DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2005/78

Digital maps of free gas distribution in marine sediments

WP2 deliverables of the METROL EU project 2003-2005

Troels Laier, Jørn Bo Jensen, Gabriel Ion, Maxim Gulin & Ulrich Fritsche

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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GEUS

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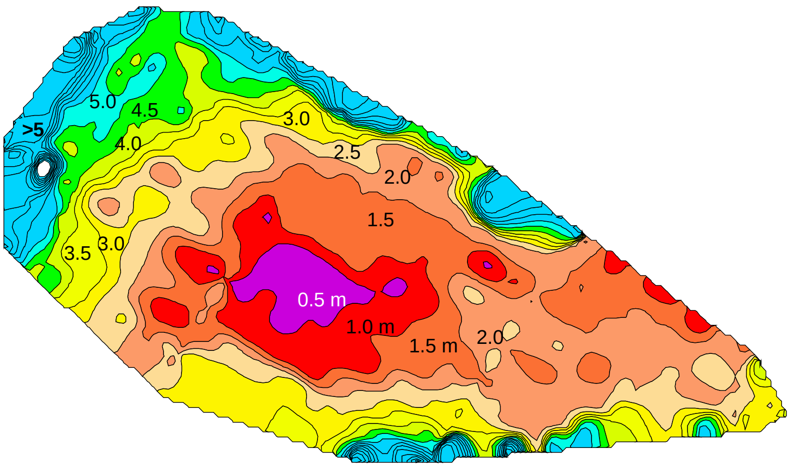
G E U S

METHANE FLUX CONTROL IN OCEAN MARGIN SEDIMENTS

Maps of free gas distribution

WP2 deliverables after 30 months



Sub-bottom depth contours of shallow gas in Aarhus Bay
based on chirp profiles

WP2 deliverables after 30 months

Deliverable 12: Maps of free gas distribution

1. Introduction

The goal of the METROL project is to understand the controls and mechanisms of methane production and breakdown in ocean margin sediments. The microbiological key process of sub-surface methane oxidation accounts for perhaps 90% of the entire methane flux in the sea floor and, therefore, plays a critical role as a barrier against methane emission to the sea and atmosphere. The efficiency of this methane oxidation and its environmental regulation are, however, still poorly constrained due to lack of relevant data and of understanding of the controlling factors. Even at methane seeps, an unknown but probably major part of the methane is biologically oxidised before it can escape into the water column. The efficiency of this process must be understood if we are to quantify current methane fluxes in marine sediments and predict the effect of environmental change on seafloor methane release.

The continued formation of methane below the sulphate zone may lead to accumulation of free gas that can be detected by acoustic methods. Areas with gas-charged sediments relevant for studies as part of the METROL project may therefore conveniently be identified from results of acoustic surveys. A large number of acoustic surveys have already been carried out on European margin sediments, which could potentially be used for this purpose. However, extra work is needed in order to extract relevant information on free gas, since very few surveys were carried out with the aim of achieving a better understanding of the methane flux. Most acoustic surveys were carried out for scientific as well as practical purposes in order to obtain a better knowledge of the sub-seafloor strata and to identify areas with valuable resources. Areas relevant for the understanding of migration pathways of industrial and agricultural pollution have also been mapped using acoustic surveys together with coring. In the above surveys presence of free gas is rather "unwanted" as this masks useful information about the sub-seafloor strata, therefore gassy areas are often not carefully mapped. Site surveys with intention of careful mapping of possible gas occurrences are carried out by industry prior to installation of offshore constructions, but site surveys usually cover smaller areas that are not generally easily accessible because of the constructions.

Maps of free gas distribution. One major objective of the METROL project was to produce maps of free gas distribution for the METROL target areas from existing acoustic data. Such maps have now been produced for the three METROL target areas: (1) Western Baltic Sea and Kattegat (GEUS), (2) Skagerrak and the North Sea (GEUS & AWI) and (3) Black Sea-western shelf and slope (GeoEcoMar & IBSS). The maps were produced in digital form suitable for GIS presentation on an interactive multimedia Web-site deliverable 8, as is described in the chapter on GIS presentation. The type and quality of acoustical data available for the construction of free gas maps in each of the three areas will be described in separate chapters below.

Gas depth contour maps. Acoustic mapping of the gas reflector may enable not only the areal extension of excessive methane accumulation but also of the depth of the gas reflector (i.e. the minimum sub-surface depth where bubbles occur in the sediment). This depth is directly related to the depth of the methane-sulfate transition, when calibrated for water depth and other measurable parameters. The transition depth, in turn, depends on the amount and quality of organic material deposited and buried in the sediment. Thus, the acoustic survey may provide rapid and detailed areal data on the long-term organic carbon flux in sediments. So it is possible that in the future acoustic surveys may partly replace the more costly monitoring activities carried out by sediment sampling in vulnerable coastal areas.

In order to develop an acoustic tool for environmental monitoring the gas maps of the Western Baltic Sea and Kattegat target area were constructed to show not only the areal distribution of free gas but also the minimum depth at which gas bubbles occurs below seafloor. Examples on how well the acoustic data fits geochemical data will be given for the Aarhus Bay within the Kattegat area.

Gas seeps. However important for the METROL studies on methane flux, it has not been possible to construct a general map showing the presence of gas seeps in all of the target areas. This was in part due to the fact that gas seeps may manifest in different ways: (1) bubble streams in the water column detectable by acoustics and/or by diving, (2) carbonate cemented structures on the seafloor detectable by seafloor morphology acoustics and sampling and (3) autotrophic communities on the seafloor detectable by ROV and/or box coring. Distribution of seeps will be presented together with maps of free gas distribution for each of the three METROL target areas, but have only been included in the GIS maps for the Kattegat and Skagerrak areas.

Acoustic profiles. Acoustic surveys were carried out during several METROL cruises for better mapping of free gas distribution in the target areas as well as for pinpointing sampling locations. GEUS was responsible for the acquisition of acoustic data during two major and two minor cruises in the Western Baltic Sea and Kattegat target area. The results of this acoustical mapping have been incorporated into the gas depth contour maps, but have also been made general available using the Sonar Web software. Examples of two sets of acoustic profiles can be seen on the CD-ROM included with this report. Examining these profiles together with the information contained in the GIS maps of the target area also the non-expert can obtain details on gas distribution that could not be included in gas depth contour maps. A short introduction on how to see the profiles on your computer is presented in Appendix 1 of this report.

GIS maps that allow the user to incorporate new data onto the maps without having to buy expensive software have been constructed by GEUS using the ArcExplorer program that can be downloaded form the internet. The GIS maps covering Skagerrak - Kattegat - Western Baltic can be seen on the CD-ROM included with this report. A short introduction on how to get started is also included in a PowerPoint presentation on the CD-ROM, the content of which is shown in Appendix 2 of this report.

2. Principles of acoustic mapping

High frequency reflection acoustic measurements at sea are based on the frequent transmission of sound pulses while the survey vessel is moving. By recording the sound energy reflected by the seabed and underlying strata, the depth of the seabed and sub-bottom strata can be determined. The acoustic profiles comprise longer transects through relevant areas as well as grid profiles with the aim of mapping local areas comprising seeps or other significant structures.

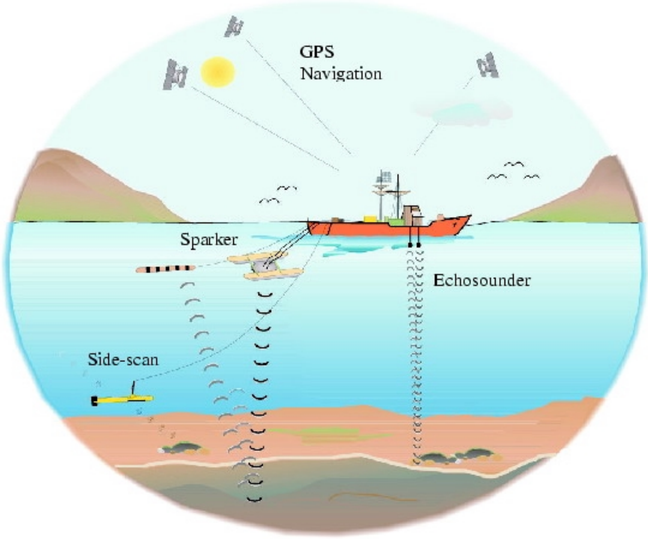


Fig. 1. Sketch of shallow acoustic methods. The high frequency echo-sounder used for depth measurements is hull mounted, while different kinds of acoustic equipment are towed behind the ship. Positioning is done by a Differential Global Positioning System (DGPS).

The acoustic data obtained give an acoustic impression of the seabed sediments and sediment strata below. This impression is visualised by acoustic imagery, in which the penetration of the sound waves into the seabed and their sub-bottom reflections in the different strata is expressed as a vertical pattern of shading. Various known types of deposition can be recognised by interpretation of the acoustic imagery: Sound waves penetrate relatively easily into fine grained sediments as mud, silt, and clay, while penetration depths are very limited in sand, gravel and glacial till. Gas, mostly methane generated form organic matter degradation in muddy sediments, imposes a particular acoustic problem. Free gas may cause turbidity or blanking due to scattering and absorption of acoustic energy thereby obscuring any information concerning the underlying sedimentary strata.

Instruments. Shallow acoustic equipment transmits sound waves in the range of 0.5-10 kHz. Within this range, a distinction can be made between high and low frequency signals, and several sound sources are often used simultaneously. Traditionally systems such as the "Pinger" and the "Boomer" emit distinct frequencies (e.g., 3.5 kHz and 0.6-2 kHz, respectively), which allow the sound waves to penetrate into the seabed to sub-bottom depths of 10 to 50 m. Resolution of these signals is 10 to 50 cm. More recently developed sound sources use wave spectra of a broader frequency range. "Chirp" systems are characterised by a combination of relatively deep sub-bottom penetration and high resolution, which is achieved through processing of the return signals. Another recently developed system is the high frequency multi-tip "Sparker" which emits strong acoustic pulses of relatively low frequency (centre frequency 0.8-1.2 kHz). This provides a better penetration than the traditional Boomer systems and is thus suitable for the analysis of deeper sedimentary deposits.

3. Mapping the gas front from acoustic profiles - Aarhus Bay

Aarhus Bay, Denmark was selected as a test area to explore the statistical and areal variations in the geochemical zonation and depth of the gas reflector. Repeated sampling and acoustic profiling has been performed in this area in the course of the METROL project. The bay is vulnerable due to eutrofication, thus gas eruptions emitting toxic hydrogen sulphide into the water column have occurred on some occasions particularly during late summer. As this area is the most thoroughly examined of the METROL areas it has been selected to demonstrate how gas maps were constructed from existing as well as new acoustic data. Examples of two acoustic profiles showing the presence of free gas are shown in Fig. 2 together with a geological interpretation of the data.

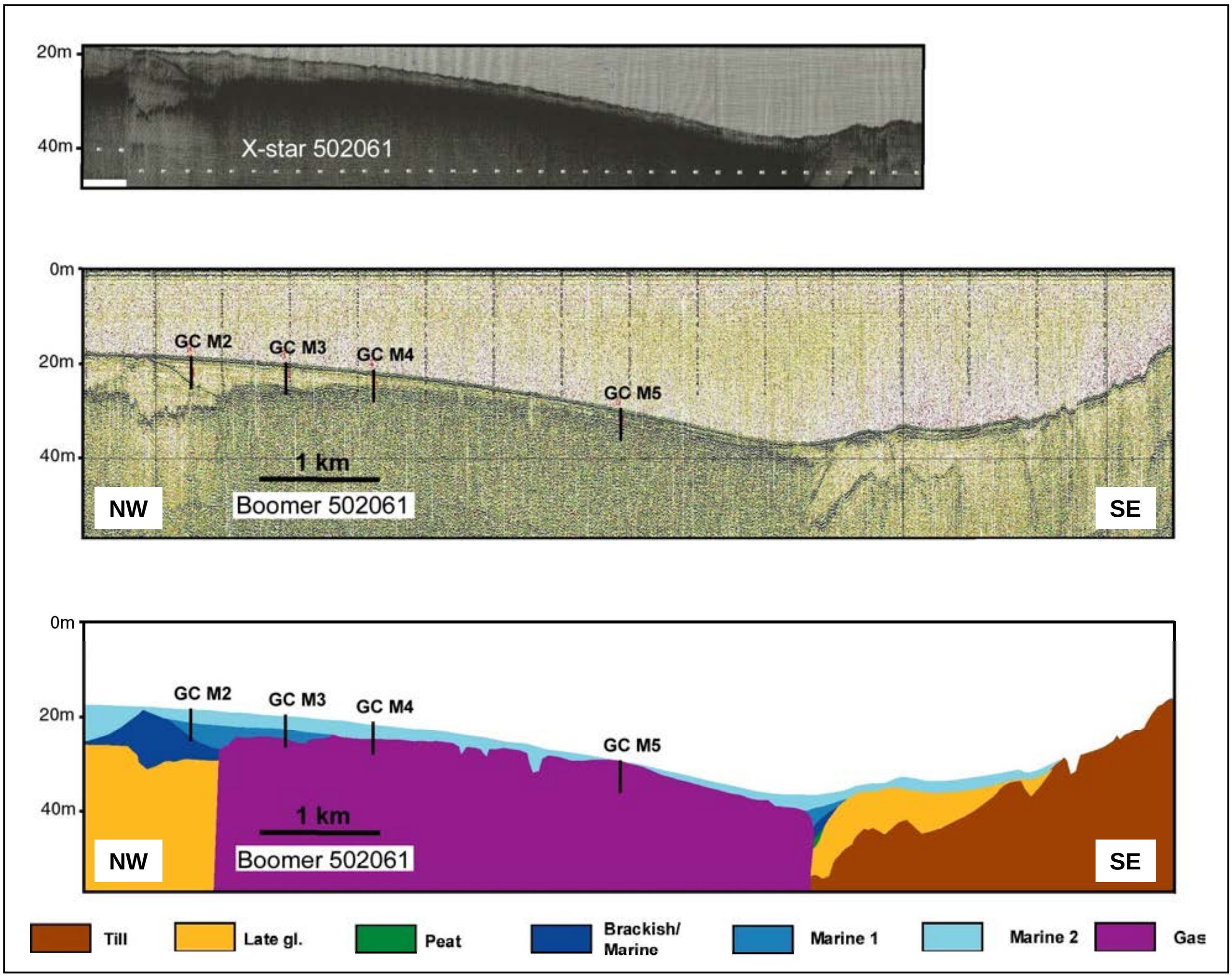


Fig. 2. Chirp (X-star) and Boomer profiles across a free gas area in Aarhus Bay. Location of profiles is shown on figure 3.Positions of sampling stations are indicated on the geological profile.

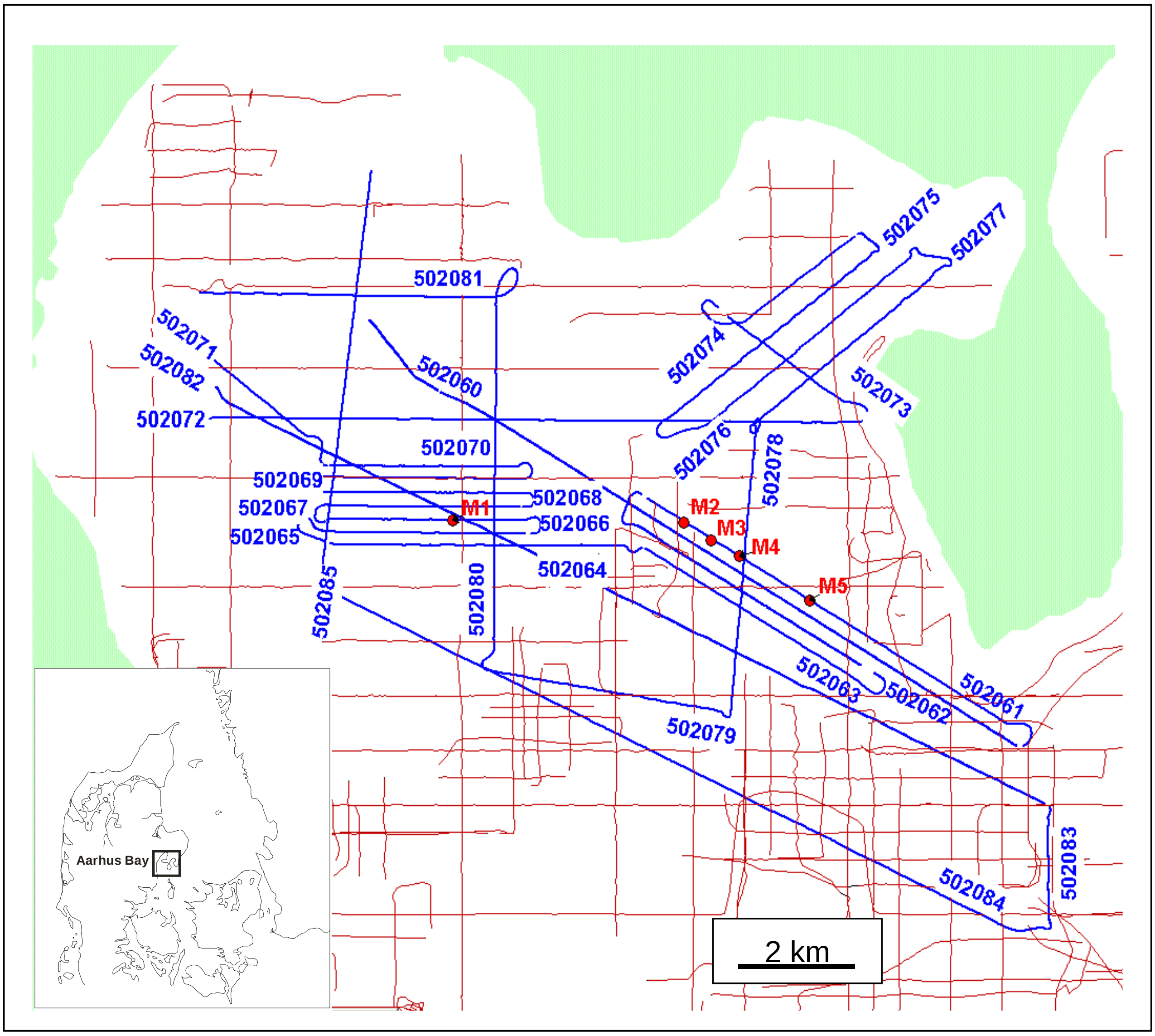


Fig. 3. Location map of Aarhus Bay area showing tracks of existing (red) and new (blue) acoustic profiles. The latter profiles were acquired during a cruise in March 2003. M1-M5 marks the sample stations for repeated sampling in the bay.

The minimum depth of the free gas zone has been clearly marked on the geological profile below the two acoustical profiles. Similar interpretations were carried out for all of the acoustic profiles shown in Fig. 3. Based on the interpreted profiles a digital gas-depth-contour map was constructed as is shown in Fig. 4. For practical reasons gas depths were divided into four different contour intervals: <0.5 m, 0.5-2 m, 2-4 m and >4 m.

Geochemical data along the profile show nearly similar variation with respect to gas distribution as do the acoustic data as can be seen comparing Figs. 2 and 5. The geochemical data shown in Fig. 5 were obtained early in the METROL project. Since then, more data both geochemical and acoustic have been acquired in order to test exactly how well the latter correspond to the geochemical observations of the sulphate/methane transition zone.

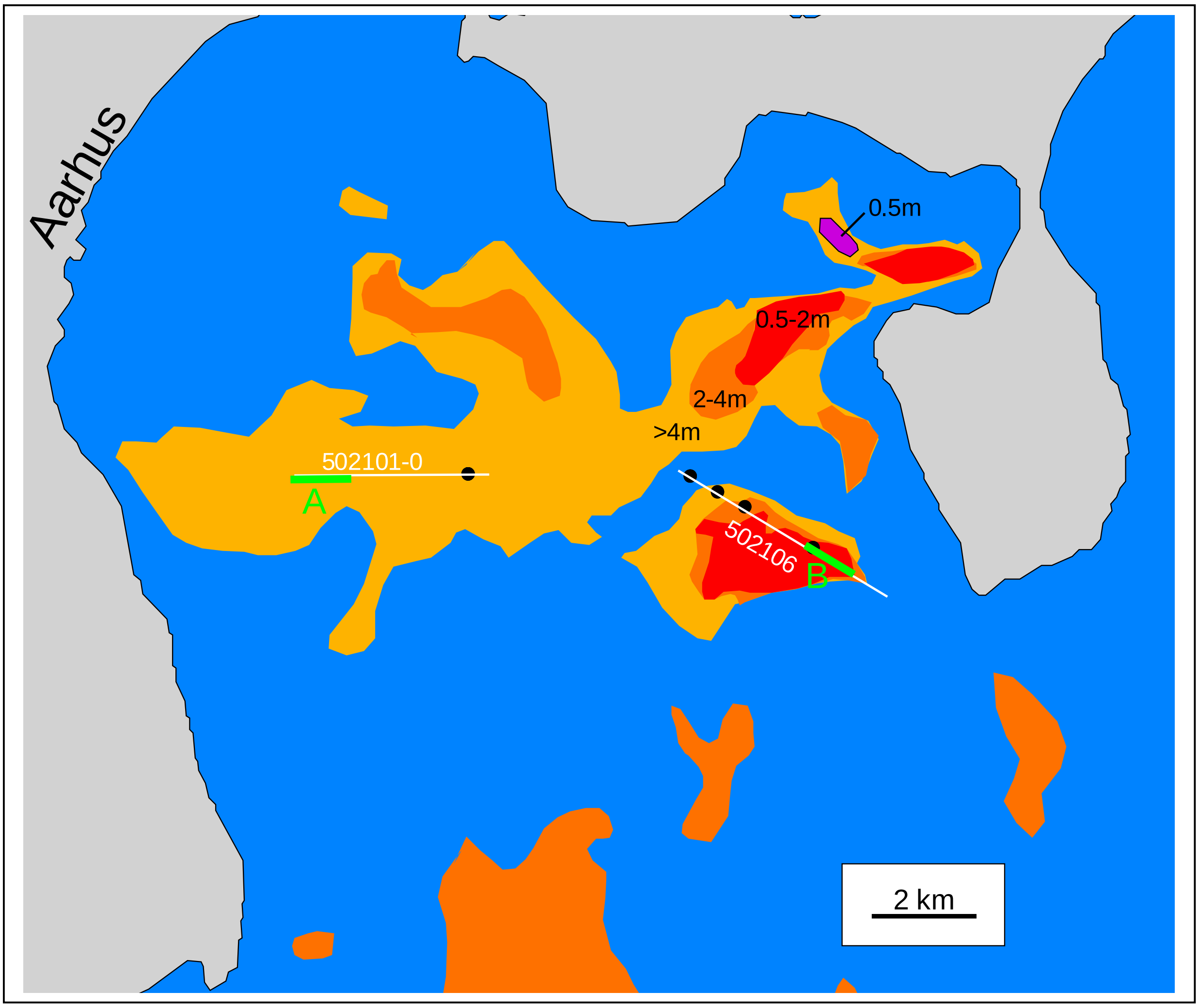
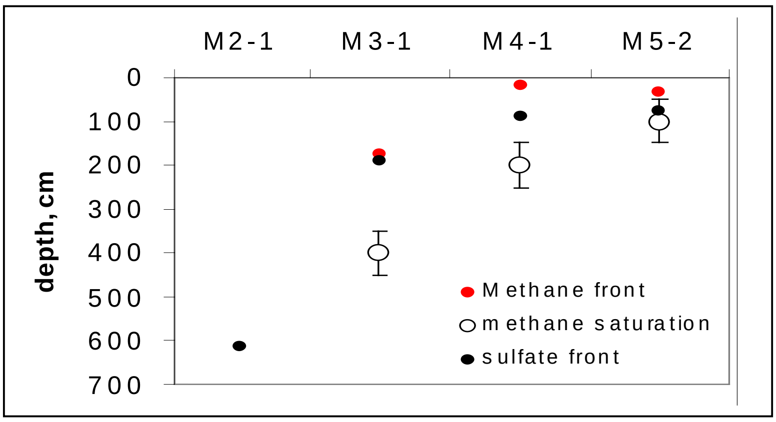


Fig. 4. Gas contour map based on interpretation of acoustic profiles indicated in Figs. 2-3.

