AL460 - Report

Track

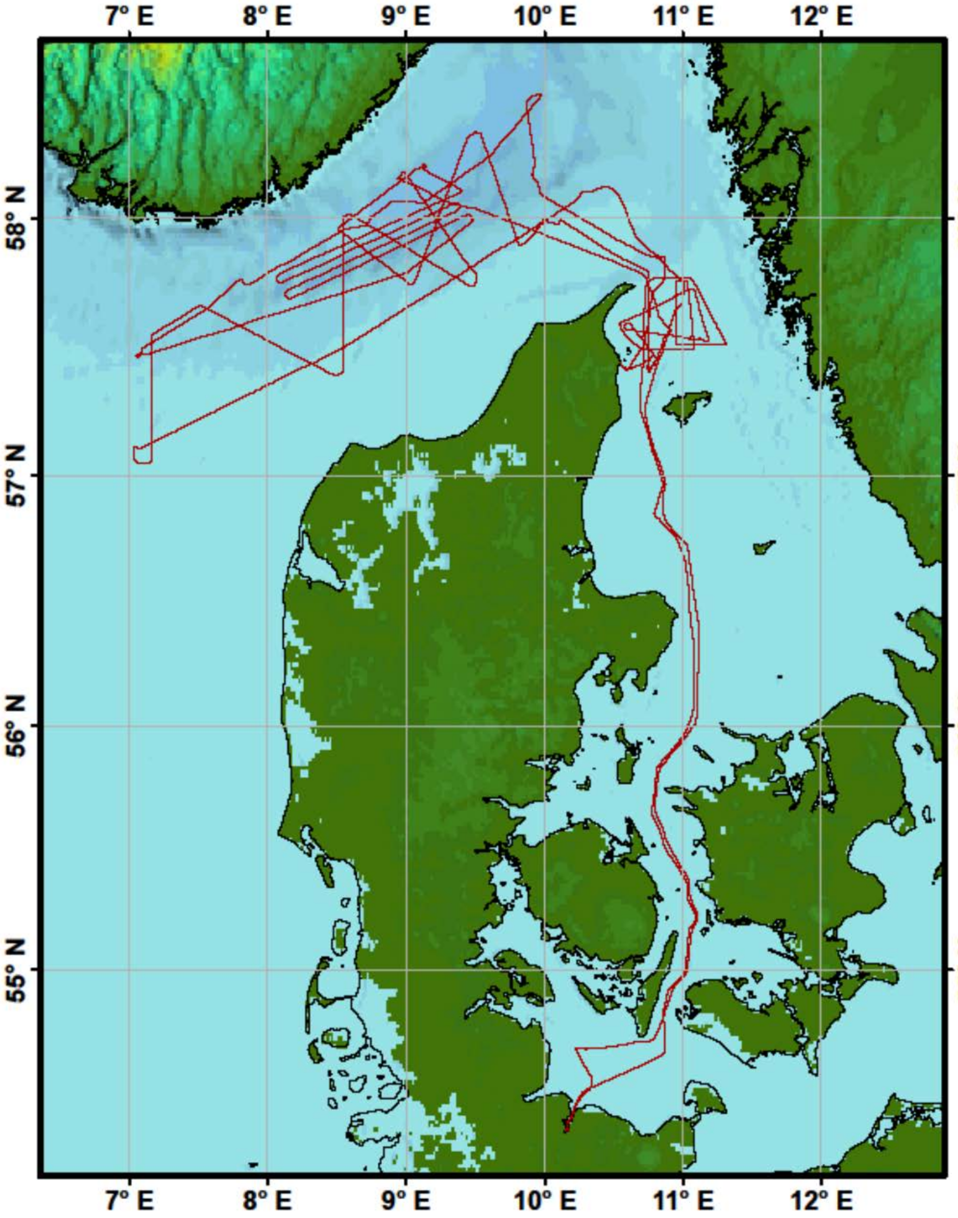


Figure 1. Cruise track AL460

The red line in Fig. 1 shows the entire cruise track (13.7.-27.7.2015), starting and ending in Kiel with a short interruption for participant exchange in Frederikshaven on July 20.

Participants

Name	**Leg1 (13.7.-20.7.)**	**Leg2 (20.7.-27.7.)**
Prof. Dr. Christian Hübscher	X	X
Sven Winter	X	X
Joachim Bülow	X	
Henrik Grob		X
Line Winslow (Denmark)	X	
Anne Mette Simonsen (Denmark)		X
Julia Gestrich	X	X
Kevin Hank	X	
Nina Hinze		X
Isabell Hochfeld	X	
Merlin Hüsing (beide?)		X
Tabea Rebekka Kilchling		X
Paul Neumann	X	
Robert-Louis Neurath	X	X
Jonas Preine	X	X
Johanna Tröndle	X	
Noah Trumpik		X
Daniel Holger Uhle	X	X

Geological Setting

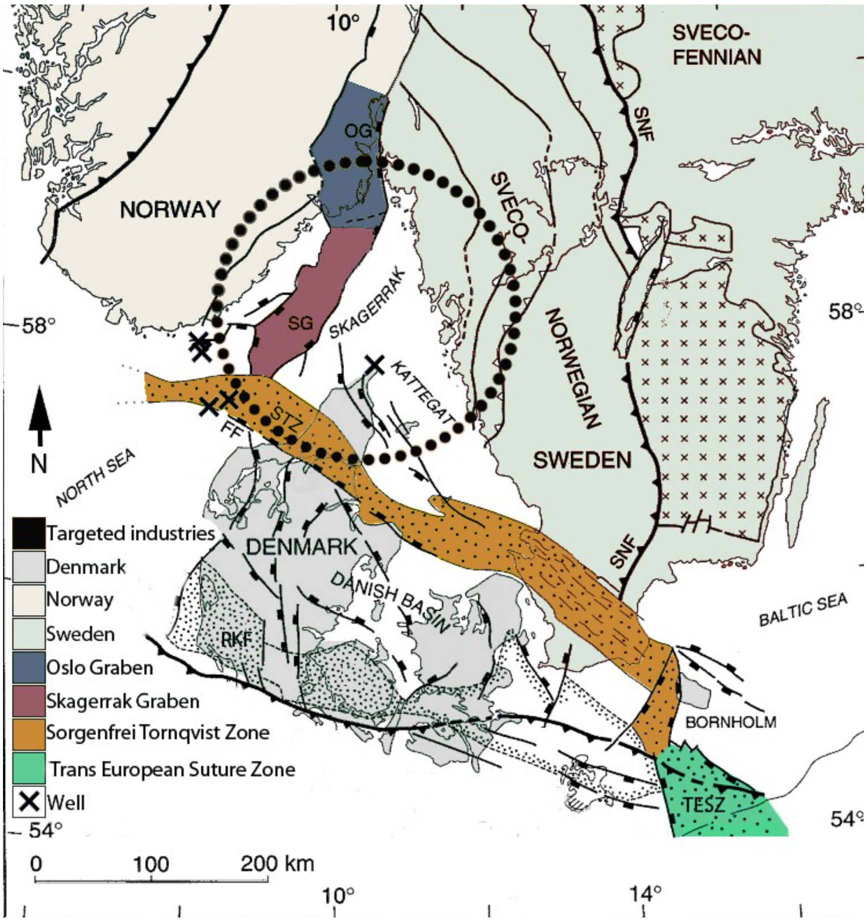


Figure 2. Tectonic map of southern Scandinavia. Several geological features are highlighted, including the Danish Basin, the Sorgenfrei-Tornquist Zone, the Skagerrak Graben and the Oslo Graben, noted with STZ, SG and OG respectively. The Fjerristslev Fault, (FF) delimits the Fjerristslev Fault Zone from the Danish Basin, the FFZ can be considered a continuation of the STZ). Taken from Weibull (2012).

Introduction

Pockmarks are small crater like structures, leaking fluids on the sea floor and are influenced by the geological succession of Skagerrak as well as contourites of the sea. Skagerrak pockmarks have been described earlier by Bøe Reidulv, et al. (1998) whose interest was to investigate the morphology and evolution of the Pockmarks in the Norwegian Trench of Skagerrak. Followed by an investigation of Leif Rise, et al. (1999) who published his work on fluid migrations of the Pockmarks. For both papers echo sounder data were used for the investigation, and first in 2003, Hübscher and Borowski (2005) published their work that reflected on seismic evidence of the fluid escape in the Skagerrak.

For the ALKOR AL460 cruise, the pockmarks of Skagerrak are investigated by multi-channel seismics and parametric echo sounder data. The particualar goal was to image sub-seafloor fluid/gas migration pathes und to understand the controlling factors. Beside that, it was intended to further understand the evolution of the

Holocene contourite that emerged along the lower slope of Jutland. The working program in the northern Kattegat was designed to understand fluid and gas migration that led to the formation of spectacular submarine features called "Bubbling reefs", as the cemented structures attract colourful animals and plants. Gravity data have been further collected throughout the survey and magnetic data along a single profile.

