target Motion Analysis (TMA), where successive bearings begin to converge as the vessel advances along a track. FM tonal sounds may be detected using an automated whistle and moan detector, or manually selected using a clip generator. Automated detections are verified manually by inspecting the spectrogram display and aurally using the headset. False automated detections attributed to other noise sources (e.g. airguns, echosounders, sub-bottom profilers, etc.) are monitored and excluded from candidate marine mammal detections by the PAM operator. LF click trains (e.g. sperm whale echolocation clicks and coda, etc.) can be tracked and plotted automatically by running automated click train ID, or manually by selecting and assigning individual target clicks to a tracked acoustic event. HF clicks are automatically classified per pre-defined parameters (e.g. MF_Pulse, HF_Pulse, NBHF, etc.) and individually inspected by click waveform, spectrum, inter-click interval (ICI) and Wigner plots to identify vocalisations (e.g. beaked whales, *Kogia*, dolphins, etc.) and other noise sources. Verified HF click trains are tracked, labelled as an acoustic event and displayed on the map. LF and HF click trains are localised automatically using the tracked click localiser function or manually using real-time TMA and the map measuring tool.

Acoustic monitoring was available 24 h, while monitoring by the PAM operator was focused during operations to assist with the MMSO for an increased chance of detecting cetaceans. Acoustic encounters were defined as different detections when it could be certain they were different groups of animals or species or when they were separated by at least 20 min without an acoustic detection. PAM effort and source operation logs were maintained and updated on standard JNCC recording forms. Sound recordings (.wav format) and screengrabs (.png) of PAMGuard displays were archived to catalogue detection events where possible. An SQLITE3 database logged GPS positional data, hydrophone depth and detection events continually throughout the project. Data acquired by the LF and HF click detectors, whistle and moan detectors and clip generators were stored in binary format and made available for offline processing in PAMGuard Viewer.

Communication and Reporting

The MMO/PAM Operator liaised directly with the seismic crew using handheld UHF radios on the appropriate working channel (Ch 4). Notification of the 60-minute pre-shoot watch for every soft start was provided by the seismic crew, along with an 'all clear' check immediately prior to starting the airguns. In the case of a mitigation event, the MMO/PAM Operator informed the seismic crew immediately that any delay or shut down of the source was required, and communication was maintained regarding animal movements and the subsequent resumption of operations.

Throughout the survey, weekly reports were submitted to the chief scientist on board *Polarstern* (Appendix 6). The reports included information on sightings, environmental conditions, mitigation, MMO/PAM effort and seismic airgun activity.

Preliminary results

Sighting conditions and observer effort

Environmental conditions can have a direct influence upon the detectability of marine mammals, and as such were recorded at a minimum of hourly intervals throughout the duration of the survey. Wind strengths experienced ranged between force 1 and did not reach over force 5 (Fig. 10.5).

The sea state was mainly glassy (52 %) or slight (47 %) during the survey. On occasions the sea state became increasingly choppy (4 %). Swell was overall less than 2 m height (100 %), (Fig. 10.6).

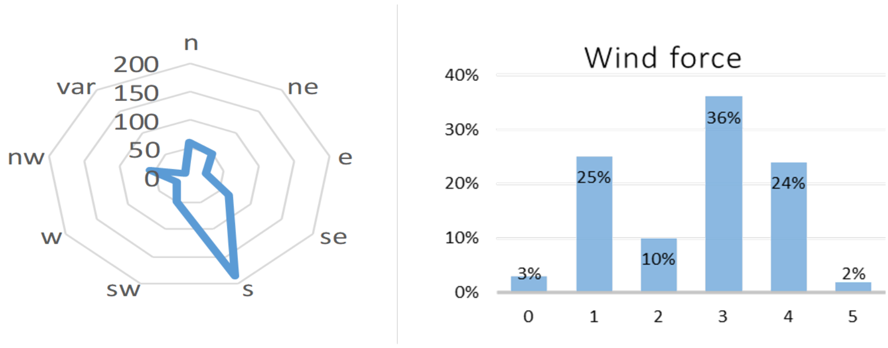

Fig. 10.5: Wind Force and Direction

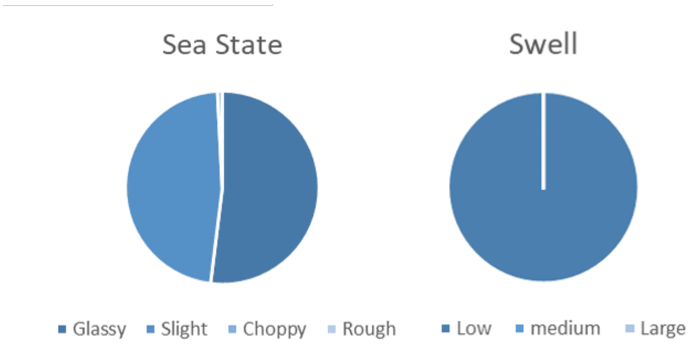

Fig. 10.6: Sea state and swell height

Clear conditions with good visibility of over 5 km were enjoyed for most of the survey (72 %). Moderate (9 %) and poor (less than 1 km), (19 %) levels of visibility were recorded during brief periods of fog and rain showers and at times when it did not look like it was going to improve, PAM was the preferred tool for monitoring marine mammals. Sun glare was mostly no sun glare (60 %) with variable strong sun glare. Precipitation can affect visibility, however during the survey there was no precipitation (93 %), with some light (3 %) and moderate 2 %) rainfall as well as snow (3 %), (Fig. 10.7).

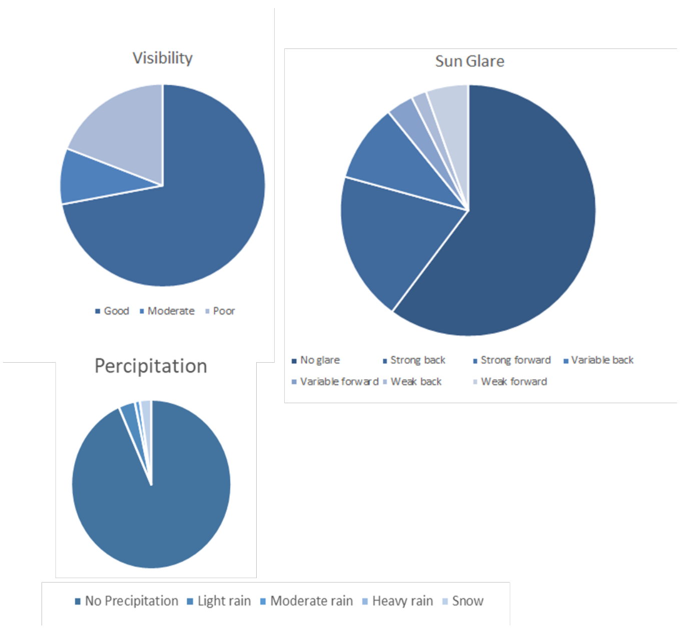

Fig. 10.7: Visibility and sun glare (upper panels) and precipitation (below)

During the survey, 88 h 03 min of dedicated **visual observation** for marine mammals were carried out by the MMOs. Visual watch was conducted in a glassy or a slight sea when the beaufort scale was less 5 or less. During the project, visual observation when the source was active was 55 hr 21 min.

A total of 313 h 43 min of **acoustic monitoring** was carried out with 306 h 04 min of monitoring while the seismic source was active on full volume, reduced volume or during testing. There was a total of 17 h 39 min of PAM monitoring while the seismic source was inactive.

Distribution and Occurrence

There were 198 sightings of marine mammals during survey operations, all consisted of pinniped species (harp seal, bearded seal, ringed seal and hooded seal), nine polar bears and one bowhead whale (Fig. 10.8, Table 10.3). There were no acoustic detections of marine mammals during the survey operation. There were seventeen sightings of cetaceans while the vessel was in transit from Tromso. There were 97 occasion where mitigation action was required to intervene with seismic survey operations, following the Greenlandic modified JNCC seismic mitigation protocol. This resulted in a temporary power-down of the seismic airguns due to the presence of a marine mammal within the exclusion zone.

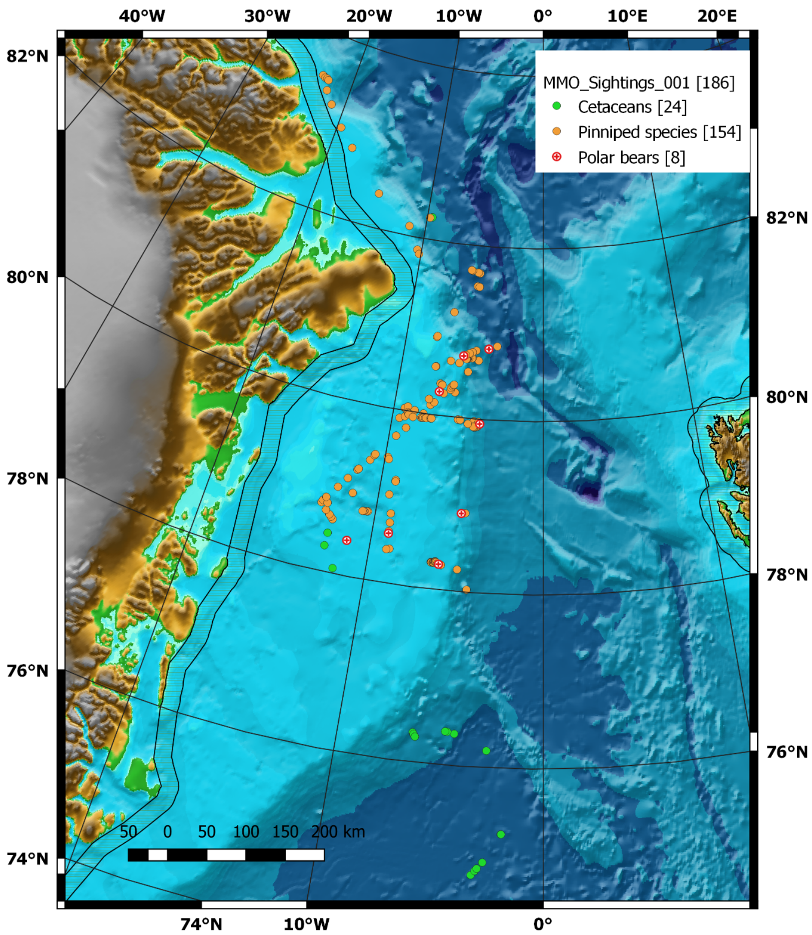

Fig. 10.8: Overview of P115/1 marine mammal sightings

On August 5, leaving Tromso harbour, there were sightings of harbour porpoises and minke whales. Whilst **on transit** and as the MMOs were recording, the first recorded sighting was of an unidentified cetacean at 18:30 UTC with small conspicuous blows which could possibly be attributed to killer whales or beaked whales, but without seeing the cetacean itself, it was impossible to identify. Other sightings along the transit included large whales such as mysticetes (blue, fin, minke, sei and humpback whales) as well as sperm whales were observed travelling at the surface blowing.

There was also one sighting (no. 4, Table 10.3) of a pod of four Killer Whales (*Orcinus orca*) including one adult male with distinctive tall upright dorsal fin with white patches above eye visible on several individuals. One animal temporarily broke away from the pod and travelled towards the vessel to investigate before heading back to the group. The main group were recorded at 1,000 m away from the vessel, firstly travelling towards the vessel then altered their direction to parallel with the vessel in the opposite direction. The pod was moving as a group, carrying out short dives suggesting they were foraging. All sightings are included in Table 10.3 and in the JNCC marine mammal recording forms.

Tab.10.3: Summary of marine mammal sightings

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
1	05/08/2018	Unidentified cetacean	4	400	88	On transit	None
2	06/08/2018	Unidentified cetacean	1	1000	1201	On transit	None
3	06/08/2018	Sperm Whale	1	500	1201	On transit	None
4	06/08/2018	Killer whale	4	1000	1200	On transit	None
5	06/08/2018	Sperm whale	2	2000	1623	On transit	None
6	07/08/2018	Fin whale	1	500	3333	On transit	None
7	07/08/2018	Unidentified cetacean	2	500	3475	On transit	None
8	07/08/2018	Unidentified cetacean	2	600	3144	On transit	None
9	07/08/2018	Fin whale	1	4000	2125	On transit	None
10	07/08/2018	Minke Whale	2	2000	2125	On transit	None
11	07/08/2018	Unidentified cetacean	1	2000		On survey site	None
12	07/08/2018	Unidentified cetacean	2	3000		On survey site	None
13	08/08/2018	Unidentified cetacean	1	3000	3697	On survey site	None
14	08/08/2018	Unidentified cetacean	1	2000	3159	On survey site	None
15	08/08/2018	Unidentified cetacean	2	4000	2387	On survey site	None

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
16	08/08/2018	Unidentified cetacean	2	3000	2380	On survey site	None
17	09/08/2018	Unidentified seal	1	700	243	On survey site	None
18	10/08/2018	Unidentified seal	1	200	200	On survey site	Power down
19	10/08/2018	Polar bear	2	300	184	On survey site	Power down
20	10/08/2018	Hooded seal	1	200	184	On survey site	Power down
21	10/08/2018	Unidentified seal	1	1200	178	On survey site	Power down
22	10/08/2018	unidentified seal	1	400	178	On survey site	Power down
23	10/08/2018	Unidentified seal	1	200	195	On survey site	Power down
24	10/08/2018	Bearded seal	1	300		On survey site	Power down
25	10/08/2018	Ringed seal	3	1000	121	On survey site	Power down
26	10/08/2018	Ringed seal	1	1000	115	On survey site	None
27	10/08/2018	Hooded seal	1	1000		On survey site	None
28	10/08/2018	Hooded seal	1	1200	181	On survey site	None
29	11/08/2018	Bearded seal	1	700	397	On survey site	None
30	11/08/2018	Harp seal	1	1000	135	On survey site	None
31	11/08/2018	Unidentified seal	1	550	278	On survey site	None
32	11/08/2018	Harp seal	1		250	On survey site	
33	11/08/2018	Bearded seal	1	500	255	On survey site	Power down
34	11/08/2018	Hooded seal	1		255	On survey site	None
35	11/08/2018	Unidentified seal	1	800	261	On survey site	Power down
36	11/08/2018	Ringed seal	6	1200	98	On survey site	Power down
37	11/08/2018	Unidentified seal	1	1700	117	On survey site	None
38	12/08/2018	Harp Seal	1	600	209	On survey site	None
39	12/08/2018	Unidentified seal	1	600	210	On survey site	None
40	12/08/2018	Ringed seal	1	750	204	On survey site	None
41	12/08/2018	Ringed seal	2	1300	318	On survey site	Power down
42	12/08/2018	Unidentified seal	2	1000	288	On survey site	Power down

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
43	12/08/2018	Unidentified seal	1	300	270	On survey site	Power down
44	12/08/2018	Unidentified seal	1	1500	280	On survey site	Power down
45	12/08/2018	Unidentified seal	1	600	300	On survey site	None
46	12/08/2018	Unidentified seal	1	500	302	On survey site	Power down
47	12/08/2018	Unidentified seal	1	500	312	On survey site	Power down
48	12/08/2018	Ringed seal	1	400	319	On survey site	Power down
49	12/08/2018	Unidentified seal	1	600	324	On survey site	Power down
50	13/08/2018	Unidentified seal, most likely Harp Seal	1	700	1613	On survey site	None
51	13/08/2018	Bearded seal	1	100	3003	On survey site	Power down
52	13/08/2018	Bearded seal	1	300	3445	On survey site	Power down
53	13/08/2018	Ringed seal	1	100	2957	On survey site	Power down
54	13/08/2018	Unidentified seal	2	100	1012	On survey site	Power down
55	13/08/2018	Unidentified seal	1	100	1012	On survey site	None
56	13/08/2018	Unidentified seal	2	700	2737	On survey site	Power down
57	13/08/2018	Unidentified seal	1	200	2649	On survey site	Power down
58	13/08/2018	Unidentified seal	1	250	1012	On survey site	Power down
59	13/08/2018	Unidentified seal	1	50	1012	On survey site	Power down
60	13/08/2018	Unidentified seal	1	80	1000	On survey site	Power down
61	14/08/2018	Unidentified seal	1	800	246	On survey site	Power down
62	14/08/2018	Ringed Seal	1	300	279	On survey site	Power down
63	14/08/2018	Unidentified seal	1	1000	1880	On survey site	Power down
64	14/08/2018	Unidentified seal	1	400	3965	On survey site	Power down
65	14/08/2018	Unidentified seal	1	1500	3457	On survey site	None

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
66	14/08/2018	Unidentified seal	1	200	3378	On survey site	Power down
67	14/08/2018	Unidentified seal	1	1500	3319	On survey site	None
68	14/08/2018	Unidentified seal	1	200	3215	On survey site	Power down
69	14/08/2018	Ringed seal	1	1700	2222	On survey site	None
70	15/08/2018	Bowhead whale	1	2500	2868	On survey site	None
71	16/08/2018	Unidentified seal	1	800	2680	On survey site	None
72	17/08/2018	Polar bear	1			On survey site	None
73	17/08/2018	Polar bear	1			On survey site	None
74	17/08/2018	Unidentified seal	1	600		On survey site	None
75	19/08/2018	Hooded seal	1	700	159	On survey site	None
76	19/08/2018	Unidentified seal	1	700	196	On survey site	Power down
77	19/08/2018	Bearded seal	1	500	196	On survey site	Power down
78	19/08/2018	Unidentified seal	2	400		On survey site	Power down
79	19/08/2018	Unidentified seal	1	1200		On survey site	None
80	20/08/2018	Unidentified seal	1	10		On survey site	Power down
81	23/08/2018	Unidentified seal	1	50	879	On survey site	None
82	24/08/2018	Ringed seal	1	500	292	On survey site	None
83	24/08/2018	Ringed seal	1	300	203	On survey site	None
84	24/08/2018	Unidentified seal	2	1000	1000	On survey site	None
85	24/08/2018	Ringed seal	1	900	900	On survey site	None
86	24/08/2018	Unidentified seal	1	800	268	On survey site	None
87	24/08/2018	Ringed seal	1	800	232	On survey site	None
88	24/08/2018	Unidentified seal	1	700	376	On survey site	None
89	25/08/2018	Hooded seal	1	400	1600	On survey site	None
90	25/08/2018					On survey site	None
91	25/08/2018	Hooded seal	1	800	2295	On survey site	None

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
92	25/08/2018	Unidentified seal	1	1000	1439	On survey site	None
93	25/08/2018	Polar bear	1	800	2568	On survey site	None
94	25/08/2018	Ringed seal	1	500	3050	On survey site	None
95	26/08/2018	Ringed seal	1	300	3029	On survey site	None
96	26/08/2018	Unidentified seal	1	1200	3029	On survey site	None
97	26/08/2018	Hooded seal	1	400	2927	On survey site	None
98	26/08/2018	Ringed seal	1	200	2682	On survey site	None
99	26/08/2018	Polar bear	1	200	2285	On survey site	None
100	26/08/2018	Unidentified seal	1	200	320	On survey site	None
101	26/08/2018	Unidentified seal	1	1000	263	On survey site	None
102	26/08/2018	Hooded seal	2	700	266	On survey site	None
103	26/08/2018	Unidentified seal	1	200	241	On survey site	None
104	26/08/2018	Unidentified seal	1	300	241	On survey site	None
105	26/08/2018	Unidentified seal	1	200	246	On survey site	None
106	26/08/2018	Unidentified seal	3	300	246	On survey site	None
107	26/08/2018	Polar bear	1	1200	271	On survey site	None
108	26/08/2018	Unidentified seal	1	700	300	On survey site	None
109	26/08/2018	Ringed seal	1	200	300	On survey site	None
110	26/08/2018	Unidentified seal	1	1500		On survey site	None
111	26/08/2018	Unidentified seal	1	500		On survey site	None
112	26/08/2018	Unidentified seal	1	1000		On survey site	None
113	26/08/2018	Hooded seal	1	300		On survey site	None
114	26/08/2018	Unidentified seal	1	350	150	On survey site	None
115	26/08/2018	Unidentified seal	1	300	319	On survey site	Delay operations
116	26/08/2018	Unidentified seal	1	500		On survey site	Delay operations

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
117	26/08/2018	Ringed seal	1	10	10	On survey site	Delay operations
118	26/08/2018	Unidentified seal	1	300	243	On survey site	Delay operations
119	26/08/2018	Unidentified seal	1	600	140	On survey site	None
120	26/08/2018	Unidentified seal	1	1200	123	On survey site	None
121	26/08/2018	Unidentified seal	1	1500	161	On survey site	None
122	26/08/2018	Unidentified seal	1	800	180	On survey site	None
123	26/08/2018	Bearded seal	1	600	180	On survey site	None
124	26/08/2018	Unidentified seal	1	400	200	On survey site	Power down
125	26/08/2018	Unidentified seal	1	1200	217	On survey site	Power down
126	26/08/2018	Unidentified seal	1	2000	227	On survey site	Power down
127	27/08/2018	Hooded seal	1	2000	243	On survey site	Power down
128	27/08/2018	Unidentified seal	1	500	247	On survey site	Power down
129	27/08/2018	Hooded seal	1	500	542	On survey site	Power down
130	27/08/2018	Hooded seal	1	600	542	On survey site	Power down
131	27/08/2018	Unidentified seal	1	400	542	On survey site	Power down
132	27/08/2018	Hooded seal	1	500	722	On survey site	Power down
133	27/08/2018	Unidentified seal	1	600	1561	On survey site	Power down
134	27/08/2018	Unidentified seal	1	150	1561	On survey site	Power down
135	27/08/2018	Unidentified seal	1	200	1836	On survey site	n
136	27/08/2018	Unidentified seal	1	100	1879	On survey site	Power down
137	27/08/2018	Polar bear	1	450	1879	On survey site	Power down
138	27/08/2018	Unidentified seal	1	700	1773	On survey site	Power down
139	27/08/2018	Unidentified seal	1	400	1732	On survey site	Power down

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
140	27/08/2018	Unidentified seal	1	450	1730	On survey site	Power down
141	27/08/2018	Unidentified seal	1	200	1591	On survey site	Power down
142	27/08/2018	Unidentified seal	2	500	1566	On survey site	Power down
143	27/08/2018	Unidentified seal	1	400	1536	On survey site	Power down
144	27/08/2018	Unidentified seal	1	500	1226	On survey site	Power down
145	27/08/2018					On survey site	None
146	28/08/2018	Unidentified seal	1	200	139	On survey site	Power down
147	28/08/2018	Hooded seal	1	800	136	On survey site	None
148	28/08/2018	Unidentified seal				On survey site	None
149	28/08/2018	Harp seal				On survey site	None
150	28/08/2018	Unidentified seal	1	400	238	On survey site	None
151	28/08/2018	Unidentified seal	1	800	184	On survey site	None
152	28/08/2018	Unidentified seal	2	400	298	On survey site	Power down
153	28/08/2018	Ringed Seal	1	300	247	On survey site	Power down
154	28/08/2018	Polar bear	1	300	265	On survey site	Power down
155	28/08/2018	Harp seal	1	400	242	On survey site	Power down
156	28/08/2018	Unidentified seal	1	300	358	On survey site	Power down
157	28/08/2018	Unidentified seal	3	1000		On survey site	Power down
158	28/08/2018	Unidentified seal	1	200		On survey site	Power down
159	28/08/2018	Unidentified seal	1	300		On survey site	Power down
160	28/08/2018	Unidentified seal	2	400	344	On survey site	Power down
161	28/08/2018	Unidentified seal	1	300		On survey site	Power down
162	28/08/2018	Ringed seal	1	200	345	On survey site	Power down
163	28/08/2018	Unidentified seal	1	400		On survey site	Power down

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
164	28/08/2018	Unidentified seal	1	700	357	On survey site	None
165	28/08/2018	Unidentified seal	1	300		On survey site	Power down
166	28/08/2018	Unidentified seal	1	200		On survey site	Power down
167	28/08/2018	Unidentified seal	1	500		On survey site	Power down
168	28/08/2018	Unidentified seal	1	500		On survey site	Power down
169	28/08/2018	Unidentified seal	1	400		On survey site	Power down
170	28/08/2018	Unidentified seal	1	250		On survey site	Power down
171	28/08/2018	Polar bear	1	850		On survey site	None
172	28/08/2018	Unidentified seal	1	300	348	On survey site	Power down
173	28/08/2018	Unidentified seal	1	700		On survey site	Power down
174	28/08/2018	Unidentified seal	1	200	352	On survey site	Power down
175	28/08/2018	Unidentified seal	2	300	352	On survey site	Power down
176	28/08/2018	Unidentified seal	1	700	350	On survey site	None
177	28/08/2018	Harp seal	2	200	462	On survey site	Power down
178	28/08/2018	Ringed seal	1	10	1893	On survey site	Power down
179	30/08/2018	Harp seal	1	150	1439	On survey site	Power down
180	30/08/2018	Polar bear	1	500	1234	On survey site	Power down
181	31/08/2018	Hooded seal	1	1200		On survey site	
182	31/08/2018	Hooded seal	1	1000	372	On survey site	Power down
183	31/08/2018	Unidentified seal	1	1100	358	On survey site	None
184	31/08/2018	Unidentified seal	1	1000	358	On survey site	Power down
185	31/08/2018	Unidentified seal	1	1200	351	On survey site	None
186	31/08/2018	Ringed seal	1	800	351	On survey site	None
187	31/08/2018	Unidentified seal	1	300	341	On survey site	Power down

Sighting no. [Acoustic ID]	Date	Species	No. of Animals	Closest distance to vessel [m]	Water depth [m]	Vessel Activity at time of sighting	Mitigation Action
188	31/08/2018	Unidentified seal	1	200	306	On survey site	None
189	31/08/2018	Unidentified seal	1	500	245	On survey site	None
190	31/08/2018	Unidentified seal	1	500	150	On survey site	None
191	31/08/2018	Unidentified cetacean	1	2000	158	On survey site	None
192	31/08/2018	Unidentified cetacean	1	2000	180	On survey site	None
193	31/08/2018	Unidentified cetacean	1	2000	175	On survey site	None
194	31/08/2018	Unidentified seal	2	200	161	On survey site	None
195	01/09/2018	Fin whale	3	300	234	On survey site	Power down
196	01/09/2018	Fin whale	1	1000	2177	On survey site	None
197	01/09/2018	Blue whale	1	400	2246	On survey site	Power down
198	01/09/2018	Unidentified cetacean	1	500	2353	On survey site	Power down

On Sept 9, we arrived on the **survey site** where seismic operations were planned to take place. On the survey site, in total there were 162 sightings of pinniped species which include the harp seal, hooded seal, bearded seal and the ringed seal. All pinniped species were detected visually both hauled out on ice packs or in the water, at the surface. They were recorded at distances first seen from 10 m to 1300 m as they are very difficult to detect far away using 7x50 binoculars. When observed hauled out on ice, as the vessel approached the pinniped species, on most occasions would vacate the ice and jump in the water, probably resulting from a startle response to the vessel. All behaviour of pinnipeds was recorded during seismic operations and when the source was not active (Appendix 6 JNCC Marine Mammal Recording forms).

