Cruise Report
BGR15-2
Project: PANORAMA-2

Geophysics, Geology and Geomicrobiology

Bundesanstalt für Geowissenschaften und Rohstoffe

RV OGS EXPLORA
15. August – 20. September 2015
Tromsø – Longyearbyen

BUNDESANSTALT FÜR GEOWISSENSCHAFTEN UND ROHSTOFFE (BGR), HANNOVER
FEDERAL INSTITUTE FOR GEOSCIENCES AND NATURAL RESOURCES

Cruise Report

BGR15-2

Project: PANORAMA-2

Fahrtbericht

BGR15-2

Projekt: PANORAMA-2

RV OGS EXPLORA

August 15th –September 20th, 2015

Tromsø – Longyearbyen

Sachbearbeiter: A. Ehrhardt (wiss. Fahrtleiter Leg-1) und
V. Damm (wiss. Fahrtleiter Leg-2)

T. Behrens, K. Berglar, R. Codligia, A. Cova, Ü. Demir, L. Facchin, M. Krüger, G. Lange, T. Lewis, R. Lutz, M. Schnabel, B. Schreckenberger, C. Seeger, I. Tomini, G. Visnovic, P. Weniger, M. Wiedicke-Hombach, D. Zoch

Auftraggeber: BGR

Datum: Februar 2016

http://www.bgr.bund.de/DE/Themen/MarineRohstoffforschung/Meeresforschung/Projekte/NIL/Berichte_Expedition_PANORAMA2.htm

Contents

SUMMARY

The PANORAMA-2 research cruise was carried out between Aug 15th and September 20th aboard the Italian research vessel OGS Explora, like the PANORAMA-1 cruise in 2013. The intended survey area was the European sector of the Arctic east and southeast of the Svalbard archipelago in the area of the northern Barents Sea.

Main target of the PANORAMA-2 cruise was the acquisition of new geophysical data and the probing of surficial sediments in the underexplored area of the Sørkapp Basin and Olga Basin.

In the course of the 20 day lasting Leg1 of the PANORAMA-2 cruise geophysical data acquisition was carried out. About 1750 km of 2D multi-channel seismic data were acquired and about 350 km of wide angle seismic data by means of sonobuoys. Sediment echosounder data, multi-beam data, gravity data and geomagnetic data were acquired during the entire cruise in a 24/7 mode within the survey area.

After a 1-day stopover in Longyearbyen for a crew change of a part of the scientific crew, the research vessel OGS Explora returned to the survey area for another 11 days. During Leg-2 of the PANORAMA-2 cruise the surficial sediments were sampled by means of gravity corer, multi corer and dredge at 34 stations all together. Sediment sampling was carried out during day-light times only. Night times were used for acquisition of geomagnetic data, gravity data, sediment echosounder data and multi-beam data.

ZUSAMMENFASSUNG

Die Forschungsfahrt PANORAMA-2 wurde in 2 Fahrtabschnitten im Zeitraum 15. August bis 20. September 2015 durchgeführt. Als Forschungsplattform stand, wie schon im Jahr 2013 für die PANORAMA-1 Expedition, das italienische Forschungsschiff OGS Explora zur Verfügung. Vorgesehenes Arbeitsgebiet war der Europäische Sektor der Arktis östlich und südöstlich von Svalbard im Bereich der nördlichen Barentssee.

Ziel der Messfahrt war die Erhebung neuer geophysikalischer Daten und die Entnahme oberflächennaher Sedimentproben in einem bislang wenig untersuchten Gebiet mit Schwerpunkt im Bereich der Sedimentbecken Olga Becken und Sørkapp Becken.

Während des 20-tägigen ersten Fahrtabschnittes wurden geophysikalische Profilarbeiten durchgeführt. Dabei wurden insgesamt 1750 km mehrkanalseismische Daten und 350 km weitwinkelseismische Daten aufgezeichnet. Zusätzlich wurden entlang dieser Profillinien magnetische und Sedimentecholot-Daten erhoben. Während des gesamten Aufenthalts im Arbeitsgebiet wurden zusätzlich kontinuierlich Schweredaten und bathymetrische Daten mit Multibeam-Echolot registriert.

Nach einem eintägigen Aufenthalt in Longyearbyen zum Austausch eines Teils der wissenschaftlichen Besatzung kehrte OGS Explora ins Arbeitsgebiet zurück. Im Verlauf dieses 11-tägigen zweiten Fahrtabschnittes wurden an insgesamt 34 Lokationen oberflächennahe Sedimente mittels Schwerelot, Multi-Corer und Dredge beprobt. Gravimetrische Daten, Sedimentecholot- und bathymetrische Daten wurden auch während dieses Fahrtabschnitts kontinuierlich aufgezeichnet.

1. SCIENTIFIC PROGRAMME

Rüdiger Lutz, Axel Ehrhardt, Volkmar Damm

The European sector of the Arctic Ocean is one of the main frontier areas for hydrocarbon exploration. Currently, more than 70% of the natural gas annually consumed in Germany is imported from coastal states of the Arctic Ocean. Because of its vicinity to the European mainland the region is expected to play an important role for Germany's future energy supply.

Over the last decades BGR conducted several onshore and offshore research projects in the Arctic to study the structural inventory and plate tectonic evolution of the circum-Arctic fold belts and evolution of the North Atlantic and West Greenland margins (**Fig. 1**).

Results of these investigations and new survey data will be used in combination with new data compilations and recently published data on the area to subsequently estimate the resource potential of this frontier area. Within the framework program PANORAMA (*Potentialanalyse des Europäischen Nordmeeres und angrenzender Randmeere der Arktis* – Petroleum Assessment of the Arctic North Atlantic and adjacent marine areas) BGR strives in a first step to complete the basic information required for a reliable assessment of the hydrocarbon potential (oil and gas accumulations) of the European sector of the Arctic. Within the period 2013 – 2018 several research cruises are planned to extend the geoscientific database of the region. Special focus will be given to the Northeast Greenland margin, the East Greenland margin including Jan Mayen, the North Barents margin with the transition into the Eurasian Basin and the West Barents Sea (**Fig. 1**).

Further, with microbiological investigations we want to study the microbial formation and degradation of hydrocarbons in Arctic sediments by widely unknown microbial communities. Results of these investigations will help to quantify the microbial degradation processes in the Arctic and to estimate consequences of potential leakages and the environmental impact which could arise from the economic development and hydrocarbon production in the Arctic.

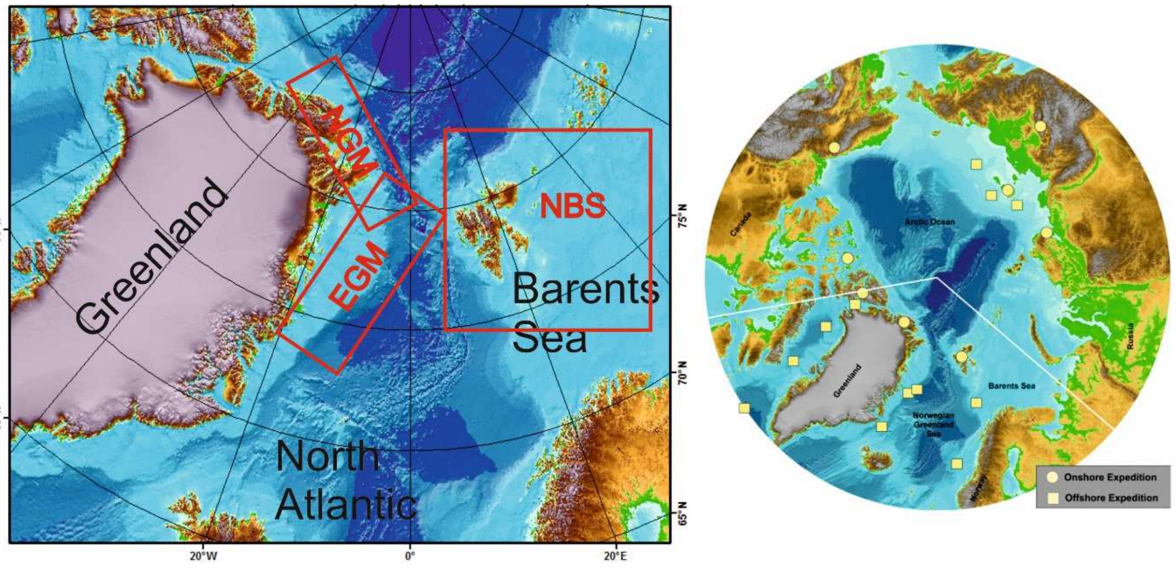


Fig. 1: Working areas of previous BGR expeditions onshore and offshore (right) and the individual working areas within the framework program PANORAMA (left).

In contrary to the southern Barents Sea where petroleum exploration is conducted since the 1980s, the northern Barents Sea north of 74.5° N is not yet opened for such activity. Although, since several decades research activities are going on in this region, it is not clear yet to what extend the northern Barents Sea contributes to the suspected petroleum potential of the Arctic offshore areas. Cenozoic uplift related to the opening of the North Atlantic and Arctic oceans and subsequent erosion of Mesozoic sequences account for a limited occurrence of post-Jurassic sediments. The Jurassic and Triassic sediments, which are the main source rocks in the southern Barents Sea, are widely covered by an only thin Quaternary cover of glacial sediments. The structural inventory and maturity of pre-Jurassic, especially Paleozoic sequences in the northern Barents Sea still need to be investigated in more detail to evaluate their source and reservoir capabilities.

Within the project PANORAMA-2 we focussed on the Olga Basin in the north-western Barents Sea, which forms a structural depression with the possibly largest post-Jurassic sedimentary rock thickness in the area north 74.5°N [*Antonsen et al.*, 1991]. The goal of the survey was twofold:

Multichannel and wide angle seismic data acquisition along lines crossing the Olga Basin were planned to image the Pre-Cretaceous sequences and structures. Multichannel seismic data images the sedimentary column down to the acoustic basement. Wide angle seismic data images the velocity structure of the sedimentary column and the underlying lithosphere. Magnetic and gravity data acquisition plus bathymetric and sediment echo sounding surveying were planned to supplement these profile work. The bathymetry and sub-bottom data aids in defining suitable coring and dredging sites for geological sampling.

The second topic of the survey was a geological sampling programme at pre-selected locations. Gravity cores of up to three meters length and multi-corer samples of up to 60 cm length were planned. Gasgeochemical analyses of adsorbed hydrocarbon gas should give information on deep-lying possible source rocks. Dredging at pre-located outcrops of older sequences was intended to provide information on lithology and age of the outcropping rocks. By sampling the uppermost sediments and subsequent geomicrobiological analyses the microbial inventory will be analysed with special focus on hydrocarbon forming and consuming communities.

This project is part of the 5-years project PANORAMA, which is dedicated to better estimate the hydrocarbon potential of the Arctic North Atlantic and possible associated risks of exploitation.

1.1. Geological and tectonic framework

The continental margin north of Svalbard is the northernmost extension of the Barents Sea. The Barents Sea forms an intra-cratonic basin which is bounded by passive margins on its western and northern rims. The area stretches between Novaya Zemlya in the east to the Atlantic margin in the west; and from Spitsbergen and Franz Josef Land in the north, to the coasts of Norway and Russia in the south [*Grogan et al.*, 1999].

The Barents Shelf consists of a complex series of basins, platforms and highs [*Anell et al.*, 2014] (**Fig. 2**) which reflect the interplay through time between major tectonic processes along the western and north-western margins of the Eurasian plate. The area of the present day Barents Sea experienced a drift from the equatorial zone in the mid-Devonian–early Carboniferous up to its present-day High Arctic latitudes, which influenced the deposition of sediments.

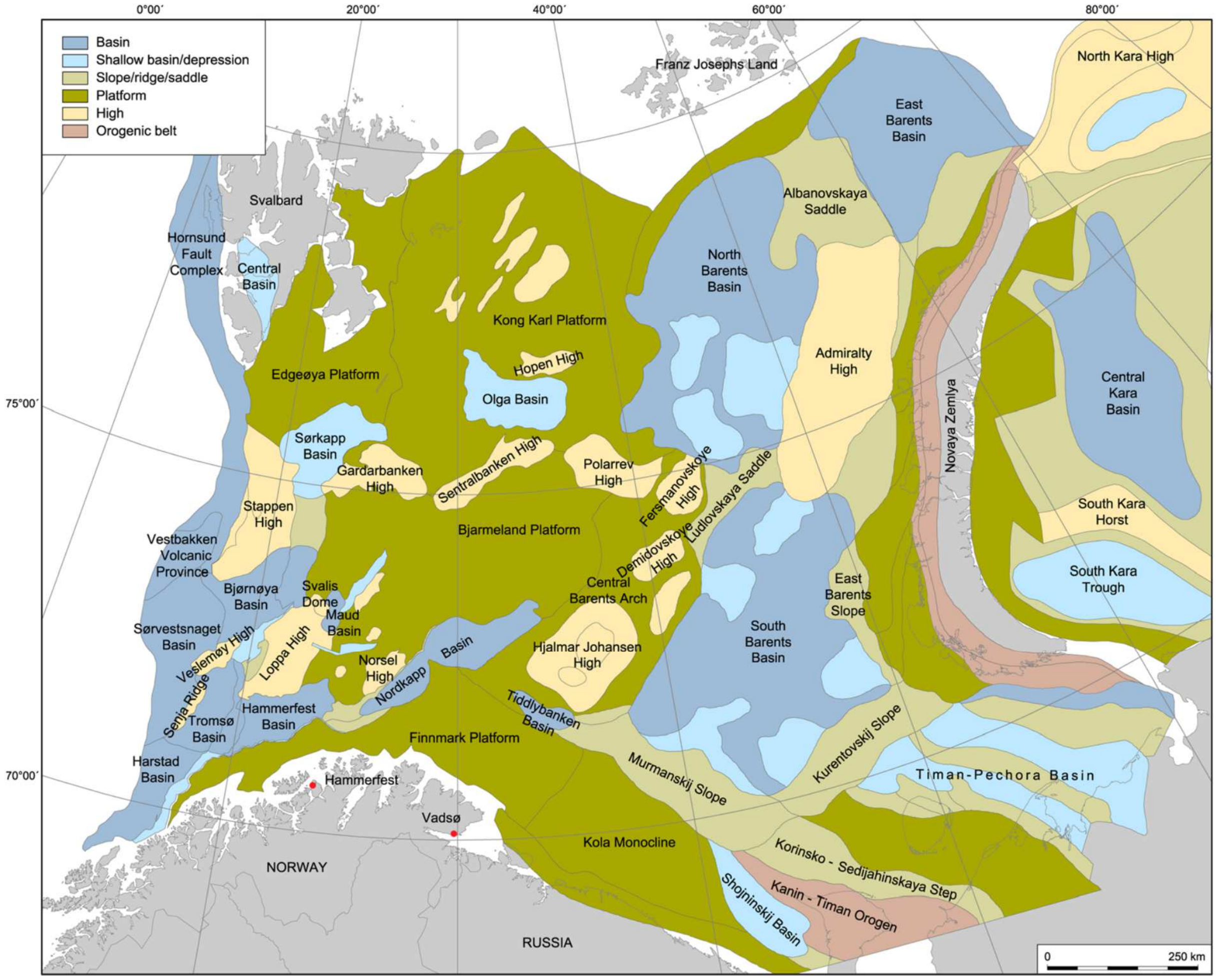


Fig. 2: Structural elements of the greater Barents Sea [*Henriksen et al.*, 2011].

The evolution includes two major continental collision events and several extensional episodes, of which the latest resulted in sea-floor spreading and continental separation between present day Norway and Greenland to the west and the Lomonosov Ridge and the Norwegian and Russian shelfs to the North. The Caledonian Orogeny between Baltica, Laurentia and Avalonia was governed by the closing of the Iapetus Ocean. The orogeny culminated around 430-400 Ma, and transition into crustal scale extension and erosion of hinterland areas was associated with deposition of old red sandstone, which characterized the Devonian. By the Early Carboniferous severe denudation of the mountain chain is documented by deposition of the low-relief, continental Billefjorden Group. A widespread extensional event caused formation of 1-3 km deep rift basins both on Svalbard and on the Barents Shelf around the mid-Carboniferous (**Fig. 2**).

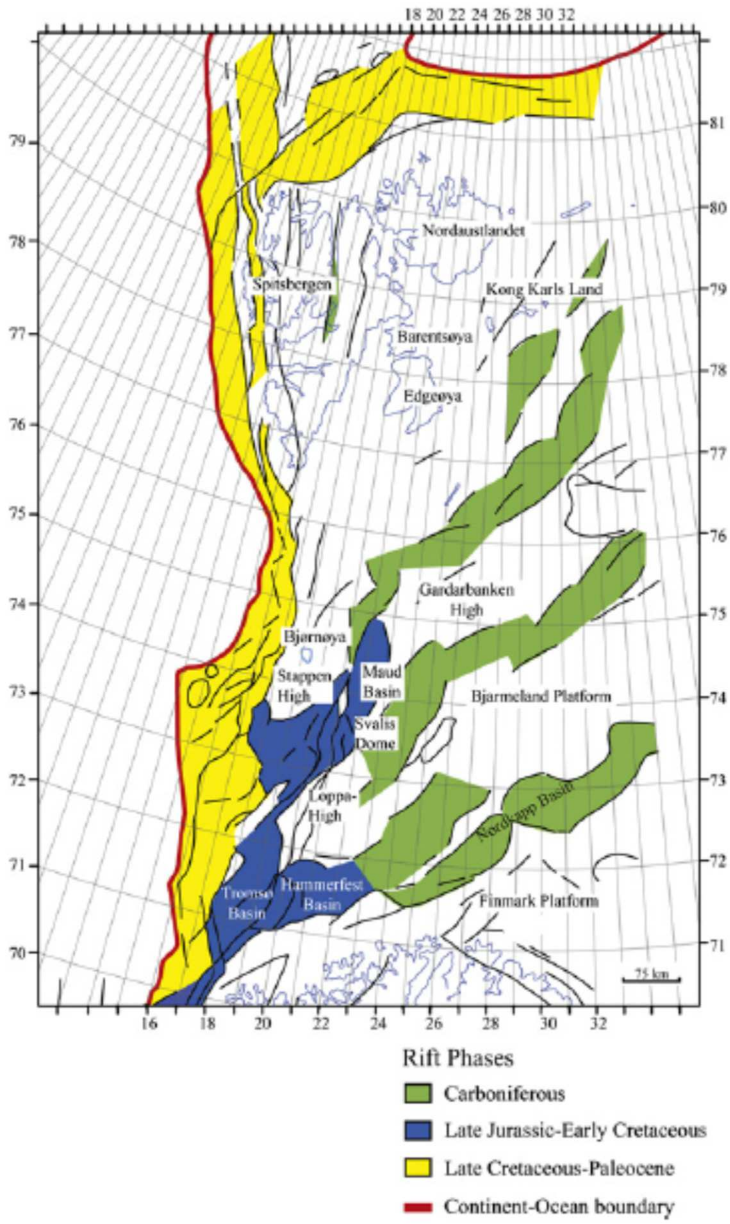


Fig. 3: Main structural elements in the Barents Sea. The colors reflect the focus of tectonic activity. Note the tectonic activity through time in the western Barents Sea [*Glørstad-Clark et al.*, 2010].

Rifting waned in the earliest Permian and the western shelf became a quiescent, stable region of continuous sedimentation. Contemporaneously, on the eastern side Laurentia collided with Siberia and the Uralide orogeny started. The western Barents Sea, on the outer edge of the orogenic foreland, developed into a shallow shelf. It was surrounded by landmasses on all sides except for an opening to Panthalassa in the North. The Uralide orogeny provided a significant sediment source and large deltasystems prograded from the southeast across the Barents Shelf from the latest Permian onwards (**Fig. 3**). These sediments filled and gradually bypassed the eastern Uralide foredeep [*Høy and Lundschien*, 2011; *Riis et al.*, 2008; *Worsley*, 2008]. Major extensional phases are recognized in the Devonian, Carboniferous, Triassic and Late Jurassic-Cretaceous. The phase of Triassic rifting is documented in the southern Barents Sea while in the north the Triassic period is generally considered quiet. Overall, the post-Paleozoic eras are thought to be mainly epirogenic and the Svalbard Platform to have been largely stable until the Late Cretaceous - Paleogene, when a major transform fault established a link between the Atlantic and Polar Basins [*Jan Inge Faleide et al.*, 2008; *J. I. Faleide et al.*, 1993; *Glørstad-Clark et al.*, 2010]. Related transpressional tectonics followed by transtension is demonstrated by the West Spitsbergen fold-and-thrust belt. A thin Quaternary overburden covers the Mesozoic rocks in the central Barents Sea. Along the western edge of the Barents Sea eroded Mesozoic and Cenozoic sediments with thicknesses of up to 10 km were deposited [*Safronova et al.*, 2014]. The Barents Sea was subjected to several erosion phases during its evolution. The most important phases of erosion regarding the petroleum systems are the Cenozoic ones. Prior to the main erosion phase the source rocks experienced the highest temperatures during maximum burial, which govern petroleum generation. Three phases of Cenozoic uplift are supposed, the first during Late Cretaceous -- early Cenozoic due to dextral shear along northern Greenland and Svalbard. This shear movement was followed by seafloor spreading in the North Atlantic from early Eocene onwards. The northern margin of the Barents Sea is formed by the Nansen Basin which developed due to slow - ultraslow seafloor spreading starting from latest Paleocene (Chron 25n) – early Eocene (Chron 24n.3n). The compressional movements together with a thinned lithosphere, possibly magmatic underplating and elevated asthenospheric temperatures are mechanisms explaining the Oligocene-Miocene uplift. The last uplift phase was caused by Northern Hemisphere Glaciation since about 2.6 Ma. Plio-Pleistocene uplift and glacial erosion resulted in deposition of large volumes of sediment on the western and northern margins of the Barents Sea [*Engen et al.*, 2009].

1.2. Previous surveys and existing data

Until now the northern Barents Sea is not open for commercial seismic surveys. The Norwegian Petroleum Directorate (NPD) carried out various seismic surveys in order to assess the area for its hydrocarbon potential. However, most of these data sets are confidential with the exception of the MAGE data sets on the Barents Sea slope towards the North Atlantic (see **Fig. 4**, orange lines).

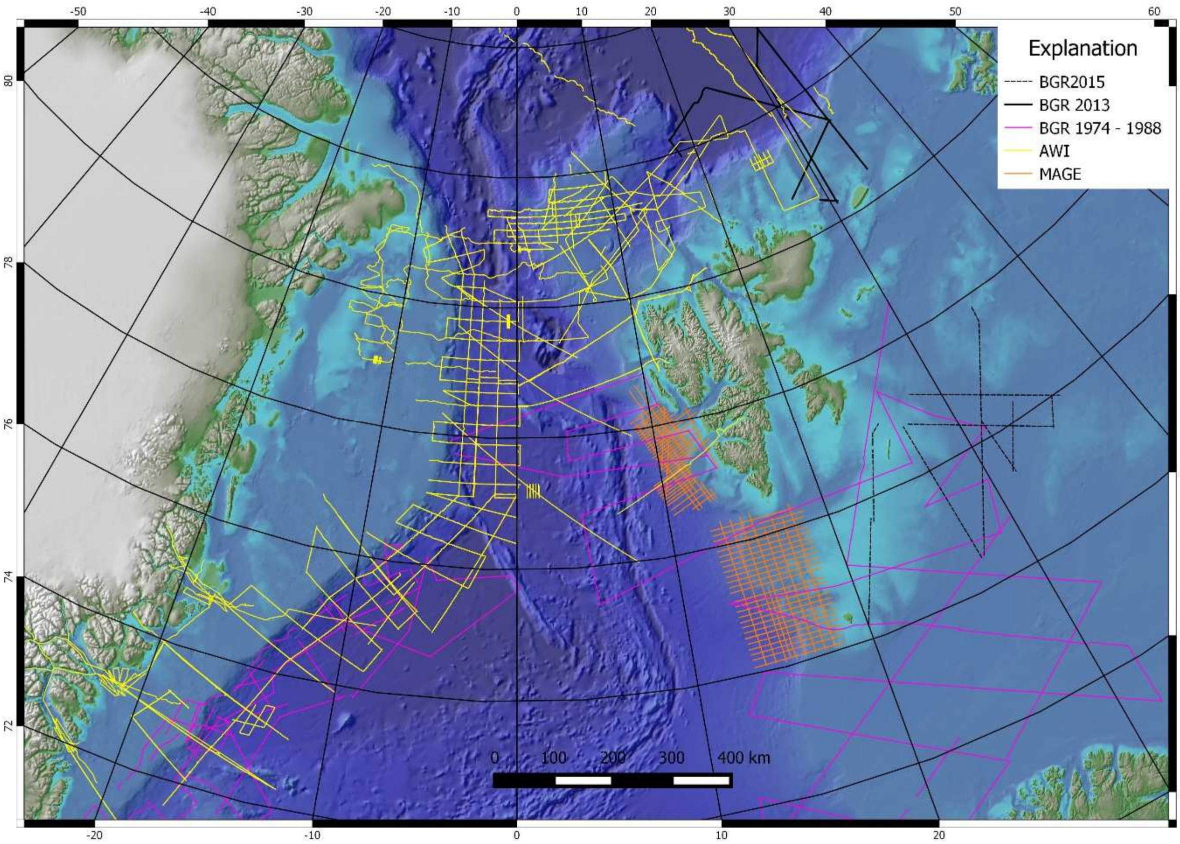


Fig. 4: Available seismic reflection data sets. BGR resumes data acquisition in 2013 in the course of the PANORAMA project. The MAGE data set was released in 2015 by the NPD. In cooperation with the AWI the AWI data sets are available for BGR.

The available data sets in the northern North-Atlantic consist out of the own data, the MAGE data sets released by the NPD, and in cooperation with the Alfred-Wegener-Institute (AWI) the AWI data sets (**Fig. 4**).

BGR carried out five seismic campaigns in the 1970s and 1980s (see **Fig. 5**) in the area around Svalbard and East-Greenland and recently resumed the acquisition in the course of the PANORAMA project. In 2013 the first PANORAMA campaign focused to the Barents Sea northeast of Svalbard (black lines in **Fig. 5**).The old data from the 1970s and 1980s will be reprocessed with modern techniques and are a valuable asset to the PANORAMA project.

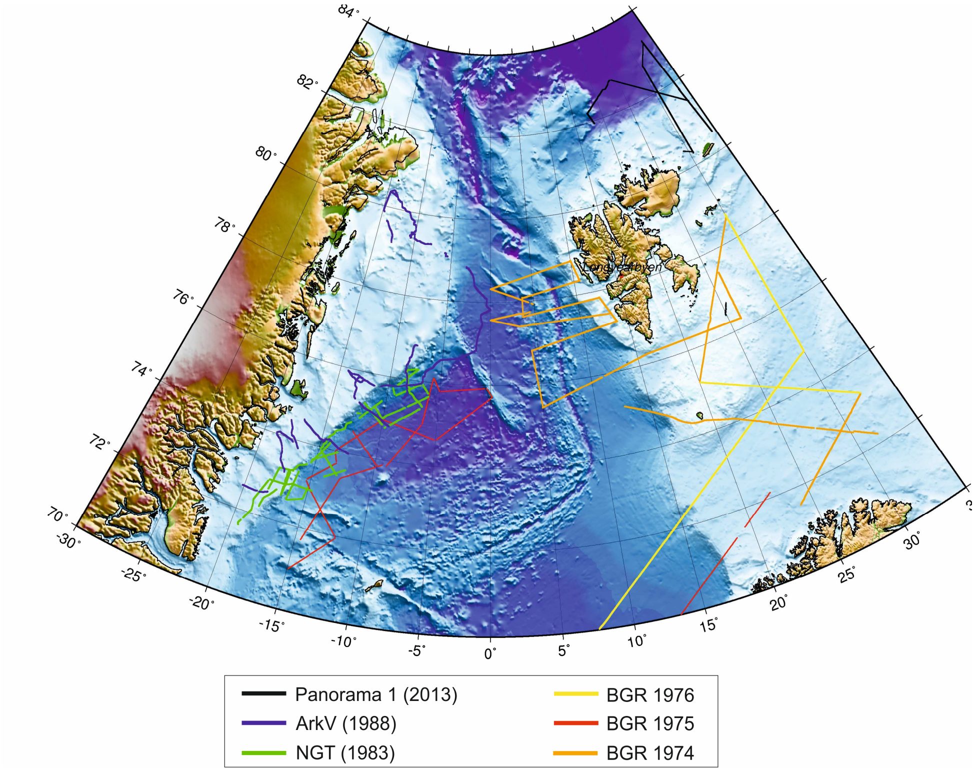


Fig. 5: MCS data of previous BGR cruises in the greater area around Svalbard and east of Greenland.

So far, scientific interest was mostly focused on the sheared continental margin west of Svalbard, the transition to the Sophia Basin, Nansen Basin and Yermak Plateau and the slope from the Barents Sea to the North Atlantic between Svalbard and Bear Island [e.g. *Berger and Jokat*, 2008; *Asbjorn Johan Breivik et al.*, 2003; *Jan Inge Faleide et al.*, 2009; *Jan Inge Faleide et al.*, 2008; *Wolfram H. Geissler and Jokat*, 2004; *W. H. Geissler et al.*, 2011; *W. Jokat*, 1998; *W. Jokat et al.*, 2008; *Wilfried Jokat et al.*, 1995; *Riefstahl et al.*, 2013; *Oliver Ritzmann and Jokat*, 2003; *O. Ritzmann et al.*, 2004; *Schlindwein et al.*, 2013; *Winkelmann et al.*, 2011]. Within the area of the northern Barents Sea most of the scientific publications are based on the NPD data sets – especially on the IKU data (now SINTEF) [e.g. *Anell et al.*, 2014; *Anell et al.*, 2013; *Asbjorn Johan Breivik et al.*, 2003; *Asbjørn Johan Breivik et al.*, 2002].

Data acquisition and subsequent processing of seismic data is challenging in the area of the Barents Sea because of shallow water depth and resulting multiple reflections. Moreover, the seafloor is an erosion surface with very old, compacted sediments. These are characterized by high p-wave velocities which results in a high reflection coefficient and thus a limited penetration of the seismic signal. In particular vintage seismic data from the 1970s which was acquired with only 48 channels and high channel spacing suffer from these boundary conditions.

1.3. Objectives and work at sea – Considerations for survey layout

The main target area of the PANORAMA-2 cruise was the northern Barents Sea. The Olga Basin, one of the sparse spots in the Barents Sea where Jurassic and Cretaceous sediments remained in the area was the focus of our survey. In addition we planned to acquire data in the area of the Sørkapp Basin on the approach to the Olga Basin and on the departure to the port in Longyearbyen.

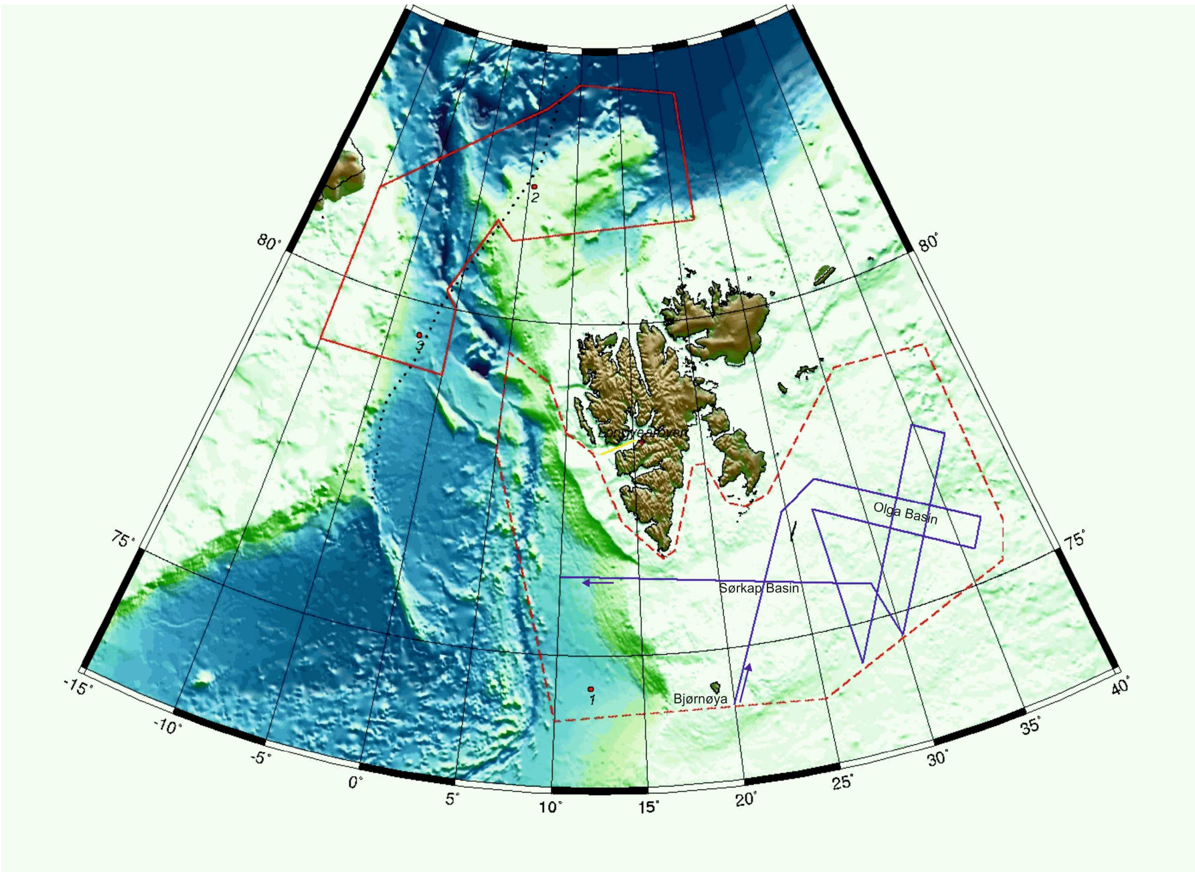


Fig. 6: Planned survey layout of the PANORAMA-2 cruise. The survey area which we applied for within our Notification of Proposed Research cruise is the red dashed box. To be prepared for extraordinary good ice conditions we also applied for the red solid box.

The objectives of this cruise are the analysis of sediment basins in the northern Barents Sea (i.e. Olga Basin and Sørkapp Basin) and their formation history in the context of the evolution of the greater Barents Sea area. The main questions were:

- How did the sediment basins develop? From previous data and publications we can assume that the basins are underlain and bounded by other (older) sediments.
- Was rifting involved in the formation of the sedimentation space of the Olga and Sørkapp Basins?
- Other observations suggest that the Olga and Sørkapp Basins are bounded by inverted sediments. If so, when did the inversion take place?
- Where was the sedimentation source of the Triassic to Cretaceous sediments?
- What can we learn about the impact of the Cenozoic uplift and the subsequent major erosion?

With the understanding of the tectonostratigraphic development of the northern Barents Sea and the identification of the sedimentary sequence and base of the basin the results of this cruise will help to evaluate the hydrocarbon potential. Microbiological and geochemical investigations using cored sediment samples were planned to be conducted to analyse the degradation potential of microbial communities in sediments of the high Arctic. These results will be brought into context with Arctic biodiversity studies and risk assessment of hydrocarbon production in the area.

The following geophysical and geological methods were employed:

- Seismics
  - up to 3600 m active digital streamer cable towed behind the research vessel for multichannel reflection seismics.
  - 8 G-Guns with a total volume of 32 l separated into two arrays with 2 clusters each, towed behind the vessel
  - 30 sonobuoys for wide angle registration
- Gravity
  - Gravimeter
- Magnetics
  - Magnetic gradiometer with two magnetometry probes towed behind the research vessel and fixed vector magnetometers on the vessel
- Bathymetry
  - deep water and shallow water multi-beam
  - sub bottom profiler
- Sediment and rock sampling
  - Gravity corer (up to 3 m)
  - Multicorer
  - Dredge

Considering the high latitude of the survey area, the final survey layout was subject to the prevailing ice and weather conditions. It was not planned to survey within moderate or even dense sea ice conditions in order to prevent any risks to the crew, the environment and the equipment.

1.4. Survey platform

We used the Italian vessel OGS Explora for survey operations. This multi-purpose research vessel is owned by the Italian Istituto Nazionale di Oceanografia e di Geofisica Spermintale (OGS) Trieste and operated by Argo Srl – Ship Management & Services, Pozzuoli (Napoli) and DIAMAR S.r.l. Napoli.The vessel was successfully used by BGR during several geophysical expeditions in the past between 1976 and 1988 and during the expedition PANORAMA-1 in 2013. The ship is well maintained and equipped with state of the art technology to conduct geophysical and geological research cruises. The vessel's specifications are listed in **Tab. 1**.

Tab. 1: R/V OGS EXPLORA specifications

The Vessel	
Built by	Elsflether Werft A.G., Germany, 1973
Owner	OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale)
Flag	Italy
Classification	Scientific or technological research RINA 100-A-1.1 IAQ-1; Ice Class B
LOA	65.42 m
Beam / Draft	11.8 m / 6.55 m
Gross tonnage	1408 T
Workboat	Zodiac Ribo 600 (6m, 70 Hp)
Endurance	50 days
Propulsion	2 x 1294.5 Kw (1780 Hp)
Cruising speed	13 Knots
Accomodation	12 technician 17 crew 1 doctor

Maritime Navigation & Communication	
VHF	2 VHF SKANTI 1000 DSC (GMDSS A4)
Immarsat	- Inmarsat C SKANTI Scansat (GMDSS A4) - Immarsat B-M NERA SATURN
Radars+ARPA	FR2117 FURUNO + AIS TM 340AM SPERRY X band Bridgemaster DECCA
Gyro Compass	3 Gyro Star II Anshutz
Autopilot	1 Naviplot AP50 FURUNO
Echo sounder	1 EA600 Simrad
Log	1 Dopplerlog EML500 Yokogawa
GPS	1 GPS Acquarius 1 GPS GB500 TOPCON 1 LANDASTAR Veripos 1 RS500 SHIPMATE (maritime only)
Magnetic Comp.	Navipol II Plath
Network	Ethernet
Network speed	100 Mb / sec

Safety	
MOB	Rescue boat PESBO BSC (40 m)
Lifeboat	Rescue boat PESBO BSC (42 people)
Life Rafts	5 x 25, 1 x 20, 1 x 6 (156 people)
Survival suits	48
Fire Fighting	- Hydrants, hoses and nozzles (3 fire pumps + 1 emergency fire pump) - 58 portable fire extinguishers (6 kg – 9 lt – 5 kg) -5 fire estiguisher 50 kg
Engine Room	CO_2
Compressor Room	Estinguisher + fixed fire CO_2

2. CRUISE NARRATIVE

Axel Ehrhardt, Volkmar Damm

15th August 2015 Saturday (227)

00:00	Port of Tromsø 69.675158° N – 018.981862°E		
06:00	Continuing MOB		
09:00	Safety Induction Drill		
18:10	Pilot on board		
18:30	Unberthed from Tromsø Harbour, transit start to survey area		hdg 26.5

16th August 2015 Sunday (228)

06:49	Position: 71.4690°N 020.8694°E	In transit	hdg 352
08:00	Emergency Drill		
21:00	Position: 73.0973°N 020.8706°E	In transit	hdg 351

17th August 2015 Monday (229)

04:09	Position: 73.8356°N 020.1297°E	In transit	hdg 352
05:40	End of transit , magnetometer calibration		
06:27	Start deploy SVP		
06:34	SVP01_20150817-063429 @ bottom lat 73.9848°N lon 019.9876°E	depth 184.40	
06:42	SVP onboard		
07:50	start deploy streamer		
09:35	MMO start watching		
10:56	**MBES SBP acquisition start**		
11:10	Starboard guns string into the water		
11:50	PAM into the water		
12:00	Portside guns string into the water Whale into the area. STAND BY		
12.45	Soft Start on		
13.12	End of Soft Start		
13.21	Seismic acquisition START: MCS Line BGR15-101 lat 74° 14' 42.0195" N lon 020° 02' 16.8334" E depth 107.79 hdg 27.9		
13.31	Stop seismic acquisition due to some problems at the compressor		

13:39 Seismic aquisition

START: MCS Line BGR15-101A lat 74° 15' 43.4786" N lon 20° 03' 47.7689" E

depth 115.26 hdg 27.9

13:42 Stop seismic acquisition due to some Recording System problems

13:59 Seismic acquisition

START: MCS Line BGR15-101B lat 74° 16' 45.8662" N lon 20° 05' 17.0354" E

depth 109.48 hdg 27.9

18th August 2015 Tuesday (230)

00:00 Position : 74.9005°N 021.0201°E hdg 27.9

MCS Line BGR15-101B acquisition

08:23 Stop seismic acquisition due to some problems at the compressor.

08:24 Seismic acquisition

START: MCS Line BGR15-101C lat 75.45306N lon 021.91865E

depth: 63.84 hdg 27.9

12:19 Stop seismic acquisition due to some problems at guns array. Guns recovery

14:52 Guns recovery end. **Loop** to restart acquisition.

16:30 A **second loop** starts now. Problem with guns requires more time. Transducers of BGR's PAM system mounted on guns arrays caused electrical problems to the arrays themselves by shaking very hard at every shot, then breaking some electrical wires on both starboard and portside arrays and one air pipe. Previous synchronization problems were very likely caused by the same reason.

Next line will be performed using only 3 guns mounted on the portside array.

18:12 Soft Start on

19:07 Seismic acquisition START: MCS Line BGR15-101D lat 75° 09' 54,89" N lon 22° 28' 22,55" E

depth: 60.55 hdg 26.0016

23:56 Problem with both the compressors, stopped seismic acquisition on Line BGR15-101D to solve the problem WP 75°59'36"N 23°01'16"E depth 62m

19th August 2015 Wednesday (231)

00.00 Position : 76°00'10"N 023°02'17"E hdg 26

00:45 Seismic acquisition

START (Soft) with 3 guns on portside array :

MCS Line BGR15-101E lat 76°02'39"N lon 23°06'28" E depth 55 hdg 26

01:07 Guns at full power

06:05 Stop Triggering and MCS acquisition **(SP1708)** to change from OGS RTS to BGR RTS system, MBES and SBP acquisition continue

06:13 Start MCS acquisition on same line BGR15-101E **(SP 1709)** lat 76°24'11"N lon 023°43'55"E depth 79.17 hdg 26

09:42 Start to deploy starboard guns array into water

09:47 Guns deployed, MCS SBP and MBES acquisition continue, switched on spare guncontroller , at the moment there's no synchronisation

10:10 Start MCS acquisition on same line BGR15-101F **(SP 1)** lat 76°39'08.41"N 024°11'13.44"E

depth 54.6 hdg 26

10:27 Stop Triggering and MCS acquisition **(SP50)** compressor problem. Whale in the area

11:08 Soft start on

11:12 Start MCS acquisition on same line BGR15-101G **(SP 1000)** lat 76°24'11"N lon 023°43'55"E

depth 79.17 hdg 26

11:19 EOL

11:20 Start MCS acquisition on same line BGR15-101H **(SP 1)** lat 76°43'56.032N lon 24°20'12.02"E

depth 36.52 hdg 26

16:15 EOL due to ice at the bow. Tail Buoy lost. Instrumentation recovery start

20:35 Streamer onboard. Transit to Tail Buoy recovery start

22:00 Tail Buoy successfully recovered on deck, transit to new position [lat 77°7.5'N lon 028°35.71'E] to avoid ice and to deploy instrumentation

23:32 Tracking point changed from "Stern" to "Zero Offset" at PDS2000 file BGR15-103-20150819-233218 for SBP motion tests

20th August 2015 Thursday (232)

00.00 Position: 77°00'02"N 026°13'29"E hdg 75.2

in transit MBES and SBP acquisition

03:30 7 up to 10 Fin Whales (Humpback Whale) at lat 77°04.3 'N lon 025°37.7'E swimming westward

05:52 Re-connecting Tail Buoy to the streamer in transit towards starting point of next MCS line

06:49 Waiting for a weather improvement, probably until noon, as actually the sea condition doesn't allow to deploy safely the instrumentation

10:00 deployment of the instrumentation Start

12:30 deployment of the instrumentation End

12:32 Start MCS acquisition on same line BGR15-103 **(SP 1)** lat 77°11'03.034N lon 28°06'17.37"E

depth 170.30 hdg 117.39

18:29 EOL

18:30 Start MCS acquisition on same line BGR15-103A **(SP 1)** lat 77°11'102.21"N 028°06'21.89"E depth 168.22 hdg 117.39

21th August 2015 Friday (233)

00:00 Position : 76°46'56.5"N 031°11'46.4"E hdg 117.39

in acquisition on line BGR15-103A, MBES and SBP

20:38 EOL before planned waypoint due to weather (EOL 75°57'08.4"N-036°24'34.8"E). Guns Recovery start.

21:11 Airguns onboard. Waiting on weather.

22nd August 2015 Saturday (234)

00.00 Position : 75°56'07.27"N 035°56'42.71" E
hdg287.9
WOW, MBES and SBP acquisition continues

08:50 Start MMO observation

09:45 deployment of portside guns Start

09:54 deployment of starboard guns Start

09:58 deployment of instrumentation End

10:06 Soft Start on

10:26 End of Soft Start

10:28 Start MCS acquisition on line BGR15-104 (SP1) lat 76°01'27"N lon 36°00'36"E
depth 246 hdg 204.17

17:30 EOL, Acquisition of SBP and MBES during LOOP

19:04 Soft Start on

19:33 Start MCS acquisition on line BGR15-105 (SP1) lat 76°01'27"N lon 36°00'36"E
depth 166 hdg 297.99

23rd August 2015 Sunday (235)

00.00 Position : 75°47'57.5"N 033°53'21.12"E hdg 297.9
in acquisition on line BGR15-105 , MCS, MBES, SBP

10:30 End of MCS acquisition on line BGR15-105 last SP 4880 before planned waypoint due to the weather (76°12'53.5"N 031°18'17.2"E), MBES SBP acquisition continues

10:35 Guns recovery start

10:52 Guns recovered @ stern, Waiting on weather

24th August 2015 Monday (236)

00:00 Position: 76°01'27.5"N 031°48'14.4"E hdg 310
WOW, MBES and SBP acquisition continue

09:23 Starboard guns fixed, end of stern operations, WOW

11:30 Mammal observer on bridge. Observation starts.

11:54 Dolphins

12:50 Switch to one engine

13:00 Deploying guns

13:15 Guns deployed

13:15 Soft start on

13:39 Start MCS acquisition on line BGR15-107 (SP1) lat 76°18’21.6”N lon 31°24’22.5”E depth 315 hdg 205.84

23:57 Unexpected crash of PDS2000 acquisition system (23:57:24) at **SP 3383** lat 75°39’15.70”N lon 029°53’30.70”E ,

23:58 Restarted acquisition (23:58:40) at **SP 3384** lat 75°39’14.03”N lon 029°53’26.9”E

25th August 2015 Tuesday (237)

00:00 Position: 75°38’42.3”N 029°52’75.5”E hdg 205.8
in acquisition on line BGR15-107 , MCS, MBES, SBP

00:13 last **XTF** file recorded **20150824-110115** file to be exported from 20150824-110446.pds on.

17:55 Mammal observer on bridge. Observation start.

18:28 EOL
Recording only SBP e MBES data

18:55 Soft Start ON

19:17 Start MCS acquisition on line BGR15-106 (SP1) lat 74°28’23.5”N lon 27°20’59.7”E depth 384 hdg 356.00

26th August 2015 Wednesday (238)

00:00 Position: 75°38’42.3”N 029°52’75.5”E hdg 356.0
in acquisition on line BGR15-106 , MCS, MBES, SBP

08:43 Start deploying pole with PAM hydrophones (Quiet Sea) in water

08:47 Pole with PAM hydrophones mounted deployed and hydrophones switched on to test the instrument

09:41 Quiet Sea hydrophones are now working

27th August 2015 Thursday (239)

00:19 Position: 76°32’21.2”N 026°46’22.7”E hdg 356.0
in acquisition on line BGR15-106 , MCS, MBES, SBP

03:00 MMO watch start

03:16 EOL
Recording only SBP e MBES data

04:06 Waiting due to the presence of several Humpbacks Whales in the mitigation zone

04:20 Soft Start ON

04:40 Start MCS acquisition on line BGR15-105A (SP1) lat 76°47’06.7”N lon 27°04’45.4”E depth 113.5 hdg 117.9

06:15 Shooting interruption at SP 588, restarted shooting at SP 589 on line BGR15_105A

17:55 17 °18’33.30”N 30°38’53.04”E . 230m offline to portside.