Skagerrak

The Skagerrak Graben is part of the Norwegian Trench and is located between Norway and Jutland (Denmark). The graben marks the boundary between the crystalline and metamorphic basement of Norway and the Pleistocene sand of northern Denmark (von Haugwitz & Wong, 1993). Extending NE – SW and NW-SE (Fig.2), which lies between two parallel trending faults in an asymmetric trench. The trench has a maximum depth reaching to more than 700m (Bøe, et al., 1998; Weibull, 2012). The northwestern flank of the depression rises from the bottom to over 1000 meters above sea level in the Norwegian Highland, while the opposing slope in the southeast as well as along the Swedish coast to the east are more gently inclined (von Haugwitz & Wong, 1993). Toward the southwest, north of Lønstrup Cliff of Jutland, the gently inclined coast is suddenly disrupted by a steep sloped escarpment separating the deep trench with a higher lying platform (Bøe et al., 1998; Weibull, 2012).

The Skagerrak area was uplifted during Late Silurian due to formation of the Caledonian Orogeny, which resulted in an erosion causing the Paleozoic sequence to be removed. Followed by a normal faulting in the Late Carboniferous due to a reactivation of the Sorgenfrei – Tornquist zone. This formed the Variscian mountain range, causing an opening of the Skagerrak Graben and the northern Oslo Graben (Weibull, 2012). In late Permian deep subsidence occurred in the Skagerrak Graben where, among others, the Zechstein were deposited, followed by a deposit of sandstone and mudstone during Early Triassic and Early Cretaceous. The Mesozoic strata is missing on land, but subcrop in the 120 km wide waterway and are separated by an angular unconformity of crystalline basement (von Haugwitz & Wong, 1993) and was later deformed by salt tectonics of Zechstein in the southwestern part of Skagerrak. Quaternary sediments rest unconformably on the Mesozoic sequence as the Cenozoic sequence was either removed due to Fennoscandian uplift of the Late Mesozoic or due to glacial erosion (von Haugwitz & Wong, 1993; Weibull, 2012). It was believed that Skagerrak was a fjord like structure during Weichselian glacial period, connecting the Norwegian Channel with the Atlantic Ocean, while the North Sea was dry and exposed to subaerial erosion (von Haugwitz & Wong, 1993). The glaciers retreated from Denmark and Germany during Late Weichselian providing meltwater streams draining into Skagerrak, forming a thick wedge of Pleistocene deposits across the southeastern slopes of Skagerrak. As the sea level rose to 60 meters below present sea level about 7800 years B.P., the North Sea was flooded transiting Skagerrak to a full marine condition, increasing the sediment input that were transported from the south along the European coastline and into Skagerrak (von Haugwitz & Wong, 1993). During the Early Holocene, the sediments were deposited at the western side of the Skagerrak Graben, but are lately deposited on the eastern side possible due to high velocity current eroding the shallow area of western Skagerrak (von Haugwitz & Wong, 1993).

Contourites

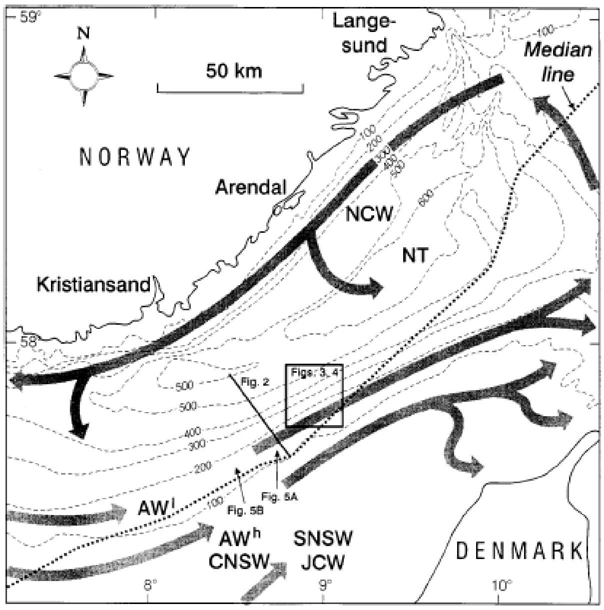


Figure 3. Bathymetry in meters and general circulation pattern of subsurface water masses in the Skagerrak. Aw^h, Atlantic water high (shallow) and Aw^l, Atlantic water low (deep) together constitute the Atlantic Current. *CNSW*=Central North Sea water (Central North Sea Current); *JCW*=Jutland Coastal water (Jutland Current); *NCW*=Norwegian Coastal water (Norwegian Coastal Current); *SNSW*=Southern North Sea water (Southern North Sea Current); *NT*=Norwegian Trench (Bøe et al., 1998).

The influx of sediments of the Skagerrak from the Atlantic Ocean and the North Sea are results of volumetric currents. The Atlantic current transports about $1km^3/s$ of high saline waters into the Skagerrak by two separate currents (Fig.3, Bøe et al., 1998).One current along the 150 m bottom contour and another current along the 70m bottom contour. The depth of the inflows increases during extreme meterological and oceanographic conditions (Bøe et al., 1998)and the anticlockwise circulation of Skagerrak is due to the southwestern influx. The influx creates sand waves, which trend parallel with the contours in an ESE-WNW direction. Sand waves occur over most of the plateau toward the south of the Norwegian trench in water depths down to ca. 270 meters (Bøe et al., 1998). The sand waves are more expressed in shallower water, where the waves length are typically in the order of 300-400 meters with an amplitude of 3-4 meters(Bøe et al., 1998). At the same time there are sedimentary gravity slides, north of the southern trench and are developed due to the deep inclined slopes (Bøe et al., 1998). The mix between the gravity sliding sediments and the sand waves develops contourites.

Pockmarks

On the southern edge of the Norwegian Trench, there is a high density of elongated depressions, at the edge of the southwestern escarpment (fig. 4). These depressions strike 40°-45° of the long axis, occur in areas of Holocene sediments, and are possible influenced by sand waves (Bøe et al., 1998; Hübscher & Borowski, 2006), similar depression also occur north of the escarpment in the deep parts of the Skagerrak Graben along grooves (fig. 5). These grooves represent ploughmarks which formed from the glaciers during Weichselian (Rise et al., 1999). These depressions are identified as Pockmarks, which forms in soft sediments of the sea floor, as circular crater like structures. They are attributes to seepage of fluids such as gas or liquid from underlying bedrock and sediments (Bøe et al., 1998; Rise et al., 1999). The upward migration of these fluids are controlled by overpressure and buoyancy (Hübscher & Borowski, 2006).

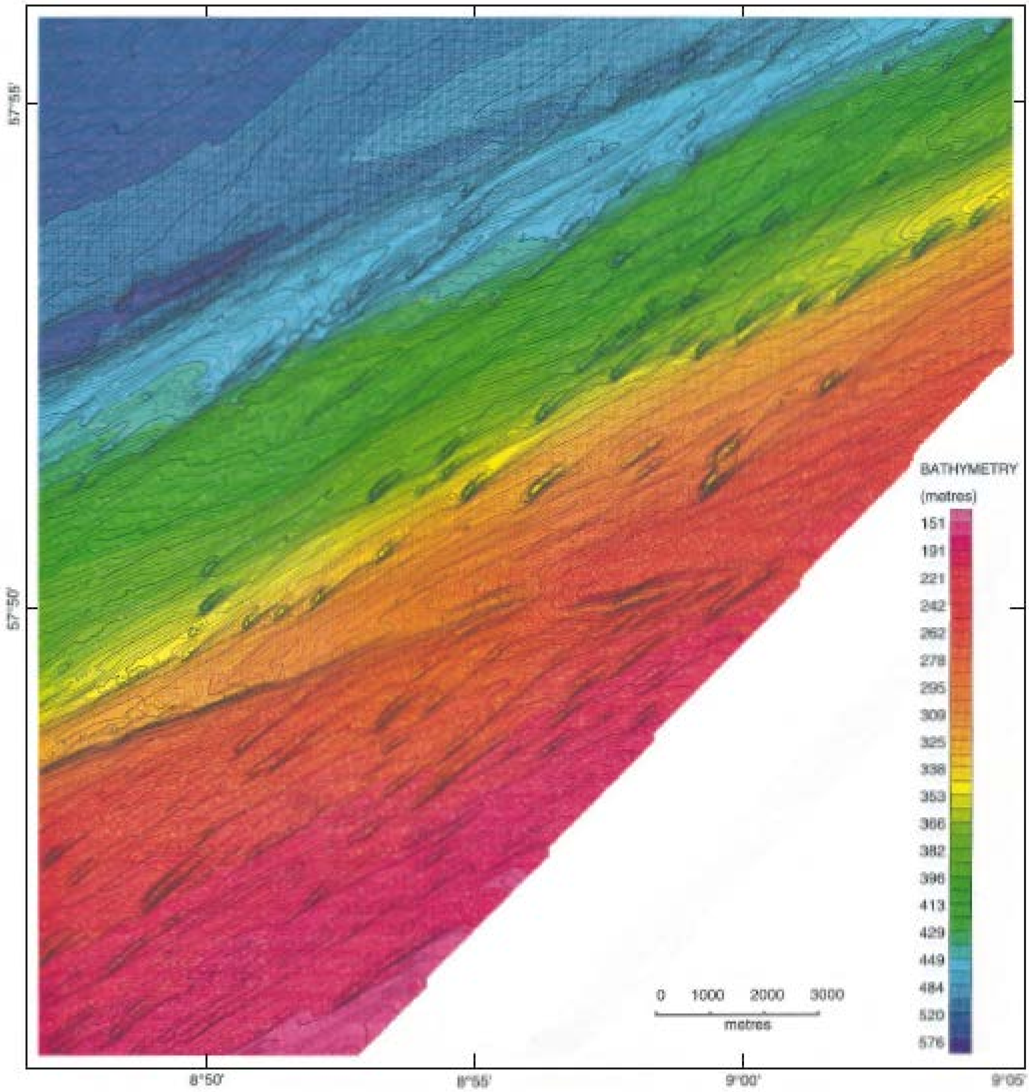


Figure 4. Detailed bathymetric map compiled from multibeam echosounder (Simrad EM 100) data. Note the ENE-trending escarpment across the central part of the figure, the NE- to ENE-trending sand waves south of the escarpment and the linear rows of depressions north of the escarpment (Bøe et al., 1998).

