Cruise Report

BARENTS-SEA CONTINENTAL MARGIN

HERMES-PROJECT

3D - FLUID FLOW OF HMMV

18-7-05 to 29-7-05

Longyearbyen – Longyearbyen

R/V Jan Mayen

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July 17th – 29th, 2005

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INTRODUCTION AND OBJECTIVES

Fluid flow in continental margins has diverse sources at different depths ranging from the crust to the upper sediment columns (Kopf, 2002). Fluid flow from mud volcanoes may originate in the deeper part of the margins providing a window to the deep earth (Planke et al., 2004). The advection of fluids and methane to the seabed has profound consequences for benthic ecosystems (Boetius et al, 2000) methane input into the ocean as well as atmosphere and climate change, and the distribution of methane hydrate. Methane hydrate contains one of the major greenhouse gases of the earth system that, if released to the ocean and to the atmosphere can have consequences for the global climate (e.g. Dickens et al., 1997; Kvenvolden, 1993; Kennett et al., 2000). Methane hydrate has also been considered as a potential source of natural gas (Kvenvolden, 1993).

As such fluid flow systems are abundant in many different tectonic settings the methane advection is of global as well as of regional importance, and are investigated on the Norwegian Margin (e.g. Mienert et al., 2001, Mienert et al., 2005, Knies, et al., 2004, Hovland et al., 2005). The selected working area to be investigated during this cruise is on the high latitude ocean margin of the Barents Sea, Norway (Figure 1 and 2).

The overall objective of the EU funded HERMES project (contract No. GOCE-CT-2005-511234) is to determine and understand hotspot ecosystems from the Mediterranean to the Barents Sea. One class of the systems to be investigated are chemosynthetic benthic ecosystems that are fuelled by fluid flow through the pore space of sediments (Boetius et al., 2000). The objective of this cruise was to investigate the source of fluid flow and their pathways at the Håkon Mosby Mud Volcano (HMMV) using high-resolution acoustic imaging methods. Such knowledge may allow understanding better the deep successions of the margin from where fluids rise to the seabed and to the water column. The technique used is based on multi-component ocean-bottom seismometer arrays that are deployed on the seabed, HighRes 3D seismics towed behind the ship, Multibeam and echolot mapping of the seabed.

Using multi-component ocean-bottom seismometers (OBS), the distribution of the velocities of P and S waves will be measured adequately in and adjacent to the fluid flow system, and the region beneath it.

The degree of heterogeneity of the developed structure of the fluid flow pathway can be assessed from 3D seismic profiling.

Gas flux for HMMV will be assessed from using 18 kHz data to map the plume itself and the size of "hole" it creates in the thermocline. We intend to use software from fisheries (NFH), and use the travel-time of direct waves of OBS. We also will use densely covered CTD stations for calibrations.

Using High-Res 3D seismic improves our understanding of the migration pathways and internal structures of the upper part of a fluid charged mud volcano, where long-term and deep sources are anticipated to exist (>2000m). The deeper structure will be assessed based on reprocessed multi-channel seismic data.

The proposed combination of seismic techniques is new and will be tested and applied for advancing the applied geophysics within the NFR funded PETROMAKS project "Quantification of geological processes that govern basin scale fluid flow" (Prosjektnr. 169514/S30). The joint inversion of P and S waves is a current research theme, which is becoming increasingly common both in industry and academia, where new additional approaches and technologies are needed. The applied seismic technique in fluid flow systems is aimed to provide representative measurements of the amount of fluids. They are assessed in a non-destructive way aimed towards mapping and quantifying this little understood, but potentially important component of ocean margin systems.

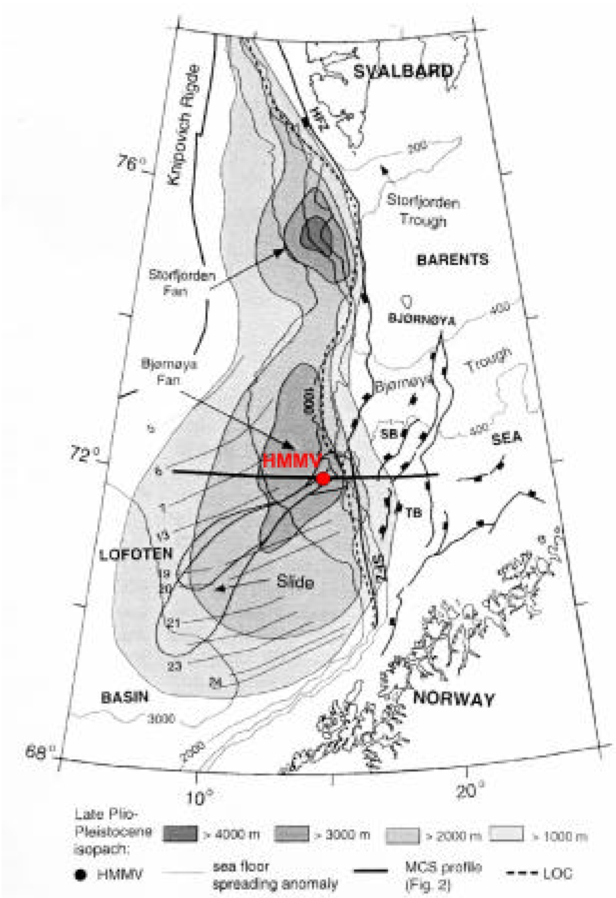


Figure 1: *Location map of the Barents Sea margin, Continent-Ocean Boundary (COB) and HMMV site (after Hjelstuen et al., 1999).*

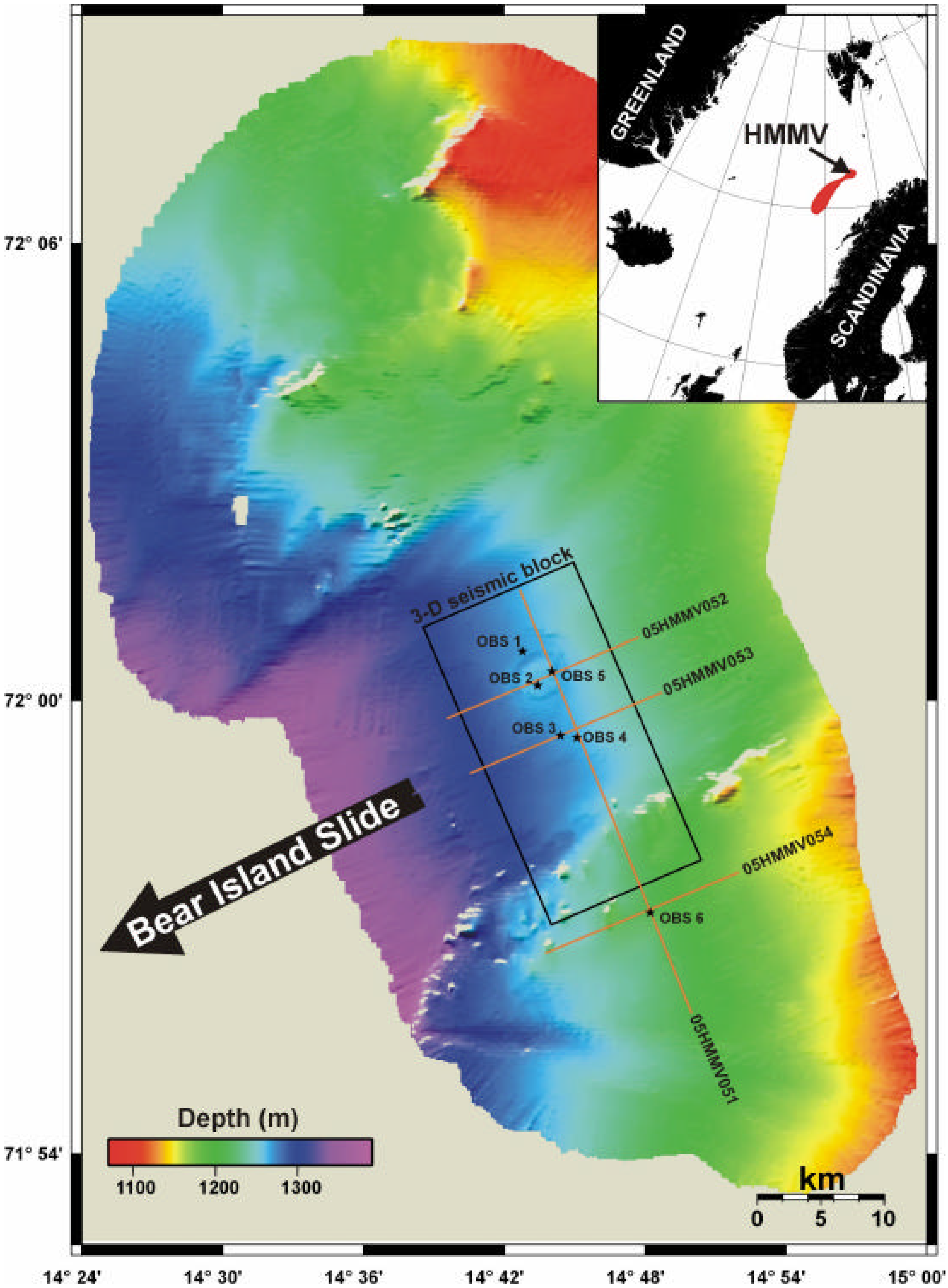


Figure 2: SIMRAD EM300 high-resolution multibeam seabed map *of the investigated area including the HMMV. Multibeam (MB) map produced and processed during this RV Jan Mayen cruise. 3D seismic area is marked by a box showing a size of ~25 km^2. Stars mark positions of the multicomponent ocean bottom seismometers. OBS 1-3 are deployed and recovered during the 3D survey. OBS 4-6 are deployed and recovered during a OBS survey shooting lines 51-54.*

BACKGROUND - HÅKON MOSBY MUD VOLCANO

The continental slope off the Barents Sea (Figure 1 and 2) was one of the key study areas of the R.V. Keldysh deep diving operation (Mienert, 1998) and RV Jan Mayen cruises (Mienert, 2001, this report) where a set of continuous single-channel airgun data was acquired, and detailed HMMV seabed photographs, sampling, and temperature measurements were collected during the dives with the MIR submersibles. Sea floor data have been acquired earlier showing patches of bacteria mats, tubeforms and gas hydrates (Milkov et al., 1999). The geothermal gradients of the upper seabed have been measured using in situ-temperature probe measurements during MIR dives. Studies of the geomicrobiology of the HMMV with RV Polarstern improved our understanding of the bacteria world in methane seeps (Klages et al., 2004).

WORKING AREA

The W-Barents Sea Svalbard continental margin (Figure 1) formed in response to the Cenozoic evolution of the Norwegian-Greenland Sea. The Norwegian and East Greenland margins underwent several post-Caledonian extensional episodes (Late Paleozoic, Mesozoic) before continental separation in the early Eocene. The northern Norwegian-Greenland Sea opened simultaneously along the Senja Fracture Zone in an oblique strike slip setting. The COB (continent-ocean boundary), being the location of change of oceanic to continental basement, lies ~ 20km W of the HMMV. The HMMV is located on 33-37 Ma oceanic crust indicated by magnetic anomaly 13 (Hjelstuen et al., 1999). Sediment thickness can exceed 6 km on the Barents Margin (Hjelstuen et al., 1999). The HMMV is located in a slide scar that is believed to be younger than 330 ka (Laberg & Vorren, 1993). MCS data show a 1-2 km wide disturbed zone characterizing the HMMV. This zone can be followed down to > 3km below the HMMV (Hjelstuen et al., 1999).

The target areas selected for the F/F Jan Mayen 2005 cruise are located on the upper part of the continental slope (Figure 2) in a region that is normally ice-free during most of the year.

SEISMIC METHODS

During this cruise we used multi-component Ocean Bottom Seismometers (OBS), high-resolution 3D seismic, a newly installed SIMRAD EM300 high-resolution multibeam seabed mapping system, a conventional single-channel reflection seismic, 18kHz echolot, 38 kHz echolot, CTD and sediment coring .

The 3D seismic data were acquired using 12 single-channel streamers. The system delivers data with approximately 10 m horizontal and 2 m vertical resolution. The 3D seismic cube covers the HMMV and an area approx. 3 km northwest and southeast of it. The cube is approximately 3 km wide and 7.2 km long (approx. 25 km^2).

Three multi-component Ocean Bottom Seismometers (OBS) were deployed in approx. N-S direction at an interval of approximately 1000 m. The first OBS is located north of the HMMV, while the second one is situated within the HMMV, and the third one on the sediment outflow regime to the south of it. A second deployment started in the south, where the first OBS (no.6) was located on a hilly terrain with mud mounds, the second OBS (no.4) on the outflow regime of the HMMV, and the third one in the HMMV (no.5) at the location of a plume (Figure 2, Tab. 1). The distance in N-S direction between OBS 5 and 4 is several 100 m, and also between OBS 4 and 6 giving a total length of 6319 m. The multi-component OBS lines were set along and transverse to the HMMV at approx. 1250 m water depth. Reflectors are recognised beneath the apparently active north eastern part of the central HMMV and are most probably caused by local shallow gas accumulations.

OBS SEISMIC EXPERIMENT AT HMMV

The experiment was designed to provide data suitable for
1. travel-time inversion,
2. pre-stack depth migration (2-D receiver-gather migration for each individual OBS),
3. 1-D waveform inversion,
4. 2-D ray-trace modelling of travel times, amplitudes and wave forms,
5. analysis and modelling of free gas, fluids, and gas hydrates.

The seismic phases required for these techniques include reflected *P* waves, refracted (diving) *P* waves, direct P waves, and *S* waves generated by mode conversion from *P* waves at boundaries on transmission or reflection (primarily by reflection). The experiment needed to be compact in design so that it would give dense enough sampling of the subsurface to reduce ambiguity between the effect of structure and velocity. A shot spacing of about 20 m was imposed by the speed of the ship for 3D seismics, 3 knots, and the limitations of the compressor supplying air to the air guns, which maintain a firing interval of 8 s.

Multi-component OBS line

The OBS systems used during this survey of the HMMV are from *Tromsø* (Figure 3a and b). It is an autonomous sea floor recording platform, designed to record both, compressional and shear waves reflected and refracted through the sediments. It consists of a steel frame with buoyancy made of syntactic foam[1], an acoustic release system[2], and a digital data recorder[3] in a separate pressure case[1]. A hydrophone and a 3-component geophone[1] are used to record the seismic wavefield. The Tromsø OBS has a 4.5 Hz

[1] www.kum-kiel.de, [2]www.oceano-instruments.fr, [3]www.send.de

geophone attached. While the hydrophone is fixed to the frame of the OBS, the geophone is attached to a crane arm. When reaching the sea floor, the geophone-housing is deployed at an offset of 1.5m from the OBS frame. This design insures that the geophone is mechanically decoupled from the frame, to avoid noise generated by the frame being recorded by the geophone.

The OBS is attached to a ground weight via the acoustic release system, to make it sink to the sea floor after deployment. When the seismic experiment is completed, the OBS is released from its ground weight by sending an acoustic code and starts it rises to the sea surface by its buoyancy.

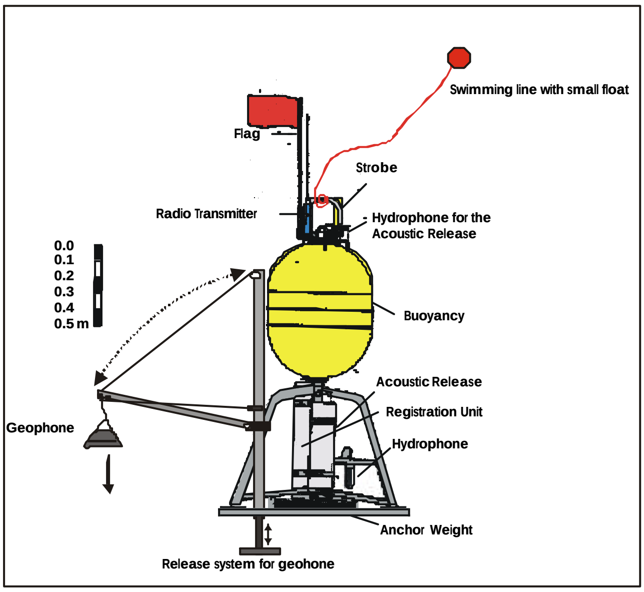


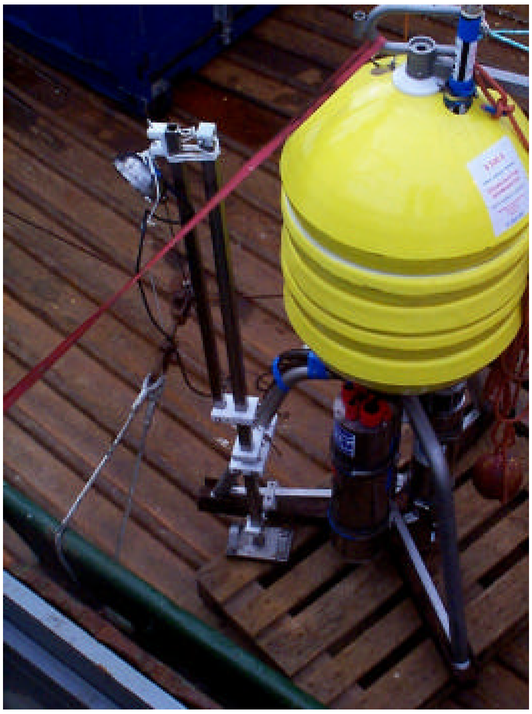
Figure 3a: *The Ocean Bottom Seismometer (OBS) system (UiT).*

The Marine Broadband Seismocorder MBS is optimised for acquisition of seismic signals in marine applications. Up to four input channels may be processed. After software selectable pre-amplification, the signals are low-pass filtered using a 5-pole Bessel filter with a –3dB corner frequency of 12kHz. Then each channel is digitised using a sigma-delta A/D converter producing a 16-bit signed digital data. After digital decimation filtering and data compression, the samples are saved on PCMCIA storage cards together with timing information. Up to four storage cards may be used, which leads to presently up to 4Gbyte of memory. The seismocorder contains a time oscillator with accuracy better than 10^{-7}. The time oscillator is synchronised at the beginning and end of each experiment via a GPS receiver, thus enabling to measure any time drift of the oscillator. A sample rate between 10 kHz and 62.5 Hz can be selected which leads to a recording time of at least 14h up to 2000h using four channels, data compression not taken into account.