Fig. 5. Results of porewater chemistry data from gravity cores collected along the acoustic profile shown in Fig. 2. Methane front, red circles, indicate shallowest level of dissolved methane. Black circles indicate deepest level of sulphate presence. Open circles indicate presence of gas bubbles.



A closer look at 2 examples of Chirp profiles acquired in March 2005 show this is not as easy as one might have hoped for, since the top of the free gas zone is not always particularly sharp.

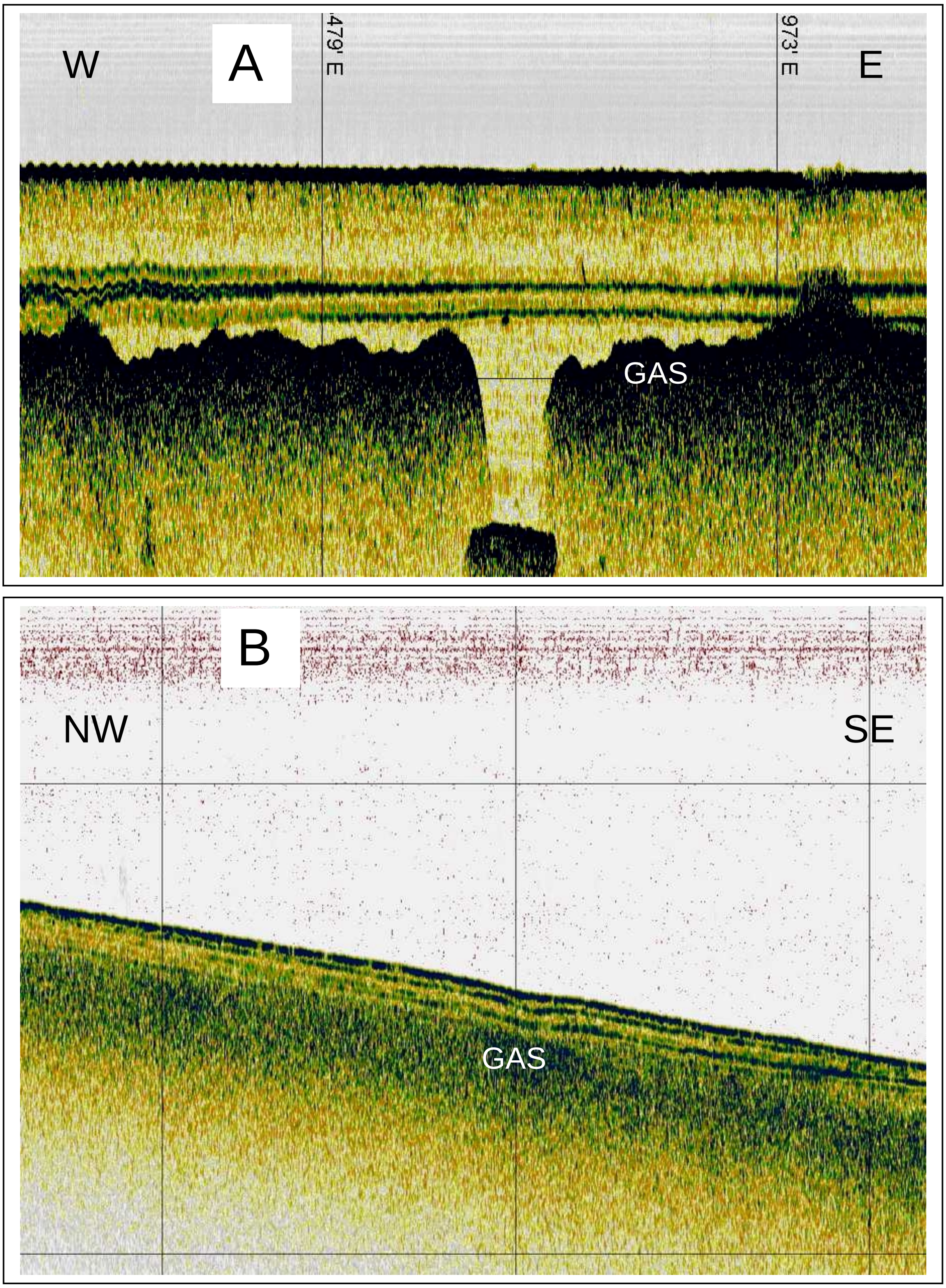


Fig 6. Chirp profiles ca. 1 km across, March 2005, location see Fig. 4. (A) Sharp gas reflector 5 m below seafloor (12 m). (B) Diffuse upper gas front 1.0 - 1.5 m below seafloor (26-32 m)

It is not known why the top of the gas front has such different appearance at the two different locations. Minor differences in grain size distribution of upper sediments may be one explanation, although both locations are in "mud" area according to the general sediment type map, Fig. 7.

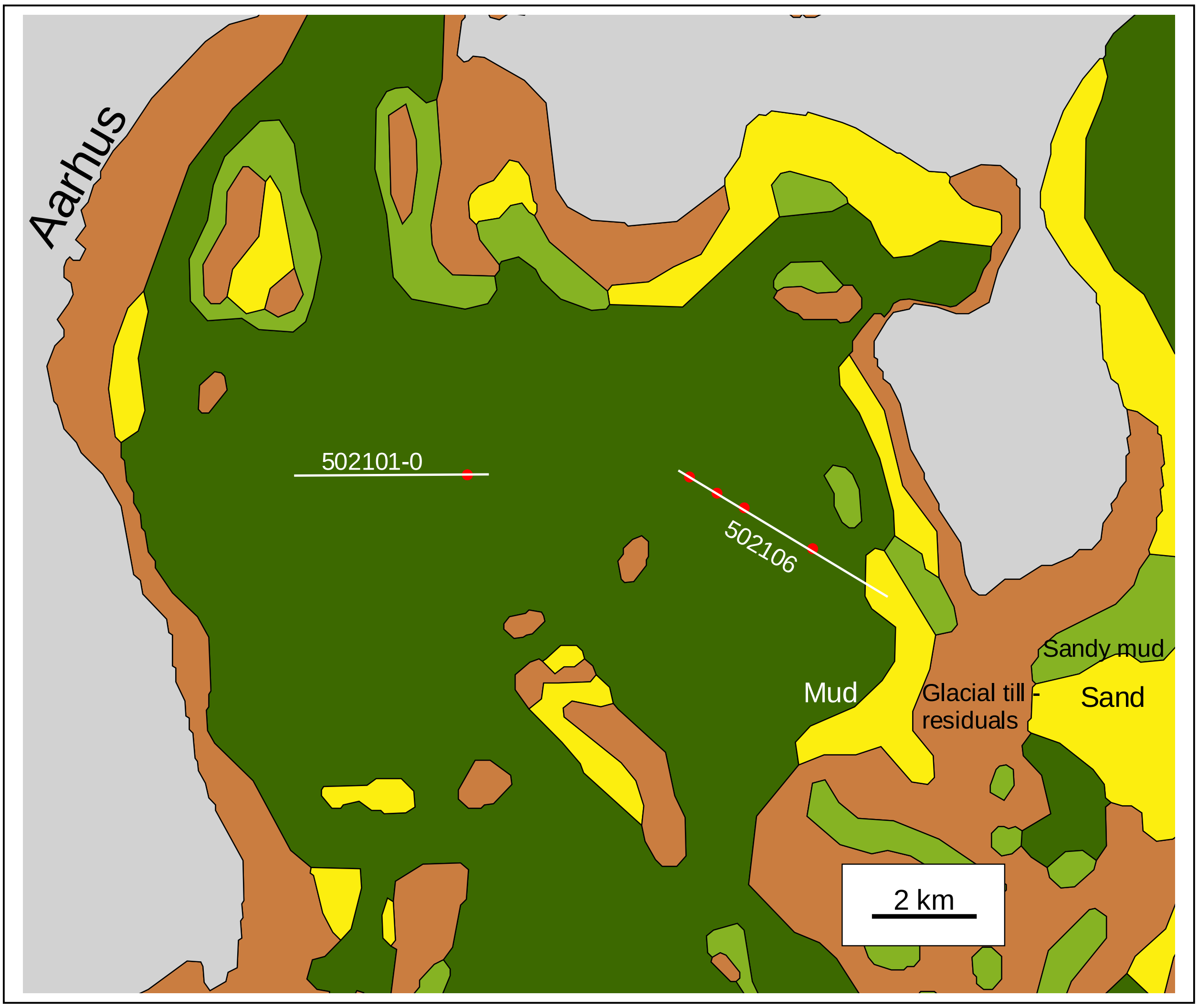


Fig. 7. Sediment type map of Aarhus Bay area.

The diffuse nature of the top gas front in certain areas complicates the construction of a gas contour map having narrower intervals than that shown in Fig. 4. The uncertainty of a more detailed gas contour map would by fairly high if the interpretation was to be based on visual inspection of printed acoustic profiles, however it could be reduced if digital acoustic data were analysed directly. This was done for the Chirp profiles of March 2005 covering a small area around the sampling stations M2 - M5. From the digital analysis of acoustic data a gas contour map constructed using the Vertical-Profile tool of MapInfo. The increments of contour intervals was set to half a metre starting with 0.5 m. Tracks of the acoustic profiles on the "old" contour map as well as the new gas contour map are shown in Fig. 8.

Both gas contour maps can be found as the GIS maps on the CD-ROM, which also shows acoustic lines and exact location of all sediment samplings. The Chirp profiles of March 2005 can also be studied in detail using the SonarWeb formatted files, which link acoustic data with navigation data.

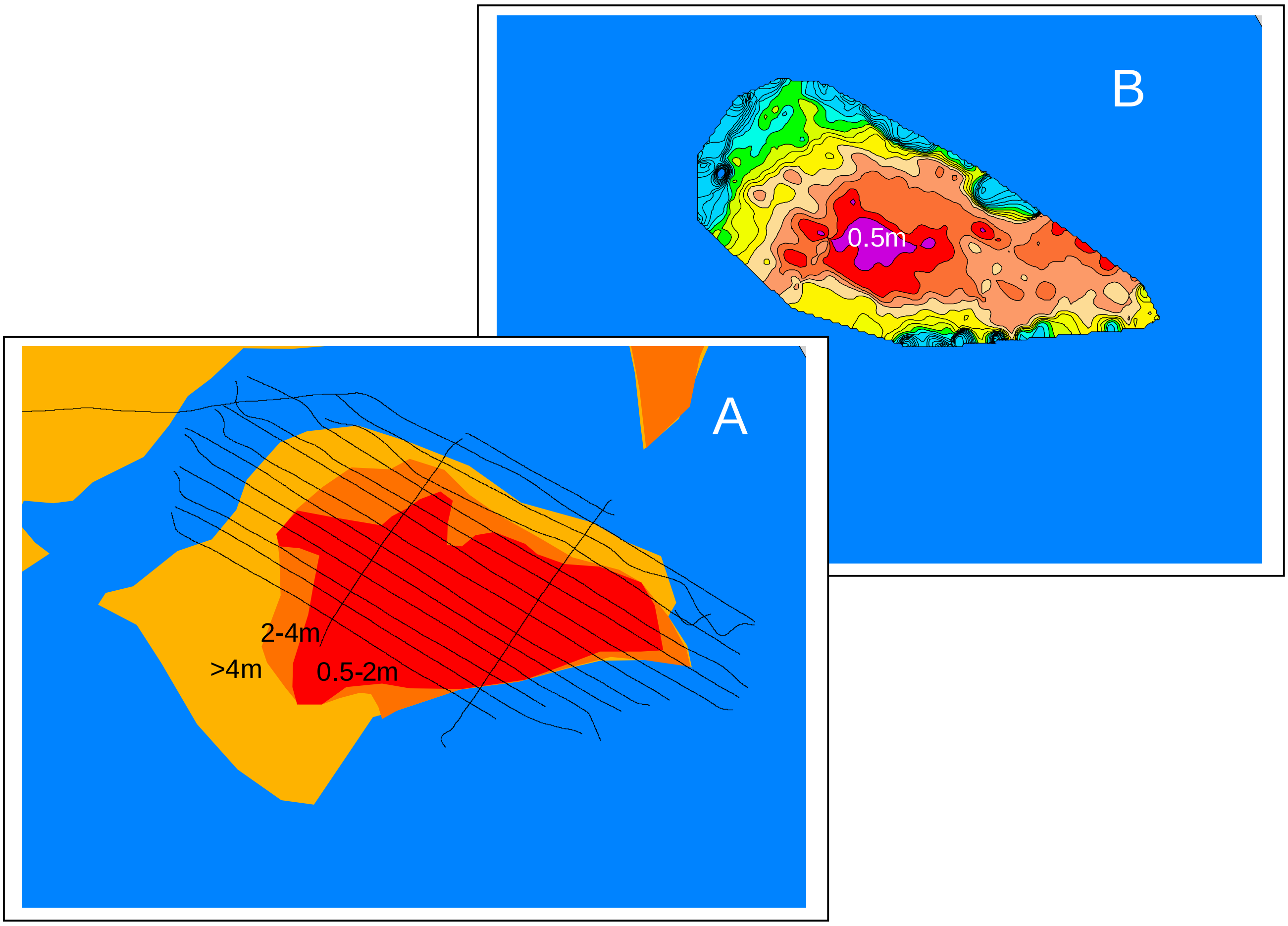


Fig. 8. (A) Chirp lines of March 2005 on "old" gas map and (B) Detailed contour map showing top gas front at 0.5 m depth intervals based on analysis of digital Chirp data.

Maps of free gas distribution for the three METROL target areas were constructed along the lines described above although in lesser detail.

4. Western Baltic and Kattegat area

4.2 Geology and shallow acoustic surveys

The Western Baltic Sea and Kattegat area form part of the North German and Danish sub-basins, that contain over 8000 m thick sedimentary deposits in the central parts. Deposits from most periods since Cambrian time are present in the sediment record revealed by drilling, although uplift and erosion has occurred in certain areas particularly during Tertiary time. Deeper hydrocarbon deposits have not been found except for some very minor ones off the North German coast in the Western Baltic Sea. Shallow gas accumulations in the area are therefore almost entirely of Holocene age although some accumulations of Pleistocene age exist in the northern Kattegat (Laier et al., 1992). Shallow gas accumulations are often found in relatively thick fine grained Holocene deposits in depressions formed by glaciers, ice-streams or melt water rivers of the last ice age (van Weering, 1982 and Fält, 1982). Van Weering (1982) and Fält (1982) both made a general outline of the shallow gas accumulations in the southern Skagerrak - northern Kattegat region that appear to hold the largest volume of shallow gas in this METROL target area.

Lines of shallow acoustic surveys available for more precise mapping of shallow gas occurrences in the target area are shown in Figs. 9-10.

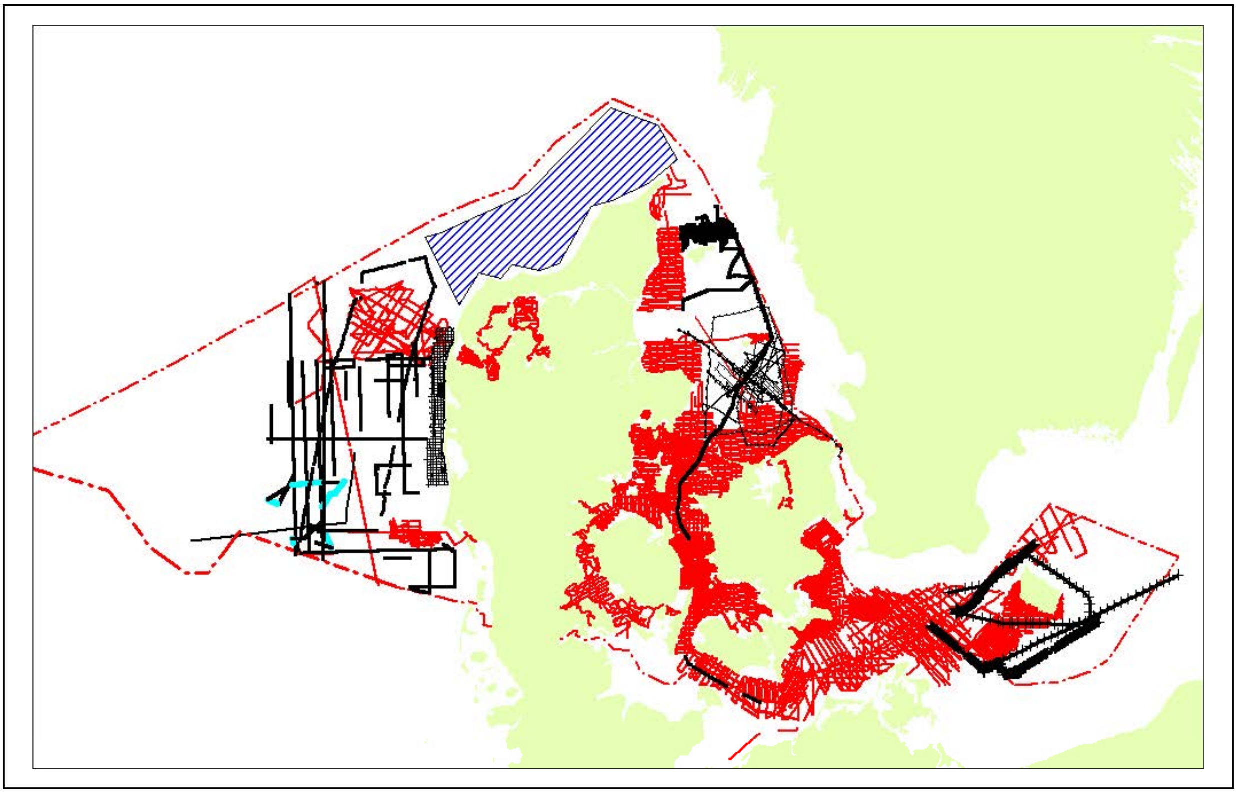


Fig. 9. Lines of shallow acoustic surveys stored at GEUS.

The surveys indicated in Fig. 9 were acquired for commercial as well as for scientific purpose. Results for many surveys are only in the form of paper charts.

In order to produce a gas map of the same quality for the whole of the contiguous shallow gas accumulations in the southern Skagerrak - northern Kattegat area it was decided to include information from acoustic surveys acquired from 1977 to 1980 stored at GEOMAR in Kiel. To be able to the use the acoustic data for construction of a GIS map, the acoustic lines needed to be digitised from paper charts, and then converted from Decca to geographical coordinates. This work was done by GEOMAR for the METROL project. The exact position of the lines may be looked up on the GIS map on the CD-ROM included with the report.

Next, acoustic profiles on paper charts were transferred from GEOMAR to GEUS for interpretation of gas occurrences. To complete the mapping within the near coastal sandy areas in southern Skagerrak off northern Denmark results of a Sparker survey acquired in 2003 was also interpreted with respect to gas occurrences.