Pockmarks are mostly reported from areas of hydrocarbon generations and accumulations such as the North Sea, however Pockmarks have also been noticed on shelfs of the Norwegian Trench of Skagerrak (Bøe et al., 1998; Hübscher & Borowski, 2006; Rise et al., 1999; Fig. 6). The gases responsible for the formation of Pockmarks are mainly petrogenic or thermogenic origins, such as methane and pore water with carbon dioxide and small amount of other gases (Bøe et al., 1998; Hübscher & Borowski, 2006; Rise et al., 1999). These gases are released along permeable

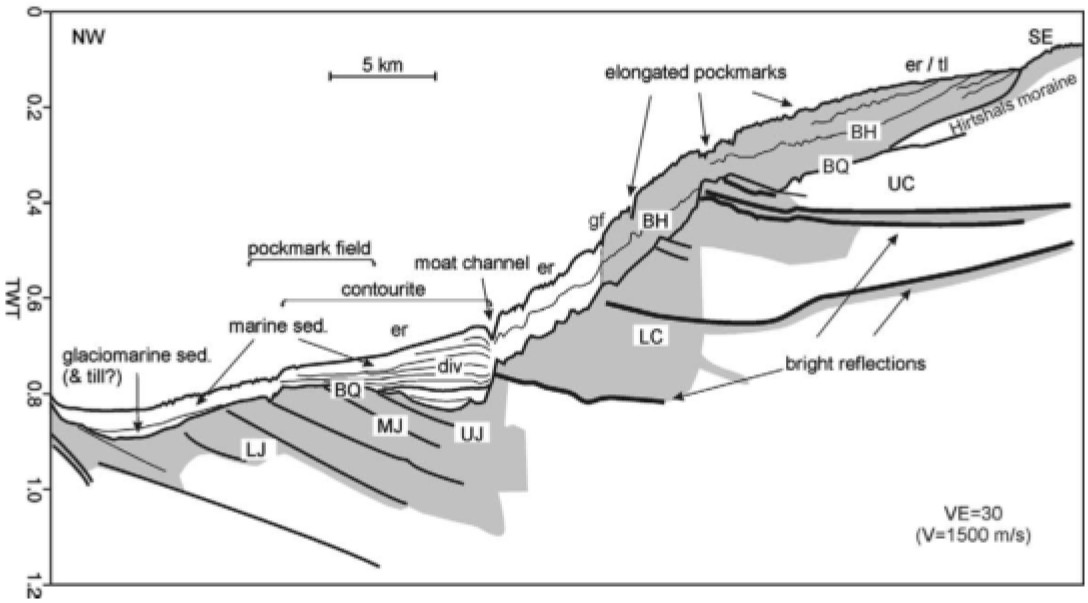


Figure 5.This profile shows the overall structure of the southern slope and center of the Norwegian Trench. The Quaternary succession overlies the Mesozoic topography. Outcropping bright reflections from within the Mesozoic strata correlate with elongated pockmarks on the sea floor Shaded areas mark acoustic turbidity. Div: divergent reflections; er: erosion; gf: gas front; tl; toplap; BH: base Holocene; BQ: base Quaternary; LJ: Lower Jurassic; MJ: Middle Jurassic; UJ: Upper Jurassic; LC: Lower Cretaceous; UC: Upper Cretaceous; VE: vertical exaggeration. Redrawn from Hübscher & Borowski (2006).

Mesozoic strata, while other pockmarks correspond to bedrock faults, which are conductive to gas migration from deeper formations (Hübscher & Borowski, 2006).

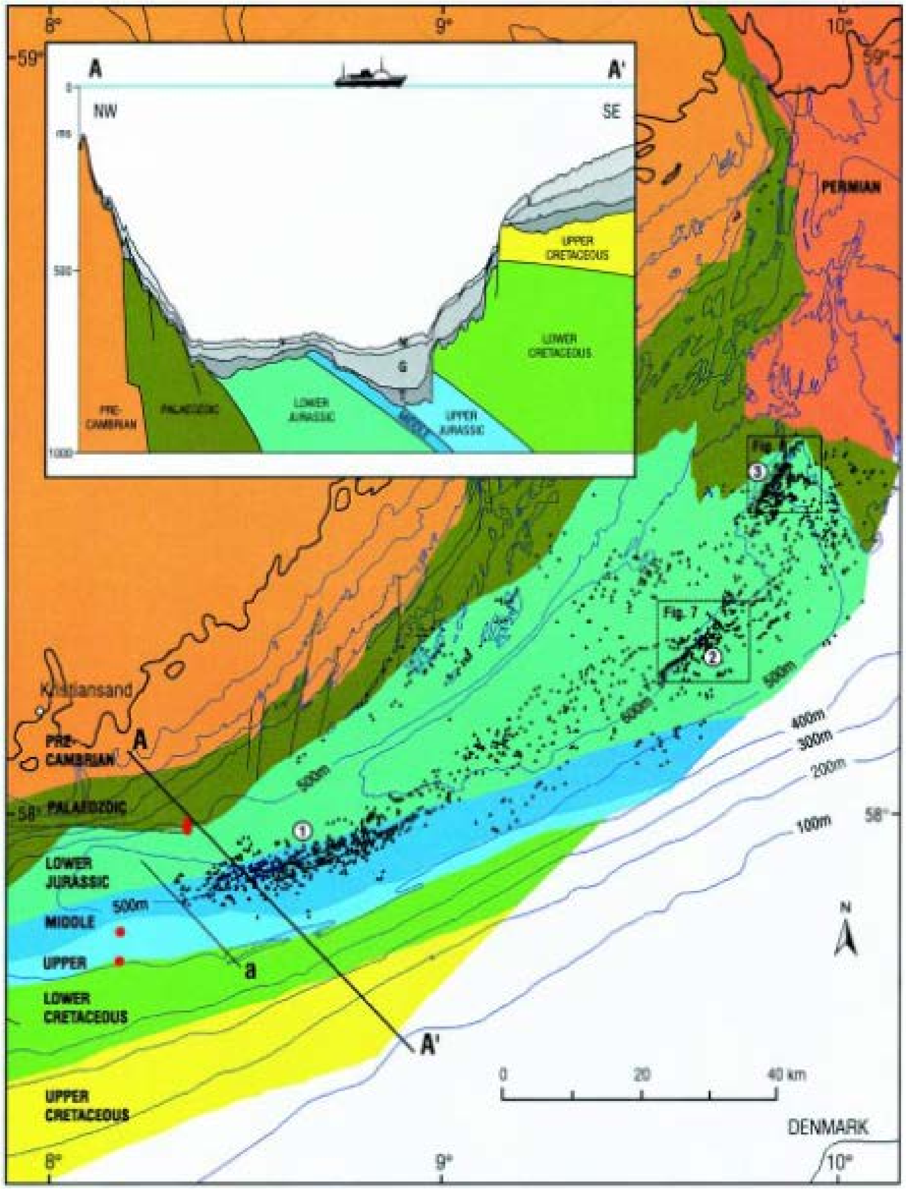


Figure 6. Bedrock map and geological profile across the Norwegian Trench. In the geological profile: T, till; G, glaciomarine sediments; M, marine sediments. The black dots represents pockmarks in the deep parts of the Norwegian Trench, and show that pockmarks origins arrive beneath glacial deposits. Modified from Rise et al. (1999). **Note: The stratigraphy contradicts the stratigraphy published by Pedersen et al. (2008). According to these authors Triassic strata crop out beneath the pockmarks in the central trench!**

Well data

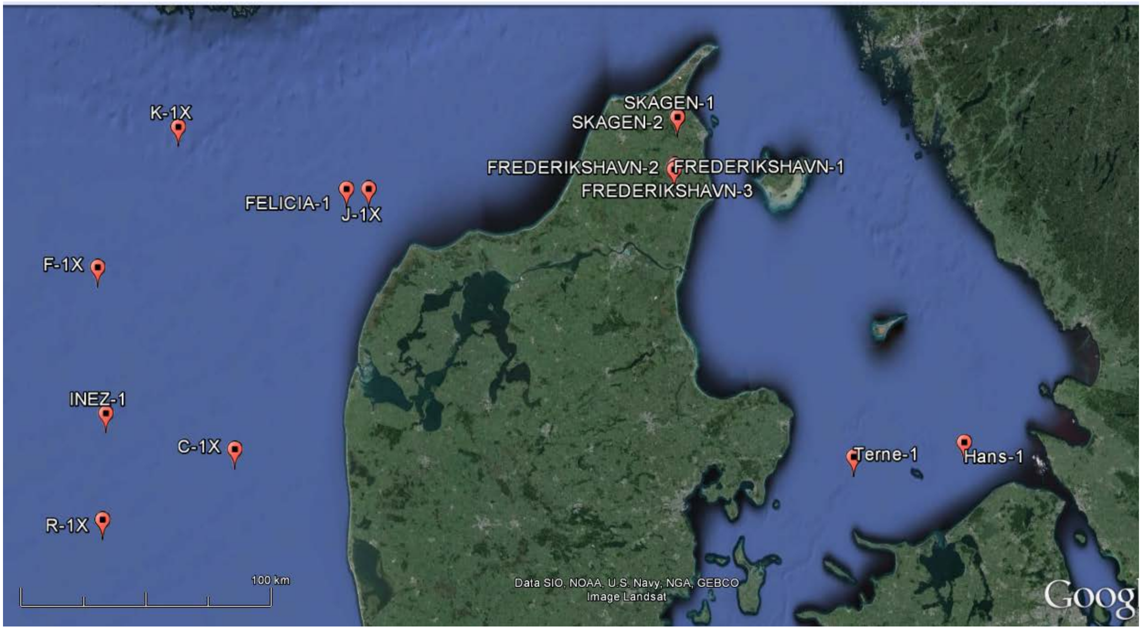


Figure 7. Location of the wells in the North Sea, Skagerrak, northern Jutland and Kattegat. The wells are described below from West toward East, and are mapped here on Google Earth. The wells are of GEUS database.