Three OBS systems were prepared and programmed prior to their deployment. A sampling frequency of 1 kHz was used during all measurements. The first channel recorded the hydrophone data, while channel two, three and four were connected to horizontal and vertical components of the geophone. Locations were selected based on previous investigations (Mienert, 1998, Mienert, 2001) and on the results from our newly collected profiles. The time for bringing the three OBS's into the water was about one hour (19/07/05: 19.40-20.40 local time).

When the systems were back on deck, the recording units were connected to a personal computer, recordings were terminated and a time synchronisation via GPS receiver was performed. Typically the time drift of the internal time oscillator of the recording unit was in the range of 0-5 milliseconds over a 3 days recording period. The flash cards were taken from the recording unit and inserted into the flash cards reader. Data were then converted and each channel written to a hard disc in (1) PASSCAL data format and (2) WAVE-audio stream. While the WAVE-audio stream was used for a first quality check of the recorded data onboard F/F Jan Mayen, the PASSCAL data will be processed further utilising the actual shot times and navigation data.

OBS on afterdeck F/F Jan Mayen



Ready for deployment with a Geophone

Figure 3b: *OBS deployed from F/F Jan Mayen.* The Tromsø OBSs systems have acoustic release and digital data recorder systems, which are housed in a separate pressure case.

REFLECTION SEISMIC AND SEABED MAPPING

Airgun array and single-channel streamer

During the survey, we recorded reflection seismic data via a single-channel streamer and a 12 single-channel PCable streamer system. The single channel streamer was towed at near-zero offset, slightly off track (Figure 4). The 12 single-channel streamer system was towed behind the ship on track center (Figure 5a). Each line of the 3D seismic profiles correspond to 12 single channel streamer recordings (05JMStn4 - 05JMStn50 and 05JMStn55 -74, line 51-54 are OBS lines, Fig.5 b) recorded analogue on an EPC 9800 Recorder via only one streamer. The filter setting of the Geopulse Receiver for the airgun system for the EPC recording was 100-700 Hz. The raw data was stored on hard disk using a Delph2 recording/processing unit on a Windows-based PC. The sampling frequencies were 2 kHz for the airgun system.

- *Midpoint position*
- *Position of the streamer: 30 m behind the vessel – 11 m out on the port side.*
- *Data are saved in SEGY format*

Data were recorded analogue on an EPC 9800 Recorder, the filter setting of the Geopulse Receiver for the airgun system for the EPC recording was 100-700 Hz and for the 3.5 kHz echo-sounder 3-5 kHz. The raw data was stored on hard disk using a Delph2 recording/processing unit on a Windows-based PC. The sampling frequencies were 2 kHz for the airgun system and 12 kHz for the 3.5 kHz echo-sounder. 3.5 kHz echo-sounder, 18 kHz and 38 kHz records have been acquired parallel to airgun profiling. The principal aims are: (1) to image the morphology of the seabed and its shallow sub-bottom sedimentary layers and structures related to fluid flow pathways, (2) to image the gas plumes in the water column. The penetration for the airgun source was up to 0.5 s TWT.

An airgun array of two 0,65 l sleeve guns was used as a source for the ocean bottom seismic experiments and the 3D seismic acquisition. The two guns are secured with chains in a steel frame (distance between them: ~1 m) (Figure 4a). The array was towed approximately 30 m behind the vessel at a water depth of about 4 m below the sea surface (Figure 4b). With a firing pressure of 130 - 140 bar and a shooting rate of 8 sec, both guns were triggered with a small time offset to obtain a sharp and mostly spiked seismic source signal. The seismic signal was observed on an oscilloscope using a near-field hydrophone. The trigger offset was 10 ms. The seismic records revealed a penetration of up to 0.5 s TWT (Two Way Travel Time). The signal-noise ratio was good and the overall quality of the records was very high during a calm sea.

Figure 4a: *The array of two sleeve guns showing the array in its steel frame.*

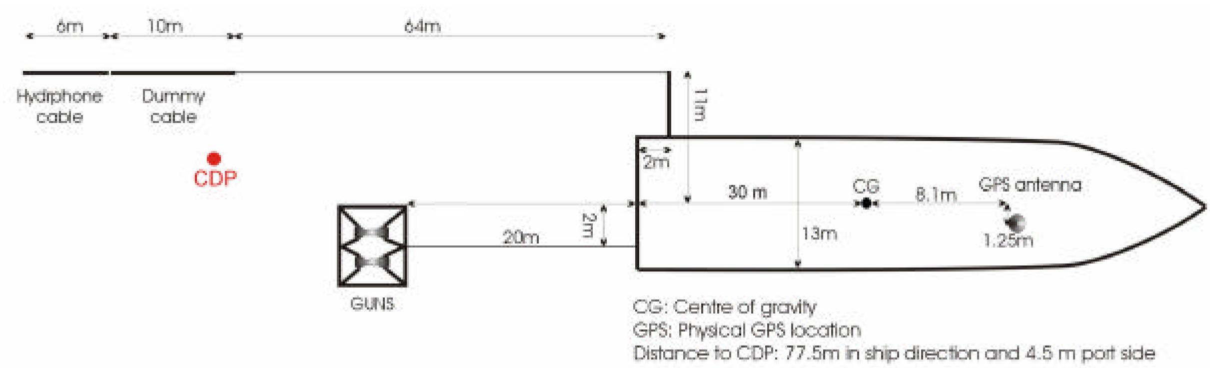


Figure 4b: *Navigation and configuration of sources, receivers, and GPS antenna*

3D High-resolution reflection seismic

In a joint effort of the Southampton Oceanography Centre (Southampton, UK) (Christian Berndt), Volcanic Basin Petroleum Research (VBPR; Oslo, Norway) (Sverre Planke), Fugro Survey (Oslo, Norway) (Stein Per Åsheim) and the Department of Geology at the University of Tromsø (Norway)) Juergen Mienert), a high-resolution 3D seismic acquisition system for shallow seismic acquisition – the PCable System - has been developed (Figure 5a-f).

The system is described in Norwegian patent application no. 20021140 and International patent application PCT/NO03/00079 by VBPR. It consists of a cross-cable towed perpendicular to the vessel's steaming direction, with 12 single-channel streamers attached to it. To stretch this cross-cable, a paravane is fixed at each end (Figure 5a). Because of their configuration and the current, the paravanes are deflected to both sides of the ship and extend the cross-cable.

The seismic system consists of12 single-channel streamers, each containing 11 hydrophones (spacing is 50 cm, active length 6 m, total length12 m). The power supply for the 12 pre-amplifiers and the recording signal are transmitted via the data cables. The analogue signal is digitized and stored as Seg Y files. The seismic data are recorded using a Geometrics GEODE 24 recording system. The spacing between the streamers is 15 m but due to curvature of the cross-cable, the effective spacing between the streamers in crossline direction is 10 m. Subsequent binning and stacking of the data construct a 3D cube. The acoustic source is composed of 2 sleeve guns running as a single source (see above).

Navigation system:
The position of the individual single-channel streamers is calculated from the length of the towing cable, the length of the cross wire and the positions known for the 2 paravanes doors (Figure 5c-d). 2 SEATRACK 220 antennas are used for positioning the doors, and one SEATRACK 320 antenna is used on the gun float. Additionally, 3 antennas are used for the accurate determination of the gravity centre of the vessel (Figure 5b-c). The GPS positions update with 1 to 6 s intervals. Accuracy of the absolute position is 1-3 m whereas relative positions are known within dm accuracy.

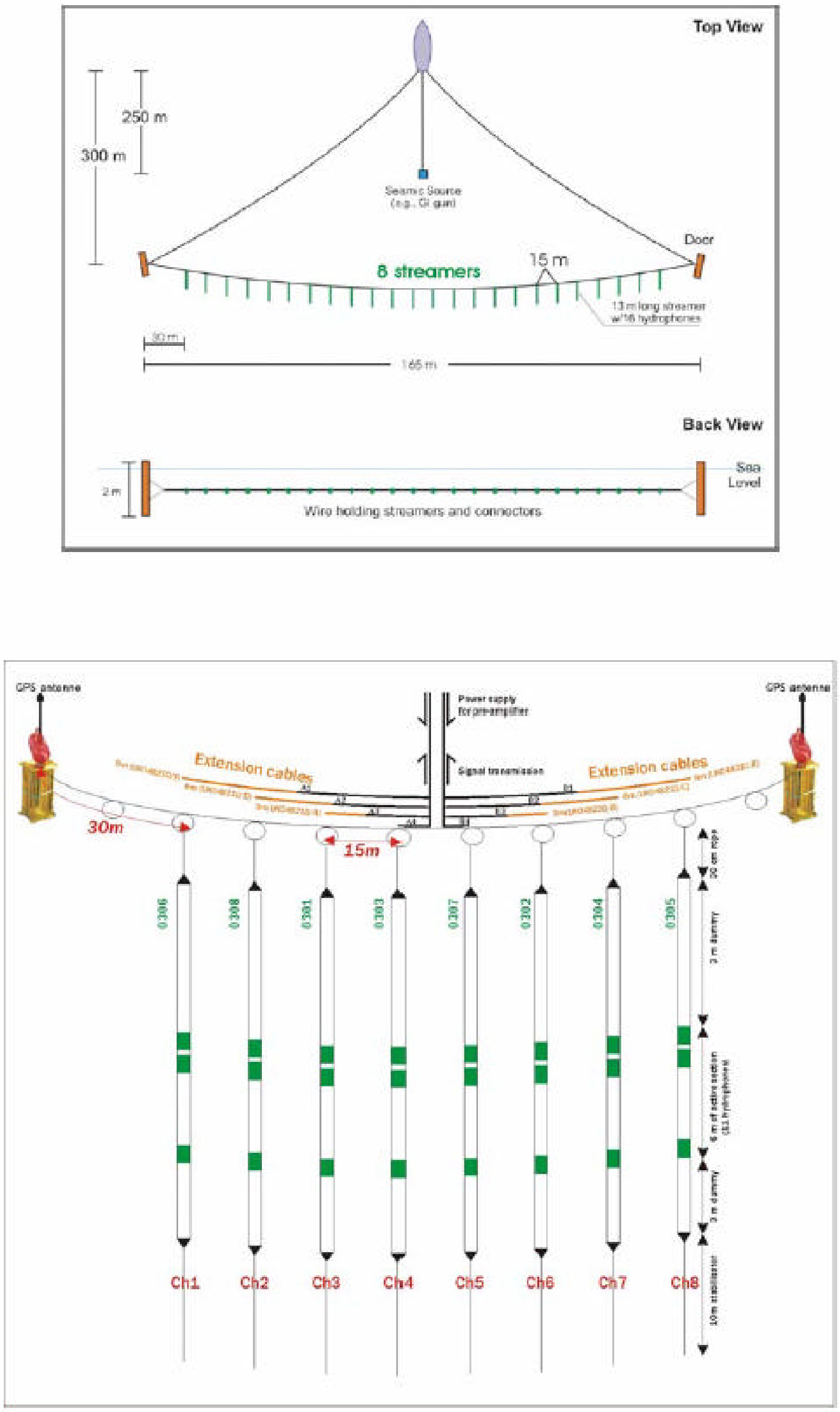


Figure 5a: *(Top) Configuration of the high-resolution 3D seismic acquisition system. (Bottom) Example of set-up shows configuration for 8 streamers. During this cruise onboard R/V Jan Mayen we used 12 streamers.*

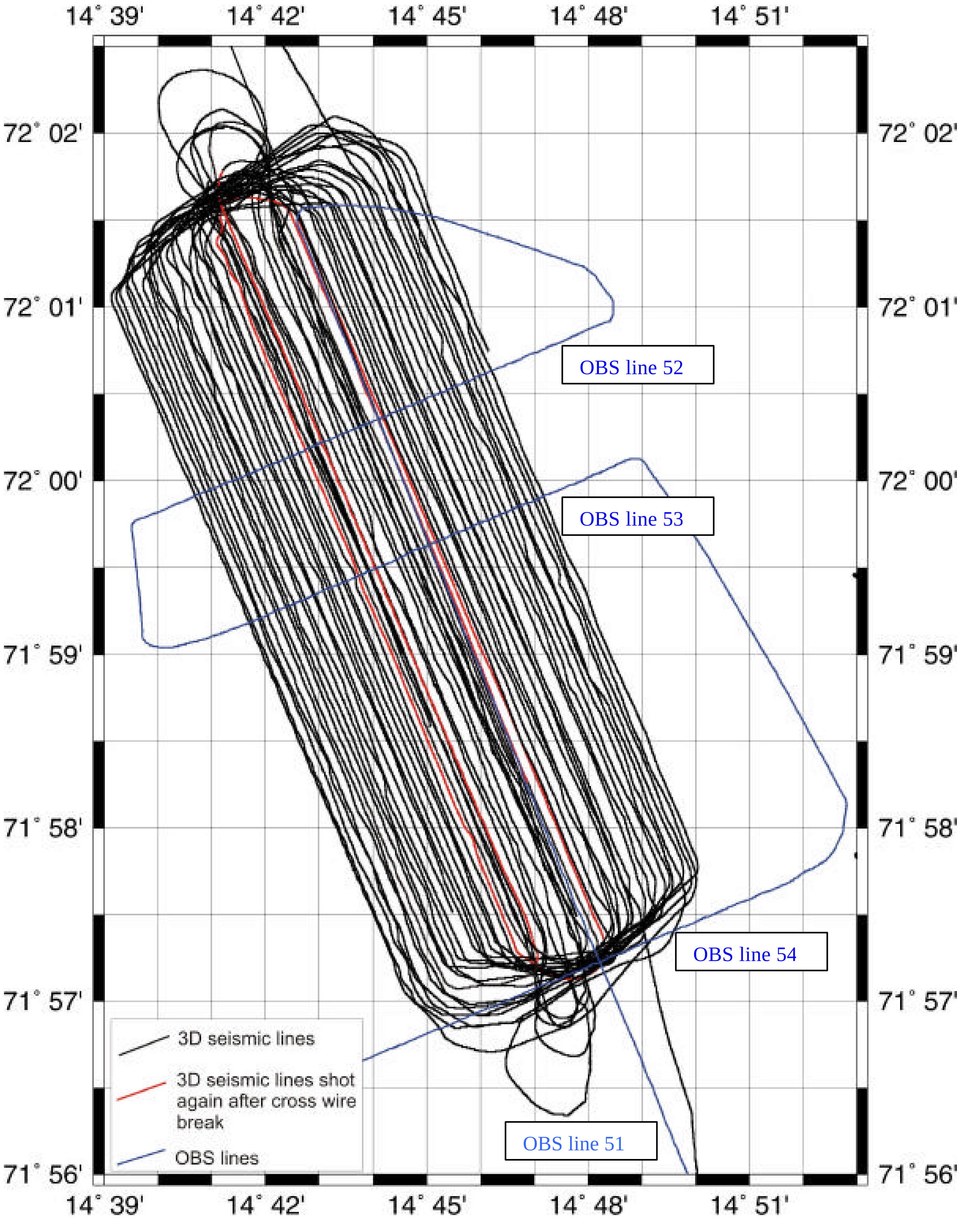


Figure 5b: *Acquisition of seismic lines at the end of the 3D survey (equidistance 60 m and 63 parallel lines).*

Figure 5c: *The high-resolution 3D system towed behind R/V Jan Mayen during this seismic survey with door positions marked.*

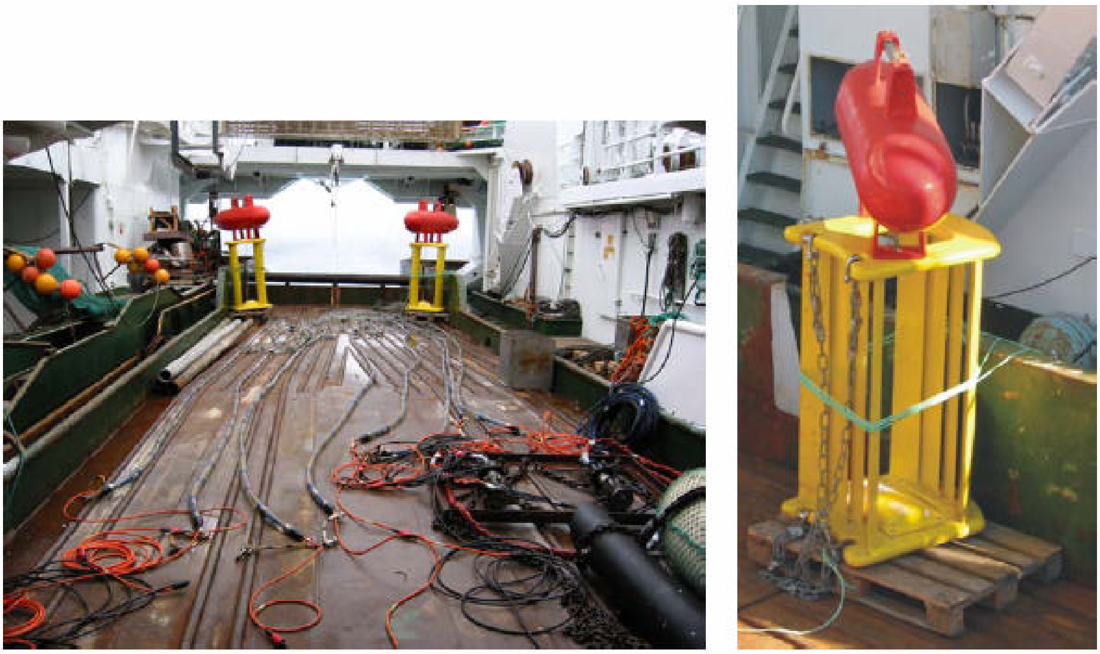


Figure 5d*: (left) Single-channel streamers and the two doors on deck before deployment. (right). Close-up of a door for the high-resolution 3D seismic system, on which a GPS antenna is to be installed.*

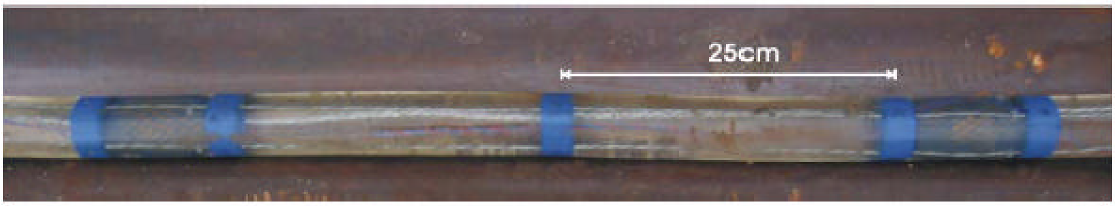


Figure 5e: *Zoom of a hydrophone section in one of the single-channel streamers.*

Configuration of the system during the expedition:
The area extent of the 3D cube is approximately (3.915x 7.745 km) 30.32 km^2 (Figure 5b). Optimal cruising speed is 3.0 kn. At higher speed, the doors collapse. Shot spacing was 8 s to achieve highest possible fold. Acquisition line interval was set at 60 m, with a total of 63 parallel profiles along slope (Figure 5b). Data were sampled at 1 kHz, with a recording length of 3.0 s. Data quality was checked on a portable computer, displaying the individual shot gathers, the individual noise levels, the amplitude spectrum of one of the channels, the navigation details and time stamps.