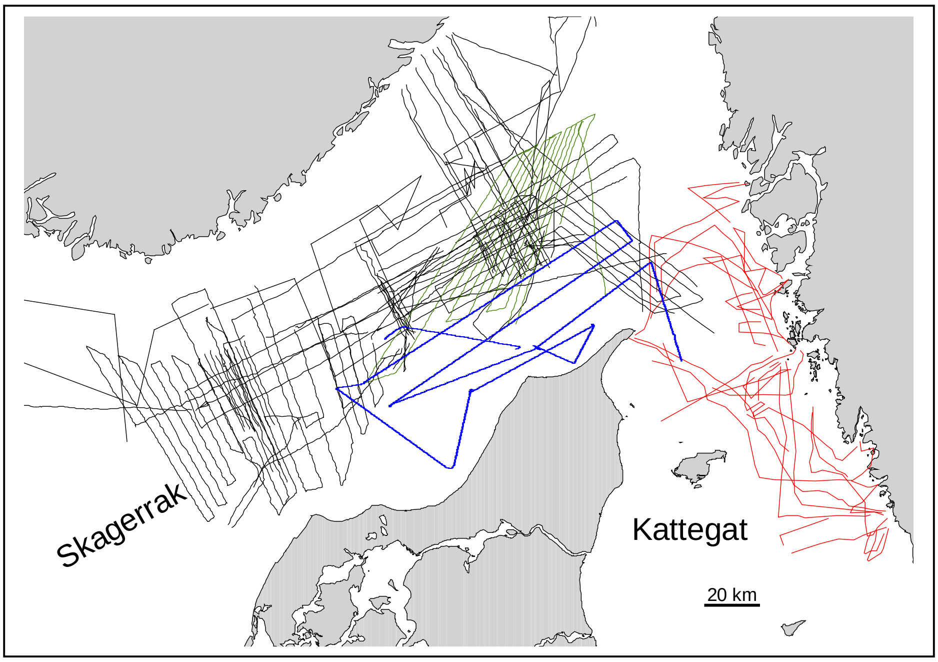


Fig. 10. GEOMAR acoustic surveys (1977-1980) in black, acoustic surveys reported by Fält (1982) in red and Sparker profiles acquired by GEUS (2003) in blue.

4.2 Gas contour map

Examples given in chapter 3 on how gas contour maps were constructed from information obtained from acoustic profiles apply for most of the Western Baltic Sea and Kattegat area. However, gas plumes which appear to be related to gas migration have only been observed in northern Kattegat near coastal sediments, see Fig. 11.

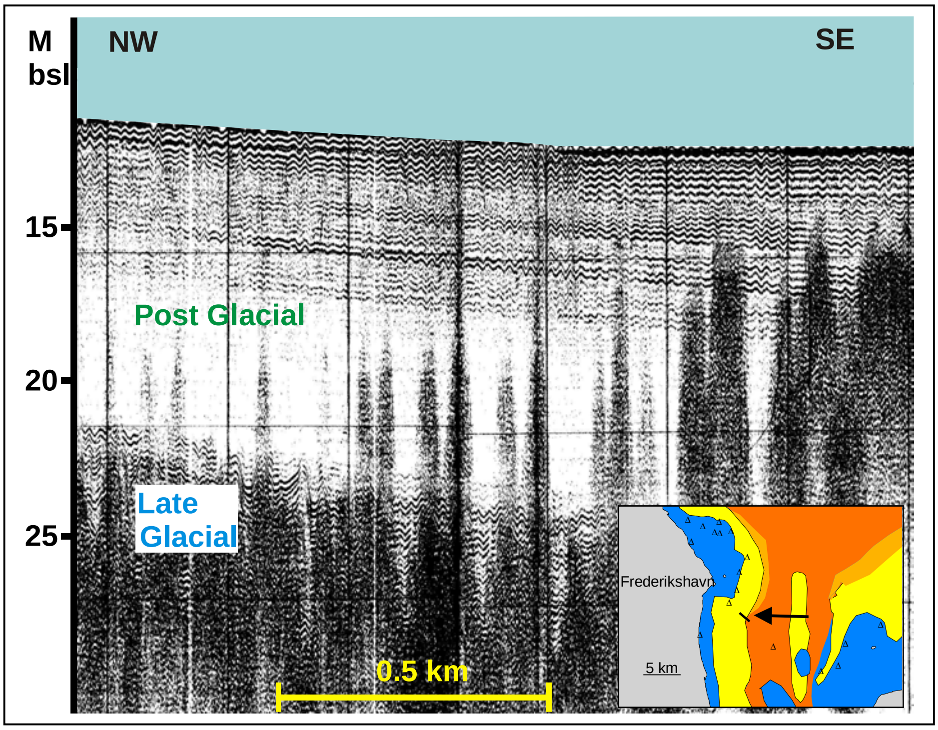


Fig. 11.Plumes indicating migration of gas from Pleistocene into Holocene deposits

Contour intervals for the whole of the target area (Fig. 12) were the same as those applied for the gas map of Aarhus Bay described in chapter 3.

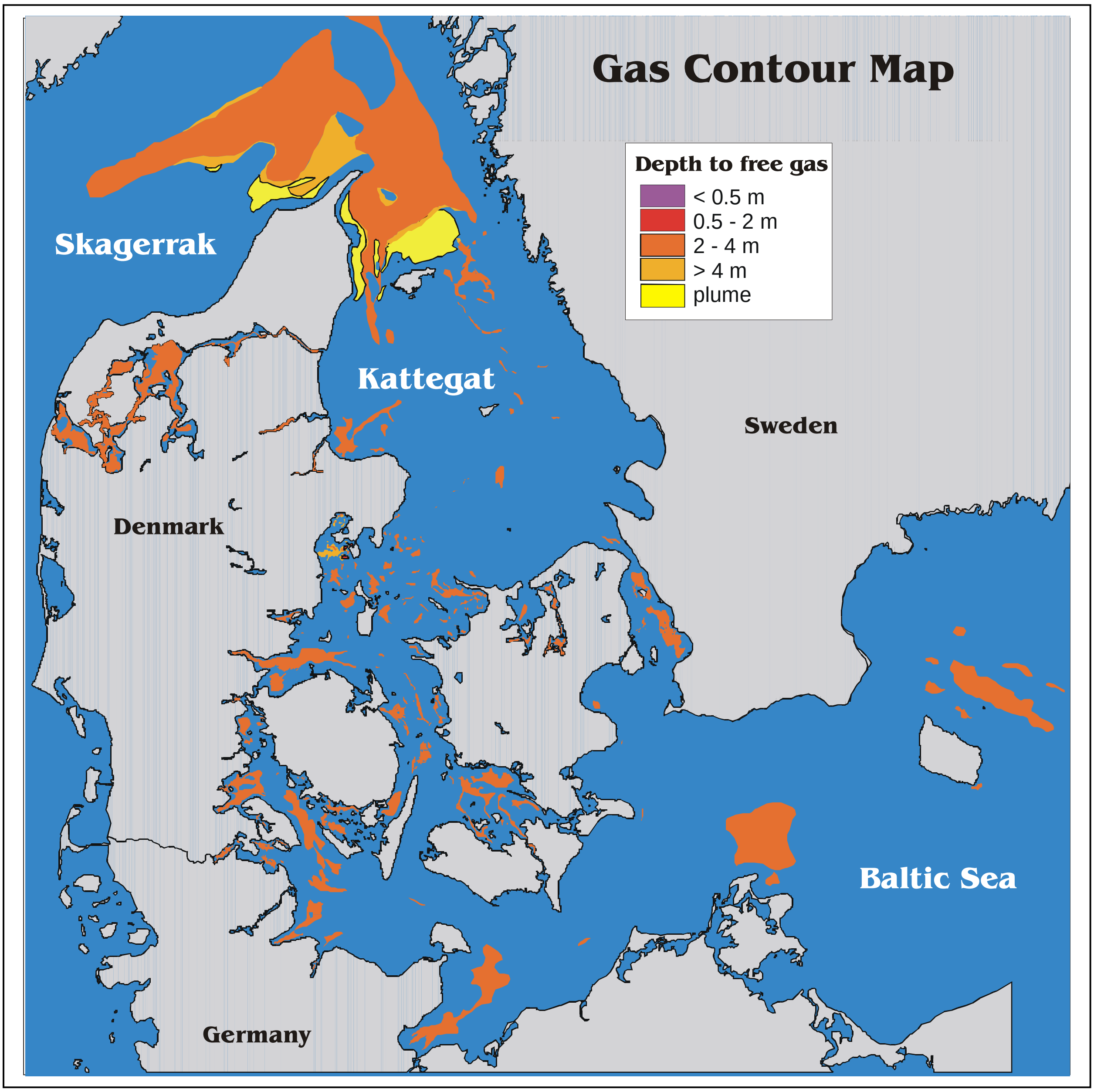


Fig. 12. Gas contour map of Western Baltic Sea - Kattegat area.

4.3 Gas seeps

Gas seeps also occur within the area characterised by gas plumes in the upper sediment layers. Seeps have been observed by scuba divers in the shallow waters and may also be seen in inter tidal coastal areas (Dando et al., 1994a). Part of the methane near the seeps is being oxidised leading to the formation of carbonate cemented structures on the seafloor known as the "Bubbling reefs" shown in Fig. 13 (Jensen et al., 1992). The locations of these structures are well known to the local fishermen, as they are fairly solid and may destroy their nets.

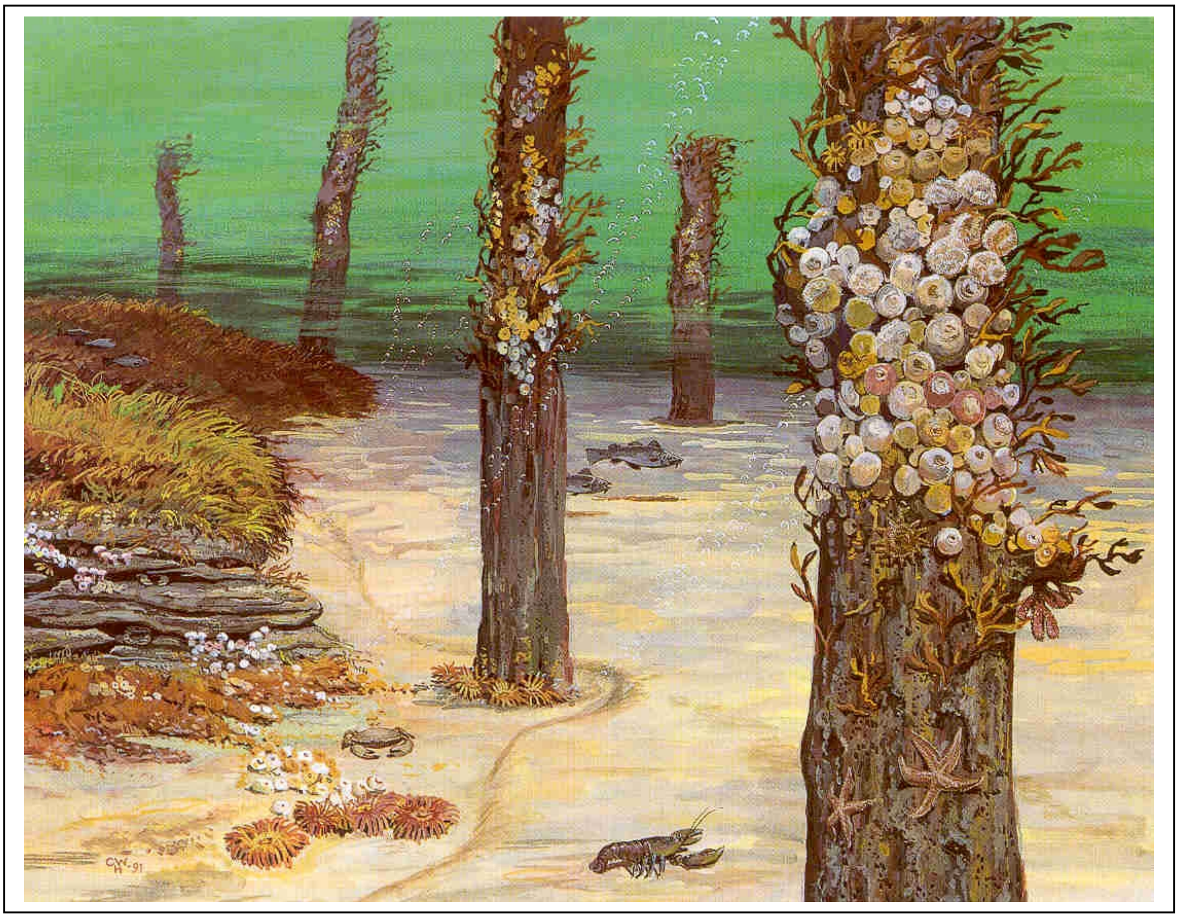


Fig. 13 Bubbling reefs located 5 km NW of Frederikshavn City. Carbonate carbon is very much depleted with respect to carbon-13 relative to normal marine carbonate indicating that it has been derived from oxidation of methane.

The location carbonate structures, shown on Fig. 14 thus indicate the presence of gas seeps whether old or still active. The sediment type map (Fig. 15) shows that the seeps mainly occur in sandy areas close to Pleistocene deposits. Radiocarbon dating of methane from seeps strongly indicates that methane originate from Pleistocene deposits (Dando et al., 1994a; Laier et al., 1996) as opposed to the young gas in the Holocene sandy mud (Laier et al., 1996). Examination of drill cores from Pleistocene deposits confirmed that these deposits could be the source of bacterial methane (Laier et al. 1992).

The geological profile, Fig .16, based on results of deep seismic investigations combined with deep onshore drilling shows that gas seeps (bubbling reefs) mainly occur in areas with very shallow Pleistocene deposits. Such areas are however not always characterised by massive gas accumulations as are areas characterised by thick Holocene deposits. An example with shallow Pleistocene and no gas can be seen on the Sparker profile, Fig. 17, across Hertha's Flak (the no gas area 5 km north of the geo-profile line on Fig. 14).

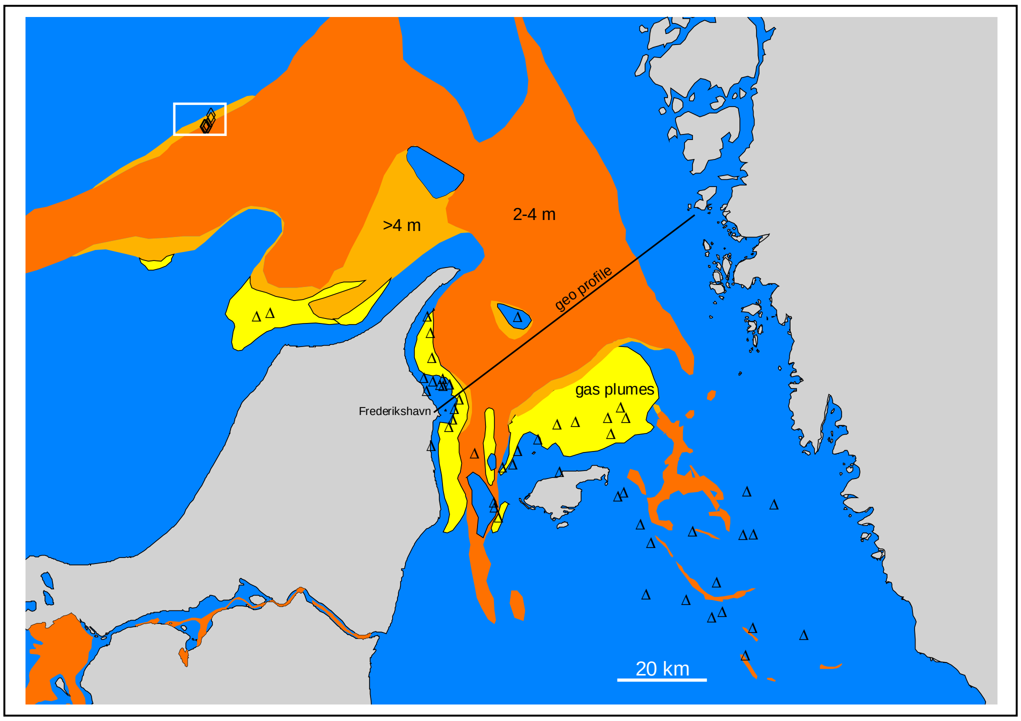


Fig. 14. Distribution of seep associated carbonate cemented sediment structures indicated by triangles. Skagerrak seeps area marked by white rectangle.

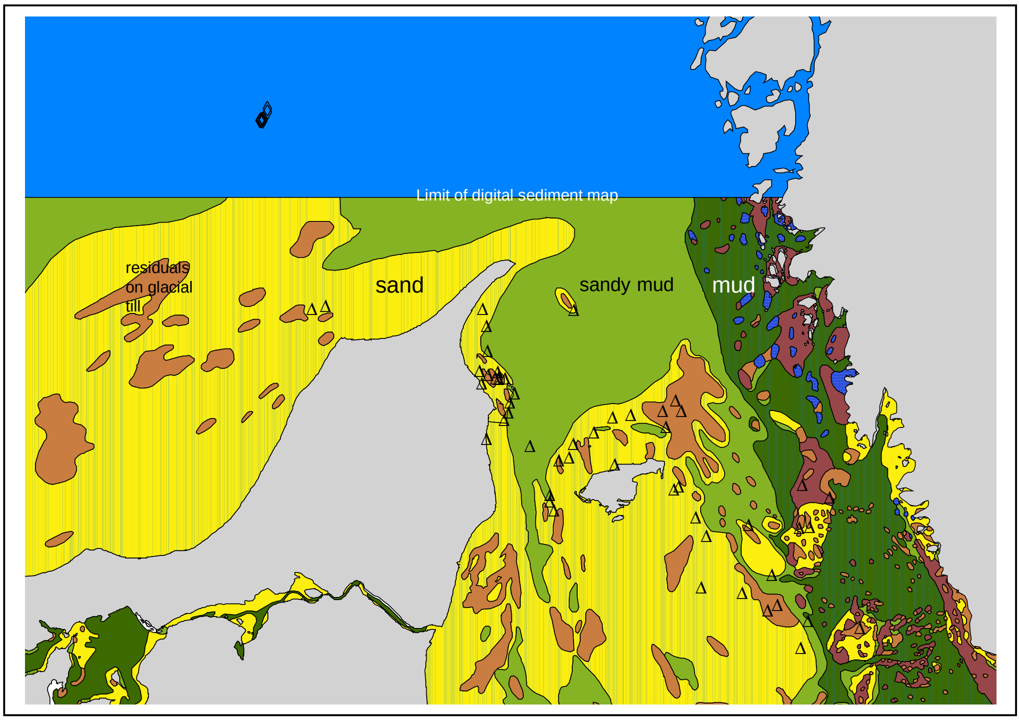


Fig. 15. Position of carbonate structures compared with type of seafloor sediment.

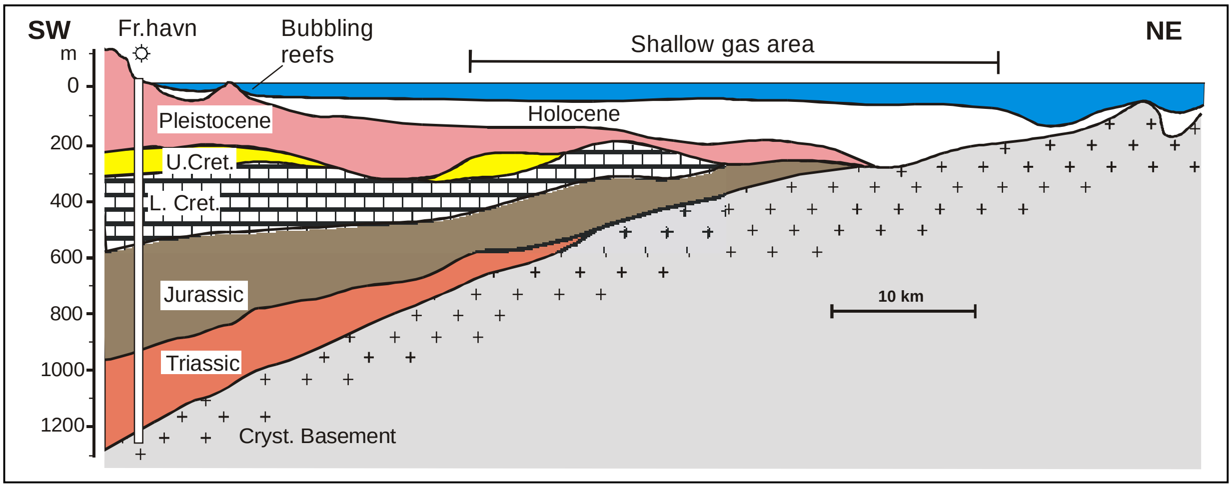


Fig. 16. Geological profile across northern Kattegat

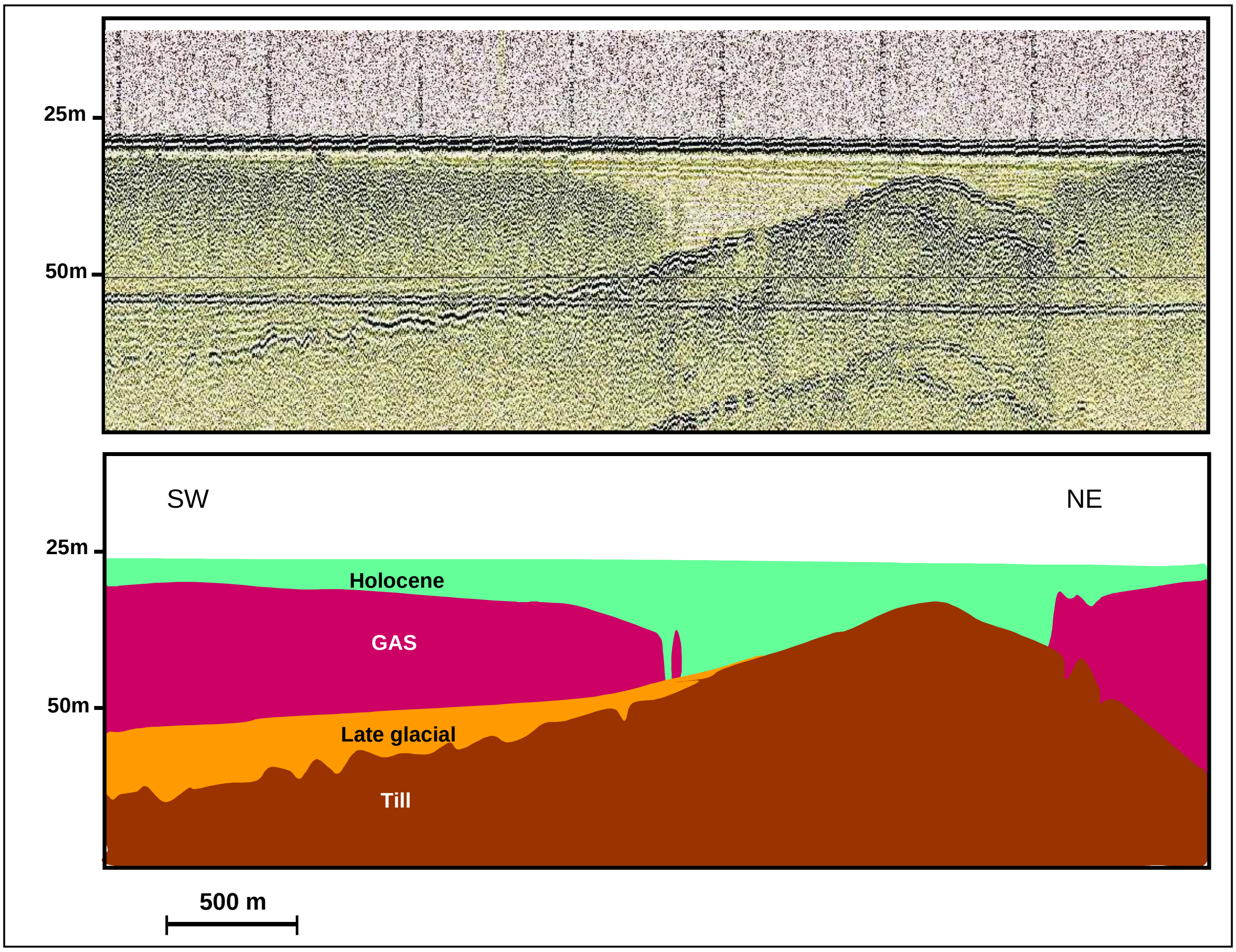


Fig 17. Sparker profile across Hertha's Flak. Free gas does not form in this area when Holocene sediment thickness goes below 20 m.