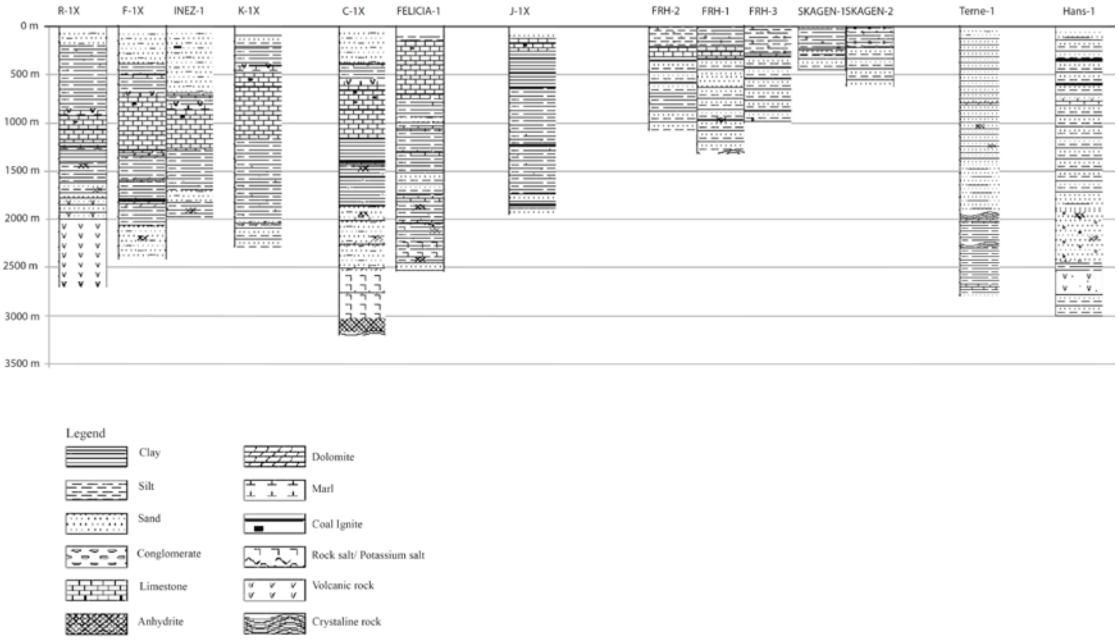


Figure 8. Well stratigraphy in Skagerak and Kattegat.

The well cores R-1X to J-1X all lie off of the western coast of Jutland, Denmark, while C-1X, FELICIA-1 and J-1X lie slightly north of Jutland. Frederikshavn 2, 1, and 3 and Skagen 1 and 2 wells lie on the eastern coast of Jutland, and Terne-1 and Hans-1 lie off of the eastcoast of Jutland (Figs. 7 and 8).

Wells off of the westcoast of Jutland have similar stratigraphy, with dominant sand, silt and clay deposits, but shallows inward toward the coast. The wells between R-1X and C-1X all show volcanic deposits on the top of the limestone. The top of the limestone lies at a depth of 800 meters of the well R-1X but is shallows inward to a depth of about 300 meters of well J-1X and Frederikshavn wells. The top of the limestone is not visible in either wells of Skagen-1 and -2,Terne-1 and Hans-1. The thickness of the limestone also thins toward the east, from a thickness of about 500-800 meters to less than 300 meters and non existing of well cores Skagen-1 and -2,Terne-1 and Hans-1. Beneath the limestone layer all wells consist mainly of sand, sill and clay with a few wells with coal ignite. Well R-1X show indication of volcanic deposits at a depth of 2000 meters, which is only reflected in well Hans-1 at a depth 2500 meters. Well C-1X show deposits of anhydrite at a depth of about 3000 meter followed by a deposit of marl at depth 2500 meters. While Terne-1 is the only well with indication of crystaline rock at a depth of 2000 meters and 2250 meters and a deep deposit of limestone at a depth of 2750 meters.

Bubbling reefs in the northern Kattegat

The phenomenon of gas seeping from the seafloor has attracted increasing interest, generally occurring in many shallow seas. Of special interest to this study, the area of Kattegat has for several years been location for investigations of gas seeps as the gas is assumed to develop bacterial activity on the seafloor and have an impact on local marine environments. The gas seepage is associated with methane-derived carbonate structures widespread on the seafloor and surrounded by gas seepage (Jørgensen, 1992). Thus, it may be concluded that gas charged fine-grained deposits in the Kattegat and Skagerrak area were pushed to shallower localities by Scandinavian glaciers during the last - Weichselian - ice age. In near coastal areas these deposits are now covered by sand that allow the gas to escape to the sea-floor before it is consumed by methanothrop s.This spectacular submarine landscape is called “Bubbling reefs” as the cemented structured attract colourful animals and plants (Jensen et al., 1992). Shallow seismic methods make it possible to extract data on gas seep occurrences in order to map the phenomenon in the Skagerak-northern Kattegat region (Laier & Jensen, 2007).

Near-surface, gas charged deposits are related to glacial tectonic processes during the last glacial period; Wechselian. The gas originates from muddy organic-rich marine deposits of Pleistocene age, which were pushed to near vertical position as a consequence of the advance of glaciers. The following migration and subsequent accumulation of gas is found in basins and depressions of thick fine-grained sandy sediments of Holocene age formed by glaciers, ice-streams or melt-water (Laier & Jensen, 2007).

The glacio-tectonic conditions allow gas to migrate through the Holocene porous sandy sediments, which is related to methane-derived carbonate cemented structures observed on the seafloor. The structures are often observed in association with surrounding gas seepage (Jensen et al, 1992). The sandstone structures occur as individual slabs or as thin pavements of 10-30 cm thickness (Jørgensen, 1989) Individual slabs can be in the shape of pillars of 4 m height. It is believed that the carbonate structures originate from the anoxic sediment layers. Precipitation of carbonates by methane-oxidation, lithifies the sediment along gas channels in gas-charged sediment. The gas channels are filled by cementation of the sediment, which forms the pillar structures (Fig. 8). The pillars grow in size as further sediment is cemented on the outside. Erosion of the surrounding unconsolidated sediment exposes the cemented structures on the seafloor, which might have been an effect of post-glacial isostatic uplift (Jensen et al., 1992).

Figure 8. Artists view of “bubbling reefs” (Laier, 2003).

The gas seepages are found as single holes or groups of holes, and are detected as pockmarks in seismic investigations. These reveal a migration of gas from the gas-charged deposits, forming plumes in the sediment above. The bacterial induced gas was formed in Eemian and early Weichselian marine material (Jensen et al., 1992). The gas seepage originates from a shallow gas field extending from northeast Jutland into the Kattegat area (Jørgensen, 1989; Jørgensen 1992). The shallow gas field was formed in Late Pleistocene age (Jensen et al., 1992).

The relationship between the two phenomenons was documented by using stable carbon isotopic analysis, which could infer the carbonate structures being formed by methane oxidation at shallow depths. The carbonate cement is compiled of high-Mg calcite, dolomite and aragonite where High-Mg Calcite acts as intergranular cement in the structures. This is the most frequent found carbonate solid phase. The High-Mg Calcite and Aragonite are primarily associated with lithified horizontal pavements and individual slabs but can also be found in the in the cement of the vertical sandstone pillars (Jensen et al, 1992).

Instruments

Gravimetry

For the gravimetric survey on the cruise we use the KSS31M Sea-Gravimeter system which consists of coupled sub-systems (Fig. 10). The heart of the system is the GSS 31M sensor. It is based on a spring-mass system which is being held at a constant temperature to reduce the instrumental drift to a value lower than 3 mGal/month. The gravity sensor is located on a gyro stabilized platform which provides a continuous compensation for earth rotation, ship's speed, accelerations and heading errors. The measurements are supervised by a control system. The gravimetry recording system consists of the Dual Pen Recorder the PC terminal (Fig. 11). The Dual Pen Recorder as the name suggests uses two pens to document gravimetric data. The blue line shows the gravity graph in time and the red line the local acceleration.