On the survey site, there were nine sightings of polar bears, most of the sightings were on ice, two whilst feeding on a recently caught seal and there were three incidents where the polar bear was observed swimming (sighting no 72, 99, 154). Sighting no. 72, the polar bear was 10 m away from the vessel. During the project, there was one confirmed sighting of a bowhead whale, the survey was far north at 82 degrees north, where not many large whales are known to inhabit. The blow was very distinctive V-shaped, and that was all that was observed at 2,500 m away from the vessel. During the last line as the vessel crossed a continental slope, 7 cetaceans were visually observed, when possible to identify them, they were identified as fin and blue whales.

There were no acoustic detections on the survey site or during transit, as the PAM array was only deployed during seismic activity. On the survey site, most sightings include pinniped species which are not as vocal as cetaceans, and polar bears which are not known to vocalise when in water. When the bow head whale was observed, the MMO went to the PAM display to see if anything was detected but there was nothing.

Fig. 10.9: Sperm whale observed on transit

Fig. 10.10: Pod of Killer whales, Killer whales' dorsal fin

Fig. 10.11: Hooded seal on ice

Fig. 10.12: Bearded seal on ice

Fig. 10.13: Ringed seal on ice

Fig. 10.14: Sighting 99, polar bear on ice

Mitigation action

In total there were one hundred mitigation actions required (Fig. 10.15, Table 10.4) ninety-six of which were for power down to mitigation gun due to marine mammals in the exclusion zone during soft-start or full power operations in, where the MMO/PAM operator would wait for the animal to pass the EZ and would give the seismic crew clearance to resume firing of the airgun array according to the Greenlandic mitigation protocol. There were four incidents of delay prior to soft-start for marine mammals in the exclusion zone. These delays all happened on one occasion, August 26th before commencement of line BGR18-113, where there was a twenty-minute delay after each sighting.

In total ninety-three mitigation action requirements including all four delays were for pinniped species, and there were four power downs for polar bears, both in water and on ice. During the last seismic line, there were three mitigation actions required for cetaceans during the P115/1 cruise.

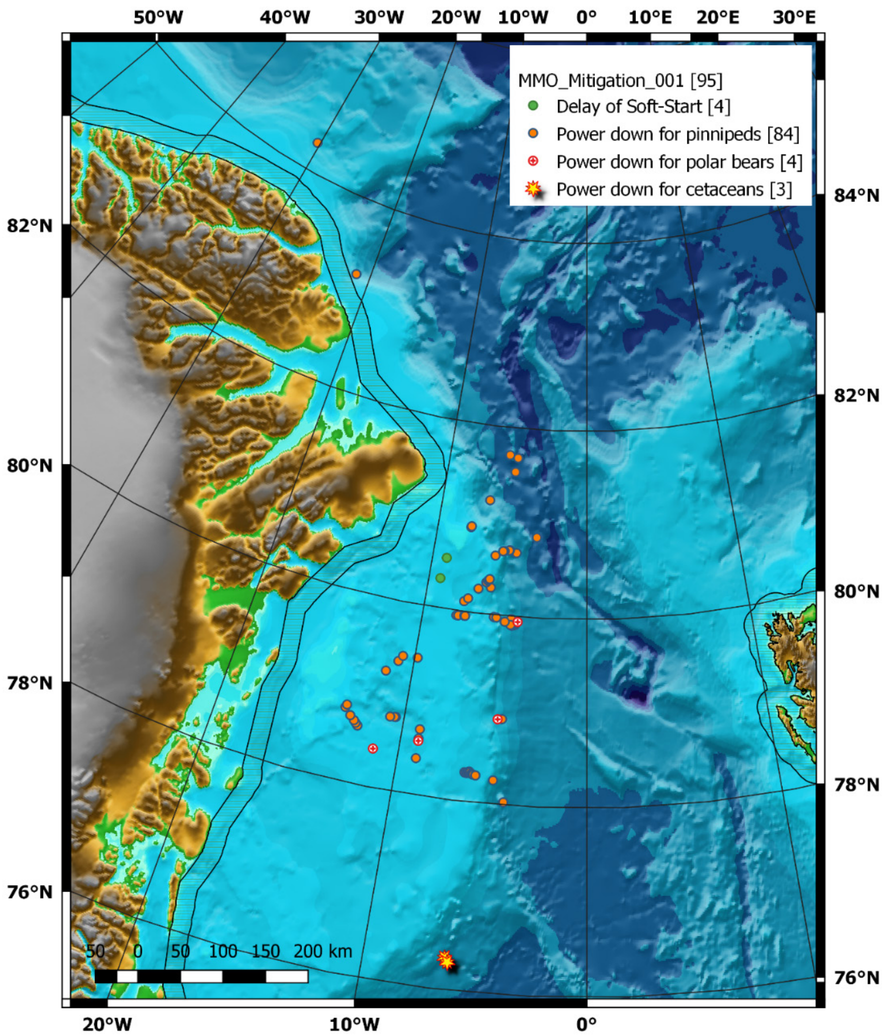

Fig. 10.15: Overview of P115/1 marine mammal mitigation

Tab. 10.4: Summary of marine mammal mitigation

Sighting number	Date	Species or species group	Range [m]	Mitigation action
18	10/08/2018	Unidentified seal	200	Power down to mitigation gun
19	10/08/2018	Polar bear	300	Power down to mitigation gun
20	10/08/2018	Hooded seal	200	Power down to mitigation gun
21	10/08/2018	Unidentified seal	1200	Power down to mitigation gun
22	10/08/2018	unidentified seal	400	Power down to mitigation gun
23	10/08/2018	Unidentified seal	200	Power down to mitigation gun
24	10/08/2018	Bearded seal	300	Power down to mitigation gun
25	10/08/2018	Ringed seal	1000	Power down to mitigation gun
33	11/08/2018	Bearded seal	500	Power down to mitigation gun
35	11/08/2018	Unidentified seal	800	Power down to mitigation gun
36	11/08/2018	Ringed seal	1200	Power down to mitigation gun
41	12/08/2018	Ringed seal	1300	Power down to mitigation gun
42	12/08/2018	Unidentified seal	1000	Power down to mitigation gun
43	12/08/2018	Unidentified seal	300	Power down to mitigation gun
44	12/08/2018	Unidentified seal	1500	Power down to mitigation gun
46	12/08/2018	Unidentified seal	500	Power down to mitigation gun
47	12/08/2018	Unidentified seal	500	Power down to mitigation gun
48	12/08/2018	Ringed seal	400	Power down to mitigation gun
49	12/08/2018	Unidentified seal	600	Power down to mitigation gun
51	13/08/2018	Bearded seal	100	Power down to mitigation gun
52	13/08/2018	Bearded seal	300	Power down to mitigation gun
53	13/08/2018	Ringed seal	100	Power down to mitigation gun
54	13/08/2018	Unidentified seal	100	Power down to mitigation gun
56	13/08/2018	Unidentified seal	700	Power down to mitigation gun
57	13/08/2018	Unidentified seal	200	Power down to mitigation gun
58	13/08/2018	Unidentified seal	250	Power down to mitigation gun
59	13/08/2018	Unidentified seal	50	Power down to mitigation gun
60	13/08/2018	Unidentified seal	80	Power down to mitigation gun
61	14/08/2018	Unidentified seal	800	Power down to mitigation gun
62	14/08/2018	Ringed Seal	300	Power down to mitigation gun
63	14/08/2018	Unidentified seal	1000	Power down to mitigation gun

Sighting number	Date	Species or species group	Range [m]	Mitigation action
64	14/08/2018	Unidentified seal	400	Power down to mitigation gun
66	14/08/2018	Unidentified seal	200	Power down to mitigation gun
68	14/08/2018	Unidentified seal	200	Power down to mitigation gun
76	19/08/2018	Unidentified seal	700	Power down to mitigation gun
77	19/08/2018	Bearded seal	500	Power down to mitigation gun
78	19/08/2018	Unidentified seal	400	Power down to mitigation gun
80	20/08/2018	Unidentified seal	10	Power down to mitigation gun
115	26/08/2018	Unidentified seal	300	Delay
116	26/08/2018	Unidentified seal	500	Delay
117	26/08/2018	Ringed seal	10	Delay
118	26/08/2018	Unidentified seal	300	Delay
124	26/08/2018	Unidentified seal	400	Power down to mitigation gun
125	26/08/2018	Unidentified seal	1200	Power down to mitigation gun
127	27/08/2018	Hooded seal	2000	Power down to mitigation gun
128	27/08/2018	Unidentified seal	500	Power down to mitigation gun
129	27/08/2018	Hooded seal	500	Power down to mitigation gun
130	27/08/2018	Hooded seal	600	Power down to mitigation gun
131	27/08/2018	Unidentified seal	400	Power down to mitigation gun
132	27/08/2018	Hooded seal	500	Power down to mitigation gun
133	27/08/2018	Unidentified seal	600	Power down to mitigation gun
134	27/08/2018	Unidentified seal	150	Power down to mitigation gun
136	27/08/2018	Unidentified seal	100	Power down to mitigation gun
137	27/08/2018	Polar bear	450	Power down to mitigation gun
138	27/08/2018	Unidentified seal	700	Power down to mitigation gun
139	27/08/2018	Unidentified seal	400	Power down to mitigation gun
140	27/08/2018	Unidentified seal	450	Power down to mitigation gun
141	27/08/2018	Unidentified seal	200	Power down to mitigation gun
142	27/08/2018	Unidentified seal	500	Power down to mitigation gun
143	27/08/2018	Unidentified seal	400	Power down to mitigation gun
144	27/08/2018	Unidentified seal	500	Power down to mitigation gun
146	28/08/2018	Unidentified seal	200	Power down to mitigation gun
152	28/08/2018	Unidentified seal	400	Power down to mitigation gun
153	28/08/2018	Ringed Seal	300	Power down to mitigation gun

Sighting number	Date	Species or species group	Range [m]	Mitigation action
154	28/08/2018	Polar bear	300	Power down to mitigation gun
155	29/08/2018	Harp seal	400	Power down to mitigation gun
156	29/08/2018	Unidentified seal	300	Power down to mitigation gun
157	29/08/2018	Unidentified seal	1000	Power down to mitigation gun
158	29/08/2018	Unidentified seal	200	Power down to mitigation gun
159	29/08/2018	Unidentified seal	300	Power down to mitigation gun
160	29/08/2018	Unidentified seal	400	Power down to mitigation gun
161	29/08/2018	Unidentified seal	300	Power down to mitigation gun
162	29/08/2018	Ringed seal	200	Power down to mitigation gun
163	29/08/2018	Unidentified seal	400	Power down to mitigation gun
165	29/08/2018	Unidentified seal	300	Power down to mitigation gun
166	29/08/2018	Unidentified seal	200	Power down to mitigation gun
167	29/08/2018	Unidentified seal	500	Power down to mitigation gun
168	29/08/2018	Unidentified seal	500	Power down to mitigation gun
169	29/08/2018	Unidentified seal	400	Power down to mitigation gun
170	29/08/2018	Unidentified seal	250	Power down to mitigation gun
172	29/08/2018	Unidentified seal	300	Power down to mitigation gun
173	29/08/2018	Unidentified seal	700	Power down to mitigation gun
174	29/08/2018	Unidentified seal	200	Power down to mitigation gun
175	29/08/2018	Unidentified seal	300	Power down to mitigation gun
176	29/08/2018	Unidentified seal	700	Power down to mitigation gun
177	29/08/2018	Harp seal	200	Power down to mitigation gun
178	29/08/2018	Ringed seal	10	Power down to mitigation gun
179	30/08/2018	Harp seal	150	Power down to mitigation gun
180	30/08/2018	Polar bear	500	Power down to mitigation gun
181	31/08/2018	Hooded seal	1200	Power down to mitigation gun
183	31/08/2018	Unidentified seal	1100	Power down to mitigation gun
186	31/08/2018	Ringed seal	800	Power down to mitigation gun
187	31/08/2018	Unidentified seal	800	Power down to mitigation gun
188	31/08/2018	Unidentified seal	300	Power down to mitigation gun
189	31/08/2018	Unidentified seal	200	Power down to mitigation gun
190	31/08/2018	Unidentified seal	500	Power down to mitigation gun
194	31/08/2018	Unidentified seal	200	Power down to mitigation gun

Sighting number	Date	Species or species group	Range [m]	Mitigation action
195	01/09/2018	Fin whale	300	Power down to mitigation gun
197	01/09/2018	Blue whale	400	Power down to mitigation gun
198	01/09/2018	Unidentified cetacean	500	Power down to mitigation gun

Potential compliance issues

There was no instance of non-compliance with mitigation protocol to report during the survey. The seismic crew from BGR cooperated and interacted openly and with efficiency throughout seismic profiling and maintained excellent communication with the MMO/PAM operators throughout the cruise and did what was advised.

Conclusion and Recommendations

The scientific crew of the *Polarstern* successfully completed a multichannel seismic and OBS profiling of North East Greenland area while showing a proactive and conservative approach to marine mammal mitigation monitoring by fully complying with all operational requirements of seismic activities underlined by the DCE Manual for seabird and marine mammal survey on seismic vessels in Greenland (April 2015), including additional mitigation requirements for bowhead whales.

Pinnipeds and were visually sighted over a widely distributed area of the region in Greenlandic waters during the PS115/1 research cruise. Areas with a high percentage of ice cover, was high in pinniped sightings. There was a definite bowhead whale was sighted in the survey area at a distance of 2,500 m away from the vessel. PAM was a favourable tool to use for most of the survey as there was 24 hr visual monitoring from MMSO, from PoLE, therefore it was good to have visual and acoustic monitoring in conjunction with seismic operations to enhance the detections of cetaceans. When there were many pinniped sightings, acoustic monitoring would pause, and the PAM operator would undertake MMO watch to work with the MMSO.

It is possible that many of the migratory species such as the humpback, fin and blue whale had already moved South towards warmer waters where they will spend the winters months breeding and mating, as there were very few occurrences of those species that often occur in large numbers in the Arctic waters during the summer months. It wasn't until the end of the survey, further south at 76 degrees which is where cetacean sightings increased, and pinniped sightings decreased. There was one recorded sighting of the critically endangered Bowhead whale and no sightings of Narwhals or Walruses.

Although none of the deep-diving beaked whales were observed, such as the Northern Bottlenose whale, these species are notoriously elusive and spend relatively short time at the surface, spending most of their time on long foraging dives.

BGR's continued best practice regime for including dedicated marine mammal observations as part of their research cruise plan is to be commended, particularly for those cruises which utilise seismic and other activities which produce anthropogenic sound emissions into the marine environment. The results presented in this report may be useful indicators of likely marine mammal occurrence in the Arctic areas of the North Atlantic at this time of year and may be considered for future survey planning.

For future research cruises in remote areas, including deep ocean and less well studies areas where marine mammal monitoring accompanies 24 h seismic operations, it is recommended to maintain simultaneous MMO and PAM effort, to allow for detection of deep-diving species and to visually verify acoustic detections. This can improve species identification and improve effectiveness of PAM localisation techniques. It is also recommended to consider other emerging technologies for marine mammal detection, such as IR thermal and HD cameras, which can assist with detection of marine mammals at night to complement PAM effort.

Acknowledgements

The MMO/PAM team would like to thank the crew of the *Polarstern* for their hospitality, co-operation, and their assistance with deploying and recovering the PAM equipment. The MMOs and PAM operators would also like to thank the scientists from BGR on board *Polarstern* for providing a professional and friendly working environment. Finally, the MMO/PAM team would like to thank the MMBO's from PoIE, for their assistance in marine mammal monitoring, which allowed visual and acoustic monitoring to commence at the same time.

Data management

Data protocols and weekly MMO reports over the whole period of the cruise are to be provided to BGR for subsequent transmittion the Greenland authorities. Sightings of marine mammals will be also delivered to JNCC to be included in the JNCC based database.

References

Chester S (2016) The Arctic Guide: Wildlife of the Far North. Princeton University Press, US.

JNCC (April 2017): Guidelines for minimising the risk of injury to marine mammals from geophysical surveys. Joint Nature Conservation Committee, Aberdeen, UK.

DCE (April 2015) Manual for seabird and marine mammal survey on seismic vessels in Greenland. 4th Revised Edition, Aarhus University, Denmark.

Shirihai H & Jarrett B (2006) Whales, dolphins and seals. A field guide to the marine mammals of the world. A & C Black, London, UK.

10.2 Automatic Infrared-based Marine Mammal Mitigation System (AIMMMS)

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Objectives

Marine mammal observations are a prerequisite for conducting marine seismic surveys nowadays. In case marine mammals encounter a predefined exclusion zone around the ship or sound source behind the ship, mitigation measures need to be employed.

To date and as it has been conducted during this cruise, marine mammal observations basically rely on visual observation of the ships perimeter as well as passive acoustic monitoring methods registering characteristic vocalizations of marine mammals.

To aid in enhanced marine mammal sightings and early sightings outside the mitigation zone, as well as more accurate distance measurements, a new complementary method based on thermal imaging of the sea surface has been developed by the AWI. The principal idea is, that marine mammals - due to their body temperature -, should produce thermal anomalies during surfacing and whale blows. In cooperation with the AWI the ***A**utomat**i**c Infrared-based **M**arine **M**ammal **M**itigation **S**ystem* was employed for this cruise to evaluate the feasibility as additional marine mammal observation method during marine seismic surveying. The acquired data in combination with the observer logs will be used to analyze the infrared detection performance and characteristics, and to further enhance and adapt the detection algorithms for the specific sea state, ice and weather conditions. Of great interest is also the detection of species other than whales, e.g the polar bear or seals.

AIMMMS description

The AIMMMS system consists of two main parts: an infrared sensor camera unit and a thermal image processing software "Tashtego"[1]. The whole system on board FS *Polarstern* is maintained by the AWI.

On board *Polarstern* a *FIRST (**F**ast **I**nfra**R**ed **S**earch and **T**rack) Navy Infrared Sensor* by *Rheinmetal Defense Electronics, Germany* is installed in the crows nest in 28.5 m height. The sensor consists of a camera mounted on an active stabilization unit (gimbal). (Fig. 10.16). The cryogenic sensor is cooled to 84 K. It scans 360° horizontally and 18° vertically at 5 revolutions per second, providing a 5-Hz video stream of the thermal field of the ship's environs at horizontal and vertical resolutions of 0.05°/pixel and 0.03°/pixel, respectively. This corresponds to 7,200 pixels per frame horizontally and 600 vertically (4.320.000 pixels/frame). The effective horizontal view is limited to ~300°, 150° to port and starboard respectively, due to the mast and a copper plate installed on the gimbal for thermal calibration of the thermal image during each revolution of the sensor.

Fig. 10.16: FIRST Navy Infrared Sensor installation in the crows nest of FS Polarstern. View from starboard. At the top the rotating sensor is shown, with the fixed copper plate for calibration to the aft. The gimbal below is mostly covered by the casing.

[1] The software name "Tashtego" refers to a character in the novel of "Moby Dick" by Robert Melville

Tashtego software

The “Tashtego” software is developed by the Ocean Acoustics Lab of the AWI. The main purpose of the software is to visualize the incoming thermal image video stream and perform auto-detection in real time. The software is undergoing continuous development. In particular, the auto-detection algorithm is experiencing improvements for robust detection of several marine mammal species under different marine and environmental conditions. The data set collected under the specific situation (eg. sea ice state) encountered during this cruise is also provided for further improvements of the auto-detection algorithm.

For the purpose of this cruise a special mitigation module has been coded, which allows to manually record and consecutively log the mitigation status on behalf of the MMO seismic operational instruction.

The “Tashtego” software is linux based and has a modular design. It runs on a workstation with three displays (Fig. 10.17). The main features for marine mammal watchkeeping purposes are:

- a real time thermal image visualization window in greyscale, with calibrated horizon and mitigation exclusion zone marks
- an automatic image recognition module running in the background; the module not only performs auto-detection of marine mammals in the infrared image stream, but also calculates heading and distance of an event, thereby giving important information for visual observation and mitigation.
- a looped snippet display of the last 8 auto-detected events for manual verification.
- a map view of picked events relative to the ship
- a mitigation status logger
- logging and data storing modules

Fig. 10.17: Workstation running “Tashtego” Software on FS Polarstern. The top shows the real time thermal image display spread over 3 screens. On port (left) and starboard side (right) the railing of the crows nest can be seen. Typical scene during the survey with some ice-rafts (brighter) and water (dark). On port side the water reflection of the low standing sun is observed. Further windows to be seen: Mitigation control window, event map track window, control window, event snippet windows of the last eight detections.

Work at sea

AIMMMS was discontinously run for testing purposes during transit to the East Greenland survey area. AIMMMS was then continuously operated during seismic activities in parallel to the MMO observations. However, running out of disk space AIMMMS operation had to be terminated on 31.8.2018 19:57 (UTC) approx. 9 hours before the end of seismic activities (EoL BGR18-120). Altogether, ~60 terabyte (10 hard discs of 6 TB each) of thermal image data during seismic activities have been collected.

Watch keepers on 2 hour shifts ensured functional operation of the system, visual observation of the real time image display and verification of automatic detected events. Possible detections of marine mammals were immediately reported to the MMO on duty providing heading and distance information for visual verification. Vice versa the MMO reported visual observations to the watch keepers for cross-checking and distance measurements on the AIMMMS display.

Preliminary results

Marine mammal and other event detections

Automatic detection of marine mammals during periods of good visibility (i.e. no fog) had varying efficiency. During the testing phase on transit to the survey area off Greenland whale blows have been detected automatically (Fig. 10.18a), demonstrating that the algorithm and system have been operating properly. These were, however, the only automatically detected whale blows during the cruise. Especially, during the first seismic lines several seals on ice were automatically detected as events, some more than 1,000 m plus away (Fig. 10.18b). Some of the seals were clearly detected before visual observation and the information provided to the MMO then guided the following visual sighting. However, not all the seals on ice were detected. Some of the seals on ice could be picked manually, partly also before visual observation by the MMO. This efficiency could not be achieved further on during the rest of the cruise. Only very few seals on ice have been automatically detected later and detection basically relied on manually picking of events. Furthermore, other marine mammals (i.e. polar bears on ice) have not been automatically detected during the cruise, but could often be detected manually (Fig. 10.18c) and allowing to track the relative position and distance to the ship (Fig. 10.18d). Table 10.5 gives a summary of the performance of event detections.

Tab. 10.5: Performance chart of AIMMMS automatic event detection during PS115/1

Marine Mammal		AIMMMS Automatic detection	AIMMMS Manual detection	Comment
Seals	On ice	Yes	Yes	Not all detected
	In the water	No	No	In general, cannot be observed by technical design. (but once observed in thermal image, very near the ship)
Polar bears	On ice	No	Yes	
	In the water	No	No	
Whales	Blow	Yes	No	Only detected on transit towards survey. Only few whale blows during the last survey lines reported by MMO, as AIMMMS was turned off already

Marine Mammal		AIMMMS Automatic detection	AIMMMS Manual detection	Comment
Other				
False detections	Antennas	From seldom to very often		Sometimes so often, making verification by watchkeeper not feasible
	Ice rafts	Quite often		Multiple detections tracking relative movement of ice rafts

The reasons for the varying performance of the detection algorithm probably are connected to changing environmental conditions, such as sea state, weather and ice conditions, sun inclination and irradiation – to name a few. A post-cruise analysis of the variations of environmental parameters might identify key parameters influencing the automatic detection performance under the encountered arctic conditions.

False events also occurred quite often. In particular, sometimes the ships antennas were detected almost every second. This complicated verification of any possible true events by the watch keepers. Reflections from drifting ice rafts also was a rather common reason for false events, often with consecutive detections tracking the relative movement of the ice raft.

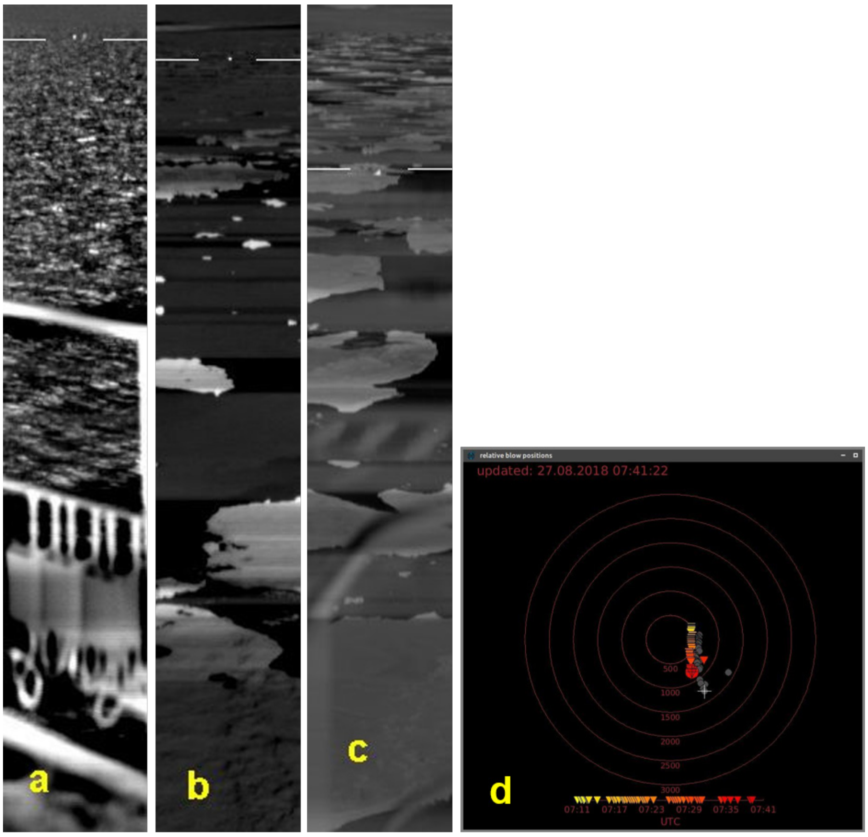

Fig. 10.18: Examples of thermographic image snippets of marine mammals detected during cruise PS115/1; the snippets show only a small sector of the whole thermographic image, with the detected event in between the horizontal marker lines: a) two simultaneous whale blows during transit; distance not recorded; automatic detection; b) seal on ice; distance ~1,200 m; automatic detection; c) polar bear on ice; distance ~ 450; manually picked; d) screenshot of track of the polar bear relative to the ship; events picked manually. The polar bear drifted on the ice, coming into the mitigation zone (500m; inner circle), passed the ship and drifted out of the mitigation zone.