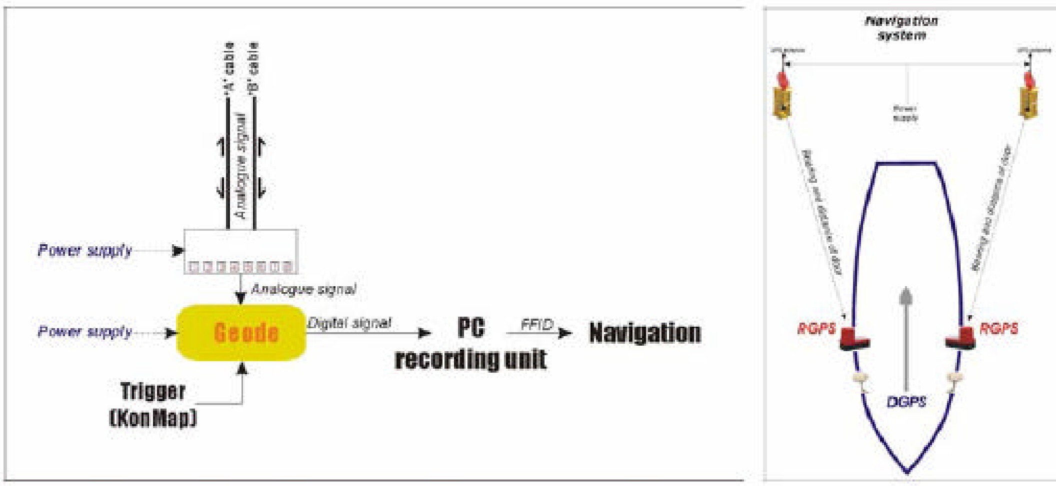
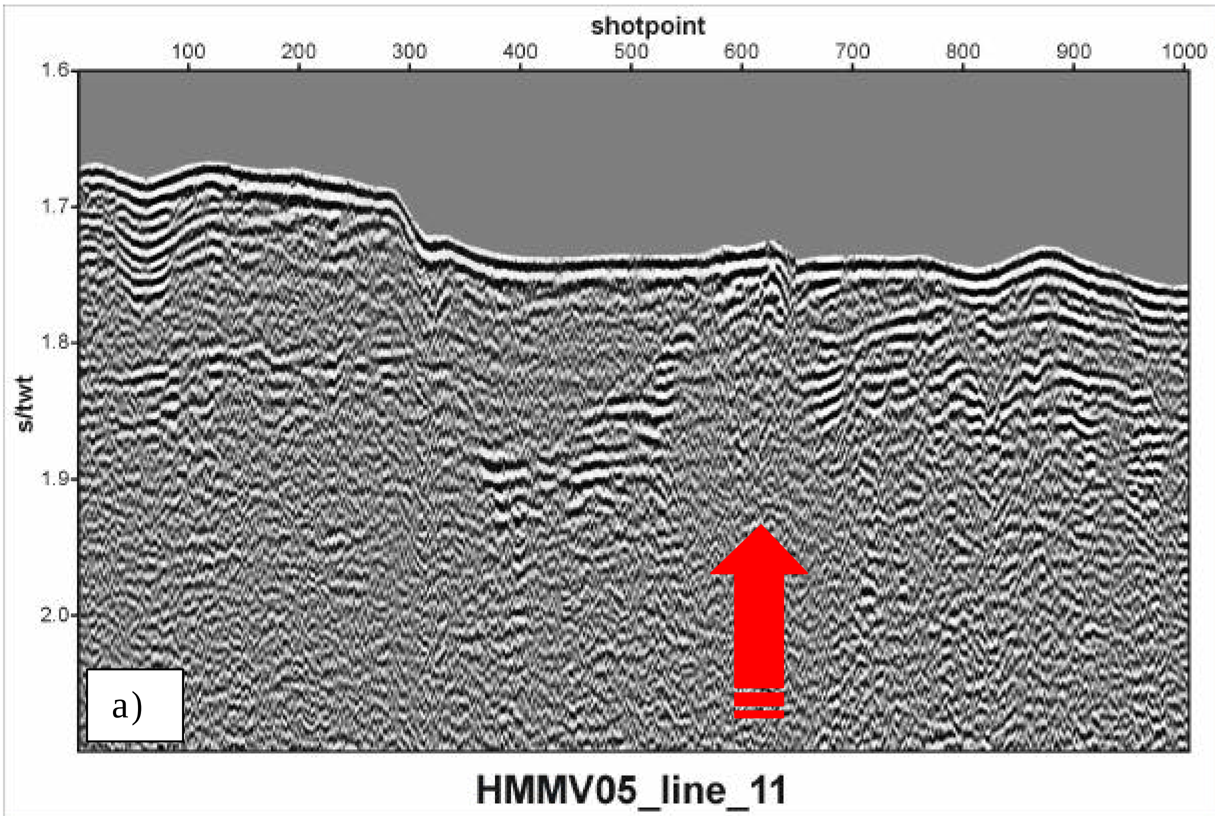
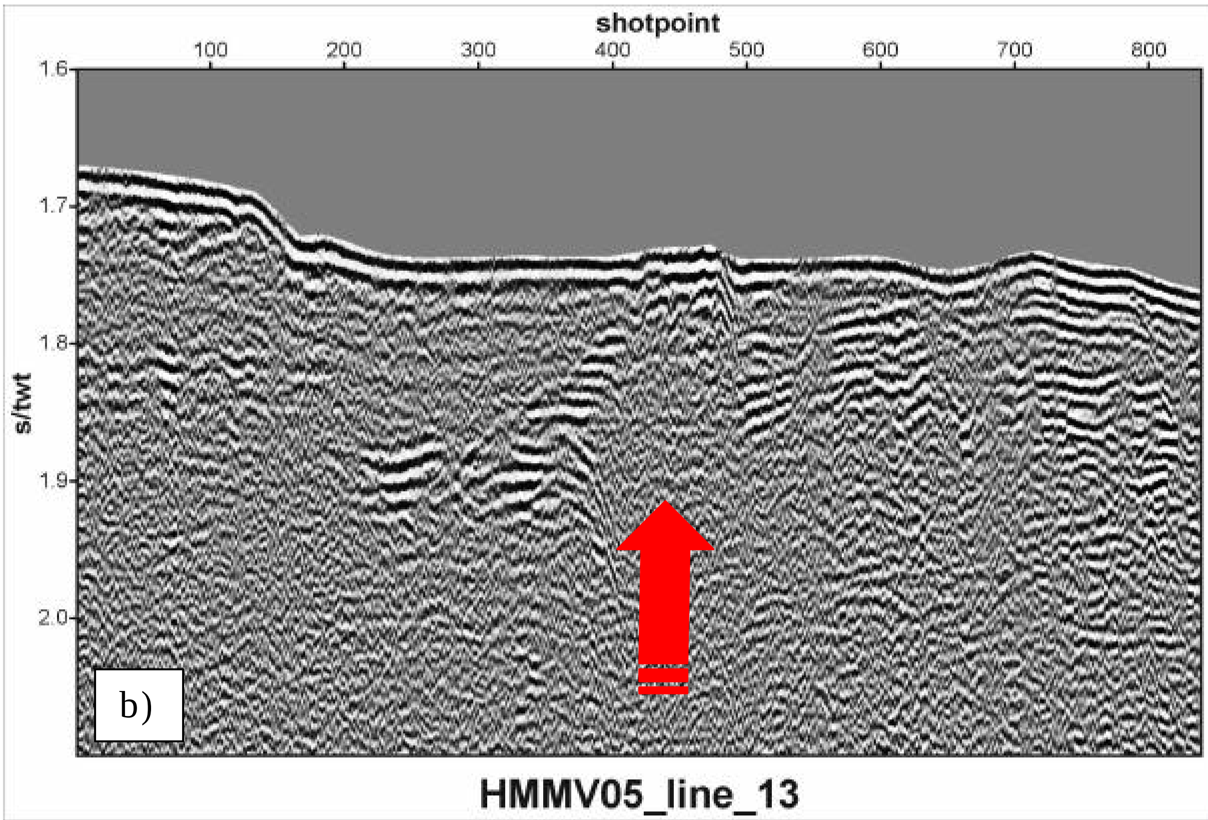


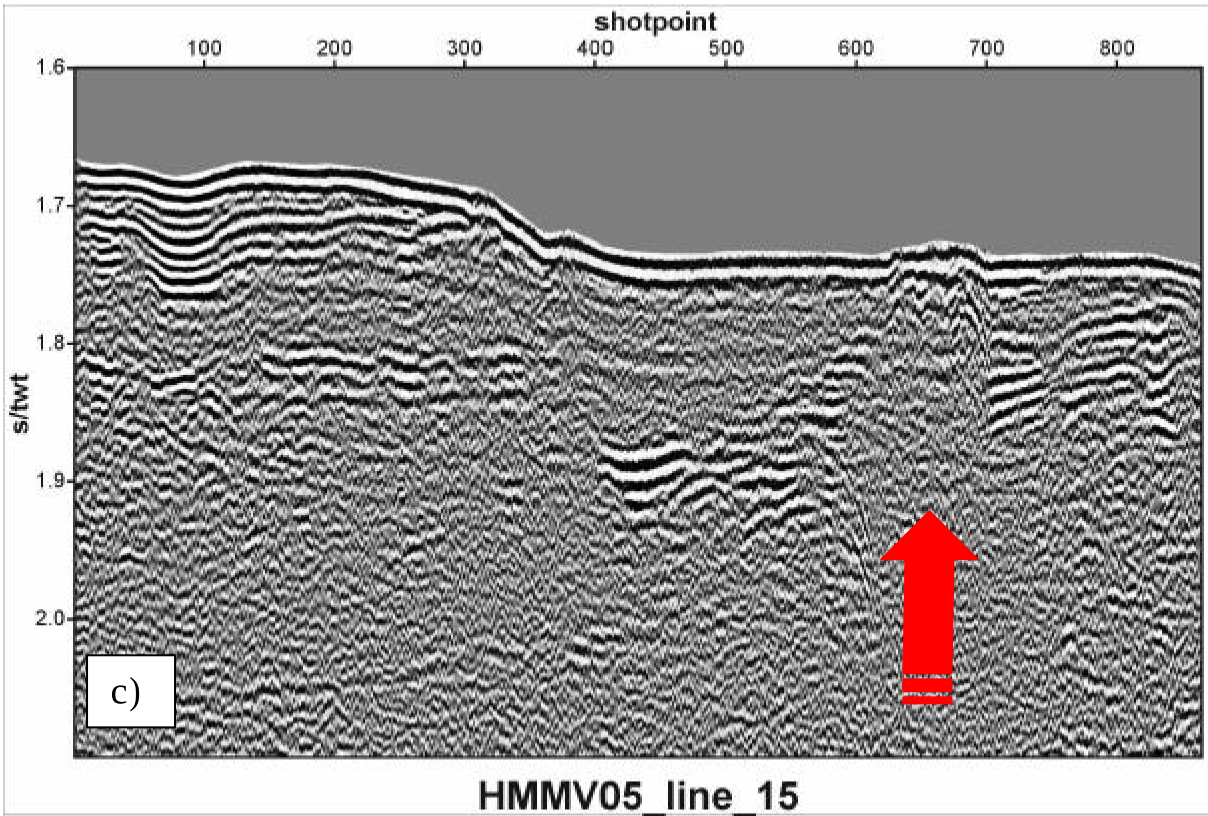
Figure 5f: *3D acquisition scheme.*

The acquisition parameters on the recording unit:
Gain for each of the channels : All high gain
Recording delay = 0 ms
Number of samples = 3000
Sampling rate = 1 kHz
Recording length = 3.0 s
Shot spacing: 8s
Vessel's speed = ~3.0 knt
Header length = 240
File format : standard SEG-Y
The navigation system of the 3D seismic:
The distance between the doors and the antenna on deck is about 78 m.
Data reference: WGS84
Position for each shot

Examples of the 2D seismic lines are shown in **Figures 6 a- c**. Red arrow marks location of HMMV.




shotpoint
100
200
300
400
500
600
700
800
1.6
1.7
1.8
1.9
2.0
s/twt
b)
HMMV05_line_13


shotpoint
100
200
300
400
500
600
700
800
1.6
1.7
1.8
1.9
2.0
s/twt
c)
HMMV05_line_15

Multibeam (MB) Kongsberg SIMRAD EM300

The EM300 multibeam system is designed to map the sea floor morphology and its acoustic backscatter from depths as shallow as 10 m, across the continental margin to beyond the continental rise (**Figure 1b**), down to about 5000 m water depths. The system includes all necessary sensor interfaces (e.g. positioning system, attitude, heading, clock, synchronisation, ...), data displays for quality control and sensor calibration, seabed visualisation and data logging are a standard part of the system, as well as integrated seabed acoustical imaging capability.

The system runs with a nominal sonar frequency of 30 kHz, in order to obtain an optimal balance between small dimensions, narrow beams and good range capability. This results in an angular coverage of up to 150 degrees and 135 beams (which are always within the active swath) per ping as narrow as 1 degree. The beam spacing is normally equidistant, with equiangle available. The transmit fan is split in several individual sectors, with independent active steering according to vessel roll, pitch and yaw to place all soundings on a best-fit to a line perpendicular to the survey line, thus ensuring a uniform sampling of the bottom and 100% coverage. Pulse length and range sampling are variable with water depths, to obtain best resolution. The swath width, dependent on seabed sediments, in shallow waters (< 500 m) is typically 5 times the water depth. Down to 2000 m, a swath width is 4-5 km is common.

The system runs on a high performance PC (dual 2.8 GHz, 2 GB RAM), displaying the data collected and logging them to hard disk. As a standard, the following parameters are logged: depth, seabed imaging, vessel position, vessel attitude, and sound speed. The operator station converts range and angle data to xyz triplets, applying all corrections required by varying vessel attitude and sound speed. Sound speeds were loaded from external data source, being CTD sound velocity through the water column, after appropriate filtering and editing. A graphical user interface provides control on the data quality and parameters used. Note that, because of the protection housing installed around the hardware to avoid damage of ice contact, the amplitudes recorded are slightly attenuated (~6 dB).

Note: During this survey, the MB data are recorded using WGS-84 datum. The accuracy of the soundings is as good < 0.5% of water depth. For near normal incidence, a centre of gravity amplitude detection of the pulses is employed, but for most of the beams the system uses interferometric phase detection.

A complete data processing system is available as well, consisting of NEPTUNE, POSEIDON, TRITON, and CFLOOR:

NEPTUNE: used for post-processing of bathymetric data collected from single beam or multibeam echo sounders, consisting of cleaning and filtering of positioning data, analysis and correction of depth data, tidal height adjustments, automated data cleaning based on statistical rules or manual editing, controlled data thinning, and export of final soundings for further data processing.

POSEIDON: used for post-processing of seabed image data (in dB) into acoustic, imagery mosaic maps and overlays. This included merging of the data from different surveys, filtering and interpolation.

TRITON: used for seabed sediment classification. It extracts signal features from the seabed image data, and feeds them to a statistical classification procedure to obtain the best estimate for seabed sediment type and segmentation as a function of position in the form of a map overlay.

CFLOOR (third-party software, ROXAR): used for digital terrain modelling and plot generation. This consists of establishing a digital terrain model from an interpolation of the sounding data. From this, the program produces contour maps, 3D plots, depth profiles along specified routes, fair sheets, volumetric calculations, etc. Results from POSEIDON and TRITON can be combined in CFLOOR.

Narrative of the cruise (18.07 - 29.07.05)

Times in this report are given in local time (local time -2 hrs = UTC), 3D seismic data are logged in UTC time and ship logs are given in UTC time. The weather throughout the cruise provides a relatively calm sea suited for a seismic survey. Eight systems HighRes 3D reflection seismic, 2D reflection seismic, Multibeam (MB) Kongsberg SIMRAD EM300, Echolot 3.5 kHz, 18 kHz, 38 kHz, multicomponent Ocean bottom seismometer, and GPS Navigation are working parallel during the cruise.

Monday, 18.07.

11:00 Scientific crew embarks in Longyearbyen, Spitsbergen
New navigation (Seadiff Kongsberg) for the high resolution (HighRes) 3D seismic system - PCable - was installed, tested, and it worked.
12.00 R/V Jan Mayen left Longyearbyen and she starts its journey, sailing in relatively stable and high air pressure condition to the target area, the Haakon Mosby Mud Volcano on the Barents-Sea continental margin. Transit time from Longyearbyen to the HMMV is estimated to be 30 hrs. Multibeam is running on Transit.
Mounting the PCable doors, and laying cables for recording.
Ocean Bottom Seismometers (OBS) is assembled and tested.