20:40 EOL. GUNS Recovery Start
20:50 Starboard side guns onboard
21:00 Portside guns onboard
21:20 Streamer Recovery Start
23:55 MMO watch start

28th August 2015 Friday (240)

00:00 Position: 76°03’06.56”N 031°39’51.79”E hdg 180
End of streamer recovering
00:14 Start transit to line BGR15_1051R0
01:23 Start Portside Guns deployment
01:28 Portside Guns deployed, start Starboard Guns deployment
01:35 All Guns deployed
01:43 MMO watch end , beginning of Soft Start
01:51 Start of Sonobuoys test line **BGR15_1051R0** keep shooting every 30 seconds hdg 297.9
01:55 **Sonobuoy 0** @ water **WD** 311 **FIX** 7 **Lat** 76°06’56.46”N **Lon** 031°56’15.41”E
02:09 End of soft Start
05:06 EOL BGR15_1051R0 **FIX 390** **WD** 304.2 76°15’27.64“N 030°59’56.18“E
05:07 MMO watch start, transit to Start of Line BGR15_1071R1
06:08 MMO watch end
06:12 Beginning of Soft Start
06:34 End of Soft start
06:41 Start of line **BGR15-(107)1R1** lat 76°11’24.78”N lon 031°07’25.52”E depth 307.9
hdg 25.8

06:44 **Sonobuoy 1** @ water **WD** 307.4 **FIX** 4 **Lat** 76°11’31.34”N **Lon** 031°07’45.30”E

07:49 **Sonobuoy 2** @ water **WD** 313.0 **FIX** 136 **Lat** 76°16’10.46”N **Lon** 031°19’00.76”E

08:55 **Sonobuoy 3** @ water **WD** 317.6 **FIX** 268 **Lat** 76°20’49.18”N **Lon** 031°30’25.77”E

10:01 **Sonobuoy 4** @ water **WD** 305.6 **FIX** 399 **Lat** 76°25’27.65”N **Lon** 031°41’56.89”E

11:06 **Sonobuoy 5** @ water **WD** 277.6 **FIX** 529 **Lat** 76°30’05.48”N **Lon** 031°53’36.38”E

12:12 **Sonobuoy 6** @ water **WD** 264.5 **FIX** 662 **Lat** 76°34’42.794”N **Lon** 032°05’24.46”E

13:18 **Sonobuoy 7** @ water **WD** 240.2 **FIX** 793 **Lat** 76°39’19.66”N **Lon** 032°17’18.82”E

14:23 **Sonobuoy 8** @ water **WD** 228.2 **FIX** 923 **Lat** 76°43’55.93”N **Lon** 032°29’23.11”E

15:29 **Sonobuoy 9** @ water **WD** 201.7 **FIX** 1055 **Lat** 76°48’31.61”N **Lon** 032°41’35.32”E

16:33 **Sonobuoy 10** @ water **WD** 178.5 **FIX** 1183 **Lat** 76°53’06.73”N **Lon** 032°53’55.40”E

17:37 **Sonobuoy 11** @ water **WD** 166.3 **FIX** 1311 **Lat** 76°57’40.75”N **Lon** 033°06’22.98”E

18:42 **Sonobuoy 12** @ water **WD** 139 **FIX** 1441 **Lat** 77°02’14.48”N **Lon** 033°19’00.07”E

19:46 **Sonobuoy 13** @ water **WD** 138.7 **FIX** 1569 **Lat** 77°06’47.54”N **Lon** 033°31’46.32”E

20:20 Fire alarm rings. Small fire in the machine room workshop quickly estinguished. Compressors stopped as a precaution.

20:34 Mammal watch start

20:52 **Sonobuoy 14** GUNS NOT SHOOTING **WD** N/A **FIX** **N/A**
Lat 77°11’19.89”N **Lon** 033°44’41.33”E

21:05 Soft Start ON

21:20 NOTE: The fire was caused by a spark produced by the usage of a grinder machine in the engine room workshop around 18:00 UTC. The spark stayed “alive” and slowly caused something to burn 2 hours later.

21:36 Soft start end. Triggering again from FIX 1701

22:00 **Sonobuoy 15** @ water **WD** 143.7 **FIX** 1751 **Lat** 77°15’51.81”N.**Lon** 033°57’45.27”E

23:02 **Sonobuoy 16** @ water **WD** 157.3 **FIX** 1877 **Lat** 77°20’22.80”N **Lon** 034°10’57.79”E

29th August 2015 Saturday (241)

00:00 Position **77°24'60”N** **034°22'57.28”E** hdg 25.8

acquisition line **BGR15-1071R1**

00:08 **Sonobuoy 17** @ water **WD** 177.5 **FIX** 2008 **Lat** 77°24’53.37”N **Lon** 034°24’20.79”E

01:11 **Sonobuoy 18** @ water **WD** 191.99 **FIX** 2134 **Lat** 77°29’23.02”N **Lon** 034°37’52.78”E

02:18 **Sonobuoy 19** @ water **WD** 219.19 **FIX** 2268 **Lat** 77°33’52.44”N **Lon** 034°51’34.98”E

04:30 EOL **BGR15-1071R1**

04:32 Guns recovery start

04:50 Guns @ stern, the guns have been checked

05:30 start transit to sonobuoys SOL **BGR15-1R2**

07:02 MMO prewatch start

08:02 Start MMO watching

08:16 Start starboard guns deployment

08:21 Stbd guns @ water

08:23 Start portside guns deployment

08:28 port guns @ water

08:34 Beginning of Soft start

08:57 End of Soft Start ; full power reached

09 :12 SOL **BGR15-1R2** lat 77°29'19.08"N lon 034°50'46.20"E depth204.89 hdg 359.8

09:15 **Sonobuoy 20** @ water **WD** 204.31 **FIX** 37 **Lat** 77°29'21.90"N **Lon** 034°50'39.18"E

10:21 **Sonobuoy 21** @ water **WD** 206.57 **FIX** 168 **Lat** 77°34'41.00"N **Lon** 034°53'54.40"E

11:24 **Sonobuoy 22** @ water **WD** 163.48 **FIX** 293 **Lat** 77°40'00.05"N **Lon** 034°57'13.59"E

12:30 **Sonobuoy 23** @ water **WD** 162.95 **FIX** 425 **Lat** 77°45'19.35"N **Lon** 035°00'37.48"E

14:30 EOL

14:48 Guns onboard

15:00 Streamer deployment start

16:40 Streamer deployed

16:55 Portside guns array into the water

17:03 Starboard side guns array into the water

17:04 Soft start

17:25 Start MCS acquisition on line **BGR15-107A** lat 77°49'17.45"N lon 35°03'07.45"E
depth 117 hdg 179.89

NOTE: 1 ballon of the starboard side guns string lost because of weather.

21:22 Starboard side string disabled. Last shot: 1159. Starboard side string recovery start

21:28 Balloon replaced. Guns redeployed

21:33 Starboard side string re-enabled at Shot 1210

30th August 2015 Sunday (242)

00:00 Position **77°26'20"N** **034°28'38"E** hdg 205.8

acquisition MCS, MBES, SBP along line **BGR15-107**

08:51 Unexpected PDS2000 crash **Last SP 4174**, immediately restarted **First SP 4175** (after query to MCS recording team) BGR15_107-20150830-085301

23:02 EOL BGR15_107 SP 7948

23 :03 SOL **BGR15-108** lat 76°17'20.6"N lon 31°22'44.2"E depth 318 hdg 172.5

31st August 2015 Monday (243)

00:00 Position **76°13'59"N** **031°22'31"E** hdg 172.5

acquisition MCS, MBES, SBP along line **BGR15-108**

13:25 Mammal observer watch start (depth > 200m, 1 hour)

14:26 Soft start ON

13:30 EOL. Loop start

14:46 Full power

14:47 Soft start end.

14.47 Start MCS acquisition on line **BGR15-109** lat 75°22'58.42"N lon 31°25'35.17"E depth 335 hdg 26.93

01st September 2015 Tuesday (244)

00:00 Position **75°57'09"N** **032°51'41"E** hdg 26.93

acquisition MCS, MBES, SBP along line **BGR15-109**

05:30 End of acquisition on line **BGR15-109** last SP 4809 lat 76°16'38.5"N lon 33°44'29.06"E

depth 297.7 hdg 26.93 cause to bad sea conditions

05:35 Start recovering equipment onboard

05:38 Starboard guns @ stern

05:44 Portside guns @ stern

08:19 streamer on board

08:37 PAM streamer recovered

08:48 Quiet Sea pole recovered

08:50 Transit start WOW

02nd September 2015 Wednesday (245)

00:00 Position **76°40'49"N** **028°17'47"E** hdg 230

acquisition MBES, SBP during transit WOW

03rd September 2015 Thursday (246)

00:00 Position **76°08'16"N** **023°56'77"E** hdg 44.8
WOW, acquisition MBES, SBP during transit to sonobuoy line BGR15-1R3
03:35 MMO watch start (depth < 200m, 30 minutes)
10:05 MMO watch end
07:22 PAM streamer deployed
07:38 Starboard guns deployed
07:46 Portside guns deployed
07:53 Beginning of Soft start
08:14 End of Soft Start
08:14 SOL line **BGR15-1R3** lat 76°16'23"N lon 023°54'31"E depth 49.48 hdg 275.9

16:22 **Sonobuoy 24** @ water **WD** 49.78 **FIX** 4 **Lat** 76°16'22"N **Lon** 023°54'06"E

09:53 **Sonobuoy 25** @ water **WD** 58.18 **FIX** 196 **Lat** 76°16'45"N **Lon** 023°20'10"E

11:06 Crash PDS2000. Fixes restart from 1000

11:30 **Sonobuoy 26** @ water **WD** 72.23 **FIX** 1048 **Lat** 76°17'03.4"N **Lon** 022°45'42.6"E

13:11 **Sonobuoy 27** @ water **WD** 111.52 **FIX** 1248 **Lat** 76°17'16.4"N **Lon** 022°12'09.8"E

14:52 **Sonobuoy 28** @ water **WD** 192.21 **FIX** 1454 **Lat** 77°17'25.16"N **Lon** 021°38'08.24"E

16:34 **Sonobuoy 29** @ water **WD** 212.94 **FIX** 1656 **Lat** 76°17'29.19"N **Lon** 021°04'06.54"E

19:04 EOL FIX 1956. Guns recovery start
19:29 Guns onboard
19:31 MBES acquisition start

04th September 2015 Friday (247)

00:00 Position **76°17'28"N** **022°00'00"E** hdg 100.9
acquisition MBES, SBP
00:28 MBES and SBP quality affected by waves
06:07 Preparing for SVP deployment
06:29 Start deploy SVP
06:39 SVP02_20150904-063927 @ bottom lat 76°18'49.23"N lon 020°04'00.77"E
depth 246.08
06:50 SVP onboard
07:03 Start magnetometer calibration
07:07 SVP02_20150904-063927 applied from file BGR15_1R3-20150904-070728

07:24 End of magnetometer calibration

07:40 Restart Mbes and SBP acquisition

12:00 Transit to Longyearbyen start. MBES, SBP acquisition along the route

05th September 2015 Saturday (248)

00:00 Position **76°25'05"N** **015°17'55"E** hdg 340.4
acquisition MBES, SBP along route to Longyearbyen

19:51 End of MBES, SBP aquisition lat 77°46'14"N lon 012°34'02"E depth 79.4

06th September 2015 Sunday (249)

00:00 Position **78°05'56"N** **013°24'23"E** hdg 45.4
in transit to Longyearbyean

06:00 Pilot on board

07:00 along Longyearbyen harbour lat 78°13'46"N lon 015°36'07"E
End of 1st Leg

12:00 Technicians and Crew changing

07th September 2015 Monday (250)

00:00 alongside in Longyearbyen harbour lat 78°13'46"N lon 015°36'07"E

08:00 start 2nd leg

15:50 pilot on board

17:15 on anchorage Longyearbyen harbour

08th September 2015 Tuesday (251)

00:00 Position **78°14'06"N** **015°35'40"E**

08:18 Pilot on board, departure from Longyearbyen harbour

14:15 start transit to working area

18:53 acquisition MBES on transit line BGR15-1SBP05 heading 170

09th September 2015 Wednesday (252)

00:00 Position **76°58'30"N** **013°37'40"E** hdg 140
in transit to Working Area MBES and SBP acquisition on line BGR15-1SBP05

07:30 SVP in position 09_09_GC01

09:00 MultiCorer operation in position 09_09_GC01

10:21 fix MUC_001 empty lat 76°12'24.80"N lon 016°50'21.57"E

11:41 fix MUC_001B good lat 76°12'23.04"N lon 016°50'19.62"E

13:00 GravityCorer operation in position 09_09_GC01
13:14 fix GC_001 1.1m lat 76°12'24.02"N lon 016°50'21.40"E
13:45 acquisition MBESand SBP in transit to position 09_09_GC02
15:32 fix GC_002 1.7m lat 76°14'58.57"N lon 017°51'40.58"E
15:45 acquisition MBESand SBP in transit to position 09_09_GC03
16:20 fix GC_003 2m lat 76°15'33.36"N lon 018°04'17.06"E
17:15 Start magnetometer deployment
17:57 Magnetometers deployed. Second sensor: Water detected in housing WARNING. Some test are performed.
18:49 Start Magnetometers recovery
19:46 rear sensor changed, and system deployed. Start test.
20:07 Test OK, system deployed 300m away from the ship.
20:43 Ship has to stop one engine, start recovery
21:14 Ship ok, system ok, deployed ready to acquire.
21:45 MB acquisition interrupted to check driver for magnetics
21:54 MB acquisition restart
22:00 Start Magnetometer acquisition on line **BGR15-201**
23:55 Second engine restarted

10th September 2015 Thursday (253)

00:00 Position **76°16'50"N** **021°39'34"E** hdg 95
MBES MAGNETOMETER and SBP acquisition on line **BGR15-201**
01:25 Start magnetometer recovery, problem on the cable.
01:54 Magnetometers on deck, MBES and SBP acquisition goes on, line **BGR15-201**
08:00 end of MBES and SBP acquisition on line **BGR15-201**
08:40 MultiCorer operation in position 10_09_MUC01
09:00 fix MUC_002 lat 76°03'26.06"N lon 026°55'44.71"E
09:45 MultiCorer operation in position 10_09_MUC02
10:00 fix MUC_003 lat 75°58'03.26"N lon 026°57'07.03"E
10:40 MultiCorer operation in position 10_09_MUC03
10:56 fix MUC_004 lat 75°52'41.24"N lon 026°59'07.20"E
12:15 MultiCorer operation in position 10_09_MUC04
12:28 fix MUC_005 lat 75°41'55.96"N lon 027°02'09.99"E
13:20 GravityCorer operation in position 10_09_GC01
13:51 fix GC_004 lat 75°47'16.79"N lon 027°00'30.68"E
15:20 GravityCorer operation in position 10_09_GC02
15:30 fix GC_005 lat 75°55'21.61"N lon 026°58'09.53"E
16:20 GravityCorer operation in position 10_09_MUC03
16:33 fix GC_006 lat 75°58'02.48"N lon 026°57'05.79"E
17:15 Start Magnetometer operation (only one sensor)
17:20 Start deployment heading west (because of weather)

17:45 Deployment completed, ship turns heading east to the line

18:12 Start acquisition

18:36 Start acquisition on line **BGR15-202** Hdg 359

23:41 EOL **BGR15-202**

23:46 SOL **BGR15-203** Hdg 118

11th September 2015 Friday (254)

00:00 Position **76°47'56"N** **026°56'20"E** hdg 118

MBES MAGNETOMETER and SBP acquisition on line **BGR15-203**

07:02 stop MBES MAGNETOMETER and SBP acquisition

07:30 SVP on position Leg2/12

08:00 stby meteo

21:25 Start MBES logging for safety reason

12th September 2015 Saturday (255)

00:00 Position **76°33'21"N** **025°17'32"E** Stand by meteo

11:00 on anchor at position lat 76°28'24"N lon 025°02'20"E

13th September 2015 Sunday (256)

00:00 on anchor at position **76°28'25"N** **025°02'22"E** Stand by meteo

15:24 transit to line **BGR15-203** – MBES logging for safety reason

18:37 Out of TW, MBES and SBP acquisition start

19:45 Start magnetometer deployment

20:11 Magnetometer deployed, some fault on connection, checking

20:15 Connection checked, OK

20:16 MBES, SBP and Magnetometer acquisition on line **BGR15-204** Hdg 118

21:50 ship out of line (iceberg on route)

22:05 Back on the line

14th September 2015 Monday (257)

00:00 Position **76°31'42"N** **029°07'47"E** hdg 118

MBES MAGNETOMETER and SBP acquisition on line **BGR15-204** Hdg118

03:33 EOL **BGR15-204** loop to **BGR15-205**

03:48 SOL **BGR15-205** Hdg 205

05:48 EOL **BGR15-205**

05:55 recovery Magnetometer

06:10 MBES – SBP acquisition on line **BGR15-205**

07:08 fix GC_007 lat 75°59'28.90"N lon 030°39'25.38"E
08:36 fix GC_008 lat 76°04'14.94"N lon 030°50'29.57"E
09:33 fix GC_009 lat 76°09'13.35"N lon 031°02'18.07"E
10:38 fix GC_010 lat 76°14'03.88"N lon 031°14'01.31"E
11:42 fix GC_011 lat 76°18'46.60"N lon 031°25'33.34"E
13:04 fix GC_012 lat 76°23'32.46"N lon 031°37'09.41"E
14:05 fix GC_013 lat 76°28'15.98"N lon 031°49'02.19"E
15:09 fix GC_014 lat 76°33'01.33"N lon 032°00'53.39"E
16:31 EOL **BGR15-205**
16 :35 deploy Magnetometer and start acquisition on line **BGR15-206**
16:43 SOL **BGR15-206** Hdg 118
19 :54 EOL **BGR15-206** loop to BGR15-207
20:07 SOL **BGR15-207** Hdg 207
23:08 EOL **BGR15-207** loop to BGR15-208
23:14 SOL **BGR15-208** Hdg 297

15th September 2015 Tuesday (258)

00:00 Position **76°03'27"N** **032°22'21"E** hdg 297
MBES MAGNETOMETER and SBP acquisition on line **BGR15-208** Hdg297
02:22 EOL **BGR15-208** loop to BGR15-209
02:37 SOL **BGR15-209** Hdg 25
05:44 EOL **BGR15-209**
05:50 recovery Magnetometer and loop to the **BGR15-1SBP09**
06:10 MBES – SBP acquisition on line **BGR15-1SBP09**
06:36 fix GC_015 lat 76°37'37.55"N lon 032°12'50.81"E
07:40 fix GC_016 lat 76°42'16.95"N lon 032°24'58.01"E
08:32 fix GC_017 lat 76°47'09.87"N lon 032°37'55.42"E
08:56 fix SVP006 lat 76°47'26.61"N lon 032°36'22.48"E
10:49 fix MUC_006 lat 76°38'01.13"N lon 032°13'57.06"E
12:11 fix MUC_007 lat 76°33'00.53"N lon 032°47'39.34"E
13:29 fix MUC_008 lat 76°27'53.49"N lon 033°21'00.77"E
14:42 fix MUC_009 lat 76°22'16.29"N lon 033°56'28.69"E
15 :40 deploy Magnetometer and start acquisition on line **BGR15-210**
15:53 SOL **BGR15-210** Hdg 118
20:50 EOL **BGR15-210** loop to BGR15-211
20:57 SOL **BGR15-211** Hdg 303
21:42 EOL **BGR15-211** loop to BGR15-212
21:46 SOL **BGR15-212** Hdg 204

16th September 2015 Wednesday (259)

00:00 Position **75°44'20"N** **035°17'47"E** hdg 204

MBES MAGNETOMETER and SBP acquisition on line **BGR15-212** Hdg204

01:02 EOL **BGR15-212** loop to BGR15-213

01:13 SOL **BGR15-213** Hdg 297

05:20 EOL **BGR15-213**

05:30 recovery Magnetometer

05:57 MBES – SBP acquisition on line **BGR15-1SBP15**

07:20 fix GC_018	lat 76°05'34.15"N	lon 033°14'04.08"E
07:41 fix SVP_007	lat 76°05'34.39"N	lon 033°14'11.98"E
09:12 fix GC_019	lat 76°33'31.32"N	lon 033°35'37.87"E
10:36 fix GC_020	lat 76°22'16.48"N	lon 033°56'31.52"E
13:00 SOL DRG_001	lat 76°22'11.54"N	lon 033°57'01.00"E
13:30 EOL DRG_001	lat 76°22'16.48"N	lon 033°56'31.52"E
14:35 SOL DRG_002	lat 76°23'50.26"N	lon 033°47'12.14"E
14:40 EOL DRG_002	lat 76°23'45.15"N	lon 033°47'33.94"E
15:38 SOL DRG_003	lat 76°23'50.26"N	lon 033°47'11.14"E on same location
15:43 EOL DRG_003	lat 76°23'45.15"N	lon 033°47'33.94"E

16:35 deploy Magnetometer and start acquisition on line **BGR15-214**

16:00 Calibration loop

16:42 SOL **BGR15-214** Hdg 137

18:05 Ship slow down to switch off one engine

18:08 Speed 2.5 knots, maggy depth 19.2m

18:09 Speed increasing, maggy depth 20.9m

18:11 Speed decreasing again to switch on again , maggy depth 13.2m

18:14 Speed increasing, ship 400m offtrack heading back to the line.

18:24 Ship on the line with two engines

19:29 Ship slow down to switch off one engine

19:32 Speed 3 knots increasing, maggy depth 16.8m. Ship 100m offtrack heading to the line

19:34 Ship on the line, speed 8 knots

20:43 Ship slow down to switch on one engine

20:45 Speed 1.8 knots increasing, maggy depth 21.4m. Ship 50m offtrack heading to the line

20:51 Ship on the line with two engines, speed 9.3 knots

21:08 Ship slow down to switch off one engine

21:10 Speed 2.5 knots increasing, maggy depth 15.3m. Ship 100m offtrack heading to the line

21:15 Ship on the line, speed 7 knots increasing

21:32 EOL **BGR15-214** loop to BGR15-215

21:32 SOL **BGR15-215** Hdg 275

21:45 Ship slow down to switch on one engine

21:10 Speed 2 knots increasing, maggy depth 23.5m. Ship 20m offtrack heading to the line

21:50 Ship on the line with two engines, speed 8.4 knots increasing

22:20 Ship slow down to switch off one engine

22:33 Ship on the line with one engine, speed 7 knots

17th September 2015 Thursday (260)

00:00 Position **75°52'54"N** **034°18'28"E** hdg 275

MBES MAGNETOMETER and SBP acquisition on line **BGR15-215** Hdg275

00:30 Ship slow down to switch on one engine

00:37 Speed 2 knots increasing, maggy depth 26.3m. Ship 100m offtrack heading to the line

00:45 Ship on the line with two engines, speed 9 knots

01:12 Ship slow down to switch off one engine

01:13 Speed 3.2 knots increasing, maggy depth 19.3m. Ship 150m offtrack heading to the line

01:22 Ship on the line with one engine, speed 7 knots

02:50 Magnetometer problem, ship slow down to 5 knots and prepare to recovery

03:12 Magnetometer on deck

03:12 EOL **BGR15-215** turn to BGR15-216

03:21 SOL **BGR15-216** Hdg 206 only MBES and SBP

03:21 Testing the magnetometers system

03:35 The problem seems to be the cable between the two sensors

08:31 SOL DRG_004 lat 75°25'22.81"N lon 031°33'24.14"E

08:54 EOL DRG_004 lat 75°24'36.11"N lon 031°33'42.26"E

09:42 fix SVP_008 lat 75°24'17.34"N lon 031°32'45.74"E

11:05 SOL DRG_005 lat 75°25'22.81"N lon 031°33'24.14"E

11:40 EOL DRG_005 lat 75°24'36.11"N lon 031°33'42.26"E

13:13 fix MUC_010 lat 75°25'41.34"N lon 031°32'20.46"E

14:16 fic GC_021 lat 75°26'10.59"N lon 031°33'27.02"E

16:14 fix GC_022 lat 75°34'49.62"N lon 031°54'31.91"E

18:00 Start magnetometer deployment. System shut down, still problem with cable, is decided to recover and deploy one sensor only

19:01 SOL **BGR15-217** Hdg 026

19:30 on the line

22:00 Heading to Longyearbyen, acquisition continues with heading 272

18th September 2015 Friday (261)

00:00 Position **75°38'24"N** **032°00'06"E** hdg 272

MBES MAGNETOMETER and SBP acquisition on line **BGR15-217** Hdg272

15 :45 transfer interrupted to sample the shallow water seabed

15:56 fix MUC_011 lat 75°59'18.51"N lon 023°00'41.29"E

16:20 transfer to Longyearbyen

19th September 2015 Saturday (262)

00:00 Position 76°16'N 020°15'E hdg 290

MBES and SBP acquisition on line BGR15-217

21:55 End of acquisition. Out of permit area.

20th September 2015 Sunday (263)

00:00 Position 77°46.3'N 012°32.7'E hdg 019

in transit to Longyearbyen

06:00 Pilot on board

07:00 along Longyearbyen harbour lat 78°13'46"N lon 015°36'07"E

End of 2nd leg

End of survey

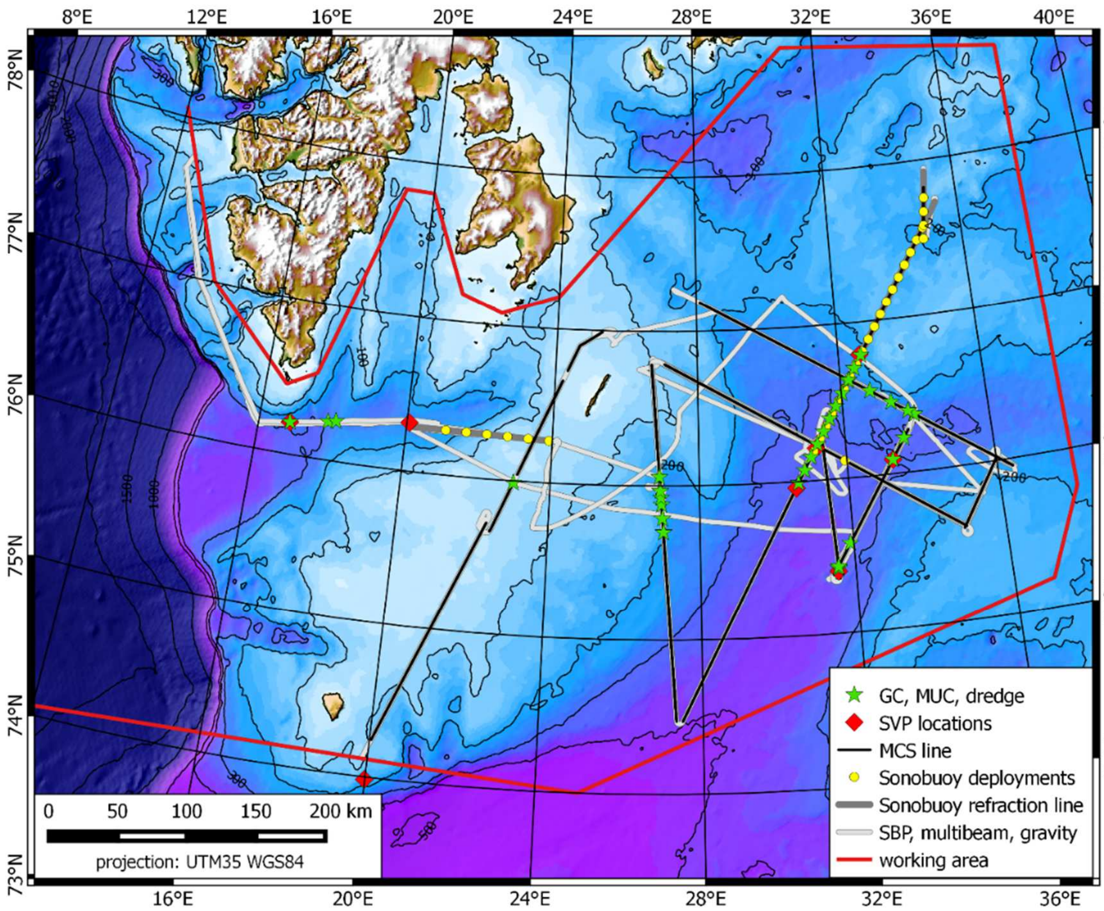


Fig. 7: Survey lines and location of coring stations of the PANORAMA-2 cruise.

3. NAVIGATION AND DATA MANAGEMENT

Lorenzo Facchin

The navigation is managed by means of Teledyne Reson PDS2000 software. This software is capable to collect the data coming from the connected devices installed onboard, and send different outputs to the equipment as well.

Additional tasks of PDS2000 are: to create guidance (routes, acquisition runlines, waypoints, etc); to do computations (as requested); data quality control; messaging output towards external acquisition systems and events marks towards external acquisition systems too, by means of serial port. For the seismic acquisition, in PANORAMA-2 project, the PDS2000 navigation system was configured to send the firing command (event) to the gun controller every 25m distance. The ship is equipped with three GPS positioning systems [Ashtec Aquarius (primary); Topcon GB-500 (GPS+GLONASS); Landstar MK Veripos (also DGPS)], directly interfaced to the inertial navigation system MRU (Motion Reference Unit) that sends heading and attitude values, position and speed both to PDS2000 and MBES; the Multibeams Systems - Reson Seabat 8150 and Reson Seabat 8111 and the Singlebeam Simrad EA600, all connected to the navigation system that receives and logs the data coming from the Gravitymeter and the Gradiometer as well. The CHIRP system receives the position information from the GPS, and the depth from the echosounder.

All data coming from the connected instruments can be visualized, real-time, both in navigation room and on the bridge.

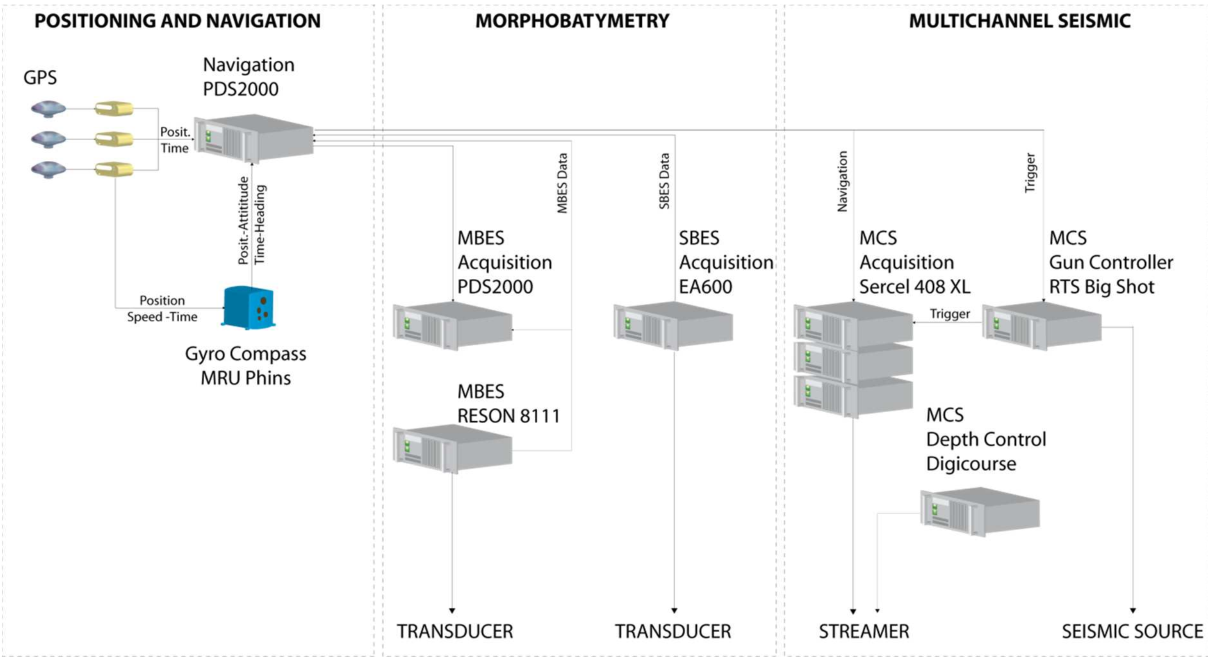


Fig. 8: General block diagram of navigation and data management.

Tab. 2: Relative positions of ship mounted instruments

Instrument	X	Y	Z
ACQUARIUS	2,24	8,20	20,00
EA600	0.29	27.23	-4.46
G- GUN port	0	-54.32	-6,0
G- GUN stbd	0	-54.32	-6.0
GRAVITYMETER	0,00	0,00	0,18
MB 8111	-0,29	17,89	-4,82
MB 8150	0,00	16,49	-4,50
OCTANS	-0,27	-0,28	0,25
SBP	-0,63	6,93	-4,32
STERN	0,00	-29,32	7,12
TOPCON	2,69	8,60	20,36
VERIPOS	-2.13	8.36	20.28
Zero Offset	0.00	0.00	0.00
Streamer nearoffset	0.00	-87.32	-12

All the information received by PDS2000 can be exported with the requested format.

For every acquired profile, depending on the instrument to which it is referred, different files have been exported.

- The "MRU" files with *Date and Time*, *Lat and Long* in DegMinSec format, and *Heading Pitch* and *Roll* values.
- The "Magnetometer" files with *Date and Time*, *Lat and Long* in Decimal degrees format, *Water Depth* and all the data coming from the towed Magnetometer.
- The "Gravitymeter" files containing *Date and Time*, *Lat and Long* in Decimal degrees format, *Water Depth* and all the data coming from the Gravitymeter.
- The "Shiptrack" files with *Date and Time*, *Lat and Long* in Decimal degrees format, and *Water Depth* from the Multibeam

4. SINGLE-BEAM ECHOSOUNDER (SBES)

Lorenzo Facchin

The Simrad EA600 Oceanic Depth Echosounder, manufactured by Kongsberg Maritime, is a Single Frequency 18 kHz system, with a maximum power of 2 kW, 160 dB of dynamic range and a transducer 12-16-60 with 16° circular, 60° passive beams. Depth values are logged by the main navigation system (PDS2000) via the RS-232 serial connection.

During this cruise the time to depth conversion velocity was set to a constant value of 1480 m/s to easily allow time gating of the chirp subbottom profiler data.

Tab. 3: EA600 features and technical specifications

Manufacturer	Simrad Kongsberg
Model	EA600
Installation	Hull mounted
Transducer type	18-11
Frequency	18 kHz
Pulse duration	8 ms
Beam angle	11°
Beam width	382 Hz
Transmit power	2000 W
Range bottom	7000
Gain function	20 log TVG, 30 log TVG, 40 log TVG, or none
Ping rate	Adjustable
Start depth and range	5 to 15.000 m in manual or auto range
Bottom detector	Software tracking algorithm

5. MULTI-BEAM BATHYMETRY

Lorenzo Facchin, Kai Berglar

5.1 Technical specifications

The R/V OGS Explora is equipped with two keel mounted Multibeam Echosounders: the Reson SeaBat 8111 (**Tab. 4**) for shallow water (up to 500 m WD); and the Reson SeaBat 7150 for deep water.

Because of shallow water depths throughout the working area, only the SeaBat 8111 was used during the PANORAMA-2 cruise.

The SeaBat 8111 operates at a frequency of 100 kHz; it illuminates a swath on the sea floor that is 150° across track by 1.5° along track. The swath consists of 101 individual 1.5° by 1.5° beams with a bottom detection range resolution of 3.7 cm. The maximum swath width (7.4 times the water depth) is reached with the system working in less than 150 meters of water. The 8111 employs Pitch Stabilization to steer the transmitted beam so that it remains vertical through pitch angles of ±10 degrees. The data are logged through the PDS2000 acquisition software.

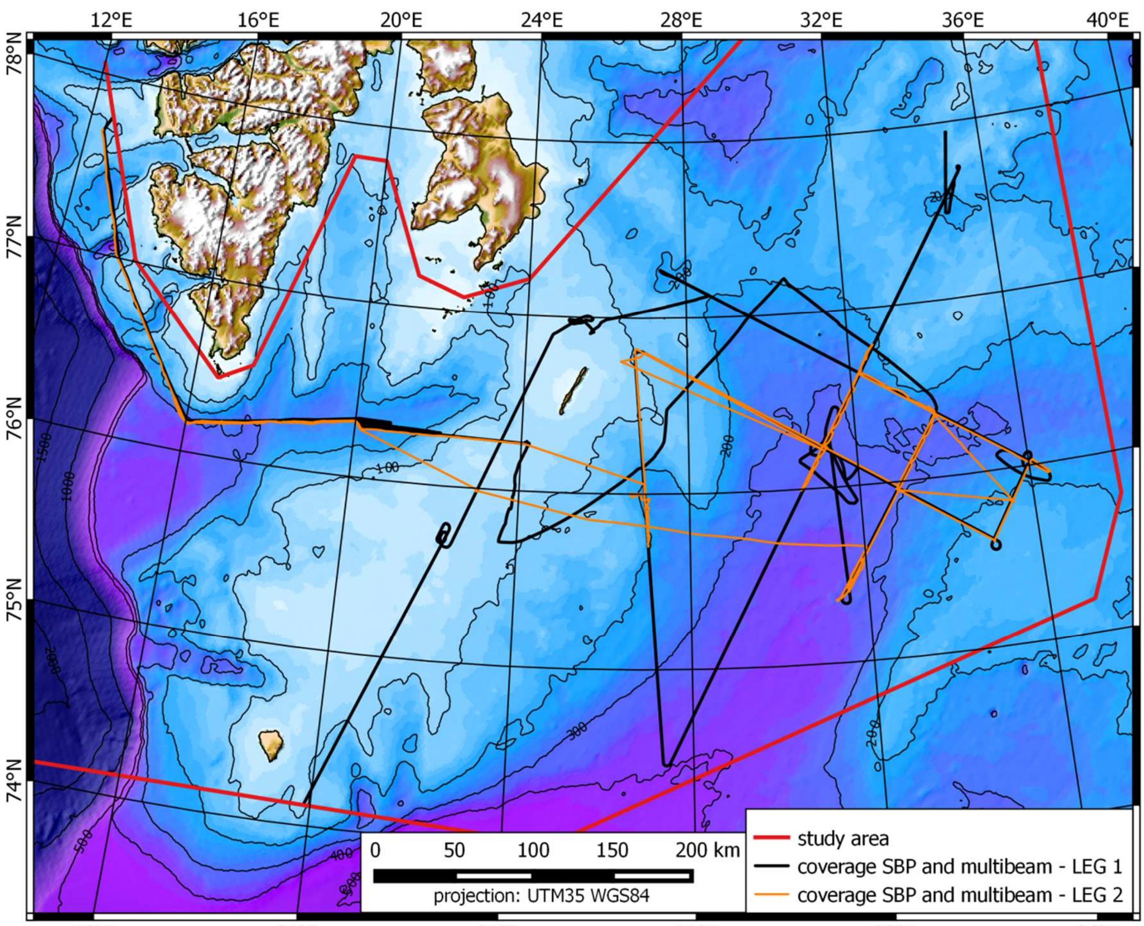


Fig. 9: Coverage of multibeam and subbottom profiler data.

5.2 Data acquisition and processing

Data acquisition was carried out from 17th of August at 10:56 (UTC TIME) with entering the survey area until the 15th of September at 01:25 (UTC TIME) as the ship exit the working area. The keel mounted shallow-water MB 8111 was run for the whole working area. Its operating frequency is 100 kHz for 101 beams with beamwidth across and along track of 1.5°; and a 150° of max swath. The quality of the data was good, with high density during the seismic acquisition, performed at 4knots. All acquired data was logged as "pds" and files format, and converted after the acquisition in XTF file format. PDS is native format for PDS200, XTF format is a standard that can be read by many processing softwares. As echosounders compute the water depth from the travel time of the acoustic signal from the transducer to the seafloor and back it is very important to know the exact sound velocity in the water column. Thus it has been necessary to perform Sound Velocity measurements by means of a sound velocity probe (MiniSVP VALEPORT) to get real time correction of the incoming raw water depth data (see chap. 6). These corrections were computed and applied to the data automatically by PDS2000 software. The total coverage of acquired multi-beam bathymetry is shown in **Fig. 9**.

The data were processed with the open source software packages MB-SYSTEM (v. 5.3) and GMT (v. 4.5.11). The raw data XTF format is a read only format in MB-SYSTEM. After conversion to the Kongsberg processing format (57), the data were auto-cleaned and the nearest SVP-measurements assigned.

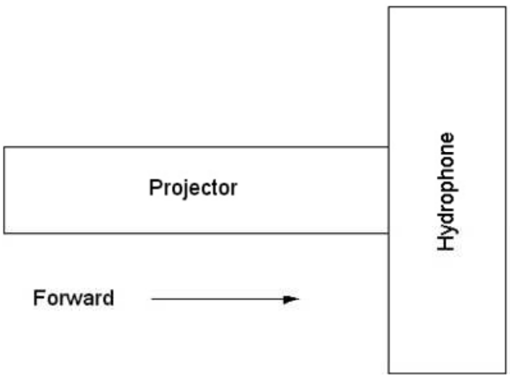
For interpretation, GeoTiff images with the IBCAO dataset as background were computed with a size of 50x50 km and a resolution of 16 meters.

MB-SYSTEM processing flow:

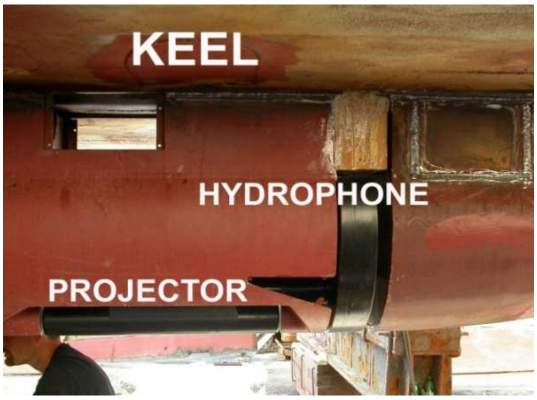
```
mbcopy       < RAWDATAFILE.XTF  -F 84/57 -P1 -O OUTFILE.mb57
mbclean      -I OUTFILE.mb-1 -M1 -X10/7 -S0.2/2 -C3.5 -D0.01/0.20 -G0.80/1.20
             -Q550/550 -R0.3
mbset        -I OUTFILE.mb-1 -PSSVFILE:SVPFILE.svp
mbprocess    -I OUTFILE.mb-1
mbgrid       -I OUTFILE_PROC.mb-1 -JUTM35N -Rxmin/xmax/ymin/ymax
             -E16/16/m -N -X -F1 -Oout.grd -C2/2 -S4
grdsample    IBCAO.grd -GIBCAO_16m.grd -I16/16/m - Rxmin/xmax/ymin/ymax
grdmath      out.grd IBCAO_16m.grd AND = combined.grd
mbm_grdtiff  -A1.3/120/40 -G2 -I combined.grd -W colorscale.cpt -X
```

Tab. 4: SEABAT 8111 features and technical specifications

Manufacturer	Reson
Model	SeaBat 8111
Installation	Hull mounted
Number of beams	101
Beamwidth across track	1.5°
Beamwidth along track	1.5°
Center-to-center beam separation	1.5°
Max Swath	150°
Max swath coverage	7.4 x water depth
Operating frequency	100 kHz
Pulse length	Variable, operator selectable
Depth range	600 m (max scale 1400 m)
Max ping rate	35 swaths per second
Max vessel speed	20 knots
Stabilization	Pitch stabilization within +/- 10°
Sound probe	Reson SVP 24
Acquisition software	PDS2000
Processing software	PDS2000
SEABAT 8111 SYSTEM CONFIGURATION	



Head orientation



The keel mounted Reson SeaBat 8111.

6. SOUND VELOCITY PROFILES

Lorenzo Facchin, Kai Berglar

Sound velocity profile (SVP) measurements are needed for correction of the multi-beam water depth data. They are supplied by means of a Sound Velocity Probe SVP-VALEPORT that also logs temperature measures along the water column. The probe is operated by a winch located on the second deck and is placed in the sea by hanging it on to the portside lateral frame pulley.

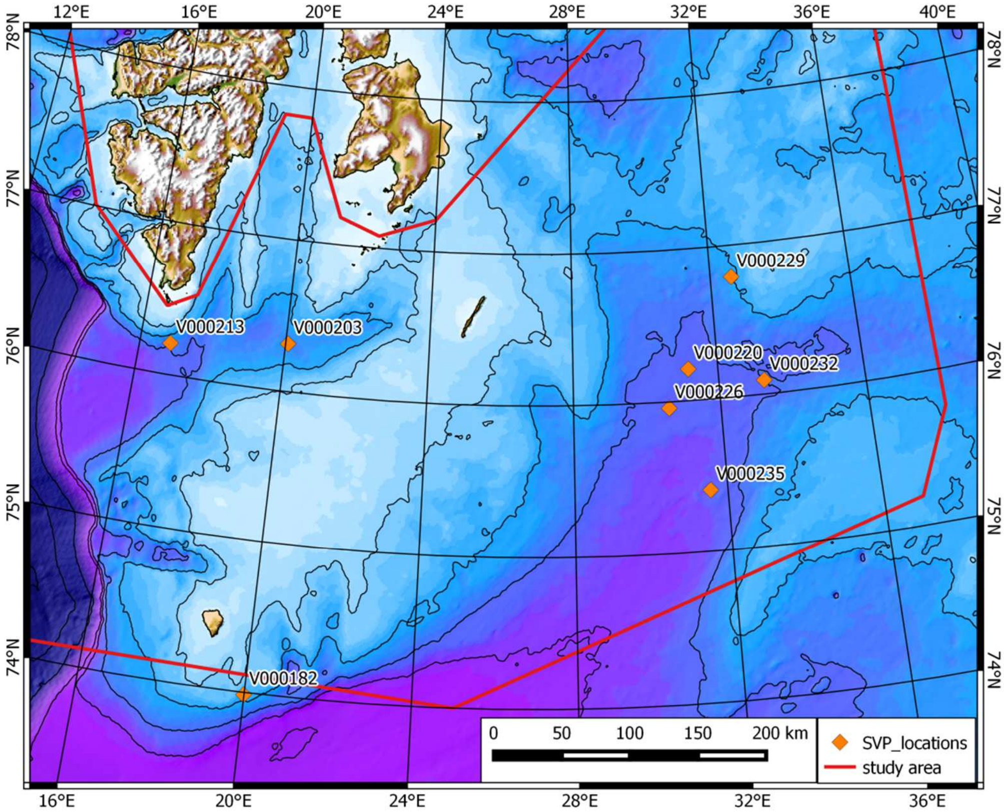


Fig. 10: Location of SVP measurements.

Tab. 5: Time and location of SVP measurements

V000182	2015/08/17	06:29:13	73.9848°N	19.9876°E
V000203	2015/09/04	06:23:06	76.3137°N	20.0667°E
V000213	2015/09/09	06:29:13	76.2067°N	16.8389°E
V000220	2015/09/11	07:38:36	76.2086°N	31.1817°E
V000226	2015/09/13	06:40:20	75.9595°N	30.5938°E
V000229	2015/09/15	08:55:56	76.7907°N	32.6023°E
V000232	2015/09/16	07:29:18	76.0929°N	33.2367°E
V000235	2015/09/17	09:28:21	75.4048°N	31.5460°E

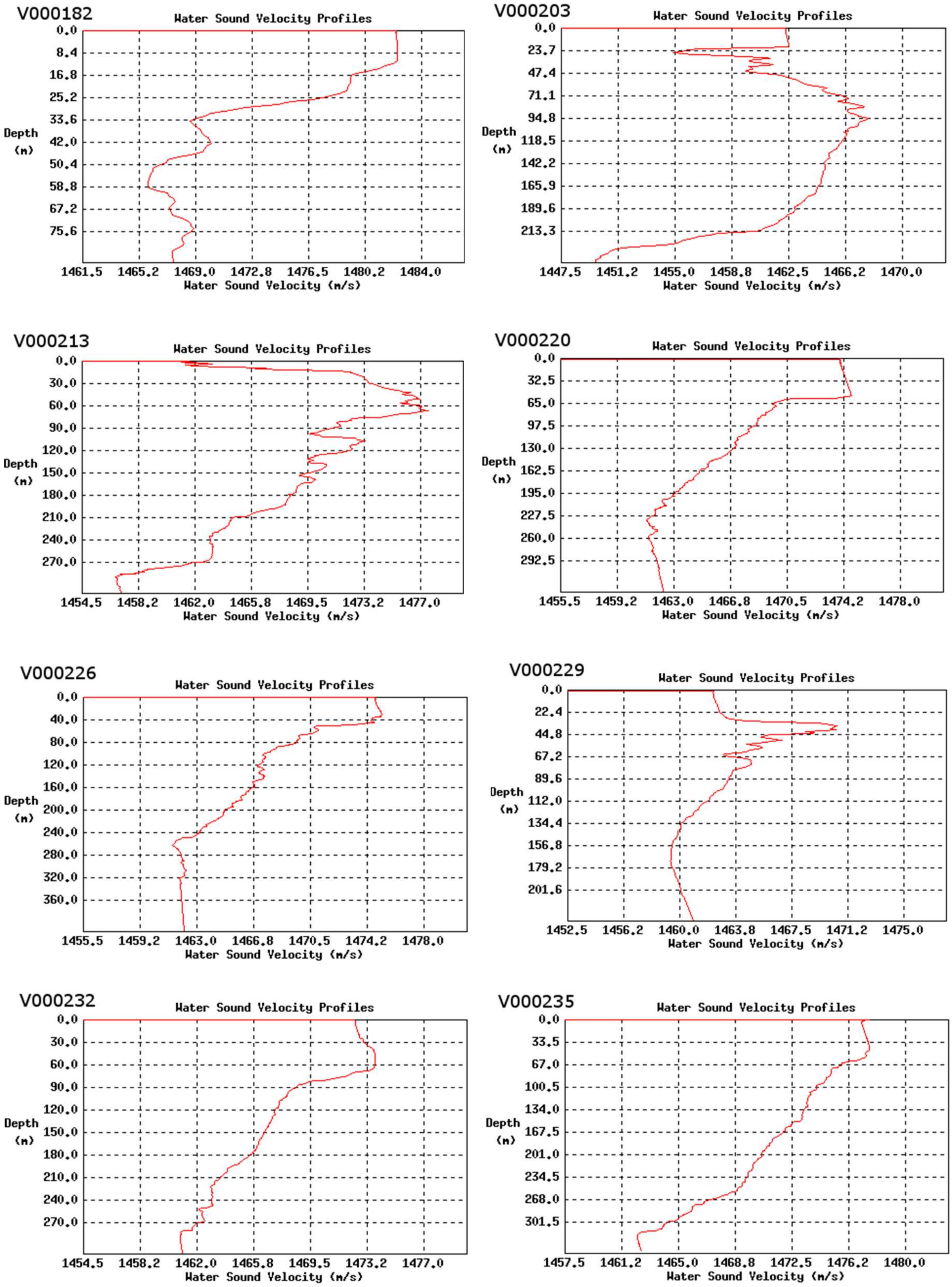


Fig. 11: SVP profiles with variable depth scales.