Finally the small gas seep area in Skagerrak at 350 m water depth will be mentioned (indicated on Fig. 14). The thickness of the Holocene sediments in this area at the edge of the free gas zone is around 60 m (Novak and Stoker, 2001). The gas do not originate from a deeper source as it was found to be younger than other gases examined by radiocarbon dating in other locations of the Kattegat - Skagerrak free gas area (Laier et al, 1996). The existence of methane seeps has been inferred from the autotrophic communities observed in number box core samples, Fig. 18, collected in the area (Dando et al., 1994b; Zimmermann et al., 1997). The depth of the free gas zone drops from 4 m to over 80 m below seafloor over a relatively short distance ca. 2 km (Cooper unpublished results). Methane is present in pore water but only in the dissolved state north of the free gas area, position 15535-1 where an 8 m long piston core had been taken. Dating of the sediments together with careful granulometric investigations showed that accumulation rate varied considerably with time (Hass, 1993)

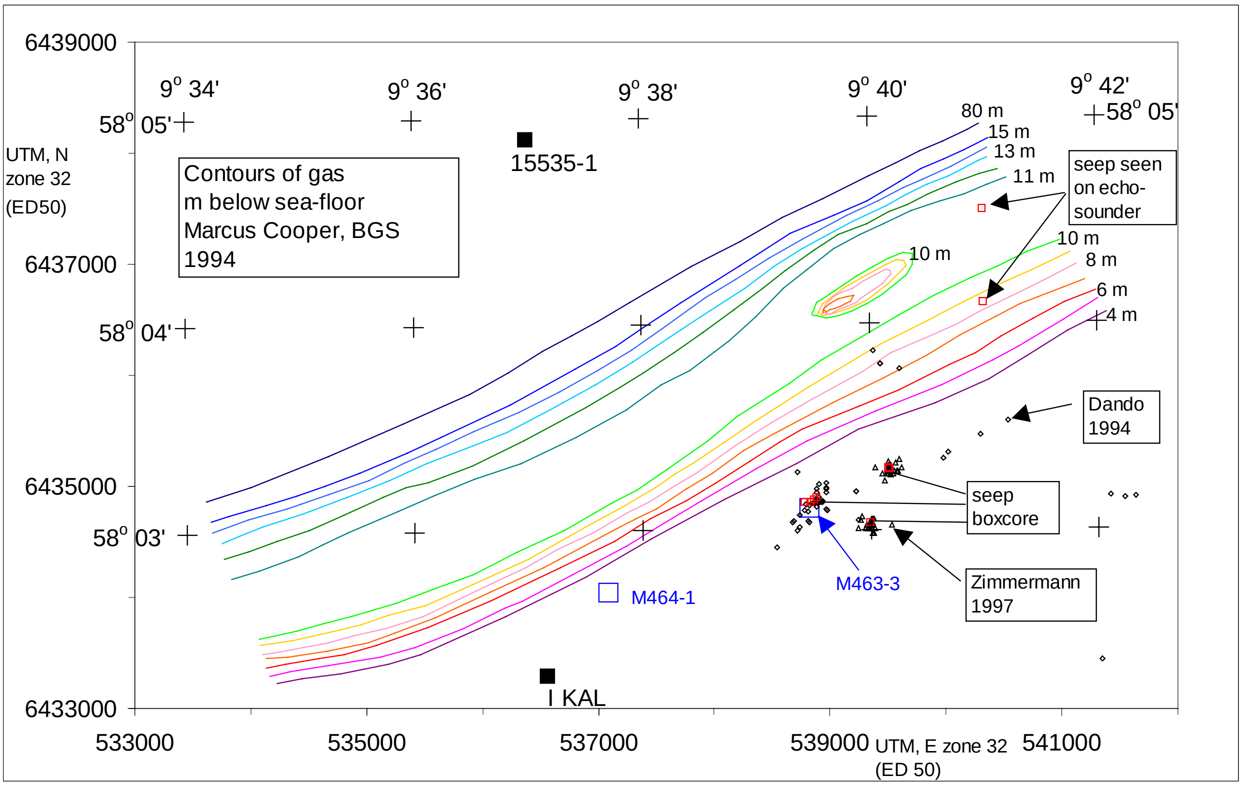


Fig 18. Seep area identified by autotrophic communities on the seafloor examined using box coring. Water depth is around 350 m. Gas depth contour lines were digitised from the map of M. Coopers MSc report.

5. North Sea and Skagerrak area

Maps of free gas distribution for this target area are mainly based on published data, which were digitised in order to produce GIS maps. An overview of the GIS map for the whole of the target area is shown in Fig. 19, together with reference to source of the data. The map may be viewed in more detail using the ArcIMS Internet Map Server from ESRI. Access to the map server at AWI is provided via the METROL web-site http://www.metrol.org.

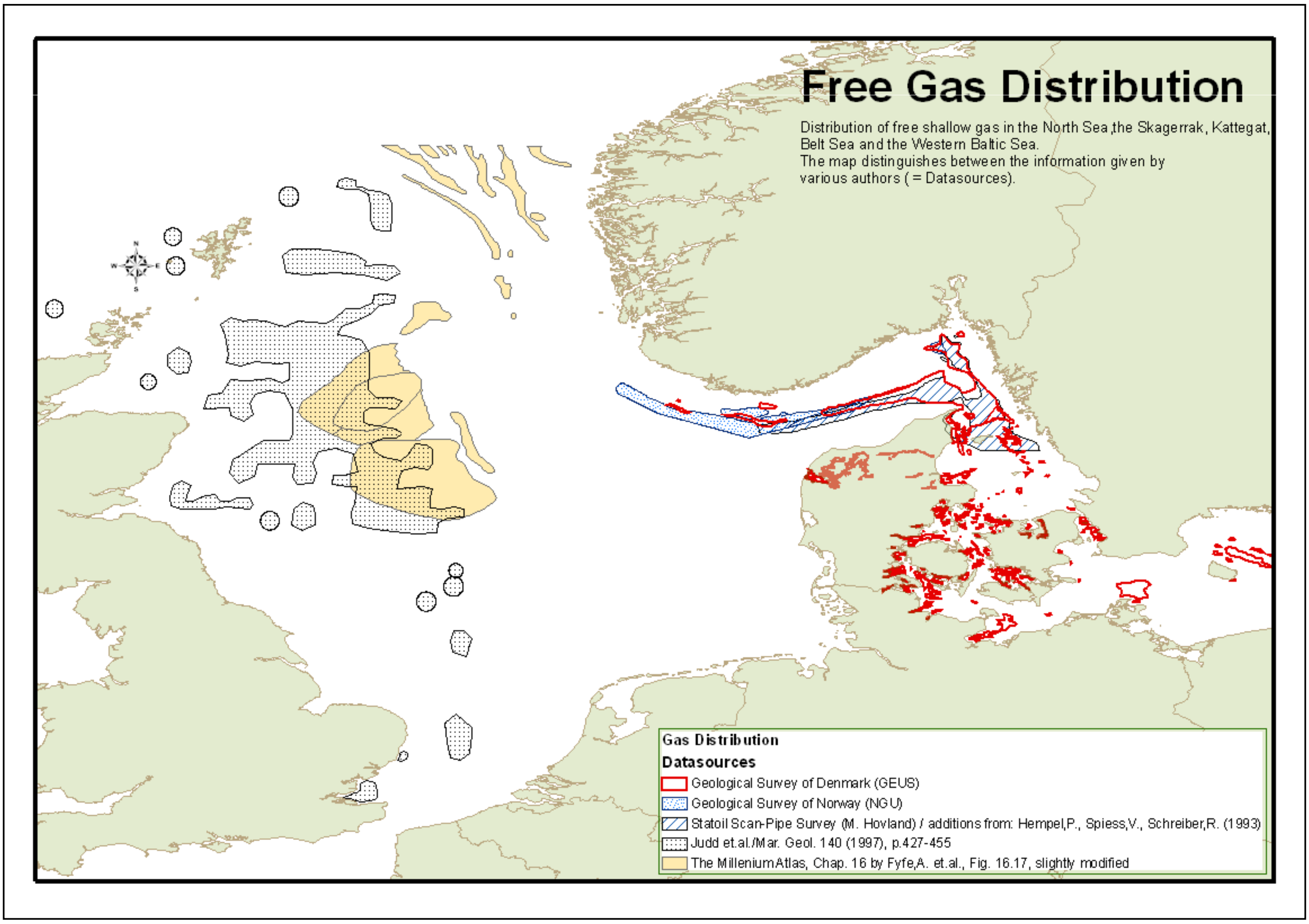


Fig. 19. Free gas distribution in the North Sea and Skagerrak area.

6. Black Sea

6.1 Geology and shallow acoustic surveys

Geology. The Black Sea is the presently largest anoxic basin in the world. Active seepage of methane gas from the seabed into the water column is a very common phenomenon, and the presence of gas seeps is direct evidence of the existence of gas charges in the sediments. Gas seeps have been mapped along the western, northern and eastern Black Sea shelf break and adjacent shelf and slope areas (Egorov et al. 1992). The most active seep sites are closely related to shelf break areas or to mud vulcanos in deep waters. However, the seismo-acoustic data used here indicate that gas-bearing sediments are spread much wider on the continental platform and slope.

The Black Sea has evolved of two extended basins that merged during Pliocene post-rift phases and which now form a single depocentre (Robinson A.G. et al., 1996). The northwestern Black Sea is a proven oil and gas producing area in which also gas hydrates occur. The depositional environment in the northwestern part has been spatially and temporally variable in the past and the structure of the present sedimentary bodies is very complex. As a result, various sedimentary facies bear gas loads: Fine grained shallow sedimentary bodies rich in organic matter contain recently produced biogenic methane, while deeper deposits can contain older gas. Here, fluid migration paths to the sea floor can be observed.

During the Quaternary, the spatial extension of the Black Sea varied strongly due to oscillating sea levels, which caused repeated changes of water coverage and exposure of the extended north western Black Sea shelf. As a result, the shapes of lower courses of the main inflow rivers to the Black Sea, the Danube, Dnieper, and Dniester, varied dramatically.

The sea level variation and regional tectonic activity have controlled the hydrological parameters of the lower paleo-rivers. Sea level variation affected the entire western shelf and produced a large variability of the drainage patterns, which influenced the development of marshes, lagoons and deltaic bodies. These were later often covered by younger sediments (Ion et al., 2002) and thus formed shallow or buried local concentrations of organic matter which was anaerobically degraded to carbon dioxide, hydrogen sulfide and methane.

Acoustic surveys. Gas charged sediments in the north-western Black Sea were mapped on the basis of existing geophysical information stored in the GeoEcoMar data bases and data which have been produced during the METROL project. The hydroacoustic data were generated using a sub-bottom profiler (3.5 kHz), chirp systems (2-16 kHz) and multichannel seismics. A good coverage of seismic lines was particularly achieved for the Romanian Black Sea sector (Fig. 20). Here, a total of 60,000 km of seismic lines has been used for the extraction of information on the distribution of shallow gas.

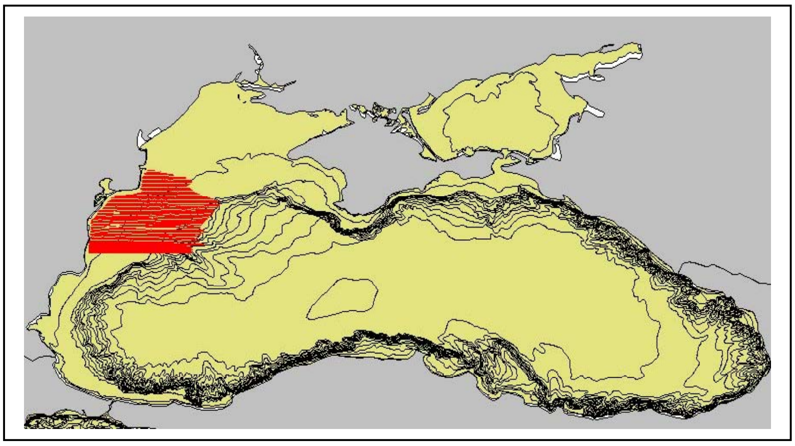


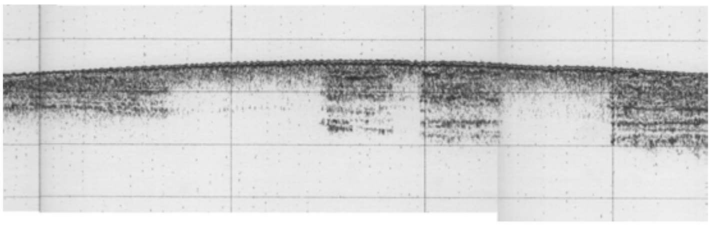
Fig. 20: Area coverage of hydro-acoustical survey lines in the Romanian sector of the Black Sea used for the extraction of information on the distribution of shallow gas.

From the geological perspective, the main controlling factors for the presence of gas in shallow Black Sea sediments are the following:

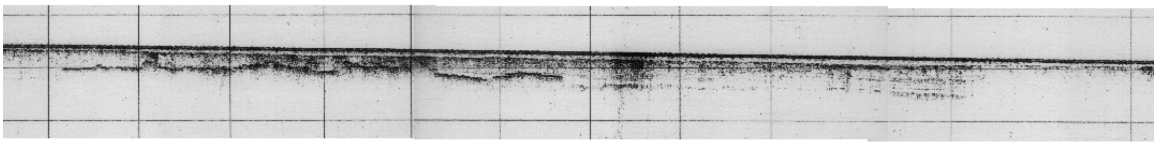
- the presence of deep accumulations of hydrocarbons which continue to migrate
- high concentrations of organic material in the sediments
- local lithology
- local seabed morphology
- overpressure as a result of dewatering by consolidation processes in areas with high sedimentation rates
- pore water chemistry
- local and general structural (tectonic) framework

These criteria served as guidelines for the interpretation of the acoustic facies for the presence of shallow gas. The main acoustic facieses considered were the following:

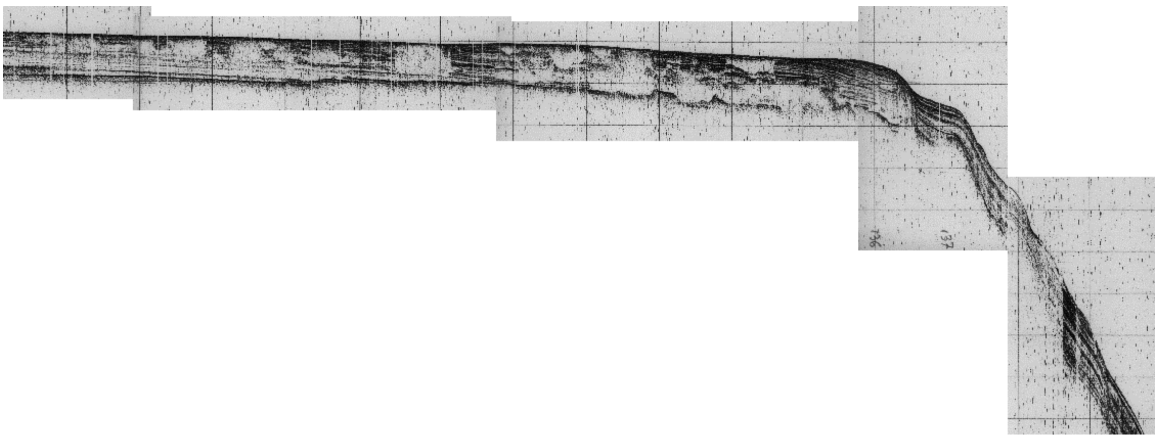
1. Acoustic voids



2. Columnar turbid zones, enhanced reflectors, gas fronts



3. Gas pockets



6.2 GIS map of free gas distribution

Based on our data, we mapped the presence of gas in shallow sediments of the north-western Black Sea shelf. Because of the complex 3D structures of the acoustic facieses, we have only mapped the presence of gas, but not the facies.

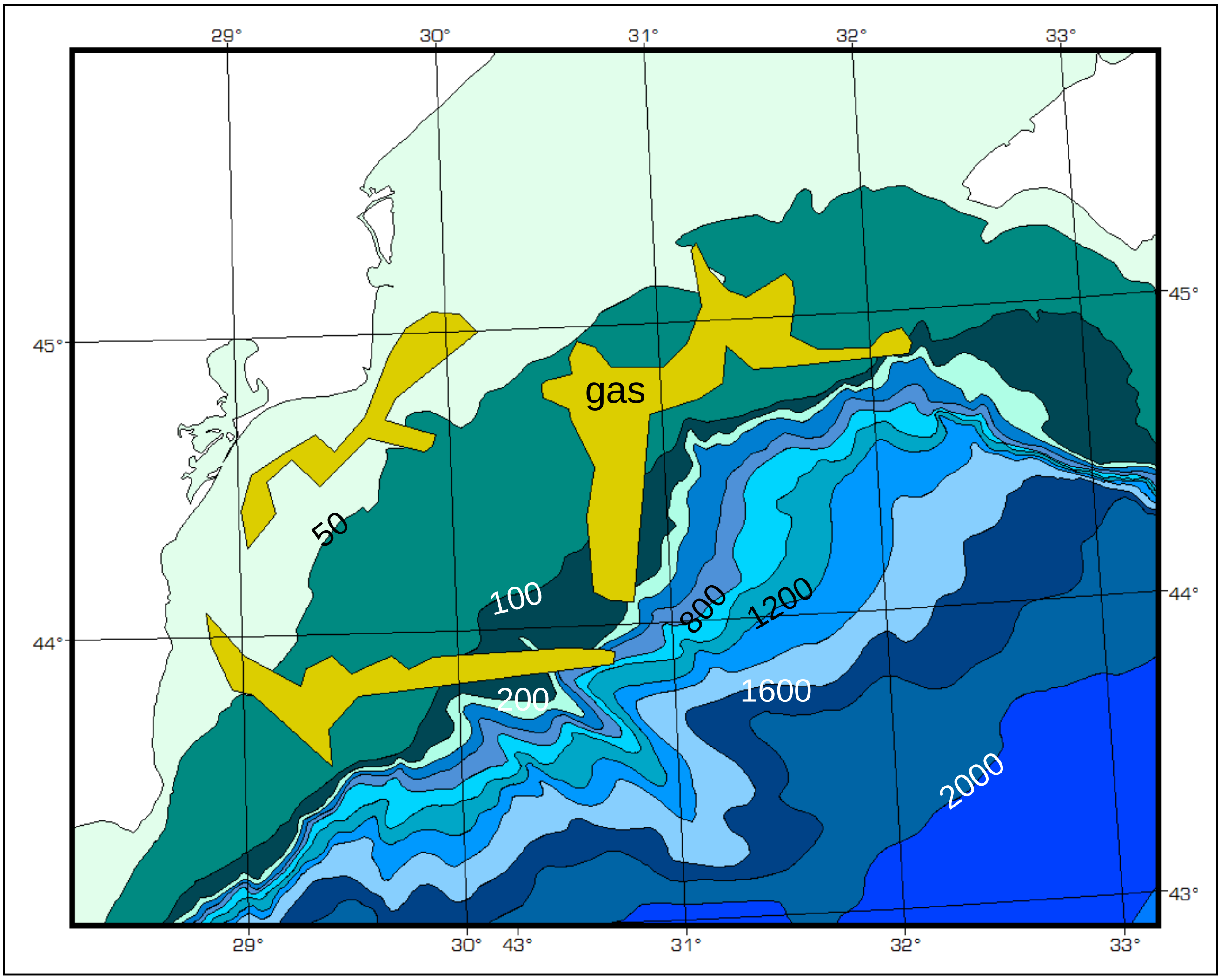
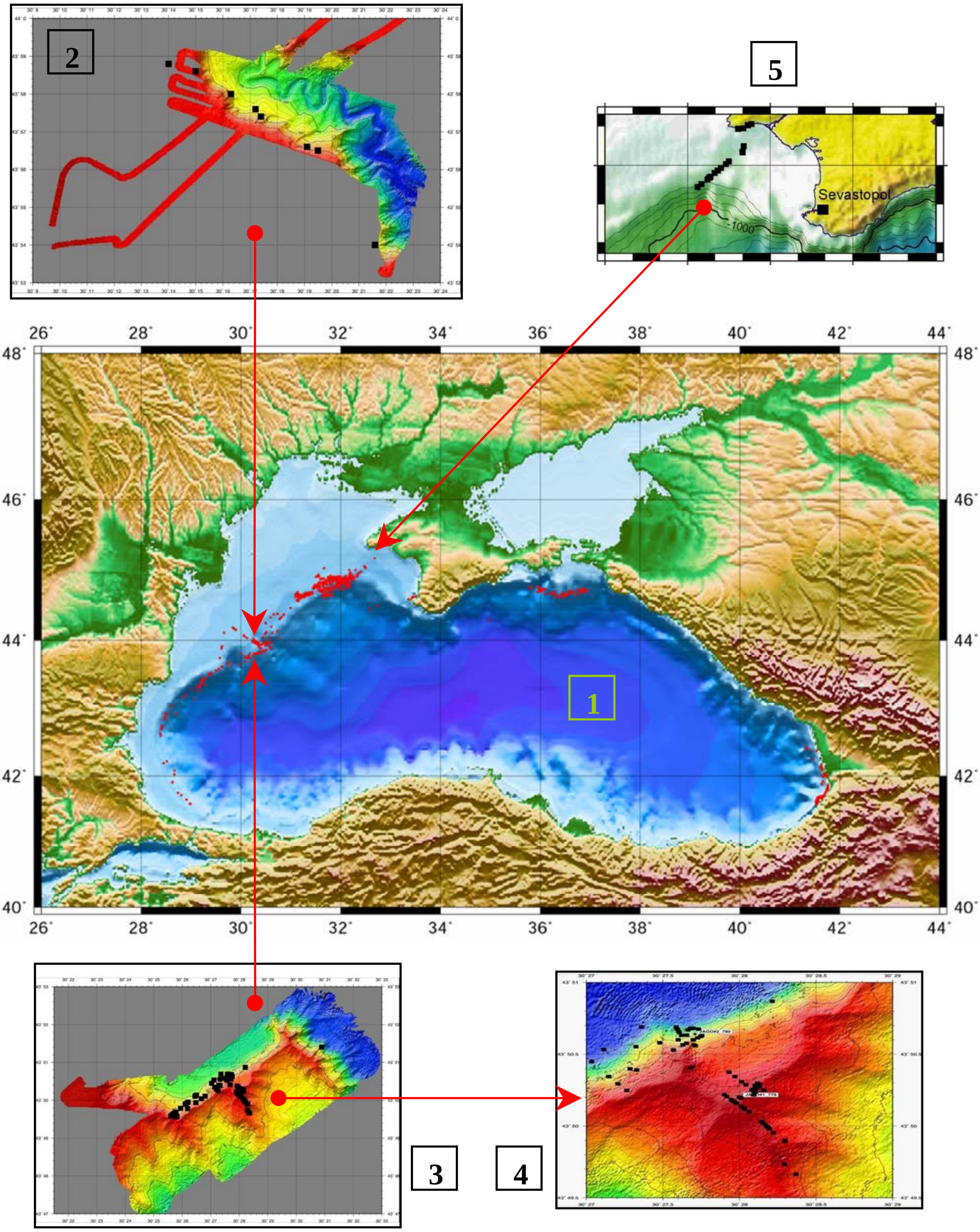