Tuesday, 19.07

08.30 Assembling the PCable doors on afterdeck
09.45 Passing 77 nm west of Bear Island
19.20 Arriving target area

21.25 (23.25 UTC) First station is CTD Stn.35. It is launched prior to a detailed MB survey and 3D seismic survey, in order to appropriately calibrate the speed of sound in water masses. Water depth is 1265 m at the location of the HMMV. OBS 2 Acoustic release system has been attached to the CTD frame and tested at 1200 m water depth. The release functioned but the on board unit did not confirm the signal.

30 min.

23.40 OBS 1 launched and sinking to seafloor. Automatic release set at 24.07, 12:00 UTC

Wednesday, 20.07.

00.20 OBS 2 launched and sinking to seafloor. Automatic release set at 24.07, 12:00
00.40 OBS 3 launched and sinking to seafloor. Automatic release set at 24.07, Doors including GPS antenna for 3D seismic launched to sea
01.00 Preparing 12 streamers for deployment of 3D seismic survey
06.05 Start of 3D seismic line Stn4, 3.5kHz, 18 kHz, 38kHz profiling, and MB survey acoustic systems are used parallel.
08.05 Start of 3D seismic line Stn5;Guns: 8 s shooting (first line was 10 s) Start of Echosounder (3.5, 18 and 38 kHz); GPS/Navigation consisting of 3 SEATRACK antennas and the vessel Tracking Unit; Wind & Waves (Bft ~ 4) at the limit for 3D seismic survey
10.15 Start of 3D seismic line Stn6 (gas plume!)
12.15 Start of 3D seismic line Stn7 (gas plume!)
14.15 Start of 3D seismic line Stn8 (gas plume!)
16.10 Start of 3D seismic line Stn9 (gas plume!)
18.00 Start of 3D seismic line Stn10 (no plume!)
19.40 Start of 3D seismic line Stn11 (gas plume!)
21.35 Start of 3D seismic line Stn12 (no plume! but thermocline interrupted, high amplitude reflector beneath HMMV indicates gas accumulation)
23.35 Start of 3D seismic line Stn13

Thursday, 21.07.

01.21 Start of 3D seismic line Stn14
02.15 Wire broke on starboard door. It was realised due to the fact that the centre buoy was drifting behind the portside.
02.31 Stop and interruption of seismic line Stn14
04.00 Took in the door and half the streamers (ca. 2 hrs). Power cable on the door was very twisted. The "eye" on the wire was sheared off at the clamp. Due to friction between the starboard block and the towing cable the towing cable twisted around its own axis. This led to (1) entanglement of the power cable for the GPS antenna with the towing cable and (2) a rotation of the sheckle joining the paravane

chains. Abrasion on the chains shows that the chains rotated approximately three times around themselves. As a consequence the crosswire that is attached to the same sheckle was twisted around the chains. Further movement and friction between the crosswire and chains twisted the crosswire until it broke. As a result the centre buoy drifted towards portside and the deck cables towed part of the streamer weight. The portside paravane continued to tow the streamers out of the ship's travel direction, so that the only surface expression of the crosswire failure was the portside displacement of the tail buoy and the increased tension on the deck cables.

The difference in offsets also resulted in a change in direct arrival and seabed arrival times in the seismic data. Whereas the portside channels continued to be semicircular with early arrivals near the door and later arrivals towards the centre buoy, the starboard seabed arrival times increased linearly from the centre buoy towards the broken end of the crosswire. Took in the PCable by pulling the signal cables. It was very heavy to do by hand. Used rope around the cable, which was pulled by a winch. However, lots of stress on the cable caused the lining to break at one point. Cross-wire fixed by adding ca. 6 m long wire ("spleisa"). Signal cable fixed (rope and tape and "krympestrømpe"). Power cable fixed (outside of cable OK but inside copper broke). New towing configuration: Swivel on trawl wire and power cable taped to a rope.

Suggested data and power transfer: use data transmitting cable down the middle (in the sea) to the centre of the cross-wire. Should give power to GPS's too. Swivels on tow cables. Hand-driven winch for signal/power cable (does not need to be strong) is to be used and central float with A/D converter and cable connections.

New 3D system should be tested thoroughly. Need to do survey where normal 3D + highRes 2D data exist. (Need improved source + towing configuration). Suggestion: Evaluate sources used by Fugro vessels. Need QC on noise level of individual streamers (processing). How can we improve S/N ratio?

08.50 2nd deployment of 3D seismic equipment after solving problems and repairing cross wire and connecting again the GPS wire to doors. Calm sea allowed to continue survey under ideal conditions.

09.26 Start of 3D seismic line Stn14B

11.26 Start of 3D seismic line 15
13.12 Start of 3D seismic line 16
14.54 Start of 3D seismic line 17
16.20 Start of 3D seismic line 18
18.40 Start of 3D seismic line 19
19.30 Start of 3D seismic line 20

20.59 Start of 3D seismic line 21 (plume on top of thermocline but no plume beneath !)
22.46 Start of 3D seismic line 22

Friday, 22.07.

00.30 Start of 3D seismic line 23
02.21 Start of 3D seismic line 24
04.10 Start of 3D seismic line 25
05.50 Start of 3D seismic line 26
07.28 Start of 3D seismic line 27
09.12 Start of 3D seismic line 28
10.50 Start of 3D seismic line 29
12.32 Start of 3D seismic line 30
14.13 Start of 3D seismic line 31
15.50 Start of 3D seismic line 32
17.27 Start of 3D seismic line 33
19.00 Start of 3D seismic line 34
20:10 Discovered air leakage at airguns and repaired the hose.
21.42 Start of 3D seismic line 35
23.27 Start of 3D seismic line 36

Saturday, 23.07.

01.14 Start of 3D seismic line 37
02.56 Start of 3D seismic line 38
04:00 MBS recorders of the OBS stop recording according to the programmed stop time. Thus, the OBS data acquisition is completed after approximately 2/3s of line 38 have been finished.
05.02 Start of 3D seismic line 39
06.34 Start of 3D seismic line 40
08.36 Start of 3D seismic line 41
10.22 Start of 3D seismic line 42
12.28 Start of 3D seismic line 43
14.07 Start of 3D seismic line 44
16.13 Start of 3D seismic line 45
17.49 Start of 3D seismic line 46
19.33 Start of 3D seismic line 47
21.11 Start of 3D seismic line 48
23.02 Start of 3D seismic line 49

Sunday, 24.07.

01.00 Start of 3D seismic line 50
02.42 End of 3D seismic line 50
02.45 Start to take up 3D seismic equipment and cable. Done at 05.00. >1 m waves. Started with starboard door, then streamers, and finally port door. Went generally well. Doors chains and swivels were OK. Main "problem" with GPS power cables (port cable twisted at least 50

times - was cut and repaired) - takes about 1 hr. Doors went up well - but "løpekatt" is a meter too short to get the doors completely on to the deck. Signal cable plastic lining broken where secured by rope on the P-wire. Fixed. One streamer was punctured (filled with air bubbles).

QC: * Signal cable (find and fix broken lining caused by ropes)
* Streamers (check bad streamers; replace with new ones)
* Power cable (seems OK; fix the way the rope is tide on to the port door)

05.00 Recovery of OBS's

OBS#1 (NW). OK recovery. However, geophone had not released. 10 V left on battery. OK data.

OBS#2 (HMMV). To surface at 06:25. (ca. 20 min rise time). Secure on deck 06:45. Geophone had not released.

OBS#3 (SE). On site 07:00. On deck 07:17. Disk in lab at 07:30. Geophone had released. Second disk drive did not work.

08.29 CTD station

All stations work with drifting (wind/current) from E to W. Ship cannot keep accurate position! Drift speed ~ 30m /min. Little obvious evidence of gas seep in T, S, Theta, and velocity data. One floating CTD station at a constant water depth of 1229 m (+- 1m) showed a minor T increase across HMMV from - 0.893 to - 0.880 Celcius (+- 0.001 Celcius).

10.39 CTD station 37
11.40 CTD station 38
12.31 CTD station 39
13.22 CTD station 40
14.27 CTD station 41
15.34 CTD station 42
16.00 Multibeam survey map a larger area.
11.30 End multibeam Survey
12.00 Start preparation of OBS

Monday, 25.07.

00.30 Start deployment of OBS.
00.34 Deployment OBS 5: 14°45.096'E 71°59.511'N, 1262.9 m, 24-07-05 22:57:30 UTC; Outflow area south of HMMV (Figure 10)
00.57 Deployment OBS 4:14°44.028'E 72°00.383'N, 1258.1 m, 24-07-05 22:34:09 UTC; Plume area center of HMMV! (Figure 10)
01.19 Deployment OBS 6: 14°48.204'E 71°57.199'N, 1210.7 m, 24-07-05 23:19:47 UTC; Mud mounds south of HMMV!; (Figure 10)
Air Guns out at 01:20
01.43 Start of OBS seismic line 51
04.00 Start of OBS seismic line 52
04.50 Start of OBS seismic line 53
06.11 Start of OBS seismic line 54
09.45 OBS 4, 5 and 6 back on board after successful release from the seabed (see Table 1).

12.31 Start of 3D seismic line 55
13.09 Start of 3D seismic line 56
15.28 Start of 3D seismic line 57
17.08 Start of 3D seismic line 58
19.12 Start of 3D seismic line 59
21.01 Start of 3D seismic line 60
23.19 Start of 3D seismic line 61

Tuesday, 26.07.

01.40 Start of 3D seismic line 62
03.49 Start of 3D seismic line 63
05.39 Start of 3D seismic line 64
07.45 Start of 3D seismic line 65
09.59 Start of 3D seismic line 66
12.11 Start of 3D seismic line 67
14.26 Start of 3D seismic line 68
16.37 Start of 3D seismic line 69
18.29 Start of 3D seismic line 70
20.41 Start of 3D seismic line 71
23.02 Start of 3D seismic line 72

Wednesday, 27.07.

01.08 Start of 3D seismic line 73
03.05 Start of 3D seismic line 74

04.45 Turn off gun, get airgun onboard, and start to pick up cable. Started with starboard door, then streamers, and finally port door. Everything worked and looked fine. Main problem is power cables to GPS. Starboard cable was broken off. And it takes a long time to remove tape and rotate cable (at least 1/2 hour for each door). Streamers disconnected and put in boxes. Big mess with cables and wires. Done packing at 08:00.
06.00 Multibeam survey continued from 06:00 to 10:30
10.49 Start of Gravity core (GC) 05JM032 (north of HMMV)
11.55 Start of Gravity core (GC) 05JM033 (north of HMMV)
12.59 Start of Gravity core (GC) 05JM034 (southwest of HMMV, outflow)
13.53 Start of Gravity core (GC) 05JM035 (south of HMMV, mud mounds)
14.43 Start of Gravity core (GC) 05JM036 (south of HMMV, mud mounds)
15.34 Start of Gravity core (GC) 05JM037 (south of HMMV, mud mounds)
16.00 Multibeam survey continued from 16:00 - 18:00

18:00 Steaming back to Longyearbyen.

Thursday, 28.07.

STEAMING TO LONGYEARBYEN

Friday, 29.07.

02.00 ARRIVING AT LONGYEARBYEN

PRELIMINARY RESULTS

HMMV - SITE

Bathymetry map of HMMV

The Multibeam (MB) Kongsberg SIMRAD EM300 map provided a detailed morphological image of the HMMV in the Bjørnøya submarine slide complex (Fig. 1a, b). A more detailed image (Figure 8) shows the crater of the mud volcano, which is approximately 10 m high giving a total water depth of 1260m. The central circular crater area has a diameter of ~500m, and the total width of the HMMV reaches 2000m. The CTD drifted at a constant water depth of 1229 m (+- 2m) across the central part of the HMMV (Fig.8). It shows a slight temperature increase from -0.893 to - 0.888 ^{0}C, which is insignificant, and does not allow to trace the HMMV outflow temperature regime with confidence. Another more promising method is acoustic imaging of the HMMV plumes (see Figure 9).

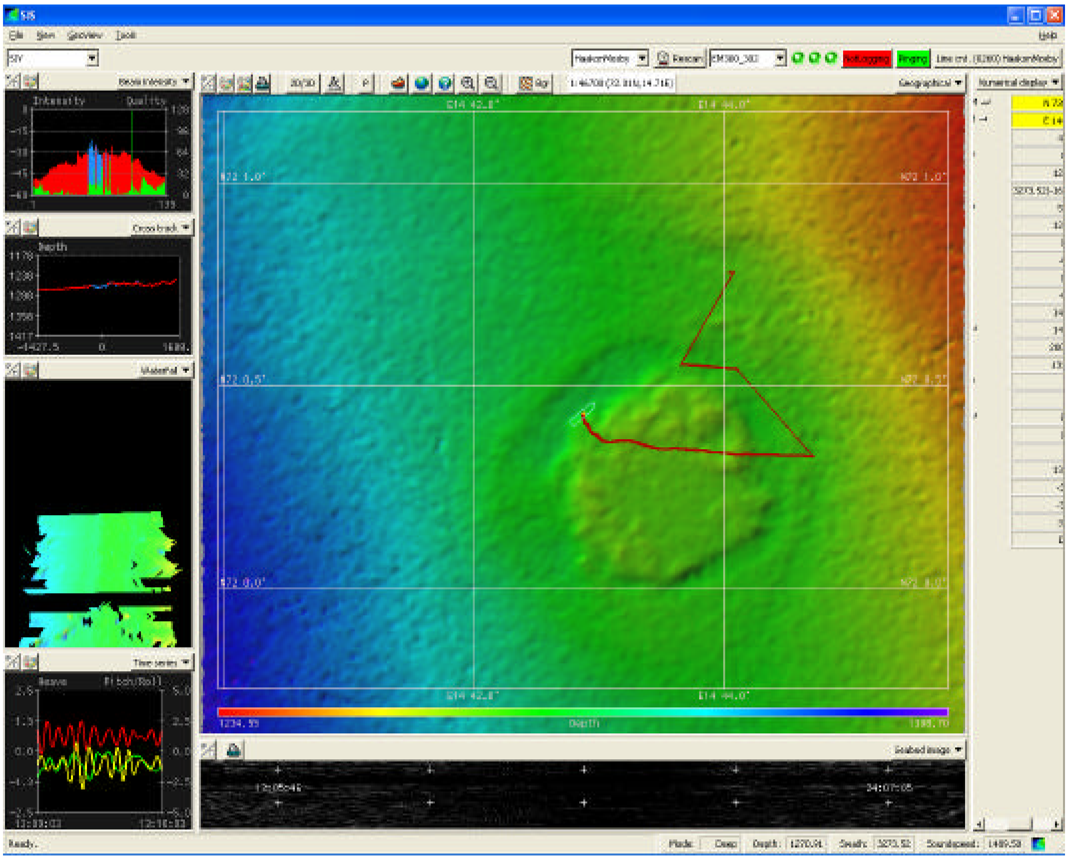


Figure 8. *a) SIMRAD EM300 acoustic image of the HMMV showing a smaller inner volcano in the northeastern area, which shows active gas flows in the acoustic data (Figure 9). The lower red line indicates the E-W drift direction of the CTD across the HMMV. b) Location of 05JM OBS stations (solid circles) and core stations (triangles) in the working area.*

HMMV plume indications using the 18kHz fishfinder echolot.

Multibeam & Echosounder survey of target area clearly identified HMMV on multibeam bathymetry (Figure 8) and on 18 kHz echo sounder a gas plume (Figure 9). The plume can be followed easily to a height of 350 m from the seabed of the HMMV. It is bowed due to deviations by bottom water currents during the time of our recording. The plume width of 300m indicates a large but focussed outflow regime on the seabed. The area where it penetrates through an acoustically observed layer at 750 m is interrupted showing no acoustic reflection. It indicates that the plume not only penetrates but also distorts this apparent water mass boundary. Individual bubbles rise from the plume drifting through the water masses (Figure 9).