On the PC terminal one finds several windows. The Plotter is the electronic equivalent to the blue pen on the Dual Pen Recorder. It allows quick illustration of the gravimetric data on variable scales in time. The Navigation Record Data window shows gravity, time and all needed navigation parameters. The recording window displays recorded data in real time and the Data record indicates if data is being recorded or not. To verify plausible data the gravimetric value and the coordinates have to be written down each half an hour. The gravimetric back up system (3) records every 5 seconds gravimetric data to text files. To ensure maximum reliability the text file needs to be closed at 8 am every day.

Magnetics

SeaSPY marine magnetometer (longitudinal gradiometer) is used for the magnetic survey on the cruise. The Overhauser sensors measure the ambient magnetic field using a specialized branch of nuclear Magnetic Resonance technology, applied specifically to hydrogen nuclei (SeaSPY Technical Application Guide rev1.4, 2007). This technology allows the sensor to have an accuracy of up to 0.2 nT and a noise level of 0.01 nT.

he magnetics terminal is displayed by a laptop connected to a separate monitor (4). It shows the total intensity of the magnetic field measured by the magnetometers as well as the gradient between the units. The results are plotted as multiple graphs in real time on a variable scale. To acquire a complete dataset all the figures below the graphs need to be grey (Fig. 12).

Sediment Echo Sounder

The Sediment Echo Sounder uses sound waves to display uppermost layers of the sea floor. The frequency of the emitted rays were 6 kHz. This means we have a very short wavelength so a high resolution of the upper sediment layers . The Transmitter is hull mounted. A motion sensor ensures pitch, roll and heave compensation. This Echo Sounder system stores the reflections of the sea floor on a hard drive. The data is tied to current location data. In order to capture the data properly the scale has to be set manually according to the sea depth (Fig. 13).

Reflection Seismics

The seismic source on this cruise is a single GI-Gun. The GI-Gun is towed in a depth of 2.5 m between the ship and the seismic streamer. It creates the seismic signal which interacts with subsurface structures. The seismic signal is then captured by the hydrophones in the streamer. The GI-Gun is controlled by a SureShot system, which we cover later on in this document. The layout of the streamer system is shown in Fig. 14. On this cruise we use a digital streamer. This means that the digitizing happens in the streamer itself by designated digitizing modules. The streamer on this cruise is the Hydroscience Technologies SeaMUX 144-channel array with an active length of 600 m. This streamer configuration utilizes seven SeaMUX 24 channel 24 bit digitizing modules which are distributed symmetrically throughout the streamer length. The sample rate is 1 ms and the whole recording length is 6 s. The digitized data is then transported by a wire system to the recording system (Fig. 15).

The PC terminal (Fig. 16) which receives data from the streamer shows single shot sections for each fired GI-Gun shot as well as the shot count and other parameters to judge acquisition quality. Seismic data is stored as SEG-D and SEG-Y file-format.

The depth of the streamer was controlled by 4 cable levelers, so called “birds”. Their main purpose is to maintain the streamer at a certain depth. The desired depth of the streamer on this cruise was 3-4 m. The Birds are controlled by a PC (Fig. 17) which is connected via a Streamer Interface Unit Modem. The software we use on the cruise is Geospace Navigator which displays all needed parameters and lets us steer the Birds to adapt a new depth according to events.

As a back-up system we tested a 64 channel and 200m long analog solid state streamer . It is filled by a solid material opposing to a fluid like in the digital streamer. A/D converting and recording was done by means of so called Geodes (Fig. 18).

The SureShot displays near field signal of each GI-Gun shot and it is used to keep the source signal at a specific time line (Fig. 19). One can change Injector delay to reduce bubble effect.

Figure 10. KSS31M Sea-Gravimeter system.

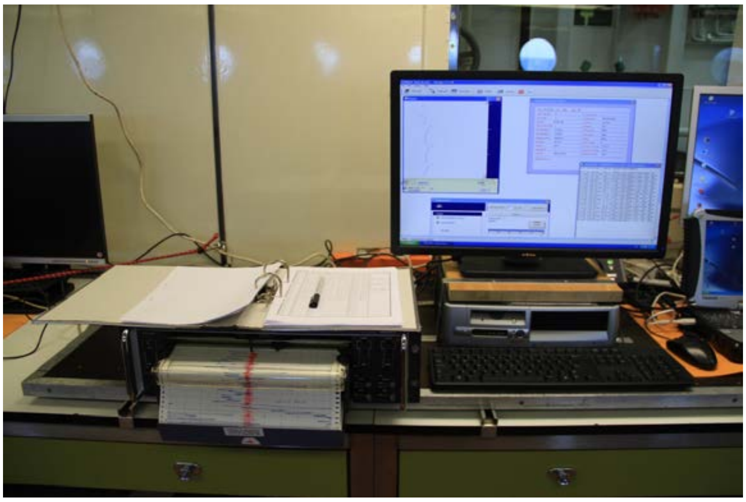


Figure 11. Pen plotter and terminal of gravimeter system.

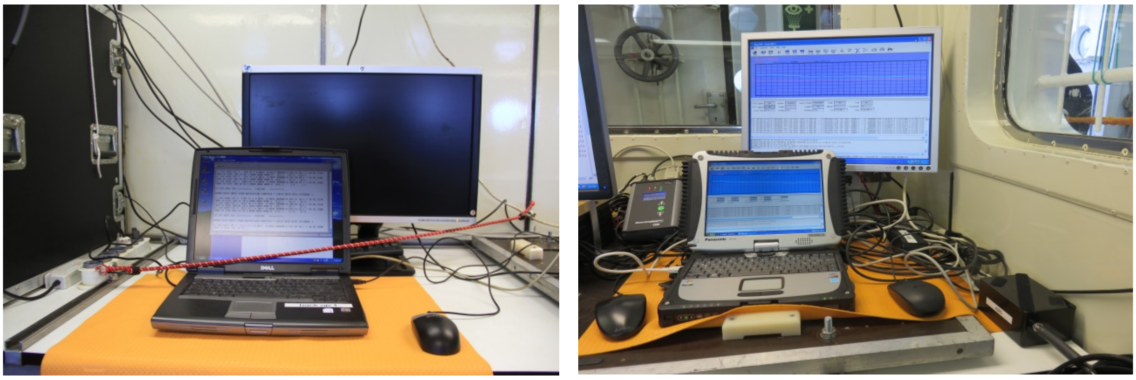


Figure 12. Terminals for SeaSPY magnetometer.

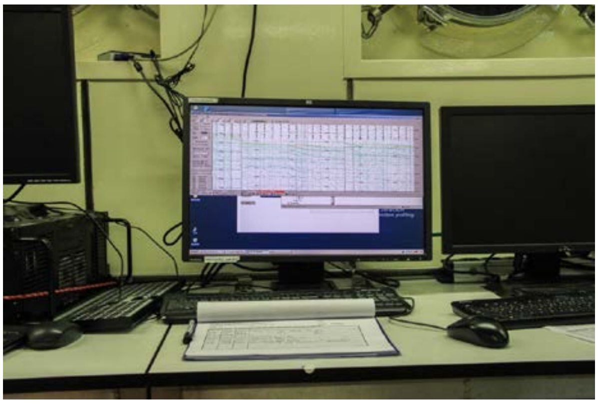


Figure 13. SES2000 echosounder display.

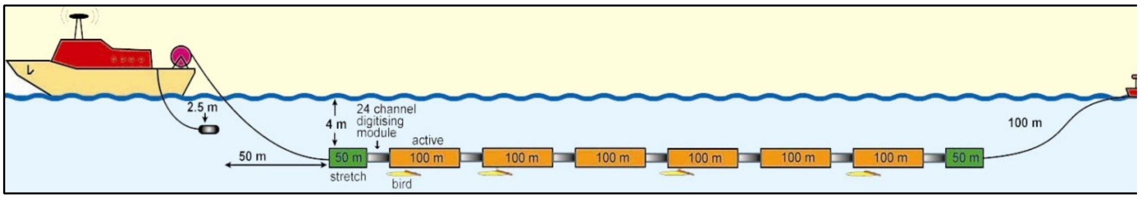


Figure 14. Design of digital seismic streamer.

Figure 15. SeaMux recording system (rack, front view).

Figure 16. SeaMux terminal system.

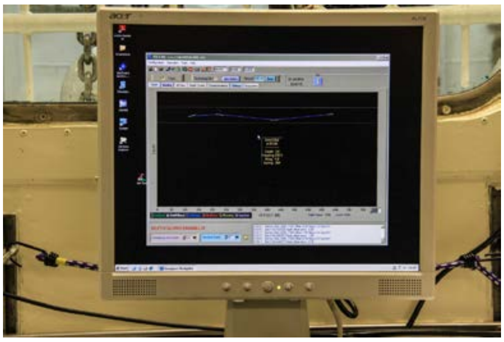


Figure 17. Screen showing depths of individual cable levelers (birds),

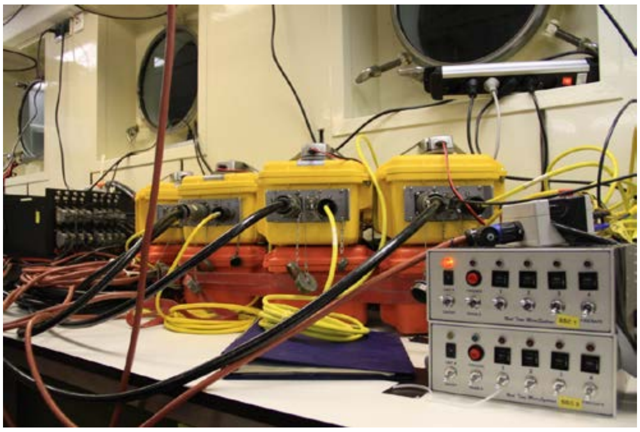


Figure 18. Geode A/D converters (yellow) and battery packs (orange). Metallic boxes (front right) are part of the trigger system.