7. SEDIMENT ECHOSOUNDING

Kai Berglar

7.1 Method and instrument control

R/V OGS EXPLORA is equipped with a hull-mounted Datasonics CAP-6600 Chirp II system allowing the acquisition of high-resolution sediment echosoundings. Technical specifications are as followed:

Tab. 6: Subbottom profiler (SBP) features and technical specifications

Manufacturer	Benthos
Model	Chirp II
Installation	Hull mounted
Number of transducers	16
Transducers type	AT 471
Signal generator / DSP	CAP-6600 Chirp II Workstation
DSP Sonar Signal Processing	16 bit A/D, continuous FFT
Operating sweep frequency	2 – 7 kHz
Ping rate	Variable, operator selectable (max 12 ping/sec)
Sweep Length	Variable, operator selectable
Multiping option	yes
Gain	Automatic gain control
Bottom tracking	Interactive
Navigation / Annotation	NMEA 0183
Data format	XTF or SEG Y
Real time printer	EPC
Acquisition software	SwanPRO / ChirpScan II
BENTHOS CHIRP II	
The system consists of sixteen hull mounted AT 471 transducers	

The Benthos Chirp II system is controlled by the acquisition software SwanPro (v 1.57). It allows adjusting the recording depth via changing the trigger rate (0.25 s - 0.625 s) preserving a fixed number of samples per record (8192) thus altering the sample rate and recording window. Data is stored in the XTF-format. Conversion to SEG-Y format is done after acquisition with the software SwanConv (v. 0.05).

Data quality mostly depends on the weather conditions, as heavy roll and pitch of the vessel results in a sideward reflection of the emitted signal. With speed in water of about 4 to 7 knots, the vessels hull is producing bubbles due to a cavitation effect which also reduce data quality. Speed at seismic acquisition was 4.5 knots over ground.

7.2 Processing

The SEG-Y converter software SwanConv resamples the data to a constant sample rate (14 kHz were used to preserve all frequencies of the sweep), looks for the minimum and maximum time in one or several XTF files and creates new traces of this length written to a SEG-Y file. This procedure can result in very large files, e.g. on the slope or in deep waters with data outliers at zero depth.

The SEG-Y files are further processed with the open source software packages seismic unix (v. 43R4) and GMT (v. 4.5.11).

Main processing steps are:

(1) Position data and heave compensation

The navigation system of OGS EXPLORA provides precise UTM-coordinates (zone 35 for this survey) and heave (z-values) in meters calculated from the motion sensor data at a frequency of 20 Hz for all ship-mounted instruments.
Depending on the variable recording frequency the Chirp system triggers about two to three times per second. As GPS times are updated only every second, an individual timestamp in 10th of seconds is interpolated for each trace using the GMT filter1d function and correlated with the data provided by the navigation system. The coordinates are written to the source and receiver group trace header words (bytes 73-76, 77-80 and 81-84, 85-88). For heave compensation the heave measurement of the motion sensor provided by the navigation system is calculated to time with a sound velocity in water of 1480 meters per second, which is then used to vertically shift the trace.

During the first week of the cruise the chirp acquisition system was partially out of time synchronization with the ship’s navigation system which resulted in a wrong heave compensation of parts of some lines.

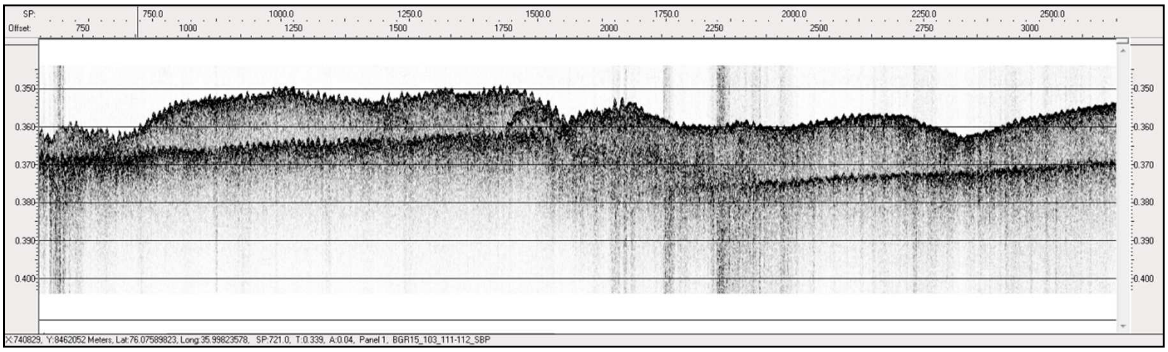


Fig. 12: Wrong heave correction due to missing time synchronization of the chirp acquisition system with the ship's navigation computer.

(2) Time gates for data reduction

Measured water depths from the vessel's 18 kHz pinger system are calculated to time (1480 m/s) and used to cut a time window of 60 ms out of the traces containing the relevant data to reduce data volume. For convenience, the 18 kHz pinger was set to use a constant sound velocity of 1480 m/s for depth calculation. Trace delay is written to trace header word bytes 109-110, water depth to trace header word bytes 181-184.

(3) Signal processing

Trace normalization was applied to improve the signal.

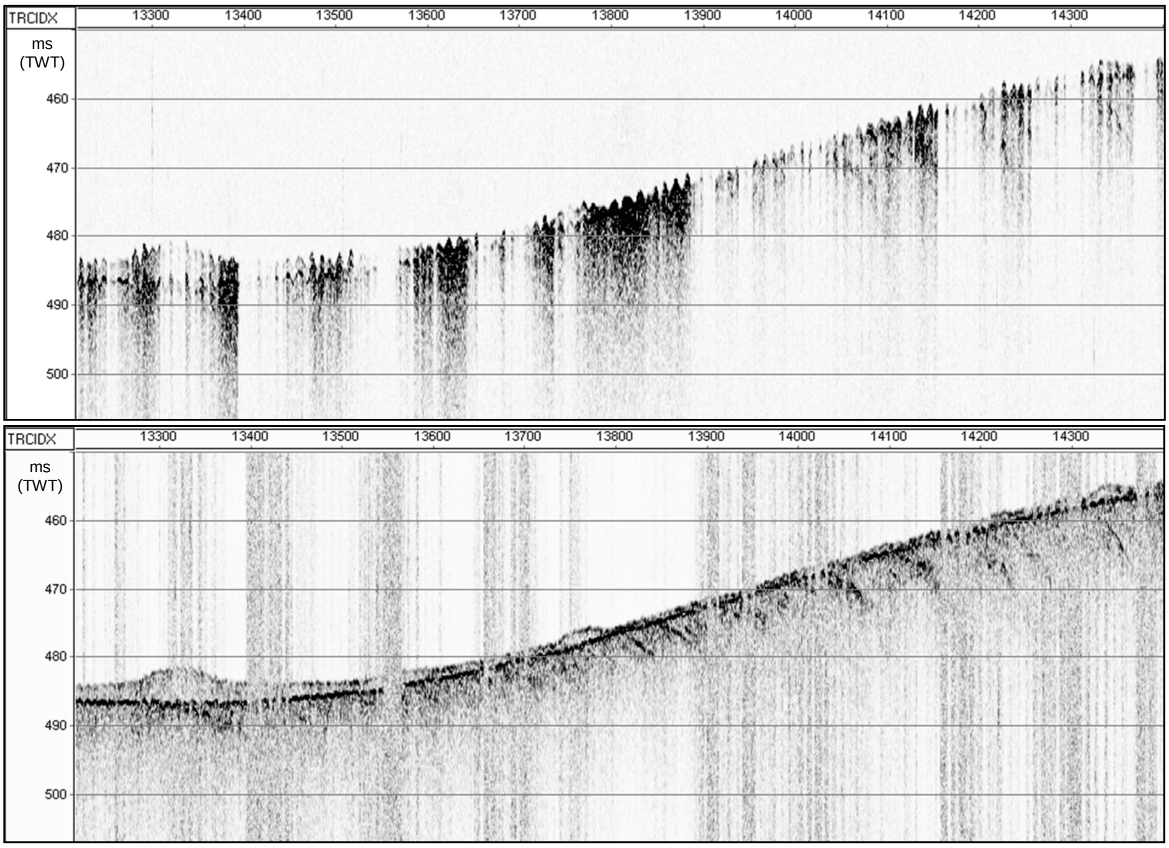


Fig. 13: Chirp data set acquired under bad weather conditions before (top) and after (bottom) processing applied.

8. GRAVIMETRY

Bernd Schreckenberger

8.1 The sea gravimeter system KSS31

During the cruise PANORAMA-2 the OGS owned sea gravimeter system KSS31, serial no. 14, was used. The KSS31 is permanently installed on RV OGS EXPLORA in the gravimeter room one level below the main deck (**Fig. 14**). The sea gravimeter is located near the vessel's nominal center of gravity 4.7 m above the vessel's keel and 29.32 m in front of the stern.

The gravimeter system KSS31 is a high-performance instrument for marine gravity measurements, manufactured by Bodenseewerk Geosystem GmbH. The KSS31 system consists of two main assemblies: the gyro-stabilized platform with the gravity sensor and a rack with the power supply, the system electronics and the data handling subsystem.

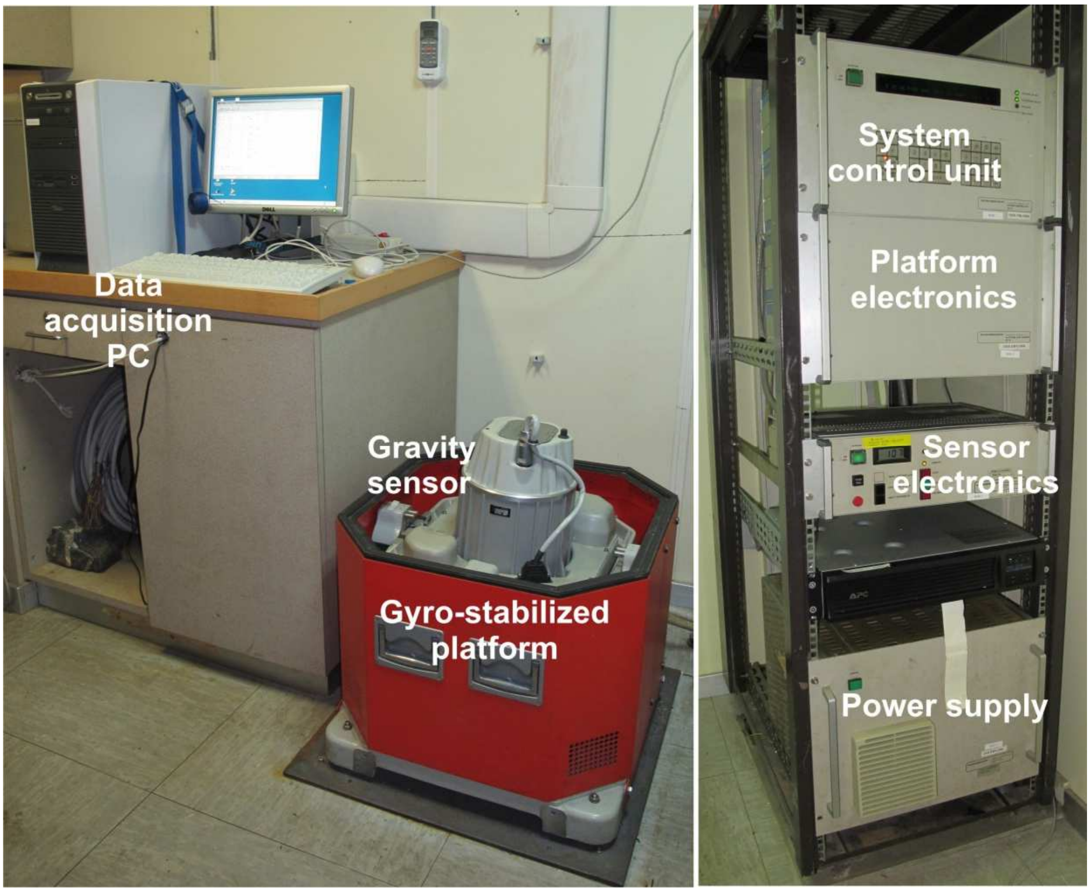


Fig. 14: KSS31gravimeter system (platform with sensor and electronics rack) in the gravimeter room on RV OGS EXPLORA (from Damm et al., 2013). On cruise PANORAMA-2 a data acquisition notebook was used instead of the PC shown.

The gravity sensor GSS31 (**Fig. 15**) consists of a tube-shaped mass that is suspended on a metal spring and guided frictionless by 5 threads. It is non-astatized and particularly designed to be insensitive to horizontal accelerations. This is achieved by limiting the motion of the mass to the vertical direction. Thus it is a straight line gravity meter avoiding cross coupling effects of beam type gravity meters. The main part of the total gravity acceleration is compensated by the mechanical spring, but gravity changes are compensated and detected by an electromagnetic system. The displacement of the spring-mass assembly with respect to the outer casing of the instrument is measured using a capacitance transducer.

The levelling subsystem consists of a platform stabilized in two axes by a vertical, electrically erected gyro. The stabilization during course changes can be improved by providing the system with online navigation data. The control electronics and the power supply of the platform are located in the data handling subsystem unit. The measured data are transmitted to the PDS2000 system and online navigation data from this system are sent to the gravity meter with a rate of 1 Hz to support the stabilizing platform. The support is realized as follows: The horizontal position of the gyro-stabilized platform is controlled by two orthogonal horizontal accelerometers. The platform is levelled in such a manner that the horizontal accelerations are zero. If the ship describes a curve, the additional horizontal acceleration will cause the platform to be levelled according to the resulting apparent vertical axis. This axis may differ substantially from the true vertical axis and will result in reduced gravity values and additionally in an effect of horizontal accelerations on the measured gravity. The latter effect is eliminated by supplying the system with online navigation data. A microprocessor calculates the levelling errors from this input and enters them into the platform electronics which corrects the platform accordingly.

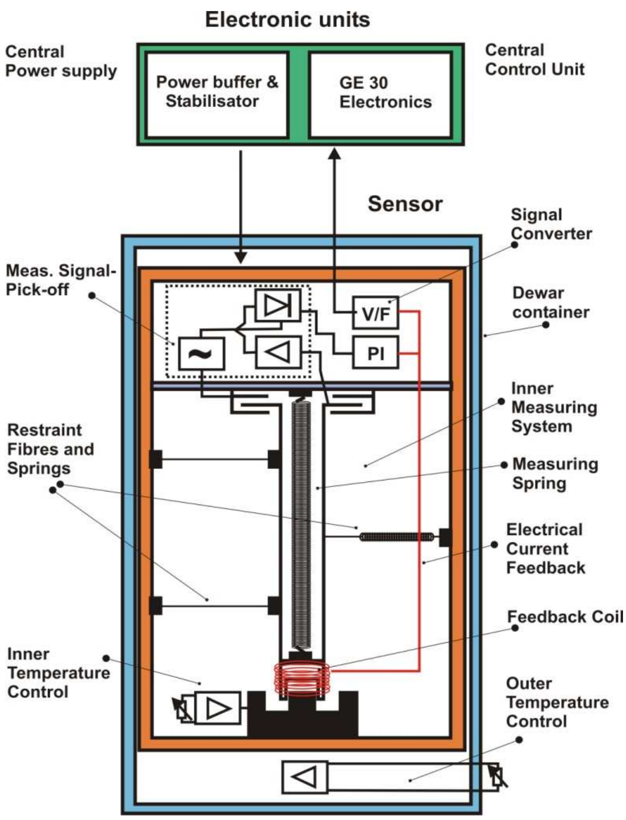


Fig. 15: Principle sketch of the gravity sensor GSS31 of the gravimeter system KSS31.

8.2 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. According to the recommendations of the IUGG, every gravity survey, marine or land, should be related to the datum and the scale of the IGSN71. Therefore, gravity measurements on land have to be carried out to connect the gravity measurements at sea with the IGSN71.

In this report we partly rely in some gravity connections performed for cruise BGR13-2 (PANORAMA-1) in 2013 [*Damm et al.*, 2013]. Therefore, we keep all designations of their reference stations (01-04, see below) and extend their list of gravity stations (A-C) by two additional stations D and E.

The following **reference stations** were used:

01: Bremerhaven, AWI building, Room 0082 981356.720 mGal (IGSN71)

02: Tromsø University Museum, Seismograph Room, Bolt R
(69°38.08'N, 18°54.76'E, 27.30 m above MSL) 982552.140 mGal (IGSN71)

03: Tromsø University Museum, Main Entrance, Bolt Q
(69°38.09'N, 18°54.84'E, 29.61 m above MSL) 982551.448 mGal (IGSN71)

04: Longyearbyen airport, Old Terminal Building, near entrance
(78°14.7'N, 15°29.9'E) 982962.784 mGal (IGSN71)

The **gravity stations** used for gravity connections in this report are:

A: Bremerhaven, outside Kaiserdock II at Lloyd shipyard

B: Tromsø, Breivika pier, 15 m from the south-western end of pier position No. 20

C: Longyearbyen, 45 m from the southeastern end of the main pier

D: Bremerhaven, Verbindungshafen, Lloyd-Werft (53°34.01'N/08°33.33'E), 85 m from the southern end of the pier.

E: Tromsø, berthing at Terminalgata (69°40.61'N/18°59.12'E), 45 m from the south-western end of pier near the 4. bollard.

We used two different LaCoste&Romberg model G gravity meter instruments (LCR G666 owned by BGR and LCR G367 owned by OGS) for the gravity connections in Bremerhaven before the cruise (D) and only LCR G367 for the gravity connections in Tromsø (E). In Bremerhaven the reference gravity station in the AWI building was used (01). 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 (02, 03).

For mobilization RV OGS EXPLORA moored at a pier in the Verbindungshafen at Lloyd shipyard in Bremerhaven about 85 m from the southern end of the pier (station D, **Fig. 16**). On August 6, 2015, tie measurements to point D on the pier next to the gravity room on RV OGS EXPLORA have been made with gravimeters G-666 and G-367 (**Tab. 7**).

On August, 14, 2015, tie measurements between two reference stations in Tromsø (02 and 03) and gravity station E (**Fig. 17**) in Tromsø harbour were performed (**Fig. 17**, **Tab. 7**).

On September, 07 and September 20, 2015, RV OGS EXPLORA moored at exactly the same place at the same pier in Longyearbyen as on September, 06, 2013 during cruise PANORAMA-1 (station C in **Fig. 18**). Therefore, no new tie measurements were made and the values for the absolute gravity on the pier at C as calculated in *Damm et al.* [2013] were used.

After her return to Bremerhaven RV OGS EXPLORA moored at the same place at the same pier in the Lloyd shipyard (gravity station A, **Fig. 16**) as 2013. Again, no new tie measurements were made and the values from Damm et al. (2013) were used.

From the IGSN71 absolute gravity values at the reference stations and **Tab. 7** we get the following absolute gravity values for gravity station D (06.08.15):

Absolute gravity at 01: 981356.720 mGal

Gravity difference D - 01 = +0.06 mGal (G367)

Gravity difference D - 01 = +0.11 mGal (G666)

Mean D - 01 = +0.08 mGal.

Absolute gravity at D: 981356.800 mGal

Corrected to water level -1.6 m: 981357.192 mGal

For the gravity connection (**Tab. 7**) in Tromsø on August, 14, we get for station E:

Absolute gravity at 03: 982551.448 mGal

Absolute gravity at 02: 982552.140 mGal

Gravity difference 02 - 03 = 0.692 mGal (Station reference sheets)

Gravity difference 02 - 03 = 0.70 mGal (according to **Tab. 7**)

Gravity difference E - 02 = +3.94 mGal

Absolute gravity at E: 982556.08 mGal

Corrected to water level -2.0m: 982556.58

The following gravity connections use tie measurements from Damm et al. (2013):

Absolute gravity at C: 982964.419 mGal

Corrected to water level -2.8 m (07.09.15): 982565.105 mGal

Corrected to water level -3.2 m (20.09.15): 982965.203 mGal

Absolute gravity at A: 981357.01 mGal

Corrected to water level -1.8 m (12.10.15): 981357.447

Tab. 7: Observation report of the gravity tie measurements in Bremerhaven, Tromsø and Longyearbyen. Observer: S, H = Schreckenberger, Heyde. Gravity in mGal using LCR G-367 and G-666 scaling tables.

Station	Instrument Observer	Date	Time UTC	Reading units	Gravity value [mGal]
D	G-367,H,S	06.08.15	13:20	4869.66	5166.39
D	G-666,H,S	06.08.15	13:30	4877.36	4932.53
01	G-367,H,S	06.08.15	14:03	4869.60	5166,32
01	G-666,H,S	06.08.15	14:15	4877.28	4932.45
D	G-367,H,S	06.08.15	14:55	4869.66	5166,39
D	G-666,H,S	06.08.15	15:00	4877.42	4932,59
E	G-367,S	14.08.15	12:05	5995.34	6364.10
02	G-367,S	14.08.15	13:00	5991.64	6360.16
03	G-367,S	14.08.15	13:10	5990.98	6359.46
E	G-367,S	14.08.15	14:10	5995.34	6364.10

Tab. 8: Summary of gravity tie measurements and drift calculations between consecutive stations. CSF: calculations using a correction to the instruments scale factor of 0.9879557 (I. Heyde in Damm et al., 2013). B: Bremerhaven; T: Tromsø; L: Longyearbyen.

Date **Place**	**Abs. gravity mGal**	Diff. Abs. Gravity mGal	**Reading KSS31 mGal**	**Reading CSF mGal**	Diff. CSF mGal	Drift mGal	Drift mGal /day
06.08.15, B	**981357.192**		**728.7**	**719.92**			
(9 days)		1199.4			1208.27	8.88	0.99
15.08.15, T	**982556.580**		**1951.7**	**1928.19**			
(23 days)		408.5			421.96	13.43	0.58
07.09.15, L	**982965.105**		**2378.80**	**2350.15**			
(13 days)		0.1			2.21	2.11	0.16
20.09.15, L	**982965.203**		**2381.04**	**2352.36**			
(22 days)		-1607.8			-1604.96	2.8	0.13
12.10.15, B	**981357.447**		**765.51**	**747.40**			

Tab. 8 contains all water level corrected absolute gravity values and the readings of the KSS31 gravity meter for the times of the measurements. I. Heyde [in *Damm et al.*, 2013] concluded that the scale factor of the instrument (0.8080, already contained in column ‘reading Kss31’ of **Tab. 8**) must be slightly wrong and estimated an additional correction factor of 0.9879557 from two tie measurements at the same gravity station (A) in Bremerhaven at the start and end of the 2013 cruise. In Tab. 8 this correction factor (CSF: correction scale factor) is additionally applied in the column ‘reading CSF’. The table also contains the differences between the reference values and the KSS31 readings for consecutive tie measurements. Large absolute drift values and drift per day values for the first two intervals (Bremerhaven- Tromsø and Tromsø-Longyearbyen) are obtained. The drift values for the final two intervals (Longyearbyen-Longyearbyen and Longyearbyen-Bremerhaven) are with 0.16 mGal/day and 0.13 mGal/day in good agreement with I. Heyde’s drift value (0.14 mGal/day) from 2013.

Unfortunately, Tab. 8 also shows that it is obviously not appropriate to calculate a drift value which is free from the scale factor problem from the two visits in Bremerhaven on 06.8.15 and 12.10.15. This calculation results in an unrealistic high drift value of +27.6 mGal within 67 days (+0.41 mGal/day) as an average between the highly variable values in the last column of **Tab. 8**.

The comparison of free-air gravity values calculated using the gravity connections from Tab. 8 for Tromsø and Longyearbyen with free-air gravity values from the DTU data set [*Andersen*, 2010] for the track line of the vessel results in a very good agreement for Leg 2 of this cruise. For Leg 1 this procedure results in big differences when the free-air gravity from the ship is compared with the DTU values. Obviously, there is something wrong with the gravity connection in Bremerhaven (06.08.15) and Tromsø (15.08.15). For the moment we will use a calculated preliminary value for the Gravity connection in Tromsø that brings the free-air anomaly from the ship into agreement with the DTU anomaly.

8.3 Gravity data processing

The raw and processed gravity data were recorded by the PDS2000 system in the navigation room with a data rate of 0.25 Hz and parallel by a separate BGR notebook installed in the gravimeter room with a data rate of 0.2 Hz using the printer interface.

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 0.808 mGal/r.u. On this cruise this was done in the system itself by hardware settings but see the discussion above regarding an additional correction to the scale factor (0.9879557).
- 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 (WGS67).

As a result, we get the so-called free-air anomaly (FAA) which in the case of marine gravity is simply the Eötvös-corrected, observed absolute gravity minus the normal gravity.

On this cruise the PDS2000 system provided only incomplete navigation data to the KSS31 gravimeter as speed, course, and heading data were missing in the transmitted string. This resulted in large disturbances in the measured gravity values during turns and course changes but also during speed changes on straight profile lines.

Gravity data were recorded on all lines in the permitted area north of Bear Island outside of the 12nm zone of Svalbard during Leg 1 and Leg 2 of the cruise. Due to the inconsistent drift values (**Tab. 8**) we have not yet calculated final gravity anomalies.

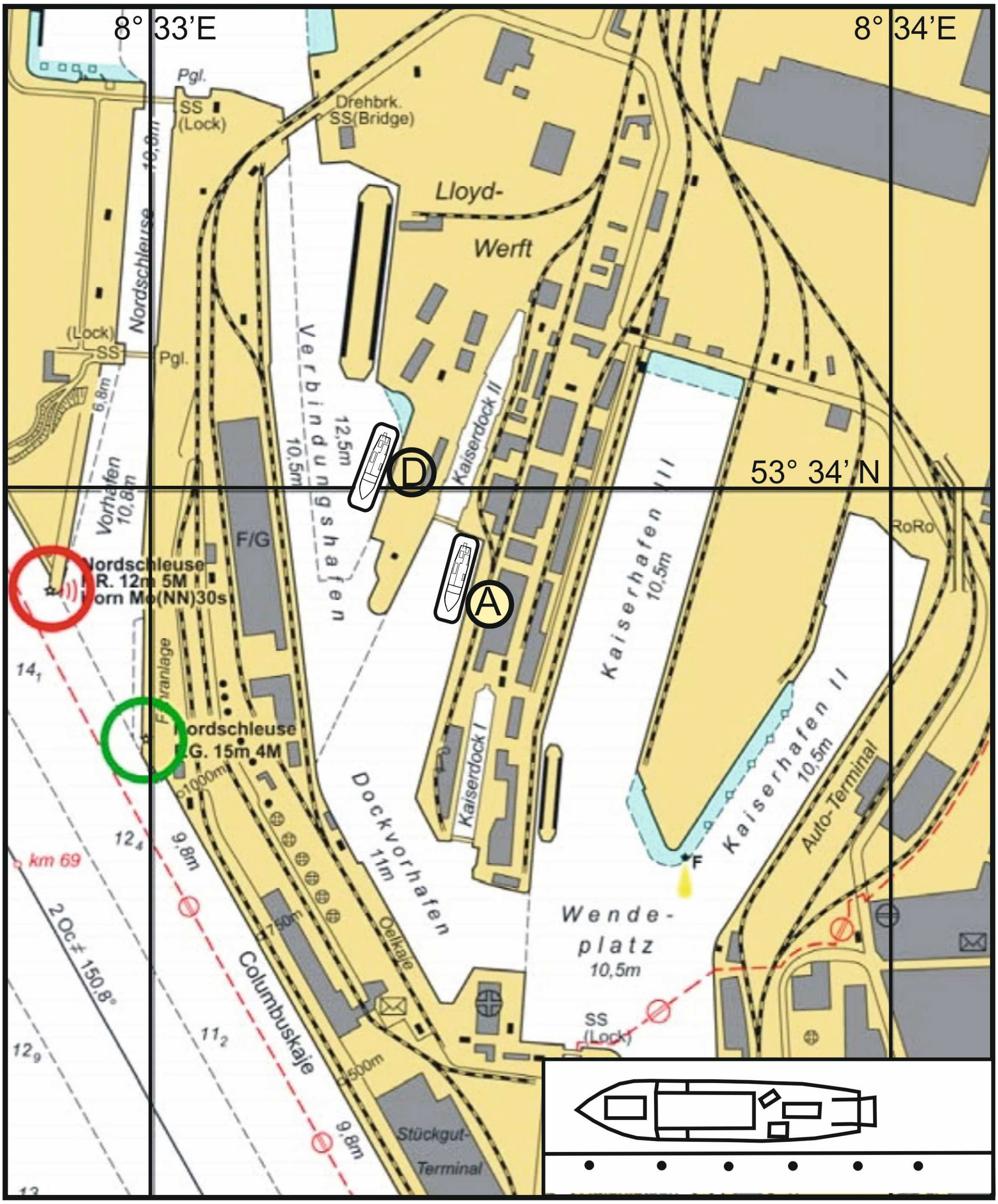


Fig. 16: Location of the mooring sites A and D of RV OGS EXPLORA at the Lloyd shipyard in Bremerhaven.

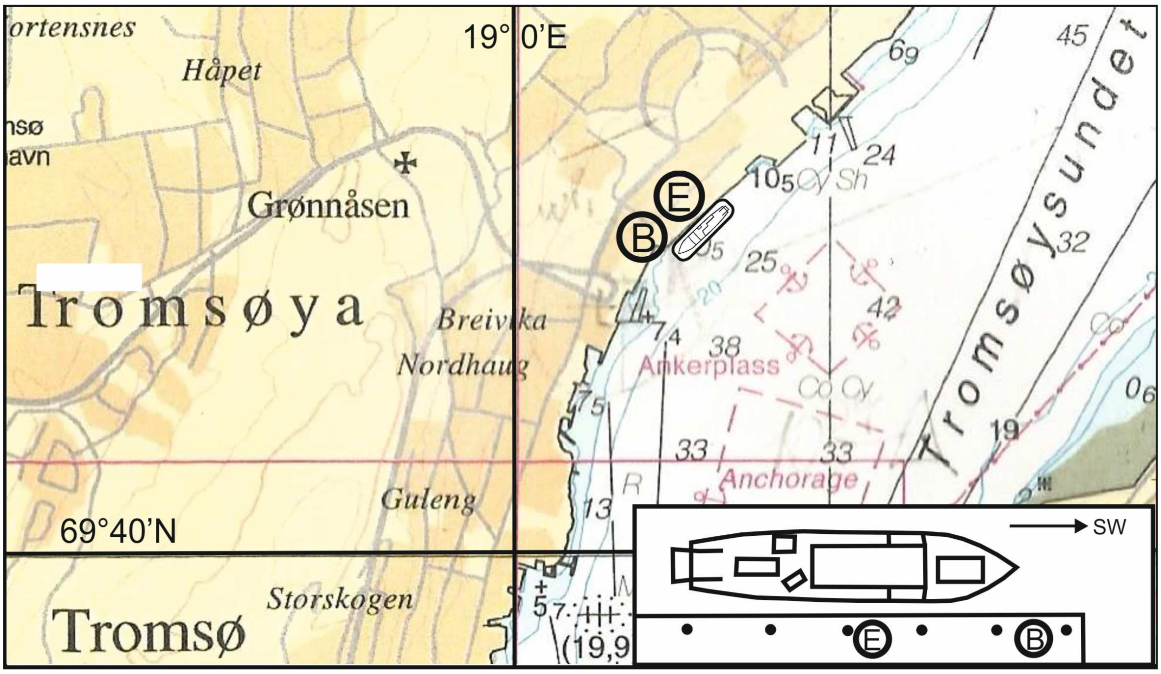


Fig. 17: Location of the mooring sites B and E of RV OGS EXPLORA at Breivika pier in Tromsø.

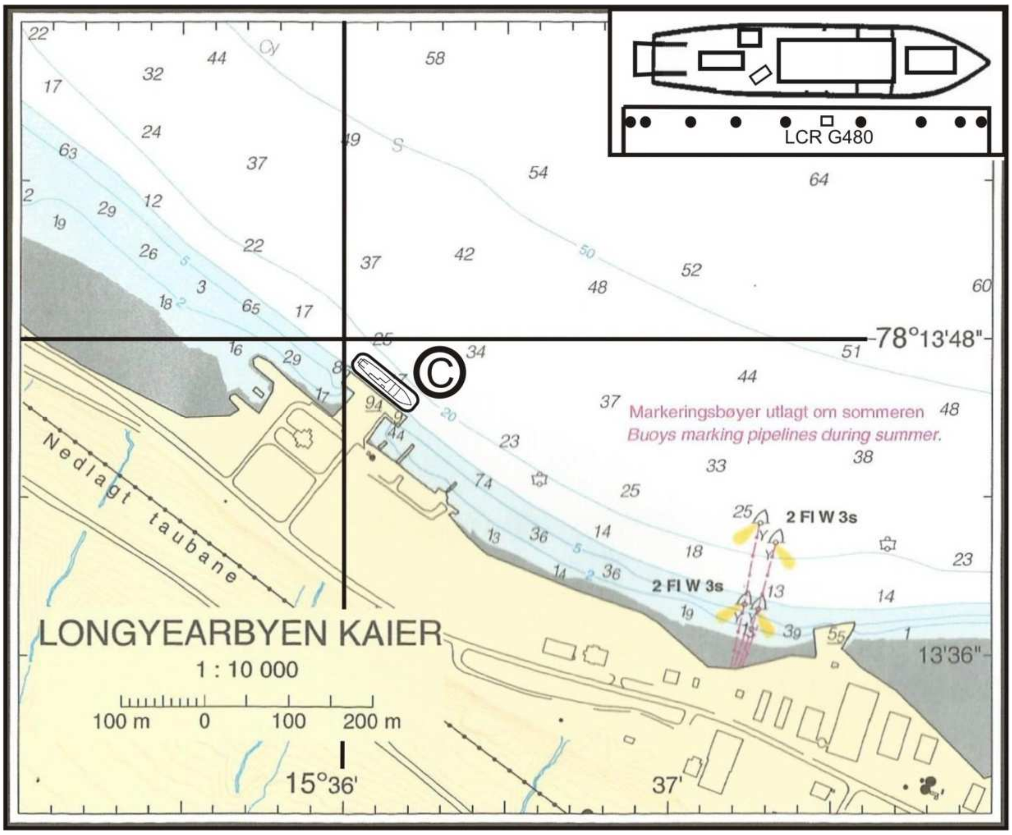


Fig. 18: Location of the mooring site C of RV OGS EXPLORA in Longyearbyen.

9. MAGNETICS

Bernd Schreckenberger

9.1 Magnetometer systems and operation

Towed magnetometer system

The SeaSpy™ gradient magnetometer system manufactured by Marine Magnetics Corp with two scalar Overhauser magnetometer sensors was used during cruise PANORAMA-2. It consists of two proton precession magnetometers, enhanced with the Overhauser effect. Two equivalent magnetometer sensors are towed 150 meters apart as a longitudinal array about 275 meters astern of the ship (**Fig. 19**). 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).

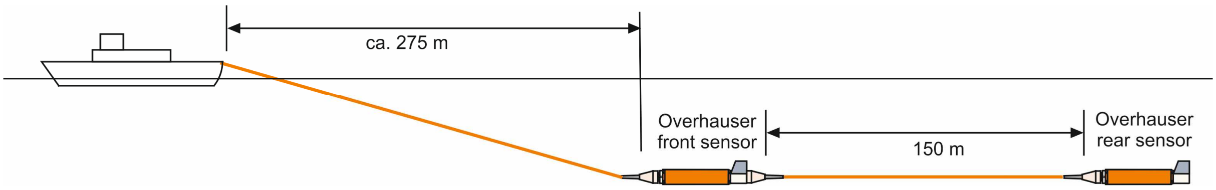


Fig. 19: Schematic sketch of the towed gradiometer system setup.

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 towed gradient magnetometer system was only used on Leg 2 of cruise PANORAMA-2. The magnetometer array according was towed over an A-frame and an additional boom on the starboard side of the vessel (**Fig. 20**).

Due to technical problems the first three profiles (BGR15-210 to -212) were surveyed with only a single magnetometer sensor (S/N 13042 and S/N 13043). On lines BGR-213 to -224 we used the gradiometer configuration (**Fig. 19**) with sensors S/N 13042 and S/N 13335. Lines BGR-225 to -227 were again surveyed with only one sensor (S/N 13042).

The effective length of the tow cable (275 m) behind the stern of the ship was shorter than normal and a significant influence of the magnetic field of the ship was visible as an offset of about 2-3 nT between the gradiometer sensors.

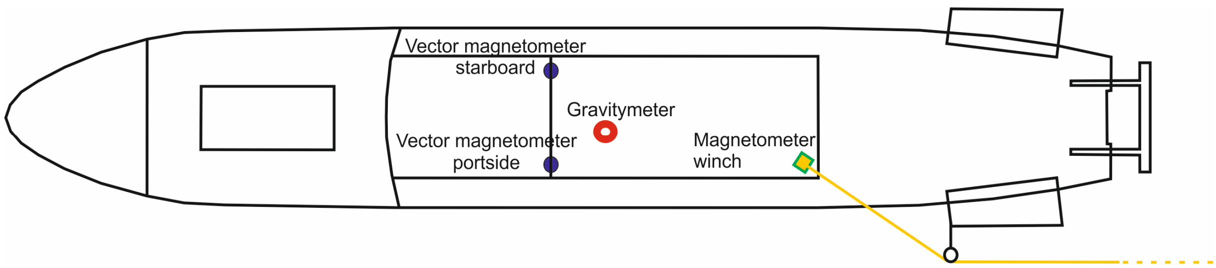


Fig. 20: Deployment configuration of the towed gradiometer array and installation locations of the ship-borne vector magnetometers.

Shipboard vector magnetometer

A vector magnetometer system was installed on the observation deck of the vessel. It consists of two separate waterproof housings that contain orthogonal digital ring core fluxgate sensors and two-axis inclinometers, a data acquisition box and a GPS mouse. The system was built by MAGSON GmbH in Berlin for BGR as an onboard system for research vessels. The sensors have a dynamic range of +/- 100000 nT and a long-term stability of <10 nT/year and were fixed to the railing on the port and starboard sides of the observation deck (**Fig. 20**). The data are recorded internally on a CF memory card. Two different types of data files are stored separately for each hour. The first file type (file extension M60) contains the values of three orthogonal vector components and the inclination values together with UTC time marks. The sampling rate can be chosen between 1 and 20 Hz. On this cruise we used 10 Hz. The second file type (file extension S60) contains time marks and latitude and longitude from the GPS receiver and temperature values for both sensors. The sensors are internally heated to a selectable temperature, on Leg1 of our cruise to 25°C and on Leg2 to 20°C. Additionally we also recorded the values from the ship's motion reference units (heave, roll, pitch, and azimuth). Experience shows that roll and pitch values from the vessel sensors are more precise than the inclinometer values from the fluxgate sensors which notoriously suffer from errors due to dynamic accelerations.

Two dedicated vector magnetometer calibration loops were performed on September 9 at 17:15 UTC and on September 16 (at 16:15 UTC).

Using the data from the calibration loops and from additional loops and turns between seismic profile lines (Leg1) and geological stations (Leg2) it will later be attempted to compensate for the ships magnetic field by estimating the compensation matrix during turns and to calculate total intensity values and magnetic anomalies from the vector components. Additionally it is intended to apply methods that were used by e.g. Seama et al. [1993], Korenaga [1995], Parker and O'Brien [1997] and Engels et al. [2008] to utilize the vector components for the determination of magnetic strike directions.

9.2 Data processing

The data from the towed magnetometer system were recorded in the PDS2000 system of the ship and via the SeaLink software by Marine Magnetics on a dedicated notebook. A first attempt to process the gradient data [*Eilers et al.*, 1994]; **Fig. 21** shows that nearly all lines are heavily disturbed by variations and that the single magnetometer data should not be used for interpretation. This also disqualifies the data for lines where only a single magnetometer was deployed (e.g. BGR15-226) from being used for any interpretation. Fortunately, the survey area west of 32°E is completely covered by a dense high quality aeromagnetic survey [*Skilbrei*, 1991] and all profiles east of 32°E were surveyed with gradient data.

After the cruise the data will be converted into the BGR data acquisition and processing framework. Then, all routine and special processing methods for gradiometer and vector magnetometer data will be available. This includes a program package described by Eilers et al. [1994] and Roeser et al. [2002] that can be used to calculate the variation-free anomalies from the gradient. An alternative program suite [*Engels et al.*, 2008] usually gives similar results for the reconstruction of the residual total magnetic field anomalies but is also able to process and calibrate the vector data.

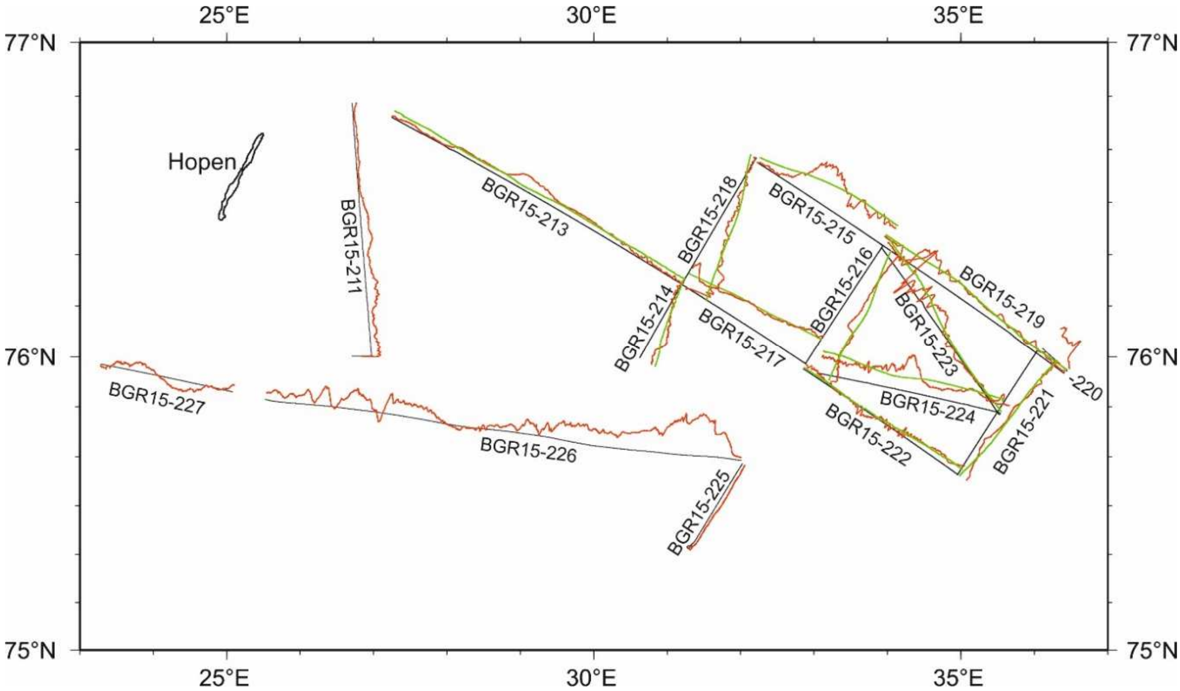


Fig. 21: Comparison of magnetic anomalies in the survey area with and without gradiometer evaluation. Red curve: single magnetometer anomaly, green curve: magnetic anomaly reconstructed from the gradient. Line BGR15-210 does not contain usable data and lies outside of the map area. Line BGR15-212 is nearly coincident with BGR15-213 and is also not shown. It is even more disturbed than BGR15-213 and does not have gradient data.

10. MULTI-CHANNEL SEISMIC REFLECTION (MCS) RECORDING SYSTEM

Michael Schnabel, Boris Hahn, Thomas Behrens, Ümit Demir, Axel Ehrhardt

Please note: The correct line/profile identifier for the PANORAMA-2 cruise is BGR15-2xx. Due to technical issues the line identifier for the seismic lines is BGR15-1xx. Therefore we will refer to any seismic line in this report as BGR15-1xx. All other data like hydroacoustic data, magnetic data and gravity data use the line identifier BGR15-2xx.

10.1 Methods

Two different types of seismic investigations were applied during the cruise in order to match the scientific tasks (**Fig. 22**). The imaging and identification of the sedimentary pattern and the uppermost crustal structure was carried out with multi-channel seismics (MCS). For a better control on the seismic velocities, the MCS method was expanded by sonobuoy wide angle and refraction measurements.

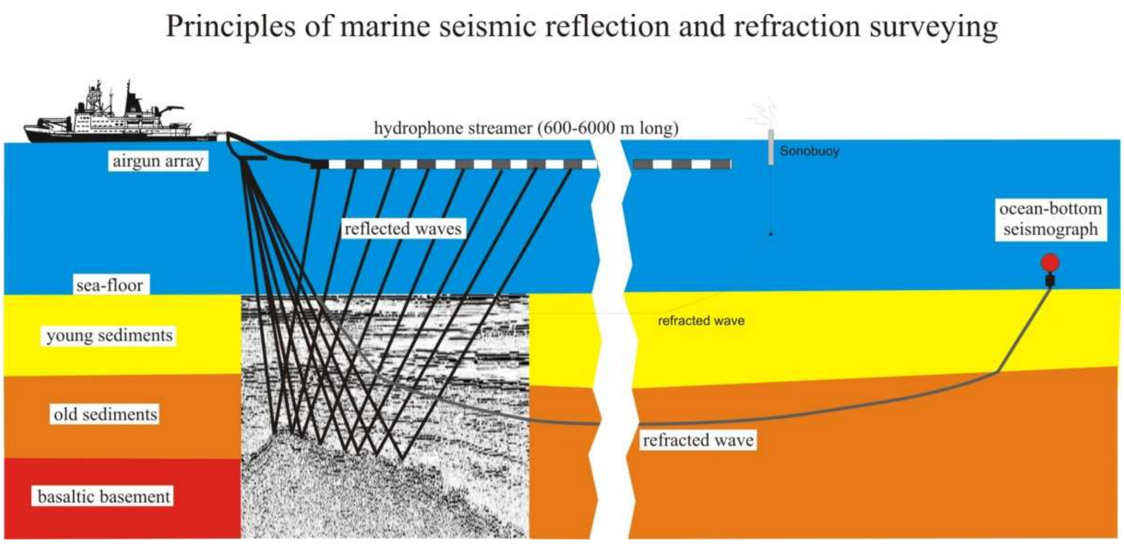


Fig. 22: Marine seismic methods: Multi-channel seismic (MCS) for recording of reflected waves, sonobuoy measurements for refracted waves (no OBS were deployed during this cruise).

All seismic operations were conducted in a way to minimize the acoustic impact and a possible disturbance of marine life as much as possible and to reduce operation times to the lowest practicable and necessary for the scientific goals. This follows best practice rules of BGR for using marine seismic methods within all own research activities. To meet this mitigation measures an external marine mammal observer was contracted (see Chap. 12).