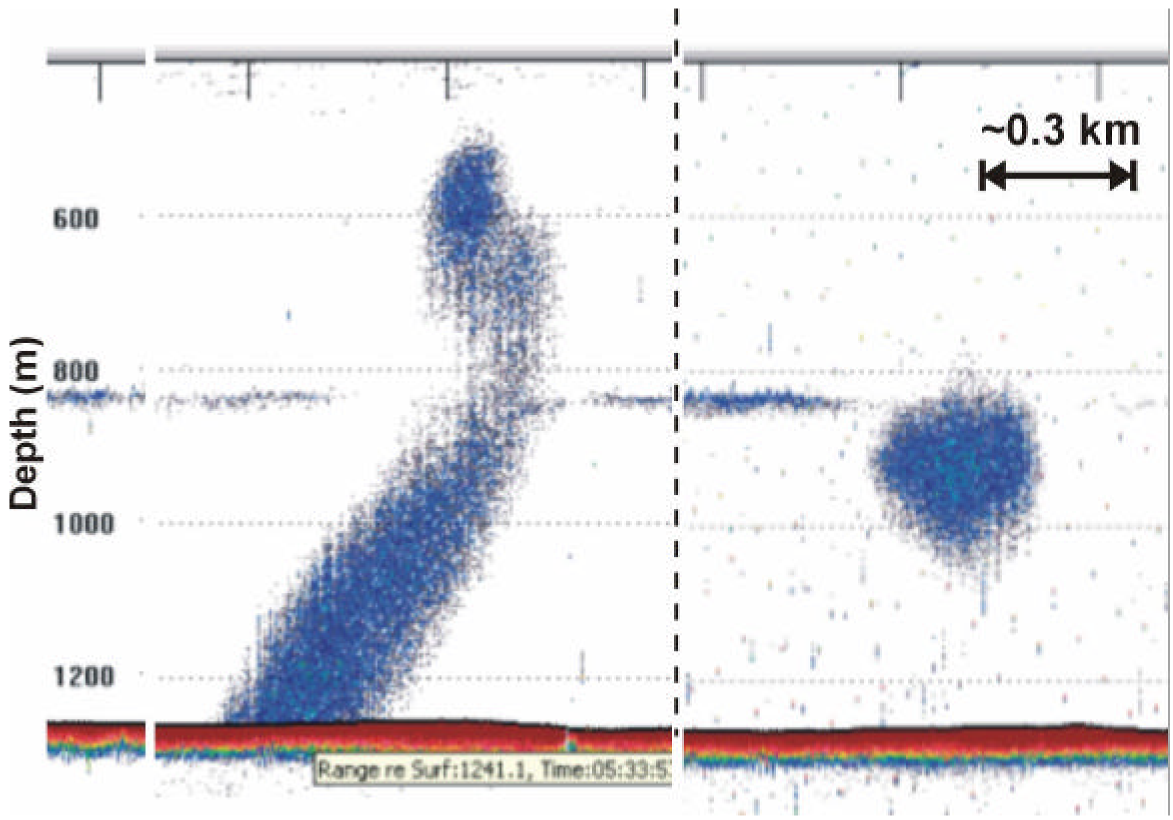


Figure 9. *Gas plumes as seen in the 18kHz fishfinder echolot.*

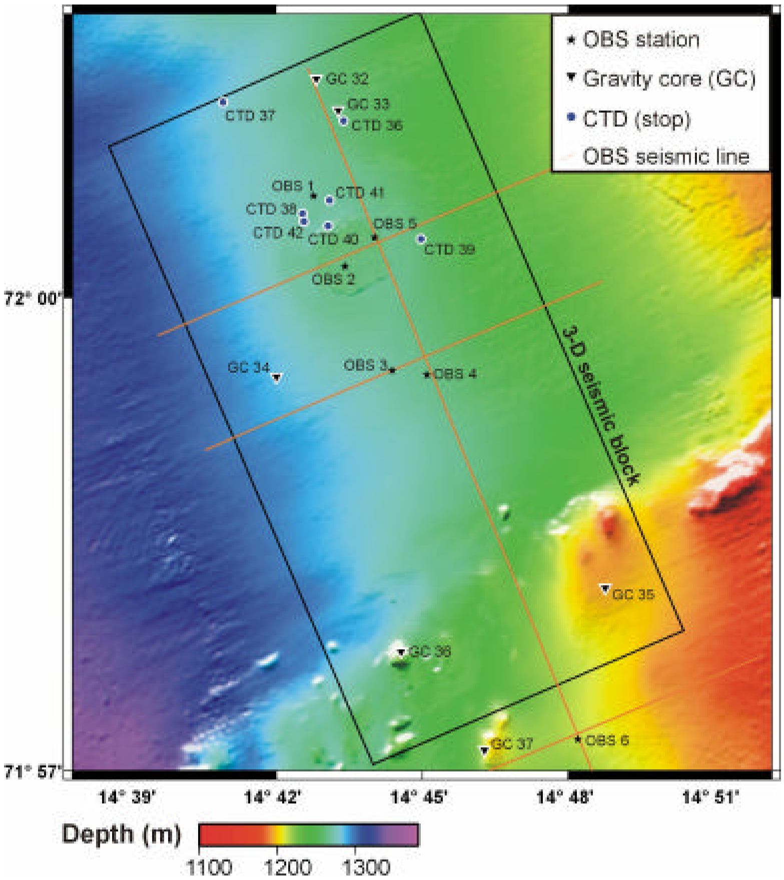


Figure 10. *Location of OBS and gravity core stations. Note that OBS 5 was directly placed in the plume area (see Figure).*

HMMV 3D Airgun and 3.5 kHz seismic lines - Observations

The high-resolution 2D and 3D seismic data reveal the complex subsurface of the study area. It can be subdivided into the topographically elevated provinces to the north and south, and into the depression in the central part. The depression is the result of a major submarine slope failure called Bjørnøya Fan Slide (Vorren and Laberg,1993), the location of the Håkon Mosby Mud Volcano.

The main target of this study is the Håkon Mosby Mud Volcano (Figure 2, 6a - e). In the 3.5 kHz data it is expressed as a slightly elevated, hummocky but overall subhorizontal seabed underlain by an opaque unit. The flanks of the mud volcano rise continually towards this central part and are well stratified. The opaque unit is conical with the greatest width at the surface and becoming more confined with depth. The high-resolution seismic data are strongly affected by diffraction hyperbola with apexes at the rim of the opaque area indicating point diffractors and strong acoustic impedance contrasts. Outside the central opaque part of the mud volcano several sedimentary units can be discerned that thicken towards the centre. The uppermost unit is between 20 and 50 ms thick and covers the entire depression.

The high-resolution data show a strong reflector at 100 to 150 ms that correlates with Hjelstuen et al (1999) reflector R0. Throughout the entire survey area, this reflector is truncated by erosional channels ranging from 100 to 500 m in apparent width. The most prominent channels are present in the northeastern part of the study area. A second reflector can be discerned at greater depth. It is shoaling northward from 500 ms beneath the seabed under the southern elevated area to 250 ms underneath the northern elevated area.

Both the 3.5 kHz and the high-resolution seismic data show prominent cone shaped seismic amplitude anomalies in the elevated area in the south (Figure 6a -e). These features range from 30 to 500 m in diameter and from 30 to 100 ms twt in height. Some of the features penetrate the seabed, and can be correlated with prominent topographic highs in the multi-beam bathymetry data (Figure 2). The high-resolution seismic data show that reflector R0 of Hjelstuen et al. (1999) is continuous underneath these features. The cone-shaped features are generally seismically transparent both in the 3.5 kHz and high-resolution seismic data. Only in few places internal reflectors are present in the 3.5 kHz data. Based on the different strength in 3.5 kHz data reflection amplitude it is possible to divide these features in two classes with low amplitude cones piggybacking on high-amplitude cones in some places.

Preliminary Interpretation

The seismic data constrain the subsurface structure of the Håkon Mosby Mud Volcano. We interpret the prominent diffraction hyperbolae to be caused by gas in the sediments, which limits the ability to image this region with P-waves. Therefore S-wave acoustic investigations are becoming more important, since the gas does not absorb the energy of shear waves. The opaqueness of the inner part of the mud volcano can be a result of such p-wave imaging difficulties but it is just as likely that it is the result of genuine disturbance of the subsurface sediments by the ascent of mud from the deeper strata. The cone shape visible in the 3.5 kHz data can be caused by three different processes: (1) decreased resistance against remobilisation of the strata within the mud volcano with greater depth not unlike the processes forming mares and diatremes in explosive volcanism, (2) a displacement and updoming of the sedimentary strata during eruption, and (3) a continuous build-up of the volcano by subsequent mud flows. Comparison of the 3.5 kHz and high-resolution seismic data showing the increasing thickness of sediment layers (Figure 6a-e) towards the centre suggest that hypothesis 3 is most likely. However, we note that modest present-day topography compared with mud volcanoes elsewhere may not suggest a prolonged activity of the Håkon Mosby Mud Volcano. The HMMV is lacking a characteristic dome shape as a result of long-term burial dependent activity that was reported for mud volcanoes in the Gulf of Cadiz. Additional processes need to be invoked for the HMMV.

The stratigraphic position of incised valleys at reflector R0 indicates a Pleistocene age significantly younger than 0.44 Ma for the observed erosion events. Stratified internally chaotic units that resemble debris flows directly overlie them. Such multiple glacial debris flows are related to ice sheet advances to the shelf edge (REFEReNCES).

The cone shaped features within the southern elevated area (Figure 2) may be explained by: (1) mud diapirism similar to the Vema Dome and Vigrid diapir fields on the mid-Norwegian Margin, and (2) build-up of carbonate mounds. The continuity of reflectors in the high-resolution seismic data underlying the cones implies that a diapiric origin is only possible if the source depth for the diapirs is shallow. If the cones are formed by cold water corals, the study area must have been an active coral reef province for an extended period of time, because some the features do not reach the surface. However, previous inspection of these mounds with a submersible did not reveal any signs of cold-water corals (Mienert, 1998). The preliminary interpretation of the data leaves us with two working hypotheses. Either the cones were formed by shallow-rooted diapirism, and the diapirs were subsequently occupied by cold water corals which would explain the two different reflection strength of the cones, or the cones are extinct coral reef mounds that are covered by a layer of hemipelagic sediments.

3D PCable TECHNOLOGY ASSESSMENT

PCable 3D Seismic Acquisition

The PCable is a cost-efficient low-fold high-resolution 3D seismic acquisition system developed by Volcanic Basin Petroleum Research (VBPR) in collaboration with National Oceanography Centre, Southampton (NOCS), University of Tromsø (UiTø), and Fugro Survey. The technology is covered by Norwegian Patent no. 317652 and PCT application no. PCT-NO03-00079. VBPR is a SME in the HERMES project, with specific aims on developing the PCable technology and acquiring, processing and interpreting PCable data in two hot-spot areas.

The PCable consist of a wire (the PWire) extended perpendicular to a ships steaming direction using two specially designed doors. Several short seismic streamers are connected to the PWire. Data from the streamers are transmitted by signal cables to an on-board recording system. The doors are towed behind the ship using trawl wires. A separate navigation system keeps track of the door positions. See http://www.pcable.com for details.

The first open-sea PCable test survey was successfully conducted west of Svalbard during three days in 2004 (Planke et al., 2004). The 05 Jan Mayen HMMVcruise was the second open water test of the technology.

Acquisition hardware

The 3D seismic acquisition system used during the HMMV05 cruise consisted of the NOCS's PCable and Geode seismic recording system, and the UiTø's air gun array.

A prototype PCable was purchased by NOCS in 2004. The system has two doors, 12 single-channel Teledyne analogue streamers, signal and towing cables, and finally a Seatex Seatrack tailbuoy tracking system with four GPS antennas. The seismic data were digitized on-board using the lightweight Geometrics Geode seismic module. Logging and quality control of the seismic data were done using the associated PC-based Seismodule Controller software.

The air gun array has two 40 cu inch sleeveguns mounted on a frame and towed at 3 m depth about 25 m behind the vessel. Gun firing is controlled by a CheapShot gun controller by Real Time MicroSystems. The near-field signal was monitored by a hydrophone mounted on the gun frame. Single-channel air gun and 3.5 kHz data were additionally acquired using the UiTø's DelphWin recording system. Navigation data for these seismic data were recorded using the on-board Seatex Seapath GPS system.

Operations

Deployment of the PCable started on Wednesday 20 July at 02.00. The doors, towing wires, signal cables, and streamers were connected to the PWire on deck. The system was then tested before the doors were deployed below the rear "helicopter deck" using a temporarily installed "running cat" launching system. The streamers where then sequentially put into the water on first the starboard and then the port side while the towing wires were extended. Power cables to the two GPS antennas on the doors were taped onto the towing wire. Finally, a tail buoy was connected to the mid-point of the PWire and launched. The PCable assembly and launching was completed by ca. 5.00. Acquisition started at about 06.00 after deploying the air guns and testing of the hardware.

The tail buoy tracking system showed that the distance between the doors was consistently 100-105 m, and that the doors were about 75 m from the air gun. This configuration gave an in-line spacing of about 6.5 m. Based on these observations it was decided to use a line distance of 60 m to obtain a good spatial coverage. The noise level on several channels, in particular Channels 6 and 7, were high.

Operations for the first day went generally well. The ship could maintain a speed of 3.0 to 3.5 knots without experiencing towing problems. The minimum air gun firing interval on R/V Jan Mayen is 8 seconds. Thus a SOG of 3.0 to 3.5 knots gave a 12 to 14 m shot point interval, i.e. about twice the in-line spacing. Both door GPS's lost power after half a day due to cable failure in heavy waves. However, this is not a serious problem as the towing configuration is quite well known and the ship or air gun positions are well determined.

A towing problem was discovered at ca. 02.00 on Thursday 21.07. The tail buoy was drifting towards the port door. It was decided to retrieve the PCable. It was then discovered that the PWire had broken on at the starboard boat. The PWire was then being towed by the starboard door and the signal cable (Figure 7). Detailed examination of the shot records showed that the wire break occurred near record 7058 (Figure 8a-c). The reason for the break was that the towing wire had been twisted numerous times causing a large shear force on the shekel connecting the towing cable and PWire. It was decided to put a swivel on the towing wire to remedy the problem. The PCable was then redeployed, and acquisition started at about 07.00.

Acquisition during the next days went well. Towing speed had to be reduced to about 2.5 to 3.0 knots during half a day when the ship was steaming south into a strong northerly current. However, at this time the ship could steam at higher speeds heading south (up to 4.0 knots). An air gun leak occurred at 19:00 Friday 22. July. However, the guns were fixed in less than two hours.

The PCable was retrieved on Saturday 23. July before picking up the ocean bottom seismometers. The streamers, signal cables, and power cables were checked, and two streamers and several lead-in signal cables were replaced. This maintenance operation lead to a good improvement in the signal/noise ratio.

The PCable was re-launched at 11:00 on Monday 25. July. Acquisition started at 13:00 and continued until 04:00 on Wednesday 27. July. The weather was fairly rough (8-12 m/s northerly wind and waves of 1-2 m), but operations went well. However, both GPS power cables failed again after about 30 hours.

Conclusions

The 05 Jan Mayen HMMV cruise has shown that the PCable technology can be used successfully to acquire high-resolution 3D seismic data in an open ocean environment.

A ca. 25 km^2 3D seismic cube with in-line spacing of ca. 6.5 m and shot point distance of ca. 13 m was acquired in 5.5 days. This time includes assembly, deployment, testing, and downtime due technical problems and re-shoot of four lines.

The experience from the cruise will be very important for improving the production rates, reliability, and quality of the PCable data. Further development of the system will include (1) better power supply to GPS on the doors to increase navigation performance, (2) digital signal transfer from the

PWire to the ship to improve signal/noise ratio, and (3) stronger doors to allow for a wider swath and more efficient acquisition.

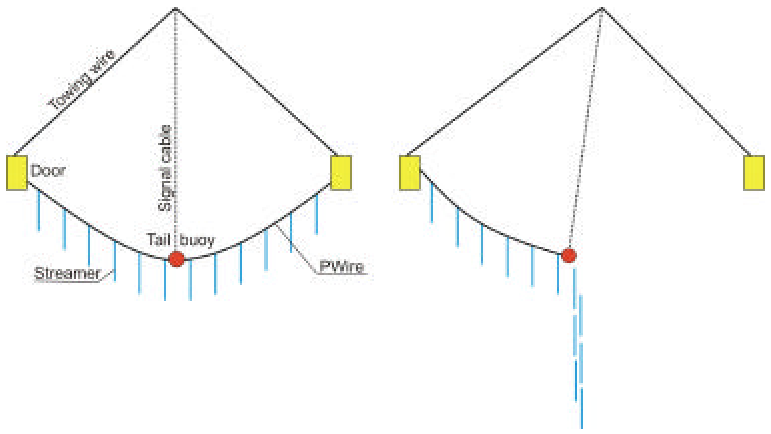


Figure 7: *PWire (left) unbroken and (right) broken shown at the starboard side of the boat. Afterwards the backboard door and the signal cable towed the PWire.*

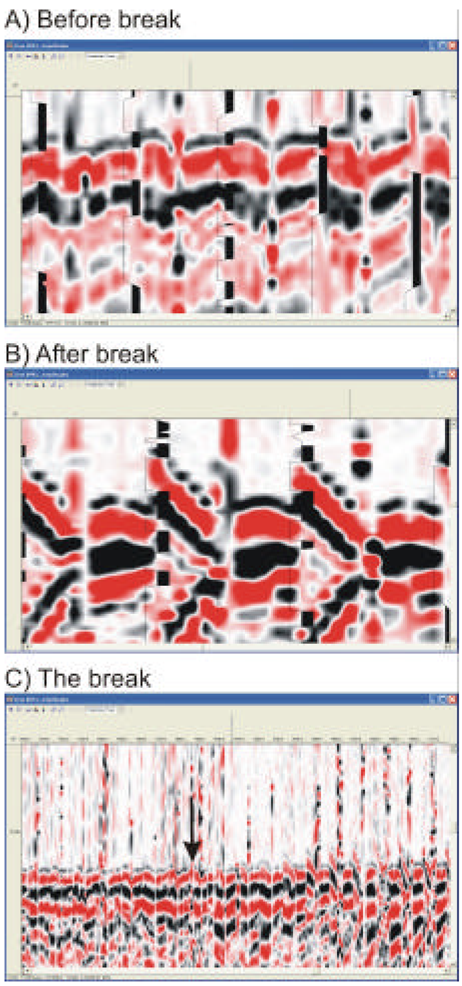


Figure 8. *Shot records a -c showing a wire break that occurred near record 7058.*