Conclusions

AIMMMS is a promising new tool for marine mammal observations in the high Arctic seas and can assist with mitigation procedures during seismic activities. At the moment the automatic/semi-automatic detection of marine mammals with the AIMMMS still has varying performance. Further improvements of the algorithm are recommended, so that detection of the presence of marine mammals on ice are more reliable and false detections, especially of floating ice rafts, are suppressed. Numerous sightings and detections of species other than whales (i.e. seals and polar bears) have been recorded with AIMMMS during the cruise. The acquired data set will therefore be a valuable asset to adapt the detection algorithm to the observed marine mammal species.

References

BGR (2018) Environmental Mitigation Assessment – EMA Report of the proposed research cruise PS115/1 with the German research icebreaker POLARSTERN to Northeast Greenland between August 5th, 2018 and September 3rd, 2018.- BGR, Hannover, submitted to MLSA. https://naalakkersuisut.gl/~/media/Nanoq/Files/Hearings/2018/VFT%20videnskabeligt%20forskningstogt/Documents/Nutaaq%20300518_SPN_ilanngussat%20teknikkimut%20tunngasoq%20tuluttuullu.pdf

JNCC (2017) JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys.- Joint Nature Conservation Committee, Inverdee House, Baxter Street, Aberdeen, AB11 9QA, United Kingdom, August 2017, 26 pp.

Zitterbart DP, Kindermann L, Burkhardt E & Boebel O (2013) Automatic Round-the-Clock Detection of Whales for Mitigation from Underwater Noise.- Impacts. PLoS ONE 8(8), e71217. doi:10.1371/journal.pone.0071217

11. OUTREACH – DOCUMENTATION OF PS115/1

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[1]HS Hannover

Grant-No. AWI_PS115/1_00

Objectives

In order to document the expedition three TV journalism master students from University of Applied Sciences Hannover were part of the scientific crew of PS115/1. The aim of the cooperation with AWI, BGR and the students from Hochschule Hannover was to capture the expedition by portraying the scientists and crew on board and capturing the work and life on *Polarstern* to create an aesthetic image of this expedition into the Arctic ocean.

The main focus for the 45 minute documentary, which will be the students' master project, is on chief scientist Volkmar Damm as the documentary's main character. Thereby the scientific works of the expedition can be displayed to a wider public focusing on a narrative storyline.

Work at sea

During the expedition from August 5 until September 3, everyday had been a production day for the film crew so that it could be ensured that all different scientific operations were captured on video and photo. In total there was 1,35 TB of raw material produced. For the farewell celebrations the film team had already edited a sneak peak of their material and screened it for both scientific and ship's crew.

Fig. 11.1: The film crew at a broad day light at 3 am in the Arctic summer (left) and during an interview (right)

Whilst being on board the journalism students also wrote articles for the Helmholtz blog about their personal experiences in combination with reports of the scientific work. Blog article topics have been the following:

- Blog #1: „Welcome on board of PS115/1“
- Blog #2: „Das war ne' super Dredge“
- Blog #3: „Das war doch nur ein kleines Schöllchen – Die Fahrteilnehmer der PS115/1 sichten Eis“
- Blog #4: „Dreifach hält besser – Die Vorsorgemaßnahmen zum Schutz der Meeresumwelt auf der PS115/1“
- Blog #5: „Luftpulser und Eiserkundung – Woche 3 auf Polarstern“
- Blog #6: „Die ersten Landbeprobungsflüge der PS115/1“
- Blog #7: „Die Ostereiersuche im arktischen Ozean“
- Blog #8: „Die letzten Tage der Fahrt PS115/1“
- Blog #9: „Die Highlights der PS115/1“

Preliminary results

In the course of the production two kinds of raw material were produced: The three students produced material for their own documentary (A-Roll) next to raw material for AWI and BGR (B-Roll). After being back in Germany, the B-Roll material was distributed to AWI and BGR.

During the cruise the film team could also send requested photos of the „Region des letzten Eises“ to the AWI public relations office when the German media was highly interested in up-to-date footage from the polynia in front of North Greenland.

With the expedition ending nine blog articles for the Helmholtz are online and have so far been commented 18 times.

Fig. 11.2: The PS115/1 film crew: Maria Bachmann, Viktoria Timkanicova and Sophie Peschke (left to right)

APPENDIX

A.1 PARTICIPATING INSTITUTIONS

A.2 CRUISE PARTICIPANTS

A.3 SHIP'S CREW

A.4 STATION LIST

A.5 LIST OF SEDIMENT CORES

A.6 MMO WEEKLY REPORTS

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTIONS

	Address
AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Geozentrum Hannover Stilleweg 2 30655 Hannover Germany
DWD	Deutscher Wetterdienst Geschäftsbereich Wettervorhersage Seeschifffahrtsberatung Bernhard Nocht Str. 76 20359 Hamburg Germany
GEOMAR	Helmholtz-Zentrum für Ozeanforschung FB1 Paläo-Ozeanographie Wischhofstr. 1-3 24148 Kiel Germany
GEUS	Geological Survey of Denmark and Greenland Øster Voldgade 10 1350 Copenhagen K Denmark
HS Hannover	Hochschule Hannover Expo Plaza 4 30539 Hannover Germany
HeliService	HeliService International GmbH Am Luneort 15 27572 Bremerhaven Germany
KIT	Karlsruher Institut für Technologie Geophysikalisches Institut Herzstr. 16 76137 Karlsruhe Germany

	Address
Laeisz	Reederei F. Laeisz (Bremerhaven) GmbH Brückenstrasse 25 27568 Bremerhaven Germany
PolE	Laboratory for Polar Ecology Rue du Fodia 18 1367 Ramillies-Offus Belgium
RBINS	Royal Belgian Institute of Natural Sciences Conservation Biology 29 Rue Vautier Brussels Belgium
Seiche	Seiche Limited Bradworthy Industrial Estate Langdon Road Bradworthy Holsworthy Devon EX22 7SF United Kingdom
U Bremen	University of Bremen FB 5 - Department of Geosciences Section Geodynamics of Polar Region Klagenfurter Str. 2 28334 Bremen Germany
UFZ	Helmholtz-Zentrum für Umweltforschung GmbH UFZ Permoserstr. 15 04318 Leipzig Germany
UiT	The Arctic University of Norway in Tromsø Department of Geosciences Dramsvegen 201 9010 Tromsø Norway

A.2 FAHRTTEILNEHMER / CRUISE PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Bachmann	Maria	HS Hannover	Student	Public outreach
Bargeloh	Hans-Otto	BGR	Engineer	Geophysics
Barnicoat	Stephanie	Seiche	Biologist MMO	Biology
Behrens	Thomas	BGR	Technician	Geophysics
Berglar	Kai	BGR	Geologist	Geology
Brotzer	Andreas	AWI	PhD student	Geophysics
Damm	Volkmar	BGR	Geophysicist	Chief scientist, Geophysics
de Jager	Harold	HeliService	Helicopter pilot	
Deppe	Joachim	BGR	Technician	Geophysics
Ebert	Timo	BGR	Technician	Geophysics
Ehrhardt	Axel	BGR	Geophysicist	Geophysics
Franke	Dieter	BGR	Geophysicist	Geophysics
Funck	Thomas	GEUS	Geophysicist	Geophysics
Geissler	Wolfram	AWI	Geophysicist	Geophysics
Hahn	Boris	BGR	Technician	Geophysics
Heyde	Ingo	BGR	Geophysicist	Geophysics
Hiller	Marc	AWI	Student	Mar. technology
Jegen	Anna	AWI	Student	Oceanography
Kruckemeyer	Isabell	BGR	Technician	Geosciences
Krüger	Martin	BGR	Biologist	Biology
Kvalheim	Eva	Seiche	Biologist MMO	Biology
Ladage	Stefan	BGR	Geologist	Geology
Lesic	Nina-Marie	AWI	Student	Oceanography
Lösing	Mareen	AWI	Student	Geosciences
Lütjens	Mona	AWI	Hydrographer	Bathymetry
Lutz	Rüdiger	BGR	Geologist	Geology
Meier	Katrin	U Bremen	Student	Geology
Meyer	Hannah	AWI	Student	Physics
Musat	Florin	UFZ	Biologist	Biology
Olsen	Ingrid	UiT	PhD student	Geology
Paulmann	Christian	DWD	Meteorologist	Meteorology
Peschke	Sophie	HS Hannover	Student	Public outreach
Richter	Roland	HeliService	Technician	
Robert	Henri	RBINS	Biologist MMBO	Biology
Rohleder	Christian	DWD	Technician	Meteorology
Ruben	Manuel	AWI	Student	Geology

Name/ Last name	**Vorname/ First name**	**Institut/ Institute**	**Beruf/ Profession**	**Fachrichtung/ Discipline**
Santos	Victor	HeliService	Technician	
Schauer	Michael	BGR	Geoscientist	Geology
Schwenke	Theresa	PoIE	Biologist MMBO	Biology
Seeger	Christian	BGR	Technician	Geosciences
Spielhagen	Robert	GEOMAR	Geologist	Geology
Steinborn	Peter	BGR	Engineer	Geophysics
Syring	Nicole	AWI	PhD student	Geology
Timkanicova	Viktoria	HS Hannover	Student	Public outreach
Watelet	Michel	PoIE	Biologist MMBO	Biology
Zehnich	Marc	GEOMAR	Student	Geology
Zillgen	Carsten	HeliService	Helicopter pilot	
Zundel	Maximilian	U Bremen	Geologist	Geology

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

No.	Name	Vorname	Rank
01	Wunderlich	Thomas	Master
02	Langhinrichs	Moritz	Ch. Off.
03	Farysch	Bernd	Ch. Eng.
04	Kentges	Felix	1. Off.
05	Fallei	Holger	2. Off.
06	Neumann	Ralph	2. Off.
07	Rudde-Teufel	Claus	Doctor
08	Grafe	Jens	2nd Eng.
09	Haack	Michael	2nd Eng.
10	Krinfeld	Oleksandr	2nd Eng.
11	Redmer	Jens	Elec. Eng.
12	Christian	Boris	Chief ELO
13	Ganter	Armin	ELO
14	Himmel	Frank	ELO
15	Hüttebräucker	Olaf	ELO
16	Nasis	Ilias	ELO
17	Loidl	Reiner	Boatsw.
18	Reise	Lutz	Carpenter
19	Brück	Sebastian	MP Rat.
20	Klee	Philipp	MP Rat.
21	Luckhardt	Arne	MP Rat.
22	Möller	Falko	MP Rat.
23	Neubauer	Werner	MP Rat.
24	Schade	Tom	MP Rat.
25	Bäcker	Andreas	A.B.
26	Hans	Stefan	A.B.
27	Wende	Uwe	A.B.
28	Preußner	Jörg	Storek.
29	Eden	Michael	Mot-man
30	Gebhardt	Norman	Mot-man
31	Schulz	Fabian	Mot-man
32	Schwarz	Uwe	Mot-man
33	Teichert	Uwe	Mot-man
34	Schnieder	Sven	Cook
35	Möller	Wolfgang	Cooksmate
36	Silinski	Frank	Cooksmate
37	Czyborra	Bärbel	1. Stwdess.
38	Wöckener	Martina	Stwdess/N.
39	Arendt	René	2. Steward
40	Chen	Dansheng	2. Steward
41	Dibenau	Torsten	2nd Steward
42	Golla	Gerald	2nd Steward
44	Silinski	Carmen	2. Stwdess

A.4 STATIONSLISTE / STATION LIST

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_0_ Underway-1	2018-08-05	08:31	69.67952	18.99657	NA	AFIM	station end	
PS115/1_0_ Underway-2	2018-08-05	06:00	69.67952	18.99656	NA	HVAIR	station end	
PS115/1_0_ Underway-3	2018-08-05	06:00	69.67952	18.99656	NA	HSPS	station end	
PS115/1_0_ Underway-4	2018-08-05	08:32	69.67952	18.99657	NA	RM	station end	
PS115/1_0_ Underway-5	2018-08-05	06:00	69.67952	18.99656	NA	WST	profile start	
PS115/1_0_ Underway-6	2018-08-06	06:24	71.69151	14.81866	1005	ADCP_150	profile start	
PS115/1_0_ Underway-6	2018-09-02	14:00	77.52767	5.54009	2616	ADCP_150	profile end	
PS115/1_0_ Underway-7	2018-08-06	07:40	71.83722	14.28072	1523	FBOX	profile start	
PS115/1_0_ Underway-7	2018-09-02	14:00	77.52700	5.53296	2612	FBOX	profile end	
PS115/1_0_ Underway-9	2018-08-06	07:40	71.83830	14.27660	1528	PCO2_SUB	profile start	
PS115/1_0_ Underway-9	2018-09-02	13:59	77.52674	5.52986	2609	PCO2_SUB	profile end	
PS115/1_0_ Underway-10	2018-08-06	06:52	71.74604	14.61771	1307	TSG_KEEL	profile start	
PS115/1_0_ Underway-10	2018-08-16	07:24	82.28042	-9.42314	2883	TSG_KEEL	profile end	
PS115/1_0_ Underway-10	2018-08-16	09:16	82.27567	-9.46702	2879	TSG_KEEL	profile start	
PS115/1_0_ Underway-10	2018-09-02	14:00	77.52750	5.53819	2614	TSG_KEEL	profile end	
PS115/1_0_ Underway-11	2018-08-06	06:52	71.74743	14.61262	1309	TSG_ KEEL_2	profile start	
PS115/1_0_ Underway-11	2018-08-16	07:23	82.28154	-9.41074	2886	TSG_ KEEL_2	profile end	
PS115/1_0_ Underway-11	2018-08-16	09:16	82.27567	-9.46698	2879	TSG_ KEEL_2	profile start	
PS115/1_0_ Underway-11	2018-09-02	14:00	77.52731	5.53625	2614	TSG_ KEEL_2	profile end	
PS115/1_0_ Underway-12	2018-08-06	05:45	71.61420	15.10088	NA	SVP	profile start	
PS115/1_0_ Underway-12	2018-09-02	14:01	77.52795	5.54305	2617	SVP	profile end	
PS115/1_0_ Underway-13	2018-08-06	06:00	71.64286	14.99751	61	HSPS	profile start	
PS115/1_0_ Underway-13	2018-09-02	10:30	77.31628	3.40850	2558	HSPS	profile end	
PS115/1_0_ Underway-14	2018-08-05	14:00	69.69847	19.04262	28.9	Observ	profile start	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_0_ Underway-14	2018-09-03	05:30	78.25212	15.07997	226	Observ	profile end	
PS115/1_0_ Underway-15	2018-08-07	07:00	74.66640	3.48127	3746	AIMMMS	profile start	
PS115/1_0_ Underway-15	2018-09-01	14:00	76.18486	-5.90837	2641	AIMMMS	profile end	
PS115/1_1-1	2018-08-07	11:01	75.25764	1.96726	NA	SVP	station start	
PS115/1_1-1	2018-08-07	11:45	75.25465	1.95877	NA	SVP	at depth	
PS115/1_1-1	2018-08-07	13:20	75.24992	1.92665	NA	SVP	station end	
PS115/1_1-2	2018-08-07	13:32	75.24812	1.92506	NA	REL	station start	
PS115/1_1-2	2018-08-07	14:01	75.24450	1.92005	NA	REL	at depth	
PS115/1_1-2	2018-08-07	15:02	75.24322	1.90211	NA	REL	station end	
PS115/1_2-1	2018-08-08	03:58	76.18623	-0.21690	1877	DRDGE	station start	
PS115/1_2-1	2018-08-08	04:50	76.18659	-0.21708	2587	DRDGE	at depth	
PS115/1_2-1	2018-08-08	05:27	76.18589	-0.26014	2577	DRDGE	profile start	
PS115/1_2-1	2018-08-08	06:49	76.18577	-0.26015	2589	DRDGE	profile end	
PS115/1_2-1	2018-08-08	07:42	76.18595	-0.26131	2579	DRDGE	station end	
PS115/1_3-1	2018-08-08	08:49	76.20238	-0.76680	2293	AIRGUN	station start	
PS115/1_3-1	2018-08-08	09:05	76.18497	-0.83266	2202	AIRGUN	station end	
PS115/1_4-1	2018-08-08	14:41	76.38672	-4.79516	2379	HF	station start	
PS115/1_4-1	2018-08-08	15:46	76.38673	-4.79685	2377	HF	at depth	
PS115/1_4-1	2018-08-08	17:13	76.38668	-4.79677	2379	HF	station end	
PS115/1_4-2	2018-08-08	17:42	76.38643	-4.79706	2379	TVMUC	station start	
PS115/1_4-2	2018-08-08	18:38	76.38671	-4.79580	2379	TVMUC	at depth	
PS115/1_4-2	2018-08-08	19:35	76.38671	-4.79574	2379	TVMUC	station end	
PS115/1_4-3	2018-08-08	21:06	76.38686	-4.79497	2382	GC	station start	
PS115/1_4-3	2018-08-08	21:40	76.38681	-4.79579	2381	GC	at depth	
PS115/1_4-3	2018-08-08	22:22	76.38607	-4.79607	2379	GC	station end	
PS115/1_5-1	2018-08-09	11:24	78.25128	-8.44820	195	GC	station start	
PS115/1_5-1	2018-08-09	11:30	78.25122	-8.44838	194	GC	at depth	
PS115/1_5-1	2018-08-09	11:45	78.25133	-8.44869	195	GC	station end	
PS115/1_5-2	2018-08-09	11:56	78.25157	-8.44764	195	TVMUC	station start	
PS115/1_5-2	2018-08-09	12:05	78.25127	-8.44834	196	TVMUC	at depth	
PS115/1_5-2	2018-08-09	12:19	78.25132	-8.44869	205	TVMUC	station end	
PS115/1_5-3	2018-08-09	12:27	78.25133	-8.44849	195	TVMUC	station start	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_5-3	2018-08-09	12:37	78.25136	-8.44979	191	TVMUC	at depth	
PS115/1_5-3	2018-08-09	12:51	78.25090	-8.45005	198	TVMUC	station end	
PS115/1_6-1	2018-08-09	15:06	78.44168	-8.95924	260	TVMUC	station start	
PS115/1_6-1	2018-08-09	15:16	78.44154	-8.95999	261	TVMUC	at depth	
PS115/1_6-1	2018-08-09	15:33	78.44135	-8.96024	261	TVMUC	station end	
PS115/1_6-2	2018-08-09	15:42	78.44111	-8.96057	261	GC	station start	
PS115/1_6-2	2018-08-09	15:50	78.44102	-8.96005	261	GC	at depth	
PS115/1_6-2	2018-08-09	16:04	78.43992	-8.96229	263	GC	station end	
PS115/1_7-1	2018-08-09	19:25	78.46250	-10.52401	263	TVMUC	station start	
PS115/1_7-1	2018-08-09	19:36	78.46292	-10.52630	260	TVMUC	at depth	
PS115/1_7-1	2018-08-09	19:51	78.46313	-10.52596	260	TVMUC	station end	
PS115/1_7-2	2018-08-09	20:00	78.46315	-10.52691	259	GC	station start	
PS115/1_7-2	2018-08-09	20:05	78.46316	-10.52673	259	GC	at depth	
PS115/1_7-2	2018-08-09	20:20	78.46334	-10.52933	257	GC	station end	
PS115/1_8-1	2018-08-09	21:15	78.46271	-10.54235	235	REFL	station start	
PS115/1_8-1	2018-08-10	04:39	78.37123	-11.12556	180	REFL	at depth	
PS115/1_8-1	2018-08-10	05:09	78.39817	-11.26752	176	REFL	profile start	
PS115/1_8-1	2018-08-10	14:42	78.93612	-12.68124	212	REFL	profile end	
PS115/1_8-1	2018-08-10	16:52	78.85391	-12.84783	195	REFL	station end	
PS115/1_9-1	2018-08-10	20:38	78.92815	-11.77424	380	GC	station start	
PS115/1_9-1	2018-08-10	20:50	78.92915	-11.77351	377	GC	at depth	
PS115/1_9-1	2018-08-10	21:04	78.92901	-11.77281	376	GC	station end	
PS115/1_9-2	2018-08-10	21:47	78.92903	-11.77351	377	GC	station start	
PS115/1_9-2	2018-08-10	21:53	78.92908	-11.77351	377	GC	at depth	
PS115/1_9-2	2018-08-10	22:09	78.92908	-11.77431	377	GC	station end	
PS115/1_9-3	2018-08-10	22:50	78.92938	-11.77014	376	GC	station start	
PS115/1_9-3	2018-08-10	22:57	78.92974	-11.76807	378	GC	at depth	
PS115/1_9-3	2018-08-10	23:10	78.93084	-11.76887	378	GC	station end	
PS115/1_9-4	2018-08-10	23:46	78.92945	-11.76585	378	GKG	station start	
PS115/1_9-4	2018-08-10	23:53	78.92960	-11.76346	378	GKG	at depth	
PS115/1_9-4	2018-08-11	00:17	78.93068	-11.74840	385	GKG	station end	
PS115/1_10-1	2018-08-11	00:30	78.93283	-11.73724	387	HSPS	profile start	
PS115/1_10-1	2018-08-11	06:33	78.94204	-11.53149	208	HSPS	profile end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_11-1	2018-08-11	06:36	78.94203	-11.53152	209	GKG	station start	
PS115/1_11-1	2018-08-11	06:42	78.94196	-11.53167	209	GKG	at depth	
PS115/1_11-1	2018-08-11	06:51	78.94197	-11.53207	209	GKG	station end	
PS115/1_11-2	2018-08-11	07:22	78.94203	-11.53229	209	GC	station start	
PS115/1_11-2	2018-08-11	07:27	78.94201	-11.53244	208	GC	at depth	
PS115/1_11-2	2018-08-11	07:44	78.94202	-11.53223	211	GC	station end	
PS115/1_11-3	2018-08-11	07:42	78.94208	-11.53208	210	GC	station start	
PS115/1_11-3	2018-08-11	07:57	78.94208	-11.53217	209	GC	at depth	
PS115/1_11-3	2018-08-11	08:11	78.94217	-11.53156	210	GC	station end	
PS115/1_12-1	2018-08-11	11:44	78.87424	-12.93504	189	REFL	station start	
PS115/1_12-1	2018-08-11	12:53	78.93595	-12.71663	220	REFL	profile start	
PS115/1_12-1	2018-08-12	07:53	80.00865	-8.03975	213	REFL	profile end	
PS115/1_12-1	2018-08-12	08:16	79.98454	-7.98961	213	REFL	station end	
PS115/1_12-1	2018-08-12	09:10	79.93452	-8.15918	163	REFL	station start	Profile / ID continued
PS115/1_12-1	2018-08-12	13:05	79.78669	-9.14144	245	REFL	profile start	
PS115/1_12-1	2018-08-13	08:11	80.91964	-3.14358	3765	REFL	profile end	
PS115/1_12-2	2018-08-12	06:25	79.93290	-8.44460	121	MAG	station start	
PS115/1_12-2	2018-08-12	08:12	79.98904	-7.99001	211	MAG	station end	
PS115/1_12-3	2018-08-12	12:12	79.76943	-8.99784	196	MAG	station start	
PS115/1_12-3	2018-08-13	07:57	80.90245	-3.15194	3716	MAG	station end	
PS115/1_13-1	2018-08-13	08:12	80.92058	-3.14737	3769	REFL	profile start	
PS115/1_13-1	2018-08-14	19:41	81.66131	-4.85469	3333	REFL	profile end	
PS115/1_13-2	2018-08-13	08:51	80.92576	-3.46916	3449	MAG	station start	
PS115/1_13-2	2018-08-13	09:31	80.87722	-3.62610	3360	MAG	station end	
PS115/1_13-2	2018-08-13	09:35	80.87303	-3.65539	3356	MAG	station start	Profile / ID continued
PS115/1_13-2	2018-08-14	17:26	81.52514	-5.38896	3477	MAG	profile end	
PS115/1_13-2	2018-08-14	17:40	81.53097	-5.24621	3478	MAG	station end	
PS115/1_13-2	2018-08-14	18:51	81.58685	-4.93968	3437	MAG	station start	Profile / ID continued
PS115/1_13-2	2018-08-14	19:14	81.62157	-4.92643	3429	MAG	station end	
PS115/1_13-2	2018-08-15	02:03	81.78154	-8.49481	2586	MAG	station start	Profile / ID continued
PS115/1_13-2	2018-08-15	18:55	82.39918	-7.72686	3072	MAG	station end	
PS115/1_13-3	2018-08-14	19:44	81.66555	-4.85617	3340	REFL	profile start	
PS115/1_13-3	2018-08-15	09:12	81.94250	-12.69931	170	REFL	profile end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_13-3	2018-08-15	09:13	81.94347	-12.70051	170	REFL	profile start	
PS115/1_13-3	2018-08-15	18:30	82.41243	-7.97748	2753	REFL	profile end	
PS115/1_13-3	2018-08-15	21:08	82.26210	-7.33021	3210	REFL	station end	
PS115/1_14-1	2018-08-15	23:24	82.30937	-7.40963	3262	HF	station start	
PS115/1_14-1	2018-08-16	00:58	82.30852	-7.40712	3262	HF	at depth	
PS115/1_14-1	2018-08-16	02:31	82.30811	-7.41067	3261	HF	station end	
PS115/1_15-1	2018-08-16	03:36	82.36950	-8.60195	3134	HF	station start	
PS115/1_15-1	2018-08-16	05:04	82.36947	-8.60445	3132	HF	at depth	
PS115/1_15-1	2018-08-16	06:35	82.36970	-8.60444	3131	HF	station end	
PS115/1_16-1	2018-08-16	07:45	82.27572	-9.46561	2878	HF	station start	
PS115/1_16-1	2018-08-16	09:04	82.27572	-9.46722	2878	HF	at depth	
PS115/1_16-1	2018-08-16	10:28	82.27485	-9.46688	2881	HF	station end	
PS115/1_16-2	2018-08-16	10:55	82.27521	-9.46622	2880	GC	station start	
PS115/1_16-2	2018-08-16	11:37	82.27511	-9.46522	2881	GC	at depth	
PS115/1_16-2	2018-08-16	12:28	82.27494	-9.46493	2881	GC	station end	
PS115/1_16-3	2018-08-16	12:50	82.27530	-9.46736	2881	BC	station start	
PS115/1_16-3	2018-08-16	13:26	82.27562	-9.46542	2907	BC	at depth	
PS115/1_16-3	2018-08-16	14:15	82.27440	-9.45798	2908	BC	station end	
PS115/1_16-4	2018-08-16	14:38	82.27575	-9.46778	2903	BC	station start	
PS115/1_16-4	2018-08-16	15:16	82.27579	-9.46668	2904	BC	at depth	
PS115/1_16-4	2018-08-16	16:07	82.27572	-9.46702	2903	BC	station end	
PS115/1_17-1	2018-08-16	17:47	82.18386	-10.51473	2567	HF	station start	
PS115/1_17-1	2018-08-16	18:54	82.18394	-10.51520	2568	HF	at depth	
PS115/1_17-1	2018-08-16	20:13	82.18398	-10.51485	2568	HF	station end	
PS115/1_17-2	2018-08-16	20:36	82.18389	-10.51507	2568	BC	station start	
PS115/1_17-2	2018-08-16	21:11	82.18389	-10.51481	2569	BC	at depth	
PS115/1_17-2	2018-08-16	21:55	82.18387	-10.51526	2567	BC	station end	
PS115/1_18-1	2018-08-16	22:50	82.11008	-11.23864	654	BC	station start	
PS115/1_18-1	2018-08-16	22:59	82.10998	-11.23881	659	BC	at depth	
PS115/1_18-1	2018-08-16	23:20	82.11014	-11.23846	659	BC	station end	
PS115/1_18-2	2018-08-16	23:42	82.10966	-11.23715	661	GC	station start	
PS115/1_18-2	2018-08-16	23:56	82.10996	-11.23861	659	GC	at depth	
PS115/1_18-2	2018-08-17	00:14	82.11021	-11.23917	659	GC	station end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_19-1	2018-08-17	01:56	81.96315	-12.65300	239	GC	station start	
PS115/1_19-1	2018-08-17	02:02	81.96323	-12.65217	239	GC	at depth	
PS115/1_19-1	2018-08-17	02:15	81.96315	-12.65246	239	GC	station end	
PS115/1_19-2	2018-08-17	02:41	81.96322	-12.65284	239	BC	station start	
PS115/1_19-2	2018-08-17	02:47	81.96319	-12.65278	239	BC	at depth	
PS115/1_19-2	2018-08-17	02:58	81.96292	-12.65227	239	BC	station end	
PS115/1_20-1	2018-08-17	03:08	81.95826	-12.65333	209	HSPS	profile start	
PS115/1_20-1	2018-08-17	13:29	82.00356	-13.23205	196	HSPS	profile end	
PS115/1_21-1	2018-08-17	13:36	82.00371	-13.22937	197	BC	station start	
PS115/1_21-1	2018-08-17	13:41	82.00366	-13.22908	197	BC	at depth	
PS115/1_21-1	2018-08-17	13:53	82.00373	-13.22870	191	BC	station end	
PS115/1_21-2	2018-08-17	14:24	82.00344	-13.23103	195	GC	station start	
PS115/1_21-2	2018-08-17	14:27	82.00347	-13.23010	196	GC	at depth	
PS115/1_21-2	2018-08-17	14:44	82.00457	-13.22148	197	GC	station end	
PS115/1_22-1	2018-08-17	19:23	82.27622	-9.46603	2903	BC	station start	First heave
PS115/1_22-1	2018-08-17	20:04	82.27581	-9.46636	2907	BC	at depth	no sediment
PS115/1_22-1	2018-08-17	20:55	82.27580	-9.46625	2908	BC	station end	
PS115/1_22-1	2018-08-17	21:05	82.27576	-9.46631	2907	BC	station start	Second heave
PS115/1_22-1	2018-08-17	21:44	82.27575	-9.46602	2905	BC	at depth	
PS115/1_22-1	2018-08-17	22:33	82.27613	-9.45755	2907	BC	station end	
PS115/1_23-1	2018-08-17	23:24	82.29274	-10.14461	2880	HSPS	profile start	
PS115/1_23-1	2018-08-18	01:05	82.43715	-11.07236	2803	HSPS	profile end	
PS115/1_24-1	2018-08-18	01:54	82.49728	-11.47140	2784	MAG	profile start	
PS115/1_24-1	2018-08-18	03:07	82.49877	-11.51011	2788	MAG	profile end	
PS115/1_25-1	2018-08-18	06:16	82.40310	-12.66967	1946	HF	station start	
PS115/1_25-1	2018-08-18	07:10	82.40115	-12.68520	1853	HF	at depth	
PS115/1_25-1	2018-08-18	07:53	82.39994	-12.68026	1816	HF	station end	
PS115/1_26-1	2018-08-18	09:51	82.50001	-11.48726	2793	GKG	station start	
PS115/1_26-1	2018-08-18	10:30	82.49997	-11.48599	2790	GKG	at depth	
PS115/1_26-1	2018-08-18	11:14	82.49874	-11.48931	2783	GKG	station end	
PS115/1_26-2	2018-08-18	11:52	82.49904	-11.48588	2791	GC	station start	
PS115/1_26-2	2018-08-18	12:32	82.49861	-11.48026	2786	GC	at depth	
PS115/1_26-2	2018-08-18	13:24	82.49629	-11.46865	2782	GC	station end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_26-3	2018-08-18	13:39	82.49353	-11.47638	2777	HF	station start	
PS115/1_26-3	2018-08-18	14:51	82.48852	-11.46871	2777	HF	at depth	
PS115/1_26-3	2018-08-18	16:10	82.48600	-11.45567	2774	HF	station end	
PS115/1_26-4	2018-08-18	16:34	82.48455	-11.44971	2777	REL	station start	
PS115/1_26-4	2018-08-18	16:53	82.48318	-11.44794	2775	REL	at depth	
PS115/1_26-4	2018-08-18	17:23	82.48159	-11.44606	2775	REL	station end	
PS115/1_27-1	2018-08-19	06:09	83.00607	-19.64271	172	REFL	station start	
PS115/1_27-1	2018-08-19	09:09	83.18376	-21.08600	243	REFL	profile start	
PS115/1_27-1	2018-08-19	11:54	83.36795	-22.23681	217	REFL	station end	
PS115/1_27-1	2018-08-19	13:32	83.30561	-21.71349	176	REFL	station start	
PS115/1_27-1	2018-08-20	06:33	84.31219	-30.44505	796	REFL	profile end	
PS115/1_27-1	2018-08-20	06:40	84.31514	-30.53664	774	REFL	station end	
PS115/1_27-1	2018-08-20	11:14	84.31493	-29.58570	811	REFL	station start	
PS115/1_27-1	2018-08-20	13:00	84.37331	-29.29436	853	REFL	profile start	
PS115/1_27-1	2018-08-21	04:35	83.91284	-31.51749	117	REFL	profile end	
PS115/1_27-1	2018-08-21	04:48	83.91966	-31.36714	117	REFL	profile start	
PS115/1_27-1	2018-08-21	20:55	83.84773	-36.02914	250	REFL	profile end	
PS115/1_27-1	2018-08-21	21:01	83.84987	-36.10592	343	REFL	station end	
PS115/1_27-1	2018-08-21	23:00	83.93946	-36.88784	367	REFL	station end	
PS115/1_27-2	2018-08-19	08:55	83.16938	-20.94360	235	MAG	station start	
PS115/1_27-2	2018-08-19	19:00	83.65338	-24.09502	197	MAG	station end	
PS115/1_27-2	2018-08-19	20:27	83.71613	-25.00859	311	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-19	21:52	83.79795	-25.80484	484	MAG	station end	
PS115/1_27-2	2018-08-19	22:26	83.83331	-26.10489	216	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-19	23:54	83.91075	-27.01140	293	MAG	station end	
PS115/1_27-2	2018-08-20	02:31	84.04174	-28.67997	562	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-20	06:59	84.33621	-30.70051	700	MAG	station end	
PS115/1_27-2	2018-08-20	07:02	84.33921	-30.70357	688	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-20	07:09	84.34916	-30.69596	659	MAG	station end	
PS115/1_27-2	2018-08-20	07:15	84.35575	-30.64767	650	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-20	07:32	84.36085	-30.42825	639	MAG	station end	
PS115/1_27-2	2018-08-20	07:35	84.35844	-30.38425	645	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-20	07:46	84.34862	-30.25641	714	MAG	station end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_27-2	2018-08-20	08:53	84.30701	-29.52398	848	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-20	09:20	84.27257	-29.61463	838	MAG	station end	
PS115/1_27-2	2018-08-20	09:31	84.26811	-29.75176	841	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-21	06:37	84.04506	-30.61968	192	MAG	station end	
PS115/1_27-2	2018-08-21	08:13	84.15993	-30.02837	853	MAG	station start	Profile / ID continued
PS115/1_27-2	2018-08-21	20:42	83.85845	-35.92787	202	MAG	station end	
PS115/1_37-1	2018-08-22	08:18	84.10168	-29.29003	838	REFR	station start	
PS115/1_37-1	2018-08-22	09:46	84.10658	-28.68106	833	REFR	profile start	
PS115/1_37-1	2018-08-22	21:00	83.81826	-36.91209	231	REFR	profile end	
PS115/1_37-1	2018-08-22	21:22	83.83152	-36.71887	221	REFR	station end	
PS115/1_37-2	2018-08-22	09:22	84.07925	-28.60714	697	MAG	station start	
PS115/1_37-2	2018-08-22	13:05	84.03705	-31.20475	282	MAG	station end	
PS115/1_37-2	2018-08-22	13:08	84.03566	-31.24104	274	MAG	station start	Profile / ID continued
PS115/1_37-2	2018-08-22	13:19	84.03082	-31.38573	240	MAG	station end	
PS115/1_37-2	2018-08-22	14:18	84.00839	-32.12372	155	MAG	station start	Profile / ID continued
PS115/1_37-2	2018-08-22	14:30	84.01042	-32.27290	155	MAG	station end	
PS115/1_37-2	2018-08-22	16:31	83.94624	-33.70426	193	MAG	station start	Profile / ID continued
PS115/1_37-2	2018-08-22	20:45	83.81773	-36.75407	209	MAG	station end	
PS115/1_38-1	2018-08-22	22:02	83.84960	-36.06214	324	OBS	station start	
PS115/1_38-1	2018-08-22	22:48	83.85546	-35.84110	210	OBS	station end	
PS115/1_39-1	2018-08-22	23:34	83.89110	-35.05076	369	OBS	station start	
PS115/1_39-1	2018-08-22	23:37	83.89104	-35.05011	369	OBS	station end	
PS115/1_39-1	2018-08-22	23:39	83.89099	-35.04859	369	OBS	station start	
PS115/1_39-1	2018-08-22	23:55	83.89003	-35.06598	375	OBS	station end	
PS115/1_40-1	2018-08-23	00:53	83.92440	-34.24771	206	OBS	station start	
PS115/1_40-1	2018-08-23	01:11	83.92251	-34.25737	207	OBS	station end	
PS115/1_41-1	2018-08-23	02:08	83.95566	-33.45359	178	OBS	station start	
PS115/1_41-1	2018-08-23	02:28	83.95489	-33.47386	185	OBS	station end	
PS115/1_42-1	2018-08-23	03:25	83.98421	-32.64813	164	OBS	station start	
PS115/1_42-1	2018-08-23	03:32	83.98415	-32.64913	164	OBS	station end	
PS115/1_42-1	2018-08-23	03:36	83.98410	-32.65636	166	OBS	station start	continued
PS115/1_42-1	2018-08-23	03:37	83.98405	-32.65635	165	OBS	station end	
PS115/1_42-1	2018-08-23	03:43	83.98458	-32.66695	167	OBS	station start	continued