10.2 Seismic equipment and survey setup

The main target for the seismic reflection survey of PANORAMA-2 campaign was to image the sedimentary sequence of the Olga and Sørkapp Basins as deep as possible, best down to the base of the basins. In order to achieve this target we chose a source volume as large as possible (8 G-Guns à 250 in³), being aware that the signal shape will not be good and that we will have to deal with a prominent bubble signal. Source designature processing is planned to overcome this handicap. For the Barents Sea survey we used a streamer cable with 3600 m active length (24 Sercel ALS sections á 150m with 12 channels each). After a collision with floating ice, we replaced the tail buoy with an inflatable buoy. The streamer winch was placed middle of the working deck and the streamer cable was deployed by use of the A-frame at the stern.

In general the streamer was towed in a depth of 12 m, for the enhancement of low frequencies and in order to avoid ice contact.

Source arrays of eight 250 in³ G-Guns were fixed in 2 rows with 4 guns each. The distance between the two arrays was 14 m. These two gun arrays were towed close to the stern of the vessel (approx. 25 m behind the stern) in order to protect the guns and umbilicals from drifting ice bergs and growlers.

Seismic sources, triggering and timing

Airgun system

On Board of OGS Explora we used the OGS GI-Gun hanger system with four 250 in³ G-Guns. The G-Gun array is subdivided into two sub-arrays. Each string consists of two clusters with two airguns each. The volume of each gun was 250 in³ (4,1l). The total volume of the array was 2000 in³ (32,8l) in use. The compressed air was produced by three LMF-Type 240HB Compressors. Each was capable to produce 24 m³/min at 140 bar working pressure. Every LMF-Compressor was powered by a 362kW MAN Diesel engine.

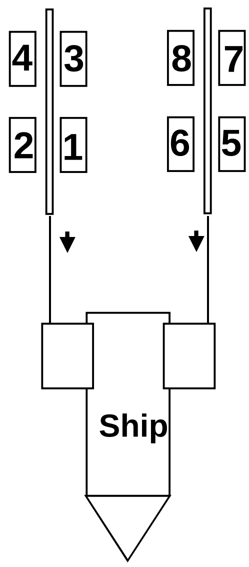


Fig. 23: Sketch of the airgun setup used on OGS Explora. The center of each string was 25 m behind the stern of the vessel.

The towing depth of the airguns was 6m throughout the survey. The center of each sub-array was 25 m behind the stern of the vessel. The lateral distance between the sub-arrays was 14m. The nominal working pressure of the guns is 2100 psi (145bar). Triggering and synchronization was controlled by a BigShot Gunsystem from “Real Time Systems”. The triggering signal was provided by the Ships navigation laboratory. Before stating the measurements we increased the airgun power stepwise during a soft-start procedure (ramp-up). The ramp-up was done by shooting with 20 sec. intervals. During this soft-start period we enabled for 3–minutes on each Gun. The complete Airgun volume was in use by 24 minutes. For details see the observer logs.

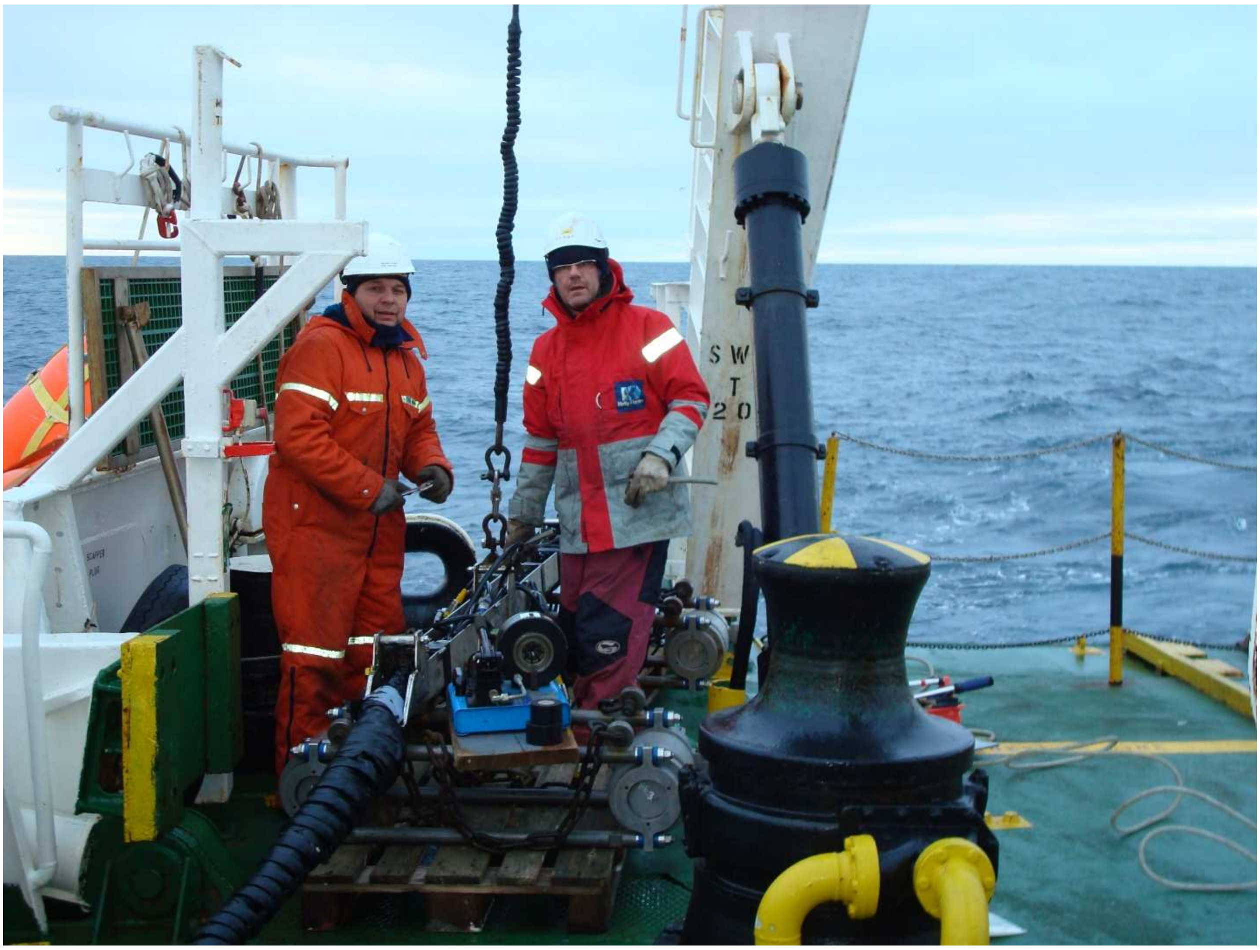


Fig. 24: Maintaining the starboard airgun cluster with four 250 in³ G-Guns. In general the airguns and the clustering of the airguns worked fine and without major problems.

Multi-channel seismic reflection (MCS) recording system

BGR's SEAL seismic recording system and a digital cable with an active length of 3600 m were used to record the seismic data. The bird controlling system (DigiCOURSE System3) and the streamer control system are interfaced with the Master PC. The system start trigger was generated by OGS-Navigation. The data for the external header, e.g. from the DigiCOURSE, navigation system, GPS-clock etc., are received and the external header was generated, stored and sent via an interface to the SEAL system (**Fig. 29**).

The DigiCOURSE System 3 was used to control the vertical streamer position (depth) and to measure the heading and temperature. DigiCOURSE System 3 is a hardware and software package that controls and collects data from a network of acoustic sensors and streamer positioning devices (**Fig. 25**). The system has online command, diagnostic, and performance-monitoring capability. System 3 employs a modular architecture which provides for a variety of configurations and levels of functionality. The minimum system equipment configuration includes two real-time processors: an Operator Interface (OI) and a Data Management Unit (DMU), a Line Interface Unit (LIU), and cable-mounted measuring devices: birds with compass. It is suggested to get the full equipped streaming device self-buoyant. To produce more buoyancy we mounted at each bird position a floatation tube or instead that a recovery system which has a self-triggering mechanism at a depth of 50 m. We operated the cable at a depth of 12 m (see **Fig. 26**)

Fig. 25: DigiCOURSE System 3 bird with compass

Streamer system

BGR's SEAL streamer consists of 24 seismic sections (24*ALS) with 288 channels (**Fig. 26**). It has a flexible architecture with redundant data transmission modes, i.e. data transmission may be reconfigured on line failure. Each channel has an individual 24 bit, Sigma Delta A/D converter. The active streamer sections have a diameter of 50 mm.

The SEAL 428 is a high-resolution seismic data acquisition system designed for marine towed streamers acquisition. The SEAL recording system is capable to handle a maximum recording capacity of 960 channels (@ 12.5 m; 2 ms) per streamer, a maximum record length of 47 s (navigation triggered, SR = 2 ms). The sampling rate may vary from 1/4 ms, 1/2 ms, 1 ms, 2 ms to 4 ms. During the cruise we sampled the data at 2 ms. The HP DL380 G7 Server is capable to support a maximum of 17500 channels (SR 2 ms).

Fahrt	PANORAMA 2 mit OSG EXPLORA												CB1	WB CB2
Profil	BGR15-101 bis BGR15-101h							Slip Ring		Lead In (200m) 30 m	SHS 6m	HAU	HESE 50m	HESA 10m
								8356-0904		M338030/01	1687	5352069	4807	4802
		CB3			CB4/R1							CB5/R2		
SNS	QS 50	ALS 1	SNS	QS 50	ALS 2	SNS	QS 50	ALS 3	SNS	QS 50	ALS 4	ALS 5	LAUM	ALS 6
50/50	1	1 - 12	50/50	2	13 - 24	50/50	3	25 - 36	50/50	4	37 - 48	49 - 60	1	61 - 72
1041328121	6686779	7018	1044624177	6686879	9251	1044624183	6686899	9256	1044624184	6687799	8637	9260	5043	9242
	CB6				CB7/R3			CB8				CB9/R4		
ALS 7	ALS 8	ALS 9	ALS 10	LAUM	ALS 11	ALS 12	ALS 13	ALS 14	ALS 15	LAUM	ALS 16	ALS 17	ALS 18	ALS 19
73 - 84	85 - 96	97 - 108	109 - 120	2	121 - 132	133 - 144	145 - 156	157 - 168	169 - 180	3	181 - 192	193 - 204	205 - 216	217 - 228
9247	9246	9252	9259	4017	9257	2175	9237B	9240	9241	4373	9253	9249	9248	9254
CB10			CB11/R5		CB12/R6									
ALS 20	LAUM	ALS 21	ALS 22	ALS 23	ALS 24	TAPU	TES	STIC						
229 - 240	4	241 - 252	253 - 264	265 - 276	277 - 288		50m	25m	TS					
9245	1710	9250	9244	5948B	7021	522	3198	429	4451					

Abstand Heck:		S/N		S/N
104	CB1 :	36056		
154 m	CB2 :	36194		
307 m	CB3 :	58797	Flotation Tube	
447 m	CB4 :	60776	Recovery 1	32159
907 m	CB5 :	37995	Recovery 2	32160
1357 m	CB6 :	60794	Flotation Tube	
1807 m	CB7 :	36274	Recovery 3	32161
2257 m	CB8 :	36192	Flotation Tube	
2707 m	CB9 :	58943	Recovery 4	32167
3157 m	CB10 :	60644	Flotation Tube	
3457 m	CB11 :	36273	Recovery 5	32165
3757 m	CB12 :	59560	Recovery 6	32164

Gesamtlänge (Heck - Endboje): 3778 m

Blaue Spule für CB: Abstand von Headkupplung 140,6m (ALS), 47,5m (HESE), Ziehstrumpf: 26,5m von Tailende LeadIn

CB: Compassbird R: Streamer Recovery Device 500 / 500S

Fahrt	PANORAMA 2 mit OSG EXPLORA												CB1	WB CB2
Profil: 102 -								Slip Ring		Lead In (200m) 30 m	SHS 6m	HAU	HESE 50m	HESA 10m
								8356-0904		M338030/01	1687	5352069	4807	4802
		CB3			CB4/R1							CB5/R2		
SNS	QS 50	ALS 1	SNS	QS 50	ALS 2	SNS	QS 50	ALS 3	SNS	QS 50	ALS 4	ALS 5	LAUM	ALS 6
50/50	1	1 - 12	50/50	2	13 - 24	50/50	3	25 - 36	50/50	4	37 - 48	49 - 60	1	61 - 72
1041328121	6686779	7018	1044624177	6686879	9251	1044624183	6686899	9256	1044624184	6687799	8637	9260	5043	9242
	CB6				CB7/R3			CB8				CB9/R4		
ALS 7	ALS 8	ALS 9	ALS 10	LAUM	ALS 11	ALS 12	ALS 13	ALS 14	ALS 15	LAUM	ALS 16	ALS 17	ALS 18	ALS 19
73 - 84	85 - 96	97 - 108	109 - 120	2	121 - 132	133 - 144	145 - 156	157 - 168	169 - 180	3	181 - 192	193 - 204	205 - 216	217 - 228
9247	9246	9252	9259	4017	9257	2175	9237B	7027	9241	4373	9253	9249	9248	9254
CB10			CB11/R5		CB12/R6									
ALS 20	LAUM	ALS 21	ALS 22	ALS 23	ALS 24	TAPU	TES	STIC						
229 - 240	4	241 - 252	253 - 264	265 - 276	277 - 288		50m	25m	TS		Ball			
9245	1710	9250	9244	5948B	7021	522	3198	429	4451					

Abstand Heck:		S/N		S/N
3757 m	CB1 :	36056		
3757 m	CB2 :	36194		
3757 m	CB3 :	58797	Flotation Tube	
3757 m	CB4 :	60776	Recovery 1	32159
3757 m	CB5 :	37995	Recovery 2	32160
3757 m	CB6 :	60794	Flotation Tube	
3757 m	CB7 :	36274	Recovery 3	32161
3757 m	CB8 :	36192	Flotation Tube	
3757 m	CB9 :	58943	Recovery 4	32167
3757 m	CB10 :	60644	Flotation Tube	
3757 m	CB11 :	36273	Recovery 5	32165
3757 m	CB12 :	59560	Recovery 6	32164

Gesamtlänge (Heck - Endboje): m

Stand:20.08.2015

Blaue Spule für CB: Abstand von Headkupplung 140,6m (ALS), 47,5m (HESE), Ziehstrumpf: 26,5m von Tailende LeadIn

CB: Compassbird R: Streamer Recovery Device 500 / 500S

Fig. 26: Streamer configuration used.

In-water equipment

The seismic data are amplified, filtered, and analogue-digital converted within the SEAL streamer by using the following main modules installed in the streamer: 4 LAUM-428, 1 TAPU428, 1 AXCU and 1 HAU-428.

Lead In — The Lead In is an armoured towing cable and tows the seismic cable. The cable contains an electric core for power transmission and four optical fibers for data transmission (two used, two spare).

HESE — Head Elastic Section Extension. The HESE is used as mechanical uncoupling between the active part of the streamer and the towing vessel.

SHS — Short Head Section. The SHS adapts mechanical the Lead-In and the streamer.

HESA — Head Elastic Section Adapter. The HESA adapt the connectors between the HESE (70 mm connector) and the active part of the streamer (50 mm connector). This includes also two Water Break hydrophones at 0.38 m and 1.07 m measured from the front.

HAU 428 — Head Auxiliary Unit 428. The HAU428 provide power to telemetry lines, provide power to the TLFOI (Tail Lead-In Fiber Optic Interface) and measures the tension on the streamer. During cruise PANORAMA 2 the tensile stress was about 800 daN.

ALS — Acquisition Liquid Section. Our Streamer was composed of 24 ALS. The Acquisition Liquid Section is filled with Isopar. To reduce fluid movement, oil block bulkheads are mounted on either side of every channel. The active sections hold the electronics for the seismic acquisition. It also contains depth bird and acoustic positioning coils. An active section is 150m long and contains six Field Digitizer Units (FDU2M) to acquire and digitize 12 channels. A channel is composed of a group of 16 hydrophones, the space between two channels is 12.5m.

LAUM — Line Acquisition Unit Marine. The LAUM performs data routing, power supply of max. 60 active channels, decimating, filtering and compressing on the data before sending it back to the DCXU 428. It also synchronise all the samples with the time break.

TAPU — Tail Acquisition and Power Unit. The TAPU includes the same functions as the LAUM. It performs also supplying 40 V_{DC}, 30 W power to the tail buoy and re-routing of the data if needed.

TES Tail Elastic Stretch. The TES is used as mechanical and noise uncoupling between the active part of the streamer and the tail equipment (e.g. tail buoy).

STIC Streamer to Tail Interface Cable. The STIC interface between streamer and tail buoy.

Onboard equipment

SERVER 428 The server computer we used is a “HP DL380 G7”. The software is based on the Linux distribution RedHat version 6.3 ES 64 bit. The HP DL380 G7 Server is capable to support a maximum of 17500 channels (SR 2 ms). The Server is used for formatting the 24 bit data from the streamer interfaces and auxiliary interfaces into IEEE standard and then to SEG-D. The server manages the export process to the external storage devices (NAS), the e-SQC Pro system and the QuietSea system.

CLIENT 428 The workstation we used is a HP Z420 computer. The software is based on the Linux distribution RedHat version 6.3 ES 64 bit. The client computer is used for user interaction with the SEAL 428 system. The operator controls the complete SEAL 428 system through the client computer.

LCI 428 Line Control Unit 428. The LCI 428 detect the T0 pulse from navigation, retrieve the navigation header by serial link and retrieve data from the AXCU´s auxiliary channels.

DCXU 428 Deck Cable Crossing Unit 428. The DCXU-428 is used as an interface between the streamer and the server. It also houses a high-voltage power supply for the streamer´s electronic. The DCXU 428 is also used as an interface between the streamer and the bird controller and QuietSea system.

Time Server The “Meinberg LanTime M300” Time server is disciplined by GPS and/or GLONASS satellites and provides a time base with an accuracy of 10^{-13} sec. The time server provides all the necessary signals to ensure the synchronisation of all SEAL components. A PPS signal and a NMEA frame synchronize all the DCXU 428 and LCI 428 and a NTP network protocol synchronizes the server and client computers.

AXCU Auxiliary Channel Unit. The AXCU is able to sample any analog signal. The AXCU was used to record the data from the Water Break hydrophone.

NAS	We used two external storages (QNAP TS-569 Pro and TS-259 Pro+) for the produced SEG-D files.

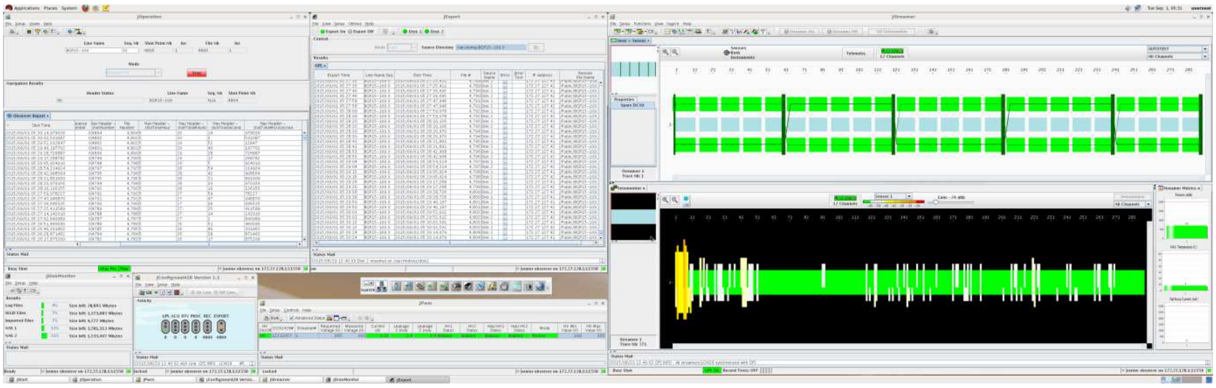


Fig. 27: Observer window on the SEAL 428 Client, displayed on two 24 inch LCD

eSQC-Pro Processing Quality Control

Continuous online seismic data quality control is performed using an eSQC-Pro client ‘HP Z420’ connected directly to the eSQC-Pro Server “HP DL380” without slowing down the acquisition. Three main windows are used for quality control:

- The History display window with bar graphs shows a summary of errors and source attributes for the successive shots processed by the eSQC-Pro. It displays the attributes of the data from the previous shots.
- The Normal display window shows the latest incoming SEGD shot record. The traces are displayed in the time/distance range with the noise of each trace on top of the display.
- The Single Trace window shows the data of one selected channel from the streamer. With each new shot the display is updated with the new acquired trace added to the window. Four single trace windows may be opened simultaneously.

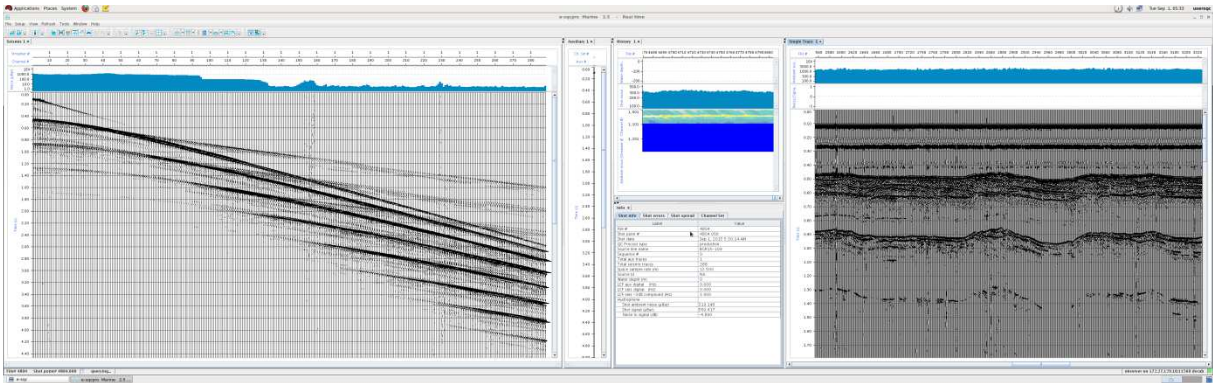


Fig. 28: Observer window on the SEAL e-SQC Client, displayed on two 24 inch LCD

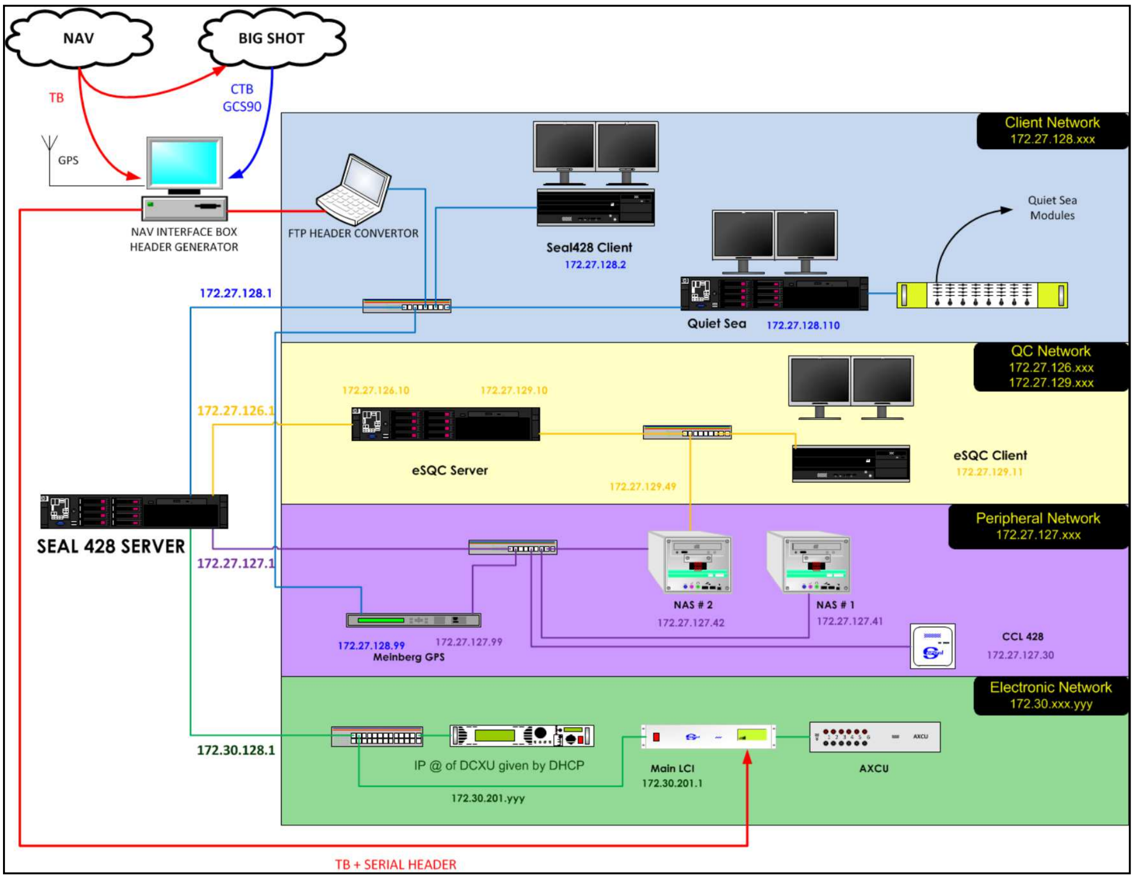


Fig. 29: Signal flow diagram for BGR's reflection seismic data acquisition system.

Shot triggering

Before starting data acquisition a soft-start procedure of the airguns was completed. During this procedure we operated 3 minutes with one gun, shooting with an interval of 20 seconds. After 3 minutes a second gun was added and two guns together were shooting every 20 seconds. So each 3 Minutes one gun was added and after 21 minutes the soft-start procedure was finished. After that the regular shooting began for production of seismic lines.

The triggering of the guns during production was performed by OGS equipment. The shots were triggered by the OGS- Navigation System PDS2000 from Reson B.V. The intended shot distance of 25 m was achieved at a speed of approx. 4.0 knots. The shot trigger was sent to the RTS BigShot and to the Master PC simultaneously. After receiving the trigger the Master PC simultaneously starts the data acquisition cycle at the Seal system 50ms before shooting and waits for the time-break signal received from Bigshot after shooting before transferring the external header data to the Seal-System. The Seal system recorded the data with a record length of 9 s. The Master PC is running under Microsoft Windows XP, the Software is LabView Ver.8.6 from National Instruments and the Master PC has a build in Meinberg GPS clock (GPS167PCI) to capture the time from the incoming time-break signal.

Shot triggering for sonobuoy profiles

The shots for the sonobuoy lines (BGR15-1R0 to BGR15-1R3) were triggered in time intervals of 30 seconds. The time-break signals are captured by the master PC, with build in high-precision GPS clock. The sonobuoy recorders are synchronized with GPS-Time over Meinberg GPS 166 clock. The shot time interval was generated by the OGS-Navigation System PDS2000 from Reson B.V. and sent to the RTS BigShot trigger device.

Quality control

Quality control during acquisition comprised:

- Observation of the hydrophone signals within the arrays and adjustment of the trigger delays for an optimum signal.
- Checking and recording the streamer depth and position (heading) every shot via the control screen of the DigiCOURSE System 3. These data are stored in the header.
- Continuous checks whether all sections of the streamer are free of abnormal noise and give about the same signal amplitude. This was done for every shot via the QC Graphics display of the SeaProQC system.
- Continuous observation of the single resp. near trace records.

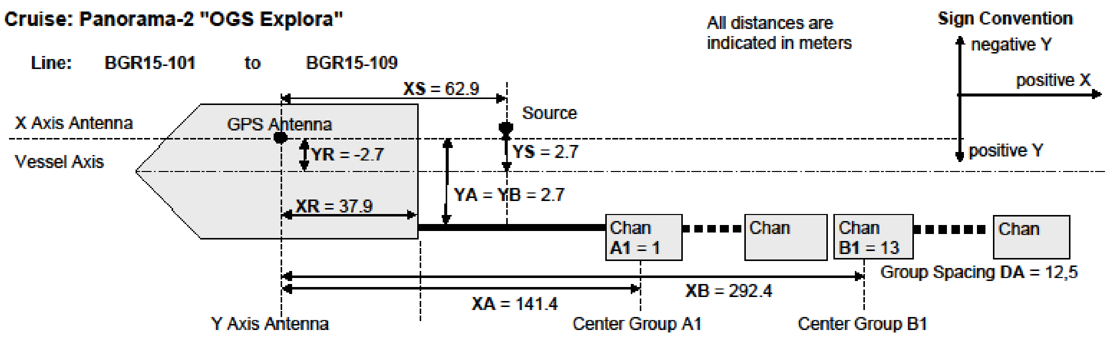
10.3 Processing of multi-channel seismic reflection data

Seismic data processing was done using a Linux workstation with ProMAX™ 2D, Version 5000.0.1 licenses. The workstation has two Quadcore AMD CPUs, a RAM of 32 GB and a 170 GB system hard drive. The operating system is CentOS Linux 5.0. Data was stored on two internal hard drives. Backup was carried out on to an attached NAS system.

Onboard processing was done for all acquired MCS data including the following steps: geometry setup, data and geometry input, prestack processing to enhance signal quality including multiple reduction, data stacking and Kirchhoff migration.

Geometry setup

The streamer – airgun setup that was used during the OGS Explora cruise is summarized in (**Fig. 30**).



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	1	12	1*		12.5	XA=141.4	YA=2.7	Streamer Patterns
2	13	24	1		12.5	XB=292.4	YB=2.7	
...	25	36	1		12.5	443.4	2.7	
	37	60	1		12.5	594.4	2.7	
	61	120	1		12.5	894.7	2.7	
	121	180	1		12.5	1645.1	2.7	
	181	240	1		12.5	2395.5	2.7	
M	241	288	1		12.5	3145.9	2.7	
M+1				1**		XS=62.9	YS=2.7	Source Patterns
...	.							

*) -1 if A1 > AN, 1 if A1 < AN   **) The Src Pattern numbers has to be indicated in the SIN Ordered Parameter File

Remarks: All positions are referenced to the Topcon antenna.

Fig. 30: Sketch of the streamer and airgun geometry aboard of RV OGS Explora.

The geometry of the source and the receivers was set up in relation to the GPS antenna position (Topcon). The active streamer length was set to 3600 m with 288 channels for all seismic lines. In ProMAX the 2D Marine Geometry Spreadsheet was used. It includes the following steps which have to be carried out in the geometry setup sequence:

File. UKOAA Import:

The navigation data were transformed by the navigation group into rectangular UTM coordinates and saved in the format “STANDARD UKOOA 90 Marine 2D”. The shot numbering from the navigation group was written to the field “Station”.

Setup:

All lines were acquired with 12.5 m nominal receiver spacing and 25 m nominal source station interval. The other parameters changed and are reported in the acquisition logs. All units are given in meters.

Sources:

The streamer azimuth has to be calculated using “auto azimuth”. The algorithm used for this by ProMAX is very crude. It is based only on the first and last source point, the calculated azimuth is assigned to all source positions. The column “Src Pattern” has to be filled with the number of the pattern defined in the next step. Shotpoint interval and error were checked by the QC tool. The navigation files sometimes show a small amount of failed triggers – these positions are deleted in the table and also in the navigation file.

Patterns:

The streamer and source patterns have to be defined according to the spreadsheet in **Fig. 30.**

Bin:

The binning consists of three steps:

1. Assign Midpoint.
2. Binning. Source station tie to CDP number: This is usually shot number 2 (sometimes shot number 1 was missed by the navigation crew). In some cases the shots were already recorded when the ramp up was applied and the vessel still turned. In these cases the first shot on the line was noted in the acquisition logs and this shot should be entered as station tie to CDP number;

   CDP Number tie to source station: 10000. This tie fulfils BGRs standard for CDP numbering: The first station with full coverage is tied approximately to CDP 10000. Distance between CDPs: 6.25 m. This implies a nominal CDP coverage of 72 (for 288 channels) in case of a shot increment of 25 m. Binning was done for CDP locations and receivers (CDP numbers and receiver numbers increasing with increasing shot number).
3. Finalize Database.

TraceQC:

Quality control of the binning. Here two checks are undertaken:

a) Checking the computed offsets with the offsets given in the streamer plan by comparing the values for the last hydrophone group (channel 288) and nearest hydrophone group (channel 1).

b) Checking if the source and receiver locations (in UTM coordinates) are behind the vessel in relation to the sense of direction.

A further quality control was done by using the graphical display tools of the database application:

c) CDP fold map (Database => View => Predefined => CDP fold map). X_COORD and Y_COORD – Axes; FOLD: Color coded and as histogram.
d) CDP fold table (Database => View => Tabular => CDP): List of CDP Number, FOLD, X_COORD and Y_COORD.

SEG-D input from NAS and geometry application

Data were loaded from NAS hard drive using the ProMAX module SEG-D Input. The SEG-D Input module fails, if the path name to the SEG-D files is too long. An acceptable work-around is to create a soft-link in the root directory to the SEG-D-file directory.

The shot-ordered data consists of 288 data channels and 5 auxiliary channels sampled at 2 ms with a recording length of 9000 ms. The auxiliary channels record data from the waterbreak hydrophone; the remaining 4 aux channels were void. With the “Display ensemble information” set to YES a summary of all imported shot is written to the log-file. This is helpful in case that there are problems during acquisition. The shot counter from the Master PC was remapped from the SEG-D main header values using the option “Input/override main header entries: SH_PC, BGR counter,5c,,,1649/” within SEG-D input.

Resampling (Resample/Desample)

The seismic data has been acquired at 2 ms sampling rate. To speed up the onboard processing, the data has been re-sampled to 4 ms applying a high-fidelity anti-alias filter.

SOD time correction (Header Statics)

The Sercel acquisition system starts registration 50 ms before triggering of the airguns occurs. This time delay has been verified on the auxiliary channel containing the signal from the waterbreak hydrophone at AUX CHAN -1 and on the direct water wave on the groups near to the source.

Geometry Apply (Inline Geometry Header Load)

With this ProMAX module, the geometry information from the database were written into the trace headers. Since there was no real-time data transfer from the navigation system to the data recording system (only triggering), it was not possible to record the original shot numbering within the seismic data. Therefore, the match between navigation and seismic data was done with the time stamp, using the headers “TIME_SHOT” and “DAY_SHOT” with a time tolerance of 1 sec. An example of the parameters used in this module is shown in **Fig. 31**.

Finally, the Trace Header Math module inserted an entry for the line number header word. The altered data was written to hard disk as new prestack data set (Disk Data Output).

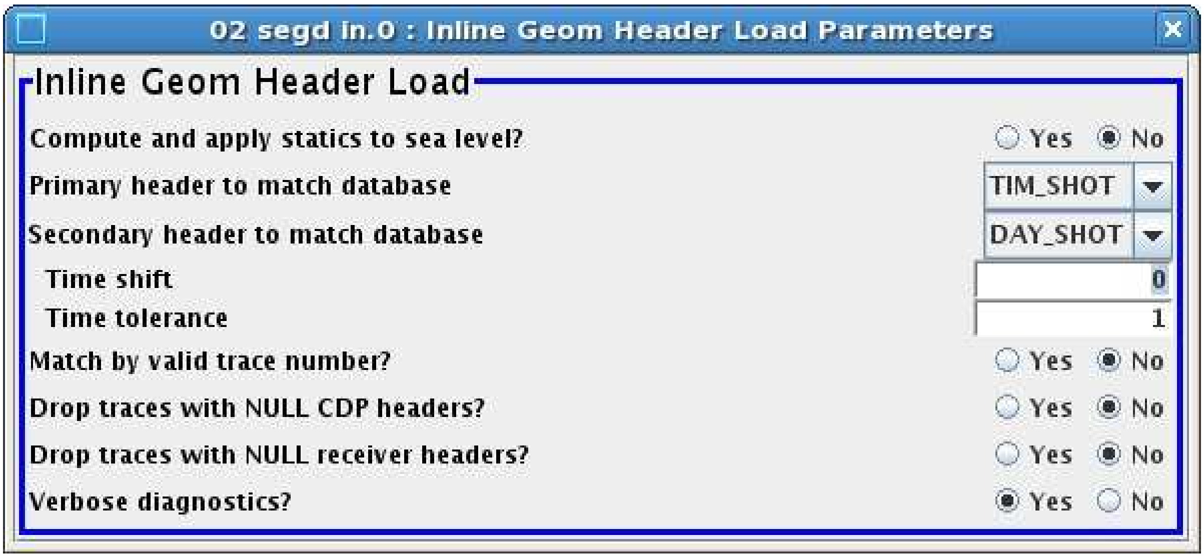


Fig. 31: Parameters used for the module "Inline Geom Header Load".

Pre-processing

Wavelet Analysis

Due to the limited possibilities aboard of RV OGS Explora, we used an airgun array which was not perfectly tuned. Therefore, we carefully analysed the shape of the produced seismic signal. We stacked the recording from the water break (auxilary channel 1) of 1200 shots along profile BGR15-103 to obtain the wavelet. The result is shown in **Fig. 32**.

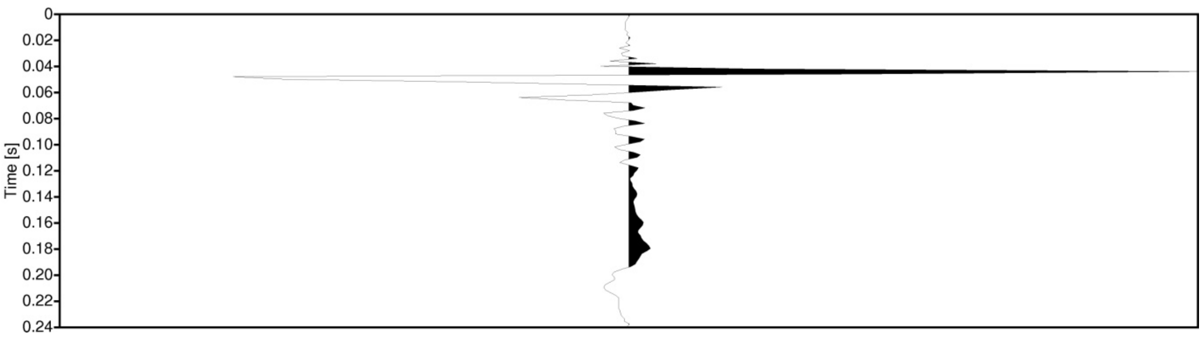


Fig. 32: Extracted wavelet for cruise PANORAMA-2. The signal shows a couple of reverberations as well as a broad bubble pulse arriving at ~ 140 ms after the direct wave.

Bad Trace Editing

The shot gathers were checked for bad traces. If present, these can be killed and thus been excluded from further processing. Anyway, the data recorded was of very good quality with no bad traces, which had to be deleted.

Bandpass Filter

After the examination of the interactive spectral analysis a zero phase Ormsby bandpass filter of 3-6-80-120 Hz was applied to the data. An example of the filtered raw data is given in **Fig. 33**.

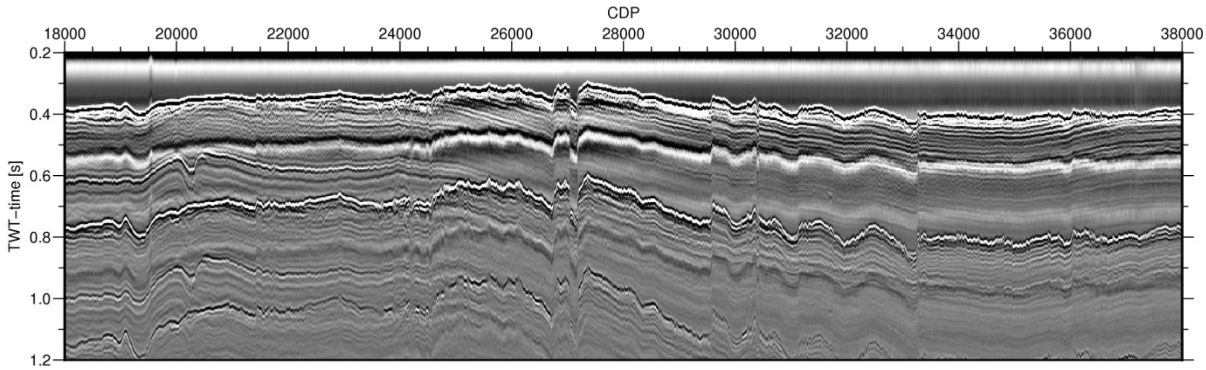


Fig. 33: Single trace display (channel 1) for the central part of profile BGR15-103a, from west (CDP 18000) to east (CDP 38000). Below the seafloor, a broad bubble is visible. Further on, the data is dominated by multiple reflections from the seafloor. A primary reflection visible at 600 ms at CDP 18000 is masked eastward of CDP 25000 by the multiple energy.

Wavelet processing

We used the recorded signal from **Fig. 32** to enhance the seismic image. First, we used the ProMAX module "*Wavelet Generation*" to create a wavelet pulse. The far field signature from the water break was used as input to this module and the onset of the signal (at 40 ms in **Fig. 32**) was shifted to the centre of a 480 ms long trace.

The model trace from "*Wavelet Generation*" was used as input to the ProMAX module "*Filter Generation*". This module creates a filter that converts the input wavelet to a minimum phase wavelet with the original amplitude spectrum. This filter is written to an output file.

Finally, this filter is applied to the data set using the ProMAX module "*Filter Application*". The result can be seen in **Fig. 34**.

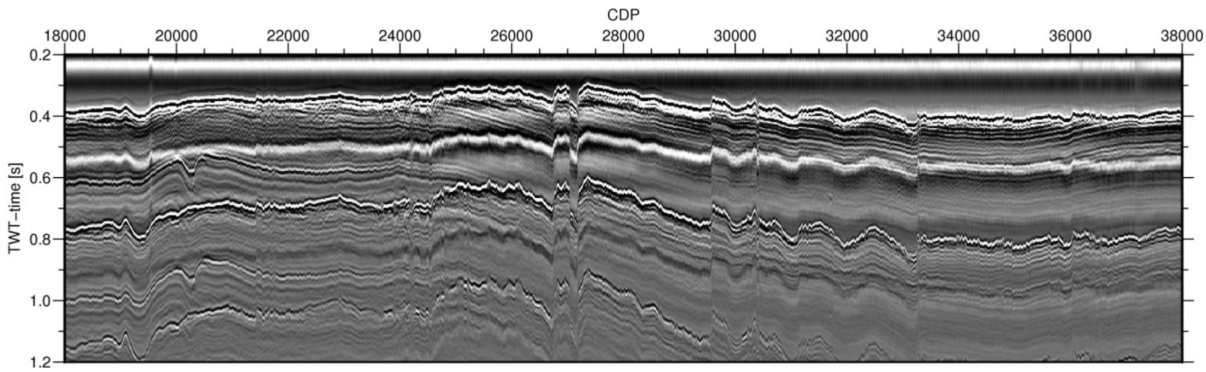


Fig. 34: Single trace display (channel 1) for the central part of profile BGR15-103a, from west (CDP 18000) to east (CDP 38000), after application of the wavelet processing.

Surface-Related Multiple Elimination

Due to the shallow and highly reflective seafloor, the appearance of multiple reflections is one of the main problems in this area of investigation. We used the ProMAX package SRME, which includes five steps.

(1) The module "*SRME Regularization*" is used in the shot domain. This tool ensures that the input traces are at a regular offset spacing, including the zone between source and first channel. The multiple velocity function was estimated to be constant at 1472 m/s.

(2) The module "*SRME Macro*" performs Surface-Related Multiple Estimation (SRME) in the shot domain. This tool produces shot ensembles that contain the multiple estimates.
(3) The original data is merged with the estimated multiples and this dataset is the input for the module "*SRME Un-Regularization*". This tool resamples the offsets of the traces within the SRME multiple model to the offsets within the original data.
(4) These ensembles – containing both data traces and modelled noise traces – form the input to the module "*SRME Match Filter*". This tool determines a single filter that best matches the noise to the data. As input the TWT-time from the seafloor is needed.
(5) Finally, the module "*SRME Adaptive Substraction*" adaptively substracts the noise from the corresponding data traces. We used the following parameters: Temporal window length (ms): 400.0, Filter length (ms): 50.0, Spatial averaging size: 500.0, Maximum filter coefficient: 3.5.

Stacking

After a rough analysis of the velocities, we corrected for spherical divergence (*True Amplitude Recovery*) and stacked the data up to offsets of 1200 m. Due to the uncertainties in the velocities, the moveout correction for the longer offsets was not reliable. The result is shown in **Fig. 35**.

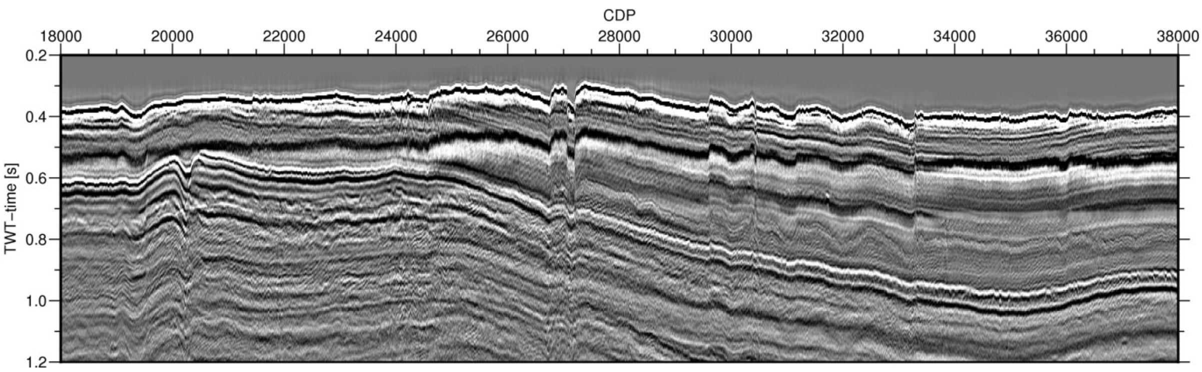


Fig. 35: Stacked seismic section for the central part of profile BGR15-103a, after application of SRME. The multiples are successfully suppressed, and the primary reflection (visible at 800 ms at CDP 18000) is imaged along the whole profile.

Migration

We applied poststack migration (*Kirchhoff Time Mig.*) using smoothed velocities.

Post-processing

To reduce random noise, we applied a Wiener Levinson deconvolution in the F-X space (*F-X Decon*). To enhance the deeper signals with lower frequencies, we applied a time and space-variant filter (*Bandpass Filter*). A weighted mix over 7 traces was also applied (*Trace Mixing*). During export to SEG-Y, the shot number was mapped to byte position 197.

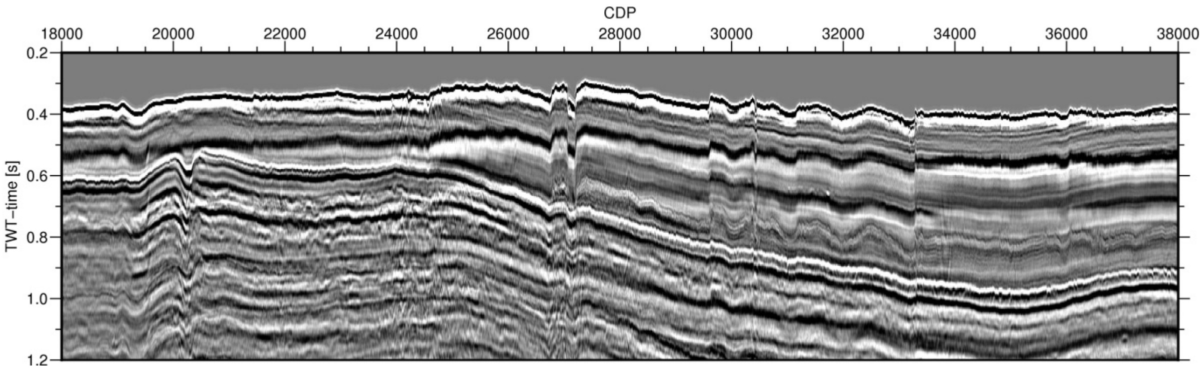


Fig. 36: Final migrated seismic section for the central part of profile BGR15-103a.

Summary and Outlook

The wavelet processing converted the data to minimum phase, which is an advantage for following processing steps. Anyhow, the final processed data shows still large energy resulting from the bubble pulse, so further signal processing (de-signature) is needed.

The suppression of multiple energy worked very well. Only around CDP 25500, where the first seafloor multiple crosses a major reflector (see **Fig. 35**), the application of SRME also reduced primary energy. This might be corrected with a more careful application of SRME.

A comparison between the raw data (**Fig. 33**) and the processed data (**Fig. 36**) shows that some details of the shallow structures are lost during processing. This problem might be solved after a velocity analysis with a higher resolution.