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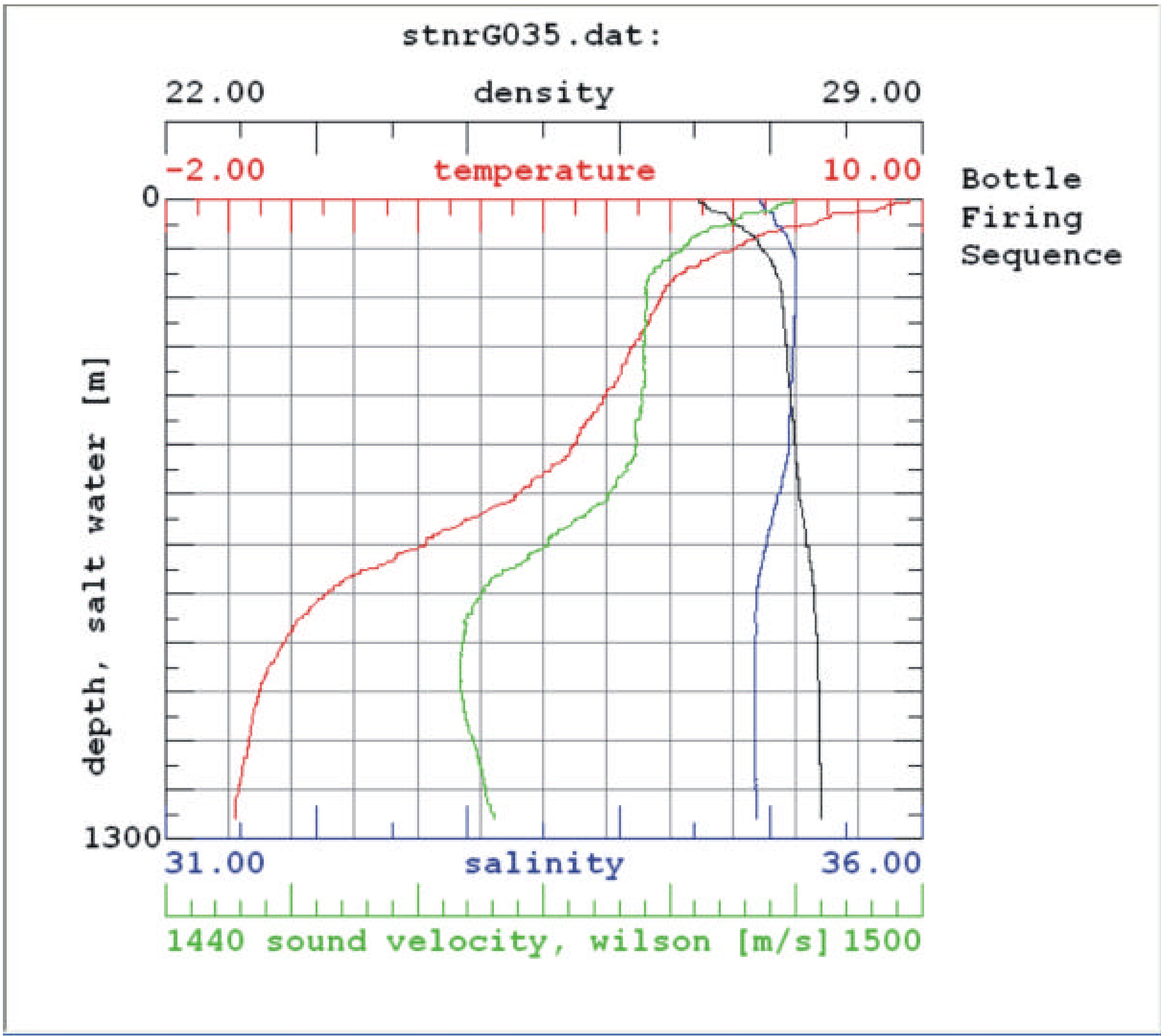
Date	Station type	UTC-time	Loc.St.no	Lattitude	Longitude	Depth
19.7	Prøvetakning med CTD. Start	19:22	35	7200.592 N	01442.936 E	1264.44
19.7	Prøvetakning med CTD. Stopp	19:55	35	7200.729 N	01442.554 E	1270
19.7	OBS drop 1	21:40	n/a	7200.646 N	01442.766 E	1269.5
19.7	OBS drop 2	22:19	n/a	7200.198 N	01443.415 E	1261
19.7	OBS drop 3	22:38	n/a	7159.540 N	01444.383 E	1268.9
24.7	Prøvetakning med CTD. Start	6:29	36	7200.799 N	01443.172 E	1264.53
24.7	Prøvetakning med CTD. Stopp	7:01	36	7201.122 N	01443.388 E	1258.14
24.7	Prøvetakning med CTD. Start	8:39	37	7201.412 N	01443.002 E	1257.38
24.7	Prøvetakning med CTD. Stopp	9:20	37	7201.239 N	01440.901 E	1277.39
24.7	Prøvetakning med CTD. Start	9:40	38	7200.555 N	01444.293 E	0
24.7	Prøvetakning med CTD. Stopp	10:09	38	7200.534 N	01442.543 E	1267.24
24.7	Prøvetakning med CTD. Start	10:31	39	7200.511 N	01444.688 E	1258.1
24.7	Prøvetakning med CTD. Stopp	11:22	39	7200.373 N	01444.969 E	1255.95
24.7	Prøvetakning med CTD. Start	11:22	40	7200.374 N	01444.967 E	1255.88
24.7	Prøvetakning med CTD. Stopp	11:52	40	7200.455 N	01443.065 E	1261.1
24.7	Prøvetakning med CTD. Start	12:27	41	7200.341 N	01445.189 E	1253.42
24.7	Prøvetakning med CTD. Stopp	13:18	41	7200.618 N	01443.096 E	1265.79
24.7	Prøvetakning med CTD. Start	13:34	42	7200.337 N	01445.759 E	0
24.7	Prøvetakning med CTD. Stopp	15:22	42	7200.484 N	01442.567 E	1267.66
24.7	OBS drop 4	22:34	n/a	7200.383 N	1444.028 E	1258.1
24.7	OBS drop 5	22:57	n/a	7159.511 N	1445.096 E	1262.9
24.7	OBS drop 6	4:33	n/a	7157.199 N	1448.204 E	1210.7
27.7	Gravity core (GC)	8:49	32	7201.347 N	01442.822 E	1261.32
27.7	Gravity core (GC)	9:55	33	7201.166 N	01443.225 E	1259.05
27.7	Gravity core (GC)	10:59	34	7159.431 N	01442.007 E	1282.4
27.7	Gravity core (GC)	11:53	35	7158.065 N	01448.747 E	1192.86
27.7	Gravity core (GC)	12:43	36	7157.701 N	01444.803 E	1236.23
27.7	Gravity core (GC)	13:34	37	7157.042 N	01446.308 E	1207.42

OBS 1
drop: 14°42.766'E 72°00.646'N, 1269.5 m, 19.07.2005, 21:40, North of HMMV!
OBS 2
drop: 14°43.415'E 72°00.198'N, 1261.0 m, 19.07.2005, 22:19, Center of HMMV!
OBS 3
drop: 14°44.383'E 71°59.540'N, 1268.9 m, 19-07.2005, 22:38, Outflow area of HMMV!
OBS 5
drop: 14°45.096'E 71°59.511'N, 1262.9 m, 24-07-05 22:57:30, Outflow area of HMMV!
OBS 4
drop: 14°44.028'E 72°00.383'N, 1258.1 m, 24-07-05 22:34:09, Plume center
OBS 6
drop: 14°48.204'E 71°57.199'N, 1210.7 m, 24-07-05 23:19:47, Mud mounds south of HMMV!

Table 1. Station list of OBS drop positions and water depths. Locations of multi-component OBS seismic lines 51 - 54 are shown in Figure 5b and Tab. 2. OBS recovery positions almost coincide with drop positions. Station list of CTD positions and water depth. Note - CTD positions are not accurate because of ship drift of 218^0 with 30 m/min. across HMMV during T-S measurements. Station list of Gravity Core (GC) positions.

Plot of CTD Stations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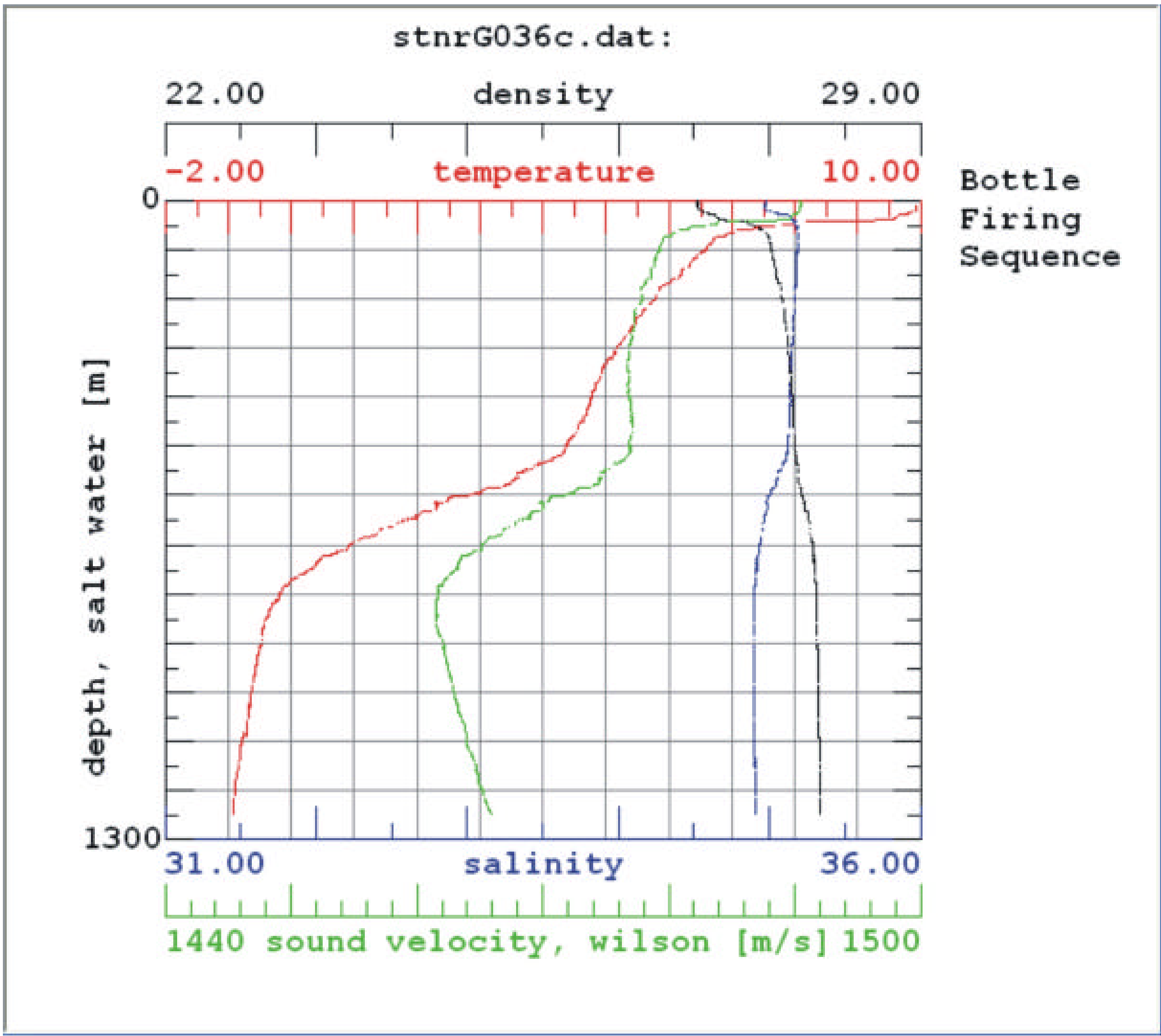
salinity
36.00
1440 sound velocity, wilson [m/s] 1500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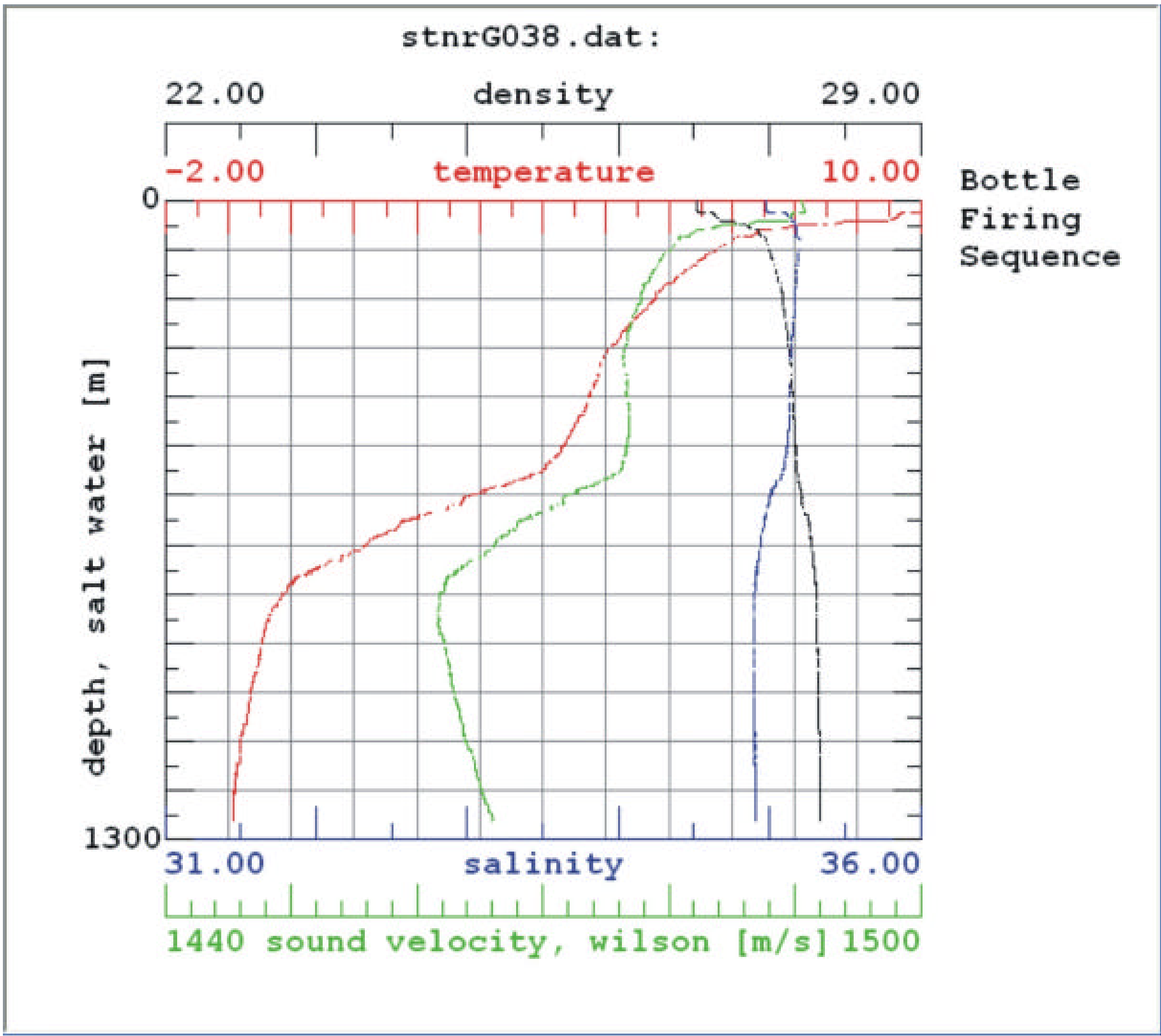
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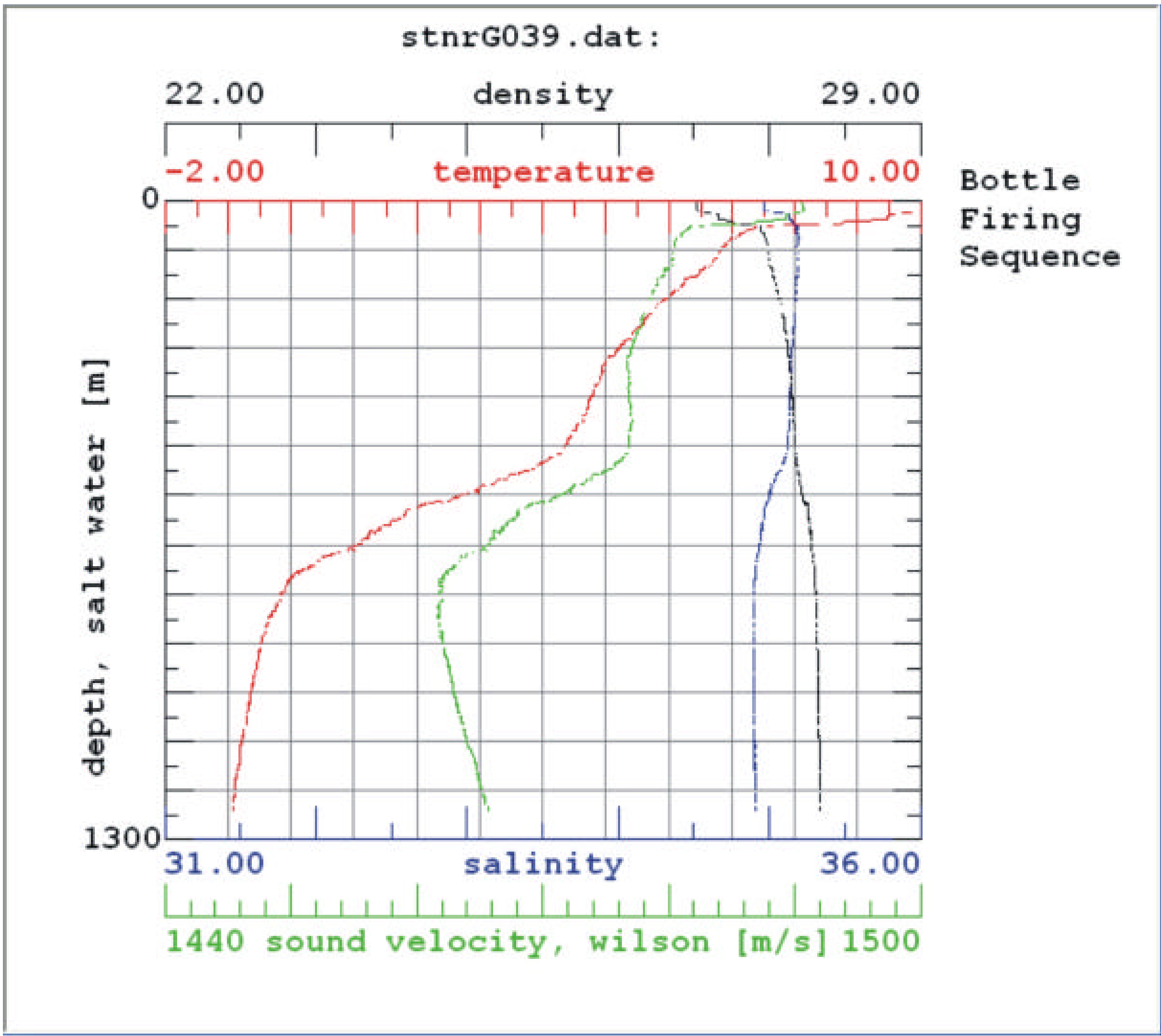
1440 sound velocity, wilson [m/s] 1500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salinity
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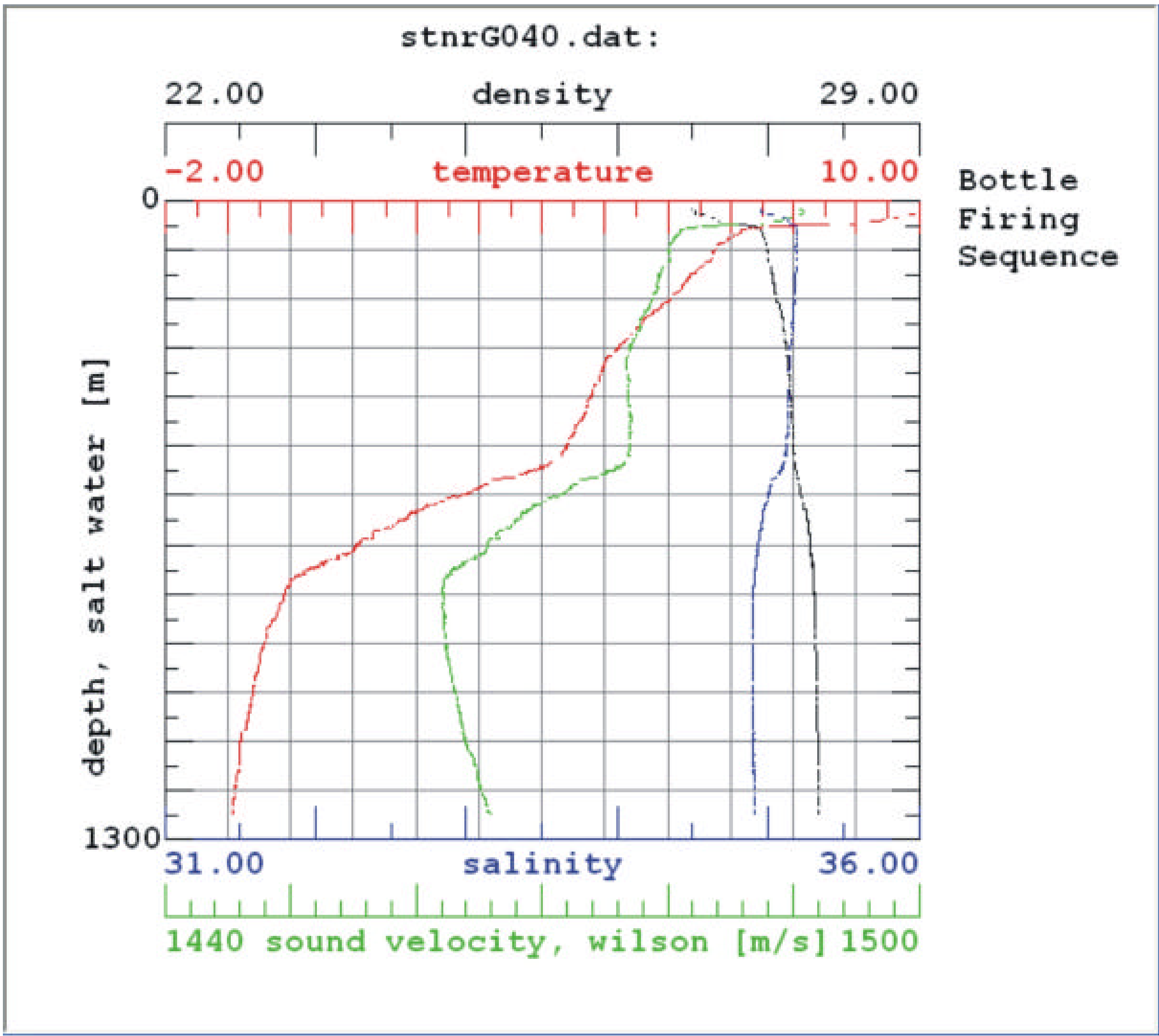
1440 sound velocity, wilson [m/s] 1500