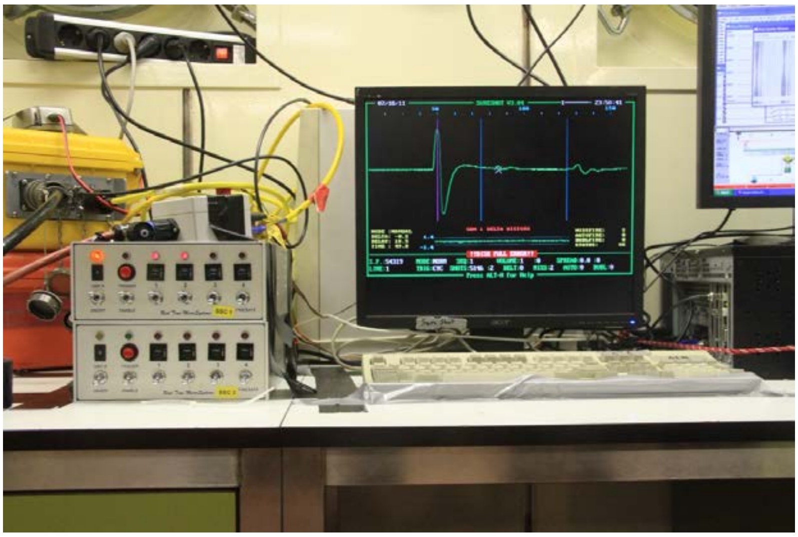
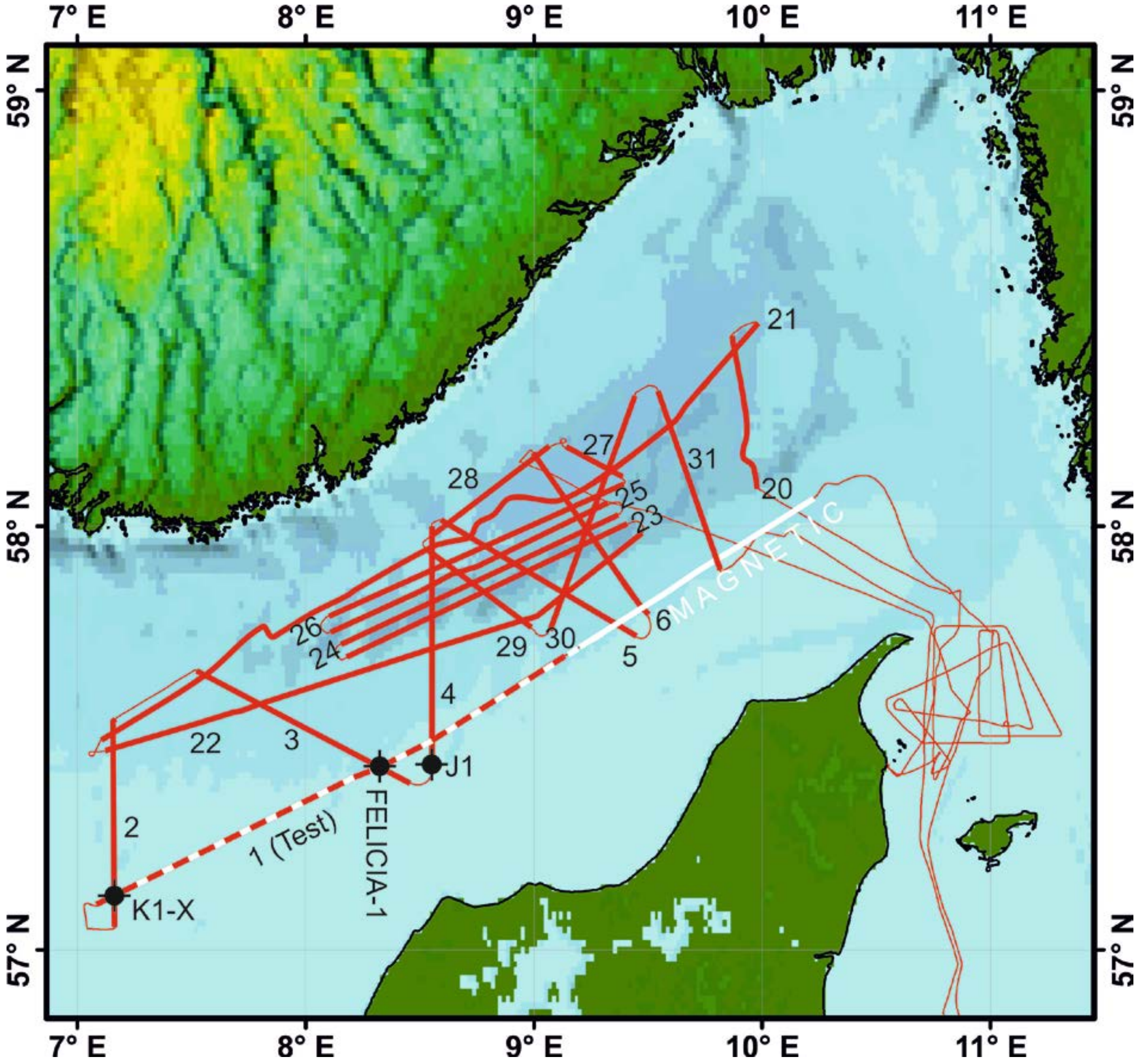


Figure 19. Trigger system.

Survey

The following basemaps show the seismic and magnetic profiles in the Skagerrak (Fig. 20) and Kattegat (Fig. 21).

Fig. 21. Basemap from Skagerrak. K1-X, J1 and FEKLICICA-1 are wells.



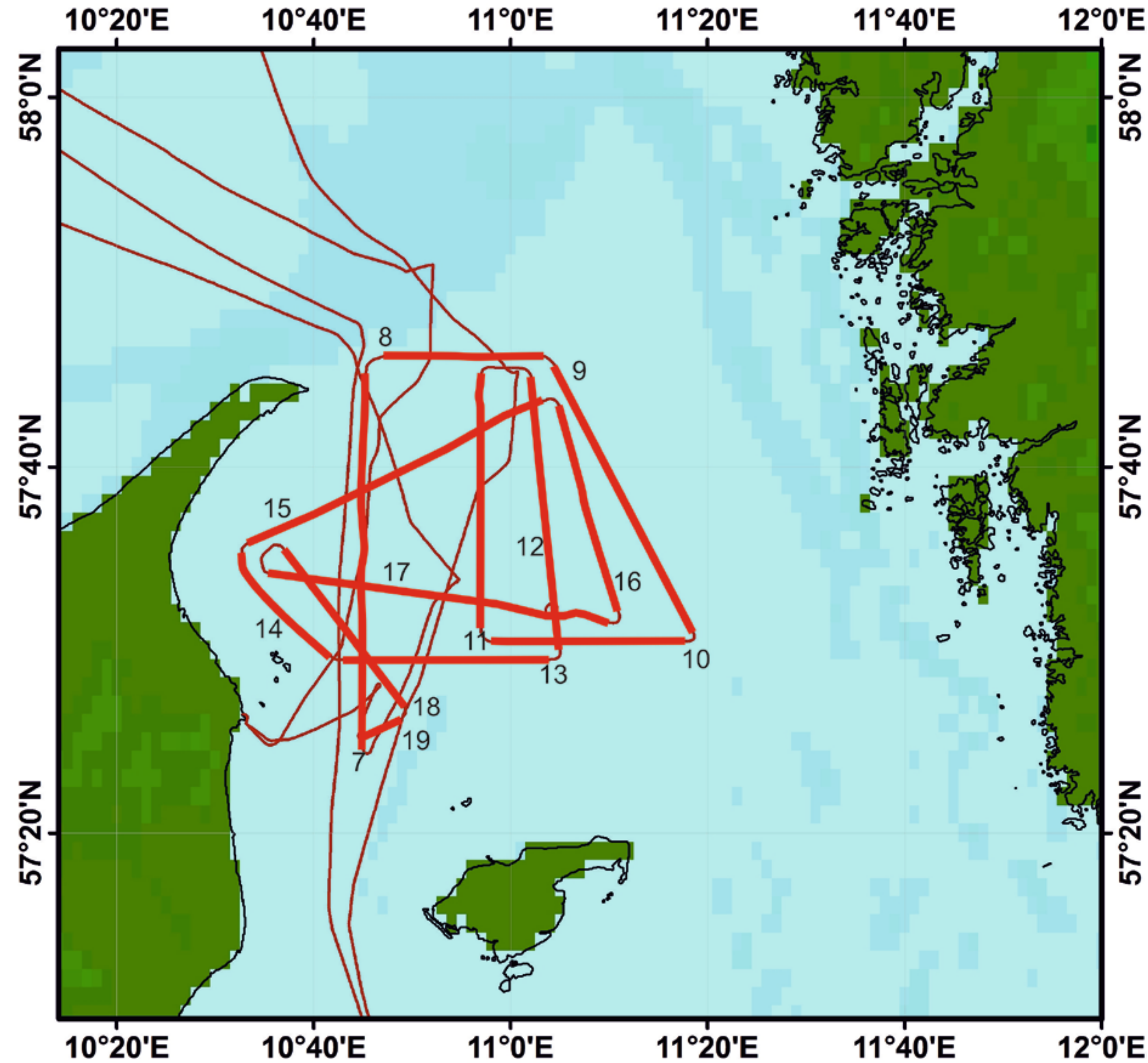


Fig. 22. Basemap from Kattegat.