Figure 21 Presence of gas in shallow sediments of the NW Black Sea based on information extracted from GeoEcoMar databases and new data produced in the METROL project

6.3 Gas seeps

The purpose of this study is to synthesise all IBSS data on sea-floor mapping and acoustic echosounding of gas seeps obtained in 1994-2003 over the Dnepr paleo-delta area (NW Black Sea shelf-break the upper slope). Figure 22 presents a summary of this work.



1 – the Black Sea map with indication of all seeps found in 1989-2004
(red dots, *after Egorov et al., 1998; 2003*);
2-4 – Danube Canyon (black dots, *Metrol data, 2004*);
5 – Shallow-water seeps near the Tarkhankut Cape (black dots, *Metrol data, 2003-2004*)

Fig. 22. Location maps of the Black Sea gas seeps.

This gives the basis for quantitative assessment of the total flux of methane emanating from the bottom sediments within this area where the most of the Black Sea seeps were found (Polikarpov et al., 1989; 1992; Egorov et al., 2003).

Acoustic measurements were carried out with the scientific echosounder SIMRAD EK-500 installed on R/V “Professor Vodyanitskiy” and equipped with the hull-mounted 37.878 kHz split-beam and 119.047 kHz single beam transducers.

The area of the Dnepr paleo-delta is almost 900 km^2. The bathymetric surveys conducted during 1994-2003 with SIMRAD EK-500 have retrieved a large canyon system related apparently to the ancient river channels. The total number of gas seeps found till now within the Dnepr paleo-delta area is over 1300. They are distributed mostly at the shelf edge and the upper slope. The shallowest seep occurs at a water depth of 65 m, the deepest seep was found at 785 m, i.e. close to the depth of the gas hydrate stability zone. Further processing of acoustic data will be used for flare imaging, single bubbles tracking and analyses of features of the gas phase flux produced by methane bubble streams.

7. GIS-maps

GIS-maps showing free gas distribution will be made public available as part of the METROL project (deliverable 8) using the ArcIMS Internet Map Server from ESRI. Access to the map server at AWI is provided via the METROL web-site http://www.metrol.org. The Internet Map Server allows the user to view and to print the maps on selected scales as needed. Presently, preliminary maps may be viewed, while fully updated maps shown in this report will be available by the end of the METROL project.

In the course of the METROL project there was a need for GIS-software that allowed for a more flexible mutual exchange of geographical data related to methane distribution than that provided by the ArcIMS accessed via the internet. Understanding and modelling the processes controlling the methane flux in marine sediments - the goal of the METROL project - requires integration of knowledge from different scientific disciplines: geophysics, geology, chemistry and microbiology. Therefore, easy access to detailed information from these disciplines related to any particular geographic area is valuable in planning new sampling locations as well as for interpretation of data obtained. An appropriate choice of GIS-software for this purpose appeared to be ArcExplorer, which may free of charge be downloaded form the ESRI web-site. Both ArcIMS and ArcExplorer require data be transformed into the ESRI shape file format in order to be imported into the viewer. Transformation of data into the shape file format may be done using different commercial products from ESRI or by software downloaded from the internet e.g. gen2shape. The advantage of ArcExplorer over ArcIMS is that it does not require access to the internet, furthermore the user may fairly easily add new data (layers) onto the view. Thus, it is useful for planning while at sea. The disadvantage of the ArcExplorer is that the user has to install the programme, which however appeared to be not very difficult. Using ArcExplorer one may choose different signatures and colours representing the data. For the beginner this may, however, seem a tedious process considering the over 40 shape files for the Skagerrak - Baltic Sea region. Therefore, particular ArcExplorer files (extension = axl) were constructed, that automatically import the relevant shape files for a given area using pre-defined signatures and colours for each data set. This way, the ArcExplorer is almost as easy to use as the ArcIMS Internet Map Server.

The CD-ROM distributed with this report contain the final gas contour maps for the Skagerrak - Baltic Sea region in the form of a shape file named gas.shp. The gas contour map may be viewed at any scale after having installed the ArcExplorer programme also contained on the CD-ROM. Furthermore, a short presentation on how to get started using ArcExplorer to view the gas contour map can be found as a power point presentation on the CD-ROM. The content of the power point presentation is shown in Appendix 2 of this report.

8 References

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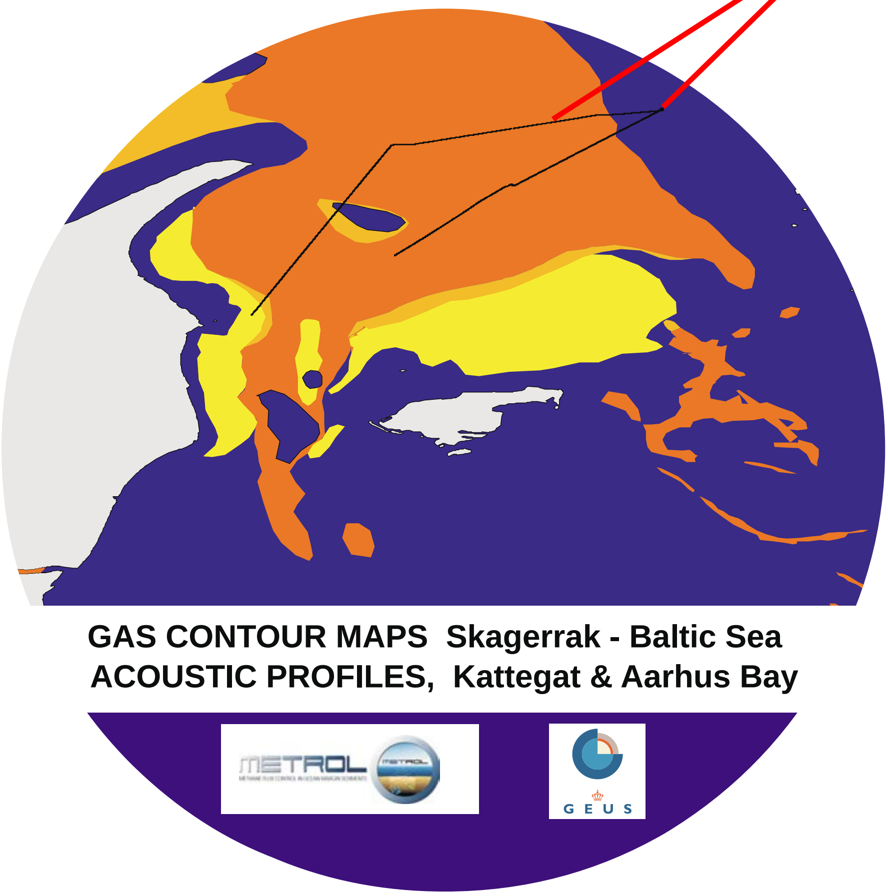
Appendix 1. How to open acoustic profiles on the CD-ROM

Digital acoustical profiles linked to navigational data constructed using SonarWeb software for display on personal computer using a web browser.

Sparker profile section "Kattegat02c1" shown on next pages



Content of readme.txt

This CD-ROM contains part of the sparker profiles that were recorded during the METROL cruise with M/S Gunnar Thorson during April 2003. See the profiles using your web browser. Simply enter the "Sparker profiles" folder, click on Index.html and follow the instructions. For more help read the “Intro to SonarWeb incl METROL acoustic profiles.pdf” file. Information on the SonarWeb software used to create the profiles for your browser see http://www.chesapeaketech.com/
Chirp profiles recorded in the Aarhus Bay area in March 2005 can be found in the “Chirp profiles” folder.

Gas contour maps based on existing acoustic profiles can been seen using a proper GIS viewer together with the ESRI shape files in the sub-folder of "Shape files" on this CD-ROM. You may use ArcExplorer in the "Viewer" sub-folder for this purpose. This GIS software has been downloaded from the www.esri.com website. To install the programme on your computer simply click on the ZIP file and follow instructions. The powerpoint presentation is intended as a "how to get started" introduction. It also contains an overview of gas contour maps in different areas of the Skagerrak-Kattegat-Baltic Sea region. Using the information on this CD-ROM you will also be able to see the location of METROL sample stations as well as the position of the acoustic lines recorded during METROL cruises. Information on gas seeps as well as other relevant data gathered from other sources have also been included on the CD-ROM.

Pre-view of Index.htlm file in "Sparker Profiles" folder

k/Greenland

kattegat-nord

Project Information	
WGS 1984 UTM, Zone 32 North, Meter	
Item	**Description**
Number of Acoustic Data Files	10
Total Acoustic Data Size (MB)	449.4
Total Line Length (Meters)	100389.1
Total Swath Area (SQ. Meters)	0.0

Click to see this section of the profile

Click on Seismic File for full Details

Data File	File Size	Start Time	End Time	Line Length
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat01a_PROC.TRA	51260 KB	Unavailable	Unavailable	11712.5
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat01b_PROC.TRA	52389 KB	Unavailable	Unavailable	12226.7
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat01c_PROC.TRA	51391 KB	Unavailable	Unavailable	12029.1
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat02a_PROC.TRA	51346 KB	Unavailable	Unavailable	11758.5
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat02b_PROC.TRA	51104 KB	Unavailable	Unavailable	11567.7
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat02c1_PROC.TRA	52480 KB	Unavailable	Unavailable	11626.8
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat02c_PROC.TRA	27280 KB	Unavailable	Unavailable	6005.9
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat06a_PROC.TRA	51391 KB	Unavailable	Unavailable	10608.2
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat06b_PROC.TRA	51366 KB	Unavailable	Unavailable	10872.2
F:\data\gunnar_metrol_03\Sparker_metrol_03\elics data\Kattegat06c_PROC.TRA	9438 KB	Unavailable	Unavailable	1981.5

Sonar Processing by SonarWeb V3.14B PRO Chesapeake Technology Inc.

Pre-view of Kattegat02c1 section

f Denmark/Greenland

kattegat-nord: File Kattegat02c1_PROC.TRA

Seismic Info		
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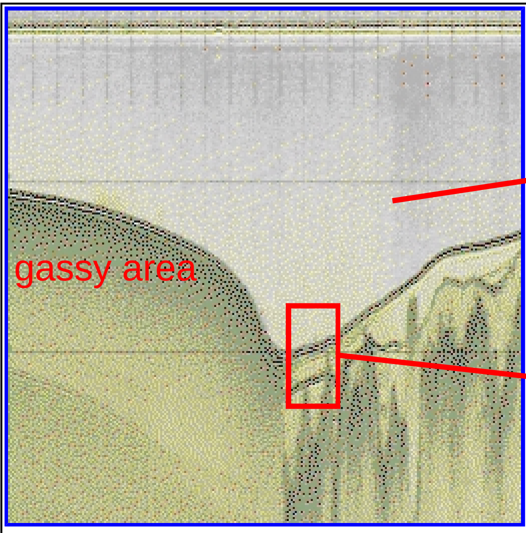
First Ping Time	Unavailable	
Last Ping Time	Unavailable	
First Ping Number	256	
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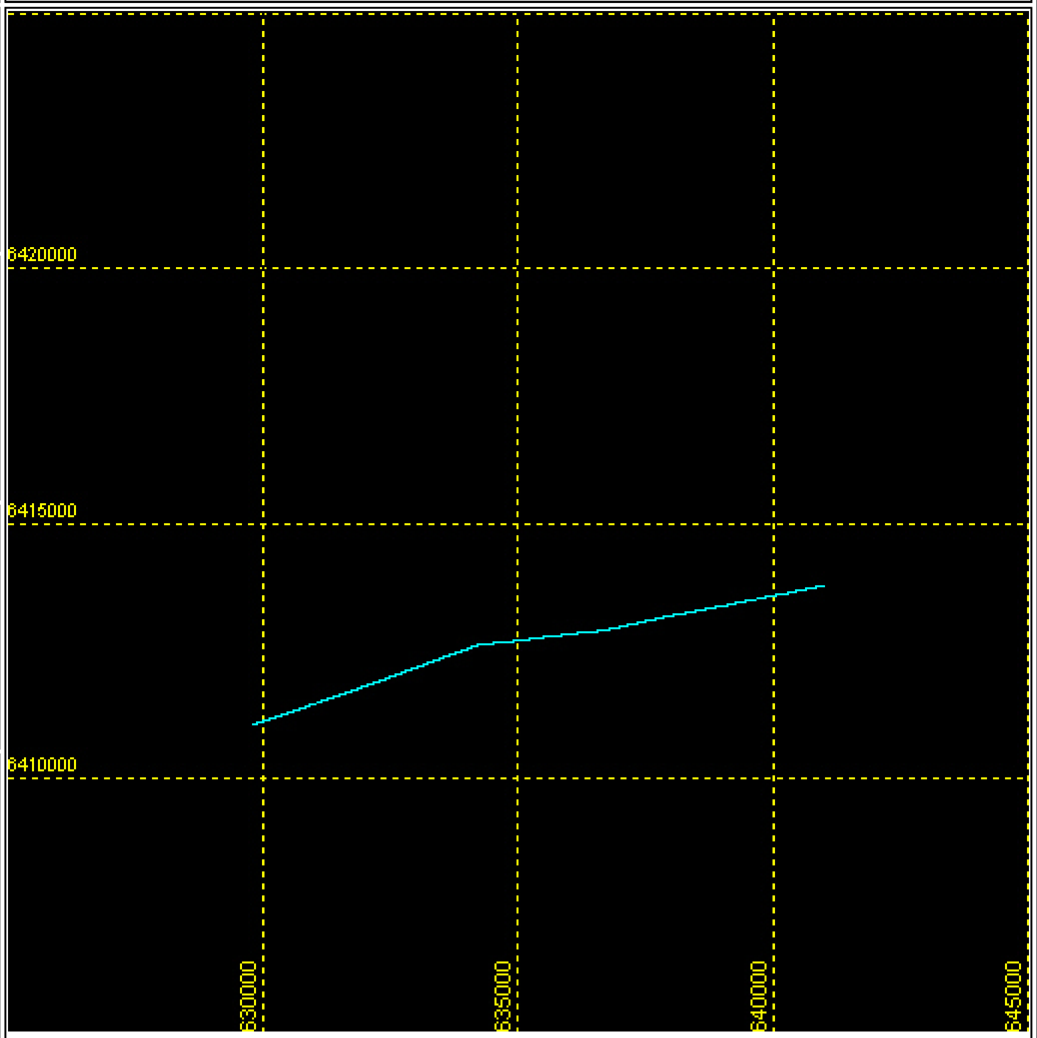
# Pings Displayed	256	

click to see the full image

Section shown on next page

Navigation Statistics		
Item	**Description**	**Details**
Minimum Northing Minimum Latitude	6411002.4 57° 49.3282' N	
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Minimum Easting Minimum Longitude	629750.3 011° 11.0701' E	
Maximum Easting Maximum Longitude	640993.6 011° 22.5141' E	