10.4 Resulting survey layout and description of exemplary seismic profiles

The survey layout for the reflection seismic lines was focused on the Olga Basin. The general objectives for the chosen survey area were already discussed in Chap. 1.3. The hashtag-like survey grid is rotated by ~15° to the east in order to cross the assumed prograding sediment structures perpendicular and parallel, respectively [e.g. *Antonsen et al.*, 1991; *Riis et al.*, 2008]. Because of unpredictable weather conditions and down-times because of system maintenance the survey layout had to be adapted to the remaining ship time. The resultant seismic grid is shown in **Fig. 37**.

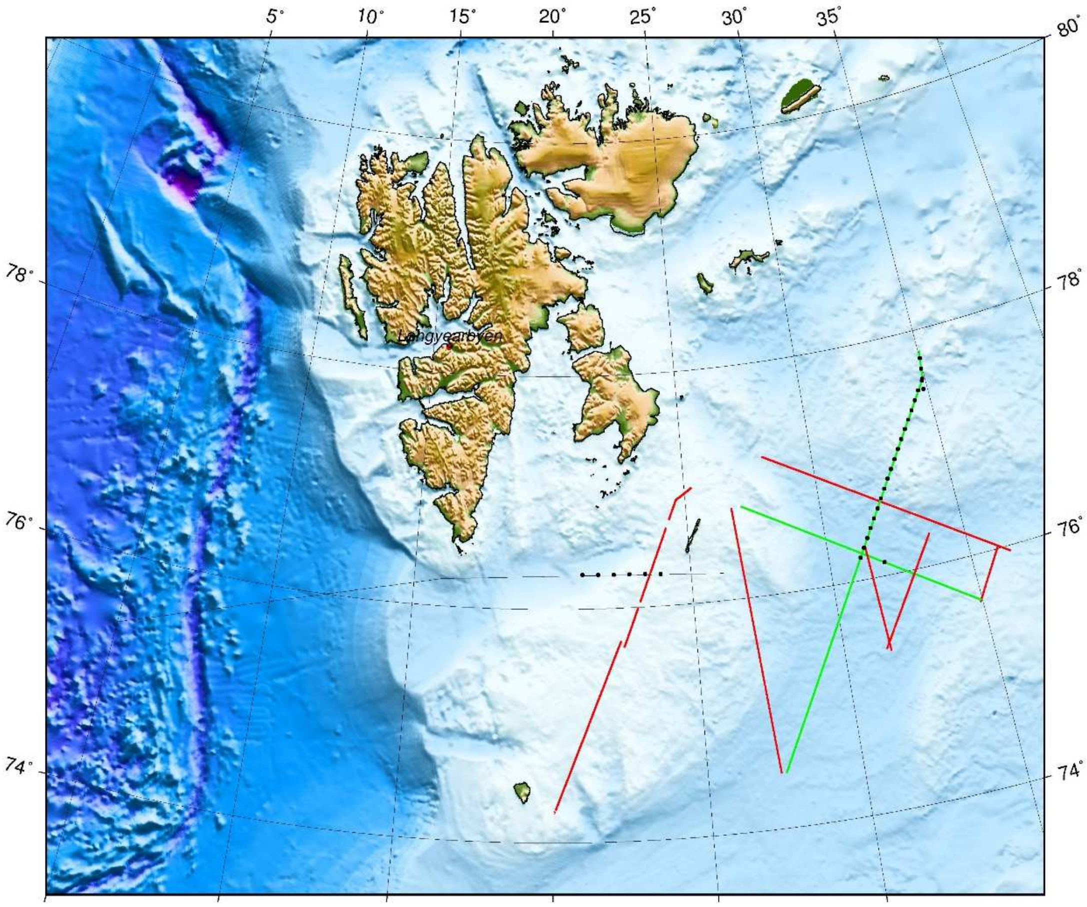


Fig. 37: Survey grid of mcs and sonobuoy data of the cruise PANORAMA-2. Red/green lines mark the acquired mcs lines. Black dots show the deployed sonobuoys. South of Edgeøya, six sonobuoys were deployed along the mcs line BGR74-23 (light black line; acquired in 1974). Green lines mark the mcs lines presented and discussed in this chapter.

The initial planning of the PANORAMA-2 cruise included 2106 km 2D mcs lines. Because of the weather and maintenance down-time the 2D mcs acquisition was limited to 1716 km, i.e. 81% of the planned survey. However, we managed to complete two of the important W-E lines and one complete N-S line across the Olga Basin. Up to now it is not clear if the N-S line across the Sørkapp Basin is useable for processing as we encountered severe trigger problems during the acquisition that were solved only after the line.

The results from the onboard processing confirmed that the processing is very challenging because of the un-tuned source signal and the resulting high bubble energy and as well because of the high multiple energy (see Chap. 10.2). Therefore, onboard processing shows only a preliminary status of the seismic images. Further processing is needed and will be done after the survey.

Exemplary seismic lines:

Four exemplary seismic lines show an N-S cross section in **Fig. 38** and a W-E cross section in **Fig. 39**.

Status of the processing:

The seismic lines are processed onboard during the acquisition of the PANORAMA-2 cruise. The processing flow is described in detail in Chap. 10.2. The removal of the seafloor multiple was already very successful. Within the areas of Olga Basin and Bjarmeland Platform we can assume to image primary reflection up to 3 to 4 sec TWT. Because of the very high p-wave velocities of the compacted sediments this corresponds to ~ 6 to 8 km depth (assuming an average velocity of 4 km/s). However, it is also clear from the presented seismic lines that there is still a lot of multiple and bubble energy left in the seismic image. The removal of this unwanted energy and a high resolved velocity analysis will be the focus on the further processing.

Preliminary description:

The Olga Basin with its Cretaceous infill is very well imaged. We can observe that the boundaries of the basin are folded and faulted on its northern, southern and eastern sides. However, the basin seems not to be limited to the Cretaceous. We can also observe a steepening of the Triassic and Paleozoic sedimentary layers towards the center of the Olga Basin. Other Paleozoic basins are indicated in the area of the Bjarmeland Platform and Storbanken High. For this reason it is not clear if the basin boundaries are inverted sediment basins as previously suggested (see Chap. 1.3). We can observe synclinal structures of the entire sediment succession and we do see some deformation at the basin boundaries. However, we do not see clear inversion of the Paleozoic sediments at the rim of the Olga Basin within our preliminary processed data. This points to an extensional process which was responsible for the subsidence and thus for the formation of the Olga Basin.

Due to the Cenozoic uplift almost all Cenozoic sediments were eroded and recent sedimentation cannot be observed. Further to the erosion we can observe recent sediment deformation in the area northwest of the Olga Basin. Faults are cutting and deforming the seafloor with normal and thrust faults.

Until now one key horizon was identified in the Olga Basin area. This high amplitude reflector is most likely the base Cretaceous (following the work of [*Grogan et al.*, 1999; *Riis et al.*, 2008]). The appearance of the Base Cretaceous reflector is phase reversed pointing to a seismic velocity inversion. This could be confirmed by the coming high resolved velocity analysis, especially where the Base Cretaceous reflector crops out at the seafloor.

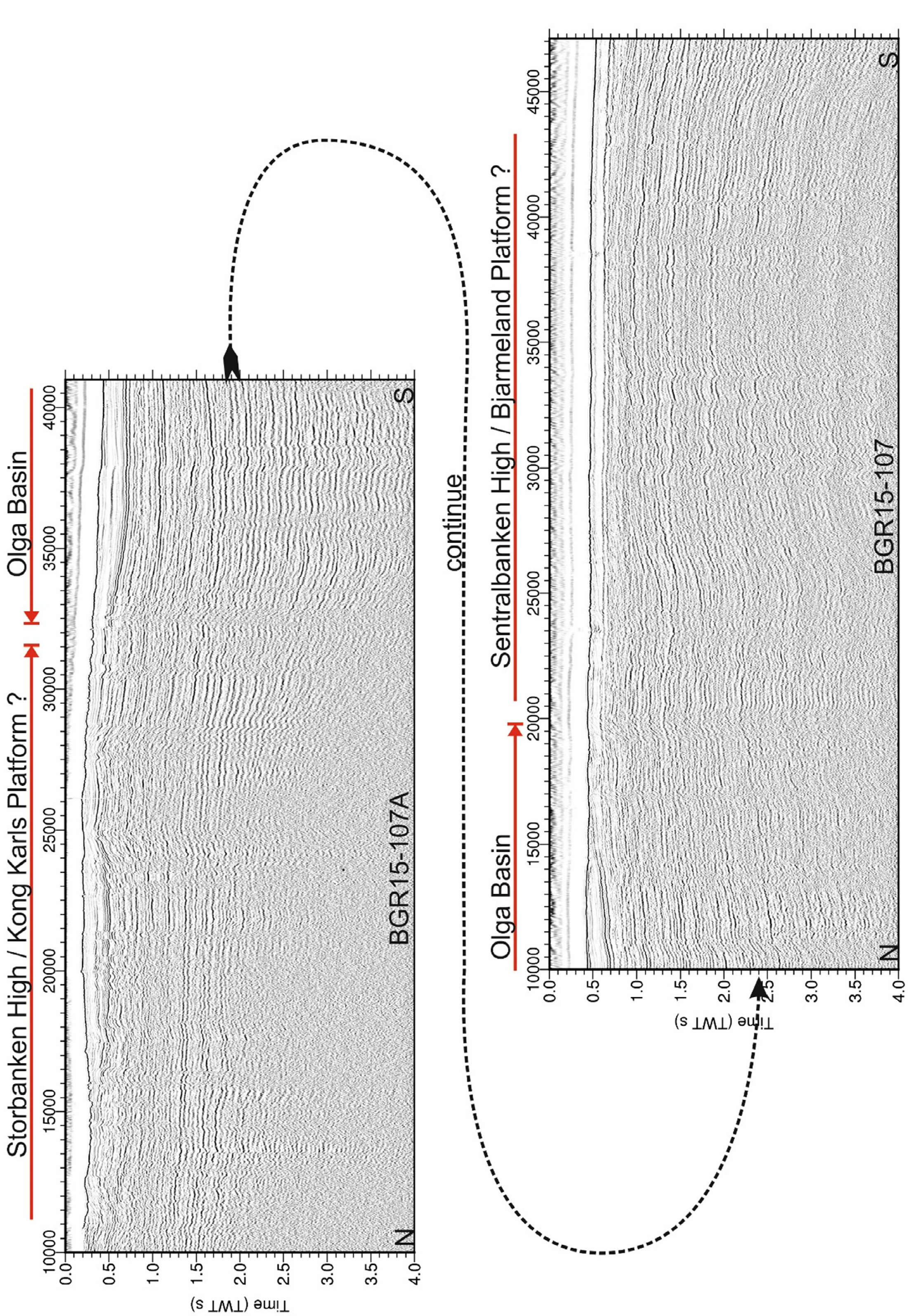


Fig. 38: Stacked seismic lines BGR15-107A and BGR15-107 crossing the Olga basin in N-S direction (see green line in Fig. 37). It is already observable that the Olga Basin boundaries are highly folded and faulted. There is still multiple energy to be removed in order to identify sedimentary layers as well as the base of the basin.

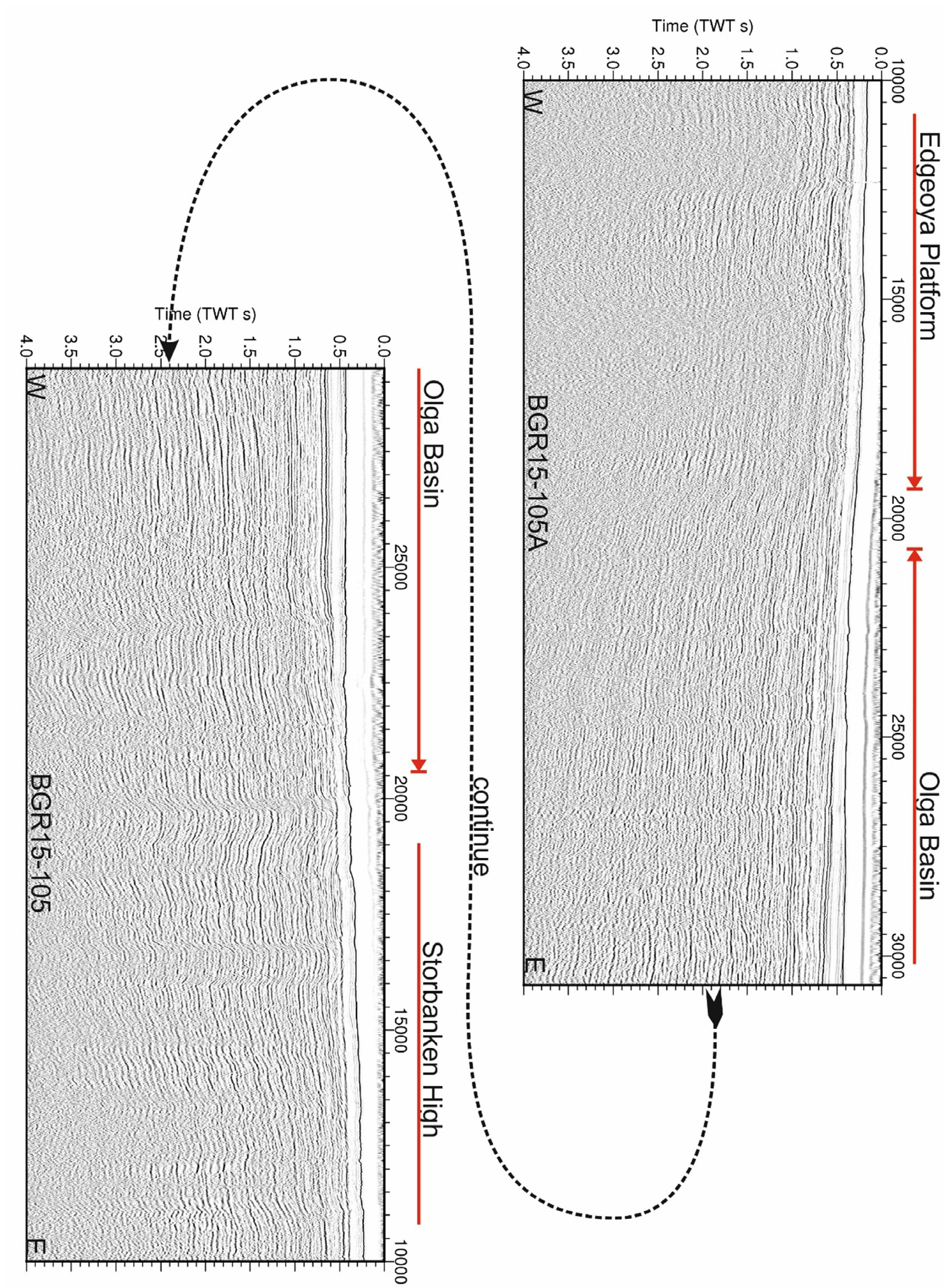


Fig. 39: Stacked seismic lines BGR15-105A and BGR15-105 crossing the Olga basin in W-E direction (see green line in Fig. 37). The Olga Basin boundaries are highly folded and faulted on its easten side towards the Storbanken High.

11. SONOBUOY OPERATION

Michael Schnabel, Axel Ehrhardt, Boris Hahn, Ümit Demir

11.1 Equipment

To enhance the possible offset-range at which seismic signals can be recorded, we deployed floating sonobuoys along selected profiles. The increase of this maximum offset allows for the estimation of seismic velocities within the deeper sub-surface, based on refraction seismic analysis.

We used a special purpose AN/SSQ-53D(3) sonobuoy from Ultra Electronics. This version is based on the AN/SSQ-53D(3) DIFAR buoy, but the omni channel response was altered to be suitable for the amplitude and frequency response of a typical refraction seismic experiment. While the low frequency sensitivity is increased in the 5-60 Hz band of interest, higher frequencies above 200 Hz are suppressed. The peak response occurs at about 50 Hz. The buoy transmits the measured seismic signal on any of 99 preselectable VHF channels in the range 136 to 173.5 MHz with 1 Watt minimum radiated RF power output.

For the reception of the radio signals from the buoys we installed two different types of antennas on the vessel (**Fig. 40**). We used two Yagi antennas mounted at a vertical distance of 1.6 m to stack the signals. These antennas (type R2-10/l from PROCOM A/S) with a length of 3.4 m and a weight of 5.2 kg have a frequency range between 145 and 165 MHz. Additionally, we installed an omnidirectional antenna at a height of 16.6 m above sea level (type CLX 2-3, PROCOM A/S).

Fig. 40: Sonobuoy antennas mounted on the monkey island of R/V OGS Explora. The height of the three antennas is given in the right picture.

To receive the data, we used three WiNRADiO Sonobuoy receivers type WR-G39WSBe. These receivers were placed on the navigation bridge to keep the needed cable length to the antennas as short as possible. These receivers were connected via USB to a laptop which allowed for tuning the appropriate frequencies.

The output from the WiNRADiO receivers was transferred to METHUSALEM-MBS recorders (Send GmbH, Hamburg). These recorders were originally developed for the use in ocean bottom seismic stations. The recorders were connected via RS232 to a laptop with SendCom 2.2 running. This was used to define measurement sequences, as well as starting and ending the recordings. An additional connection of the recorder to a Meinberg clock (type 166) allowed for time syncronisation (DCF77) at the beginning and the end of a measurement sequence. The seismic data was written to PCMCIA micro-drives within the MBS recorder.

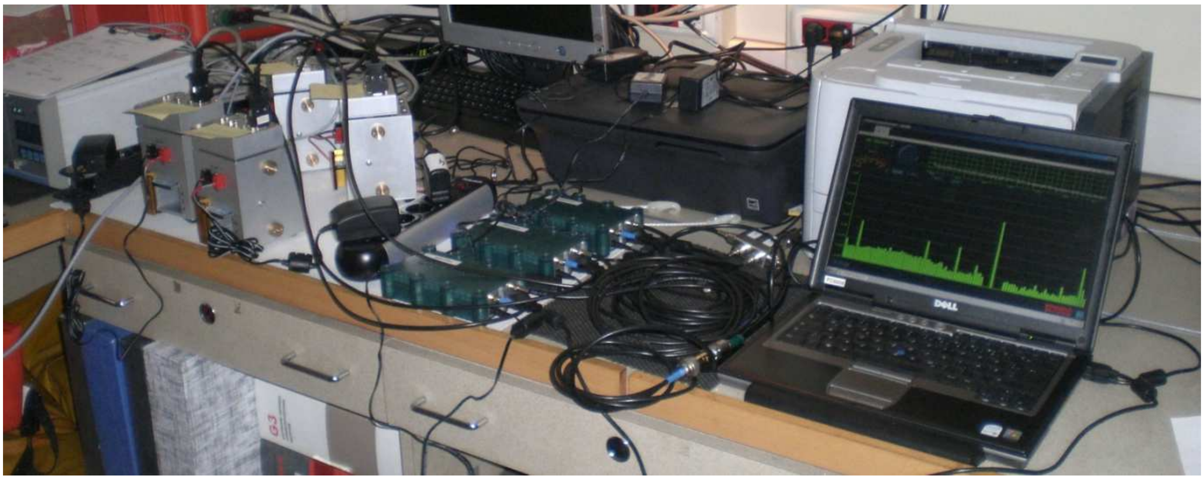


Fig. 41: From right to left: laptop controlling the winradio receivers, 3 winradios (green boxes), four MBS recorders, GPS receiver for time sync.

11.2 Operations

During this cruise, we acquired data with 30 sonobuoys along four profiles (**Fig. 42**). We deployed the stations with a relative distance of 10 km to each other and set the hydrophone depth to 60 m. On profile BGR15-1R3 the buoys had a relative distance of 15 km and a hydrophone depth of 30 m. Further details of the stations are given in the Appendix A. 5.

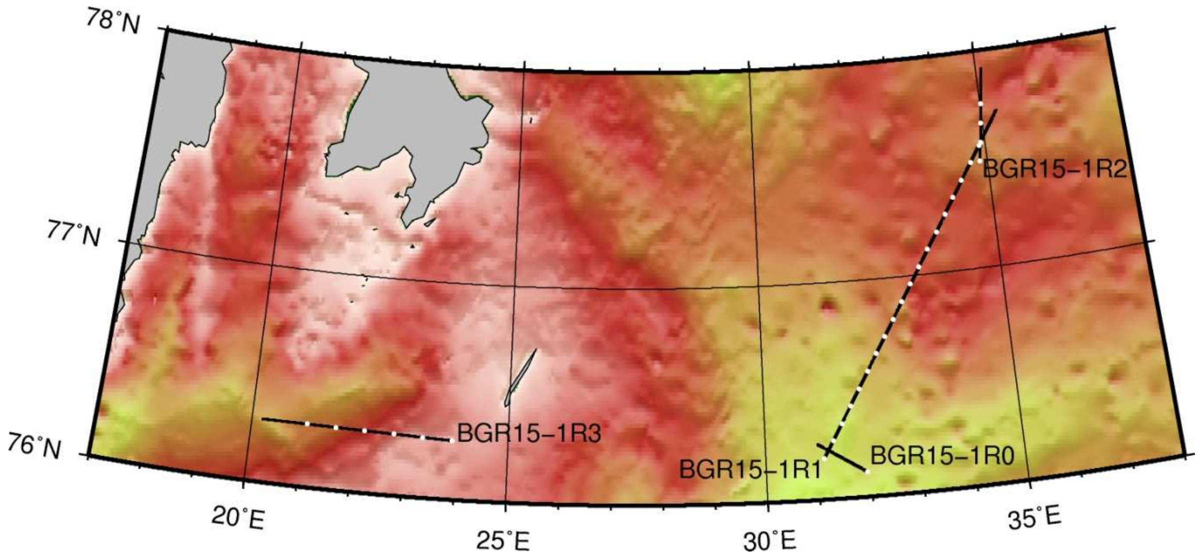


Fig. 42: Map showing the location of four sonobuoy profiles (BGR15-1R0 to BGR15-1R3) as well as deployment positions of 30 sonobuoys (white circles).

We launched the buoys from the bridge deck (starboard side). The height of the bridge deck allowed the sonobuoys to reach the water with a sufficient distance from the ship to prevent a collision with the air guns. The guns were trigged with an interval of 30 sec and the exact time was captured in the seismic lab using a Meinberg clock. Signals from the sonobuoys were recorded for three hours. At a mean ship speed of 5 knots this represents a distance of roughly 27 km.

11.3 Processing and Results

After copying the recorded data from PCMCIA cards to a linux-based PC, the following processing was done using the program package SEND2X v2.71. The processing was done by using three different programs:

- mbsread: Reads the recorded raw data and corrects for the time drift based on the DCF77 signal. The output is stored as internal send2x format.
- seedwrite: Takes the send2x format and converts to SEED (Standard for the Exchange of Earthquake Data). This data is used for quality control using PQL II (see **Fig. 43**).
- seg-ywrite: This program divides the continuous recordings into seismic sections based on the shooting time (see **Fig. 44**).

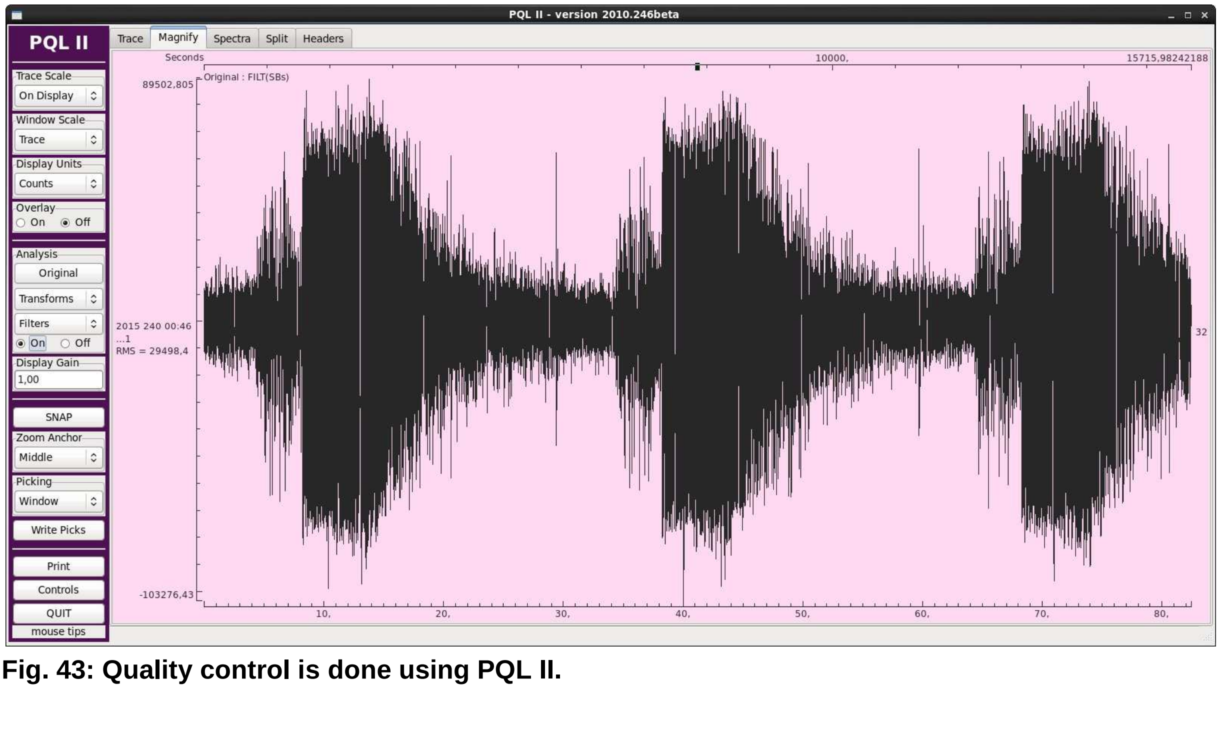
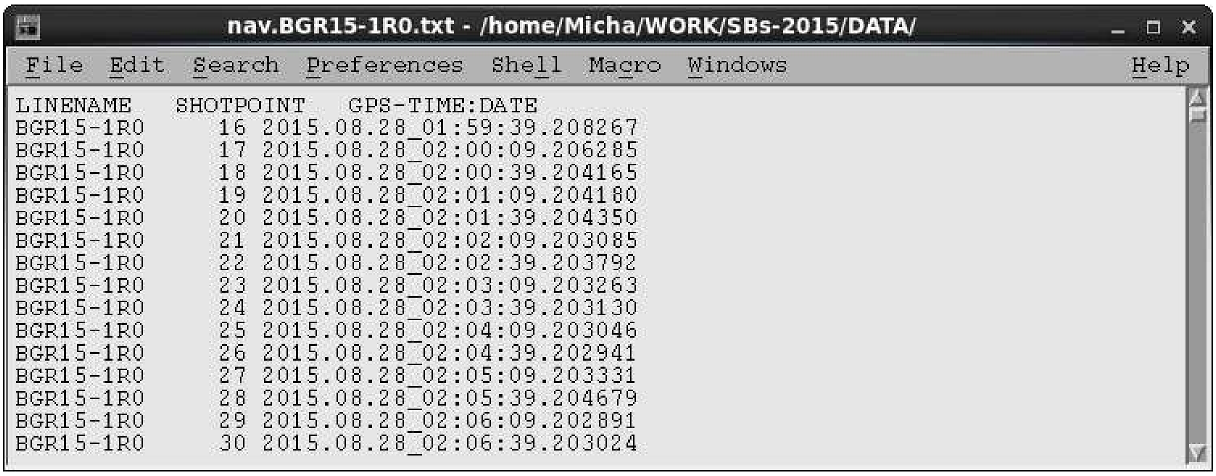


Fig. 43: Quality control is done using PQL II.

A first quality control of the continuous recorded data is performed using PQL II. **Fig. 43** shows the direct arrivals of three shots with an interval of 30 sec (the lower scale represents seconds). Approximately 3 sec before the direct arrivals refracted phases are recorded with a lower amplitude.

Based on the time of the airgun shots, the continuous recordings are cut into seismic sections. An example of the determined shot times is given in **Fig. 44**. The last six digits in this file represent micro-seconds (the trigger was captured in the seismic lab with a Meinberg clock). The exact firing time can deviate up to 1 millisecond from the ideal 30 sec interval.


nav.BGR15-1R0.txt - /home/Micha/WORK/SBs-2015/DATA/

File Edit Search Preferences Shell Macro Windows Help

```
LINENAME    SHOTPOINT   GPS-TIME:DATE
BGR15-1R0      16 2015.08.28_01:59:39.208267
BGR15-1R0      17 2015.08.28_02:00:09.206285
BGR15-1R0      18 2015.08.28_02:00:39.204165
BGR15-1R0      19 2015.08.28_02:01:09.204180
BGR15-1R0      20 2015.08.28_02:01:39.204350
BGR15-1R0      21 2015.08.28_02:02:09.203085
BGR15-1R0      22 2015.08.28_02:02:39.203792
BGR15-1R0      23 2015.08.28_02:03:09.203263
BGR15-1R0      24 2015.08.28_02:03:39.203130
BGR15-1R0      25 2015.08.28_02:04:09.203046
BGR15-1R0      26 2015.08.28_02:04:39.202941
BGR15-1R0      27 2015.08.28_02:05:09.203331
BGR15-1R0      28 2015.08.28_02:05:39.204679
BGR15-1R0      29 2015.08.28_02:06:09.202891
BGR15-1R0      30 2015.08.28_02:06:39.203024
```

Fig. 44: Additionally input for seg-ywrite. This file contains mainly the shotpoint number and the according date and time.

In a final step, the distances between shot points and the location of the dropped sonobuoys were calculated and these values were written to the segy-headers.

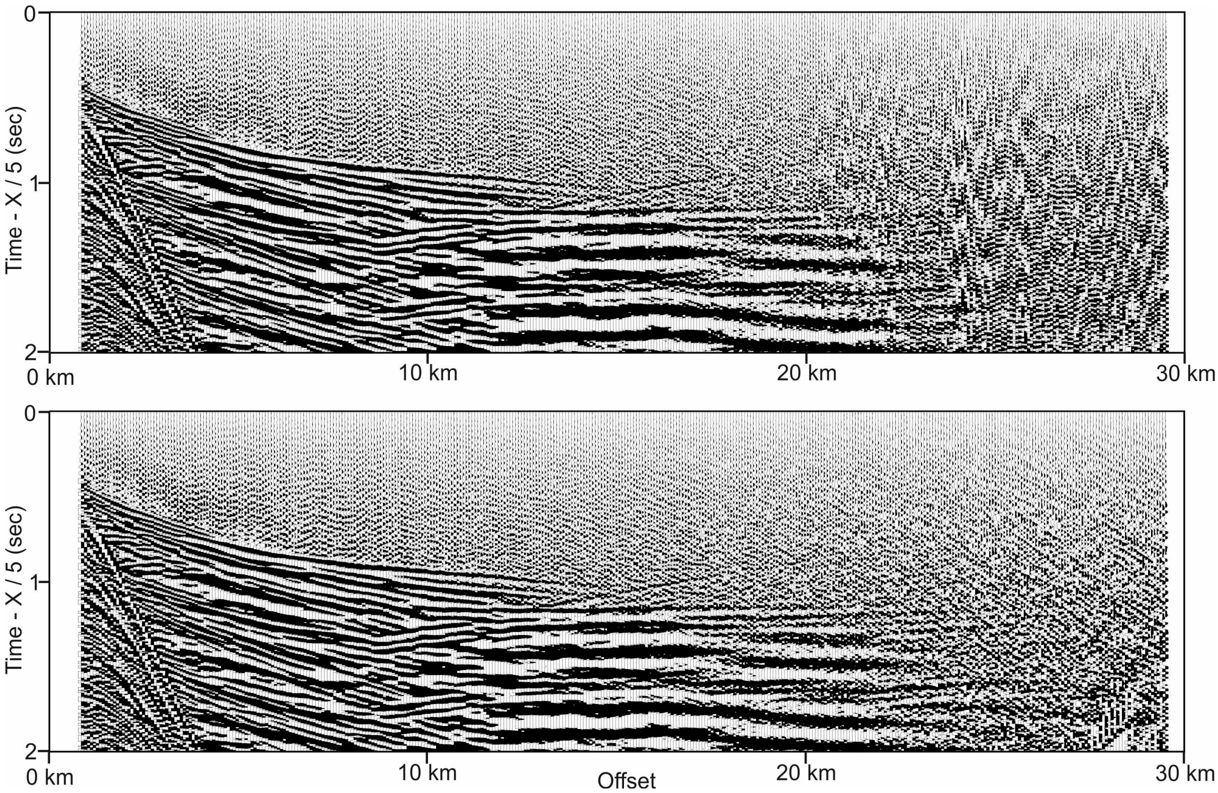


Fig. 45: Seismic sections of SB-00 along profile BGR15-1R0. A reduction velocity of 5.0 km/s was applied. The uppermost panel shows data received with the omnidirectional antenna, the data from the lowermost panel was received with the stacked Yagi array.

The offset values in the traces headers can be used to perform a travel time reduction with a constant reduction velocity. **Fig. 45** shows an example with a reduction velocity of 5 km/s – this means that refracted arrivals with a velocity of 5 km/s appear horizontally in the section. Phases with a negative dip with increasing offset represent layers with smaller velocities (in **Fig. 45** up to 15 km offset) while phases with a positive dip with increasing offset a travelling through layers with a higher velocity (in **Fig. 45** between 15 and 20 km offset).

Sonobuoy SB-00 on profile BGR15-1R0 was recorded using both available antennas. The result of this comparison is presented in **Fig. 45**. The upper panel represents the data as received through the omnidirectional antenna. Beyond 20 km offset, the data shows significant noise. The lower panel demonstrates the quality of the stacked Yagi antennas. Some phases can be clearly identified beyond 25 km offset. Anyhow, the amplitudes of the first break are too weak to be identified at these offsets. When discussing these maximum offsets we should keep in mind the limited height of R/V OGS Explora – the position of the uppermost Yagi-antenna results in a theoretical line of sight in the range of 16 km. After this first station we decided to use the Yagi antennas for all following buoys.

The recorded sections (e.g., **Fig. 45**) show at the first 15 km of offset first breaks with a velocity ranging between 3 to 5 km/s. These refracted waves are travelling the sedimentary column and will deliver to us a reliable velocity-depth-distribution to enhance the processing of the multichannel seismic data. Beyond offsets of 15 km, a first break with a velocity slightly exceeding 6 km/s is visible. This phase most probably travels through the uppermost basement. The basement in this area can be found at deeps between 8 and 12 km and is characterised by seismic velocities around 6.3 km/s [*Asbjørn Johan Breivik et al.*, 2002].

A first on-board quality control has shown that all 30 sonobuoy stations show this first break with a velocity reaching 6 km/s. All stations successfully covered the whole column of sediments.

12. MARINE MAMMAL OBSERVATION TO COMPLY WITH ENVIRONMENTAL REQUIREMENTS

Volkmar Damm, Tim Lewis

The Norwegian Government required particular measures during seismic operations to ensure minimum impact on marine wildlife. According to the Norwegian research permission seismic surveying had to comply with JNCC guidelines for safeguarding marine mammals.

Notwithstanding the above, in the adoption of best practice to international standards, BGR generally implements a MMO regime for seismic surveying identical to these requests (http://www.bgr.bund.de/DE/Themen/GG_Geophysik/Marine_Geophysik/Seismik/MM_Observer.html?nn=1542296).

Accordingly the UK's Joint Nature Conservation Committee's (JNCC) "Guidelines for minimizing the risk of injury and disturbance to marine mammals from seismic surveys" (August 2010)[1] were adopted and adapted for use on this survey. The key conditions of these guidelines are summarized below.

To implement these guidelines a single combined MMO and PAM operator was contracted through RPS Energy in the UK. As per the guidelines he was JNCC certified and appropriately experienced. Additionally, a number of the BGR scientific crew had JNCC MMO certification.

In addition to **standard visual observations** two PAM systems were used on the vessel during the cruise, primarily for marine mammal mitigation but additionally for comparison purposes. This chapter describes the efforts, summarizes the main results and review each method. For passive acoustic monitoring the following systems were employed:

1. Seiche Measurement Limited's (SML) standard 4-element towed array and acoustic processing system (http://www.seiche.com/topics/73-towed-pam-system) using the PAMGuard analysis software (http://www.pamguard.org/), setup and operated by the PAM operator, and

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 hydrophones on the gun arrays.

The combined MMO and PAM operator prioritized visual observations during the pre-shooting search periods if the visibility was conducive. The SML PAM system was available for periods of poor visibility e.g. during fog and darkness. The QuietSea™ system is a new Sercel product which was recently purchased by BGR and used for the first time during this cruise. Synchronous operation of both PAM systems provides a good opportunity to estimate the degree of reliance by comparing the results of both systems.

The QuietSea™ system was installed with support of a SERCEL technician and operated by BGR personnel.

[1] (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/50005/jncc-seismic-guide .pdf)

The contracted MMO/PAM operator was responsible for filling in all JNCC forms relating to seismic operations, visual and acoustic effort, sightings and acoustic detections with the SML PAM. Furthermore the MMO/PAM operator was responsible for providing advice on the application of the JNCC Guidelines.

The roles of the MMOs were as follows:

- Conduct 60 minute (for waters over 200m deep) pre-shooting watches of a 500m exclusion zone around the source array to ensure the absence of marine mammals before the commencement of soft-starts.
- To monitor soft-starts of the seismic array to ensure a minimum of 20 minutes (and no greater than 40 minutes) in duration.
- To ensure that marine mammals have the opportunity to leave the survey area and request a delay to the soft-start if a marine mammal is sighted within the exclusion zone.
- To advise the crew on the procedures set out in the JNCC Guidelines and to provide advice to ensure that the survey programme is undertaken in accordance with those Guidelines.
- To conduct watches in daylight hours, and so document any marine mammal sightings.
- To operate the SML PAM system and to ensure the absence of marine mammals before the commencement of soft-starts during periods of poor visibility e.g. during fog and darkness.
- To document and report all source array use hours, observation effort hours, mammal sightings and mitigation and compliance issues.

The JNCC Guidelines state that MMO/PAM operators prioritize watches so that they are available for pre-shooting searches but that additional visual or acoustic watches can be performed if time allows acquiring information on the presence of marine mammal species. With only a single MMO/PAM operator on board additional periods of visual and acoustic watches were limited, but effort was made to encourage and record the reporting of sightings by other crew members and the bridge crew.

Air-gun array and soft-start procedure

A summary of seismic source characteristics, as required by JNCC, relevant to mitigation used on the OGS Explora during the 2D seismic survey are given in **Tab. 9**, more details on the seismic source are provided elsewhere within this report. N.b. both sub-arrays were fired simultaneously rather than flip-flop.

Tab. 9: Summary of seismic source characteristics relating to mitigation.

Characteristic	Value	Unit
Number of airgun sub-arrays	2	
Number of airguns in each sub-array	4	
Airgun type	Sercel G-Gun	
Airgun volume	250	inch³
" "	4.1	l
Total number of air-guns	8	
Total array volume	2,000	inch³
" "	32.8	l
Source depth	6	m
Inter-sub-array distance	14	m
Shot-point interval	25	m
Nominal working pressure	2.100	psi
" "	145	bar
" "	14.5	MPa
Peak frequency range (Peak -3 dB)	10-65	Hz
Intensity	45.1 +/- 0.797	bar metre
" "	253	dB re. 1 µPa @ 1 m

The soft-start procedure used involved ramping up the acoustic power by increasing the number of guns while maintaining the operational pressure. Guns were fired at 30 s intervals starting with a single gun and adding in a new gun (of 250 in³) every 3 minutes until all 8 guns (totaling 2,000 in³) were fired 21 minutes after the start of the soft-start - in line with the JNCC Guidelines.

The procedure to conduct the seismic data acquisition along pre-defined survey lines by following the above guidelines of JNCC is described in detail in the Cruise Report BGR13-2, Project PANORAMA-1[2].

12.1 Conventional visual observations

Visual observations for marine mammals were carried out during daylight hours primarily during seismic source pre-shooting search periods, but also at other times particularly during line changes (before pre-shooting search and from soft-start to start-of-line). The MMO was equipped with a digital SLR camera (Nikon D600 & NIKKOR 70-200mm f/2.8G ED VRII lens) to assist in species identification, documentation and range determination. Distances to sightings were estimated by eye, but where images were obtained distances to animals were verified using the video range tracking (VRT) module in PAMGuard (see **Fig. 46** for example) following calibration of the camera and lens and the measurement of the height of vantage points on the vessel.

[2](http://www.bgr.bund.de/EN/Themen/MarineRohstoffforschung/Downloads/PANORAMA_1_Cruise_Report_en.pdf?__blob=publicationFile&v=4) (pp 62)

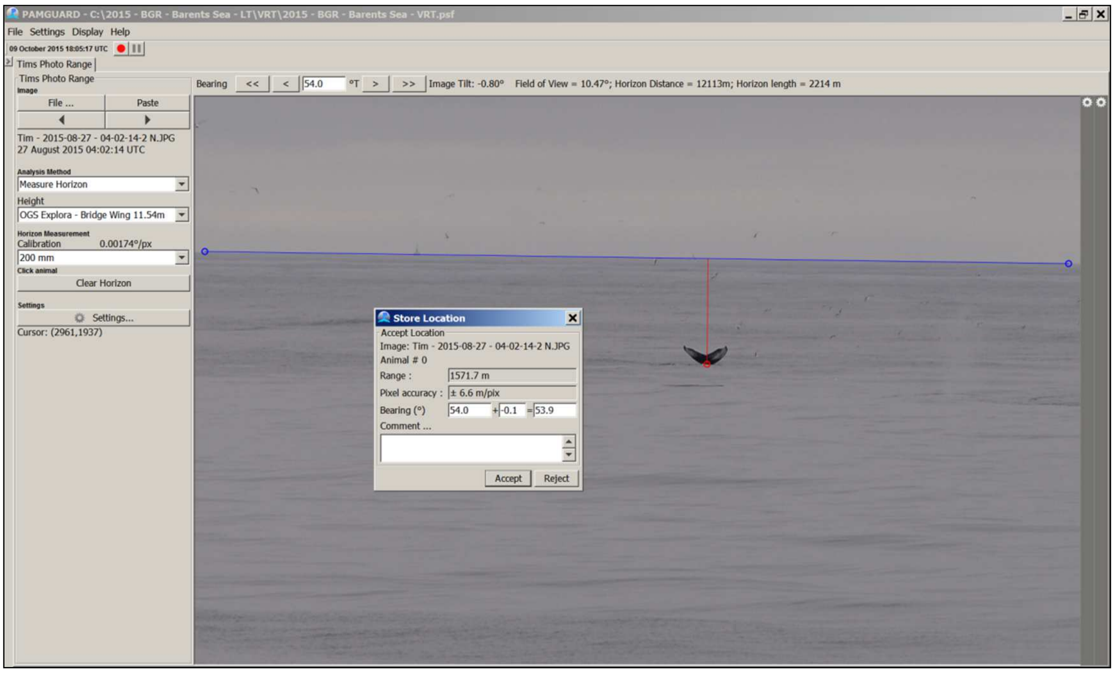


Fig. 46: Screen shot of PAMGuard's Video Range Tracking module with example range determination for a humpback whale - the module uses photogrammetry to calculate the distance of the animal from the camera (based on angular distance to the horizon).

There were 17 visual pre-shooting searches carried out prior to soft-starts totalling 25 hours 42 minutes. 16 soft-starts preceded line starts and one preceded a gun test which was followed immediately by a survey line. There were a further 13 hours 43 minutes of dedicated visual monitoring effort at other times e.g. during soft-starts, between soft-starts and starts of line, during lines and when the source was not active. Brief details of sightings are provided in **Tab. 10** and sightings are summarized by species in **Tab. 11**.

Tab. 10: Brief details of sightings and their relationship to seismic operations. Notes: 1 type of visual effort when sighting made: D = dedicated watch, I = incidental sighting & A = acoustically cued sighting; 2 where sighting duration is given as 0:00 this is a single instantaneous sighting of an animal.

ID #	Date & time of sighting (d/m hh:mm) (Year=2015)	Observer effort when sighted[1]	Sighting duration[2] (h:mm)	Species or species group	Total # of animals	Position (of vessel when initially sighted)	Depth (m)	Initial range to animal (m)	Initial bearing to animal (True)	Closest distance to animal (m)	Seismic status during sighting	Mitigating action
1	17/8 05:00	I	0:01	Fin whale	4	73°50.875'N, 020°09.857'E	310	1000	090°	1000	Not firing	None
2	17/8 11:01	D	1:01	Humpback whale	2	74°07.350'N, 019°51.876'E	84	4000	055°	1	Not firing	None
3	19/8 10:44	D	0:01	Minke whale	1	76°41.247'N, 024°15.133'E	54	100	343°	75	Not firing	None
4	20/8 01:57	I	0:01	Humpback whale	1	77°02.485'N, 027°00.617'E	129	30	103°	120	Not firing	None
5	20/8 03:30	I	0:30	Humpback whale	13	77°04.382'N, 027°37.985'E	149	1000	067°	60	Not firing	None
6	20/8 09:55	I	0:25	Fin whale	3	77°15.769'N, 027°22.053'E	213	1000	099°	800	Not firing	None
7	21/8 05:15	I	0:01	Unidentified large baleen whale	1	76°34.618'N, 032°36.717'E	255	8334	127°	8334	Full power	None
8	21/8 09:15	I	0:01	Humpback whale	1	76°25.176'N, 033°38.165'E	260	150	222°	155	Full power	None
9	21/8 11:15	I	0:01	Humpback whale	1	76°20.454'N, 034°07.769'E	277	500	168°	500	Full power	None
10	22/8 05:00	I	0:05	Unidentified dolphin	5	76°06.150'N, 035°22.563'E	270	40	070°	130	Not firing	None
11	22/8 23:00	I	0:03	Unidentified dolphin	5	75°45.435'N, 034°08.155'E	210	300	286°	100	Not firing	None
12	23/8 18:45	I	0:02	White-beaked dolphin	2	75°57.097'N, 031°50.568'E	325	30	170°	120	Not firing	None
13	24/8 11:50	D	0:04	White-beaked dolphin	3	76°24.852'N, 031°37.488'E	306	50	130°	100	Not firing	None
14	25/8 09:20	I	0:04	Unidentified dolphin	2	75°03.638'N, 028°38.493'E	349	1500	167°	1150	Full power	None
15	25/8 13:42	I	0:12	White-beaked dolphin	3	74°46.656'N, 028°04.969'E	347	80	155°	105	Full power	None
16	25/8 14:48	A	0:04	White-beaked dolphin	9	74°42.481'N, 027°56.979'E	360	70	113°	80	Full power	None
17	26/8 07:42	I	0:04	White-beaked dolphin	4	75°22.342'N, 027°07.388'E	229	40	011°	110	Full power	None
18	26/8 12:45	I	1:55	White-beaked dolphin	20	75°44.269'N, 027°01.341'E	186	4000	353°	800	Full power	None
19	27/8 03:07	D	0:06	Humpback whale	3	76°46.304'N, 026°42.530'E	110	2000	095°	2000	Full power	None
20	27/8 03:40	D	0:39	Humpback whale	6	76°48.422'N, 026°46.063'E	106	3670	070°	1150	Not firing	None
21	27/8 03:40	D	0:39	Minke whale	3	76°48.422'N, 026°46.063'E	106	3680	072°	1500	Not firing	None
22	27/8 03:42	I	0:01	Unidentified whale	1	76°48.459'N, 026°46.750'E	107	400	357°	400	Not firing	None[†]
23	27/8 04:09	D	0:32	Humpback whale	1	76°48.226'N, 026°55.462'E	112	2300	143°	1017	Not firing, soft start & full power	None
24	27/8 04:10	D	0:31	Humpback whale	1	76°48.194'N, 026°55.725'E	113	2600	117°	325	Not firing, soft start & full power	None
25	27/8 04:15	D	1:00	Humpback whale	3	76°48.019'N, 026°57.319'E	116	3900	123°	195	Not firing, soft start & full power	None
26	27/8 04:22	D	0:02	Minke whale	1	76°48.226'N, 026°55.462'E	112	1050	210°	971	Soft start	None
27	27/8 04:22	D	0:02	Humpback whale	3	76°48.226'N, 026°55.462'E	112	5300	209°	5300	Soft start	None
28	27/8 04:37	D	0:02	Humpback whale	1	76°47.229'N, 027°03.706'E	113	1100	191°	1070	Soft start	None
29	27/8 04:39	D	0:00	Humpback whale	2	76°47.229'N, 027°03.706'E	113	3960	189°	3960	Soft start	None
30	27/8 04:45	D	0:05	Humpback whale	1	76°46.958'N, 027°05.952'E	115	2970	170°	2570	Full power	None
31	27/8 04:45	D	0:05	Humpback whale	5	76°46.958'N, 027°05.952'E	115	3600	162°	3122	Full power	None
32	27/8 05:04	D	0:01	Humpback whale	1	76°46.292'N, 027°11.402'E	118	860	027°	860	Full power	None
33	27/8 05:04	D	0:05	Humpback whale	1	76°46.337'N, 027°11.034'E	118	2210	087°	1850	Full power	None
34	27/8 17:35	I	0:01	Minke whale	1	76°19.268'N, 030°33.904'E	299	2500	177°	2510	Full power	None
35	28/8 05:24	I	0:06	Minke whale	1	76°14.946'N, 030°55.900'E	300	900	162°	490	Not firing	None
36	28/8 05:41	I	0:19	Minke whale	1	76°13.609'N, 030°54.422'E	299	3000	173°	2000	Not firing	None
37	28/8 06:31	I	0:18	White-beaked dolphin	6	76°11.196'N, 031°03.968'E	307	1400	064°	60	Soft start & full power	None
38	28/8 20:09	I	0:11	Minke whale	1	77°08.294'N, 033°36.040'E	0	500	047°	400	Full power	None
39	29/8 06:57	I	0:38	Fin whale	2	77°38.233'N, 035°09.699'E	152	1500	207°	1500	Not firing	None
40	29/8 07:00	I	0:35	Unidentified large baleen whale	3	77°38.003'N, 035°09.284'E	152	4000	278°	400	Not firing	None
41	1/9 14:11	I	0:01	Unidentified dolphin	1	76°56.926'N, 031°43.388'E	229	5	350°	5	Not firing	None
42	2/9 03:25	I	0:00	Unidentified dolphin	2	76°22.006'N, 027°26.705'E	102	100	279°	100	Not firing	None
43	2/9 12:30	I	0:05	White-beaked dolphin	5	75°42.303'N, 023°48.263'E	90	150	353°	150	Not firing	None
44	2/9 12:43	I	0:12	Humpback whale	5	75°42.284'N, 023°41.659'E	89	5000	260°	2300	Not firing	None
45	2/9 16:50	I	0:55	Humpback whale	30	75°53.833'N, 023°48.407'E	74	480	065°	100	Not firing	None
46	2/9 18:29	I	0:19	Humpback whale	10	75°57.874'N, 023°51.257'E	57	324	090°	175	Not firing	None
47	3/9 18:30	I	0:15	Unidentified large baleen whale	1	76°17.467'N, 020°23.571'E	253	8000	220°	8000	Full power	None
48	3/9 18:30	I	0:15	Unidentified large baleen whale	1	76°17.467'N, 020°23.571'E	253	7000	250°	7000	Full power	None
49	5/9 14:19	I	0:01	White-beaked dolphin	6	77°18.333'N, 012°43.248'E	220	1840	246°	1811	Not firing	None
50	5/9 14:47	I	0:01	Unidentified large baleen whale	1	77°20.071'N, 012°38.194'E	215	4242	046°	4242	Not firing	None
51	5/9 14:47	I	0:00	Minke whale	1	77°20.071'N, 012°38.194'E	215	3531	090°	3531	Not firing	None
52	5/9 14:54	I	0:02	Unidentified large baleen whale	1	77°20.505'N, 012°36.931'E	210	3972	100°	3972	Not firing	None
53	5/9 15:06	I	0:00	White-beaked dolphin	1	77°21.251'N, 012°34.765'E	208	1391	046°	1391	Not firing	None
54	5/9 16:03	I	0:17	White-beaked dolphin	8	77°24.789'N, 012°24.477'E	175	482	346°	100	Not firing	None

Tab. 11: Summary of sightings by species or species group, sub-totalled for dolphins and whales.