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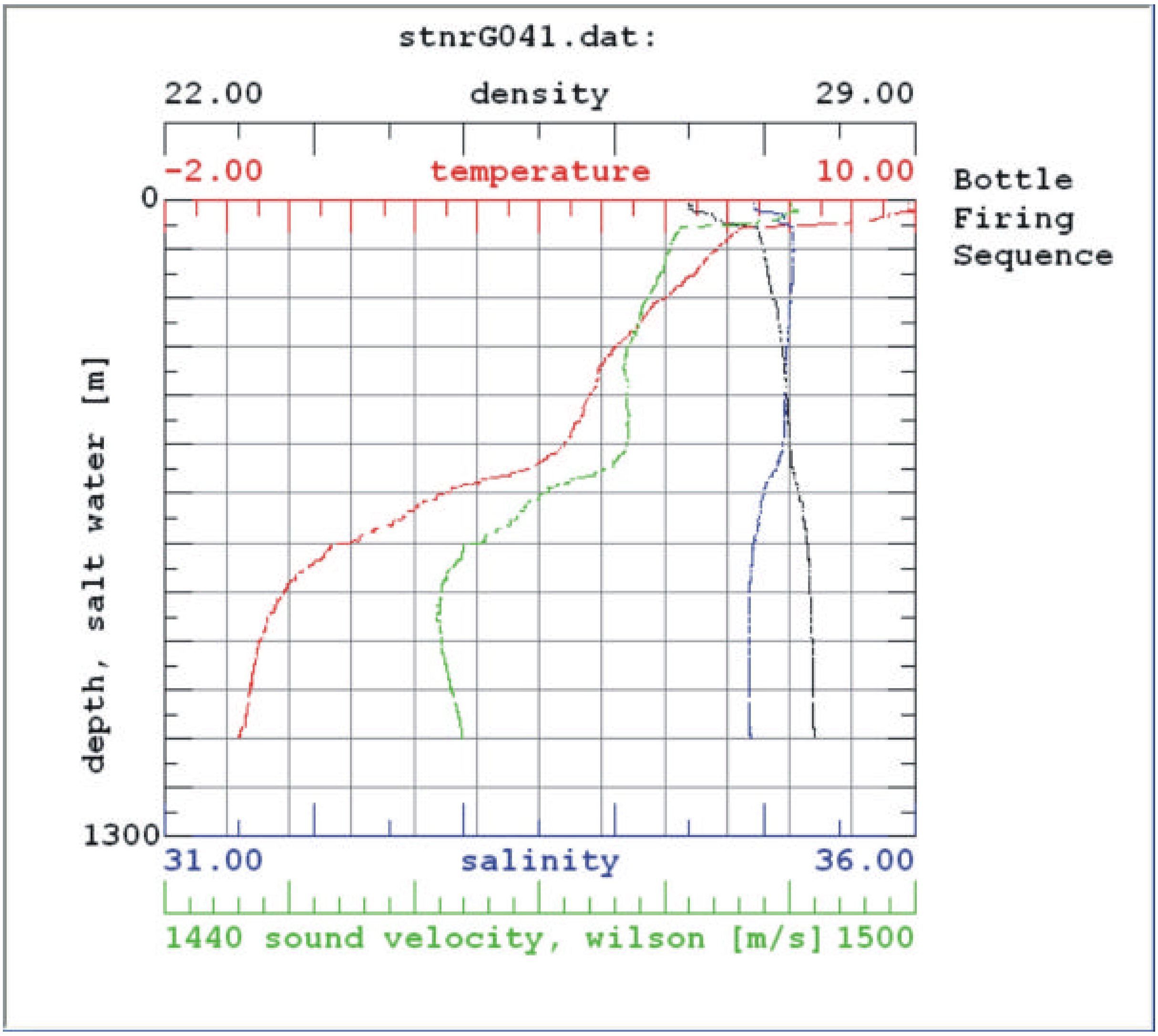
1440 sound velocity, wilson [m/s] 1500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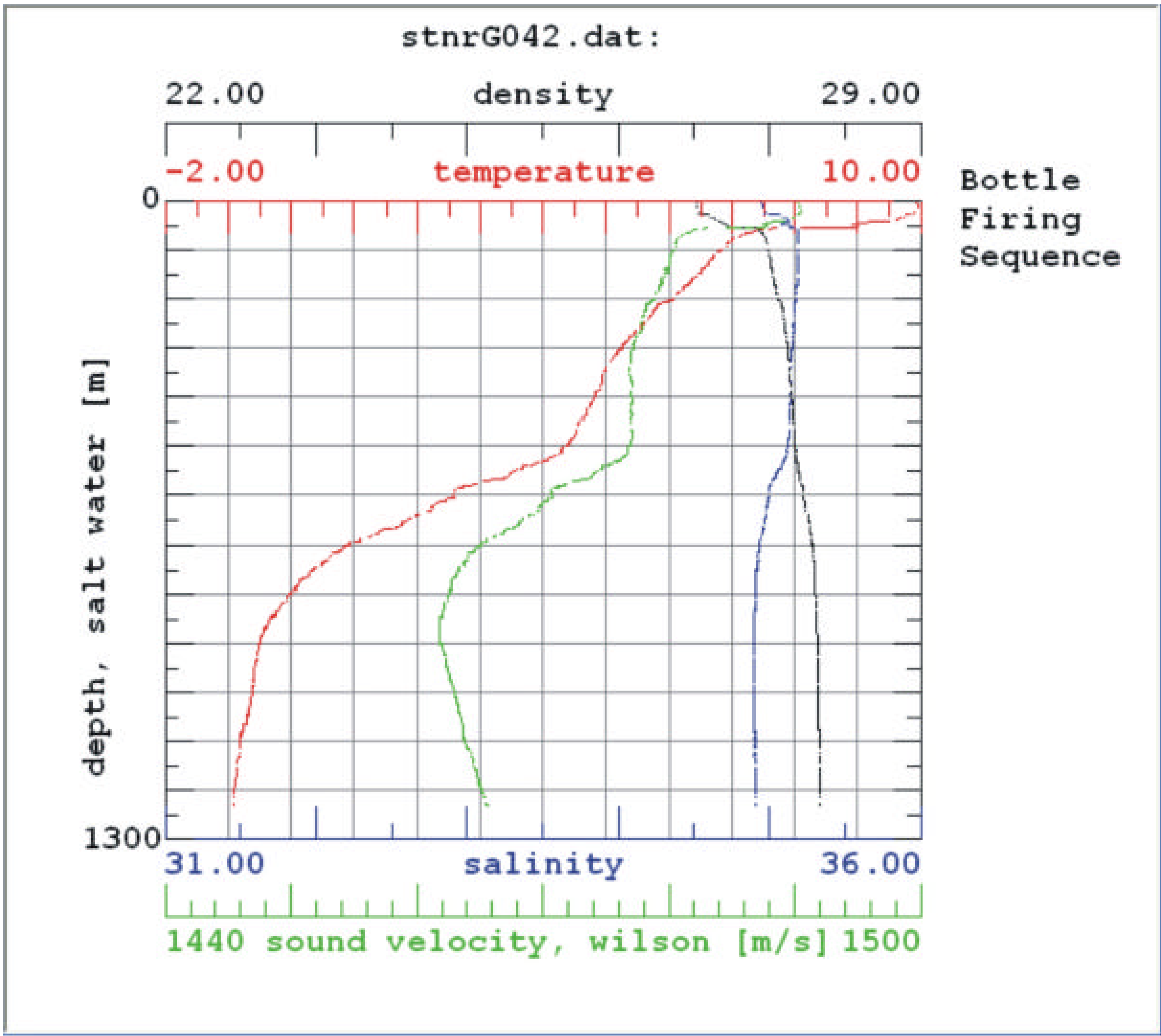
1440 sound velocity, wilson [m/s] 1500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salinity
36.00
1440 sound velocity, wilson [m/s] 1500

Line Name	Date	Start time UTC	Start sp no for 2D aquisition	Longitude WGS84	Latitude WGS84	End time UTC	Longitude WGS84	Latitude WGS84	End sp no for 2D aquisition
Line 05HV005	20.07.2005	06:09	0375	014 47.18787	71 57.50452	07:28	014 42.02926	72 01.31154	0968
Line 05HV006	20.07.2005	08:16	0353	014 41.77756	72 01.33753	09:45	014 47.07497	71 57.48647	1021
Line 05HV007	20.07.2005	10:15	0220	014 47.31619	71 57.51787	11:42	014 42.02102	72 01.37448	0870
Line 05HV008	20.07.2005	12:18	0243	014 41.68723	72 01.32922	13:38	014 47.00042	71 57.47582	0845
Line 05HV009	20.07.2005	14:11	0225	014 47.51105	71 57.54621	15:31	014 42.17058	72 01.38971	0819
Line 05HV010	20.07.2005		No record						
Line 05HV011	20.07.2005	17:40	0173	014 47.53429	71 57.54709	19:01	014 42.25895	72 01.40269	0782
Line 05HV012	20.07.2005	19:34	0013	014 41.52403	72 01.30114	20:59	014 46.74255	71 57.45173	0653
Line 05HV013	21.07.2005	21:29	0015	014 47.60188	71 57.56540	22:49	014 42.34120	72 01.40977	0621
Line 05HV014b	21.07.2005	23:22	0022	014 41.43294	72 01.29173	00:19	014 45.04439	71 58.64469	0450
Line 05HV014	21.07.2005	07:25	0023	014 41.40136	72 01.29301	08:58	014 46.69026	71 57.43683	0724
Line 05HV015	21.07.2005	09:26	0198	014 47.75816	71 57.57925	10:52	014 42.45963	72 01.42551	0841
Line 05HV016	21.07.2005	11:13	0127	014 41.31380	72 01.27286	12:37	014 46.61065	71 57.42444	0753
Line 05HV017	21.07.2005	12:55	0069	014 47.81504	71 57.58676	14:04	014 42.57603	72 01.44206	0589
Line 05HV018	21.07.2005	14:21	0110	014 41.26169	72 01.26724	15:38	014 46.49920	71 57.42013	0687
Line 05HV019	21.07.2005	15:58	0104	014 47.93845	71 57.60147	17:12	014 42.66387	72 01.45727	0661
Line 05HV020	21.07.2005	17:32	0084	014 41.18572	72 01.25617	18:37	014 46.43133	71 57.40379	0573
Line 05HV021	22.07.2005	19:01	0114	014 48.00314	71 57.60823	20:27	014 42.71914	72 01.46195	0762
Line 05HV022	22.07.2005	20:47	0911	014 41.02148	72 01.23632	22:09	014 46.25703	71 57.40174	1528
Line 05HV023	22.07.2005	22:32	0162	014 48.11203	71 57.62498	23:57	014 42.90615	72 01.45931	0797
Line 05HV024	22.07.2005	00:22	0184	014 40.96997	72 01.22595	01:50	014 46.20175	71 57.37779	0843
Line 05HV025	22.07.2005	02:11	0130	014 48.25624	71 57.64068	03:25	014 42.96529	72 01.48933	0684
Line 05HV026	22.07.2005	03:51	0183	014 40.91883	72 01.21923	05:08	014 46.10797	71 57.35695	0759
Line 05HV027	22.07.2005	05:30	0156	014 48.33041	71 57.65598	06:51	014 43.07378	72 01.48599	0762
Line 05HV028	22.07.2005	07:12	0156	014 40.75064	72 01.19770	08:26	014 46.01833	71 57.34034	0714
Line 05HV029	22.07.2005	08:51	0150	014 48.40582	71 57.66693	10:10	014 43.11808	72 01.52615	0739
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Line 05HV031	22.07.2005	12:13	0119	014 48.51119	71 57.68162	13:25	014 43.26060	72 01.53285	0655
Line 05HV032	22.07.2005	13:51	0124	014 40.61618	72 01.18067	15:06	014 45.81725	71 57.32673	0683
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Line 05HV037	23.07.2005	23:15	0186	014 48.76619	71 57.71152	00:30	014 43.53473	72 01.57054	0755
Line 05HV038	23.07.2005	00:58	0184	014 40.22881	72 01.13203	02:33	014 45.51069	71 57.28240	0899
Line 05HV039	23.07.2005	03:03	0206	014 48.90321	71 57.72863	04:08	014 43.60458	72 01.58182	0693
Line 05HV040	23.07.2005	04:33	0113	014 39.99474	72 01.24534	06:01	014 45.44473	71 57.27854	0771
Line 05HV041	23.07.2005	06:37	0255	014 49.03049	71 57.74917	07:53	014 43.76474	72 01.59873	0827
Line 05HV042	23.07.2005	08:24	0213	014 40.00522	72 01.10746	09:52	014 45.33601	71 57.26194	0876
Line 05HV043	23.07.2005	10:27	0059	014 49.16835	71 57.76856	11:36	014 43.87908	72 01.61930	0577
Line 05HV044	23.07.2005	12:08	0220	014 39.95471	72 01.09334	13:47	014 45.54714	71 57.19372	0964
Line 05HV045	23.07.2005	14:14	0177	014 49.31050	71 57.78276	15:16	014 43.99367	72 01.63063	0643
Line 05HV046	23.07.2005	15:50	0240	014 39.89177	72 01.08695	17:15	014 45.15911	71 57.23276	0877
Line 05HV047	23.07.2005	17:34	0133	014 46.87181	71 57.45884	18:44	014 41.56362	72 01.30476	0660
Line 05HV048	23.07.2005	19:10	0141	014 42.25251	72 01.40267	20:46	014 47.60020	71 57.56855	0859
Line 05HV049	24.07.2005	21:03	0124	014 46.72329	71 57.43980	22:30	014 41.50231	72 01.25539	0781
Line 05HV050	24.07.2005	22:59	0208	014 42.32171	72 01.41165	00:43	014 47.70127	71 57.56997	0993
Line 05HV051	25.07.2005	00:30	0238	014 47.72714	71 57.57389	01:27	014 42.61195	72 01.44393	0669
Line 05HV052	25.07.2005	01:58	0207	014 48.45653	72 00.92993	02:40	014 39.51830	71 59.76069	0519
Line 05HV053	25.07.2005	02:52	0068	014 40.44443	71 59.05801	03:36	014 48.73740	72 00.12695	0398
Line 05HV054	25.07.2005	04:12	0264	014 52.38513	71 57.80388	04:52	014 43.44588	71 56.61190	0568
Line 05HV055	25.07.2005	11:10	0528	014 44.09799	72 01.64551	12:50	014 49.43192	71 57.79805	1278
Line 05HV056	25.07.2005	13:28	0263	014 45.03945	71 57.22174	14:35	014 39.75350	72 01.06662	0764
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Line 05HV058	25.07.2005	17:12	0303	014 44.98401	71 57.20680	18:24	014 39.74322	72 00.99354	0846
Line 05HV059	25.07.2005	19:02	0277	014 44.32304	72 01.67918	20:35	014 49.48484	71 57.87429	0977
Line 05HV060	26.07.2005	21:24	0001	014 44.70262	71 57.24847	22:49	014 39.57156	72 01.04543	0644
Line 05HV061	26.07.2005	23:40	0326	014 44.39062	72 01.68206	01:09	014 49.70964	71 57.84011	0995
Line 05HV062	26.07.2005	01:50	0294	014 44.72309	71 57.17497	03:03	014 39.49371	72 01.03239	0841
Line 05HV063	26.07.2005	03:40	0272	014 44.49369	72 01.70268	04:55	014 49.77914	71 57.84712	0834
Line 05HV064	26.07.2005	05:44	0333	014 44.67608	71 57.17520	07:11	014 39.35485	72 01.02082	0984
Line 05HV065	26.07.2005	08:00	0358	014 44.57814	72 01.70917	09:22	014 49.88013	71 57.85419	0976
Line 05HV066	26.07.2005	10:11	0166	014 44.52766	71 57.15139	11:38	014 39.26145	72 01.00328	0817