Data examples and preliminary interpretation

In the Albaek Bay we focused on the two topics ‘glaciotectonic’ and ‘methane escape’. Fig. 22 strikes N-S and is about 5km long. The sea floor represents an erosional unconformity. Seismic data reveal ramps and flats forming a branching thrust-fault imbricate fan. This is a typical glaciotectonic feature created by bulldozering underlying strata by advancing ice sheets (for a summary of glaciotectonics see Pedersen 2004).

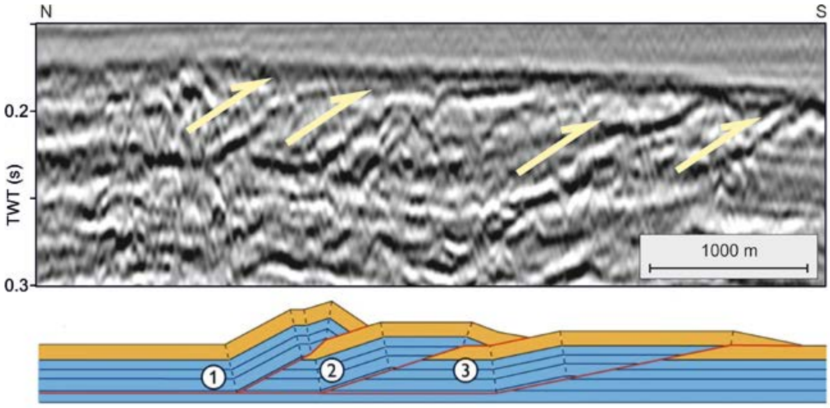


Fig. 22. Seismic profile (top) from Albaek Bay showing ramps and flats forming a branching thrust-fault imbricate fan. This is a typical glaciotectonic feature created by bulldozering underlying strata by advancing ice sheets. Conceptual sketch (bottom) from Pedersen (2004).

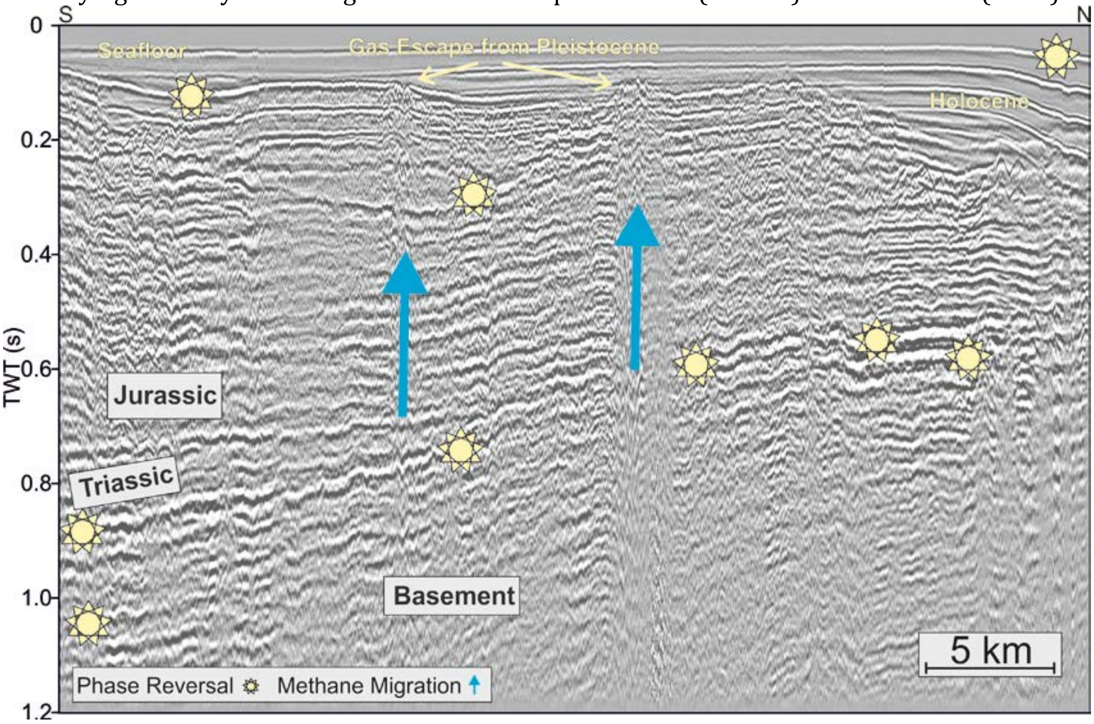


Fig. 23. Seismic profile from Albaek Bay showing phase reversals at the sea floor reflection, bas Holocene mud, and lower Triassic. Note the shown data are a brute stack and that later data processing will significantly improve data quality.

Phase reversals, a classical indicator for velocity inversion due to gas charging, are abundant in the Kattegat. The seafloor reflection in the seismic section of Fig. 23 reveals phase reversal towards the north due to an increasing thickness and consequently increasing biogenic gas content of the Holocene mud (note the strong multiples masking the internal Holocene). Two areas of the “bubbling reefs” have been crossed. The escaping gas creates chaotic reflections on the base of the Holocene mud. The stratigraphy of the Mesozoic strata can be derived from the Frederikshaven-1 well. Phase reversals can be observed in the lower Triassic as well, suggesting thermogenic hydrocarbon. Later refined data processing will help to discuss possible gas migration from Mesozoic reservoirs towards the sea floor.

A seismic section from the Jutland shelf into the Skagerrak trench is shown in Fig. 24. The sea floor on the shelf is characterized by sediment waves and pockmarks. A relatively straight, sometimes interrupted and phase reversed reflection separates the upslope migrating sediment waves from horizontal and parallel strata beneath. Cretaceous strata subcropping beneath a plastered drift that evolved on the slope reveal cuesta type topography. Several intra-Cretaceous reflections are phase reversed. On the lower slope the plastered drift is underlain by a sediment accumulation interpreted as till. A moat channel separates the plastered drift from an elongated, lenticular mounded drift. Pockmarks are abundant above Jurassic strata in the central trench. The Jurassic is characterized by disrupted, partly chaotic reflections. The Triassic reveals parallel to sub-parallel reflections.

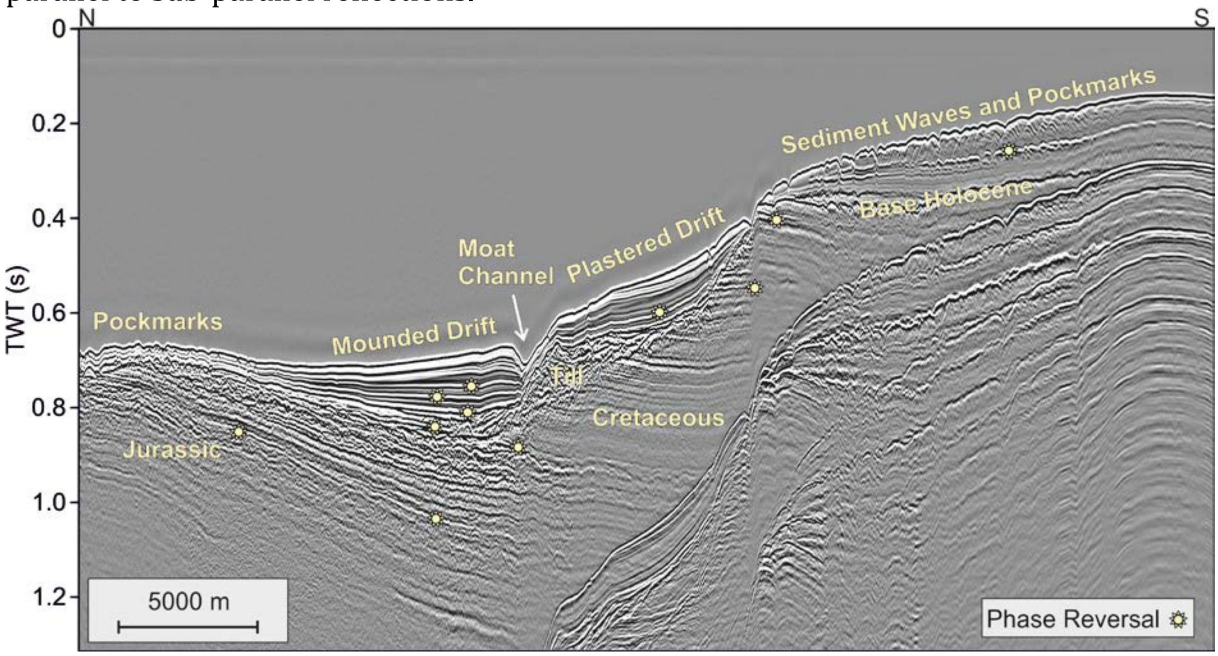


Fig. 24. Seismic section from Jutland shelf into the trench. See text for discussion.