Species or species group	Events (sightings of individuals or groups)	Group size range	Number of animals	Mean group size
White-beaked dolphin	11	1 - 20	67	6.1
Unidentified dolphin	5	1 - 5	15	3.0
All dolphins	16	1 - 20	82	5.1
Minke whale	8	1 - 3	10	1.3
Humpback whale	20	1 - 30	91	4.6
Fin whale	3	2 - 4	9	3.0
Unidentified large baleen whale	6	1 - 3	8	1.3
Unidentified whale	1	1	1	1.0
All whales	38	1 - 30	119	3.1
All marine mammals	54	-	201	3.7

There were a total of 54 sightings of which 42 were identified to species level. The remaining 12 sightings were identified to species group level.

Since there were no definite sightings of any dolphin species other than white-beaked dolphins, and as no other dolphin species are documented as regularly frequenting this area it is likely that all sightings of dolphin (16) were of white-beaked dolphin. These dolphins were usually sighted in small groups (mean group size 5) and often associated with the vessel, though usually not bow-riding, perhaps due to the relatively slow speed of the vessel during seismic operations.

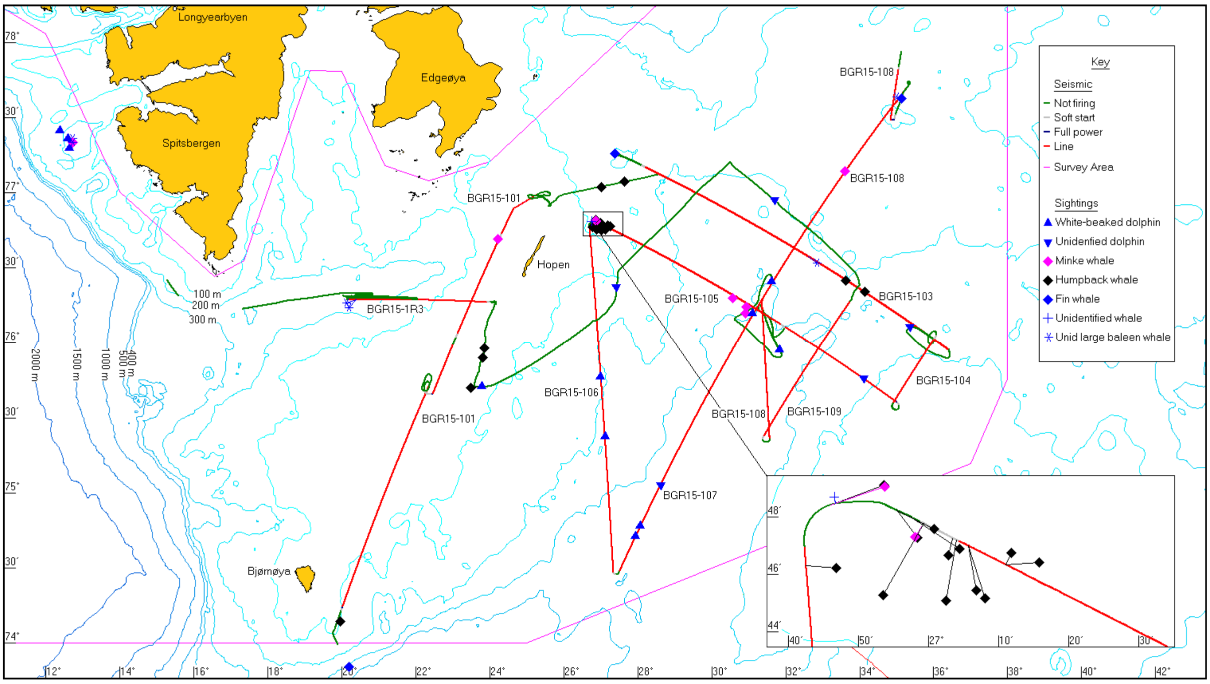


Fig. 47: Map showing principal seismic survey lines, seismic source status and marine mammal sightings together with bathymetry and principal land features. Details for the first line start on 27/8/2015 are expanded and inset because of their complexity. Symbols for sightings are located at the range and bearing from the track where they were first sighted.

On several occasions groups appeared to be feeding near the surface as evidenced by surface diving activity and presence of seabirds. Dolphins were sighted in the deeper areas of the survey area with only 1 of 16 sightings in water shallower than 100 m, 3 of 16 between 100-200 m and the remainder (12 of 16 sightings) in waters deeper than 200 m.

Minke whales were sighted on 8 occasions (see **Fig. 48** for example photographs), usually as singles but once 3 animals were seen apparently feeding in relatively close proximity. 4 minke whales were sighted in areas where humpback whales were feeding - suggesting they may be feeding on similar prey species in these locations.

There were three rather distant sightings of fin whales (see **Fig. 48** for example photographs), while there were a further 6 sightings classified as 'large baleen whales' (i.e. humpback, fin or blue) and one unidentified whale.

Humpback whales were sighted (see **Fig. 48** for example photographs) on 20 occasions (91 animals), the majority of these occurred in three feeding concentrations in relatively shallow water on the banks adjacent to Hopen Island. The first concentration was about 30 km to the ENE of Hopen in depths 100-120 m and comprised of 12 sightings (28 animals), a second pair of sightings occurred at 55 and 70 km to the NE of Hopen in depths of 130 and 150 m and comprised of 14 animals, while a third concentration occurred at about 60 km to the SSW of Hopen in depths of 50-90 m and comprised of 3 sightings of 40 animals. In the last concentration one sighting was estimated to have a minimum of 30 animals but there were likely to be more at greater distances. In all these concentrations animals appeared to be feeding close to the surface (shallow dives in multiple directions, lunging and mouth closing at surface, side flukes, large numbers of feeding seabirds, etc). Additionally there was a sighting some 30 km to the SE of Bjørnøya (2 animals) again in relatively shallow water (84 m).

A large number of images were taken of marine mammals; these were used to aid and/or confirm species identification, assist with counting animal numbers, for calculating animal's ranges and to document behaviour. Where available a set of sample images has been selected for each sighting and archived with the data.

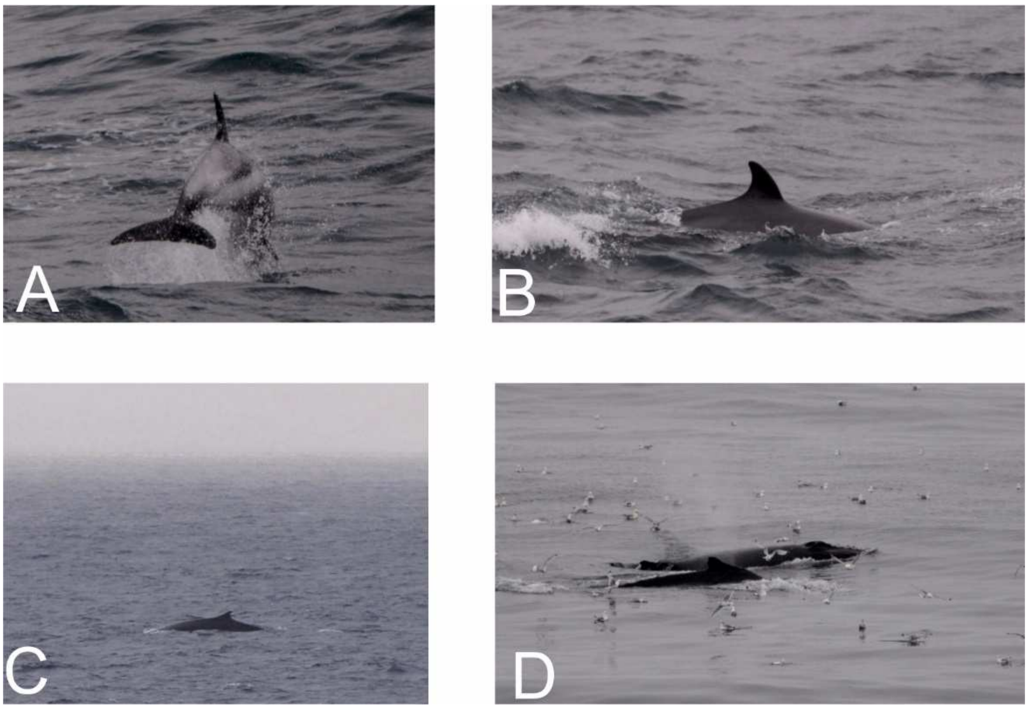


Fig. 48: Examples for viewings of marine mammals during the survey. A: White-beaked dolphin; B: Minke whale; C: Fin whale; D: Humpback whales

12.2 Conventional passive acoustic monitoring PAM

Passive acoustic monitoring was used to detect marine mammals in the vicinity of the seismic source during pre-shooting search periods if these were in periods of poor visibility e.g. darkness, fog, high sea-states, etc. Additional acoustic monitoring was carried out as time allowed. During dedicated acoustic monitoring periods the PAM operator would listen to filtered (i.e. to remove noise such as seismic shots) medium-frequency sounds through noise cancelling headphones and observe graphical displays of low and high-frequency tonal and impulsive sounds on the PAMGuard displays.

The hydrophone array and sound processing and analysis system used was supplied by Seiche Measurements Ltd (SML) (http://www.seiche.com/topics/73-towed-pam-system). The system comprised of a four-element array (2 x broadband hydrophone elements for low frequencies and 2 x standard elements for high frequencies together with respective pre-amplifiers) and a depth sensor at the end of a 250 m tow cable which carried power and analogue signals. A schematic of the array is shown in **Fig. 49** and a specification for the elements in **Tab. 12**. The array (except deck connector) was rated to a depth of 100 m.

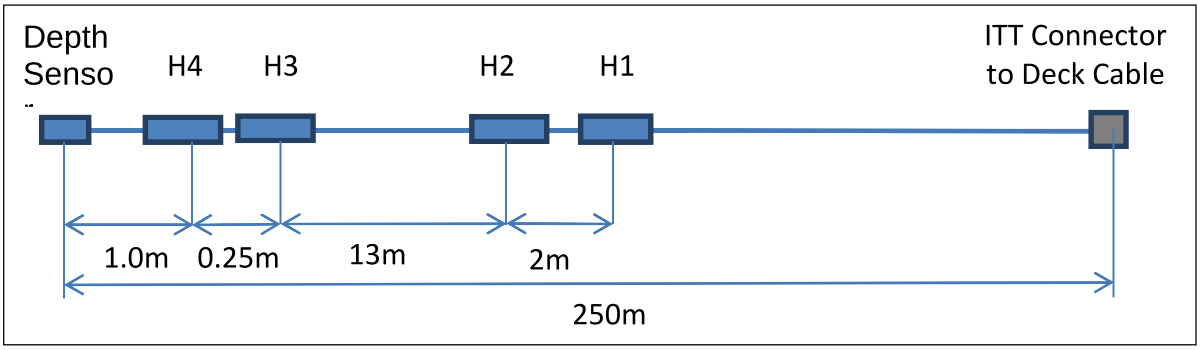


Fig. 49: Hydrophone and depth sensor specification (values used in PAMGuard analysis).

Tab. 12: Specifications of hydrophons and sensors of Seiche System.

Element	Type	Position relative to preceeding element (m)	Position relative to preceeding element† (ms)	Position relative to first (H1) element (m)	Position relative to first (H1) element† (ms)	Frequency range (-3 dB points)	Sensitivity
H1	Broadband	0.00	0.00	0	0.00	200 Hz to 200 kHz	-166 dB re. 1 V/µPa
H2	Broadband	2.00	1.39	2.00	1.39	200 Hz to 200 kHz	-166 dB re. 1 V/µPa
H3	Standard	13.00	9.03	15.00	10.42	2 kHz to 200 kHz	-157 dB re. 1 V/µPa
H4	Standard	0.25	0.17	15.25	10.59	2 kHz to 200 kHz	-157 dB re. 1 V/µPa
DS	*Depth sensor*	*1.00*		*16.25*			
† Assumed speed of sound in sea water =			1440.0 m/s				

At times when the SML PAM array was deployed the system ran making continuous 4-channel low- and medium-frequency recordings and logging additional data e.g. GPS, hydrophone depth, candidate detections, etc. It was decided not to make continuous recordings of high-frequency sound because of the large amount of data that would be generated when weighed against the chances of a species producing high-frequency sound being in the area.

A 100m decks cable connected the outboard parts to the PAM workstation in the lab. The decks unit provides an audio output, signal processing, visualization and analysis and data storage. The PAMGuard (www.pamguard.org) sound processing and analysis system ran on the PAM workstation. A standard mitigation configuration file for SML's four-element towed array was adapted and configured for use on the OGS Explora.

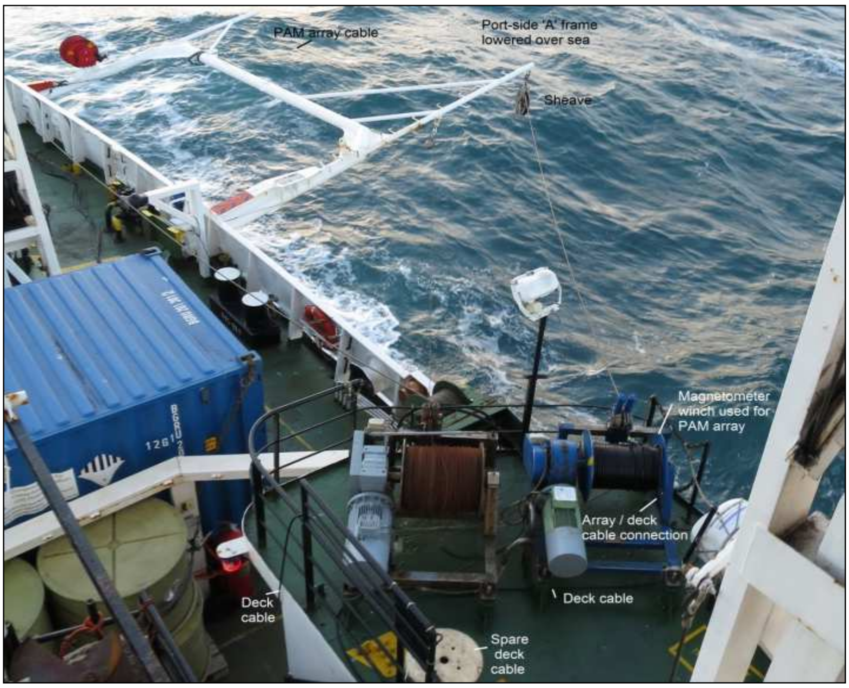


Fig. 50: Annotated image of the deployed PAM array, winch and deck cable.

There were two pre-shooting acoustic searches carried out prior to soft-starts during periods of bad visibility totalling 54 minutes of acoustic effort. The first pre-shooting acoustic search was carried during the first line-start to supplement a visual search when fog descended and visibility was compromised. The second pre-shooting acoustic search was carried during the second seismic start in addition to a visual search. After the second seismic start the MMO/PAM operator was asked to prioritise visual searches (unless visibility was compromised in which case PAM would be used). Outside of these periods (pre-shooting acoustic searches and dedicated acoustic monitoring) the system mostly ran continuously unattended (while the PAM array was deployed) and made continuous 4-channel low- and medium-frequency recordings as well as recording broadband and high-frequency impulsive sounds (potential marine mammal clicks) for possible use in comparison with the QuietSea PAM system. There were 324 hours (13.5 days) of 4-channel recordings and the same duration of both broadband and high-frequency click files. The PAM array and PAM processing and analysis system ran without problems throughout the project.

There were several sources of anthropogenic impulsive sounds of the vessel, which had to be filtered out by the PAMGuard software. These included:

- 2 to 7 kHz sub-bottom profiler
- 18 kHz vessel's echo-sounder
- 100 kHz multi-beam echo-sounder

These ran continuously and were added by the seismic shot and its echo(es).

With the conventional Seiche PAM system there was only one acoustic detection during periods of dedicated acoustic monitoring for pre-shooting acoustic searches (event #16 in **Tab. 10**) – **Fig. 51**. Since the MMO/PAM operator prioritised visual searches during the dedicated pre-shooting time periods (25 hours 42 minutes in total), unless visibility was compromised in which case PAM was used (54 minutes in total) this small number of acoustic detections compared to 17 visual detections does not surprise. Because of the limited time during the survey for analysing PAM data other than within the dedicated time periods, acoustic localizations out of the whole dataset of 324 hours (13.5 days) of unattended PAM operation is still open and must be subject to further post-processing and interpretation.

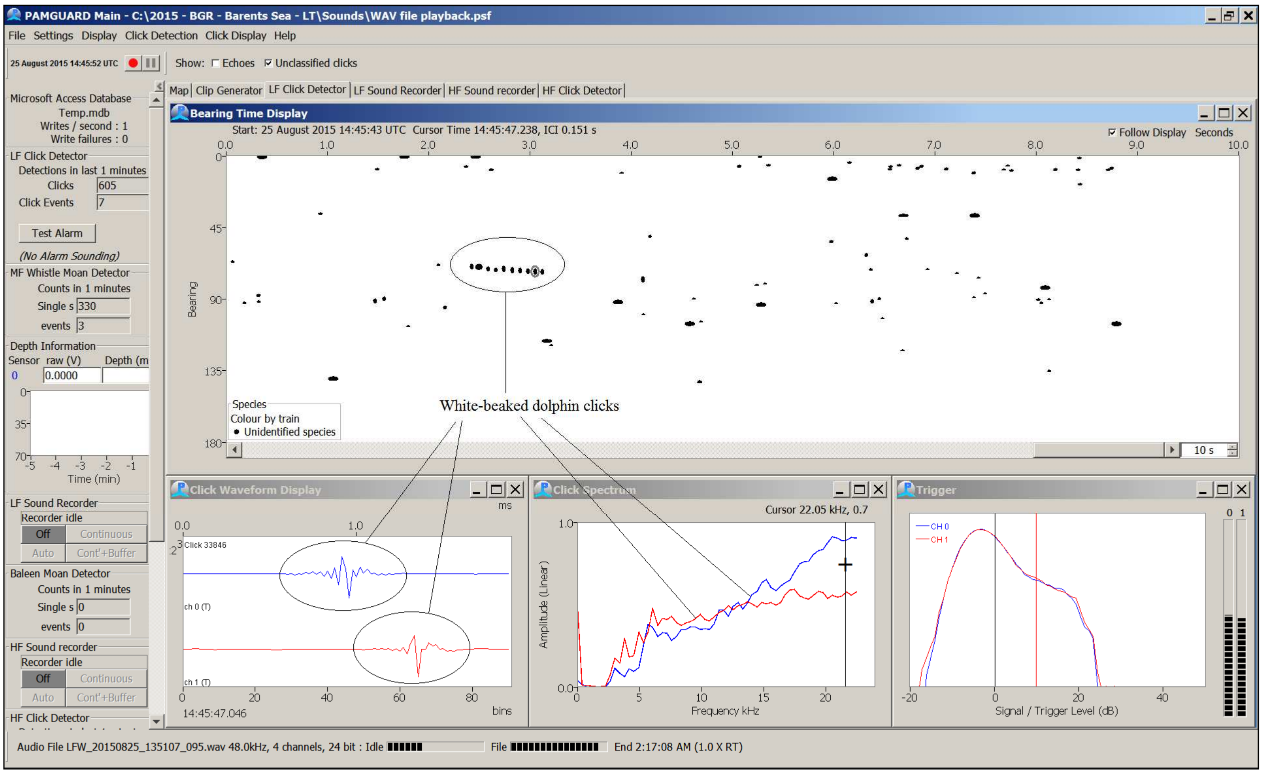


Fig. 51: Annotated plot of impulsive sounds showing a click-train produced by white-beaked dolphins. Shows burst of 10 clicks with click-train ≈ 0.8 s long with ICI of ≈ 0.15 s, sharp impulsive clicks with energy from ≈ 3 kHz to > 23 kHz with maximum energy ≈ 22 kHz. Rapid bearing change relative to the PAM array, i.e. increasing from 69° to 73° in 0.8 s, therefore animal passing from forward of array to astern close to array and guns.

Conclusions regarding mitigation & compliance with JNCC guidelines

The JNCC (2010) ‘Guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys’ were controlled by the followed throughout the survey.

There were a total of 17 seismic soft-starts during the survey. 16 soft-starts preceded line starts and one preceded a gun test which was followed immediately by a survey line. All 17 soft-starts were preceded by visual pre-shooting searches. Two of the soft-starts were also preceded by acoustic pre-shooting monitoring, one was required because of the presence of fog banks and the other was discretionary.

Due to virtually 24 hour daylight in these latitudes at this time of the year darkness was not an issue until near the end of the survey period; however it was not necessary to start any lines in periods of darkness.

Of the 17 soft-starts: 10 were in areas with depths less than 200 m which required pre-shooting searches of at least 30 minutes, while 7 were in areas with depths greater than 200 m which required pre-shooting searches of at least 60 minutes.

Two of the soft-starts (BGR15-101H & BGR15-108) were recorded by the navigators as 19 minutes in duration which would make them just under the recommended 20 minutes, - in any case the duration was marginal and not of great concern.

On one line start (BGR15-101D) problems with turning and issues with the guns meant that the soft-start was extended to 43 minutes in duration (exceeding the recommended 40 minutes) and consequently the period from the start of soft-start to the start of the line was 52 minutes (again exceeding the recommended 40 minutes). There were no occasions when mitigating action was required. Other than the minor issues with the soft-starts, outlined above, the survey was compliant with the JNCC guidelines.

12.3 QuietSea system for passive acoustic monitoring

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 (ALS,Sentinel, Sentinel RD and Sentinel MS) 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. Monitoring is conducted by automated detection and localization algorithms.

During the 2D seismic operation of PANORAMA-2 for the high-frequency detections 4 QS streamer modules (**Fig. 52**, left) plus 2 QS aux modules (**Fig. 52**, right) were employed.

Fig. 52: QS streamer module (left) and QS auxiliary module (right) within protective cage (frequency bandwidth 200Hz to 96kHz)

The QS streamer modules were integrated between the first 4 active sections of the streamer, separated 150 m to each other, the QS aux modules were connected to the gun floats.

During PANORAMA-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 2500m. For general layout of the in-sea modules see **Fig. 53**. The detailed position of each QS node with reference to the vessel was configured in an appropriate node file to be read in into the QS software.

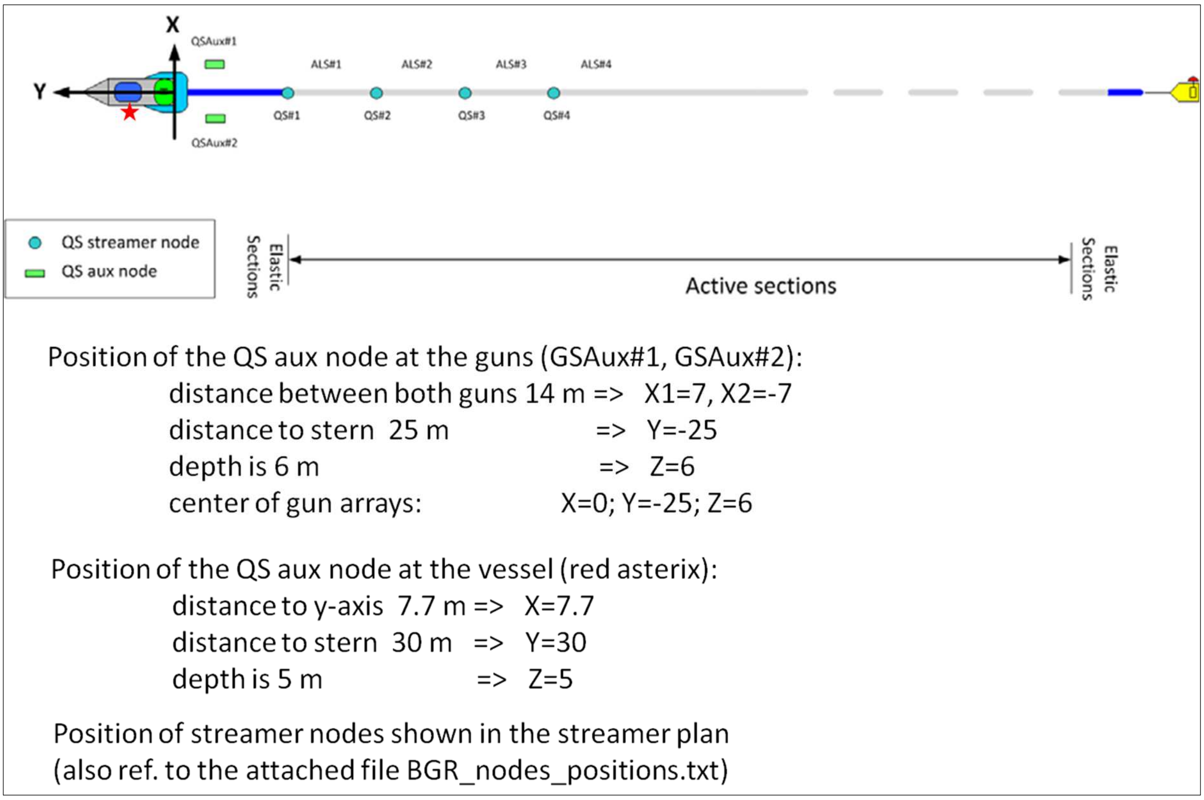


Fig. 53: 2D seismic vessel configuration of QS high frequency components.
Note: gun module QS aux#2 was shifted to the portside (red asterix) after repair

Each in-sea module integrates the QuietSea detection function and the results are sent in near real-time 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. (see **Fig. 55**)

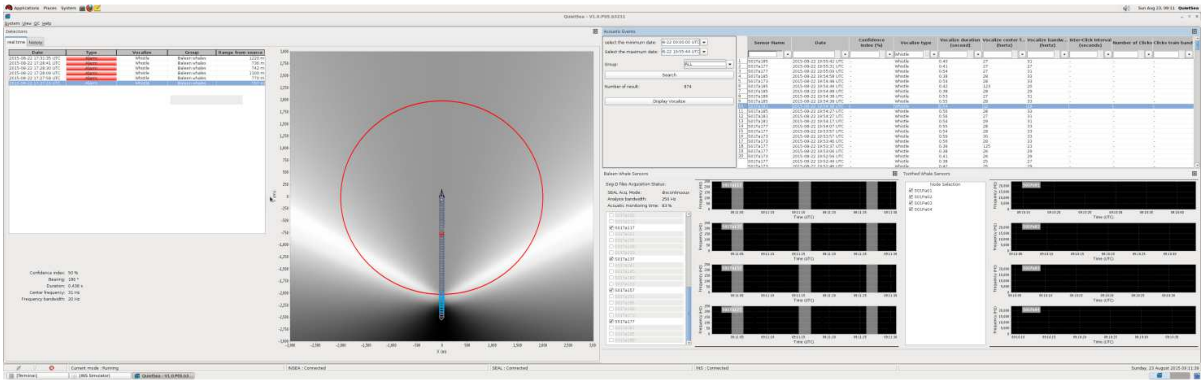


Fig. 54: Screen shot of the QuietSea monitor. Four low-frequency channels (lower left panel) and four high-frequency channels (lower right panel) were selected for display. The vertical grey stripes mark the preset dead time of data analyzing during shooting of the airguns.

The detected acoustic events may be vocalized to discriminate between noise, artificial and significant signals. (see **Fig. 56**)

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 (**Fig. 55**). With 2D configuration localization results are mostly ambiguous, whereas with 3D configuration positions of acoustic signal sources can be defined unambiguously.

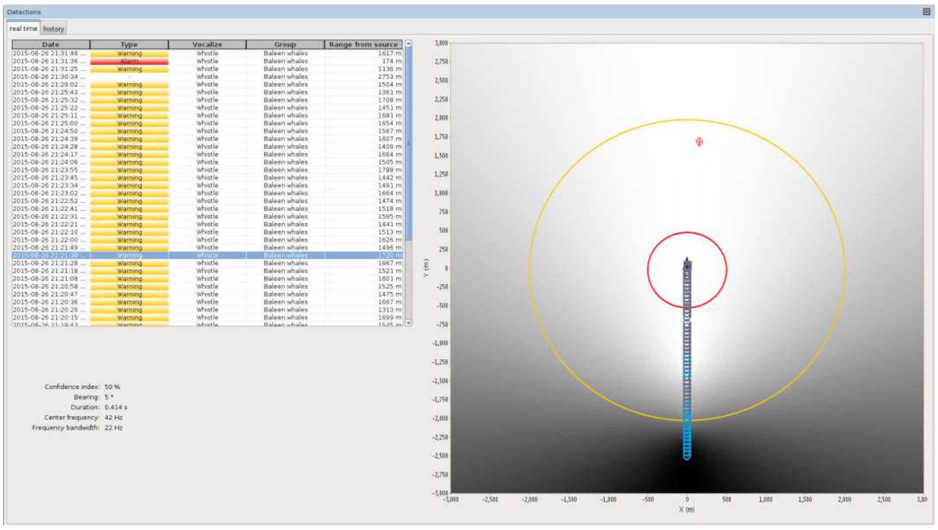


Fig. 55: QuietSea navigation monitor with event logging (left) and localization result (right) with preset warning and mitigation circles (red dot within bright sector – estimated position of detected acoustic source)

During PANORAMA-2 the total monitoring time with QuietSea covered 303 hours and 32 minutes within the time period August 17th until September 1st (see **Tab. 13**).

Tab. 13: QuietSea daily monitoring times

Date	Monitoring time	Period (UTC time)
15/08	00H02mn	15:45 → 15:47
16/08	01H20mn	05:04 → 06:24
17/08	15H41mn	06:28 → 23:59
18/08	23H39m	
19/08	19H46mn	00:00 → 11:08 11:49 → 18:56 20:04 → 21:26
20/08	15H02mn	06:12 → 14:40 14:52 → 17:48 18:34 → 23:59
21/08	23H17mn	
22/08	23H53mn	
23/08	23H58mn	
24/08	24H00mn	
25/08	23H58mn	
26/08	23H45mn	
27/08	21H14mn	00:00 → 21:14
28/08	00H00mn	
29/08	10H14mn	13:46 → 23:59
30/08	24H00mn	
31/08	23H49mn	
01/09	05H54mn	00:00 → 05:54

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.

Nevertheless, there were a much larger number of acoustic events detected for the high frequency range. These acoustic signals are whistles emitted by toothed whales and sperm whale clicks. In general, the toothed whale whistles show clear features which point to the characteristic vocalizations of dolphins (**Fig. 56**). The high-frequency suspected sperm whale clicks very often proved themselves as false alarms. More than 346 false detections, mainly provided by the same sensor, were probably caused by a damaged gun auxiliary module or were strongly biased by the echosounder of the vessel, even though the selected bandwidth of the preset notch filter should exclude them to be used for the automatic detection algorithm of the QuietSea software.

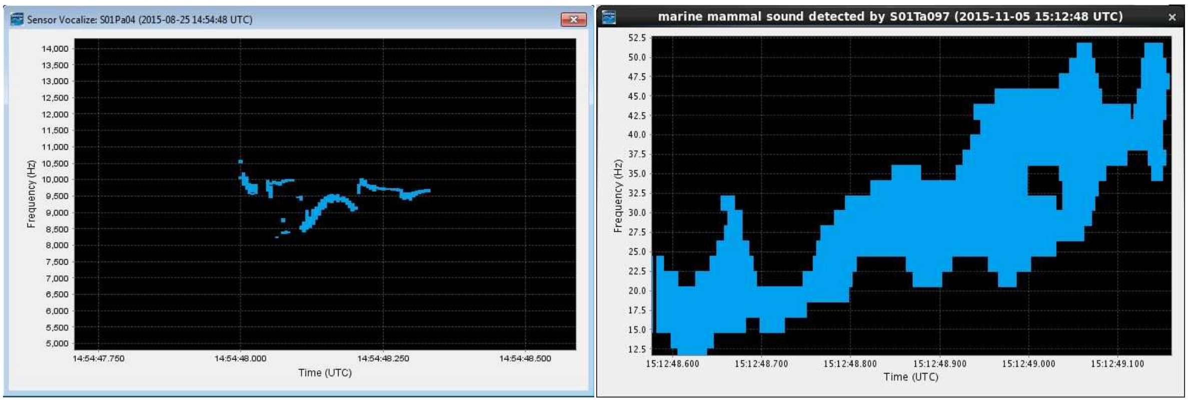
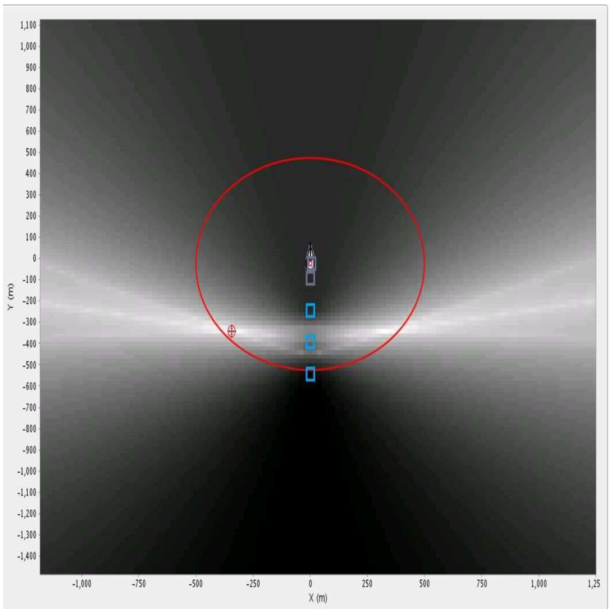


Fig. 56: Whistles in high-frequency range recorded at streamer module S01Pa04 (left) and a (suspected false?) acoustic event in low-frequency range at channel #97 (right).

There were a smaller number of low-frequency detections in the logged data. After re-analysing the obtained signals it appears that most of them are false detections. The detected signals mostly show a frequency bandwidth between 25 and 55Hz (see **Fig. 56**, right). There was an unusual periodicity of unknown reason in part of the data which did not coincide with the shot intervals. These periodic events demonstrated themselves as reverberations of the shots. A point to mention is that false detections are concentrated on the farthest seismic channels. It is suspected that modal dispersion in shallow water (water depth was always less than 300 meters) and/or multiple reflections of the seismic signals caused this unusual periodicity. The low frequency recordings need to be analysed in more detail subsequently which is subject to further investigations.

Based on these first results Sercel upgraded the QuietSea firmware from Patch05 to Patch06. It is supposed that with this upgrade the discrimination between artificial and natural sounds will be improved and the number of false alarms in the low-frequency range will be remarkably reduced.

The firmware upgrade also eliminated errors in the localization of acoustic events. In **Fig. 57** the acoustic event of August 25th, 14:56:53, which was detected several times within a time period of some minutes was analysed. This event was also detected by the conventional Seiche PAM (see event#16 in **Tab. 10** and **Fig. 51**). It was identified there as whistles of a white-beaked dolphin. In general, the position of a signal source (red circles in **Fig. 57**) is the intersection of all (symmetrical) cones of confidence (bright sectors in **Fig. 57**), defined by each QuietSea sensor which detected this signal. With Patch05 the localized signal sources sometimes did not coincide with the intersections of all cones of confidence source for an acoustic signal (see **Fig. 57**, upper right). Reanalysing this event with the upgraded QuietSea firmware provides the correct localization for this event.



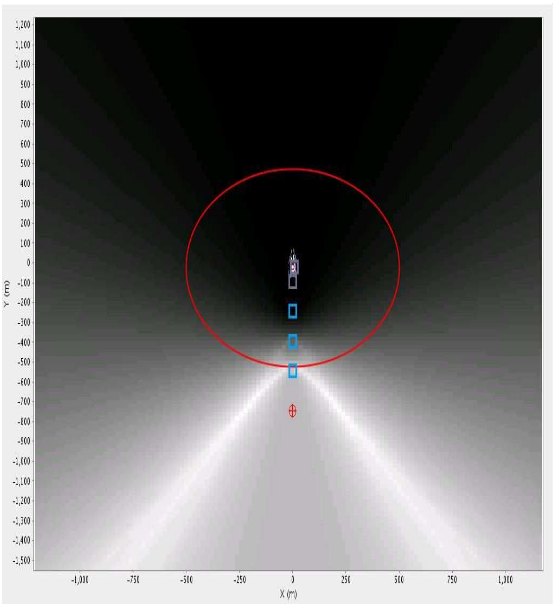
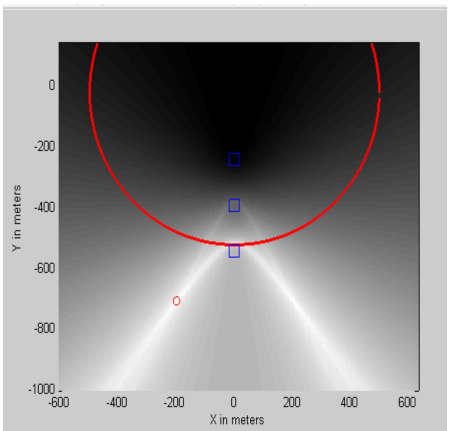


Fig. 57:
Whistle localized at 471m by QuietSea at 14:54:48 UTC, August 25th 2015 by red circle inside the mitigation radius (upper left),
whistle localized 2 minutes later at 722m at 14:56:53 UTC, the dolphin is now outside the mitigation radius of 500m, but the position is not represented by the intersection of bright sectors (upper right),
whistle localized at 713m at 14:56:53 UTC after new range estimation with Patch06 upgrade (lower right), note: all positions are symmetrical ambiguous



12.4 Comparison of results derived by visual, PAM and QuietSea observations

Three independent methods of marine mammal observation were employed during the seismic survey. For a short period of about 1 hour (at August 25, starting about 13:30) all methods were applied simultaneously and results were intensively analysed, which provides a first database for comparing purposes. Over a period of 38,5 hours visual observations were conducted, but only part of this coincides with the 303,5 hours period of QuietSea records. Seiche PAM data are available for a time period of 324 hours of unattended recordings.

Within the 1 hours period of simultaneous watch one single event was identified by all three methods. The visual sighting (event#15 in Table 10) of a white-beaked dolphin for about 12 minutes starting at 13:42 belongs with high probability to the same animal (or animal group) which was acoustically detected for a couple of minutes by the PAM starting at 14:48 and the QuietSea system in the same time span.

Affirming this result that QuietSea is able to provide data of marine mammal detection and localization at least comparable to PAM, needs further efforts in analysing the existing datasets. For the Seiche PAM data, this applies for a qualified analysis acquired during the unattended operation period of 324 hours. To verify the reliability of the QuietSea system it is necessary to improve the algorithm for discriminating between artificial (seismic) signals and natural sounds in the low frequency bandwidth. Moreover, a statistical evaluation of analysed acoustic events detected by PAM and QuietSea is necessary before finally reviewing this promising new method to reduce any risk during marine seismic operations.

13. GEOLOGICAL SAMPLING

Martin Krüger, Christian Seeger, Philipp Weniger, Michael Wiedicke-Hombach, Daniela Zoch

13.1 Marine geological setting and sampling objectives

The study area is located in the northern Barents Sea, south and southeast of Spitsbergen. While some sampling locations were selected on the E-W running transit profile (SBP04), the main focus of activities was concentrated in the area between Hopen Island in the west, Storbanken in the north and Sentralbanken in the southeast. This target area is considered to cover much of the so-called Olga Basin.

The main objectives of the sampling campaign were:

- Recovery of Mesozoic rock samples to verify stratigraphy and characterize lithology of the deeper subsurface
- Recovery of fine-grained soft sediments below the highly disturbed surface layer for organic geochemical analysis of light hydrocarbons for petroleum and gas prospecting
- Recovery of high-quality surface samples for microbiological investigations of the hydrocarbon degradation potential of the indigenous microbial communities
- Recovery of ocean water samples for geochemical analysis of dissolved gases

In order to properly handle the challenges and problems trying to address the above outlined objectives a good understanding of the shallow near-surface geological situation of the survey area is required. The two most important aspects are briefly summarized below:

a. *Acoustic basement*
   The acoustic base in the survey area is expected to consist of lithified, predominantly clastic sediment sequences of Mesozoic age; in the western part Triassic sediments are known to occur (e.g. Hopen Island exposes thick clastic horizontally layered Triassic sequences) while for the southeastern part of the area Jurassic to Cretaceous sediments are thought to form the basement [e.g. *Elverhoi and Lauritzen*, 1983].

b. *Soft sediment cover*
   The above described basement is covered by a thin veneer of Quaternary soft sediments of less than 10 m thickness. According to *Elverhoi et al.* [1989] this cover is made of several units of tillite and unsorted glaciomarine sediments which indicate the existence of a grounded ice sheet during the last glaciation for much of the Barents Sea. The Quaternary sequence is topped by less than 0.5 meter of Holocene soft (sandy/pebbly) mud.
   The glacial sediments are not evenly spread but may vary in extent and thickness. In rare cases the basement may crop out (which would offer chances to obtain basement rock samples by dredging). The surface of the thin Quaternary sequence is heavily affected by (post glacial) iceberg scours which appear as several hundred meters long and several meters deep ploughmarks. In some areas numerous relatively small pockmarks have been observed, indicating potential sites of hydrocarbon seepage.

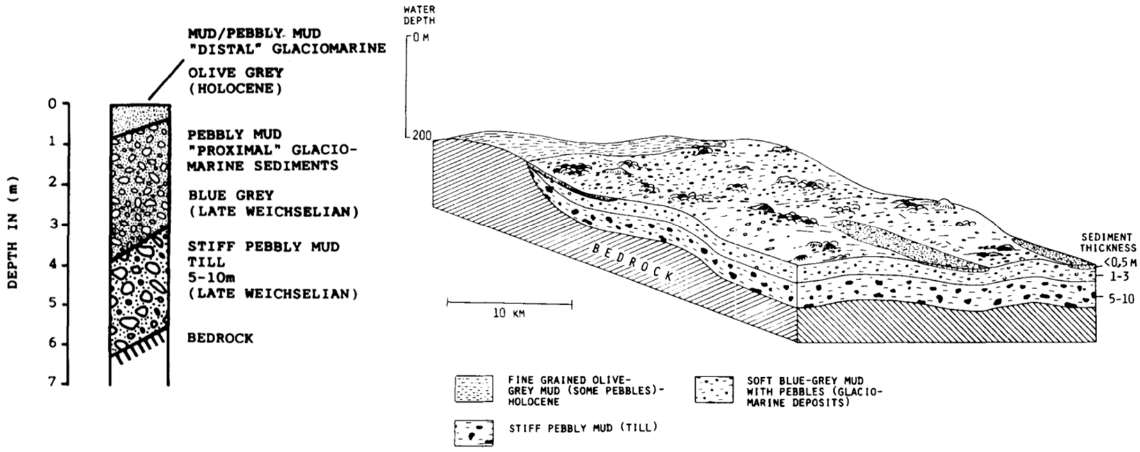


Fig. 58: Generalized stratigraphical /geological shallow subsurface profile in the northeastern Barents Sea (left) and a 3D sketch of the areal expression (right) [modified from Elverhoi et al., 1989; Elverhoi and Solheim, 1983].

13.2 Sea floor sampling methods (incl. water sampling)

Depending on the objectives and the specifics of individual targets, four different instruments were used to recover samples from the sea floor or the water column:

- A multicorer to collect up to 0.5 m cores of undisturbed ocean floor sediment and water samples,
- A gravity corer to retrieve up to 3 m long soft sediment cores,
- A chain-bag dredge to obtain hard rock samples,
- A Niskin bottle to collect water samples from the water column above the ocean floor

All seafloor sampling devices were deployed via the A-frame of the vessel. The Niskin water sampler was mounted to the cable of the SVP probe and deployed via the portside winch of the vessel.

Multicorer (MUC)

The multicorer comprises eight 0.6 m long plastic barrels, mounted in a steel frame with a footprint of 3 m in diameter (**Fig. 59**). Due to limited deck space, a location between A-frame and hydraulic crane at the starboard side was chosen to store the instrument between sampling times. The hydraulic crane was used to place the instrument close to the A-frame, from where it could be deployed. The handling needs great care to bypass several obstacles at the deck and therefore was restricted to fair weather conditions. Despite the relatively low weight of the instrument of about 800 kg the touch down to the sea floor leads to a marked decrease in load of the wire providing a 'visible' control of the coring process. In addition a tension meter indicates bottom contact of the device.

The multicorer can be equipped with up to 8 transparent sampling tubes, which allow retrieval of up to 50 cm long sediment cores including the interface between the topmost sediments and the ocean bottom water. After touch-down of the instrument on the ocean floor, the plastic barrels are driven into the sediment by a weight mounted above the coring barrels. During pull-out of the instrument, a trigger mechanism seals the plastic barrels on both sides, preventing loss of sediment and water during recovery. Depending on the physical properties of the sea floor, the weight of the instrument can be slightly varied to optimize the penetration process. Due to transport damage of the device, only 7 tubes could be mounted for each deployment. During the initial few sampling stations between 2 and 7 short cores were recovered. Sampling sites and core recovery are listed in Fig. 65 and Appendix A. 6). The sediment samples will be used for geomicrobiological and geochemical analyses (see Chap. 14).

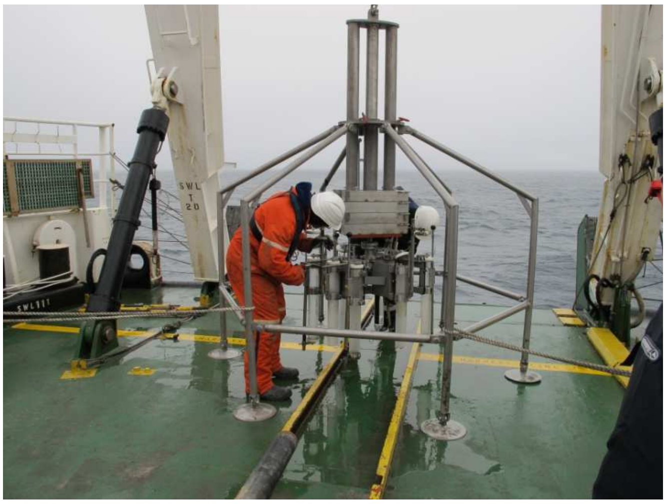


Fig. 59: Preparation of the multicorer (MUC) onboard OGS Explora. The MUC is used to obtain high-quality surface sediment and water samples from the sea floor.