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_42-1	2018-08-23	04:10	83.98346	-32.66889	169	OBS	station end	
PS115/1_43-1	2018-08-23	06:05	84.01422	-31.85163	157	OBS	station start	
PS115/1_43-1	2018-08-23	06:08	84.01381	-31.84961	157	OBS	station end	
PS115/1_43-1	2018-08-23	06:29	84.01357	-31.87117	156	OBS	station start	continued
PS115/1_43-1	2018-08-23	06:46	84.01276	-31.84873	153	OBS	station end	
PS115/1_44-1	2018-08-23	07:42	84.04331	-31.01312	422	OBS	station start	
PS115/1_44-1	2018-08-23	08:00	84.04102	-31.03062	351	OBS	station end	
PS115/1_45-1	2018-08-23	09:11	84.06947	-30.20959	724	OBS	station start	
PS115/1_45-1	2018-08-23	09:14	84.06941	-30.20943	725	OBS	station end	
PS115/1_45-1	2018-08-23	09:38	84.06958	-30.19531	727	OBS	station start	
PS115/1_45-1	2018-08-23	10:04	84.06780	-30.21049	721	OBS	station end	
PS115/1_46-1	2018-08-23	11:19	84.09642	-29.34417	828	OBS	station start	
PS115/1_46-1	2018-08-23	11:52	84.09813	-29.35334	831	OBS	station end	
PS115/1_47-1	2018-08-23	13:43	84.24292	-29.59568	874	BC	station start	
PS115/1_47-1	2018-08-23	13:59	84.24276	-29.59590	878	BC	at depth	
PS115/1_47-1	2018-08-23	14:16	84.24256	-29.59634	876	BC	station end	
PS115/1_47-2	2018-08-23	14:26	84.24201	-29.59645	878	BC	station start	
PS115/1_47-2	2018-08-23	14:39	84.24150	-29.59460	879	BC	at depth	
PS115/1_47-2	2018-08-23	15:00	84.24040	-29.59047	876	BC	station end	
PS115/1_47-3	2018-08-23	15:26	84.23801	-29.59259	879	GC	station start	
PS115/1_47-3	2018-08-23	15:38	84.23736	-29.59220	882	GC	at depth	
PS115/1_47-3	2018-08-23	16:02	84.23555	-29.58721	881	GC	station end	
PS115/1_47-4	2018-08-23	16:29	84.23330	-29.58298	883	GC	station start	
PS115/1_47-4	2018-08-23	16:41	84.23217	-29.58416	879	GC	at depth	
PS115/1_47-4	2018-08-23	17:04	84.23112	-29.58123	881	GC	station end	
PS115/1_47-5	2018-08-23	17:50	84.22892	-29.58166	881	GC	station start	
PS115/1_47-5	2018-08-23	18:03	84.22844	-29.58054	886	GC	at depth	
PS115/1_47-5	2018-08-23	18:27	84.22780	-29.58506	875	GC	station end	
PS115/1_48-1	2018-08-24	11:28	83.12177	-20.53715	226	BC	station start	
PS115/1_48-1	2018-08-24	11:36	83.12178	-20.53724	226	BC	at depth	
PS115/1_48-1	2018-08-24	11:49	83.12160	-20.53749	226	BC	station end	
PS115/1_49-1	2018-08-24	12:09	83.10049	-20.29859	181	MAG	station start	
PS115/1_49-1	2018-08-24	12:25	83.07378	-20.09238	186	MAG	station end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_49-1	2018-08-24	12:41	83.04859	-19.87308	152	MAG	station start	
PS115/1_49-1	2018-08-24	12:50	83.03691	-19.77471	159	MAG	station end	
PS115/1_50-1	2018-08-25	14:07	80.89211	-3.54080	3379	HF	station start	
PS115/1_50-1	2018-08-25	15:43	80.88901	-3.48605	3376	HF	at depth	
PS115/1_50-1	2018-08-25	17:39	80.88096	-3.44788	3375	HF	station end	
PS115/1_50-2	2018-08-25	17:55	80.87950	-3.44340	3372	BC	station start	
PS115/1_50-2	2018-08-25	18:46	80.87663	-3.43055	3375	BC	at depth	
PS115/1_50-2	2018-08-25	19:40	80.87216	-3.42211	3372	BC	station end	
PS115/1_50-3	2018-08-25	20:15	80.86789	-3.44723	3397	GC	station start	
PS115/1_50-3	2018-08-25	21:53	80.86445	-3.43307	3398	GC	station end	
PS115/1_51-1	2018-08-26	04:34	80.48047	-8.48648	290	GC	station start	
PS115/1_51-1	2018-08-26	04:40	80.48055	-8.48637	291	GC	at depth	
PS115/1_51-1	2018-08-26	04:53	80.48058	-8.48559	291	GC	station end	
PS115/1_51-2	2018-08-26	05:12	80.48071	-8.48621	290	BC	station start	
PS115/1_51-2	2018-08-26	05:19	80.48078	-8.48586	290	BC	at depth	
PS115/1_51-2	2018-08-26	05:29	80.48070	-8.48690	290	BC	station end	
PS115/1_52-1	2018-08-26	07:40	80.34810	-6.83590	257	GC	station start	
PS115/1_52-1	2018-08-26	07:53	80.34783	-6.83894	255	GC	at depth	
PS115/1_52-1	2018-08-26	08:05	80.34779	-6.83890	255	GC	station end	
PS115/1_52-2	2018-08-26	08:14	80.34782	-6.83928	255	TVMUC	station start	
PS115/1_52-2	2018-08-26	08:23	80.34793	-6.83973	255	TVMUC	at depth	
PS115/1_52-2	2018-08-26	08:41	80.34791	-6.83976	255	TVMUC	station end	
PS115/1_53-1	2018-08-26	13:20	79.83089	-8.90790	170	GC	station start	
PS115/1_53-1	2018-08-26	13:24	79.83097	-8.90713	170	GC	at depth	
PS115/1_53-1	2018-08-26	13:35	79.83086	-8.90701	170	GC	station end	
PS115/1_53-2	2018-08-26	13:52	79.83101	-8.91276	169	TVMUC	at depth	
PS115/1_53-2	2018-08-26	14:09	79.83121	-8.91437	169	TVMUC	station end	
PS115/1_54-1	2018-08-26	16:42	79.92884	-9.30094	122	REFL	station start	
PS115/1_54-1	2018-08-26	16:45	79.93027	-9.27960	126	REFL	at depth	
PS115/1_54-1	2018-08-26	21:46	79.94279	-8.72257	117	REFL	profile start	
PS115/1_54-1	2018-08-27	07:41	79.92646	-4.26966	1833	REFL	profile end	
PS115/1_54-1	2018-08-27	07:42	79.92561	-4.27418	1831	REFL	profile start	
PS115/1_54-1	2018-08-27	19:48	80.38420	-9.33638	296	REFL	profile end	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_54-1	2018-08-27	19:54	80.38896	-9.38129	298	REFL	station end	
PS115/1_54-1	2018-08-27	20:30	80.41760	-9.30815	262	REFL	station start	
PS115/1_54-1	2018-08-27	20:56	80.38380	-9.24897	289	REFL	profile start	
PS115/1_54-1	2018-08-28	14:37	79.00696	-9.09688	245	REFL	profile end	
PS115/1_54-1	2018-08-28	14:49	78.99022	-9.10793	243	REFL	station end	
PS115/1_54-1	2018-08-28	17:52	79.01264	-9.20833	232	REFL	station start	
PS115/1_54-1	2018-08-28	18:18	78.98918	-9.08742	245	REFL	profile start	
PS115/1_54-1	2018-08-29	01:21	78.36956	-9.03103	232	REFL	station end	
PS115/1_54-1	2018-08-29	02:13	78.35947	-9.31639	254	REFL	station start	
PS115/1_54-1	2018-08-29	02:41	78.39366	-9.35204	261	REFL	profile start	
PS115/1_54-1	2018-08-29	19:54	78.16403	-2.48671	2825	REFL	profile end	
PS115/1_54-1	2018-08-29	21:11	78.12858	-2.59610	2814	REFL	profile start	
PS115/1_54-1	2018-08-30	06:58	78.95133	-3.10280	2402	REFL	profile end	
PS115/1_54-1	2018-08-30	07:08	78.96219	-3.06724	2405	REFL	station end	
PS115/1_54-1	2018-08-30	08:09	78.94034	-2.94194	2460	REFL	station start	
PS115/1_54-1	2018-08-30	08:31	78.93846	-3.11126	2405	REFL	profile start	
PS115/1_54-1	2018-08-31	04:30	78.73444	-12.23045	143	REFL	profile end	
PS115/1_54-1	2018-08-31	04:38	78.72389	-12.24964	133	REFL	station end	
PS115/1_54-1	2018-08-31	05:52	78.61478	-12.34062	193	REFL	station start	
PS115/1_54-1	2018-08-31	06:16	78.57959	-12.37211	202	REFL	profile start	
PS115/1_54-1	2018-08-31	08:50	78.33417	-12.61690	176	REFL	profile end	
PS115/1_54-1	2018-08-31	08:51	78.33188	-12.61542	175	REFL	profile start	
PS115/1_54-1	2018-09-01	13:10	76.24007	-6.07070	2504	REFL	profile end	
PS115/1_54-1	2018-09-01	15:51	76.06785	-5.55028	2867	REFL	station end	
PS115/1_54-2	2018-08-26	20:45	79.99779	-9.08003	347	MAG	station start	
PS115/1_54-2	2018-08-27	03:18	79.97386	-6.07905	315	MAG	station end	
PS115/1_54-2	2018-08-27	13:07	80.10459	-6.51163	312	MAG	station start	
PS115/1_54-2	2018-08-28	08:11	79.46996	-9.86143	139	MAG	station end	
PS115/1_54-2	2018-08-28	09:20	79.39231	-9.59922	175	MAG	station start	
PS115/1_54-2	2018-08-29	10:37	78.30450	-6.15563	347	MAG	station end	
PS115/1_54-2	2018-08-29	14:02	78.25072	-4.80475	755	MAG	station start	
PS115/1_54-2	2018-08-29	15:25	78.23079	-4.26373	1898	MAG	station end	
PS115/1_54-2	2018-08-30	06:31	78.91311	-3.07912	2436	MAG	station start	

Station	Date	Time	Latitude	Longitude	Depth [m]	Gear	Action	Comment
PS115/1_54-2	2018-08-31	02:36	78.76311	-11.38771	239	MAG	station end	
PS115/1_54-2	2018-08-31	09:24	78.28283	-12.47504	157	MAG	station start	
PS115/1_54-2	2018-08-31	10:11	78.21912	-12.30166	177	MAG	station end	
PS115/1_54-3	2018-08-27	21:22	80.34939	-9.25007	335	SONO_B	deployed	
PS115/1_54-4	2018-08-28	13:47	79.07397	-9.08314	136	SONO_B	deployed	
PS115/1_54-5	2018-08-31	14:04	77.93647	-11.38966	213	SONO_B	deployed	
PS115/1_54-6	2018-08-31	23:05	77.30663	-9.34574	283	SONO_B	deployed	
PS115/1_54-7	2018-09-01	03:04	77.00785	-8.40392	336	SONO_B	deployed	
PS115/1_54-8	2018-09-01	06:39	76.72776	-7.54175	310	SONO_B	deployed	

Gear abbreviations	**Gear**
ADCP_150	ADCP 150 kHz
AFIM	AutoFim
AIMMMS	AIMMMS
AIRGUN	Air Gun
BC	Box Corer
DRDGE	Dredge
FBOX	FerryBox
GC	Gravity Corer
GKG	Box Grab
HF	Heat Flow Probe
HSPS	Hydrosweep-Parasound
HVAIR	High Volume Air Sampler
MAG	Magnetometer
OBS	Ocean Bottom Seismograph
Observ	Observer
PCO2_SUB	pCO_2 Subctech
REFL	Seismic reflection
REFR	OBS-Refraktionsseismik
REL	Releaser
RM	Radiation Measurements
SONO_B	Sono Buoy
SVP	Sound Velocity Profiler
TSG_KEEL	Thermosalinograph Keel
TSG_KEEL_2	Thermosalinograph Keel 2
TVMUC	Video Multi Corer
WST	Weatherstation

A.5 LIST OF SEDIMENT CORES

- SL – gravity corer
- GKG – box corer

Legend

Lithology

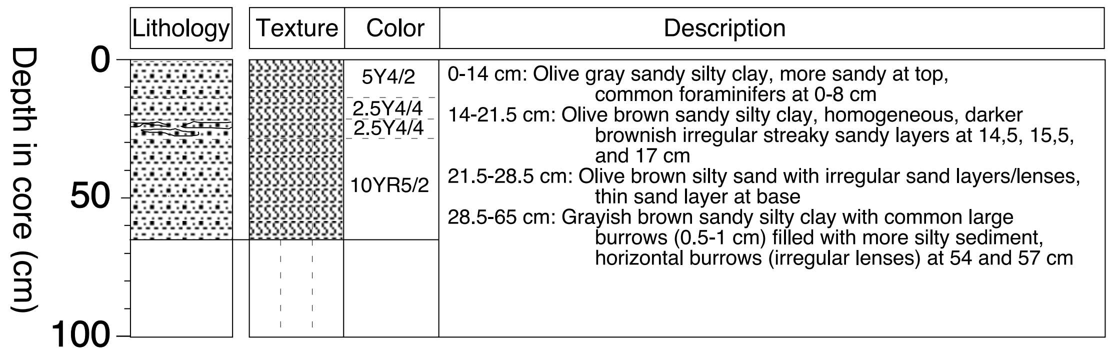
- Sand
- Sandy silt
- Clayey sandy silt
- Sandy silty clay
- Silty clay
- Dropstones

Structure

- Bioturbation
- Sharp boundary
- Gradational boundary
- Wavy boundary

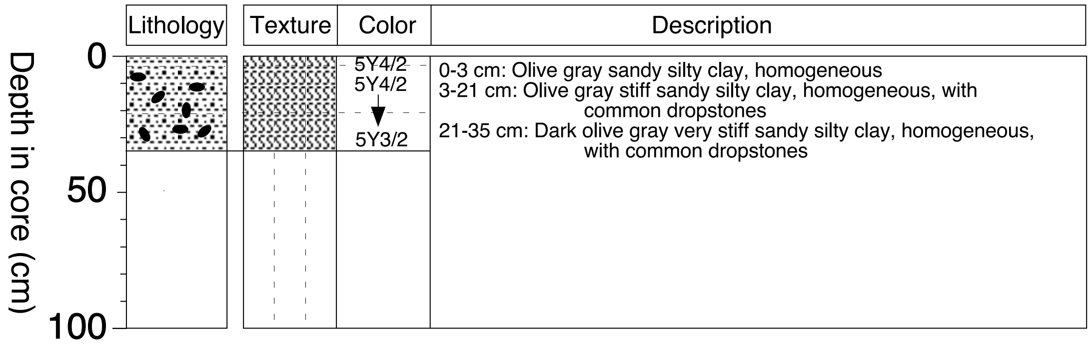
PS115/1_4-3 (SL) East Greenland continental margin