General File Information	
Item	**Description**
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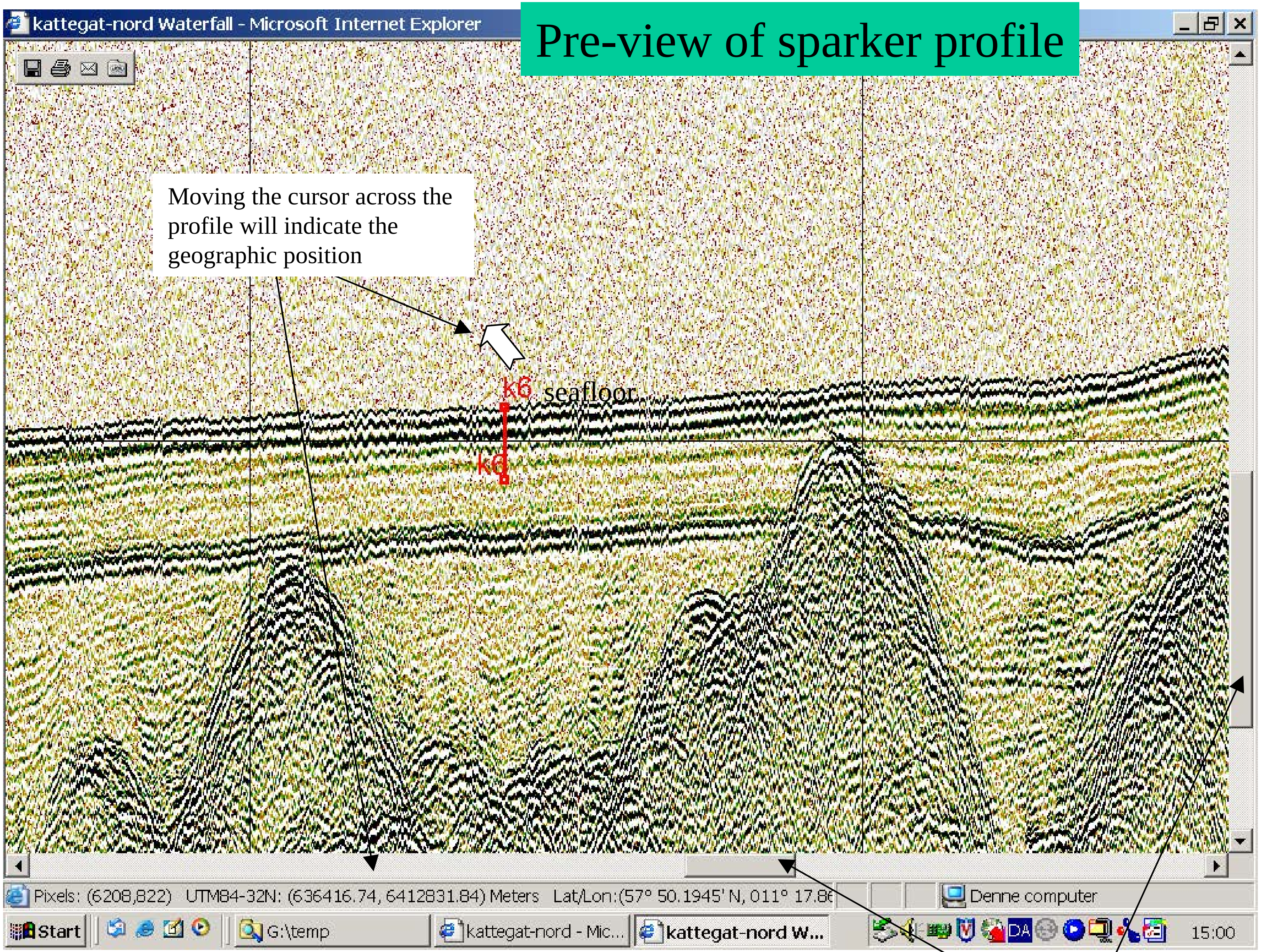
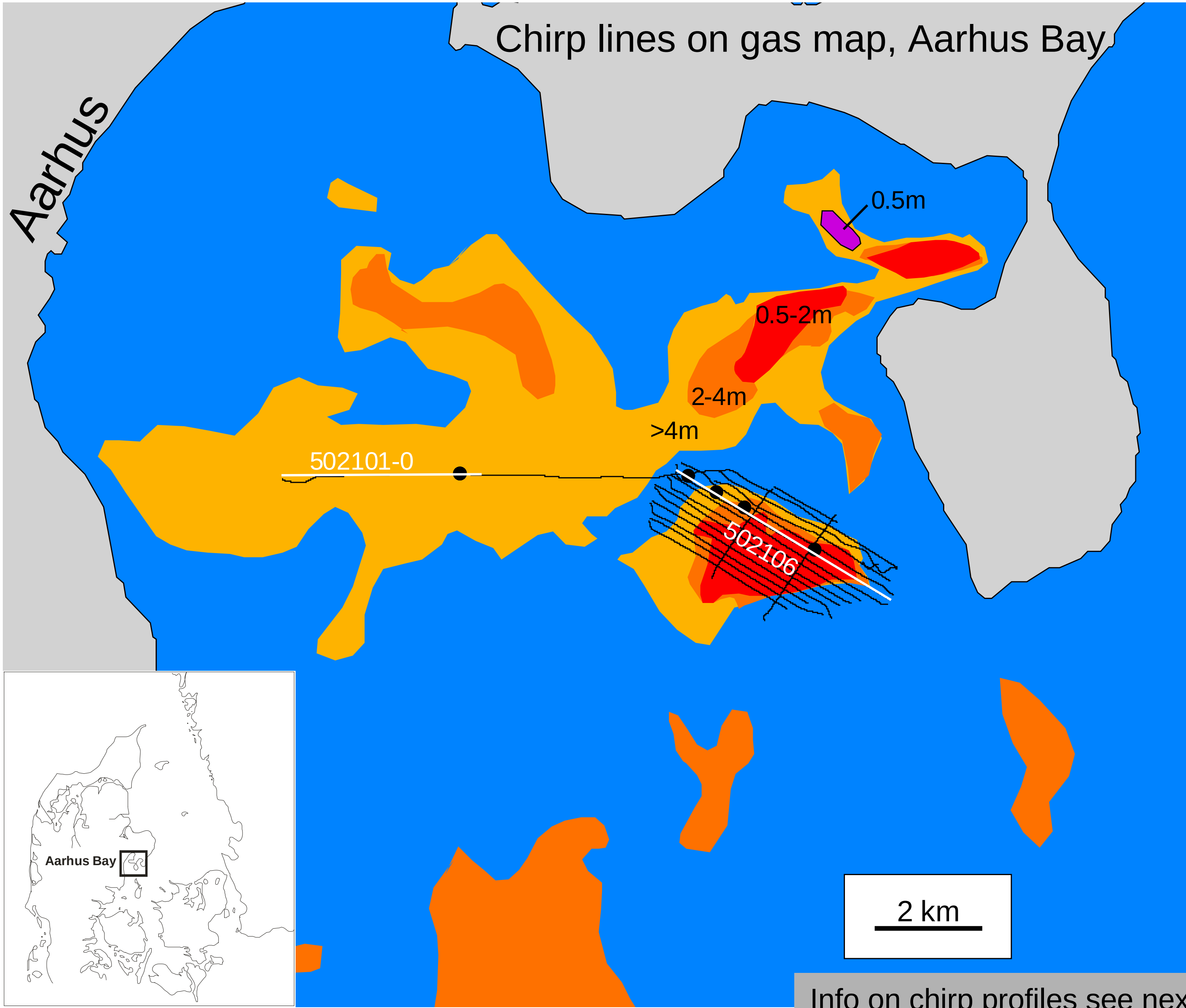
EBCDIC Header	

Pre-view of sparker profile



Scroll to see all of the profile section



Info on chirp profiles see next pages

Pre-view of index.htlm file in "Chirp Profiles" folder

Sonar Processing by SonarWeb V3.16ZD PRO Chesapeake Technology, Inc To replace this message choose a custom logo under the 'HTML Title Block' Option	nd

chirp genetica

Project Information		
WGS-84 UTM, Zone 32-V, Meters		
Item	Description	Click thumbnail to see full navigation
Number of Acoustic Data Files	20	Click to see entire image
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Total Line Length (meters)	70572.0	
Total Swath Area (SQ. meters)	0.0	

click to see this section of the profile

Click on Seismic File for full Details				
Data File	File Size	Start Time	End Time	Line Length
N:\jbj\GENETICA 2005 METROL\502101-000.sgy	80001 KB	03/08/2005 16:59:48	03/08/2005 17:17:54	3711.4
N:\jbj\GENETICA 2005 METROL\502101-001.sgy	80001 KB	03/08/2005 17:17:54	03/08/2005 17:36:01	3925.5
N:\jbj\GENETICA 2005 METROL\502101-002.sgy	80001 KB	03/08/2005 17:36:01	03/08/2005 17:54:09	3965.8
N:\jbj\GENETICA 2005 METROL\502101-003.sgy	20044 KB	03/08/2005 17:54:09	03/08/2005 17:58:40	1019.7
N:\jbj\GENETICA 2005 METROL\502103.sgy	8274 KB	03/08/2005 18:01:25	03/08/2005 18:03:16	380.0
N:\jbj\GENETICA 2005 METROL\502103a.sgy	91937 KB	03/08/2005 18:09:25	03/08/2005 18:30:14	4154.9
N:\jbj\GENETICA 2005 METROL\502104.sgy	83998 KB	03/08/2005 18:33:24	03/08/2005 18:52:25	4001.0
N:\jbj\GENETICA 2005 METROL\502105.sgy	105955 KB	03/08/2005 18:55:06	03/08/2005 19:19:06	4915.5
N:\jbj\GENETICA 2005 METROL\502106.sgy	104408 KB	03/08/2005 19:20:07	03/08/2005 19:43:45	5054.5
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N:\jbj\GENETICA 2005 METROL\502115.sgy	55963 KB	03/08/2005 22:41:19	03/08/2005 22:53:59	2534.9
N:\jbj\GENETICA 2005 METROL\502116.sgy	30709 KB	03/08/2005 22:55:21	03/08/2005 23:02:12	1412.7
N:\jbj\GENETICA 2005 METROL\502117.sgy	44727 KB	03/08/2005 23:02:45	03/08/2005 23:12:51	2108.6

Sonar Processing by SonarWeb V3.16ZD PRO Chesapeake Technology Inc.

Sonar Processing by SonarWeb V3.16ZD PRO Chesapeake Technology, Inc To replace this message choose a custom logo under the 'HTML Title Block' Option	Geological Survey of Denmark/Greenland Jørn Jensen

chirp genetica: File 502101-000.sgy

Seismic Info		
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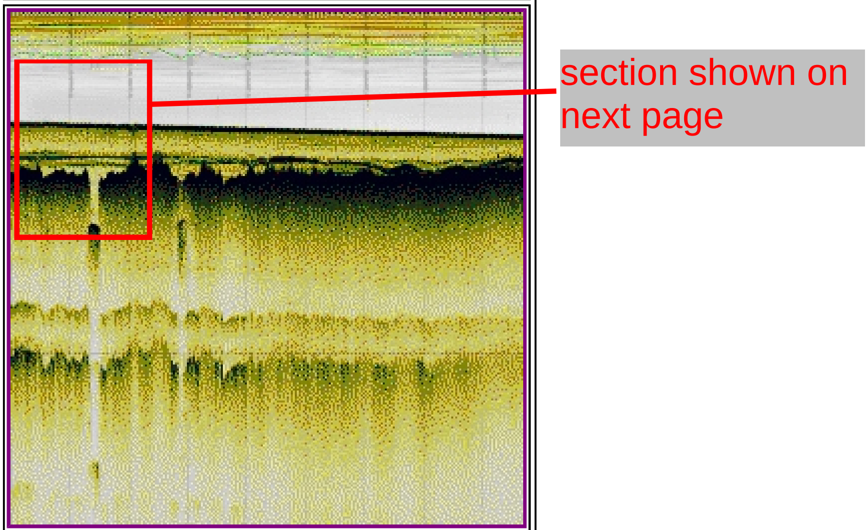
First Ping Time	03/08/2005 16:59:48	
Last Ping Time	03/08/2005 17:17:54	
First Ping Number	1	
Last Ping Number	4343	
# Pings Displayed	256	

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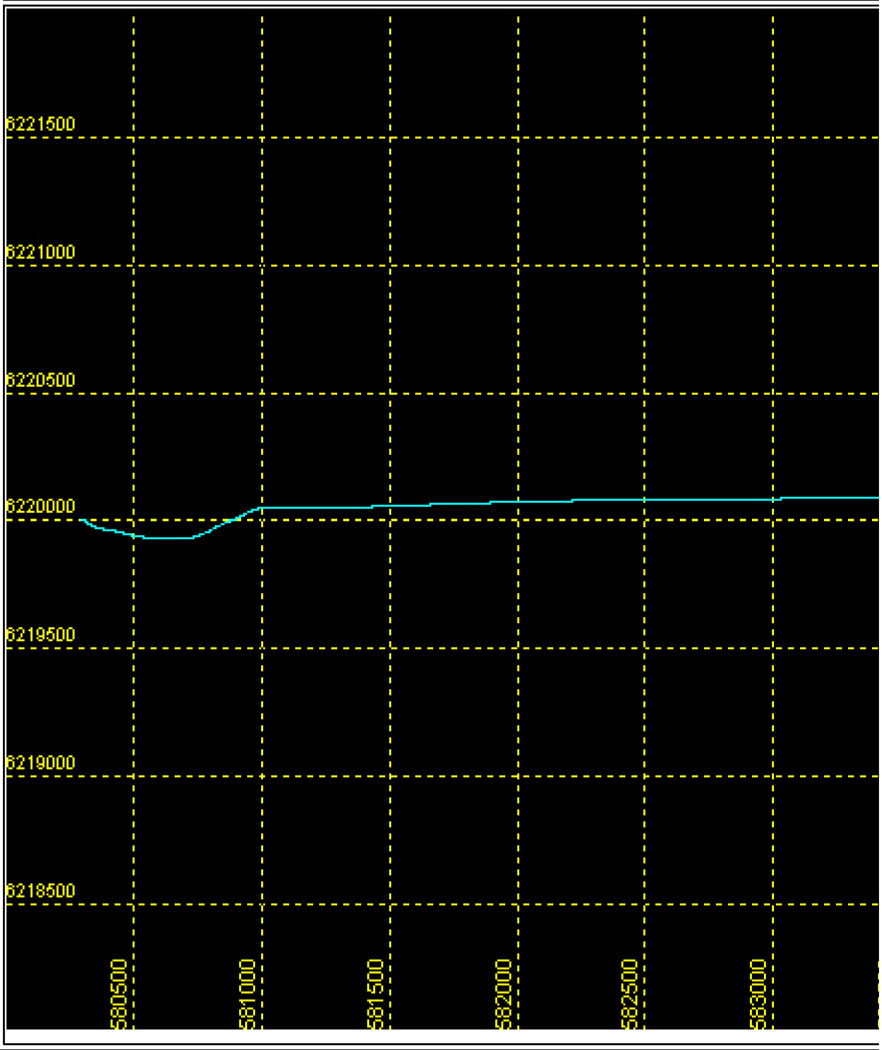
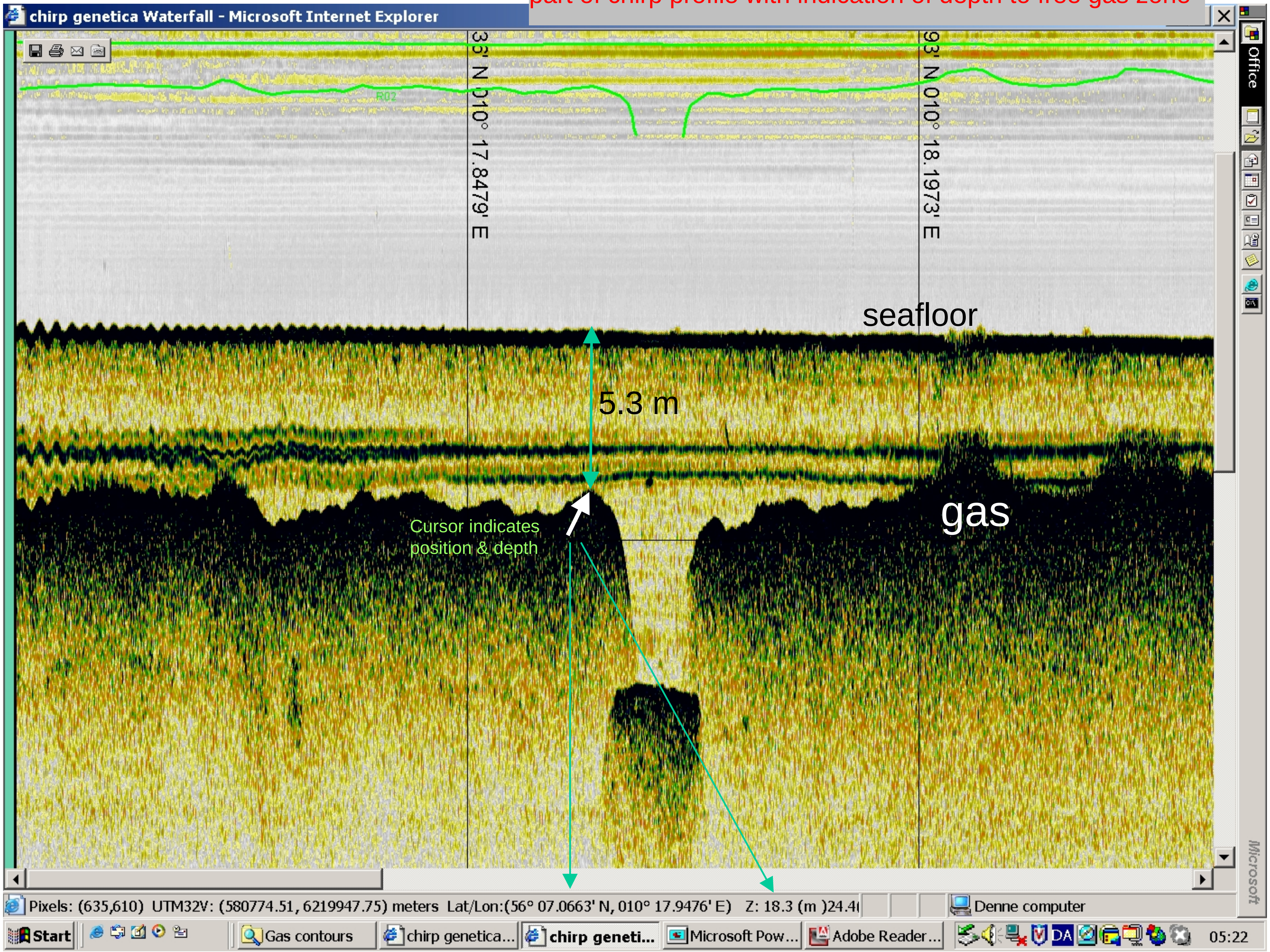
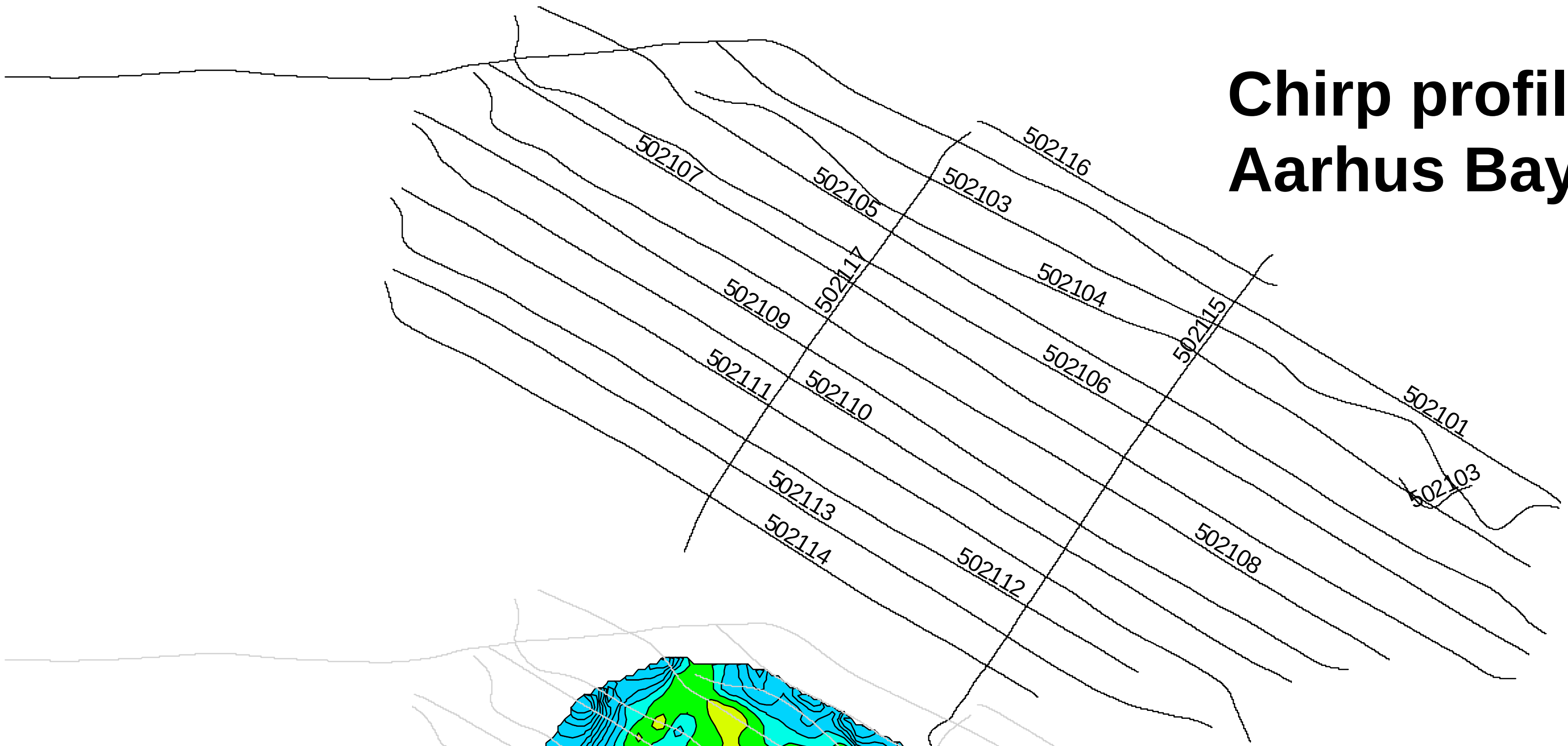
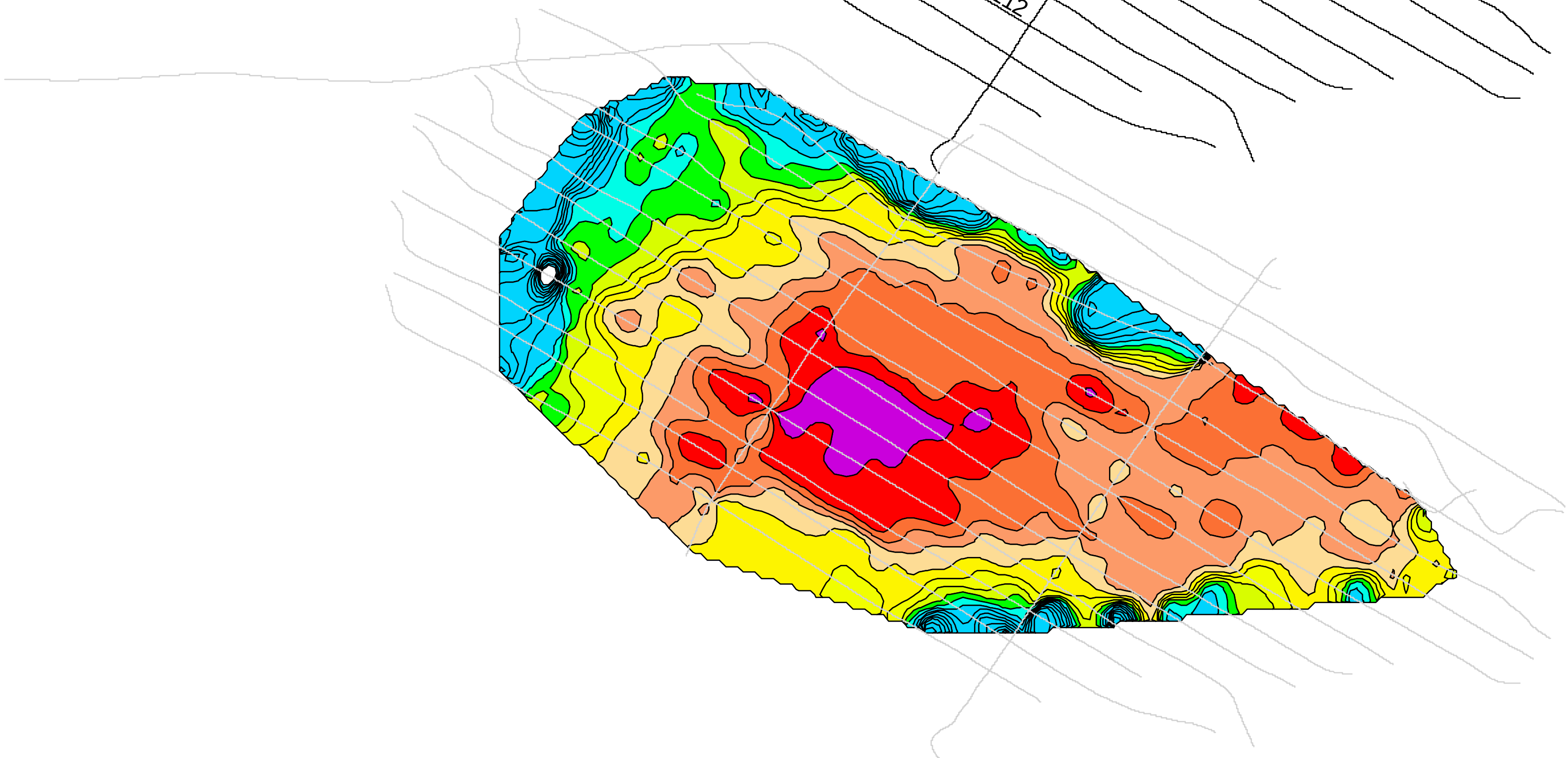
Minimum Northing Minimum Latitude	6219915.0 56° 07.0535' N	
Maximum Northing Maximum Latitude	6220113.7 56° 07.1228' N	
Minimum Easting Minimum Longitude	580290.4 010° 17.4800' E	
Maximum Easting Maximum Longitude	583958.1 010° 21.0220' E	