Gravity corer

A ship owned gravity corer consisting of a 3 m long open barrel attached to a 1000 kg lead weight (corer body) was used to obtain soft sediment cores (**Fig. 60**). The corer is lowered to the sea floor by a winch via the ship’s A-frame. When approaching the sea floor the instrument is lowered with maximum speed of the winch until bottom contact to ensure good penetration of near-surface sediment. Once back to the sea surface, the recovery of the instrument with the A-frame is supported by two metal noses mounted to the vessel to help catching the instrument. After fixing the corer to a deck-mounted sliding sledge, the corer is transported to the back deck and secured (**Fig. 61**). The core cutter is removed and the liner with the sediment core pulled out of the barrel and cut into 1 m segments. The sediment cores will be used to determine the characteristics of adsorbed hydrocarbon gases thought to rise from the subsurface. Due to the robust construction and the supporting equipment of the vessel, this device can still be deployed with fairly rough weather conditions (Bf 5-6, wave height ~2.5 m).

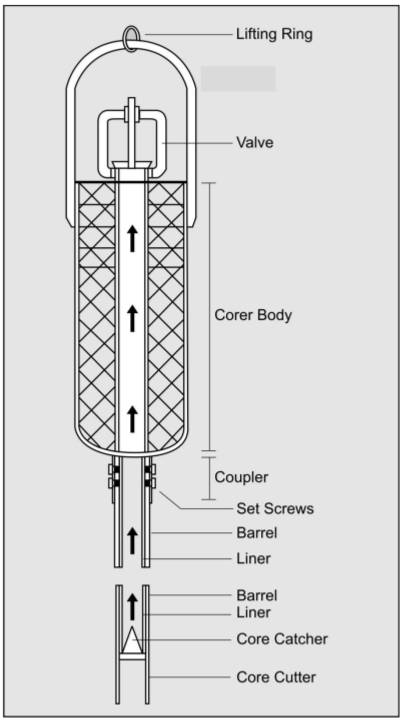


Fig. 60: Schematic of an open barrel gravity core [from Abrams, 2013].

Fig. 61: Gravity corer still mounted to the sledge onboard of OGS Explora before deployment.

Chain bag dredge

For hard rock sampling BGR's chain bag dredge with a mouth opening of 100 x 40 cm was used. Between the dredge and the pulling wire a weak link with a break-load of 3.1 t was inserted. Mounting the weak link in U shape increased the breaking point to a load between 4-5 t. To prevent loss of the instrument, an additional safety cable was attached to the back of the chain bag. This cable ensured a recovery of the dredge in case the weak link would break (**Fig. 62**).

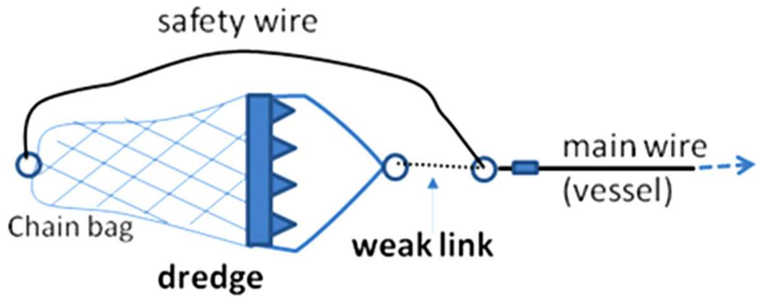


Fig. 62: Set up of the dredge used during Leg 2 of PANORAMA-2. The weak link was mounted to ensure, that the load on the vessel's main wire did not exceed 6 t.

The dredging operation was performed as follows: The dredge was lowered to the sea floor at the base of a topographic structure of the sea floor. Once the dredge had been laid down at the sea floor, the vessel slowly moved 'uphill' of the sea floor target continuously paying wire with the winch to avoid pulling the dredge early. Once the vessel had passed the end of the envisaged dredge track the winch was stopped while the vessel very slowly moved on. This set up allowed a proper start of the dredging process. At the end of the dredge pass the vessel was stopped and the dredge recovered via the winch.

Fig. 63: BGR's chain bag dredge hanging at the A frame of the vessel; ready for deployment. This device was used to sample hard rock outcrops at the sea floor.

Water sampling

At multicorer stations the near-bottom water captured in the MUC sampling tubes was subsampled routinely. In addition, at selected locations (e.g. at some GC sampling sites) a dedicated near-bottom water sample was retrieved by using a 5 L Niskin bottle attached to the cable of the SVP probe using a winch located at the second deck and deployed via the portside of the vessel (**Fig. 64**). Once the Niskin bottle reached the sampling depth, a trigger-weight ("messanger") was attached to the wire and send down to trigger the closing mechanism of the bottle.

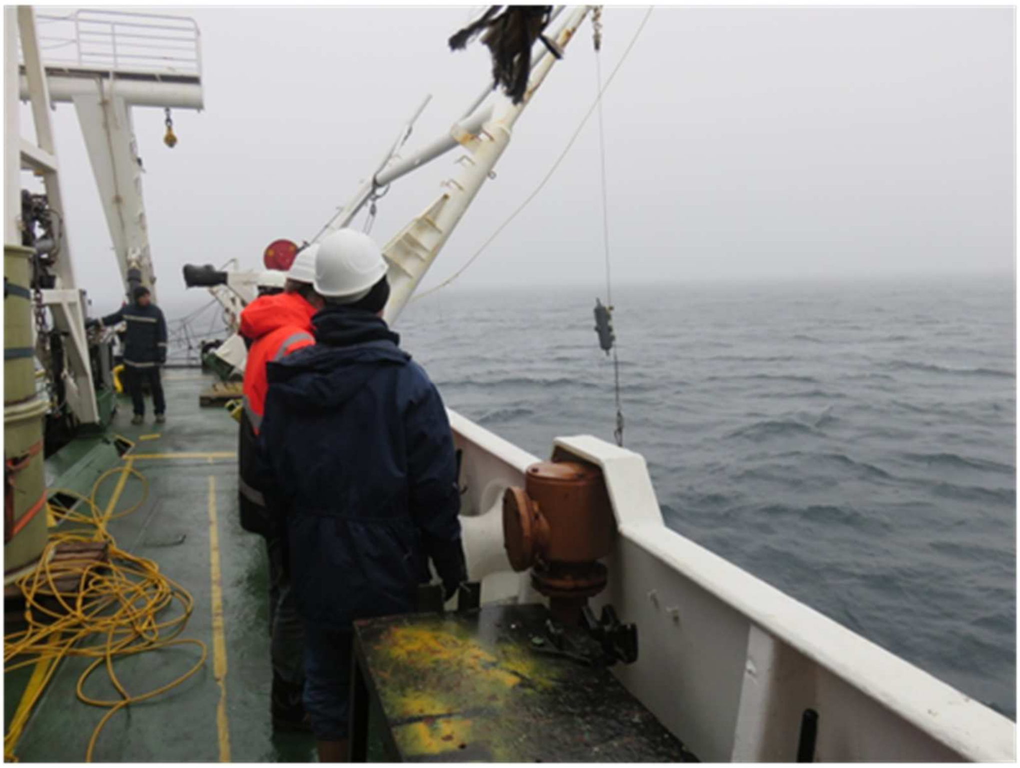


Fig. 64: Niskin bottle attached to the cable of the SVP probe to collect water samples.

13.3 Sampling results

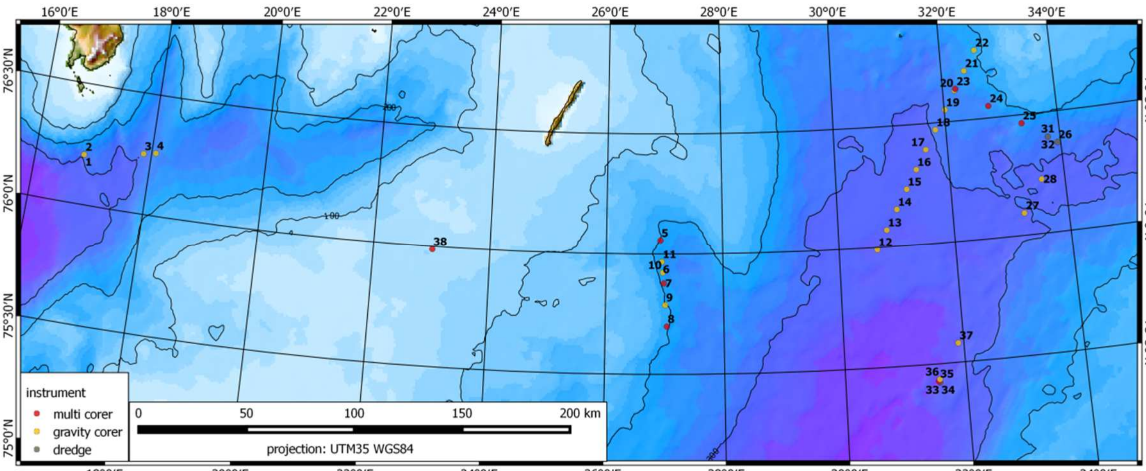


Fig. 65: Location of samples collected during PANORAMA-2 Leg 2. Gravity core sites = yellow; multicorer sites = red; dredge sites = grey.

Multicorer sampling

Due to transport damage during mobilization, only 6 of the 8 core barrels were functional during the first two days. After the damage was repaired, 7 barrels were functional and the multicorer recovered 6-7 near surface cores of 20-35 cm length during the following deployments. During the expedition the multicorer was deployed 11 times and a total number of 30 near surface sediment cores were recovered. The trapped near-bottom water was also sampled from one barrel during each deployment. Annex A. 6 provides an overview of the sampling stations.

Gravity corer sampling

Gravity coring proved to be a very reliable sampling technique. However, recovery of cores longer than 1.8 m turned out to be challenging. A total of 22 gravity cores were collected with a length of recovered sediment ranging from 0.61 m to 1.90 m. Particularly the short cores (60-90 cm) encountered glacial sediments at their base such as pebble-rich glacial tills or strongly consolidated glacial clays with physical properties preventing further penetration of the device. These sediment types mark a (natural) limitation for a sampling technique of this kind. An overview of gravity cores collected during the expedition and the respective core recovery is provided in **Fig. 66**.

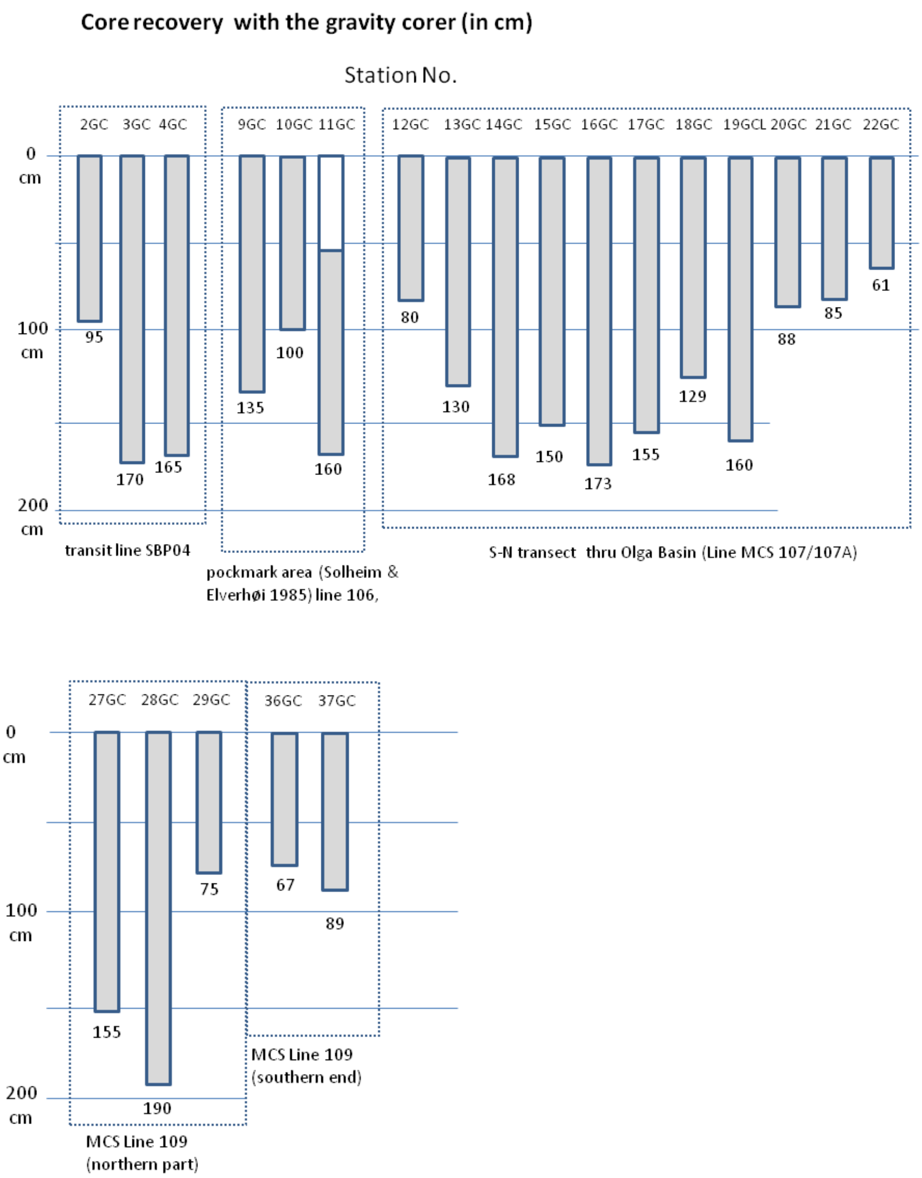


Fig. 66: Core recovery as achieved with gravity core sampling at all 22 stations.

Water sampling

Water samples were collected from one multicorer barrel during each of the 11 multicorer deployments. Additionally, water samples were collected three times from the water column near the sea floor using the Niskin bottle. Water samples were transferred into two 50 ml headspace vials, sealed with butyl-rubber septum crimp caps and stored in a refrigerator. 15 mg of mercury chloride (HgCl) were added to each vial to inhibit microbial activity.

Dredge sampling

The chain bag dredge was deployed 5 times. Precaution was taken to ensure that the wire load did not exceed the limit set for the vessel (**Fig. 62**). Weather conditions during all dredging stations were good and did not impose limitations. Maneuvering of the vessel to place the dredge at the proper starting position at the foot of small slopes and also recovery after reaching the end of the desired dredge track went smoothly. Dredging operations were performed with the slowest speed of the vessel which still allowed appropriate maneuvering (ca. 1.5 kts). No pulls higher than approximately 1.2 t were recorded during the dredging. Dredge tracks were kept restricted to the expected hard rock outcrops, to prevent unnecessary coverage of Quaternary sediments.

All dredge hauls successfully brought up hard rock samples. However, the recovered material was less than expected. In most cases these rocks had to be picked out of a huge pile of sticky grey soft mud which the dredge had recovered. Further work on the rock samples will have to verify whether the objective to sample the outcropping Mesozoic basement has been satisfied. Results of the dredge sampling are listed in **Tab. 14**.

Tab. 14: Characteristics of the five dredging stations of Leg 2. All dredge deployments brought up hard rock samples of limited amount. Staining of rock fragments indicates exposure to sea water. No fresh broken surface could be observed. Interpretation of the results needs further work on the lithologies and potential age determinations /stratigraphy.

Dredge deployments

#	Station	Water depth (m)	Target	Slope height	Loca tion		Hard rock recov. (kg)	Sample Description
1	30 DRG 01	280 - 264	steep slope, fault plane cropping out	25 m	1		ca. 0.5	angular rock fragments (up to 10 cm), 1 large pebble, platy encrusted sediment fragments (hardground)
2	31 DRG 02	272 - 252	steep slope, fault plane cropping out	20 m	2	2 runs at same target	ca. 1.5	angular sandstone fragments(15 cm), encrusted sediment fragments (hardground)
3	32 DRG 03						ca. 5	angular (silicified?) rock fragments (20 cm), several angular grey sandstone fragments
4	33 DRG 04	364 - 328	inclined strata cropping out (fold), no young cover	gentle slope	3	2 runs at same target	ca. 1	sandstone (transported), small angular rock fragments
5	34 DRG 05						ca. 1	angular sandstone pieces, rock fragments, black platy fragile rock (shale, small pieces)

Description of sampling at selected sites

Each of the three devices available for seafloor sediment sampling required a careful selection of sites for their deployment.

The multicorer (MUC) can sample the uppermost 30 cm of the seafloor. Therefore a thin cover of soft sediment is sufficient to successfully use this device. A cover of Quarternary sediments is generally present throughout most of study area. As an example the location of the first station which was selected for a MUC deployment is shown in **Fig. 67**. One objective was to sample active fluid escape features e.g. pockmarks which form in these sediments. Sampling could provide a hydrocarbon signature extracted from the sediment sample. **Fig. 67** shows a circular structure at the sea floor with a diameter of 100 m which might be an active or inactive pockmark. Station 01MUC was placed in the center of this feature.

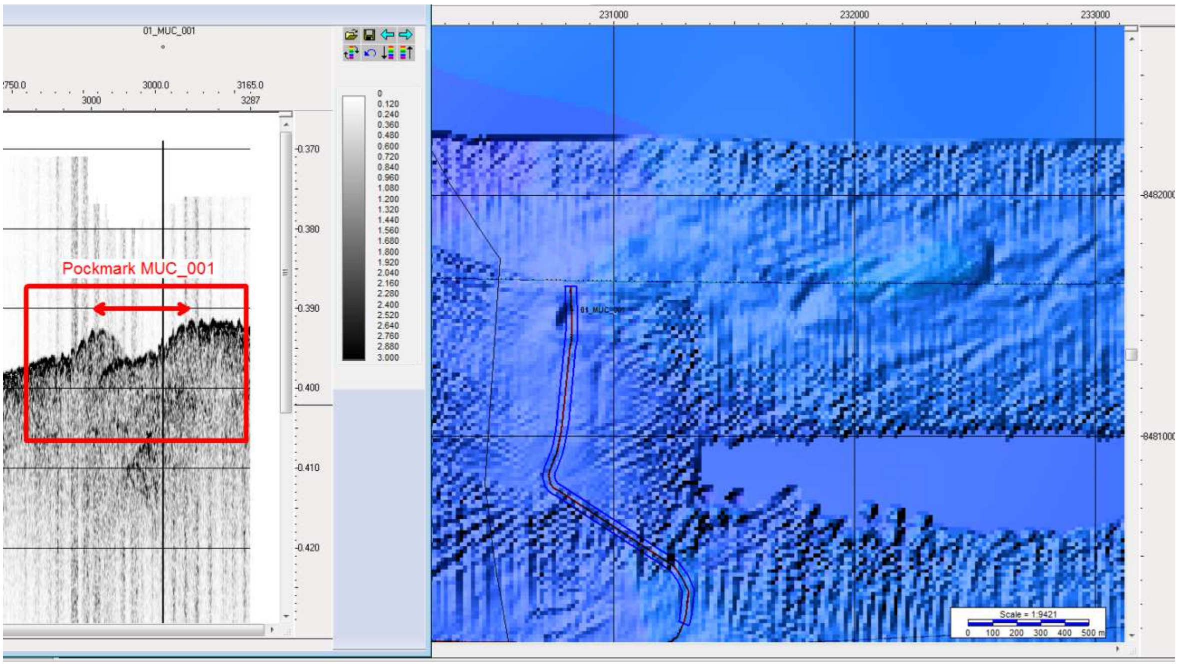


Fig. 67: Circular structure in multibeam bathymetry data shown on the right. At the left this feature is captured with CHIRP data. The structure has a diameter of around 100 m.

The chain-bag dredge is used to collect hard rock samples from outcrops at the seafloor. Therefore dredging sites need as little cover of soft sediments as possible; ideally they should be devoid of soft young sediments. Additionally, the seafloor needs to be inclined, so that the chain-bag dredge can break off rock fragments. One example of a dredge site is displayed in **Fig. 68** where inclined basement reflectors crop out over a distance of more than 1 km and hardly any young coverage can be observed. This site became the target for stations 33DRG and 34DRG.

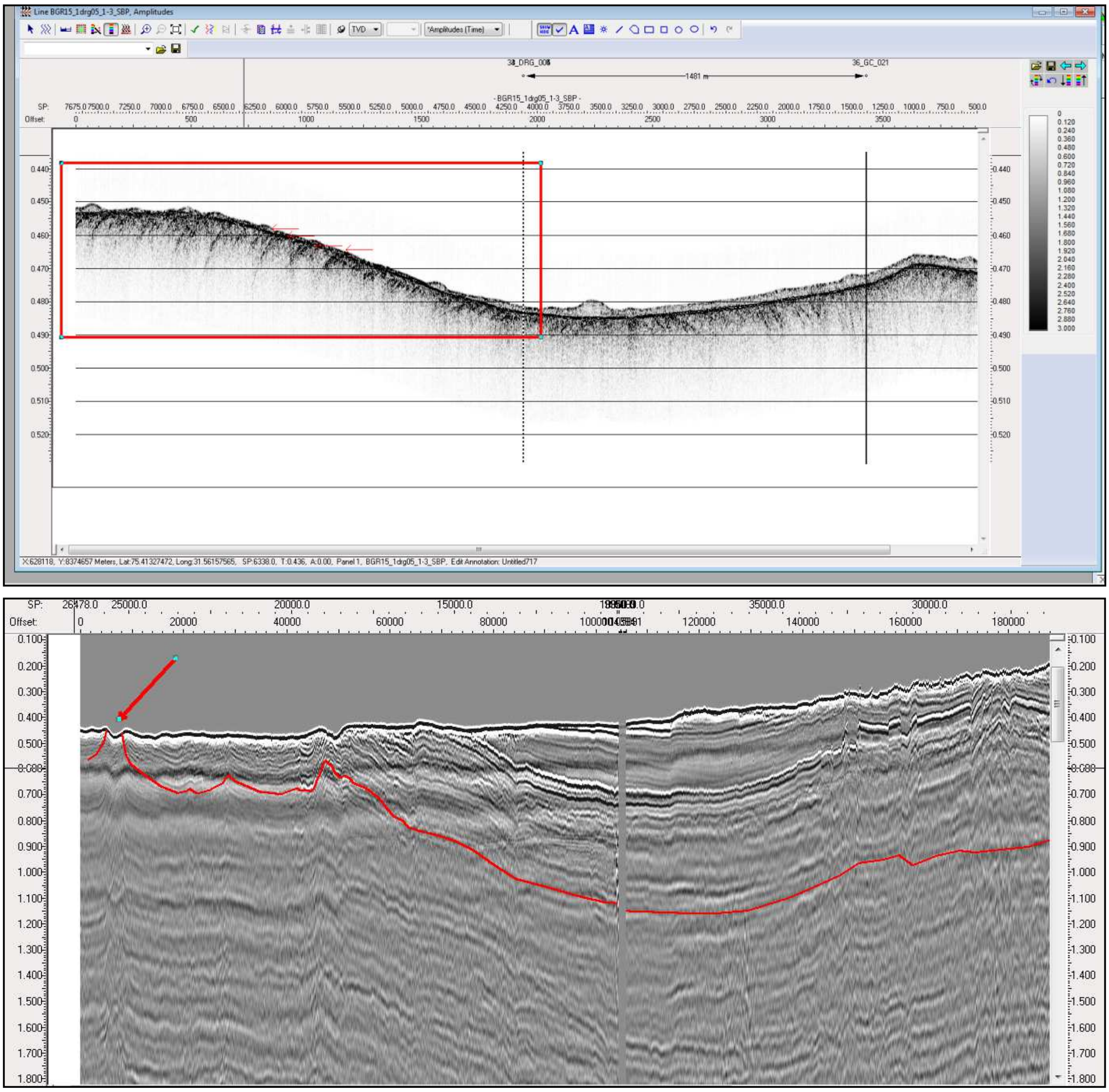


Fig. 68: Top shows CHIRP data of dredge site 33_DRG_004 and 34_DRG_005. The inclined seafloor is almost devoid of sediments and the red arrows point to outcropping rocks, probably of Mesozoic age. At the bottom the same location is indicated with a thick red arrow in multichannel seismic data (preliminary onboard processing). The interpreted horizon indicates possible outcrop of Mesozoic rocks and its continuation to greater depth.

The gravity corer is able to sample the uppermost 3 m of sediments, which requires a selection of sites with a soft sediment cover over the Mesozoic rocks. An example of a gravity corer site is displayed in **Fig. 69**.

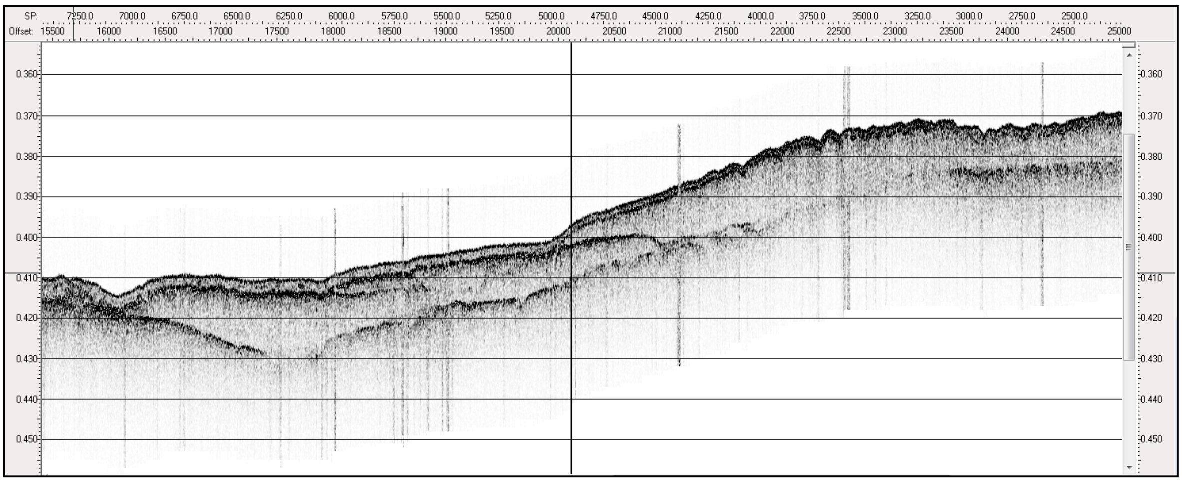


Fig. 69: Sequence of three sediment layers at site 03_GC_002. The topmost thin Holocene layer is underlain by two probably glacial sediment bodies of irregular extent and partial overlap, which cover the acoustic basement thought to consist of Mesozoic sediments at this site.

An example of another morphological feature observed at the sea floor of the Barents Sea is included in this section as it complicates the sampling strategy in general – iceberg scours. The thin Quaternary sediment cover frequently shows numerous elongated depressions. They can be straight, curved and sometimes angular and can be several hundred meters long and several meters deep. They were generated by drifting icebergs the base of which touched the sea floor ploughing long but often irregular scours in the soft sediment. **Fig. 70** shows the bathymetric expression (top) and the appearance in the chirp recording (below).

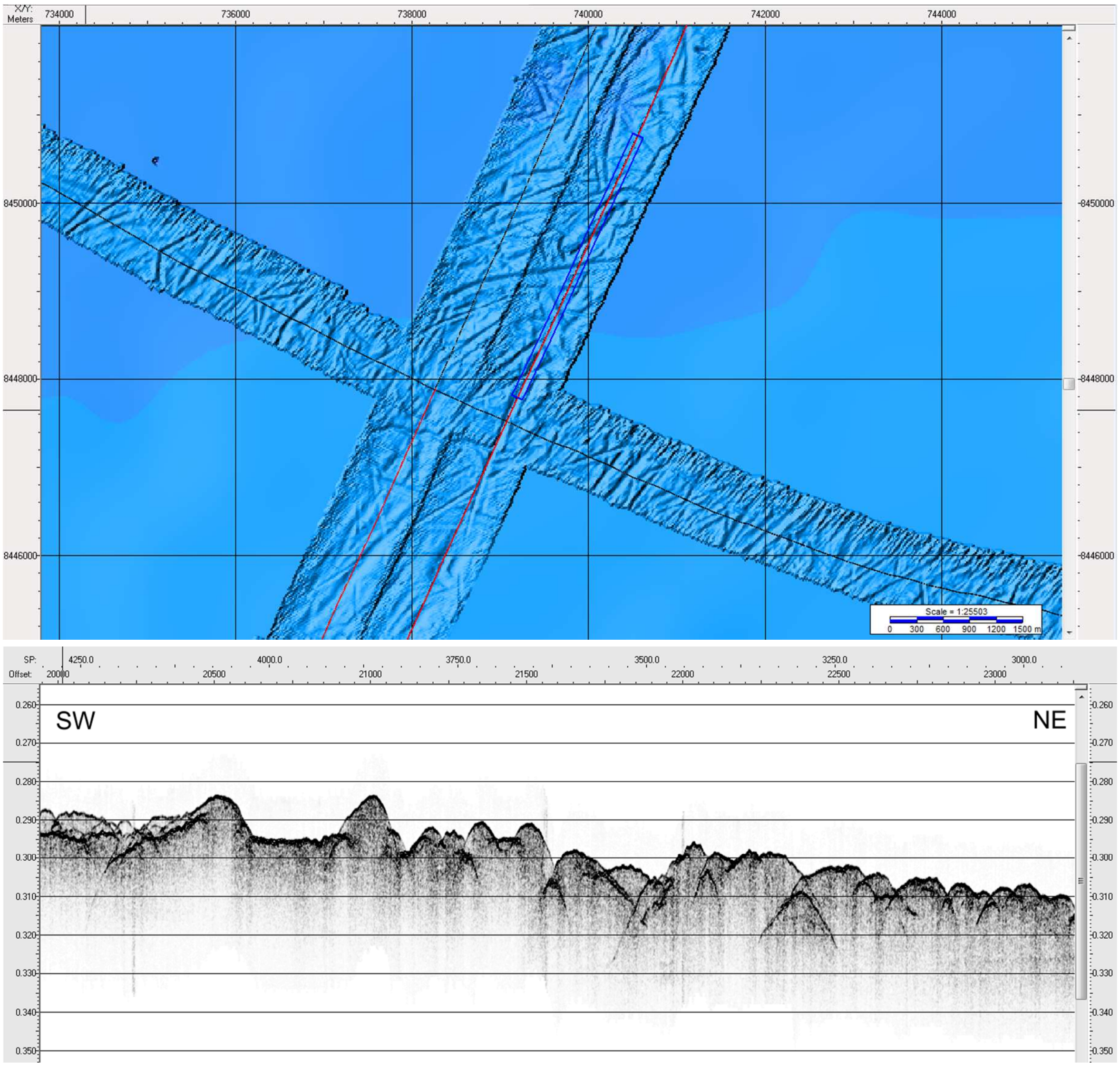


Fig. 70: Iceberg scours as recorded in the bathymetric map (top) and the associated chirp recording (below).

14. ORGANIC GEOCHEMISTRY, BIOGEOCHEMISTRY AND GEOMICROBIOLOGY

Martin Krüger

14.1 Objectives

Subsurface hydrocarbons can leak from reservoirs and migrate to the surface in form of macro- and microseepage. Traces of migrated hydrocarbons remain in near-surface sediments as free gas in the open pore space, as dissolved gas in pore water or the water column and as gas bound in the sediment matrix by physical and chemical processes. Quantitative and qualitative analysis of the geochemical and stable isotopic gas composition allows differentiation between biogenic and petrogenic (thermogenic) sources. Furthermore, it provides information on the origin and thermal maturity of thermogenic gas. Investigation of hydrocarbon seeps in the northern Barents Sea by direct methods (echosounder, gas geochemical investigations in the water column) and indirect methods (organic geochemical and geomicrobiological analyses of near-surface sediments) can support assessment of the hydrocarbon potential in this frontier region.

Microbiological investigations of the hydrocarbon degradation potential of the indigenous microbial communities by molecular-biological analysis together with the cultivation of such microorganisms can give additional useful data on the potential of the microbial communities in this area to react to natural or man-made accidental oil spills.

Additionally, this study contributes to the understanding of one of the least known and most extreme ecosystems in these permanently cold and presumably nutrient-limited marine sediments. In fact, very little is known about the nature and activity of microbial life in remote Arctic marine sediments. The phylogenetic and physiological diversity of marine Arctic sediment communities of the northern Barents Sea is largely unknown.

14.2 Gravity corer

Gravity cores where taken at 22 stations to obtain sediment samples for gas geochemical and microbiological analyses (see Appendix A. 6) for detailed coring list, and **Fig. 65** for their location). A gravity corer with a three meter core barrel was used at all stations. The filled part of the liner (between 70 to 190 cm) was cut into one-meter sections using a commercial tube cutting tool and a clean masonry spatula. Before splitting the one-meter core sections, samples for gas analyses were collected (see below for detailed description).

After gas sampling was completed, core sections were laterally opened using two sledge-mounted vibrational saws. The end caps were cut with a conventional cutting blade. When the liner and the end caps were separated, a simple, hand-held device with a thin stainless steel wire was used to separate the two halves of the section. The two halves were split by hitting the separated section on two wooden supports. Splitting was sometimes incomplete and required the additional help of a masonry spatula. All masonry spatulas, the saw blades, the cutter and steel wire were sterilized before usage. For geochemical analyses, 200-500g of sediment was collected from the base, middle and top section (directly below the olive-green Holocene mud) of the cores, wrapped in aluminum foil and stored in a deep freezer. Additionally, the lowermost sediment from the core cutter was collected for geochemical analysis. Rock fragments found within the soft clay and mud were collected for further lithological analyses.

14.3 Multicorer system

Multicorer (MUC) cores where taken at 11 stations to obtain undisturbed surface sediment samples for gas geochemical and microbiological analyses (Coring list – see Appendix). The MUC was able to collect up to seven cores with a maximum length of 35 cm and a diameter of 8 cm. Directly after retrieval cores barrels were sealed with butyl stoppers and transported to the onboard laboratory and subsamples from the water on top of the sediment of one core barrel were collected for geochemical analyses of dissolved gases. The sediment was sampled using a piston to push out the sediment in defined volumes. Samples were collected with sterile syringes or spatulas for molecular analyses in three cm intervals, for gas- and geochemical analyses as well as microbiological experiments in five cm intervals over the complete length of the cores.

Furthermore, samples for molecular biological studies of the quantitative and qualitative microbial community composition were collected, processed on board and preserved for subsequent analysis.

The sediments sampled with both coring systems will be used to study the quantity, the chemical and the isotopic composition of gases in the porewater and adsorbed to the pore surface of the sediment matrix. These compositional data will be integrated into a model of hydrocarbon generation and migration. Additionally, the sampling material will be used to analyze in great detail geochemical, mineralogical and geomicrobiological sedimentary features and hydrocarbon degradation potential of indigenous microbial communities.

14.4 Methods and instruments

Gas geochemical profiles along the cores

The gravity core was quickly cut into 1 m sections. For the gas analysis, and to avoid degassing, holes of 2 cm diameter were cut into the liner at short intervals starting at 10 cm below the sediment surface/top of the core. Five ml of sediment were sampled with a cut 5 ml syringe. Holes were immediately sealed with tape after sample retrieval. Extracted sediment samples were placed in glass serum vials (50 ml of volume), suspended in 5 ml of $HgCl_2$ solution (400 mg/l) and after sealing with butyl septa and crimp caps vigorously mixed. 100 µl from the headspace from each serum vial will be measured onshore for methane and carbon dioxide concentration and respective stable isotopic composition by gas chromatography and stable isotope ratio mass spectrometry. Based on these results, depth profiles of stable C- and H-isotope ratios will be obtained to decipher the biogenic or thermogenic origin of the present gases.

Porewater samples for geochemical analysis along the cores

Since the diameter of the gravity cores was less than 90 mm, both half-core sections had to be used for geochemical and microbiological analysis. Similar to the sampling procedure from the MUC, gravity core samples were collected from selected depth intervals. During sampling, the outer surface of the core was carefully left in place to avoid contamination with seawater. In total 75 sediment samples were subjected to porewater extraction.

Interstitial water samples were extracted from sediments with a pore water press designed by the BGR. Compact PTFE sample vessels with a maximum volume of 125 ml were used to collect the samples. Luer Lock outlets for the sample water and self-locking sea-waterproof V4A-stainless steel intergas-valves guaranteed a contamination-free sample preparation procedure. Also a specially designed quick lock support and a miniaturised pressure gas distribution-block improved the handling of multiple samples.

The selected sediment slices were then transferred to a sample vessel using metal-free spoons or spatulas. After covering the sample with Parafilm and NBR-rubber mats the vessels were mounted in the pore water press stand. Extraction time was usually about 10-15 minutes and a pressure of 3 to 8 bar (argon gas) was applied. Depending on the composition of the sediment 10 mL to 40 mL of pore water was gained. Each sample was filtered through a 'Sartorius' cellulose nitrate filter 0.45 µm type 11306-100-K and directly collected in a 25 mL PE Roth vial. The sampled pore water was then transferred into a 30 mL slip tip syringe and filtered with a 'Sartorius' Minisart High-Flow single use syringe filter (0.2 µm, polyethersulfone) to remove particles and microorganisms. With the syringe, subsamples were directly filled into different sample vials for shore-based laboratory analyses:

Subsamples were taken for:

- Metal ion analyses with ICP-OES (5 mL sample volume acidified with 50 µL HNO_3 in 25 mL PP Roth vials)
- Anion analysis with ion chromatography (5 mL sample volume in 8 mL glass vials)
- Analysis of sulphide after fixation with $ZnCL_2$ (20%) solution.
- Analysis of $\delta^{13}C$ of porewater DIC after fixation with saturated $HgCl_2$ solution.
- $\delta^{13}C$ from TOC and biomarker analyses (from frozen squeeze cakes)
- Total C, total N, total S and $CaCO_3$ analyses (from squeeze cakes)

14.5 Geomicrobiology

Microbiological samples for the qualitative and quantitative description of the microbial populations within the sediment and cultivation of specific microorganisms were taken from the uncontaminated centre of the sediment cores immediately after splicing in two halves (GC) or mounting on the piston (MUC). These samples were prepared for subsequent laboratory analysis:

Quantification of living Bacteria and Archaea by CARD-FISH (Catalyzed Reporter Deposition-Fluorescence In Situ Hybridisation).

from selected depths was placed in sterile 2ml-Eppendorf tubes and fixed in 1 ml of a cold 4% formaldehyde-PBS solution (phosphate buffered saline, 130 mmol Sodium chloride, 7 mmol di-Sodium hydrogen phosphate, 3 mmol Sodium di-hydrogen phosphate, sterile filtered 0.2 µm) for 2 hours at room temperature (20°C), washed twice with cold PBS using an Eppendorf centrifuge at 13000 rpm for 10 min and finally stored at -20°C in 1 ml PBS-ethanol (1:1). All samples were frozen at -20ºC until analysis in the shore-based laboratory. In total, 137 samples were collected and fixed for later FISH analyses.

Qualitative and quantitative description of microbial communities inhabiting the sediments via DNA analyses

Around 15 ml of sediment were sampled in duplicates with a cut sterile 2 ml/ 5 ml syringe and placed in Falcon screw capped vials. All samples were immediately frozen at -80°C until analysed. Further analysis of the 137 samples collected involves DNA extraction, quantification of specific Prokaryote groups with Q-PCR as well as clone libraries and amplicon pyrosequencing for a detailed microbial community analysis.

Determination of microbial activities

The sediment samples collected in the different sampling areas will allow to investigate the metabolic potentials of indigenous microbial communities in a broad range of different environmental and geological settings. Furthermore, it will enable to study the ability of the indigenous microbial communities to react to naturally or accidentally spilled hydrocarbons. This might also aid in the identification of hydrocarbon seepage as indicators of subsurface reservoirs and thus the potential presence of adapted microbial communities. Altogether, 81 microbiological samples for the quantification of related microbial activities and communities have been collected roughly from the same depths as the geochemistry samples. The sediment was transferred into sterile glass bottles, which were then closed with thick butyl rubber stoppers and screw caps. To remove residual oxygen, the bottles were flushed with N2 for several minutes and then stored at 4°C until further processing. Sediment microcosms will be set-up onshore to measure in vitro potential rates of important microbial processes, i.e. sulphate reduction, methane and carbon dioxide formation and consumption, as well as the degradation of different higher hydrocarbons.

In combination, the geochemical and geomicrobiological results will increase the up to date very scarce database on Arctic sediments / seafloor environments. Besides a detailed characterisation of the present microbial biodiversity and its environmental controls, a special focus will be on the potential of the indigenous microbial communities to degrade hydrocarbons. This will help to estimate consequences of a potential oil spill.

15. ACKNOWLEDGEMENTS

Two years after the successful PANORAMA-1 cruise aboard the Italian research vessel OGS-Explora we were able to charter the OGS-Explora again for the PANORAMA-2 cruise. We really appreciated our expedition aboard OGS-Explora and we are thankful to Master Franco Sedmak and his entire crew for their excellent cooperation and support. We felt save and at home during our cruise.

We are thankful for the cooperation with OGS during the cruise, especially with Isabelle Tomini, Andrea Cova, Paolo Visnovic, Riccardo Codiglia and Lorenzo Facchin. We want to acknowledge the support during the preparation and mobilization of Dr. Franco Coren, General Director of OGS and Dr. Fabrizio Zgur, Head of OGS Explora management group at OGS.

We appreciate the support of the Norwegian Petroleum Directorate (NPD) who helped us during the preparation and realization of the PANORAMA-2 cruise.

Many thanks also to Prof. Jan-Inge Faleide for his support.

We are thankful to everybody who was involved into the successful realization of the PANORAMA-2 cruise, especially from the administration section of BGR.

16. REFERENCES

Abrams, M. (2013), Best Practices for the Collection, Analysis, and Interpretation of Seabed Geochemical Samples To Evaluate Subsurface Hydrocarbon Generation and Entrapment., *Offshore Technology Conference*.

Andersen, O. B. (2010), The DTU10 Gravity field and Mean sea surface, in *Second international symposium of the gravity field of the Earth (IGFS2)*, edited, Fairbanks, Alaska.

Anell, I., A. Braathen, and S. Olaussen (2014), Regional constraints of the Sørkapp Basin: A Carboniferous relic or a Cretaceous depression?, *Marine and Petroleum Geology*, *54*, 123-138, doi:http://dx.doi.org/10.1016/j.marpetgeo.2014.02.023.

Anell, I., A. Braathen, S. Olaussen, and P. T. Osmundsen (2013), Evidence of faulting contradicts a quiescent northern Barents Shelf during the Triassic, *First Break*, *31*, 67-76.

Antonsen, P., A. Elverhoi, H. Dypvik, and A. Solheim (1991), Shallow Bedrock Geology of the Olga Basin Area, Northwestern Barents Sea, *The American Association of Petroleum Geologists Bulletin*, *75*(7), 15.

Berger, D., and W. Jokat (2008), A seismic study along the East Greenland margin from 72 degrees N to 77 degrees N, *Geophysical Journal International*, *174*(2), 733-748, doi:10.1111/j.1365-246X.2008.038794.x.

Breivik, A. J., R. Mjelde, P. Grogan, H. Shimamura, Y. Murai, and Y. Nishimura (2003), Crustal structure and transform margin development south of Svalbard based on ocean bottom seismometer data, *Tectonophysics*, *369*(1-2), 37-70, doi:10.1016/s0040-1951(03)00131-8.

Breivik, A. J., R. Mjelde, P. Grogan, H. Shimamura, Y. Murai, Y. Nishimura, and A. Kuwano (2002), A possible Caledonide arm through the Barents Sea imaged by OBS data, *Tectonophysics*, *355*(1–4), 67-97, doi:http://dx.doi.org/10.1016/S0040-1951(02)00135-X.

Damm, V., et al. (2013), Cruise Report Panorama-1, *BGR*, *http://www.bgr.bund.de/DE/Themen/MarineRohstoffforschung/Meeresforschung/Downloads/Panorama_1_Cruise_Report.pdf?__blob=publicationFile&v=7*.

Eilers, G., H. A. Roeser, and P. Kewitsch (1994), *Reduktion geomagnetischer Variationen durch ein Gradientenmagnetometer*, 1-73 pp., Federal Institute for Geosciences and Natural Resources, Hannover.

Elverhoi, A., and O. Lauritzen (1983), Bedrock geology of the northern Barents Sea (west of 35°E) as inferred from the overlying Quaternary deposits. , *Nor. Polarinst. Skr.*, *180*, 12.

Elverhoi, A., S. Pfirmann, A. Solheim, and B. Larssen (1989), Glaciomarine sedimentation in epicontinental seas exemplified by the northern Barents Sea., *Marine Geology*
85, 6.

Elverhoi, A., and A. Solheim (1983), The Barents Sea ice sheet - a sedimentological discussion., *Polar Research Inst.*, 10.

Engels, M., U. Barckhausen, and J. S. Gee (2008), A new towed marine vector magnetometer: methods and results from a Central Pacific cruise, *Geophysical Journal International*, *172*(1), 115-129, doi:10.1111/j.1365-246X.2007.03601.x.

Engen, O., J. A. Gjengedal, J. I. Faleide, Y. Kristoffersen, and O. Eldholm (2009), Seismic stratigraphy and sediment thickness of the Nansen Basin, Arctic Ocean,

Geophysical Journal International, *176*(3), 805-821, doi:10.1111/j.1365-246X.2008.04028.x.
Faleide, J. I., F. Tsikalas, A. J. Breivik, R. Mjelde, O. A. Blaich, and O. Eldholm (2009), Structure and Evolution of the NE Atlantic Region and Links to the Arctic, in *AAPG 3-P Arctic Conference and Exhibition*, edited, AAPG Search and Discover Article #90096, Moscow, Russia.
Faleide, J. I., F. Tsikalas, A. J. Breivik, R. Mjelde, O. Ritzmann, O. Engen, J. Wilson, and O. Eldholm (2008), Structure and evolution of the continental margin off Norway and the Barents Sea, *Episodes*, *31*(1), 82-91.
Faleide, J. I., E. Vågnes, and S. T. Gudlaugsson (1993), Late Mesozoic–Cenozoic evolution of the southwestern Barents Sea, *Geological Society, London, Petroleum Geology Conference series*, *4*, 933-950, doi:10.1144/0040933.
Geissler, W. H., and W. Jokat (2004), A geophysical study of the northern Svalbard continental margin, *Geophysical Journal International*, *158*(1), 50-66, doi:10.1111/j.1365-246X.2004.02315.x.
Geissler, W. H., W. Jokat, and H. Brekke (2011), The Yermak Plateau in the Arctic Ocean in the light of reflection seismic data—implication for its tectonic and sedimentary evolution, *Geophysical Journal International*, *187*(3), 1334-1362, doi:10.1111/j.1365-246X.2011.05197.x.
Glørstad-Clark, E., J. I. Faleide, B. A. Lundschien, and J. P. Nystuen (2010), Triassic seismic sequence stratigraphy and paleogeography of the western Barents Sea area, *Marine and Petroleum Geology*, *27*(7), 1448-1475, doi:http://dx.doi.org/10.1016/j.marpetgeo.2010.02.008.
Grogan, P., A. M. Ostvedt-Ghazi, G. B. Larssen, B. Fotland, K. Nyberg, S. Dahlgren, and T. Eidvin (1999), Structural elements and petroleum geology of the Norwegian sector of the northern Barents Sea, *Geological Society, London, Petroleum Geology Conference series*, *5*, 247-259, doi:10.1144/0050247.
Henriksen, E., A. E. Ryseth, G. B. Larssen, T. Heide, K. Rønning, K. Sollid, and A. V. Stoupakova (2011), Chapter 10 Tectonostratigraphy of the greater Barents Sea: implications for petroleum systems, *Geological Society, London, Memoirs*, *35*(1), 163-195, doi:10.1144/m35.10.
Høy, T., and B. A. Lundschien (2011), Chapter 15 Triassic deltaic sequences in the northern Barents Sea, *Geological Society, London, Memoirs*, *35*(1), 249-260, doi:10.1144/m35.15.
Jokat, W. (1998), Structure and sediment distribution on the North Greenland continental margin and in the Fram Strait north of 80 degrees N, *Annales Geophysicae [1988]*, *16, Suppl. 1*, 289-289.
Jokat, W., W. Geissler, and M. Voss (2008), Basement structure of the north-western Yermak Plateau, *Geophysical Research Letters*, *35*(5), L05309, doi:10.1029/2007gl032892.
Jokat, W., E. Weigelt, Y. Kristoffersen, T. Rasmussen, and T. Schone (1995), New geophysical results from the south-western Eurasian Basin (Morris Jesup Rise, Gakkel Ridge, Yermak Plateau) and the Fram Strait, *Geophysical Journal International*, *123*(2), 601-610.
Korenaga, J. (1995), Comprehensive analysis of marine magnetic vector anomalies, *Journal of Geophysical Research: Solid Earth*, *100*(B1), 365-378, doi:10.1029/94jb02596.
Morelli, C. (Ed.) (1974), *The International Standardization Net 1971*, 194 pp.