Recovery: 0.65 m 76° 23.21'N, 4° 47.75'W Water depth: 2381 m



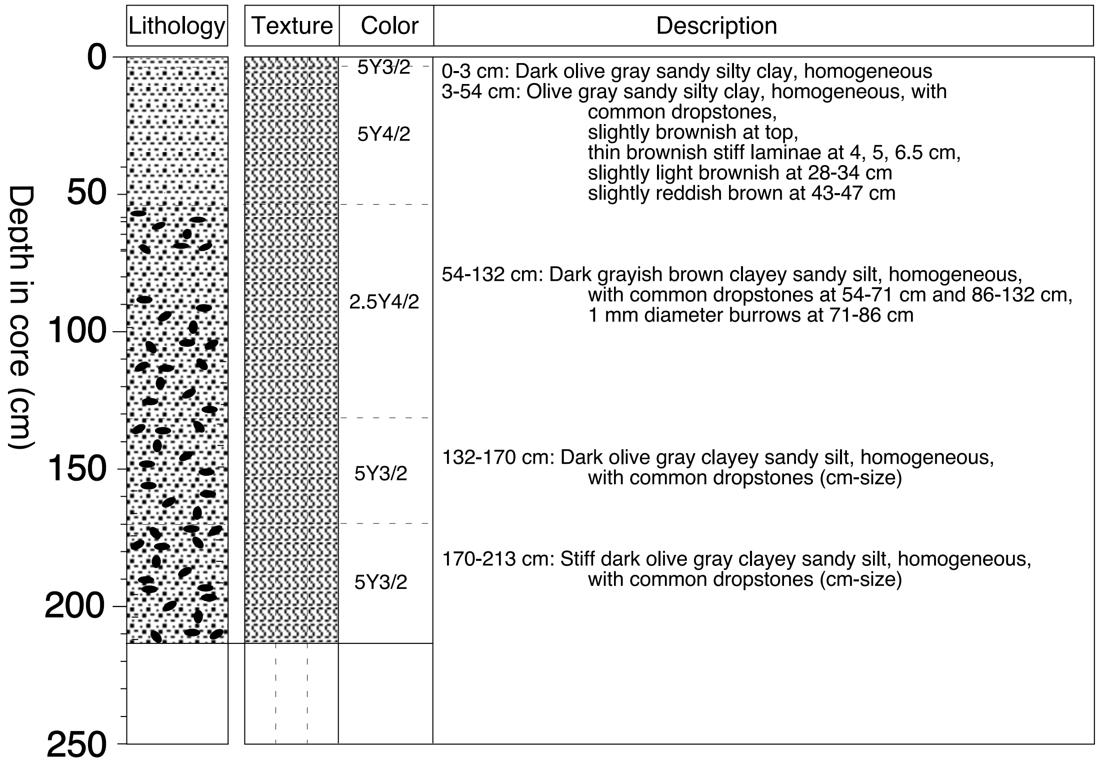
PS115/1_5-1 (SL) Northeast Greenland continental shelf

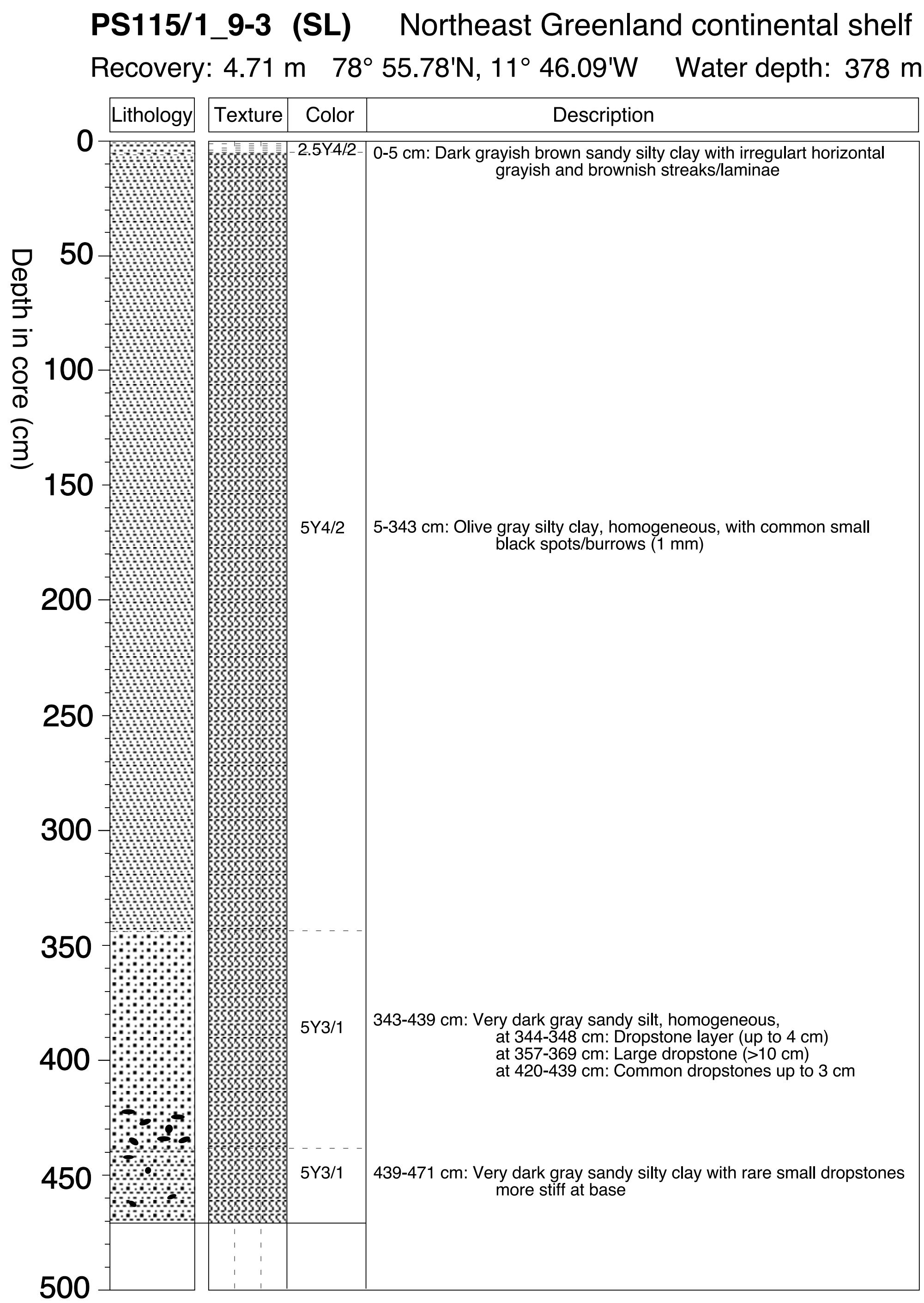
Recovery: 0.35 m 78° 15.07'N, 8° 26.90'W Water depth: 194 m



PS115/1_6-2 (SL) Northeast Greenland continental shelf

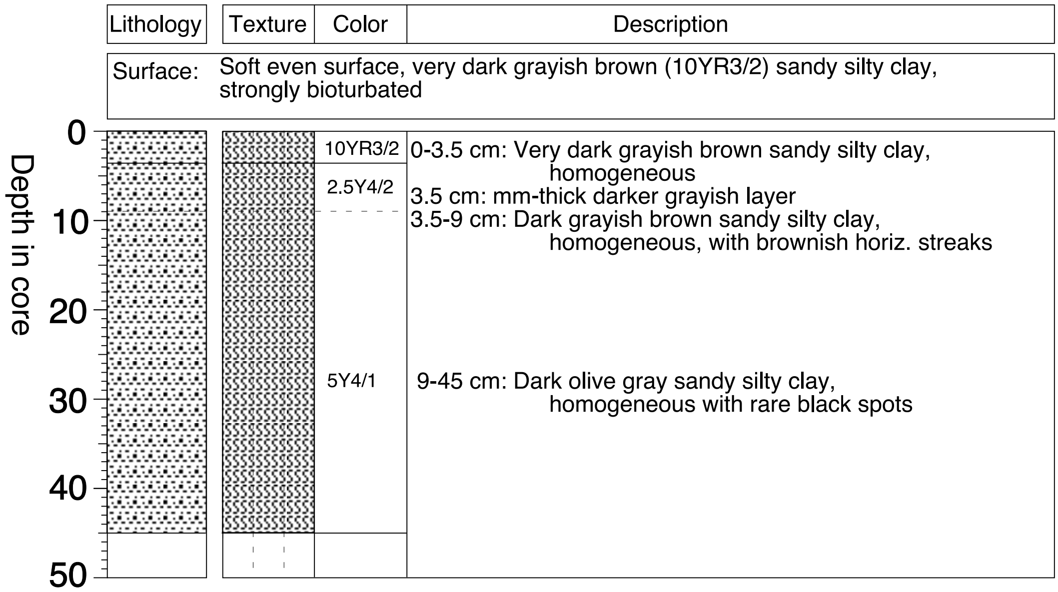
Recovery: 2.13 m 78° 26.46'N, 8° 57.60'W Water depth: 261 m




PS115/1_9-3 (SL) Northeast Greenland continental shelf
Recovery: 4.71 m 78° 55.78'N, 11° 46.09'W Water depth: 378 m
Lithology
Texture
Color
Description
Depth in core (cm)
0
50
100
150
200
250
300
350
400
450
500
2.5Y4/2
0-5 cm: Dark grayish brown sandy silty clay with irregulart horizontal grayish and brownish streaks/laminae
5Y4/2
5-343 cm: Olive gray silty clay, homogeneous, with common small black spots/burrows (1 mm)
5Y3/1
343-439 cm: Very dark gray sandy silt, homogeneous,
at 344-348 cm: Dropstone layer (up to 4 cm)
at 357-369 cm: Large dropstone (>10 cm)
at 420-439 cm: Common dropstones up to 3 cm
5Y3/1
439-471 cm: Very dark gray sandy silty clay with rare small dropstones more stiff at base

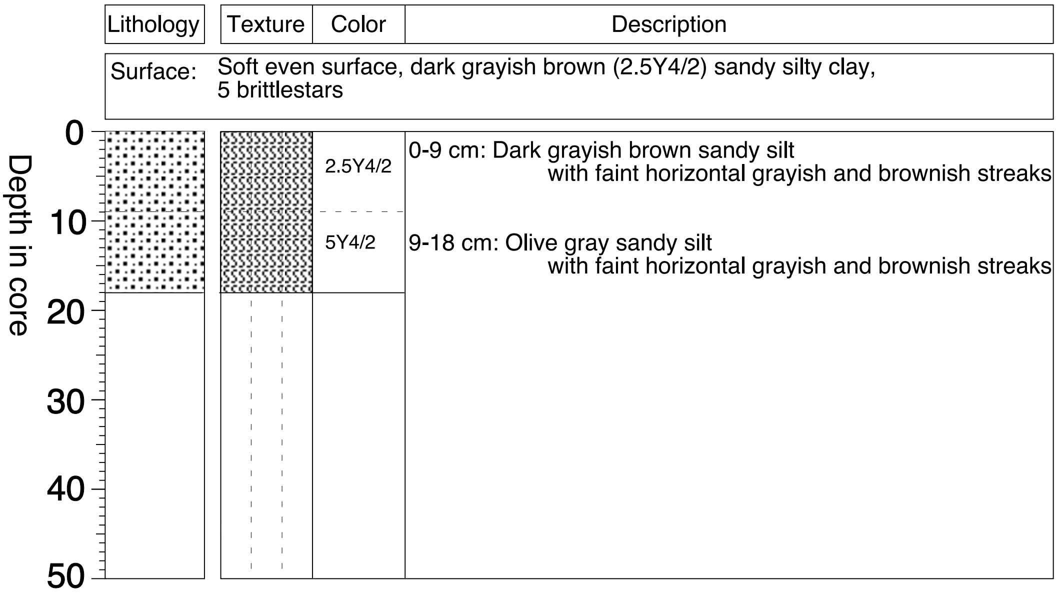
PS115/1_9-4 (GKG) Northeast Greenland continental shelf

Recovery: 0.45 m 78° 55.78'N, 11° 45.81'W Water depth: 378 m



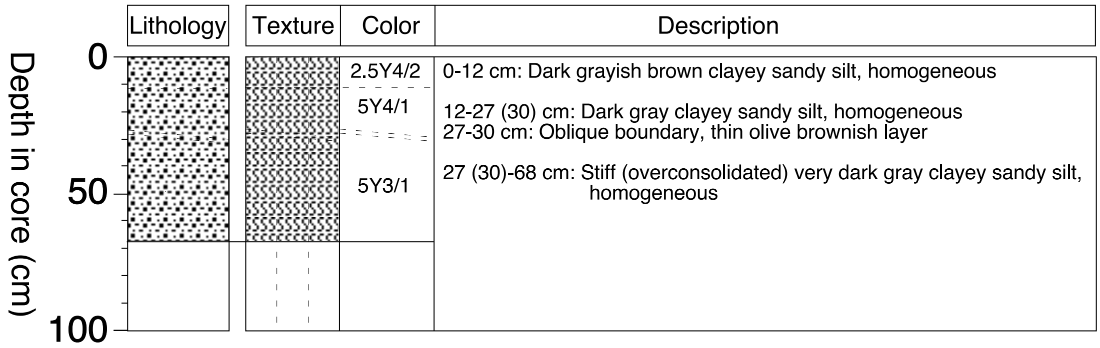
PS115/1_11-1 (GKG) Northeast Greenland continental shelf

Recovery: 0.18 m 78° 56.52'N, 11° 31.90'W Water depth: 209 m



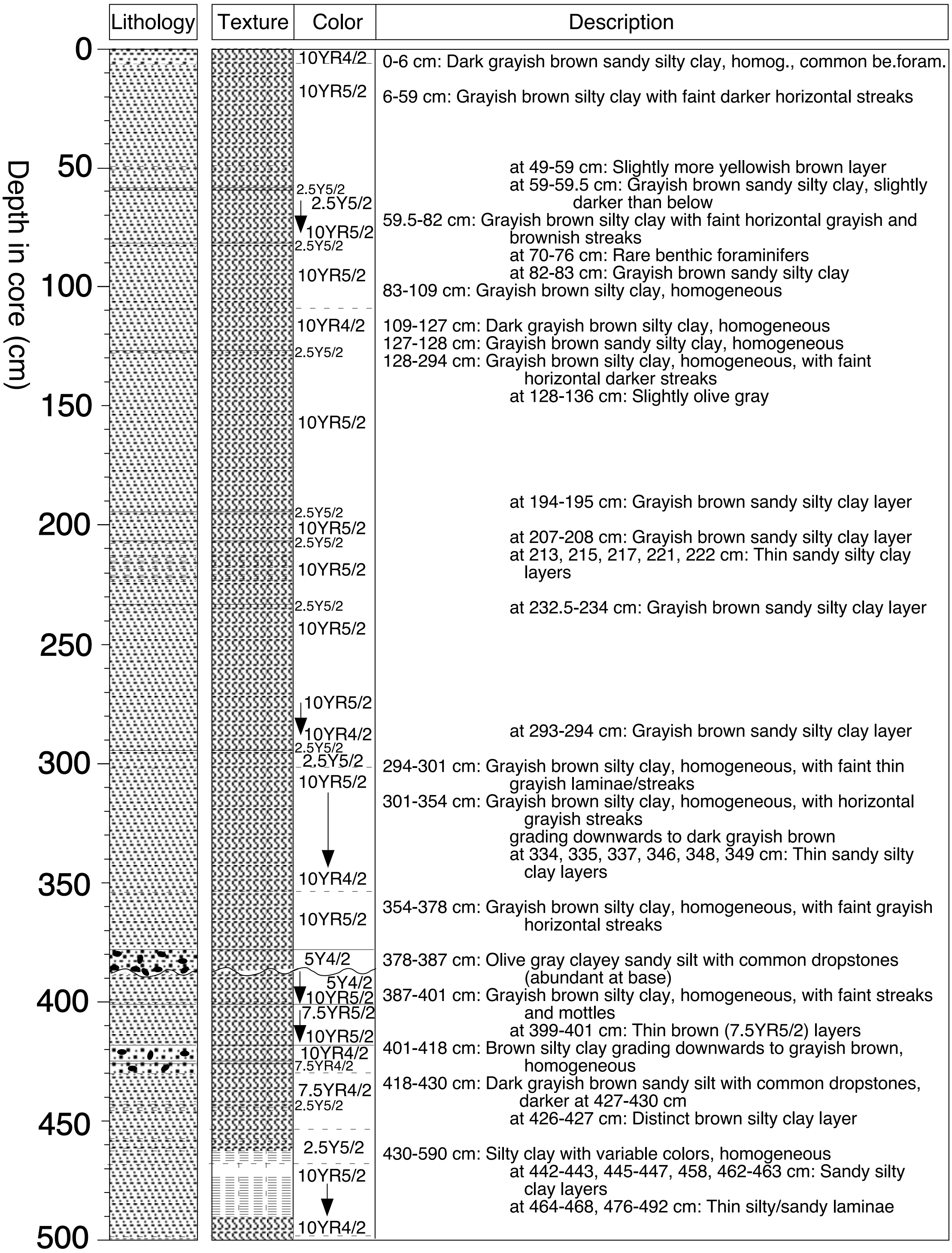
PS115/1_11-3 (SL) Northeast Greenland continental shelf

Recovery: 0.68 m 78° 56.53'N, 11° 31.93'W Water depth: 209 m



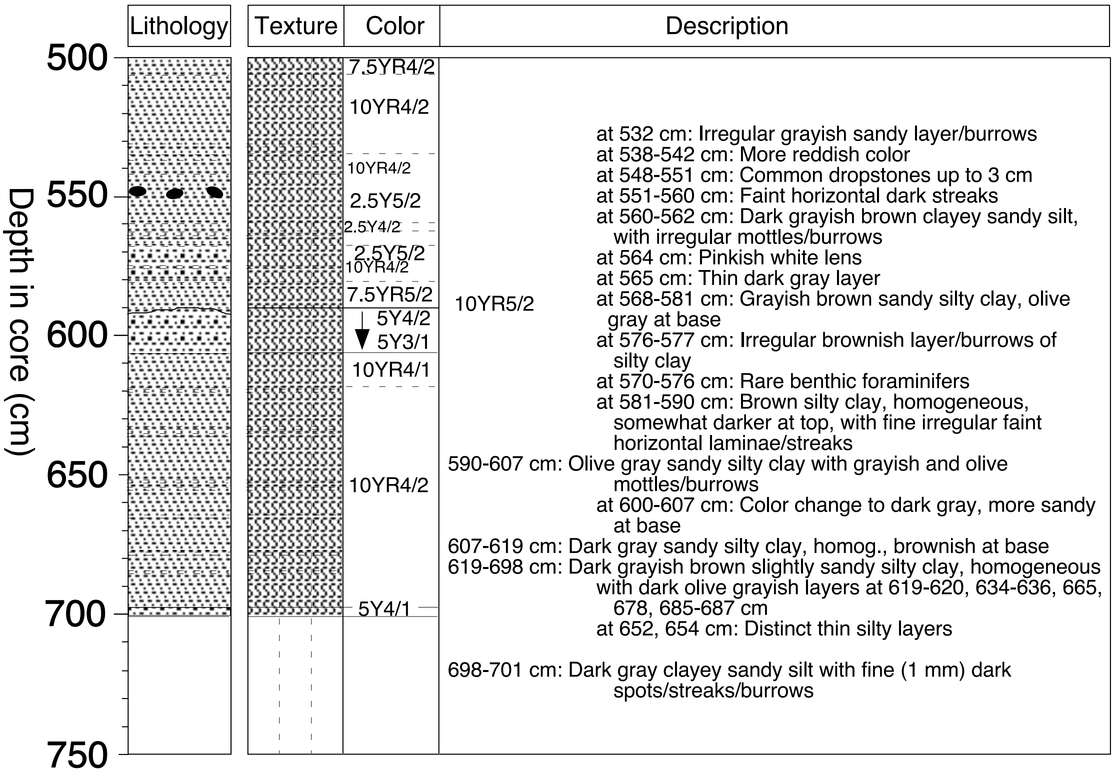
PS115/1_16-2 (SL) Wandel Sea

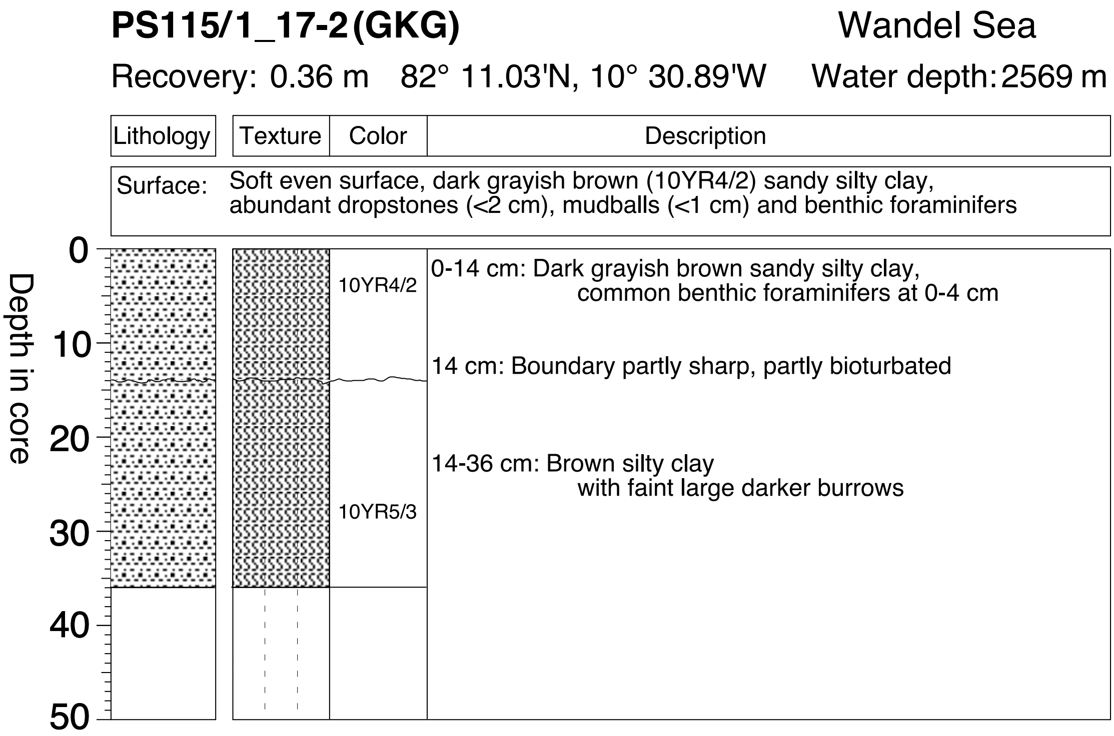
Recovery: 7.01 m 82° 16.51'N, 9° 27.9'W Water depth: 2881 m



PS115/1_16-2 (SL) Wandel Sea

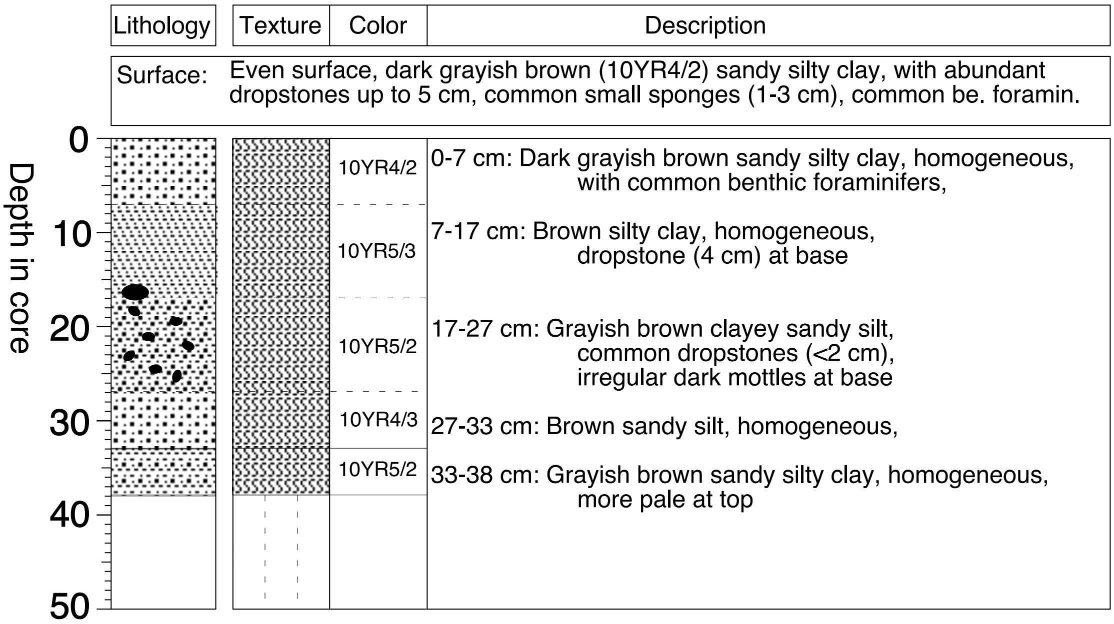
Recovery: 7.01 m 82° 16.51'N, 9° 27.9'W Water depth: 2881 m




PS115/1_17-2 (GKG)
Wandel Sea
Recovery: 0.36 m 82° 11.03'N, 10° 30.89'W Water depth: 2569 m
Lithology
Texture
Color
Description
Surface: Soft even surface, dark grayish brown (10YR4/2) sandy silty clay, abundant dropstones (<2 cm), mudballs (<1 cm) and benthic foraminifers
Depth in core
0
10
20
30
40
50
10YR4/2
10YR5/3
0-14 cm: Dark grayish brown sandy silty clay, common benthic foraminifers at 0-4 cm
14 cm: Boundary partly sharp, partly bioturbated
14-36 cm: Brown silty clay with faint large darker burrows