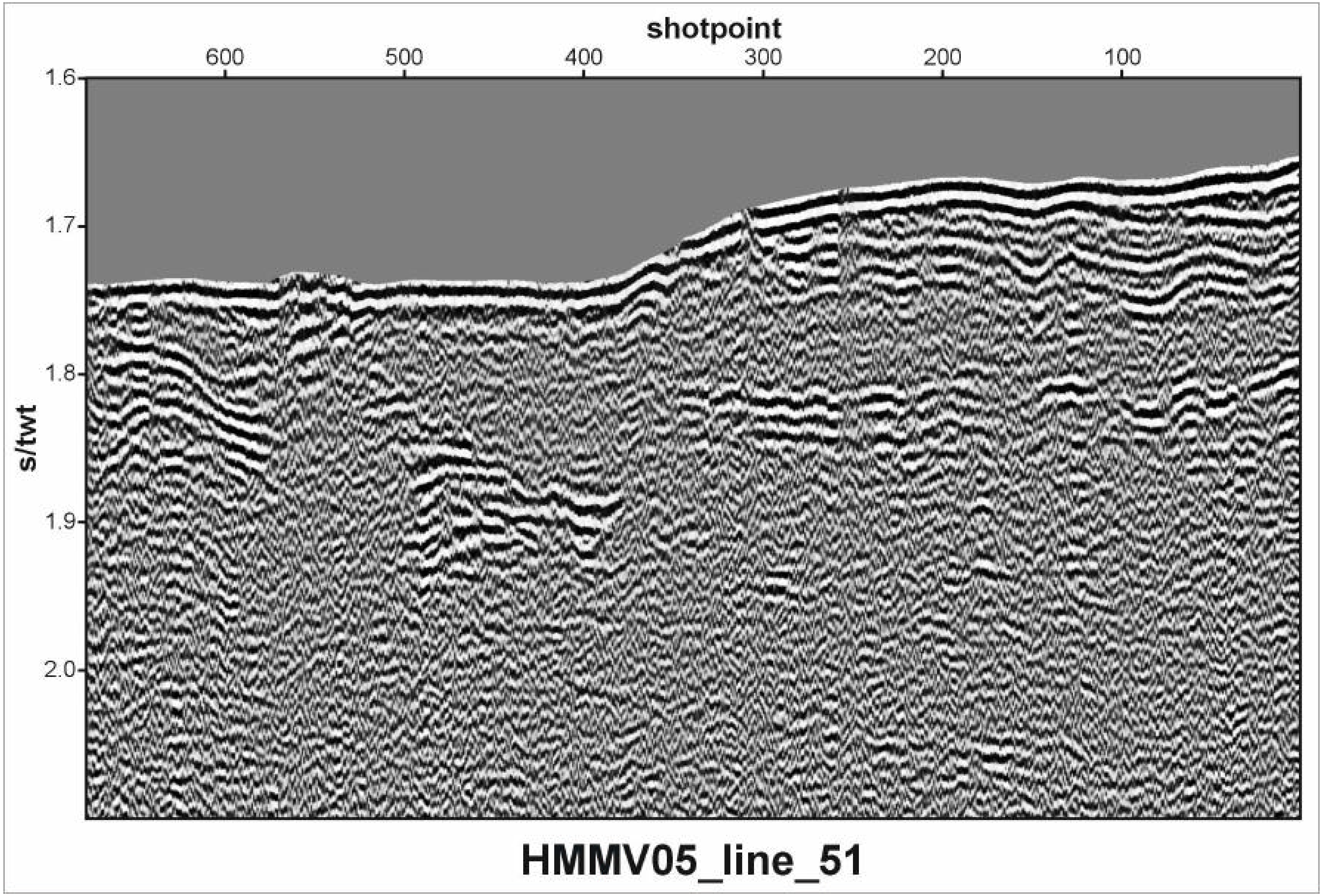
Line 05HV067	26.07.2005	12:27	0083	014 44.72188	72 01.73215	13:50	014 49.97334	71 57.86210	0709
Line 05HV068	26.07.2005	14:37	0337	014 44.44781	71 57.14479	15:51	014 39.16814	72 00.99125	0894
Line 05HV069	26.07.2005	16:31	0260	014 44.83420	72 01.74647	17:46	014 50.06043	71 57.88535	0829
Line 05HV070	26.07.2005	18:42	0403	014 44.37866	71 57.13329	20:20	014 39.10964	72 00.97852	1133
Line 05HV071	27.07.2005	21:03	0021	014 44.88078	72 01.74982	22:24	014 50.05553	71 57.95794	0628
Line 05HV072	27.07.2005	23:08	0308	014 45.41702	71 57.27058	00:37	014 39.71082	72 01.05786	0973
Line 05HV073	27.07.2005	01:10	0180	014 41.89063	72 01.35182	02:24	014 47.30429	71 57.52198	0739

Table 2: Station list of seismic profiles with date, time (UTC), shot points, and positions. Note location time is given (-2h = UTC!). The ship speed used was 2.5 - 3 knt during seismic profiling.

APPENDIX

OBS seismic lines 51- 54

(see also Figure 5b and Tab 2 for locations)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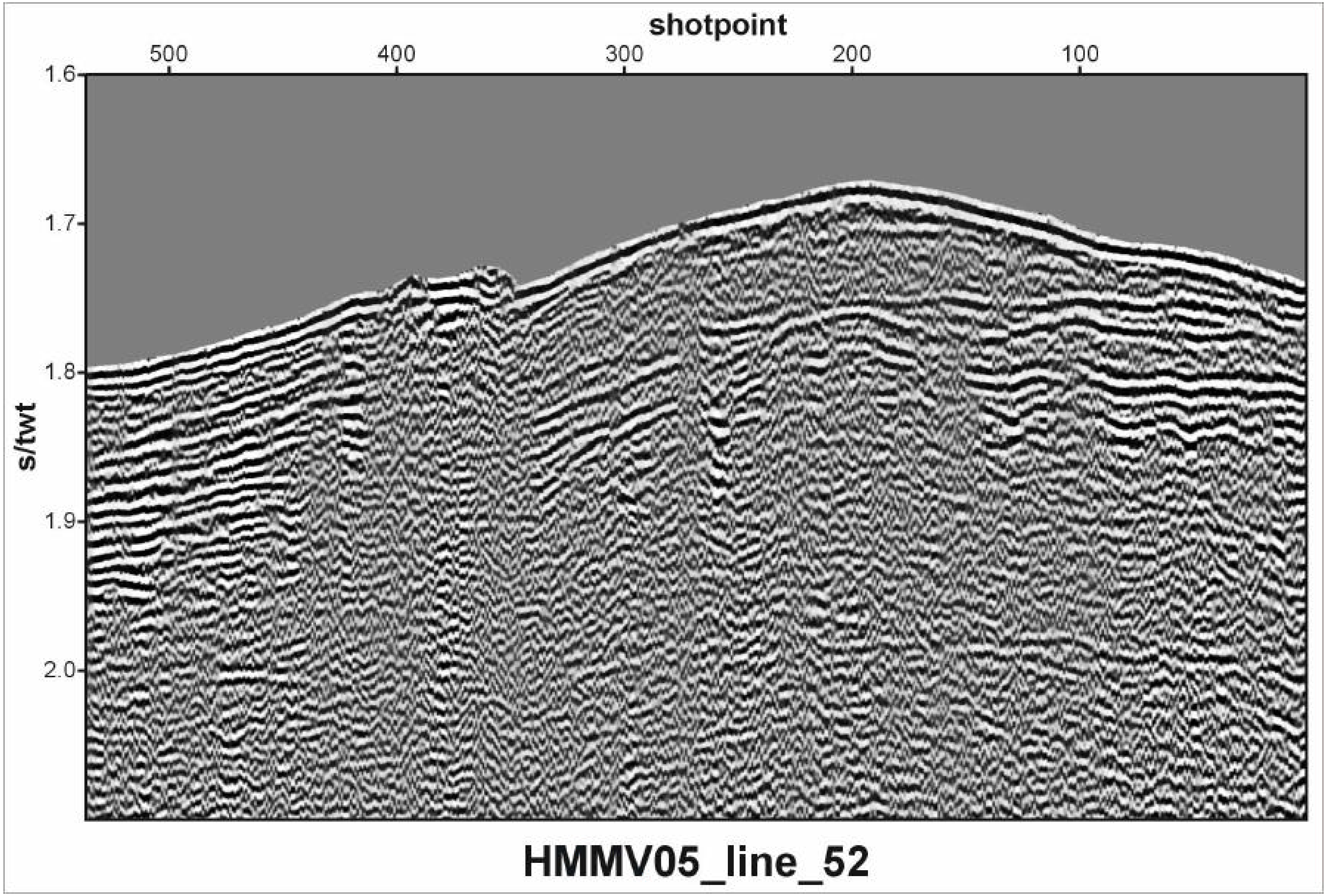
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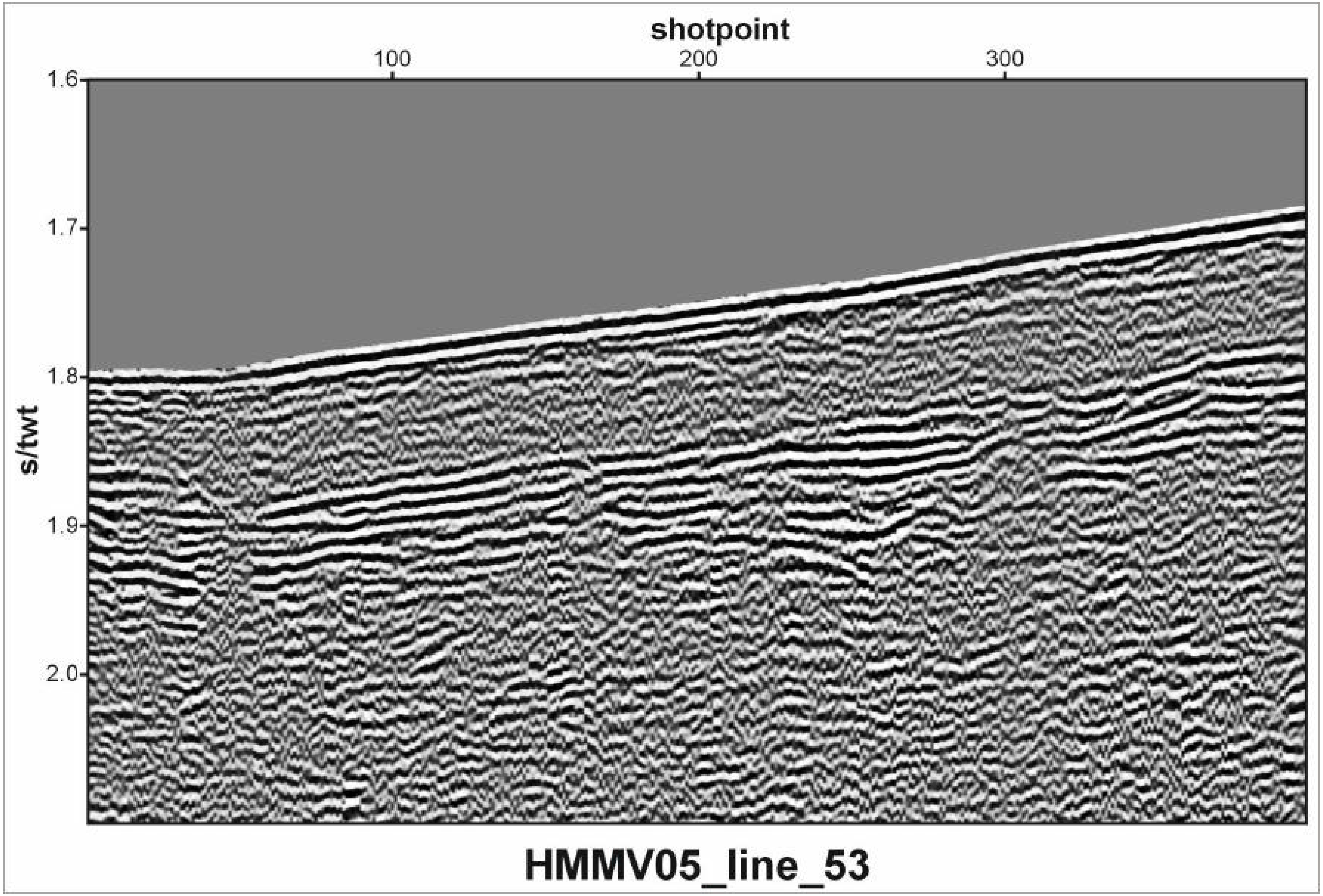
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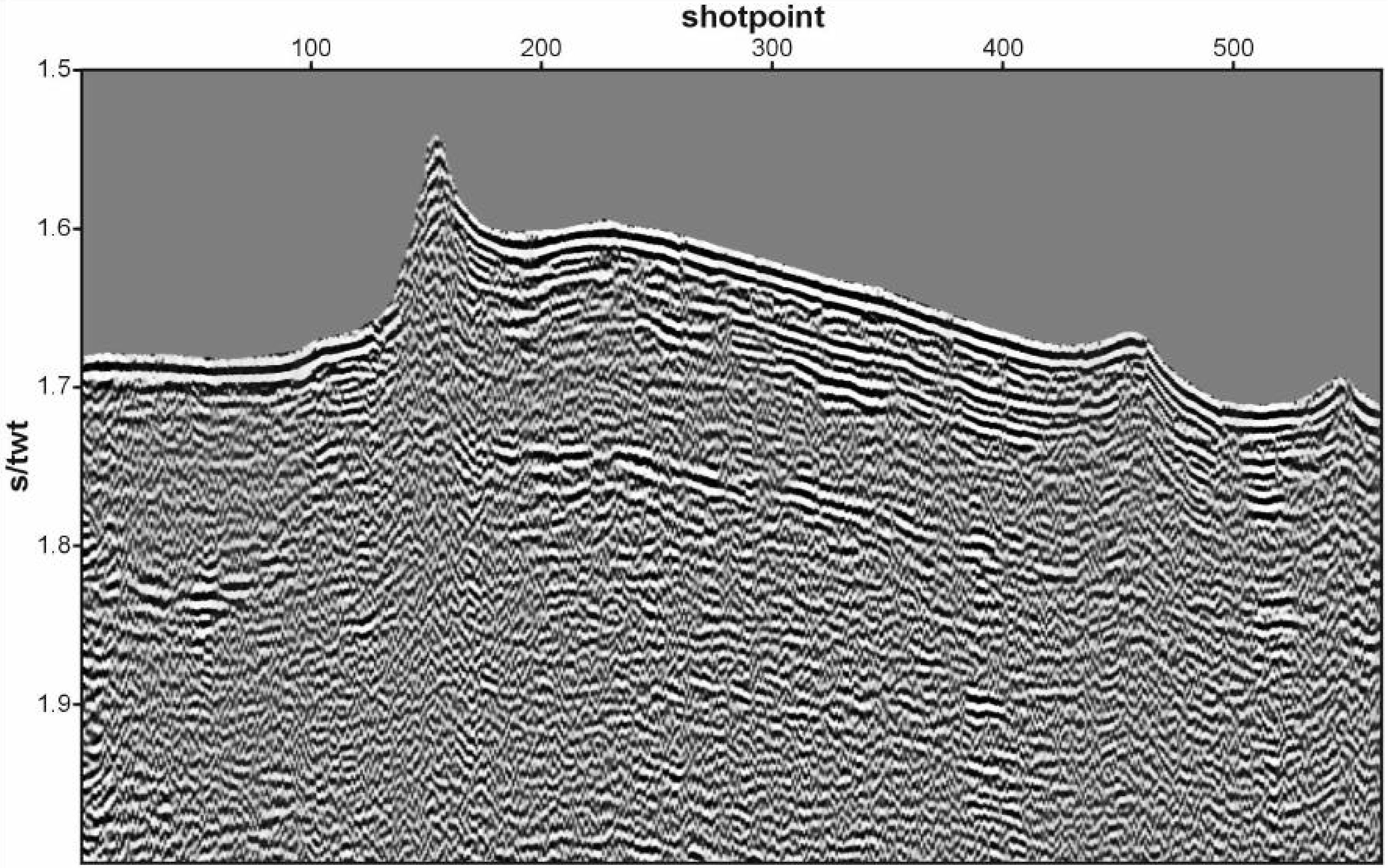

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