A seismic line along the Norwegian trench covers the Holocene deposits overlying the glacial erosional unconformity, the Triassic succession and the faulted Paleozoic basement (Fig. 25). The subparallel Triassic strata are blurred NE of a fault that cuts through the Triassic and Paleozoic. A sea floor pockmark is present above the projected piercing point of the fault. The top Paleozoic reflection has a peculiar long period and high amplitude. Thrust faults a phase reversed (SW end of section). Above, Triassic strata are masked by curved reflections. The data reveal several reflection patterns typical of gas charged strata, such as the blurred reflections, the masking, phase reversals and pockmark. One may speculate that gas migrates upwards along faults within the Paleozoic basement, and across the stratigraphic orientation of the Jurassic.

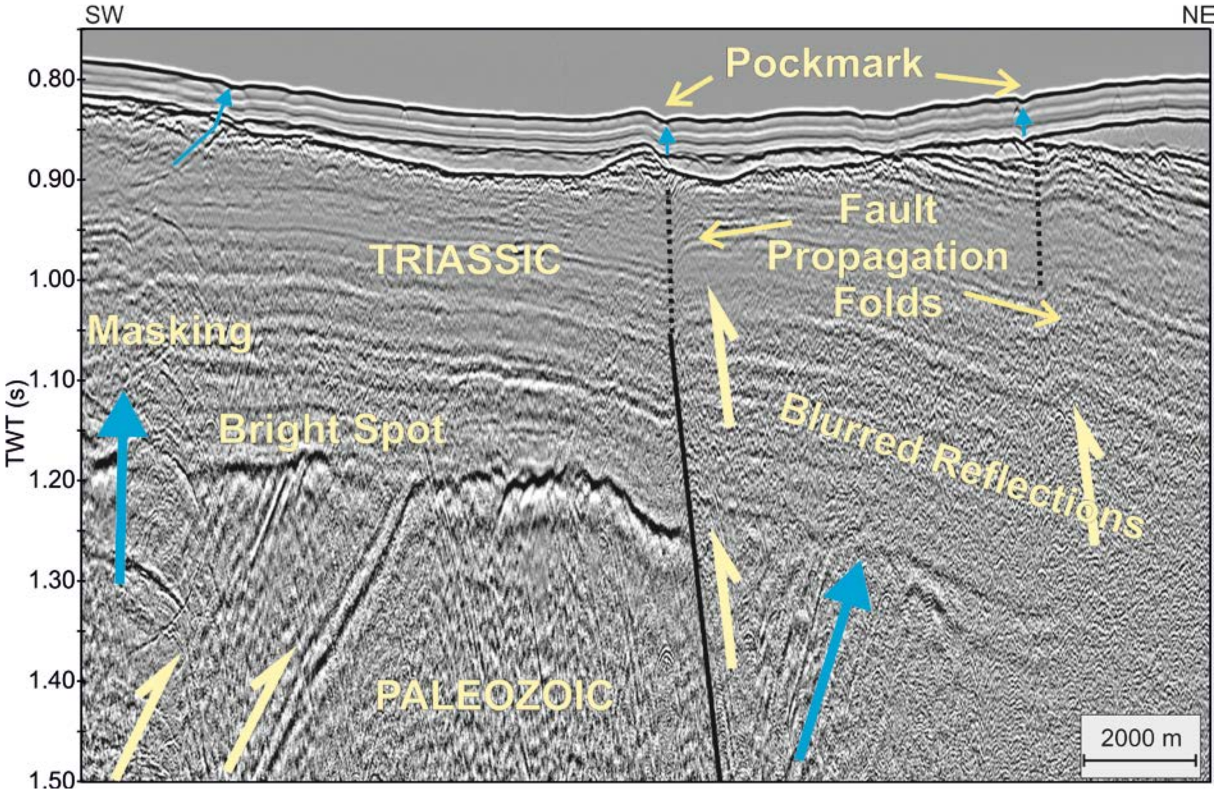


Fig. 25. Seismic section from central Norwegian Trench. See text for discussion.

A second and similar example is shown in Fig. 26. Here, the Jurassic underlies the Holocene, uppermost strata. Beneath the south-westwards outcropping Jurassic strata a phase reversed reflection pinpoints an impermeable gas barrier. Again, blurred reflections and strong arcuate reflections indicate upwards directed fluid migration across the stratigraphic layering.

The fluid pathways are peculiar. We can just speculate that the load of the ice sheets during the glacials greats faults and cracks which act as the pathways. This hypothesis is supported by faults that pierce the seafloor, an example is shown in Fig. 27.

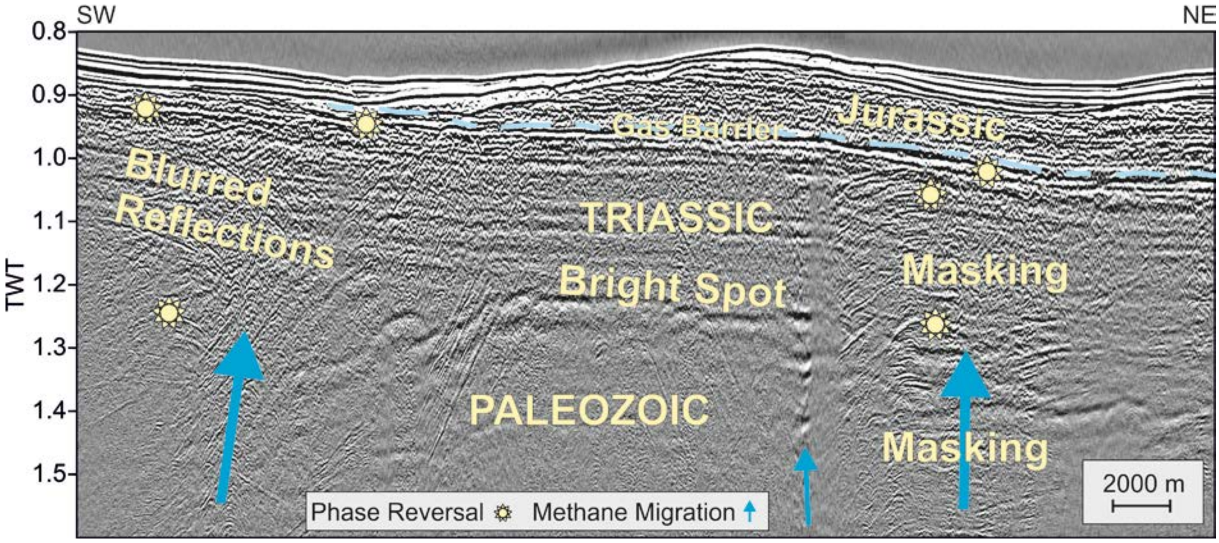


Fig. 26. Gas loading at the Triassic-Jurassic boundary.

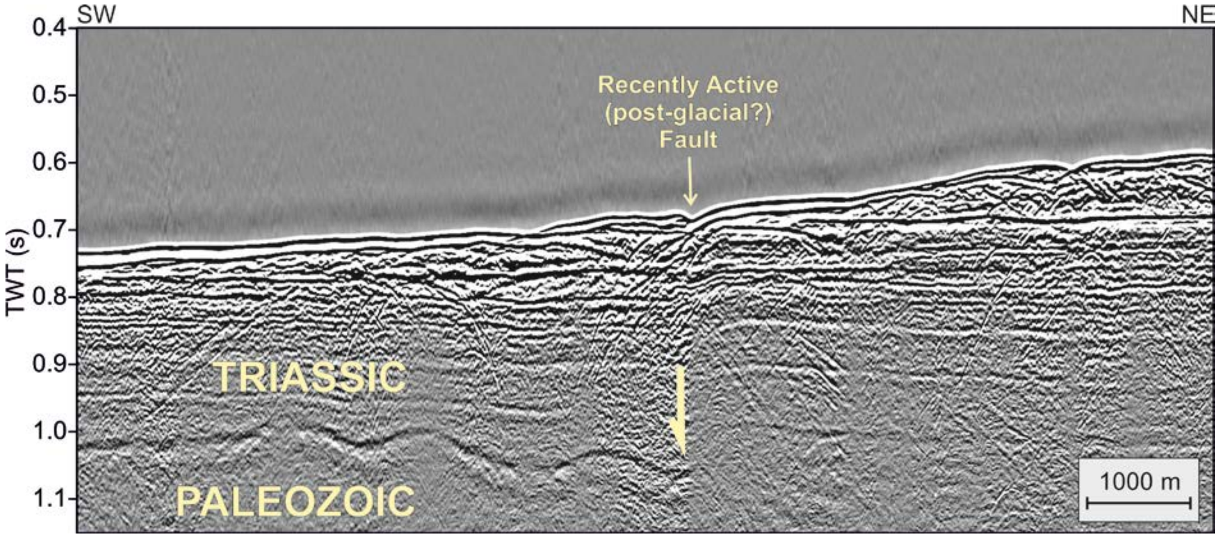


Fig. 27. Seismic section showing a recently active fault that pierces the sea floor.

Outlook

The preliminary interpretations are based on so-called brutstacks. Refined data processing and mapping of relevant features will allow for testing the following scientific hypotheses:

Fluids escape from Mesozoic strata.

More specific:

Fluids migrate along the Upper Cretaceous permeable layers and escape at the cuesta type glacial erosional surface.

Fluids migrate across Triassic strata, possibly along faults and cracks created by ice-load induced tectonics.

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