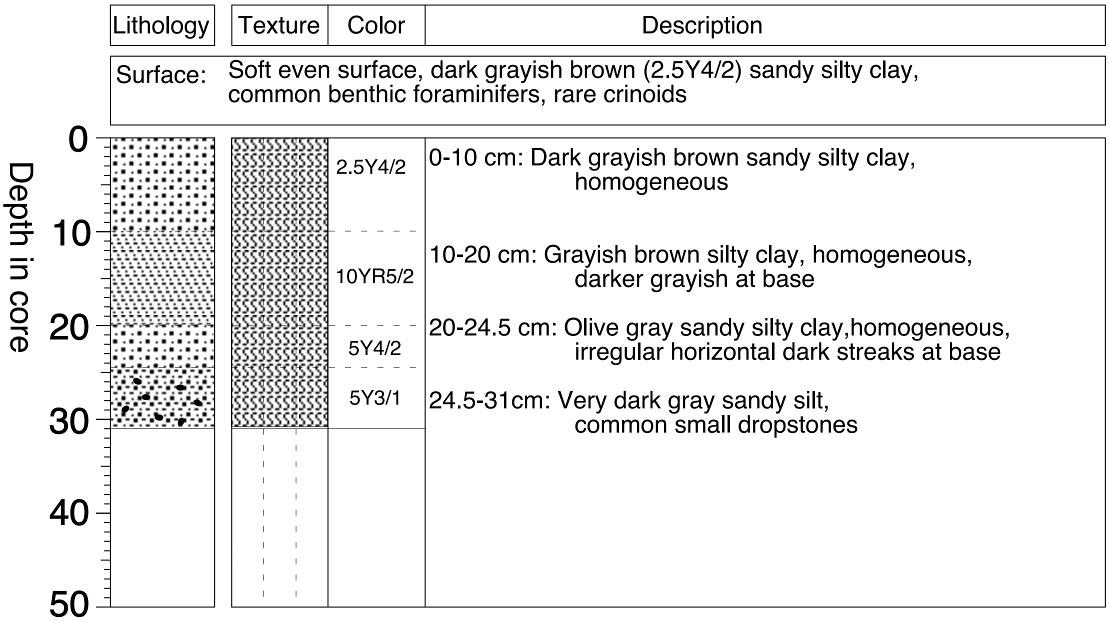
PS115/1_18-1 (GKG) Wandel Sea

Recovery: 0.38 m 82° 06.60'N, 11° 14.33'W Water depth: 659 m



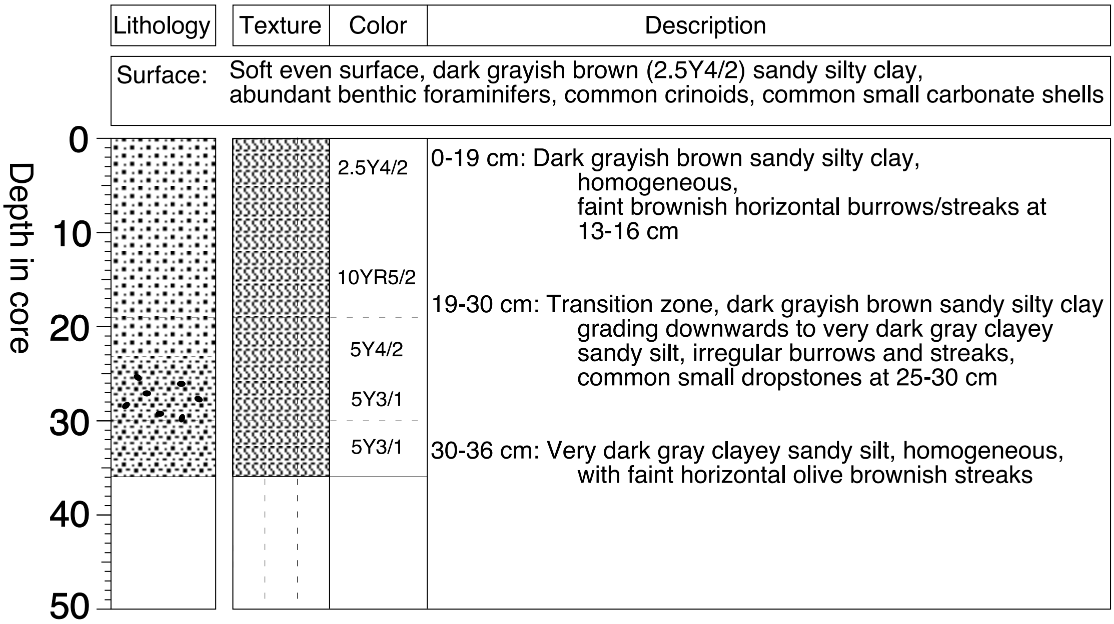
PS115/1_19-2 (GKG) Wandel Sea

Recovery: 0.31 m 81° 57.79'N, 12° 39.17'W Water depth: 239 m



PS115/1_21-1 (GKG) Wandel Sea

Recovery: 0.36 m 82° 00.22'N, 13° 13.75'W Water depth: 197 m

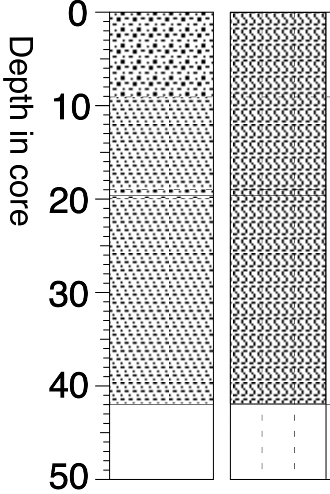


PS115/1_22-2 (GKG) Wandel Sea

Recovery: 0.42 m 82° 16.55'N, 09° 27.98'W Water depth: 2906 m

Lithology	Texture	Color	Description

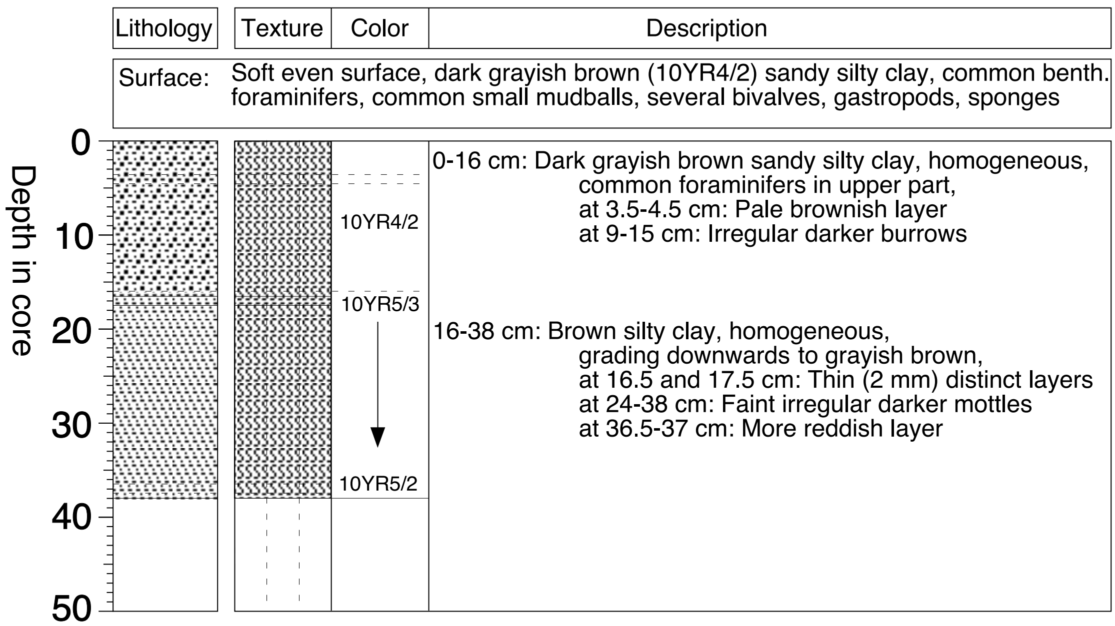
Surface: Soft even surface, dark grayish brown (10YR4/2) sandy silty clay, common benth. foraminifers, common light grayish brown mudballs, common small dropstones



Color	Description
10YR4/2	0-9 cm: Dark grayish brown sandy silty clay, homogeneous, dark brown at 0-3 cm, common foraminifers, irreg. pale brownish at 3-4 cm
10YR5/2	9-19 cm: Grayish brown silty clay, homogeneous, irregular dark grayish brown horizontal streaks at 9-13 cm (common) and 13-17 cm (rare)
10YR5/2	19.0-19.5 cm: Grayish brown layer of sandy silt
10YR5/3	19.5-42 cm: Brown silty clay, homogeneous, with faint darker grayish mottles and burrows

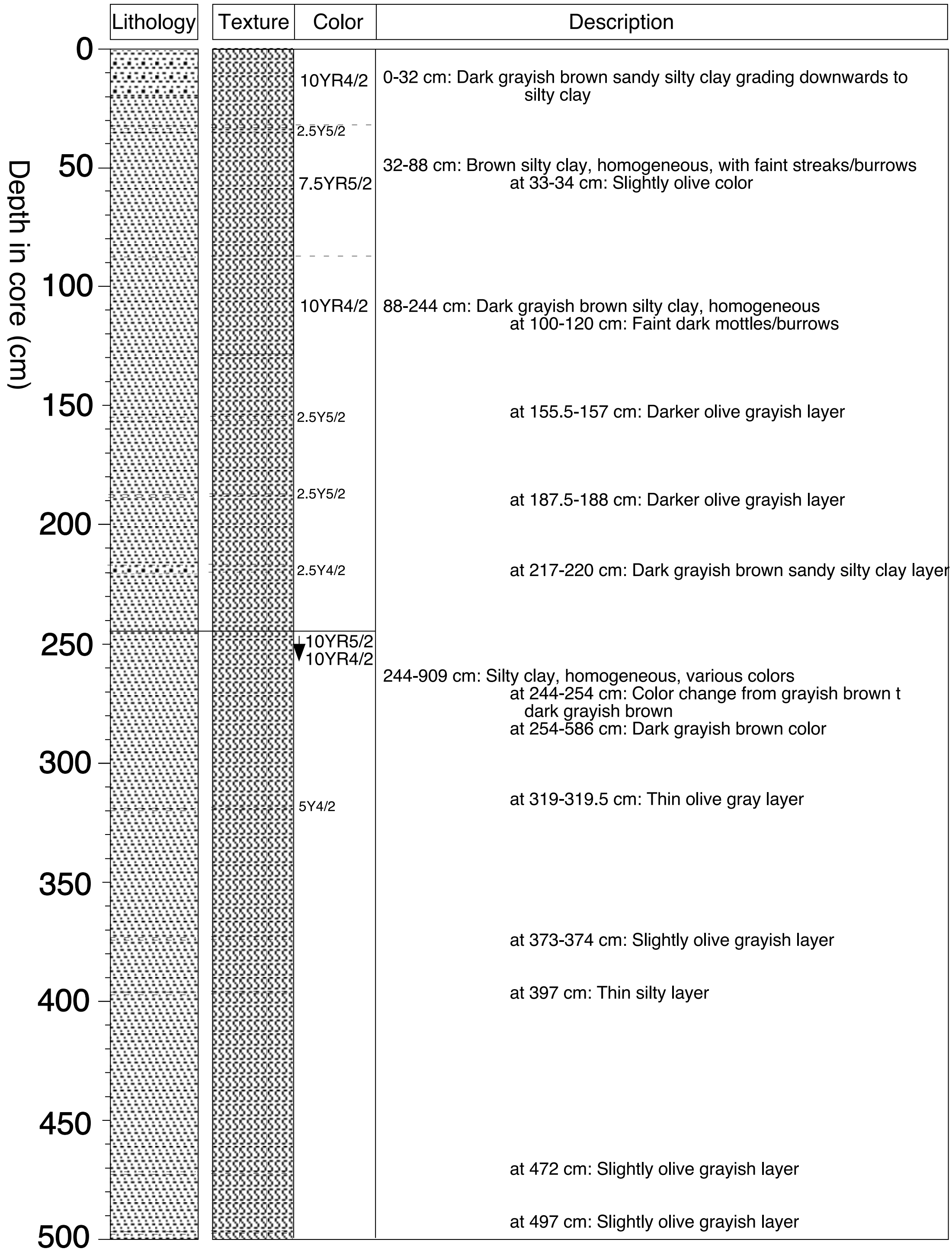
PS115/1_26-1 (GKG) Wandel Sea

Recovery: 0.38 m 82° 30.00'N, 11° 29.16'W Water depth: 2790 m



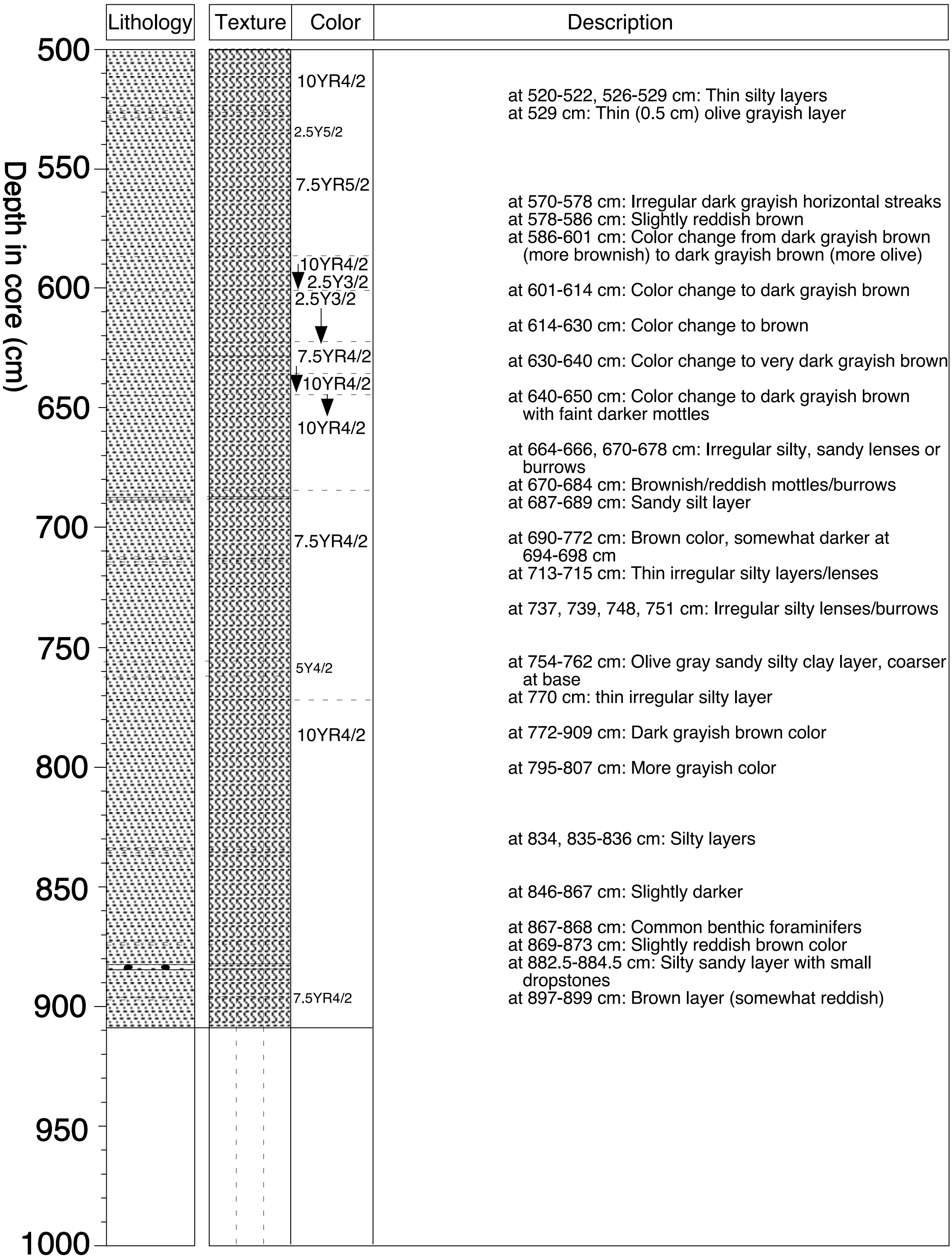
PS115/1_26-2 (SL) Wandel Sea

Recovery: 9.09 m 82° 29.92'N, 11° 28.82'W Water depth: 2786 m



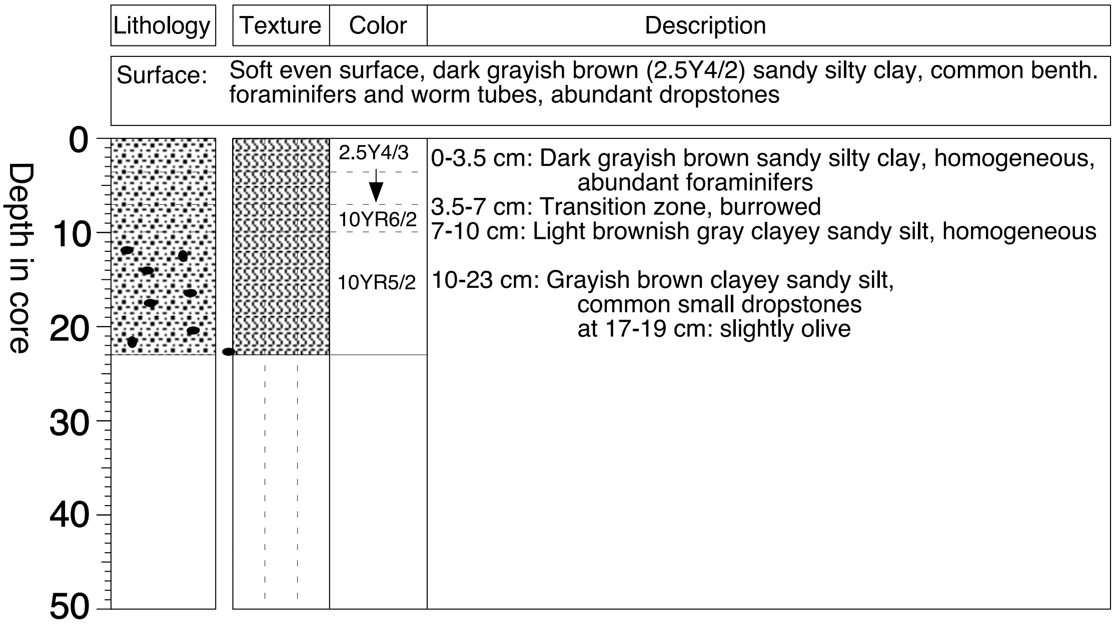
PS115/1_26-2 (SL) Wandel Sea

Recovery: 9.09 m 82° 29.92'N, 11° 28.82'W Water depth: 2786 m



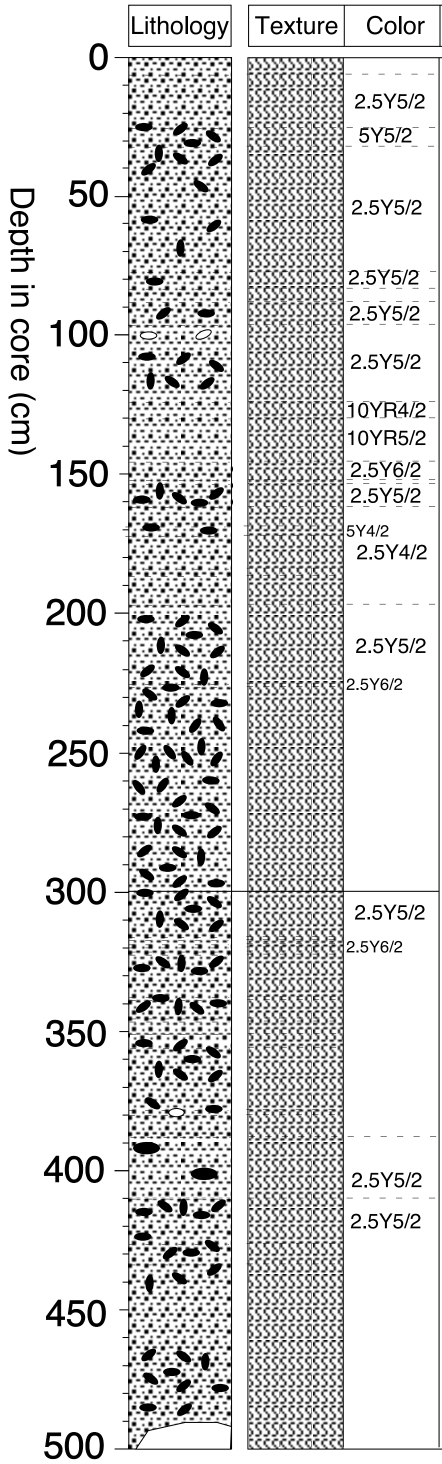
PS115/1_47-2 (GKG) Southern Morris Jesup Rise

Recovery: 0.23 m 84° 14.46'N, 29° 35.69'W Water depth: 879 m



PS115/1_47-3 (SL) Southern Morris Jesup Rise

Recovery: 5.00 m 84° 14.24'N, 29° 35.53'W Water depth: 882 m



Description

0-6 cm: Burrowed transition from Dark grayish brown (2.5Y4/2) sandy silty clay to light brownish gray (10YR6/2) clayey sandy silt
6-26 cm: Grayish brown clayey sandy silt with common dropstones
26-31 cm: Olive gray clayey sandy silt
31-32 cm: Grayish brown (2.5Y5/2) clayey sandy silt
32-78 cm: Grayish brown clayey sandy silt with rare small dropstones
- at 41-44, 47-50 cm: Darker irregular grayish mottles
- at 63-64 cm: Lighter grayish brown layer

78-84 cm: Grayish brown clayey sandy silt with 2 cm dropstones
84-88 cm: Dark grayish brown (10YR4/2) grading downwards to grayish brown (2.5Y5/2) clayey sandy silt
88-96 cm: Grayish brown clayey sandy silt with rare dropstones
- at 91 cm: Thin lighter layer

96-124 cm: Grayish brown clayey sandy silt
- at 99-101 cm: Layer with consolidated small (1-5 mm) light gray (10YR7/2) silty clay mudballs
- at 106-112 cm: Olive grayish
- at 107-111, 117-119 cm: Common dropstones

124-130 cm: Dark grayish brown sandy silty clay
130-146 cm: Grayish brown sandy silty clay
146-153 cm: Light brownish gray clayey sandy silt (reddish), burrowed
153-155 cm: Brown (7.5YR5/2) clayey sandy silt
155-162 cm: Grayish brown clayey sandy silt with abundant dropstones
162-197 cm: Dark grayish brown sandy silty clay
- at 169-172 cm: olive gray, common dropstones
- at 178-179 cm: Common small dropstones
- at 184-186 cm: Olive grayish

197-299 cm: Grayish brown clayey sandy silt with common dropstones
- at 203-208 cm: Irreg. brownish and grayish streaks
- at 218-221 cm: Slightly olive gray
- at 226-227 cm: Irreg. light brownish gray layer
- at 256 cm: Thin (3-5 mm) irreg. silty sand layer
- at 264-266 cm: Slightly brownish
- at 273-275 cm: Brownish mottles
- at 291 cm: Mottled/burrowed olive gray layer
- at 292-293 cm: Irreg. light brownish layer, burrowed
- at 299 cm: Lighter grayish brown layer

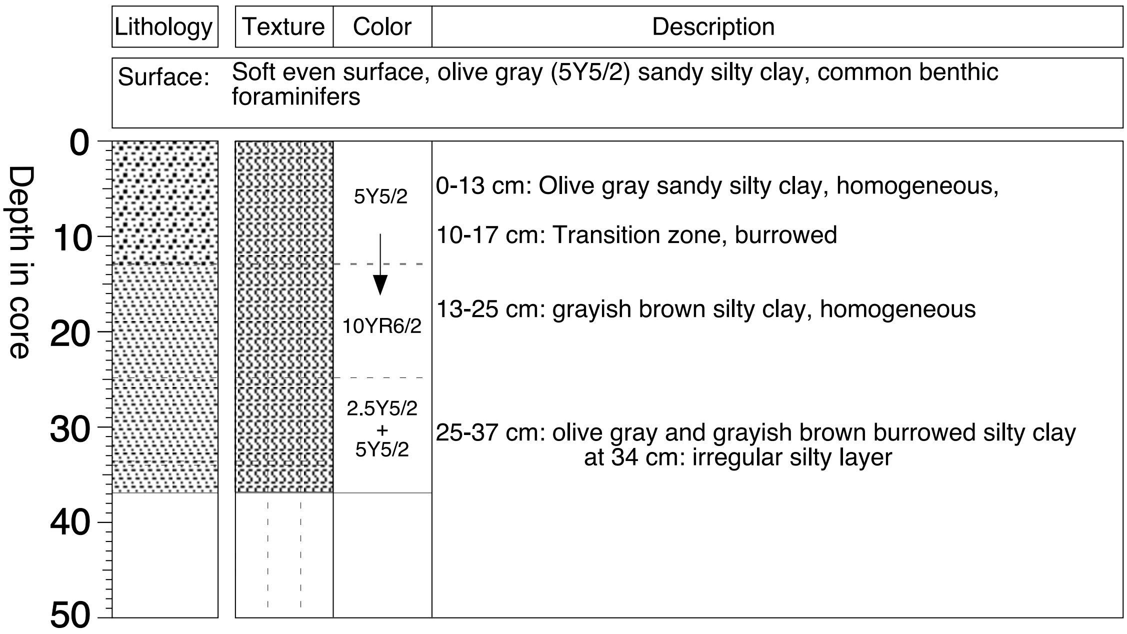
300-388 cm: Grayish brown sandy silty clay
- at 300-316 cm: Common dropstones
- at 317-319 cm: More olive gray
- at 319-320 cm: Light olive gray layer, burrowed
- at 321-323 cm: More brownish
- at 326-330, 338-346 cm: Common dropstones
- at 336-338 cm: Lighter brownish gray layer, mottled
- at 346 cm: Thin sandy layer
- at 352-357 cm: Sandy silt layer w. common dropstones
- at 363-368 cm: Slightly darker, common dropstones
- at 374-378 cm: Rare dropstones
- at 378-380 cm: Sandy silt layer, few consolidated yellowish brown silty clay mudballs

388-410 cm: Grayish brown clayey sandy silt
- at 391, 401-404 cm: Large dropstones (3 cm)

410-500 cm: Grayish brown sandy silty clay
- at 410-411 cm: More grayish
- at 412-415 cm: More brownish
- at 414-417, 421-434, 438-446 cm: Common dropstones
- at 415-416 cm: Slightly more olive
- at 427-434 cm: More sandy layer, more brownish
- at 446-453, 459-464, 468-470 cm: More brownish
- at 459-462 cm: Common benthic foraminifers
- at 465-500 cm: Common dropstones
- at 490-500 cm: Disturbed by core catcher