part of chirp profile with indication of depth to free gas zone

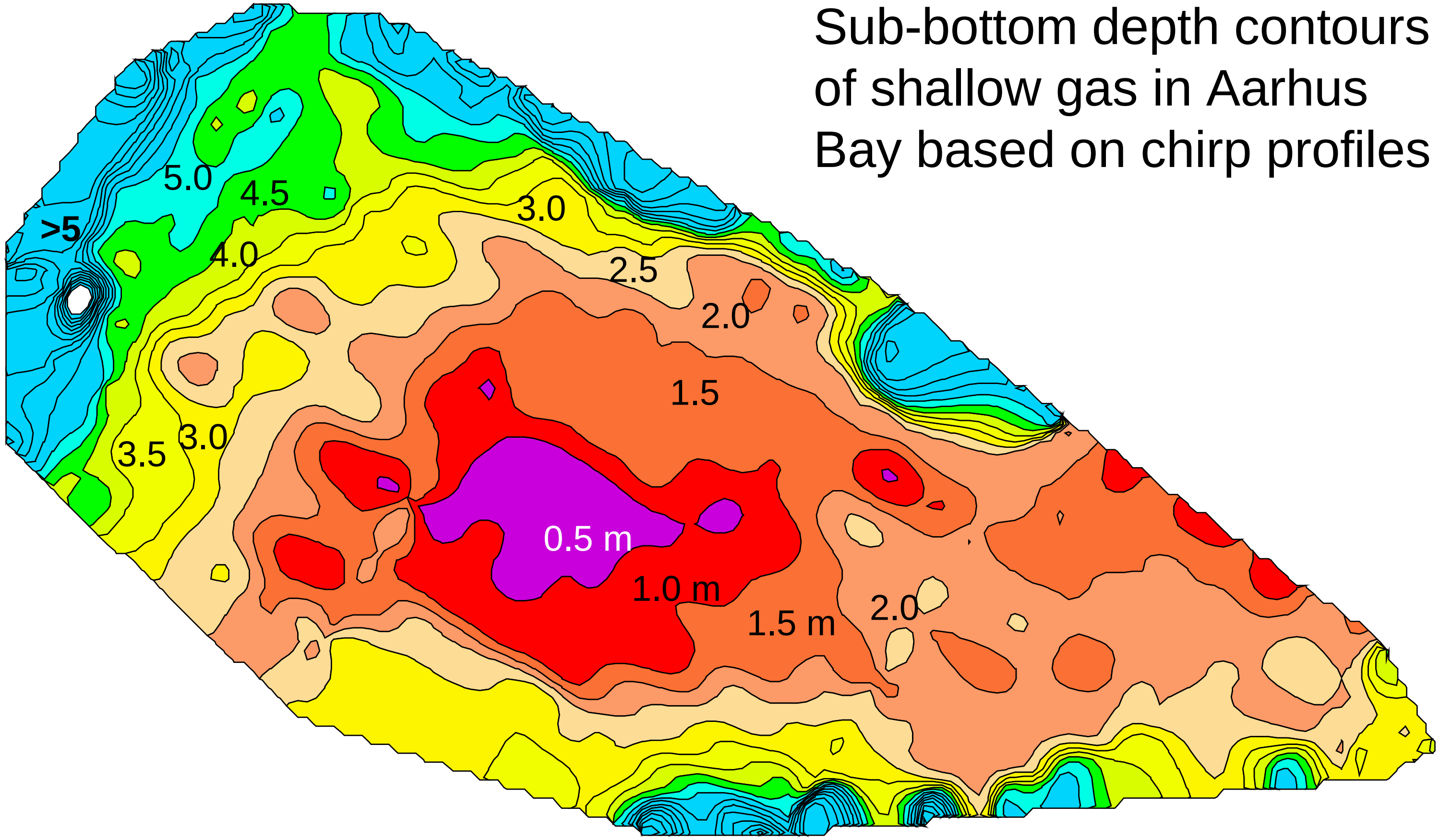


Chirp profiles Aarhus Bay





Sub-bottom depth contours of shallow gas in Aarhus Bay based on chirp profiles



Appendix 2. How to open the GIS maps on the CD-ROM

Content of PowerPoint file, that gives a short introduction to the ArcExplorer GIS programme, plus an overview of GIS maps.

Distribution of free gas in sediments

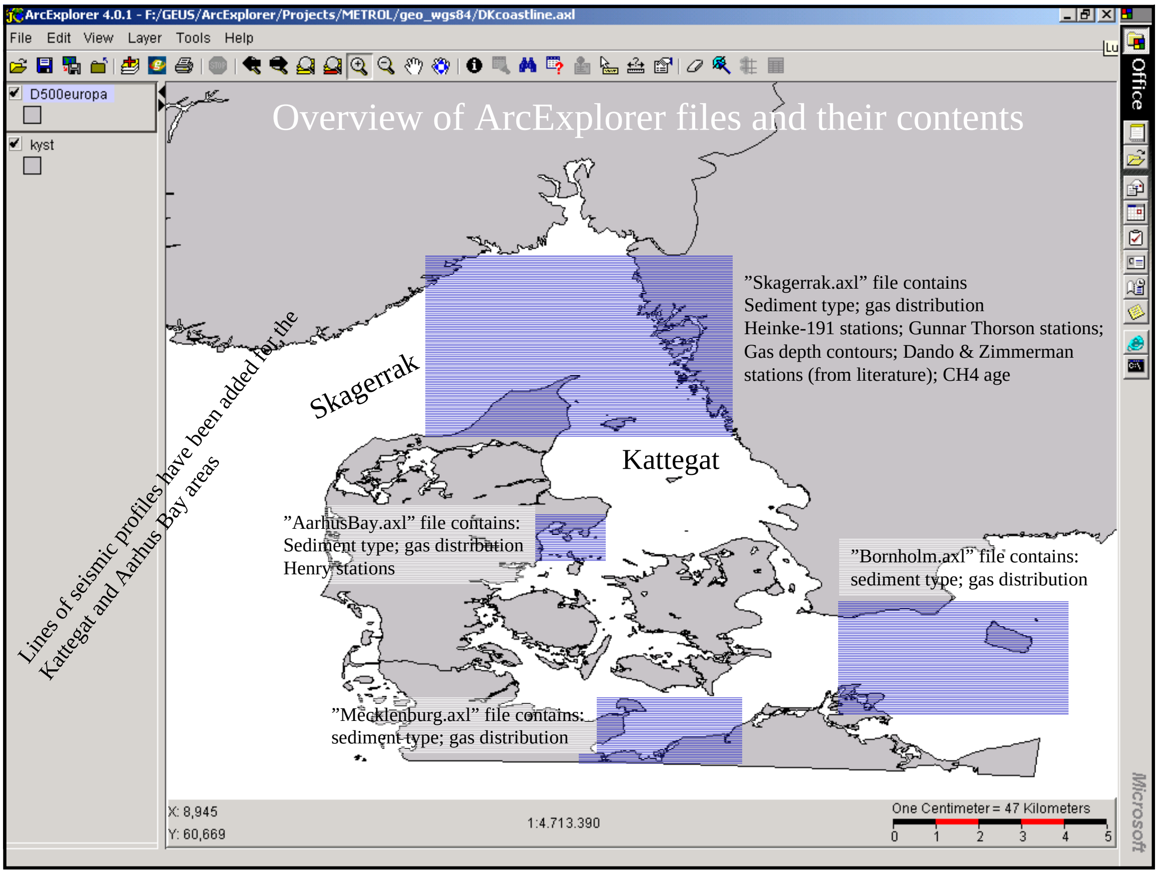
Based on existing acoustic data

Information on free gas distribution is located in the shape file ”gas.shp” (together with gas.shz and gas.dbf)

The data may be viewed using either ArcView or ArcExplorer. The latter being freeware can be found on the CD-ROM.

Data on sediment type and sample stations are included in other shape files together with ”gas.shp” in the ”Shape Files” sub-folder. A list of all shape files may be found on the last slide of this presentation.

The following short introduction should make it possible to get started without having to read any manual



The ArcExplorer file ”name.axl” is a simple text file that tells the program which shape files to include in the view. Furthermore, it includes legends for the various shape files (ensures that we all use the same colours for different sediment types).

Once ArcExplorer is running simply open one of the ”*.axl” files and you will get a view of the shape files associated with that ”axl” file, as is demonstrated later.

You may later choose to add more shape files (layers) and save the view in a new ”axl” file. Should you want to move your files a new directory or share this information with others please note the following.

Example of an axl file

```
<?xml version="1.0" encoding="UTF-8"?>

<ARCXML version="1.1">
  <CONFIG>
    <ENVIRONMENT>
      <LOCALE country="DK" language="da" variant="" />
      <UIFONT color="0,0,0" name="dialog" size="12" style="regular" />
      <SCREEN dpi="120" />
    </ENVIRONMENT>
    <MAP>
      <PROPERTIES>
                 <ENVELOPE minx="8,070298850112398" miny="53,75078746336937" maxx="15,838311740669077" maxy="57,86583697223469" name="Initial_Extent" />
                 <MAPUNITS units="decimal_degrees" />
      </PROPERTIES>
      <WORKSPACES>
                 <SHAPEWORKSPACE name="shp_ws-0" directory="." />
      </WORKSPACES>
      <LAYER type="featureclass" name="kyst" visible="true" id="0">
                 <DATASET name="kyst" type="polygon" workspace="shp_ws-0" />
                 <SIMPLERENDERER>
                   <SIMPLEPOLYGONSYMBOL boundarytransparency="1,0" filltransparency="1,0" fillcolor="192,192,192" boundarycaptype="round" />
                 </SIMPLERENDERER>
      </LAYER>
    </MAP>
  </CONFIG>
</ARCXML>
```

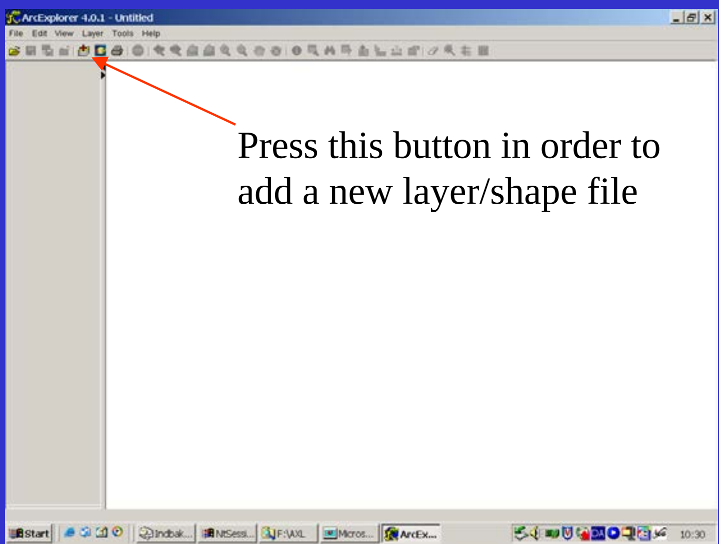
Name of original directory was changed to a dot. This allows the axl file to be used in any directory as long as shape files are in the same directory as the ”axl”.

Saving a view will put the name of the current directory in this place, meaning that you can only open the axl in that directory. You may simply change dir name to a dot using a text editor to be able to open axl in any directory.

A bit more complicated for Macintosh though, see the following

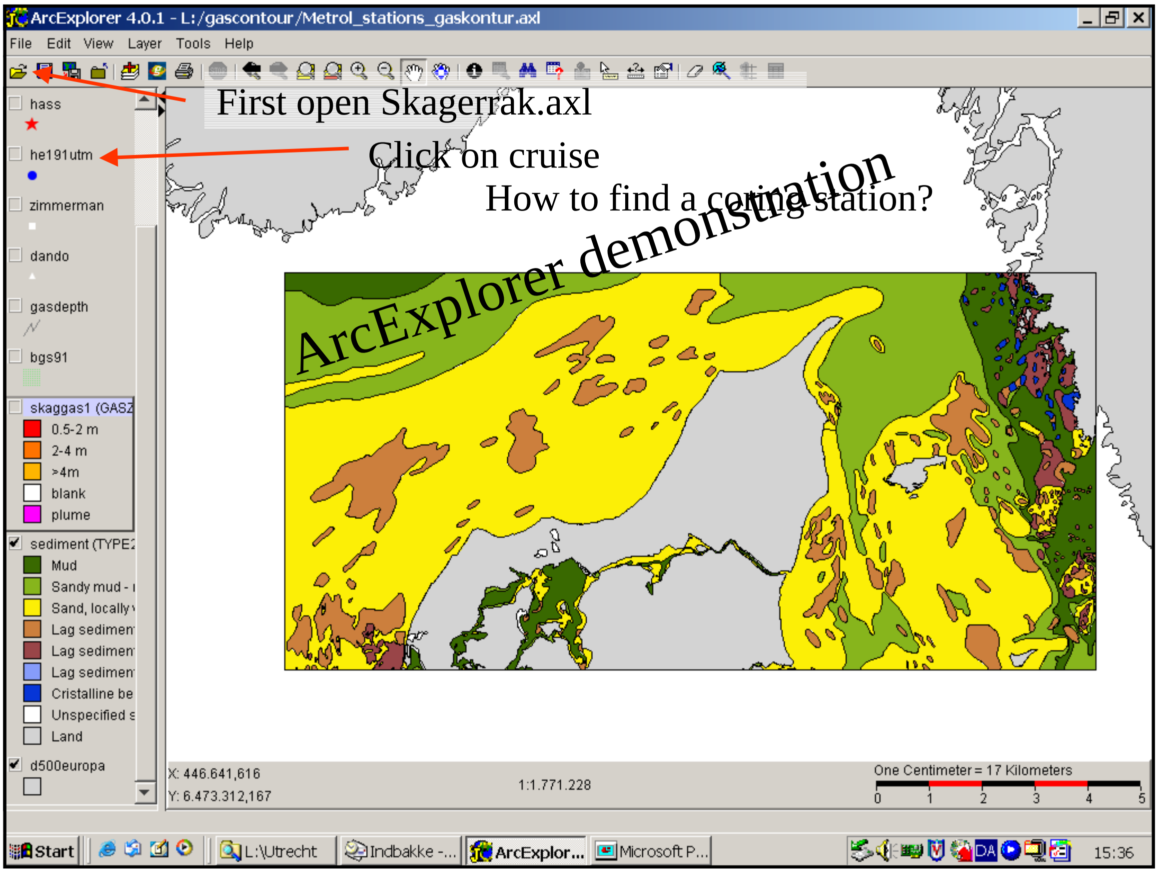
Macintosh users will have to edit the ”axl” file replacing the dot with /directory name before being able to open the axl file in ArcExplorer.

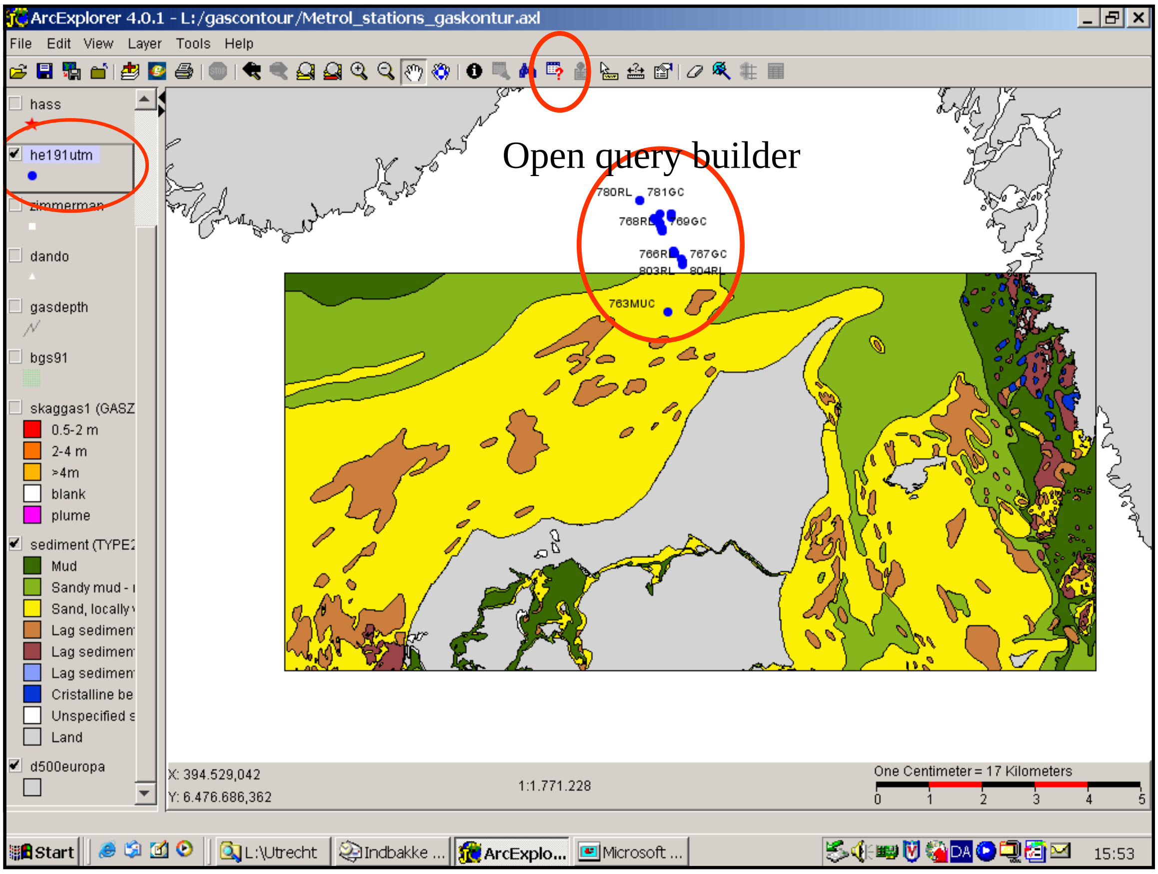
If you are not sure of the ”format” of the line in question you may open ArcExplorer, add any shp file from the ”Shape files” sub-directory to the empty view, then save as an axl file and look up the ”format” using a text editor.