Parker, R. L., and M. S. O'Brien (1997), Spectral analysis of vector magnetic field profiles, *Journal of Geophysical Research: Solid Earth*, *102*(B11), 24815-24824, doi:10.1029/97jb02130.
Riefstahl, F., S. Estrada, W. H. Geissler, W. Jokat, R. Stein, H. Kämpf, P. Dulski, R. Naumann, and C. Spiegel (2013), Provenance and characteristics of rocks from the Yermak Plateau, Arctic Ocean: Petrographic, geochemical and geochronological constraints, *Marine Geology*(0), doi:http://dx.doi.org/10.1016/j.margeo.2013.06.009.
Riis, F., B. A. Lundschien, T. Høy, A. Mørk, and M. B. E. Mørk (2008), Evolution of the Triassic shelf in the northern Barents Sea region, *Polar Research*, *27*(3), 318-338, doi:10.1111/j.1751-8369.2008.00086.x.
Ritzmann, O., and W. Jokat (2003), Crustal structure of northwestern Svalbard and the adjacent Yermak Plateau: evidence for Oligocene detachment tectonics and non-volcanic breakup, *Geophysical Journal International*, *152*(1), 139-159, doi:10.1046/j.1365-246X.2003.01836.x.
Ritzmann, O., W. Jokat, W. Czuba, A. Guterch, R. Mjelde, and Y. Nishimura (2004), A deep seismic transect from Hovgård Ridge to northwestern Svalbard across the continental-ocean transition: A sheared margin study, *Geophysical Journal International*, *157*(2), 683-702, doi:10.1111/j.1365-246X.2004.02204.x.
Roeser, H. A., C. Steiner, B. Schreckenberger, and M. Block (2002), Structural development of the Jurassic Magnetic Quiet Zone off Morocco and identification of Middle Jurassic magnetic lineations, *Journal of Geophysical Research: Solid Earth*, *107*(B10), 2207, doi:10.1029/2000jb000094.
Safronova, P. A., S. Henriksen, K. Andreassen, J. S. Laberg, and T. O. Vorren (2014), Evolution of shelf-margin clinoforms and deep-water fans during the middle Eocene in the SØrvestsnaget Basin, southwest Barents Sea, *AAPG Bulletin*, *98*(3), 515-544, doi:10.1306/08221312208.
Schlindwein, V., A. Demuth, W. H. Geissler, and W. Jokat (2013), Seismic gap beneath Logachev Seamount: Indicator for melt focusing at an ultraslow mid-ocean ridge?, *Geophysical Research Letters*, n/a-n/a, doi:10.1002/grl.50329.
Seama, N., Y. Nogi, and N. Isezaki (1993), A New Method For Precise Determination of the Position and Strike of Magnetic Boundaries Using Vector Data of the Geomagnetic Anomaly Field, *Geophysical Journal International*, *113*(1), 155-164, doi:10.1111/j.1365-246X.1993.tb02536.x.
Skilbrei, J. R. (1991), Interpretation of depth to the magnetic basement in the northern Barents Sea (south of Svalbard), *Tectonophysics*, *200*(1–3), 127-141, doi:http://dx.doi.org/10.1016/0040-1951(91)90010-P.
Winkelmann, D., W. H. Geissler, and S. Krastel (2011), The Hinlopen/Yermak Megaslide - Understanding an exceptional submarine landslide, its consequences and relation to the deep basement structure, edited.
Worsley, D. (2008), The post-Caledonian development of Svalbard and the western Barents Sea, *Polar Research*, *27*, 298-317, doi:doi:10.1111/j.1751-8369.2008.00085.x.

ANNEX

A. 1 Participating Institutions

	16.1 **Address**
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe Stilleweg 2 30655 Hannover Germany
ARGO	Argo Srl – Ship Management & Services Via Campi Flegrei 34 80078 Pozzuoli (Napoli) Italy
DIAMAR	DIAMAR S.r.l. Via G. Porzio n°4 Centro Direzionale Isola G.2 – int. 44 80143 Napoli Italy
OGS	OGS Trieste Istituto Nazionale di Oceanografia e di Geofisica Spermintale Borgo Grotta Gigante 42/c 34010 Sgonico (Trieste) Italy
RPS	RPS Energy Nelson House, Coombe Lane Axminster, Devon, EX 13 5 AX United Kingdom

A. 2: Cruise Participants

Leg 1

	Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession
1.	Ehrhardt	Axel	BGR	Geophysicist, Chief Scientist
2.	Damm	Volkmar	BGR	Geophysicist, Deputy Ch. Sc.
3.	Behrens	Thomas	BGR	Technician
4.	Berglar	Kai	BGR	Geologist
5.	Cova	Andrea	OGS	Geophysicist
6.	Demir	Ümit	BGR	Technician
7.	Hahn	Boris	BGR	Technician
8.	Lange	Gerhard	BGR	Technician
9.	Lewis	Timothy	RPS	Geophysicist, MMO
10.	Schnabel	Michael	BGR	Geophysicist
11.	Tomini	Isabelle	OGS	Technician
12.	Visnovic	Gianpaolo	OGS	Technician

Leg 2

	Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession
1.	Damm	Volkmar	BGR	Geophysicist, Chief Scientist
2.	Wiedicke-Hombach	Michael	BGR	Geologist, Deputy Ch. Sc.
3.	Berglar	Kai	BGR	Geologist
4.	Codiglia	Riccardo	OGS	Engineer
5.	Facchin	Lorenzo	OGS	Geophysicist
6.	Krüger	Martin	BGR	Geomicrobiologist
7.	Lutz	Rüdiger	BGR	Geologist
8.	Schreckenberger	Bernd	BGR	Geophysicist
9.	Seeger	Christian	BGR	Geomicrobiologist
10.	Wegener	Philipp	BGR	Geologist
11.	Zoch	Daniela	BGR	Technician

A. 3: Ship's Crew

	Name	Rank
1.	SEDMAK, Franco	Master
2.	CAMBONE, Ciro	1st Offc.
3.	DI SILVESTRI, Matteo	Nav. Offc.
4.	SCOTTO D'APOLLONIA, Valentino	Nav. Offc.
5.	MAGAS, Klaudio	Ch. Eng. (Leg 1 only)
6.	RADINOVIC, Bozidar	Ch. Eng. (Leg 2 only)
7.	SOLLAZZO, Ciro	2nd Eng.
8.	MARCHELLI Marcello	Eng. Off.
9.	GENZO, Gianfranco	A.B.
10.	ANDRIANI, Davide	A.B.
11.	GUAIANA, Antonio Maurizio	A.B.
12.	JOVICIC, Zoran	Motorman
13.	STJEPANOVIC, Davor	Electrician SN
14.	SCHIANO DI COLA, Ciro	Cook
15.	PUGLIESE, Enrico	Cook (Leg 1 only)
16.	PELUSO, Giuseppe	Cook (Leg 2 only)
17.	AIALE, Vincenzo	O/S
18.	ONORATO, Ciro	Deck Boy (Leg 1 only)
19.	DI STASIO, Marco	Deck Boy (Leg 1 only)
20.	RUGGIERO, Fabio	Deck Boy (Leg 2 only)
21.	FRANCO, Salvatore	Deck Boy (Leg 2 only)
22.	PUGLIESE, Salvatore	Wiper
23.	ACCARDO, Pasquale	Doctor SN (Leg 1 only)
24.	SINNO, Vincenzo	Doctor SN (Leg 2 only)

A. 4: Seismic profiles

Line number	Shot point	Date	Time (UTC)	Lat. (N)	Long. (E)	Course	Methods	Length
BGR15-101	2	17.08.15	13:20:33	74°14.720	20°02.299		S,M,B,SE	
	48	17.08.15	13:30:53	74°15.288	20°03.137	22°		1.13 km
BGR15-101A	1	17.08.15	13:32:18	74°15.364	20°03.240		S,M,B,SE	
	32	17.08.15	13:46:37	74°16.115	20°04.334	22°		1.50 km
BGR15-101B	1	17.08.15	13:59:27	74°16.785	20°05.294		S,M,B,SE	
	5685	18.08.15	08:23:02	75°27.100	21°54.978	21°		140.69 km
BGR15-101C	2	18.08.15	08:24:18	75°27.184	21°55.119		S,M,B,SE	
	1288	18.08.15	12:19:53	75°43.004	22°22.424	23°		31.91 km
BGR15-101D	2	18.08.15	19:05:02	75°39.915	22°28.376		S,M,B,SE	
	1612	18.08.15	23:58:13	75°59.798	23°01.627	22°		39.81 km
BGR15-101E	2	19.08.15	00:45:09	76°02.606	23°06.348		S,M,B,SE	
	2950	19.08.15	10:11:16	76°39.128	24°11.200	22°		73.39 km
BGR15-101F	1	19.08.15	10:11:28	76°39.140	24°11.224		S,M,B,SE	
	50	19.08.15	10:24:19	76°39.951	24°12.735	23°		1.53 km
BGR15-101G	1000	19.08.15	11:28:34	76°43.934	24°20.200		S,M,B,SE	
	1184	19.08.15	12:01:16	76°46.064	24°24.225	23°		4.30 km
BGR15-101H	1	19.08.15	12:01:28	76°46.077	24°24.248		S,M,B,SE	
	1387	19.08.15	16:15:41	76°59.397	25°16.774	41°		33.13 km
BGR15-103	1	20.08.15	12:38:26	77°11.053	28°06.247		S,M,B,SE	
	1896	20.08.15	18:28:52	76°58.702	29°44.729	118°		46.78 km
BGR15-104	2	22.08.15	10:30:30	76°01.536	36°00.939		S,M,B,SE	
	2270	22.08.15	17:33:33	75°35.962	34°54.833	213°		56.10 km
BGR15-105	2	22.08.15	19:32:57	75°36.640	34°58.315		S,M,B,SE	
	4880	23.08.15	10:30:21	76°12.861	31°17.361	306°		120.14 km
BGR15-107	1	24.08.15	13:39:08	76°18.325	31°24.300		S,M,B,SE	
	9390	25.08.15	18:28:19	74°28.345	27°30.381	210°		231.20 km
BGR15-106	1	25.08.15	19:17:08	74°28.412	27°21.003		S,M,B,SE	
	10450	27.08.15	03:16:21	76°46.998	26°42.316	356°		257.44 km
BGR15-105A	1	27.08.15	04:40:17	76°47.142	27°04.429		S,M,B,SE	
	5209	27.08.15	20:40:07	76°12.232	31°21.588	118°		128.69 km

(A.4: Seismic Lines continued)

BGR15-1R0	1	28.08.15	01:52:09	76°06.830	31°57.074		SB,M,B,SE	
	390	28.08.15	05:06:39	76°15.479	30°59.844	303°		29.97 km
BGR15-1R1	1	28.08.15	06:42:09	76°11.430	31°07.479		SB,M,B,SE	
	2530	28.08.15	04:29:39	77°43.072	35°19.917	30°		199.89 km
BGR15-1R2	31	29.08.15	09:12:39	77°29.297	34°50.917		SB,M,B,SE	
	666	29.08.15	14:30:09	77°55.256	35°07.053	7°		48.53 km
BGR15-107A	0	29.08.15	17:23:25	77°49.286	35°03.123		S,M,B,SE	
	7948	30.08.15	23:02:58	76°17.396	31°22.814	210°		193.22 km
BGR15-108	1	30.08.15	23:04:50	76°17.294	31°22.684		S,M,B,SE	
	4208	31.08.15	13:30:38	75°21.444	31°34.354	177°		103.64 km
BGR15-109	2	31.08.15	14:47:10	75°22.990	31°25.635		S,M,B,SE	
	4809	01.09.15	05:30:14	76°16.612	33°44.391	31°		117.62 km
BGR15-1R3	0	03.09.15	08:14:22	76°16.383	23°54.622		SB,M,B,SE	
	1956	03.09.15	19:04:18	76°17.419	20°11.258	273°		98.17 km

Please note: The correct line/profile identifier for the PANORAMA-2 cruise is BGR15-2xx. Due to technical issues the line identifier for the seismic lines is BGR15-1xx. Therefore we will refer to any seismic line in this report as BGR15-1xx. All other data like hydroacoustic data, magnetic data and gravity data use the line identifier BGR15-2xx.

A. 5: Sonobuoy stations

Station	Profile	Channel	Duration	Depth (feet)	Lat. (N)	Long. (E)	Date	Time (UTC)	SN MBS	Skew
SB00	1R0	02	8 h	200	76° 06.91‘	31° 56.41‘	28.08.2015	01:54	021162	-
SB01	1R1	08	4 h	200	76° 11.48‘	31° 07.65‘	28.08.2015	06:43	021164	+1 ms
SB02	1R1	64	4 h	200	76° 16.18‘	31° 19.07‘	28.08.2015	07:49	021162	-1 ms
SB03	1R1	84	4 h	200	76° 20.80‘	31° 30.39‘	28.08.2015	08:55	021165	+2 ms
SB04	1R1	95	4 h	200	76° 25.42‘	31° 41.87‘	28.08.2015	10:00	021161	+2 ms
SB05	1R1	68	4 h	200	76° 30.05‘	31° 53.50‘	28.08.2015	11:04	021164	+2 ms
SB06	1R1	90	4 h	200	76° 34.68‘	32° 05.31‘	28.08.2015	12:10	021162	-1 ms
SB07	1R1	86	4 h	200	76° 39.31‘	32° 17.28‘	28.08.2015	13:16	021165	+2 ms
SB08	1R1	76	4 h	200	76° 43.91‘	32° 29.32‘	28.08.2015	14:23	021161	+2 ms
SB09	1R1	02	4 h	200	76° 48.48‘	32° 41.46‘	28.08.2015	15:27	021164	+2 ms
SB10	1R1	82	4 h	200	76° 53.02‘	32° 53.68‘	28.08.2015	16:33	021162	-1 ms
SB11	1R1	71	4 h	200	76° 57.67‘	33° 06.36‘	28.08.2015	17:37	021165	+2 ms
SB12	1R1	87	4 h	200	77° 02.22‘	33° 18.98‘	28.08.2015	18:42	021161	+1 ms
SB13	1R1	66	4 h	200	77° 06.78‘	33° 31.76‘	28.08.2015	19:46	021164	+2 ms
SB14	1R1	94	4 h	200	77° 11.36‘	33° 44.79‘	28.08.2015	20:52	021162	-1 ms
SB15	1R1	19	4 h	200	77° 15.85‘	33° 57.77‘	28.08.2015	21:59	021165	+2 ms
SB16	1R1	71	4 h	200	77° 20.33‘	34° 10.83‘	28.08.2015	23:02	021161	+2 ms
SB17	1R1	08	4 h	200	77° 24.84‘	34° 24.22‘	29.08.2015	00:07	021164	+2 ms
SB18	1R1	90	4 h	200	77° 29.35‘	34° 37.74‘	29.08.2015	01:11	021162	-1 ms
SB19	1R1	76	4 h	200	77° 33.83‘	34° 51.45‘	29.08.2015	02:17	021165	+1 ms
SB20	1R2	02	4 h	200	77° 29.46‘	34° 50.58‘	29.09.2015	09:15	021164	+2 ms
SB21	1R2	90	4 h	200	77° 34.64‘	34° 53.90‘	29.09.2015	10:19	021162	-1 ms
SB22	1R2	84	4 h	200	77° 39.90‘	34° 57.17‘	29.09.2015	11:23	021165	+2 ms
SB23	1R2	82	4 h	200	77° 45.27‘	35° 00.59‘	29.09.2015	12:29	021161	+1 ms
SB24	1R3	87	4 h	90	76° 16.38‘	23° 54.52‘	03.09.2015	08:14	021165	+3 ms
SB25	1R3	71	4 h	90	76° 16.76‘	23° 20.36‘	03.09.2015	09:52	021161	+2 ms
SB26	1R3	93	4 h	90	76° 17.05‘	22° 46.38‘	03.09.2015	11:29	021164	+2 ms
SB27	1R3	03	4 h	90	76° 17.27‘	22° 12.25‘	03.09.2015	13:09	021162	-1 ms
SB28	1R3	65	4 h	90	76° 17.42‘	21° 38.44‘	03.09.2015	14:52	021165	+2 ms
SB29	1R3	84	4 h	90	76° 17.49‘	21° 04.50‘	03.09.2015	16:33	021161	+2 ms

A. 6: Coring Station List

Station No.	Name	Water Depth (m)	Recovery (core length)	on Line no.	Target	Lat	Long	Date	Time (UTC)	Comme nt	
Leg 2/**1**	01_MUC _001	291	2 tubes	SBP04	oval depression	76° 12' 24.80'' N	16° 50' 19.62'' E	09.09.2015	11:41	2 trials	
	02_GC_ 001	291	0.95 m	SBP04	oval depression	76° 12' 24.02'' N	16° 50' 21.40'' E	09.09.2015	13:14		
Leg 2/**2**	03_GC_ 002	284	1.70 m	SBP04	two sed. bodies, overlappin g	76° 14' 58.57'' N	17° 51' 40.58'' E	09.09.2015	15:32		
Leg 2/**3**	04_GC_ 003	267	1.65 m	SBP04	two sed. bodies, overlappin g	76° 15' 33.36'' N	18° 04' 17.06'' E	09.09.2015	16:20	thin cover, chance to reach	
Leg 2/**5**	05_MUC _002	201	4 tubes	106		76° 03' 26.06'' N	26° 55' 44.71'' E	10.09.2015	09:00		pockmark area
Leg 2/**6**	06_MUC _003	229	4 tubes	106	large pockmark (?)	75° 58' 03.26'' N	26° 57' 07.03'' E	10.09.2015	10:00		
Leg 2/**7**	07_MUC _004	207	2 tubes	106		75° 52' 41.24'' N	26° 59' 07.20'' E	10.09.2015	10:56		
Leg 2/**8**	08_MUC _005	191	6 tubes	106		75° 41' 55.96'' N	27° 02' 09.99'' E	10.09.2015	12:28		
Leg 2/**9**	09_GC_ 004	193	1.35 m	106		75° 47' 16.79'' N	27° 00' 30.68'' E	10.09.2015	13:51		
Leg 2/**10**	10_GC_ 005	210	1.00 m	106		75° 55' 21.61'' N	26° 58' 09.53'' E	10.09.2015	15:30		
Leg 2/**11**	11_GC_ 006	229	1.60 m	106	large pockmark (?)	75° 58' 02.48'' N	26° 57' 05.79'' E	10.09.2015	16:33	close to station no.06	
Leg 2/**16**	12_GC_ 007	330	0.80 m	107		75° 59' 28.90'' N	30° 39' 25.38'' E	14.09.2015	07:08	with H2O	Olga Basin transect S-N
Leg 2/**17**	13_GC_ 008	328	1.30 m	107		76° 04' 14.94'' N	30° 50' 29.57'' E	14.09.2015	08:36	red siltstone	
Leg 2/**18**	14_GC_ 009	307	1.68 m	107		76° 09' 13.35'' N	31° 02' 18.07'' E	14.09.2015	09:33		
Leg 2/**19**	15_GC_ 010	312	1.50 m	107		76° 14' 03.88'' N	31° 14' 01.31'' E	14.09.2015	10:38		
Leg 2/**20**	16_GC_ 011	316	1.73 m	107a		76° 18' 46.60'' N	31° 25' 33.34'' E	14.09.2015	11:42	with H2O	
Leg 2/**21**	17_GC_ 012	306	1.55 m	107a		76° 23' 32.46'' N	31° 37' 09.41'' E	14.09.2015	13:04		
Leg 2/**22**	18_GC_ 013	275	1.29 m	107a		76° 28' 15.98'' N	31° 49' 02.19'' E	14.09.2015	14:05		
Leg 2/**23**	19_GC_ 014	270	1.60 m	107a		76° 33' 01.33'' N	32° 00' 53.39'' E	14.09.2015	15:09	with H2O	
Leg 2/**29**	20_GC_ 015	262		107a		76° 37' 37.55'' N	32° 12' 50.81'' E	15.09.2015	06:36		
Leg 2/**30**	21_GC_ 016	223		107a		76° 42' 16.95'' N	32° 24' 58.01'' E	15.09.2015	07:40		
Leg 2/**31**	22_GC_ 017	215		107a		76° 47' 09.87'' N	32° 37' 55.42'' E	15.09.2015	08:32		
		210			SVP_006	76° 47' 26.61'' N	32° 36' 22.48'' E	15.09.2015	08:56		
Leg 2/**32**	23_MUC _006	253	5 tubes	107a/103		76° 38' 01.13'' N	32° 13' 57.06'' E	15.09.2015	10:49		Olga B. transect E-W
Leg 2/**33**	24_MUC _007	240	7 tubes	103		76° 33' 00.53'' N	32° 47' 39.34'' E	15.09.2015	12:11		
Leg 2/**34**	25_MUC _008	218		103		76° 27' 53.49'' N	33° 21' 00.77'' E	15.09.2015	13:29		
Leg 2/**35**	26_MUC _009	256		103/109		76° 22' 16.29'' N	33° 56' 28.69'' E	15.09.2015	14:42		

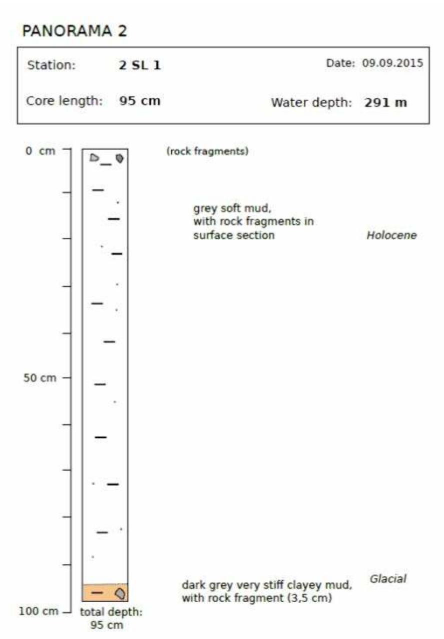
(A6: Coring station list continued)

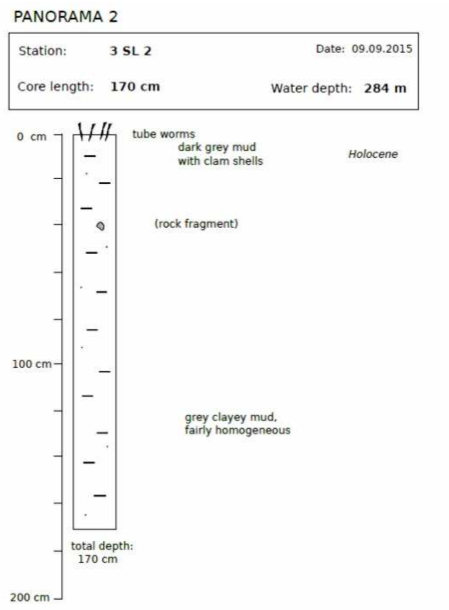
Station No.	Name	Water Depth (m)	Recovery (core length)	on Line no.	Target	Lat	Long	Date	Time (UTC)	Comment	
Leg 2/**40**	27_GC_018	296		109		76° 05' 34.15'' N	33° 14' 04.08'' E	16.09.2015	07:20		
		296			SVP_007	76° 05' 34.39'' N	33° 14' 11.98'' E	16.09.2015	07:41		
Leg 2/**41**	28_GC_019	305		109		76° 13' 31.32'' N	33° 35' 37.87'' E	16.09.2015	09:12		
Leg 2/**42**	29_GC_020	257		103/109		76° 22' 16.48'' N	33° 56' 31.52'' E	16.09.2015	10:36	same position	
Leg 2/**43**	30_DRG_001	280		103		76° 22' 11.54'' N	33° 57' 01.00'' E	16.09.2015	13:00	SOL	
		264				76° 22' 16.48'' N	33° 56' 31.52'' E	16.09.2015	13:30	EOL	
Leg 2/**44**	31_DRG_002	272		103		76° 23' 50.26'' N	33° 47' 12.14'' E	16.09.2015	14:35	SOL	
		252				76° 23' 45.15'' N	33° 47' 33.94'' E	16.09.2015	14:40	EOL	
	32_DRG_003	272		103	2nd attempt, same location	76° 23' 50.26'' N	33° 47' 12.14'' E	16.09.2015	15:38	SOL	
		252				76° 23' 45.15'' N	33° 47' 33.94'' E	16.09.2015	15:43	EOL	
Leg 2/**48**	33_DRG_004	346		108		75° 25' 22.81'' N	31° 33' 24.14'' E	17.09.2015	08:31	SOL	
		328				75° 24' 36.11'' N	31° 33' 42.26'' E	17.09.2015	08:54	EOL	
		328			SVP_008	75° 24' 17.34'' N	31° 32' 45.74'' E	17.09.2015	09:42		
	34_DRG_005	346		108	2nd attempt, same location	75° 25' 22.81'' N	31° 33' 24.14'' E	17.09.2015	11:05	SOL	
		328				75° 24' 36.11'' N	31° 33' 42.26'' E	17.09.2015	11:40	EOL	
Leg 2/**49**	35_MUC_010	345		108/109		75° 25' 41.34'' N	31° 32' 20.46'' E	17.09.2015	13:13		
Leg 2/**50**	36_GC_021	338		109		75° 26' 10.59'' N	31° 33' 27.02'' E	17.09.2015	14:16		
Leg 2/**51**	37_GC_022	326		109		75° 34' 49.62'' N	31° 54' 31.91'' E	17.09.2015	16:14		
Leg 2/**54**	38_MUC_011	65		101		75° 59' 18.51'' N	23° 00' 41.29'' E	18.09.2015	15:56		

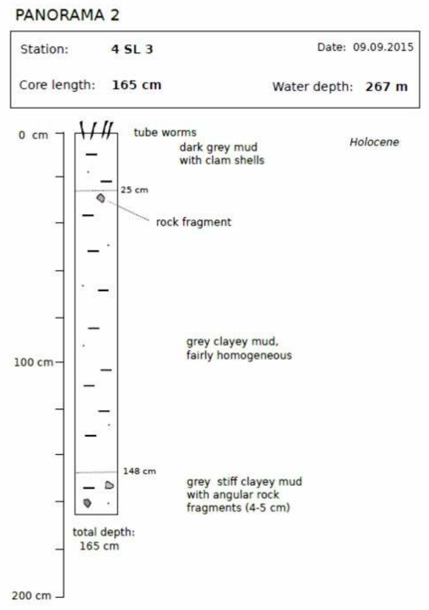
(A6: Coring station list continued)

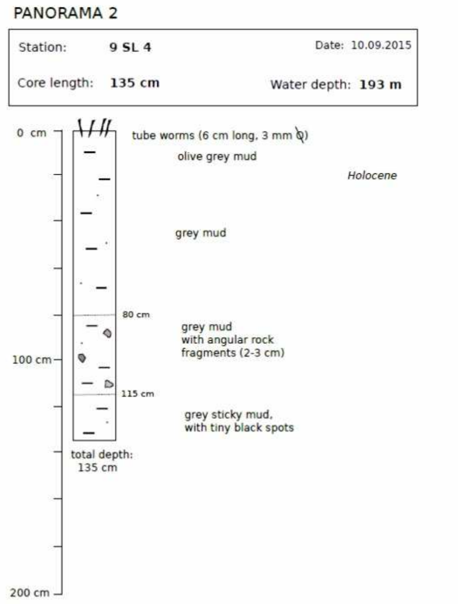
Sample Code	Water Depth [m]	Latitude	Longitude	Date	Time UTC	Sub-sample Code	depth from top	sample type
01_MUC_001	291	76° 12' 24.80" N	16° 50' 19.62" E	09.09.2015	11:41			
						01_MUC_001_10-16	Okt 16	sediment
						01_MUC_001_11-23	Nov 23	sediment
						01_MUC_001_water		water (MUC)
02_GC_001	291	76° 12' 24.02" N	16° 50' 21.40" E	09.09.2015	13:14			
						02_GC_001_100-120	100-120	sediment
03_GC_002	284	76° 14' 58.57" N	17° 51' 40.58" E	09.09.2015	15:32			
						03_GC_002_60-70	60-70	sediment
						03_GC_002_75-80	75-80	sediment
						03_GC_002_140-170	140-170	sediment
04_GC_003	267	76° 15' 33.36" N	18° 04' 17.06" E	09.09.2015	16:20			
						04_GC_003_50-65	50-65	sediment
						04_GC_003_150-165	150-164	sediment
						04_GC_003_165-174	164-174	sediment (cutter)
05_MUC_002	201	76° 03' 26.06" N	26° 55' 44.71" E	10.09.2015	09:00			
						05_MUC_002_10-25	Okt 25	sediment
						05_MUC_002_water		water (MUC)
06_MUC_003	229	75° 58' 03.26" N	26° 57' 07.03" E	10.09.2015	10:00			
						06_MUC_003_20-29	20-29	sediment
						06_MUC_003_water		water (MUC)
07_MUC_004	207	75° 52' 41.24" N	26° 59' 07.20" E	10.09.2015	10:56			
						07_MUC_004_15-21	15-21	sediment
						07_MUC_004_water		water (MUC)
08_MUC_005	191	75° 41' 55.96" N	27° 02' 09.99" E	10.09.2015	12:28			
						08_MUC_005_20-25	20-25	sediment
						08_MUC_005_water		water (MUC)
09_GC_004	193	75° 47' 16.79" N	27° 00' 30.68" E	10.09.2015	13:51			
						09_GC_004_20-30	20-30	sediment
						09_GC_004_120-130	120-130	sediment
10_GC_005	210	75° 55' 21.61" N	26° 58' 09.53" E	10.09.2015	15:30			
						10_GC_005_30-45	30-45	sediment
						10_GC_005_89-100	89-100	sediment
						10_GC_005_100-110	100-110	sediment (cutter)
11_GC_006	229	75° 58' 02.48" N	26° 57' 05.79" E	10.09.2015	16:33			
						11_GC_006_150-165	150-165	sediment
12_GC_007	330	75° 59' 28.90" N	30° 39' 25.38" E	14.09.2015	07:08			
						12_GC_007_25-35	25-35	sediment
						12_GC_007_75-85	75-85	sediment
						12_GC_007_water		water (Niskin)

A. 7: Core Description

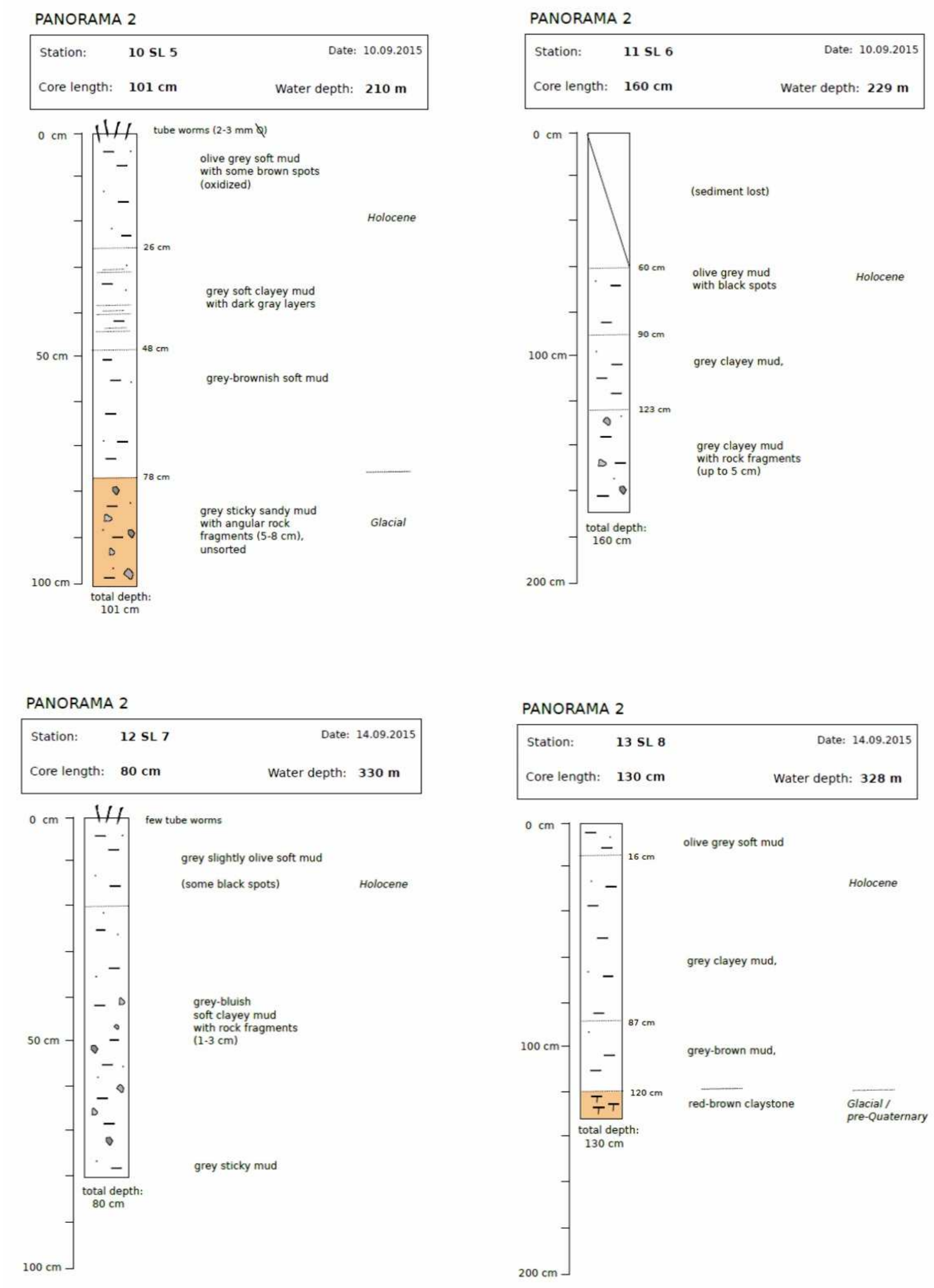




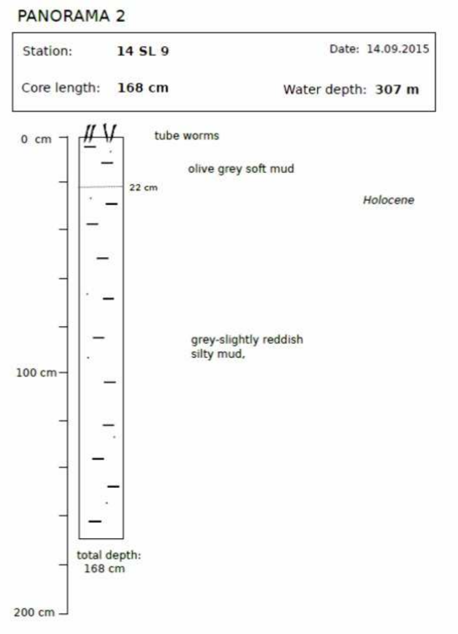


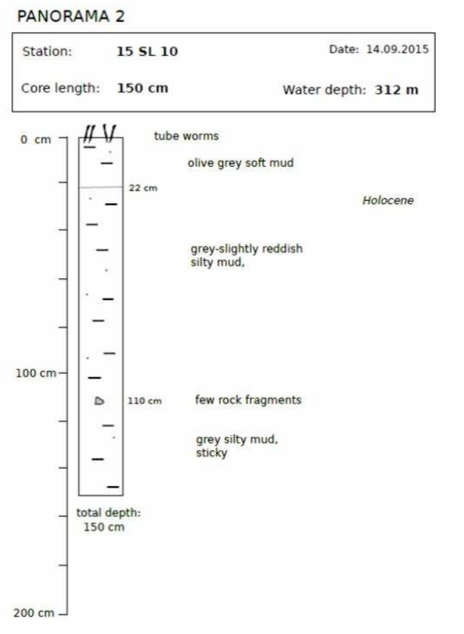


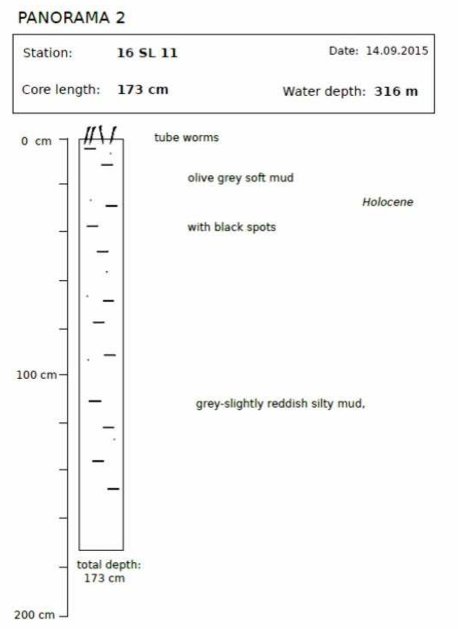
(A7: CORING DESCRIPTION CONTINUED)

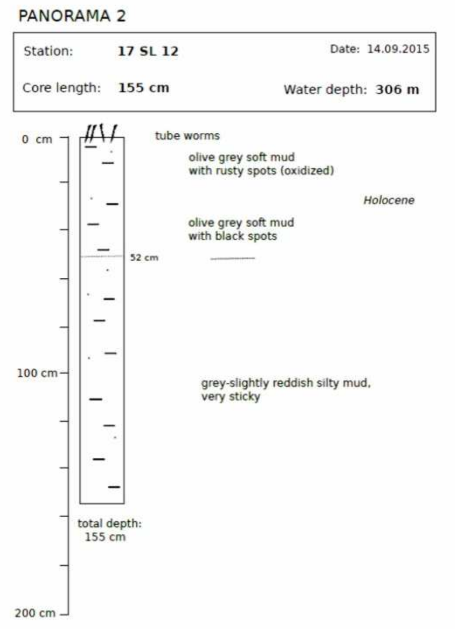


(A7: CORING DESCRIPTION CONTINUED)

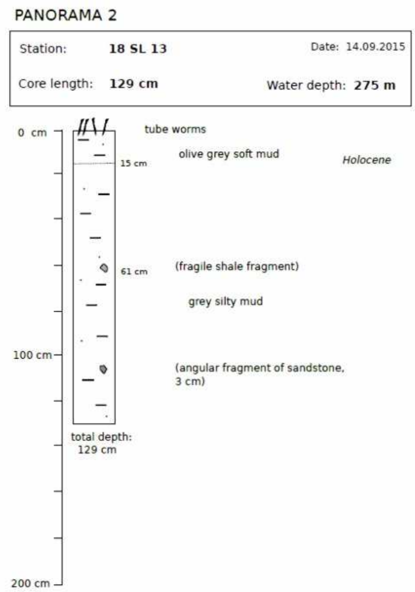


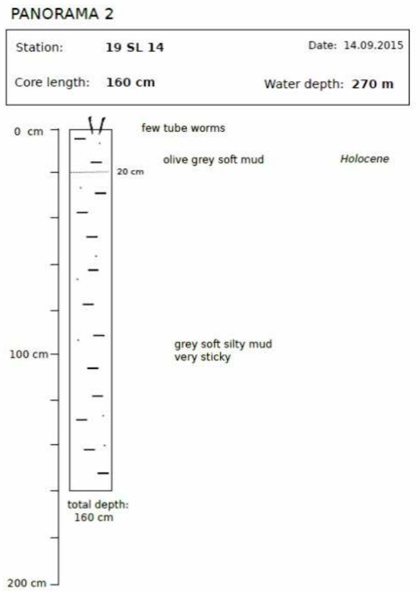


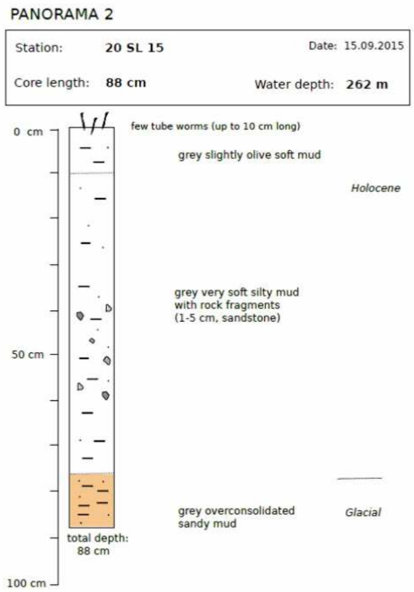


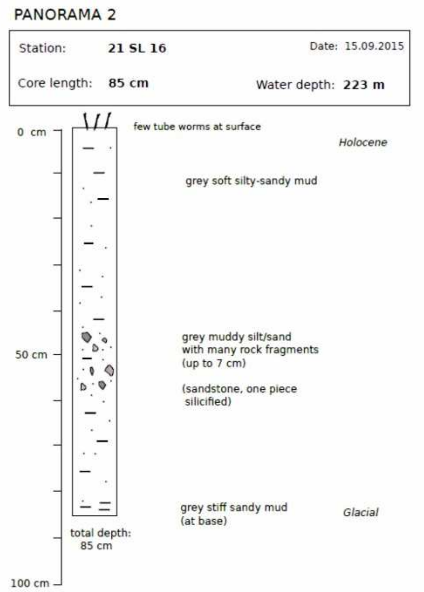


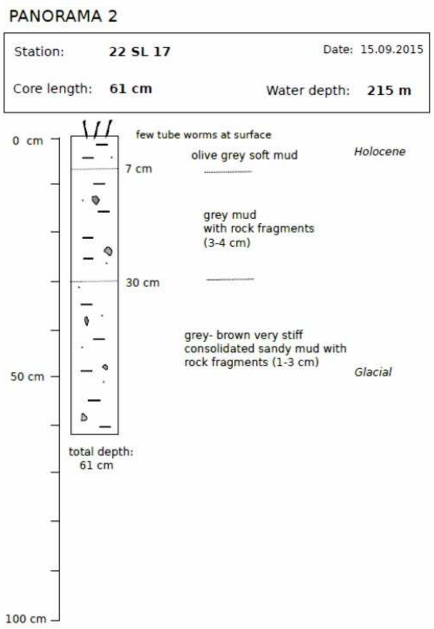
(A7: CORING DESCRIPTION CONTINUED)

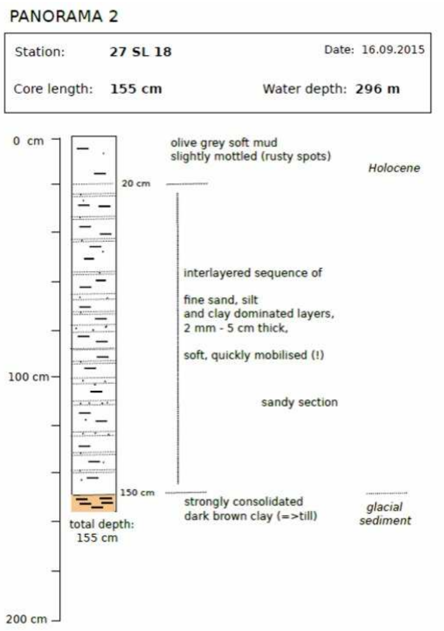


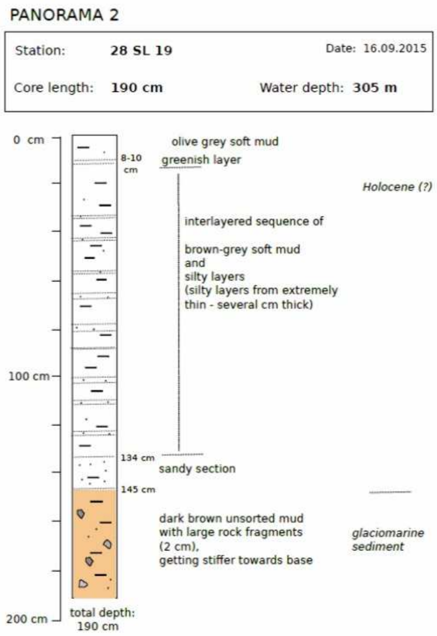


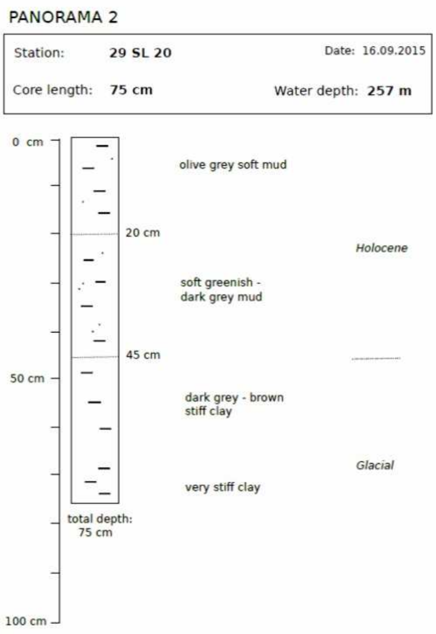




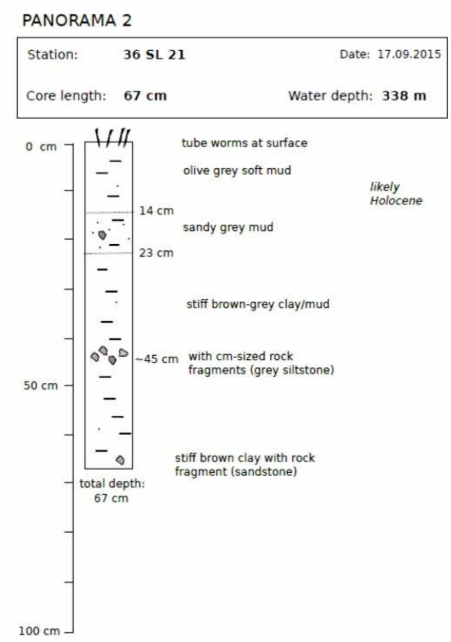

PANORAMA 2
Station: 22 SL 17
Date: 15.09.2015
Core length: 61 cm
Water depth: 215 m
0 cm
few tube worms at surface
olive grey soft mud
Holocene
7 cm
grey mud
with rock fragments
(3-4 cm)
30 cm
grey- brown very stiff
consolidated sandy mud with
rock fragments (1-3 cm)
Glacial
50 cm
total depth:
61 cm
100 cm

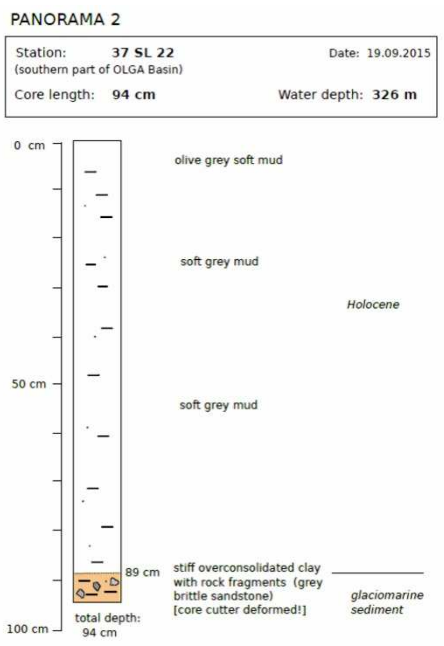

PANORAMA 2
Station: 27 SL 18
Date: 16.09.2015
Core length: 155 cm
Water depth: 296 m
0 cm
olive grey soft mud
slightly mottled (rusty spots)
Holocene
20 cm
interlayered sequence of
fine sand, silt
and clay dominated layers,
2 mm - 5 cm thick,
soft, quickly mobilised (!)
100 cm
sandy section
150 cm
strongly consolidated
dark brown clay (=>till)
glacial
sediment
total depth:
155 cm
200 cm


PANORAMA 2
Station: 28 SL 19
Date: 16.09.2015
Core length: 190 cm
Water depth: 305 m
0 cm
olive grey soft mud
8-10
cm
greenish layer
Holocene (?)
interlayered sequence of
brown-grey soft mud
and
silty layers
(silty layers from extremely
thin - several cm thick)
100 cm
134 cm
sandy section
145 cm
dark brown unsorted mud
with large rock fragments
(2 cm),
getting stiffer towards base
glaciomarine
sediment
200 cm
total depth:
190 cm


PANORAMA 2
Station: 29 SL 20
Date: 16.09.2015
Core length: 75 cm
Water depth: 257 m
0 cm
olive grey soft mud
20 cm
Holocene
soft greenish -
dark grey mud
45 cm
50 cm
dark grey - brown
stiff clay
Glacial
very stiff clay
total depth:
75 cm
100 cm

(A7: CORING DESCRIPTION CONTINUED)





A.8 List of Figures

A.9 List of Tables