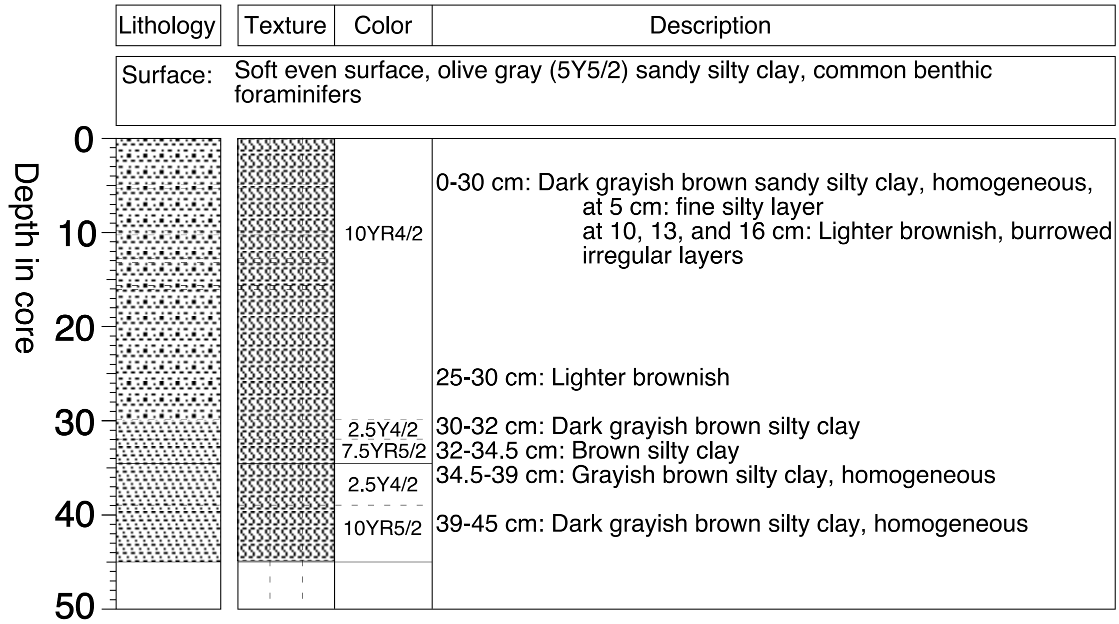
PS115/1_48-1 (GKG) Wandel Sea

Recovery: 0.37 m 83° 07.31'N, 20° 32.24'W Water depth: 226 m



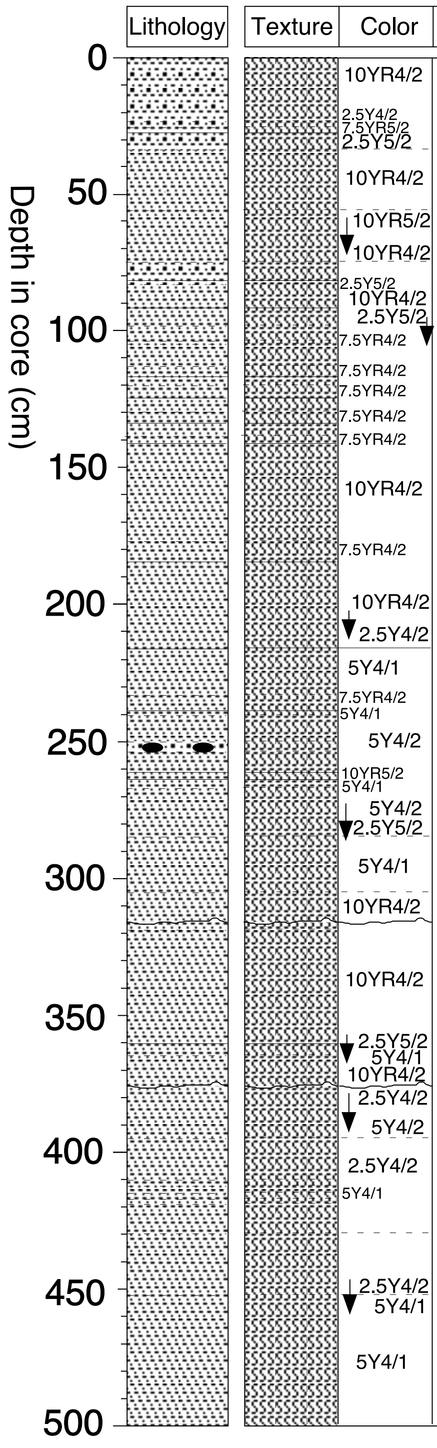
PS115/1_50-2 (GKG) Western Fram Strait

Recovery: 0.45 m 80° 52.60'N, 3° 25.83'W Water depth: 3375 m



PS115/1_50-3 (SL) Western Fram Strait

Recovery: 6.27 m 80° 51.99'N, 3° 26.73'W Water depth: 3393 m

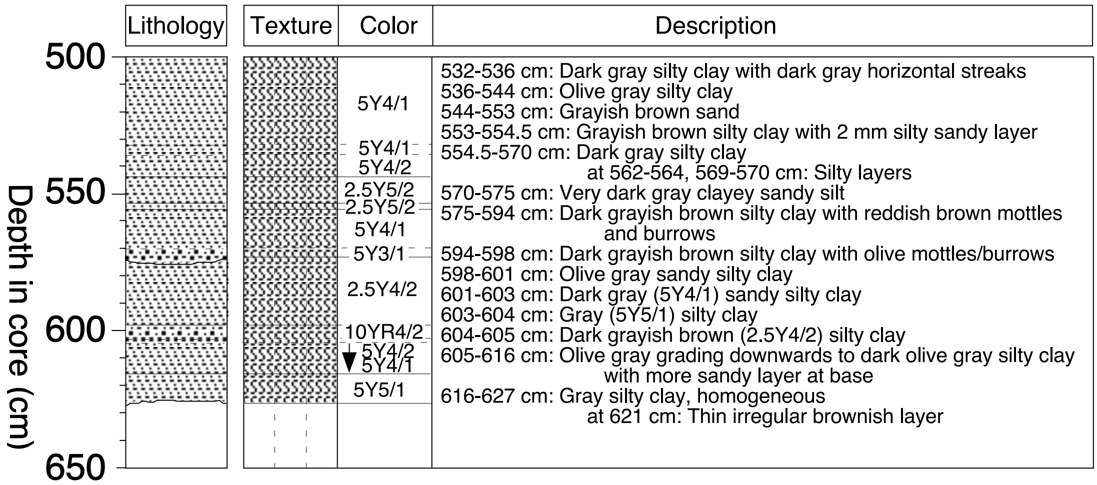


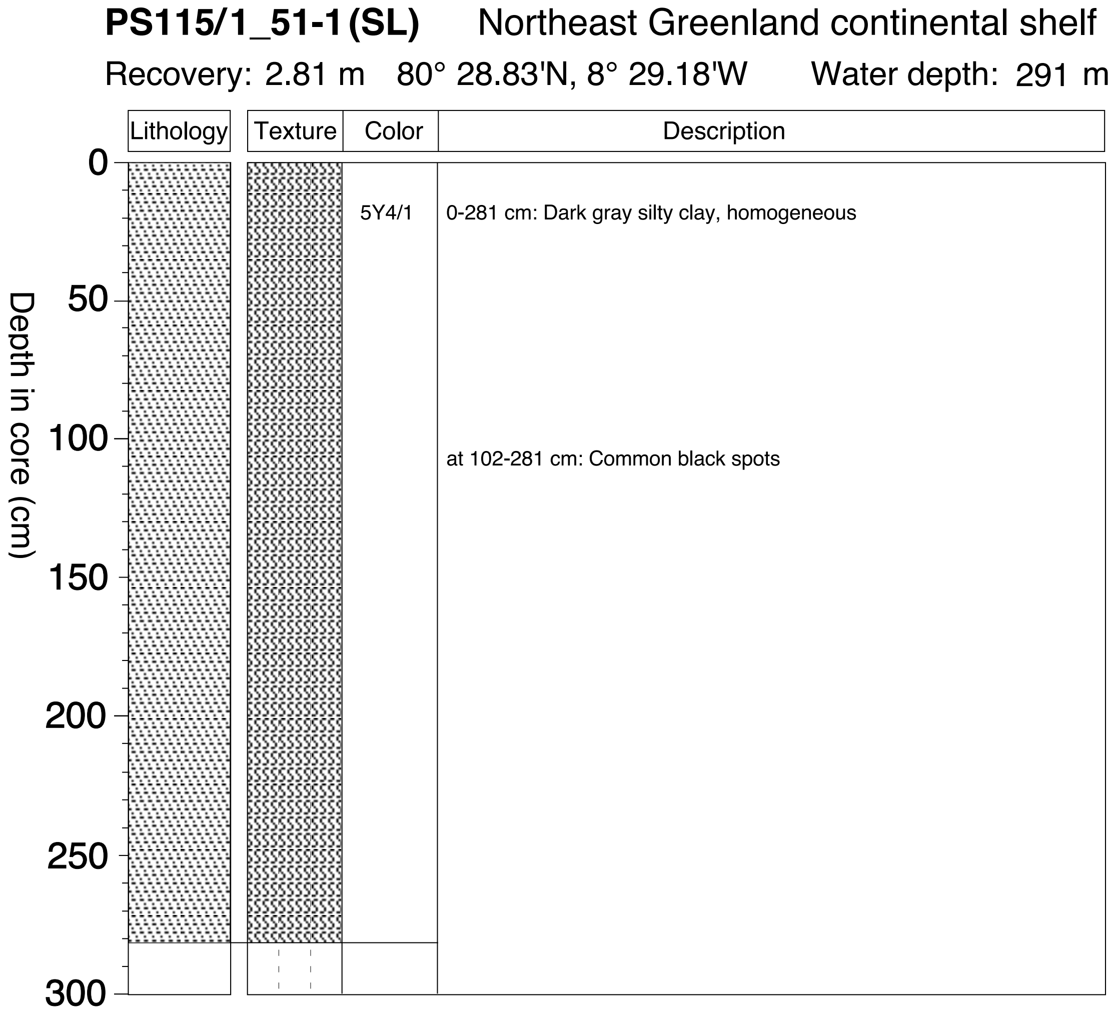
Description

0-24 cm: Dark grayish brown sandy silty clay, homogeneous
at 4, 7, 10 cm: Irreg. lighter brownish layers, burrowed
at 19-24 cm: Lighter brownish
24-26 cm: Dark grayish brown sandy silty clay
26-28.5 cm: Brown silty clay
28.5 cm: Corresponds to 34.5 cm in box core PS115/1_50-2
28.5-33 cm: Dark grayish brown sandy silty clay
33-56 cm: Dark grayish brown silty clay, homogeneous
56-75 cm: Grayish brown silty clay, homogeneous, grading downwards to dark grayish brown, darker brownish horiz. streaks and mottles in lower part
75-81 cm: Dark olive gray (5Y3/2) grading downwards to very dark gray (5Y3/1) sandy silty clay with rare dropstones
81-82 cm: Grayish brown sandy silty clay
82-92 cm: Dark grayish brown silty clay, homogeneous, with faint darker and lighter brownish mottles/burrows
92-98 cm: Dark grayish brown (olive) silty clay grading downwards to dark grayish brown (brownish), homogeneous, with faint horizontal dark grayish streaks
98-217 cm: Dark grayish brown silty clay, homogeneous
at 104-105 cm: Slightly reddish brown
at 106-112 cm: Irregular grayish mottles
at 113-117, 120-125, 130-134.5, 139-141 cm: Brown layers (reddish color)
at 129-130 cm: Grayish layer
at 141-171 cm: Irregular brownish and grayish mottles
at 177-184 cm: Brown layer (reddish color)
at 184-204 cm: Irregular gray mottles
at 200-2-16.5 cm: Mottled color change from dark grayish brown (brownish) to dk. grayish brown (olive)
217-233 cm: Dark gray silty clay, homogeneous
233-239 cm: Brown silty clay (reddish), homogeneous
239-240 cm: Dark gray silty clay, slightly blueish
240-261 cm: Olive gray silty clay, mottled/burrowed
at 250-253 cm: Sandy silt layer, common dropstones
at 253-254 cm: Slightly brownish
at 254-259 cm: Slightly grayish
261-263 cm: Grayish brown silty clay
263-265 cm: Dark gray silty clay
265-277 cm: Olive gray silty clay, homogeneous
277-284 cm: Burrowed color change to dark olive brown
284-305 cm: Dark gray silty clay
305-316 cm: Dark grayish brown silty clay, homogeneous
316-319 cm: Dark grayish brown silty clay, darker brownish than above
319-360.5 cm: Dark grayish brown silty clay with irregular dark grayish brown (live) layers mottles at 320, 329-334.5, 335-341, 351-354 cm
at 354-360.5 cm: Irregular dark grayish mottles/burrows
360.5-364.5 cm: Dark grayish brown to dark gray silty clay, grading downwards to sandy silty clay
at 362.5-363.5 cm: Very dark gray (5Y3/1) semi-consolidated mudballs <0.5 cm
364.5-375.5 cm: Dark grayish brown silty clay, burrowed, slightly olive at 371-372 cm
375.5-395 cm: Dark grayish brown grading downwards to olive gray silty clay, burrowed
395-430 cm: Dark grayish brown silty clay, homogeneous
at 410 cm: Thin lighter sandy silty clay layer
at 412 cm: Thin (mm) reddish brown layer
at 412-415 cm: Small dark burrows
at 415-417 cm: Dark gray layer with fine brownish burr.
at 419.5 cm: Thin dark gray layer
430-453 cm: Dark grayish brown silty clay
445-460 cm: Mottled/burrowed transition
453-532 cm: Dark gray silty clay, homogeneous

PS115/1_50-3 (SL) Western Fram Strait

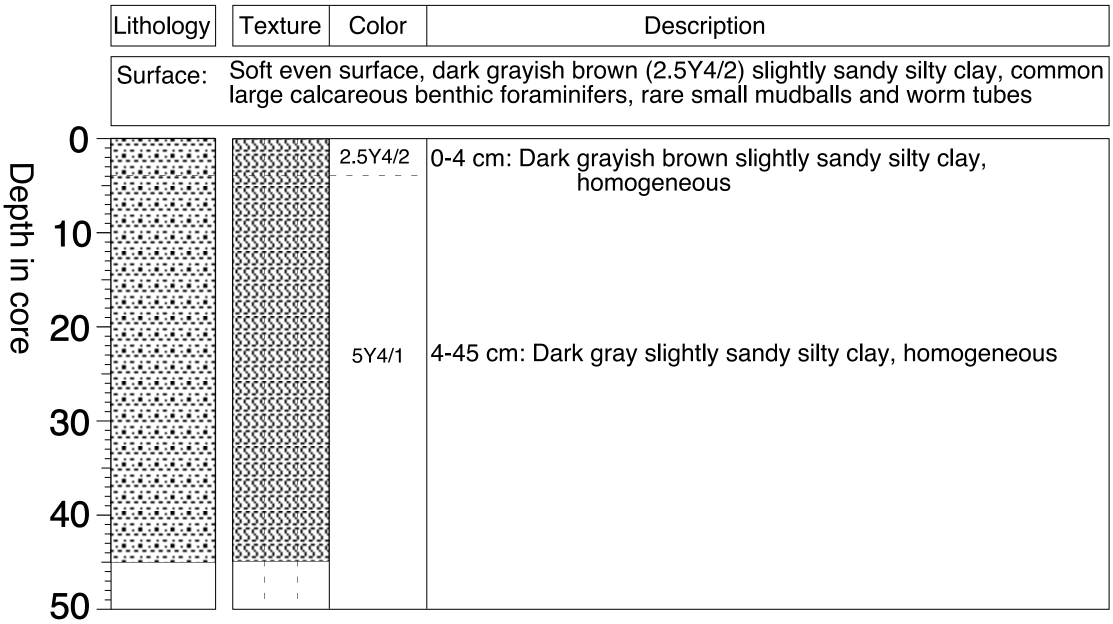
Recovery: 6.27 m 80° 51.99'N, 3° 26.73'W Water depth: 3393 m




PS115/1_51-1 (SL) Northeast Greenland continental shelf
Recovery: 2.81 m 80° 28.83'N, 8° 29.18'W Water depth: 291 m
Lithology
Texture
Color
Description
Depth in core (cm)
0
50
100
150
200
250
300
5Y4/1
0-281 cm: Dark gray silty clay, homogeneous
at 102-281 cm: Common black spots

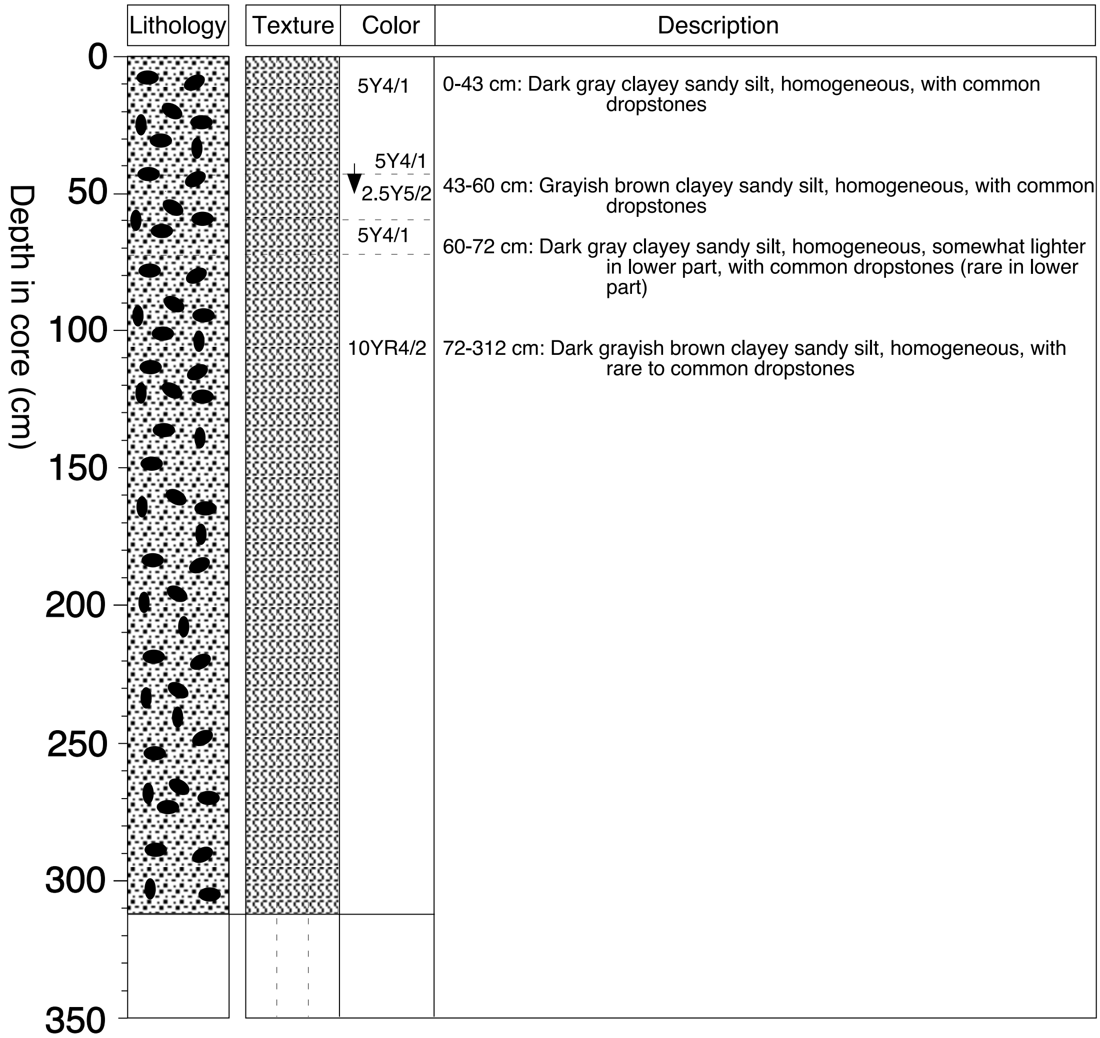
PS115/1_51-2 (GKG) Northeast Greenland continental shelf

Recovery: 0.47 m 80° 28.83'N, 8° 29.18'W Water depth: 290 m



PS115/1_52-1 (SL) Northeast Greenland continental shelf

Recovery: 3.12 m 80° 20.87'N, 6° 50.34'W Water depth: 255 m



A.6 MMO WEEKLY REPORTS

Marine Mammal Observation Weekly Summary
PS115/1
06/18/2018 to 12/08/2018

MMO/PAM Stephanie Barnicoat, Eva Kvalheim
MMSO Henri Robert, Michel Watelet, Theresa Schwenke

Client	**BGR**	**Seismic Contractor**	**BGR**
Survey Location	NE Greenland	**Vessel Name**	Polarstern
Regulator Reference Number		**Report Number**	**01**

Operations Summary Table

Description of Operations	Weekly	Project Total
Duration of full volume acquisition:	32:25	32:25
Duration of reduced volume acquisition operations:	1:56	1:56
Duration of soft starts:	01:04	01:04
Duration of source testing:	0	0
Total duration of source operations:	**35:25**	**35:25**

Monitoring Effort Summary Table MMO and PAM

Visual and Acoustic Monitoring Efforts								
Monitoring Method	**Source Inactive**		**Source Active**		**Total Monitoring Effort**		**Number of Soft Starts (per method)**	
	Weekly	**Project Total**	**Weekly**	**Project Total**	**Weekly**	**Project Total**	**Weekly**	**Project Total**
Visual	23:18	23:18	8:21	8:21	31:39	31:39	1	1
Acoustic	2:58	2:58	15:46	15:46	18:44	18:44	1	1
Both Visual and PAM	1:15	1:15	11:17	11:17	12:32	12:32	1	1

Detection summary

There were 39 visual sightings this week, sighting numbers 2 to 11 were on transit to the survey area. During the week, there were no acoustic detections.

Marine Mammal Detection summary

Sighting number	Date	Time (UTC)	Position Latitude and Longitude						Depth (m)	Species	Distance (m)
2	06/08/2018	04:55	71	30.86	n	15	27.9	e	1201	Unidentified cetacean	1000
3	06/08/2018	04:58	71	30.86	n	15	27.9	e	1201	Sperm Whale	500
4	06/08/2018	05:18	71	34.33	n	1	15.2	e	1200	Killer whale	1000
5	06/08/2018	10:00	72	7.26	n	13	13.2	e	1623	Sperm whale	2000
6	07/08/2018	07:35	74	45.85	n	3	10.1	e	3333	Fin whale	500
7	07/08/2018	07:51	74	48.84	n	3	0.41	e	3475	Unidentified cetacean	500
8	07/08/2018	08:15	74	50.45	n	2	55.4	e	3144	Unidentified cetacean	600
9	07/08/2018	08:50	74	54.85	n	2	41.2	e	2125	Fin whale	4000
10	07/08/2018	09:15	74	54.85	n	2	41.2	e	2125	Minke Whale	2000
11	07/08/2018	14:10	75	14.66	n	1	55	e		Unidentified cetacean	2000
12	07/08/2018	14:36	75	14.64	n	1	54.4	e		Unidentified cetacean	3000
13	08/08/2018	11:39	76	11.76	n	2	44.5	w	3697	Unidentified cetacean	3000
14	08/08/2018	13:47	76	21.99	n	4	20.6	w	3159	Unidentified cetacean	2000
15	08/08/2018	14:13	76	23.06	n	4	41.4	w	2387	Unidentified cetacean	4000
16	08/08/2018	14:26	76	23.22	n	4	47.7	w	2380	Unidentified cetacean	3000
17	09/08/2018	14:19	78	23.96	n	8	51.1	w	243	Unidentified seal	700
18	10/08/2018	05:00	78	36.8	n	12	24	w	200	Unidentified seal	200
19	10/08/2018	05:16	78	24.5	n	11	20.5	w	184	Polar bear	300
20	10/08/2018	09:03	78	36.8	n	12	24	w	184	Hooded seal	200
21	10/08/2018	09:26	78	38.22	n	12	31.4	w	178	Unidentified seal	1200
22	10/08/2018	09:50	78	39.65	n	12	38.5	w	178	unidentified seal	400
23	10/08/2018	10:44	78	42.2	n	12	53.6	w	195	Unidentified seal	200
24	10/08/2018	11:48	78	46.6	n	13	15	w		Bearded seal	300
25	10/08/2018	12:15	78	48.36	n	13	11.7	w	121	Ringed seal	1000
26	10/08/2018	12:32	78	47.15	n	12	53.6	w	115	Ringed seal	1000
27	10/08/2018	13:18	78	50.92	n	13	2.69	w		Hooded seal	1000
28	10/08/2018	15:00			n				181	Hooded seal	1200
29	11/08/2018	00:50	78	57.48	n	11	33	w	397	Bearded seal	700
30	11/08/2018	13:53	78	59.5	n	12	29.8	w	135	Harp seal	1000
31	11/08/2018	15:50	79	6.84	n	12	1.17	w	278	Unidentified seal	550
32	11/08/2018	17:55	79	13.9	n	11	33	w	250	Harp seal	
33	11/08/2018	18:04	79	14.7	n	11	29.1	w	255	Bearded seal	500
34	11/08/2018	18:05	79	14.71	n	11	29.1	w	255	Hooded seal	
35	11/08/2018	20:20	79	22.25	n	10	53.6	w	261	Unidentified seal	800
36	11/08/2018	21:30	79	26	n	10	41.1	w	98	Ringed seal	1200
37	11/08/2018	21:45	79	26.84	n	10	38.5	w	117	Unidentified seal	1700
38	12/08/2018	02:10	79	41.9	n	9	32.8	w	209	Harp Seal	600
39	12/08/2018	08:02	79	59.98	n	7	60	w	210	Unidentified seal	600
40	12/08/2018	13:33	79	48.4	n	8	59.8	w	204	Ringed seal	750
41	12/08/2018	18:10	80	6.57	n	7	36.52	w	318	Ringed seal	1300
42	12/08/2018	18:45	80	8.72	n	7	22.85	w	288	Unidentified seal	1000

Mitigation Actions Summary Table

There were 14 mitigation actions during the week, 13 were for pinniped species and 1 mitigation requirement was for a mother polar bear and two older cubs. All mitigation requirements required the source to power down to mitigation gun until the animals were outside the EZ. There were no requirements for any shutdowns. There was one incidence for sighting no 32, no mitigation action was taken due to a communication fault with the UHF radios on the MMO/MMSO team.

Mitigation Summary					
Sighting no	Date	Time (UTC)	Species	Closest Distance (m)	Mitigation Action
18	10/08/2018	05:00	Unidentified seal	200	Reduced source to mitigation gun
19	10/08/2018	05:16	Polar bear	300	Reduced source to mitigation gun
20	10/08/2018	09:03	Hooded seal	200	Reduced source to mitigation gun
21	10/08/2018	09:26	Unidentified seal	400	Continued at reduced source
22	10/08/2018	09:50	unidentified seal	300	Reduced source to mitigation gun
23	10/08/2018	10:44	Unidentified seal	150	Reduced source to mitigation gun
24	10/08/2018	11:48	Bearded seal	150	Reduced source to mitigation gun
25	10/08/2018	12:15	Ringed seal	150	Reduced source to mitigation gun
32	11/08/2018	17:55	Harp seal	400	MMO was not notified of this seal
33	11/08/2018	18:04	Bearded seal	200	Reduced source to mitigation gun
35	11/08/2018	20:20	Unidentified seal	400	Reduced source to mitigation gun
36	11/08/2018	21:30	Ringed seal	300	Reduced source to mitigation gun
41	12/08/2018	18:10	Ringed seal	300	Reduced source to mitigation gun
42	12/08/2018	18:45	Unidentified seal	250	Reduced source to mitigation gun

PAM Equipment Hardware/Software Status

On the 10th August PAM was prepared and deployed at 04:30 UTC for the first time to ensure an adequate deployment method was in place within the Icey waters, where the first seismic line was completed. At 14:41 UTC, the second seismic line was aborted due to problems with the airguns. PAM was retrieved. PAM was deployed again on the 11th at 11:00 UTC ready for seismic operations.

Summary of Environmental Conditions

Environmental conditions for the week have been better than expected with a glassy sea sate (mirror) and a low swell (<2 m), with many ice caps. Wind direction started North westerly altering to southerly winds with a Beaufort Scale 1 to 3. The visibility has been very good throughout the week (>5 km), with variable sun glare from none to strong sun glare and with periods of fog, resulting in poor visibility (< 500 m).

Marine Mammal Observation Weekly Summary
PS115/1
13/18/2018 to 19/08/2018

MMO/PAM Stephanie Barnicoat, Eva Kvalheim

Client	**BGR**	**Seismic Contractor**	**BGR**
Survey Location	NE Greenland	**Vessel Name**	Polarstern
Regulator Reference Number		**Report Number**	**02**

Operations Summary Table:

Description of Operations	Weekly	Project Total
Duration of full volume acquisition:	71:30	163:23
Duration of reduced volume acquisition operations:	02:25	6:56
Duration of soft starts:	00:40	01:44
Duration of source testing:	0	0
Total duration of source operations:	**74:35**	**172:03**

Monitoring Effort Summary Table MMO and PAM

Visual and Acoustic Monitoring Efforts								
Monitoring Method	**Source Inactive**		**Source Active**		**Total Monitoring Effort**		**Number of Soft Starts (per method)**	
	Weekly	**Project Total**	**Weekly**	**Project Total**	**Weekly**	**Project Total**	**Weekly**	**Project Total**
Visual	2:19	25:37	15:28	23:49	17:47	49:36	1	2
Acoustic	1:58	4:56	62:24	78:00	64:22	82:56	1	3
Both Visual and PAM	00:00	1:15	00:00	11:17	00:00	12:32	0	1

Detection summary

There were 30 visual sightings this week. Sighting number 73 and 74 were made via helicopter, in a close distance to the vessel. During the week, there were no acoustic detections.

Sighting number	Date	Time)	Position	Position					Water depth (m)	Species or species group
50	13/08/2018	1:30	80	32.30	n	5	17.60	w	1613.0	Unidentified seal, most likely Harp Seal
51	13/08/2018	3:41	80	40.63	n	4	36.41	w	3003.0	Bearded seal
52	13/08/2018	7:11	80	51.35	n	3	20.43	w	3445.0	Bearded seal
53	13/08/2018	13:00	80	42.06	n	5	3.79	w	2957.0	Ringed seal
54	13/08/2018	13:25	80	41.87	n	5	5.77	w	1012.0	Unidentified seal
55	13/08/2018	13:34	80	41.57	n	5	18.49	w	1012.0	Unidentified seal
56	13/08/2018	13:45	80	41.20	n	5	24.09	w	2737.0	Unidentified seal
57	13/08/2018	13:51	80	41.12	n	5	27.14	w	2649.0	Unidentified seal
58	13/08/2018	13:57	80	41.02	n	5	29.65	w	1012.0	Unidentified seal
59	13/08/2018	14:05	80	41.02	n	5	29.50	w	1012.0	Unidentified seal
60	13/08/2018	15:04	80	37.80	n	5	58.10	w	1000.0	Unidentified seal
61	14/08/2018	9:15	80	53.92	n	7	47.28	w	246.0	Unidentified seal
62	14/08/2018	9:24	80	54.60	n	7	45.27	w	279.0	Ringed Seal
63	14/08/2018	13:08	81	12.50	n	6	44.20	w	1880.0	Unidentified seal
64	14/08/2018	17:44	81	32.05	n	5	9.02	w	3965.0	Unidentified seal
65	14/08/2018	18:02	81	31.67	n	4	59.64	w	3457.0	Unidentified seal
66	14/08/2018	20:06	81	41.07	n	5	2.91	w	3378.0	Unidentified seal
67	14/08/2018	20:22	81	41.53	n	5	10.95	w	3319.0	Unidentified seal
68	14/08/2018	21:12	81	42.51	n	5	39.39	w	3215.0	Unidentified seal
69	14/08/2018	21:22	81	42.83	n	5	44.44	w	2222.0	Ringed seal
70	15/08/2018	15:25	82	15.60	n	9	34.90	w	2868.0	Bowhead whale
71	16/08/2018	16:35	82	15.03	n	9	46.28	w	2680.0	Unidentified seal
72	17/08/2018	8:15								Polar bear
73	17/08/2018									Polar bear
74	17/08/2018	10:50	82	24.00	n	14	33.00	w		Unidentified seal
75	19/08/2018	5:35	83	0.23	n	19	37.30	w	159.0	Hooded seal
76	19/08/2018	9:35	83	12.96	n	21	15.93	w	196.0	Unidentified seal
77	19/08/2018	9:36	83	12.96	n	21	15.93	w	196.0	Bearded seal
78	19/08/2018	11:04								Unidentified seal
79	19/08/2018	11:30								Unidentified seal

Mitigation Actions Summary Table

There were 18 mitigation actions during the week for pinniped species which required the source to power down to mitigation gun until the animals were outside the EZ. There were no requirements for any shutdowns.

Sighting number	Date	Time	Species or species group	Range (m)	Mitigation action
51	13/08/2018	3:41	Bearded seal	100	Reduced source to mitigation gun
52	13/08/2018	7:11	Bearded seal	300	Reduced source to mitigation gun
53	13/08/2018	13:00	Ringed seal	100	Reduced source to mitigation gun
54	13/08/2018	13:25	Unidentified seal	100	Reduced source to mitigation gun
56	13/08/2018	13:45	Unidentified seal	700	Reduced source to mitigation gun
57	13/08/2018	13:51	Unidentified seal	200	Reduced source to mitigation gun
58	13/08/2018	13:57	Unidentified seal	250	Reduced source to mitigation gun
59	13/08/2018	14:05	Unidentified seal	50	Reduced source to mitigation gun
60	13/08/2018	15:04	Unidentified seal	80	Reduced source to mitigation gun
61	14/08/2018	9:15	Unidentified seal	800	Reduced source to mitigation gun
62	14/08/2018	9:24	Ringed Seal	300	Reduced source to mitigation gun
63	14/08/2018	13:08	Unidentified seal	1000	Reduced source to mitigation gun
64	14/08/2018	17:44	Unidentified seal	400	Reduced source to mitigation gun
66	14/08/2018	20:06	Unidentified seal	200	Reduced source to mitigation gun
68	14/08/2018	21:12	Unidentified seal	200	Reduced source to mitigation gun
76	19/08/2018	9:35	Unidentified seal	700	Reduced source to mitigation gun
77	19/08/2018	9:36	Bearded seal	500	Reduced source to mitigation gun
78	19/08/2018	11:04	Unidentified seal	400	Reduced source to mitigation gun

PAM Equipment Hardware/Software Status

On the 15th August, the PAM cable was retrieved at 18:30 UTC. The PAM was deployed again om 19th August at 06:00 UTC ready for seismic operations.

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Summary of Environmental Conditions

Environmental conditions for the week have been good with a glassy sea sate (mirror) and a low swell (<2 m), with many ice caps. Wind direction started southerly altering northerly winds with a Beaufort Scale 1 to 4. The visibility has been very good throughout the week (>5 km), with variable sun glare from none to strong sun glare and with periods of fog, resulting in poor visibility (< 500 m).

Marine Mammal Observation Weekly Summary
PS115/1
20/08/2018 to 26/08/2018

MMO/PAM Stephanie Barnicoat, Eva Kvalheim

Client	**BGR**	**Seismic Contractor**	**BGR**
Survey Location	NE Greenland	**Vessel Name**	Polarstern
Regulator Reference Number		**Report Number**	**03**

Operations Summary Table:

Description of Operations	Weekly	Project Total
Duration of full volume acquisition:	43:03	206:23
Duration of reduced volume acquisition operations:	00:11	7:07
Duration of soft starts:	00:48	02:32
Duration of source testing:	0	0
Total duration of source operations:	**44:02**	**216:02**

Monitoring Effort Summary Table MMO and PAM

Visual and Acoustic Monitoring Efforts								
Monitoring Method	Source Inactive		Source Active		Total Monitoring Effort		Number of Soft Starts (per method)	
	Weekly	Project Total	Weekly	Project Total	Weekly	Project Total	Weekly	Project Total
Visual	17:30	43:07	6:00	29:49	26:00	72:56	0	2
Acoustic	4:33	9:29	36:39	114:39	40:12	123:08	2	5
Both Visual and PAM	00:00	1:15	2:00	13:17	2:00	14:32	0	1

Detection summary

There were 13 visual sighting this week, all pinniped species. Sighting 81 and 82 were close to the vessel. Sighting 81 was sighted during dredging of sediments, not during seismic activity. There were also 2 sightings of polar bears from the helicopter expeditions, one on ice and one on land.

Sighting number	Date	Time (UTC)	Position	Water depth (m)	Species or species group
80	20.08.18	14:17	84 18.01 n 30 17.78 w		Unidentified seal
81	23.08.18	15:15	84 14.27 n 29 35.54 w	879	Unidentified seal
82	24.08.18	1:06	83 54.11 n 26 43.57 w	292	Ringed seal
83	24.08.18	6:10	83 29.27 n 23 2.58 w	203	Ringed seal
84	24.08.18	6:35	83 29.56 n 23 9.86 w	1000	Unidentified seal
85	24.08.18	6:56	83 28.61 n 22 51.06 w	900	Ringed seal
86	24.08.18	7:17	83 28.57 n 22 37.18 w	268	Unidentified seal
87	24.08.18	7:30	83 27.85 n 22 27.22 w	232	Ringed seal
88	24.08.18	15:08	82 49.33 n 18 1.13 w	376	Unidentifed seal
89	25.08.18	00:15	82 6.82 n 11 22.52 w	1600	Hooded seal
90	25.08.18				Unidentified seal
91	25.08.18	3:12	81 51.68 n 10 21.55 w	2295	Hooded seal
92	25.08.18	3:45	81 48.91 n 10 9.43 w	1439	Unidentified seal

Mitigation Actions Summary Table

There was one mitigation action during the week where seismic operations had to power down to mitigation gun as a seal was in the exclusion zone.

Sighting number	Date	Time (UTC)	Species or species group	Range (m)	Mitigation action
80	20.08.18	14:17	Unidentified seal	10	Power down to mitigation gun

PAM Equipment Hardware/Software Status

On the 21st August, the PAM cable was retrieved at 20:52 UTC after the reflection line. The PAM was deployed again on 22nd August at 08:00 UTC ready for seismic operations for the refraction line. Once the line was completed, the PAM array was retrieved and secured on deck at 21:00 UTC.

Summary of Environmental Conditions

Environmental conditions for the week have been good with a glassy sea sate (mirror), increasing to a slight sea state (no/few white caps) and a low swell (<2 m), with areas of little and lots of ice. Wind direction has been north or north west with a Beaufort Scale 1 to 5. The visibility has been very good throughout the week (>5 km), with variable sun glare from none to strong sun glare and with periods of fog, resulting in poor visibility (< 500 m).

Marine Mammal Observation Weekly Summary
PS115/1
27/08/2018 to 01/09/2018

MMO/PAM Stephanie Barnicoat, Eva Kvalheim

Client	BGR	Seismic Contractor	BGR
Survey Location	NE Greenland	Vessel Name	Polarstern
Regulator Reference Number		Report Number	04

Operations Summary Table:

Description of Operations	Weekly	Project Total
Duration of full volume acquisition:	111:31	274:54
Duration of reduced volume acquisition operations:	7:14	14:21
Duration of soft starts:	2:13	4:46
Duration of source testing:	0	0
Total duration of source operations:	**120:58**	**294:01**

Monitoring Effort Summary Table MMO and PAM

Visual and Acoustic Monitoring Efforts								
Monitoring Method	Source Inactive		Source Active		Total Monitoring Effort		Number of Soft Starts (per method)	
	Weekly	Project Total	Weekly	Project Total	Weekly	Project Total	Weekly	Project Total
Visual	1:25	29:32	13:04	42:53	14:29	72:25	1	3
Acoustic	6:05	15:34	97:24	212:03	103:29	226:37	5	10
Both Visual and PAM	00:00	1:15	2:00	13:17	2:00	14:32	0	1

Monitoring Effort Summary Table MMO and PAM

Detection summary

There were 84 visual sighting this week, which mainly consisted of pinniped species, 4 polar bears and 3 unidentified cetaceans and 1 fin whale.

Sighting number	Date	Time)	Position						Water depth (m)	Species or species group
112	26/08/2018	16:10	79	54.54	n	9	31.31	w		Unidentified seal
113	26/08/2018	16:55	79	56.17	n	9	11.12	w		Hooded seal
114	26/08/2018	18:34	80	1.36	n	8	36.28	w	150.0	Unidentified seal
115	26/08/2018	20:12	80	1.89	n	9	16.89	w	319.0	Unidentified seal
116	26/08/2018	20:30			n			w		Unidentified seal
117	26/08/2018	20:38	79	59.29	n	9	2.61	w	10.0	Ringed seal
118	26/08/2018	21:02	79	58.55	n	8	59.71	w	243.0	Unidentified seal
119	26/08/2018	21:06	79	57.90	n	8	56.99	w	140.0	Unidentified seal
120	26/08/2018	21:21	79	56.60	n	8	39.38	w	123.0	Unidentified seal
121	26/08/2018	23:00	79	56.94	n	8	7.25	w	161.0	Unidentified seal
122	26/08/2018	23:12	79	57.00	n	8	1.58	w	180.0	Unidentified seal
123	26/08/2018	23:12	79	57.00	n	8	1.58	w	180.0	Bearded seal
124	26/08/2018	23:21	79	57.06	n	7	57.51	w	200.0	Unidentified seal
125	26/08/2018	23:34	79	57.11	n	7	50.55	w	217.0	Unidentified seal
126	26/08/2018	23:45	79	57.18	n	7	46.14	w	227.0	Unidentified seal
127	27/08/2018	0:20	79	57.38	n	7	28.84	w	243.0	Hooded seal
128	27/08/2018	0:28	79	57.38	n	7	25.65	w	247.0	Unidentified seal
129	27/08/2018	4:08	79	58.72	n	5	40.55	w	542.0	Hooded seal
130	27/08/2018	4:08	79	58.72	n	5	40.55	w	542.0	Hooded seal
131	27/08/2018	4:08	79	58.72	n	5	40.55	w	542.0	Unidentified seal
132	27/08/2018	4:27	79	58.60	n	5	31.31	w	722.0	Hooded seal
133	27/08/2018	6:20	79	58.45	n	4	36.94	w	1561.0	Unidentified seal
134	27/08/2018	6:21	79	58.45	n	4	36.94	w	1561.0	Unidentified seal
135	27/08/2018	7:00	79	58.32	n	4	17.66	w	1836.0	Unidentified seal
136	27/08/2018	7:23	79	56.89	n	4	12.82	w	1879.0	Unidentified seal
137	27/08/2018	7:25	79	56.89	n	4	12.82	w	1879.0	Polar bear
138	27/08/2018	7:52	79	55.03	n	4	20.39	w	1773.0	Unidentified seal
139	27/08/2018	7:58	79	54.85	n	4	23.54	w	1732.0	Unidentified seal
140	27/08/2018	8:05	79	54.55	n	4	27.24	w	1730.0	Unidentified seal
141	27/08/2018	8:21	79	54.28	n	4	33.46	w	1591.0	Unidentified seal
142	27/08/2018	8:24	79	54.35	n	4	35.04	w	1566.0	Unidentified seal
143	27/08/2018	8:31	79	54.62	n	4	38.13	w	1536.0	Unidentified seal
144	27/08/2018	9:23	79	56.37	n	4	59.72	w	1226.0	Unidentified seal
145	27/08/2018	10:42								Unidentified seal
146	28/08/2018	8:32	79	26.48	n	9	50.07	w	139.0	Unidentified seal
147	28/08/2018	8:51	79	25.11	n	9	44.96	w	136.0	Hooded seal
148	28/08/2018	12:23								Unidentified seal
149	28/08/2018	12:27								Harp seal
150	28/08/2018	17:24	79	1.02	n	9	21.63	w	238.0	Unidentified seal
151	28/08/2018	20:12	78	48.20	n	9	5.37	w	184.0	Unidentified seal
152	28/08/2018	21:44	78	41.87	n	9	3.52	w	298.0	Unidentified seal
153	28/08/2018	22:53	78	35.87	n	9	2.93	w	247.0	Ringed Seal
154	28/08/2018	23:06	78	34.40	n	9	2.65	w	265.0	Polar bear
155	29/08/2018	1:09	78	23.31	n	9	1.54	w	242.0	Harp seal
156	29/08/2018	9:57	78	18.63	n	6	24.37	w	358.0	Unidentified seal
157	29/08/2018	10:01	78		n	6		w		Unidentified seal
158	29/08/2018	10:03	78		n	6		w		Unidentified seal

159	29/08/2018	10:04	78		n	6		w		Unidentified seal
160	29/08/2018	10:16	78	18.27	n	6	17.98	w	344.0	Unidentified seal
161	29/08/2018	10:18	78	18.27	n	6	16.67	w		Unidentified seal
162	29/08/2018	10:20	78	18.28	n	6	15.26	w	345.0	Ringed seal
163	29/08/2018	10:24	78	18.45	n	6	12.08	w		Unidentified seal
164	29/08/2018	10:32	78	19.39	n	6	10.90	w	357.0	Unidentified seal
165	29/08/2018	10:34	78	19.42	n	6	10.22	w		Unidentified seal
166	29/08/2018	10:36	78	19.15	n	6	10.01	w		Unidentified seal
167	29/08/2018	10:38	78	19.13	n	6	9.82	w		Unidentified seal
168	29/08/2018	10:41	78	19.09	n	6	9.14	w		Unidentified seal
169	29/08/2018	10:51	78	18.84	n	6	7.05	w		Unidentified seal
170	29/08/2018	10:58	78	18.01	n	6	2.41	w		Unidentified seal
171	29/08/2018	11:00	78	17.69	n	5	57.95	w		Polar bear
172	29/08/2018	11:08	78	17.61	n	5	57.89	w	348.0	Unidentified seal
173	29/08/2018	11:10	78	17.57	n	5	56.41	w		Unidentified seal
174	29/08/2018	11:15	78	17.31	n	5	49.23	w	352.0	Unidentified seal
175	29/08/2018	11:15	78	17.31	n	5	49.23	w	352.0	Unidentified seal
176	29/08/2018	11:15	78	17.31	n	5	49.23	w	350.0	Unidentified seal
177	29/08/2018	13:40	78	15.22	n	4	53.13	w	462.0	Harp seal
178	29/08/2018	15:24	78	1.85	n	4	16.18	w	1893.0	Ringed seal
179	30/08/2018	11:51	78	54.47	n	4	40.60	w	1439.0	Harp seal
180	30/08/2018	12:30	78	54.14	n	4	54.96	w	1234.0	Polar bear
181	31/08/2018	0:30	78	46.98	n	10	26.86	w	372.0	Hooded seal
182	31/08/2018	0:40	78	46.87	n	10	31.41	w	358.0	Hooded seal
183	31/08/2018	0:40	78	46.87	n	10	31.41	w	358.0	Unidentified seal
184	31/08/2018	1:00	78	46.72	n	10	39.26	w	351.0	Unidentified seal
185	31/08/2018	1:07	78	46.65	n	10	42.05	w	351.0	Unidentified seal
186	31/08/2018	1:10	78	46.58	n	10	45.75	w	341.0	Ringed seal
187	31/08/2018	1:55	78	46.18	n	11	4.06	w	306.0	Unidentified seal
188	31/08/2018	3:18	78	45.19	n	11	42.81	w	245.0	Unidentified seal
189	31/08/2018	4:15	78	44.81	n	12	8.87	w	150.0	Unidentified seal
190	31/08/2018	6:50	78	31.66	n	12	25.18	w	158.0	Unidentified seal
191	31/08/2018	7:30	78	26.91	n	12	30.44	w	180.0	Unidentified cetacean
192	31/08/2018	09:15	78	17.99	n	12	31.94	w	175.0	Unidentified cetacean
193	31/08/2018	12:15	78	3.71	n	11	48.74	w	161.0	Unidentified cetacean
194	31/08/2018	15:00	78	50.39	n	11	4.09	w	234.0	Unidentified seal
195	01/09/2018	11:33	76	20.40	n	6	21.78	w	2177	Fin whale
196	01/09/2018	11:55	76	19.29	n	6	18.73	w	2246	Fin whale
197	01/09/2018	12:01	76	17.65	n	6	13.88	w	2535	Blue whale
198	01/09/2018	12:05	76	17.65	n	6	13.88	w	2535	Unidentified mysticete

Mitigation Actions Summary Table

In total there were 63 incidents where mitigation action was required, 4 of which were delays prior to line BGR18-113. There were 59 incidents for mainly pinniped species and on 3 occasions for polar bears. As *Polarstern* headed south, at 76 degrees, there were 3 mitigation incidents for mysticete whales, the fin and blue whale, where source operations were powered down to mitigation gun until the MMO could be certain that the Exclusion zone is clear of marine mammals.

Sighting number	Date	Time	Species or species group	Range (m)	Mitigation action
115	26/08/2018	20:12	Unidentified seal	300	Delay
116	26/08/2018	20:30	Unidentified seal	500	Delay
117	26/08/2018	20:38	Ringed seal	10	Delay
118	26/08/2018	21:02	Unidentified seal	300	Delay
124	26/08/2018	23:21	Unidentified seal	400	Power down to mitigation gun
125	26/08/2018	23:34	Unidentified seal	1200	Power down to mitigation gun
127	27/08/2018	0:20	Hooded seal	2000	Power down to mitigation gun
128	27/08/2018	0:28	Unidentified seal	500	Power down to mitigation gun
129	27/08/2018	4:08	Hooded seal	500	Power down to mitigation gun
130	27/08/2018	4:08	Hooded seal	600	Power down to mitigation gun
131	27/08/2018	4:08	Unidentified seal	400	Power down to mitigation gun
132	27/08/2018	4:27	Hooded seal	500	Power down to mitigation gun
133	27/08/2018	6:20	Unidentified seal	600	Power down to mitigation gun
134	27/08/2018	6:21	Unidentified seal	150	Power down to mitigation gun
136	27/08/2018	7:23	Unidentified seal	100	Power down to mitigation gun
137	27/08/2018	7:25	Polar bear	450	Power down to mitigation gun
138	27/08/2018	7:52	Unidentified seal	700	Power down to mitigation gun
139	27/08/2018	7:58	Unidentified seal	400	Power down to mitigation gun
140	27/08/2018	8:05	Unidentified seal	450	Power down to mitigation gun
141	27/08/2018	8:21	Unidentified seal	200	Power down to mitigation gun
142	27/08/2018	8:24	Unidentified seal	500	Power down to mitigation gun
143	27/08/2018	8:31	Unidentified seal	400	Power down to mitigation gun
144	27/08/2018	9:23	Unidentified seal	500	Power down to mitigation gun
146	28/08/2018	8:32	Unidentified seal	200	Power down to mitigation gun
152	28/08/2018	21:44	Unidentified seal	400	Power down to mitigation gun
153	28/08/2018	22:53	Ringed Seal	300	Power down to mitigation gun
154	28/08/2018	23:06	Polar bear	300	Power down to mitigation gun
155	29/08/2018	1:09	Harp seal	400	Power down to mitigation gun
156	29/08/2018	9:57	Unidentified seal	300	Power down to mitigation gun
157	29/08/2018	10:01	Unidentified seal	1000	Power down to mitigation gun
158	29/08/2018	10:03	Unidentified seal	200	Power down to mitigation gun
159	29/08/2018	10:04	Unidentified seal	300	Power down to mitigation gun
160	29/08/2018	10:16	Unidentified seal	400	Power down to mitigation gun
161	29/08/2018	10:18	Unidentified seal	300	Power down to mitigation gun
162	29/08/2018	10:20	Ringed seal	200	Power down to mitigation gun
163	29/08/2018	10:24	Unidentified seal	400	Power down to mitigation gun
165	29/08/2018	10:34	Unidentified seal	300	Power down to mitigation gun
166	29/08/2018	10:36	Unidentified seal	200	Power down to mitigation gun
167	29/08/2018	10:38	Unidentified seal	500	Power down to mitigation gun
168	29/08/2018	10:41	Unidentified seal	500	Power down to mitigation gun
169	29/08/2018	10:51	Unidentified seal	400	Power down to mitigation gun
170	29/08/2018	10:58	Unidentified seal	250	Power down to mitigation gun

172	29/08/2018	11:08	Unidentified seal	300	Power down to mitigation gun
173	29/08/2018	11:10	Unidentified seal	700	Power down to mitigation gun
174	29/08/2018	11:15	Unidentified seal	200	Power down to mitigation gun
175	29/08/2018	11:15	Unidentified seal	300	Power down to mitigation gun
176	29/08/2018	11:15	Unidentified seal	700	Power down to mitigation gun
177	29/08/2018	13:40	Harp seal	200	Power down to mitigation gun
178	29/08/2018	15:24	Ringed seal	10	Power down to mitigation gun
179	30/08/2018	11:51	Harp seal	150	Power down to mitigation gun
180	30/08/2018	12:30	Polar bear	500	Power down to mitigation gun
181	31/08/2018	0:30	Hooded seal	1200	Power down to mitigation gun
182	31/08/2018	0:40	Hooded seal	1000	Power down to mitigation gun
183	31/08/2018	0:40	Unidentified seal	1100	Power down to mitigation gun
186	31/08/2018	1:10	Ringed seal	800	Power down to mitigation gun
187	31/08/2018	1:52	Unidentified seal	800	Power down to mitigation gun
188	31/08/2018	3:18	Unidentified seal	300	Power down to mitigation gun
189	31/08/2018	4:15	Unidentified seal	200	Power down to mitigation gun
190	31/08/2018	6:50	Unidentified seal	500	Power down to mitigation gun
194	31/08/2018	15:00	Unidentified seal	200	Power down to mitigation gun
195	01/09/2018	11:30	Fin whale	300	Power down to mitigation gun
197	01/09/2018	12:01	Blue whale	400	Power down to mitigation gun
198	01/09/2018	12:05	Unidentified mysticete	500	Remain on mitigation gun

PAM Equipment Hardware/Software Status

On August 26th, PAM was deployed at 17:00 UTC ready for seismic operations. PAM was retrieved after completion of the last survey line on 1st September.

Summary of Environmental Conditions

Environmental conditions for the week have been good with a glassy sea sate (mirror), increasing to a slight sea state (no/few white caps) and a low swell (<2 m), with areas of little and lots of ice. Wind direction has been northerly and southerly with a Beaufort Scale 1 to 5. The visibility has been very good throughout the week (>5 km), with variable sun glare from none to strong sun glare and with periods of fog, resulting in poor visibility (< 500 m).

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