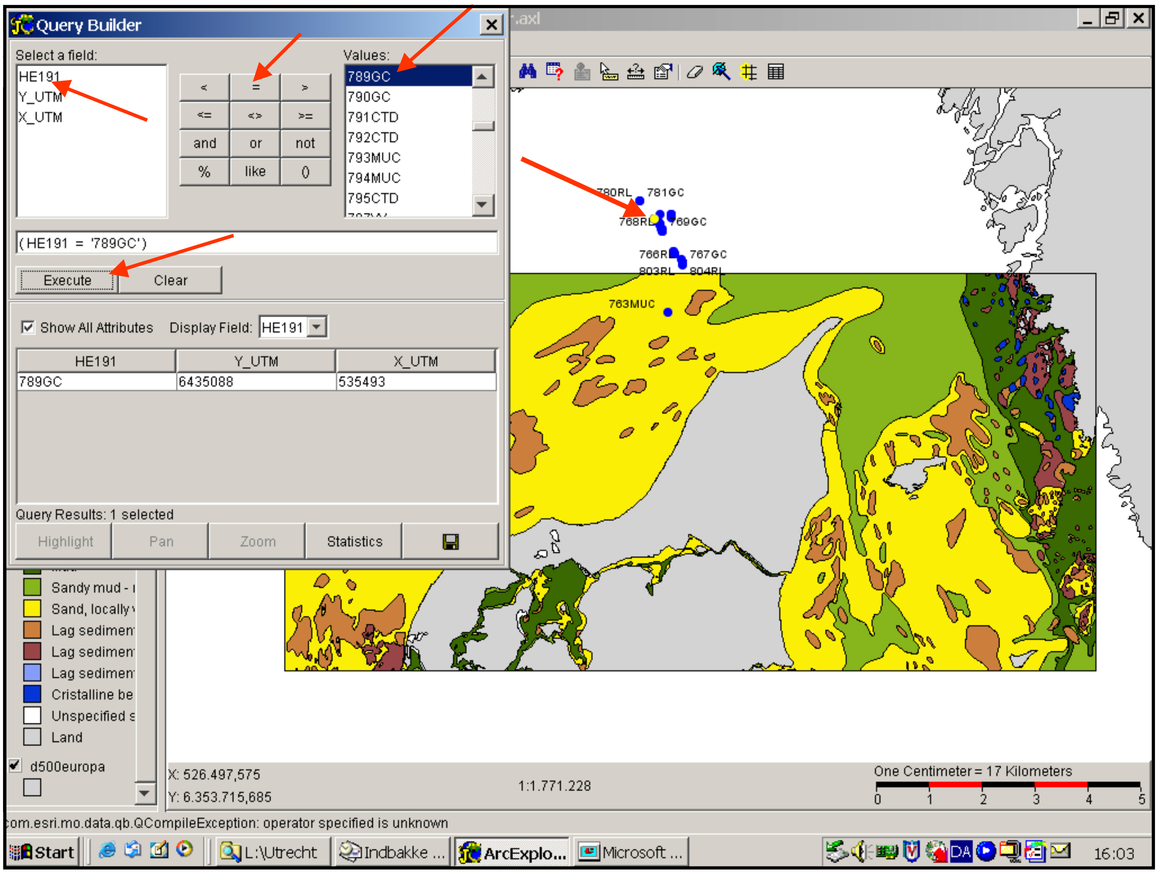


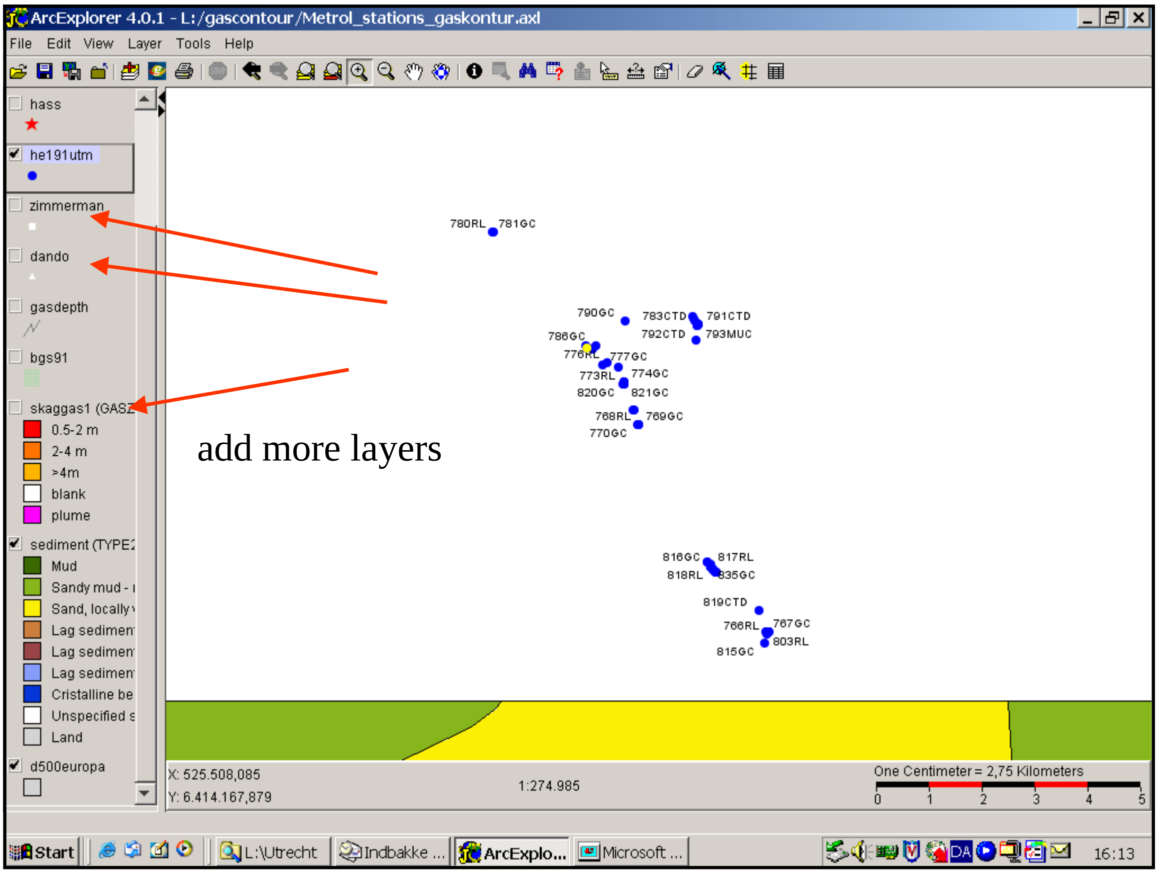
By the way, Macintosh users may obtain the ArcExplorer from this site:

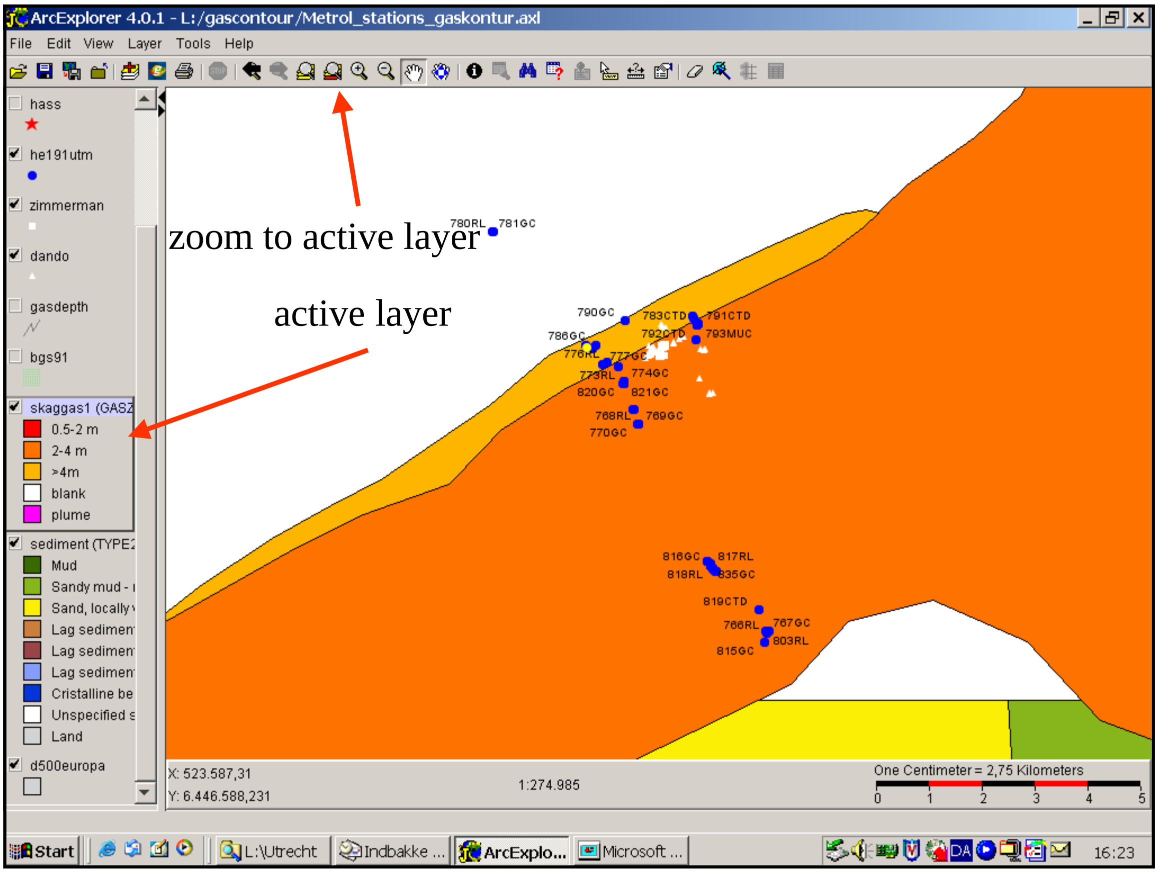
http://support.esri.com/index.cfm?fa=downloads.samplesUtilities.listSamples&PID=28

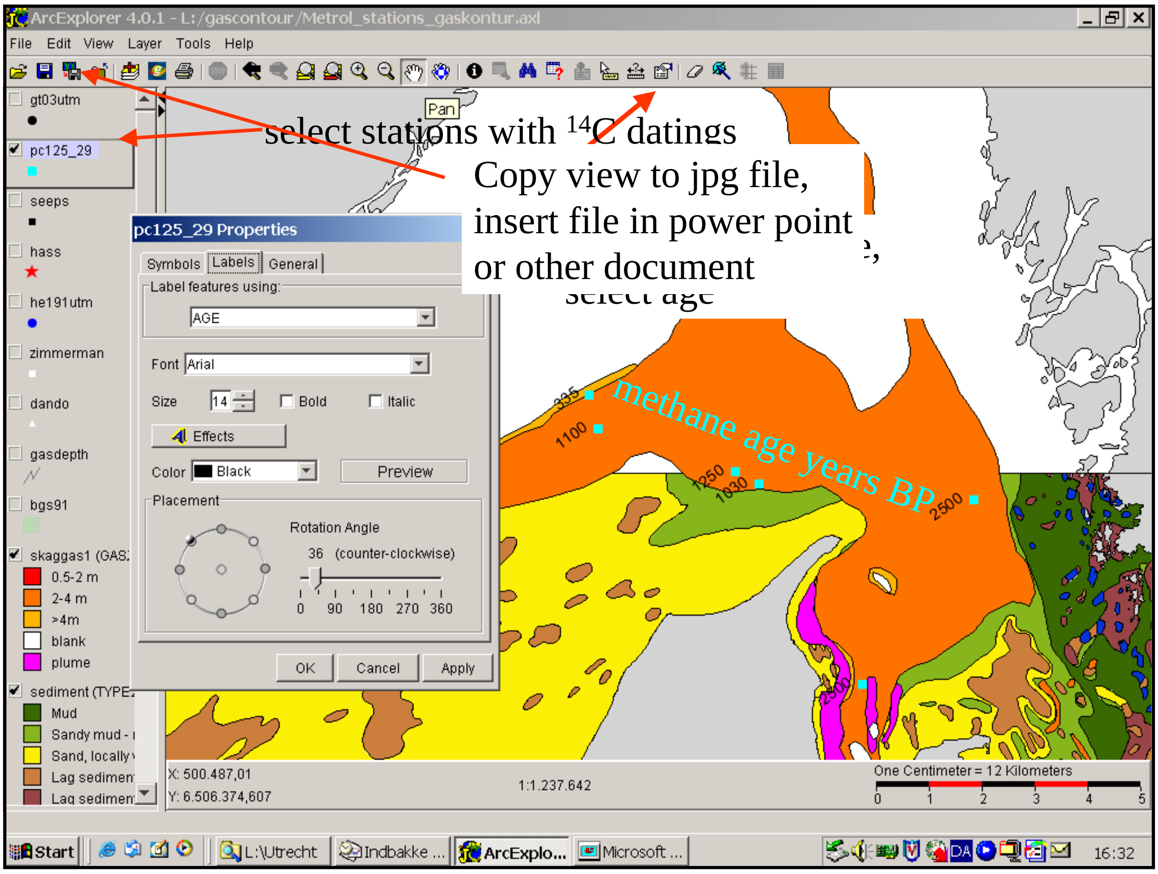

ArcExplorer 4.0.1 - L:/gascontour/Metrol_stations_gaskontur.axl
File Edit View Layer Tools Help
First open Skagerrak.axl
Click on cruise
How to find a coring station?
ArcExplorer demonstration
hass
he191utm
zimmerman
dando
gasdepth
bgs91
skaggas1 (GASZ
0.5-2 m
2-4 m
>4m
blank
plume
sediment (TYPE2
Mud
Sandy mud - i
Sand, locally v
Lag sedimen
Lag sedimen
Lag sedimen
Cristalline be
Unspecified s
Land
d500europa
X: 446.641,616
Y: 6.473.312,167
1:1.771.228
One Centimeter = 17 Kilometers
0 1 2 3 4 5
Start
L:\Utrecht
Indbakke -...
ArcExplor...
Microsoft P...
15:36

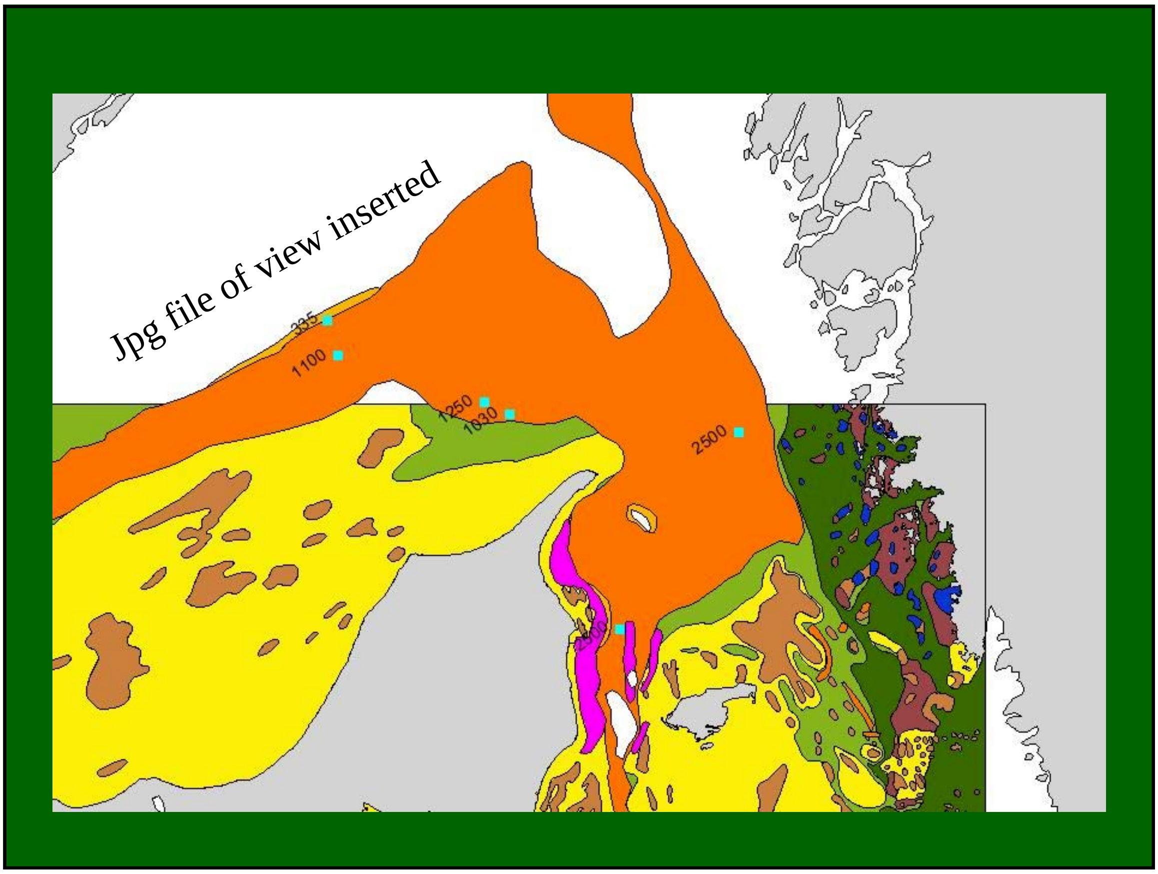

ArcExplorer 4.0.1 - L:/gascontour/Metrol_stations_gaskontur.axl
File Edit View Layer Tools Help
Open query builder
780RL
781GC
768RL
769GC
766RL
767GC
803RL
804RL
763MUC
hass
he191utm
zimmerman
dando
gasdepth
bgs91
skaggas1 (GASZ
0.5-2 m
2-4 m
>4m
blank
plume
sediment (TYPE2
Mud
Sandy mud - i
Sand, locally v
Lag sedimen
Lag sedimen
Lag sedimen
Cristalline be
Unspecified s
Land
d500europa
X: 394.529,042
Y: 6.476.686,362
1:1.771.228
One Centimeter = 17 Kilometers
0 1 2 3 4 5
Start
L:\Utrecht
Indbakke ...
ArcExplo...
Microsoft ...
15:53

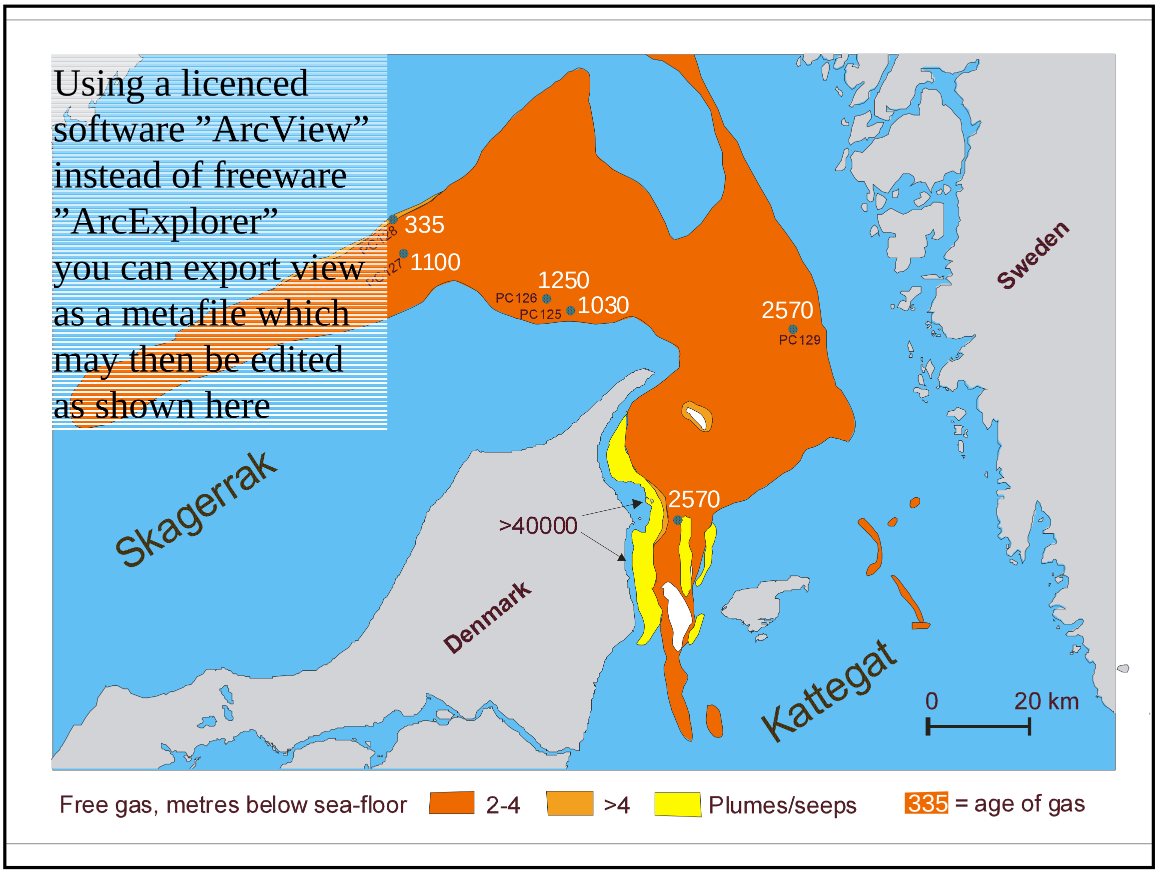

Query Builder
Select a field:
HE191
Y_UTM
X_UTM
Values:
789GC
790GC
791CTD
792CTD
793MUC
794MUC
795CTD
(HE191 = '789GC')
Execute
Clear
Show All Attributes
Display Field:
HE191
Y_UTM
X_UTM
789GC
6435088
535493
Query Results: 1 selected
Highlight
Pan
Zoom
Statistics
X: 526.497,575
Y: 6.353.715,685
1:1.771.228
One Centimeter = 17 Kilometers
com.esri.mo.data.qb.QCompileException: operator specified is unknown


ArcExplorer 4.0.1 - L:/gascontour/Metrol_stations_gaskontur.axl
File
Edit
View
Layer
Tools
Help
hass
he191utm
zimmerman
dando
gasdepth
bgs91
0.5-2 m
2-4 m
>4m
blank
plume
Mud
Cristalline be
Land
d500europa
add more layers
X: 525.508,085
Y: 6.414.167,879
1:274.985
One Centimeter = 2,75 Kilometers


ArcExplorer 4.0.1 - L:/gascontour/Metrol_stations_gaskontur.axl
File Edit View Layer Tools Help
hass
he191utm
zimmerman
dando
gasdepth
bgs91
skaggas1 (GASZ
0.5-2 m
2-4 m
>4m
blank
plume
sediment (TYPE2
Mud
Sandy mud -
Sand, locally
Lag sedimen
Lag sedimen
Lag sedimen
Cristalline be
Unspecified s
Land
d500europa
zoom to active layer
active layer
780RL
781GC
790GC
783CTD
791CTD
786GC
792CTD
793MUC
776RL
777GC
773RL
774GC
820GC
821GC
768RL
769GC
770GC
816GC
817RL
818RL
835GC
819CTD
766RL
767GC
803RL
815GC
X: 523.587,31
Y: 6.446.588,231
1:274.985
One Centimeter = 2,75 Kilometers
0 1 2 3 4 5
Start
L:\Utrecht
Indbakke ...
ArcExplo...
Microsoft ...
16:23


ArcExplorer 4.0.1 - L:/gascontour/Metrol_stations_gaskontur.axl
File Edit View Layer Tools Help
gt03utm
pc125_29
seeps
hass
he191utm
zimmerman
dando
gasdepth
bgs91
skaggas1 (GASZ
0.5-2 m
2-4 m
>4m
blank
plume
sediment (TYPE2
Mud
Sandy mud -
Sand, locally
Lag sedimen
Lag sedimen
Pan
select stations with ¹⁴C datings
Copy view to jpg file,
insert file in power point
or other document
pc125_29 Properties
Symbols
Labels
General
Label features using:
AGE
Font
Arial
Size
14
Bold
Italic
Effects
Color
Black
Preview
Placement
Rotation Angle
36 (counter-clockwise)
0 90 180 270 360
OK
Cancel
Apply
methane age years BP
335
1100
1250
1030
2500
2500
X: 500.487,01
Y: 6.506.374,607
1:1.237.642
One Centimeter = 12 Kilometers
0 1 2 3 4 5
Start
L:\Utrecht
Indbakke ...
ArcExplo...
Microsoft ...
16:32

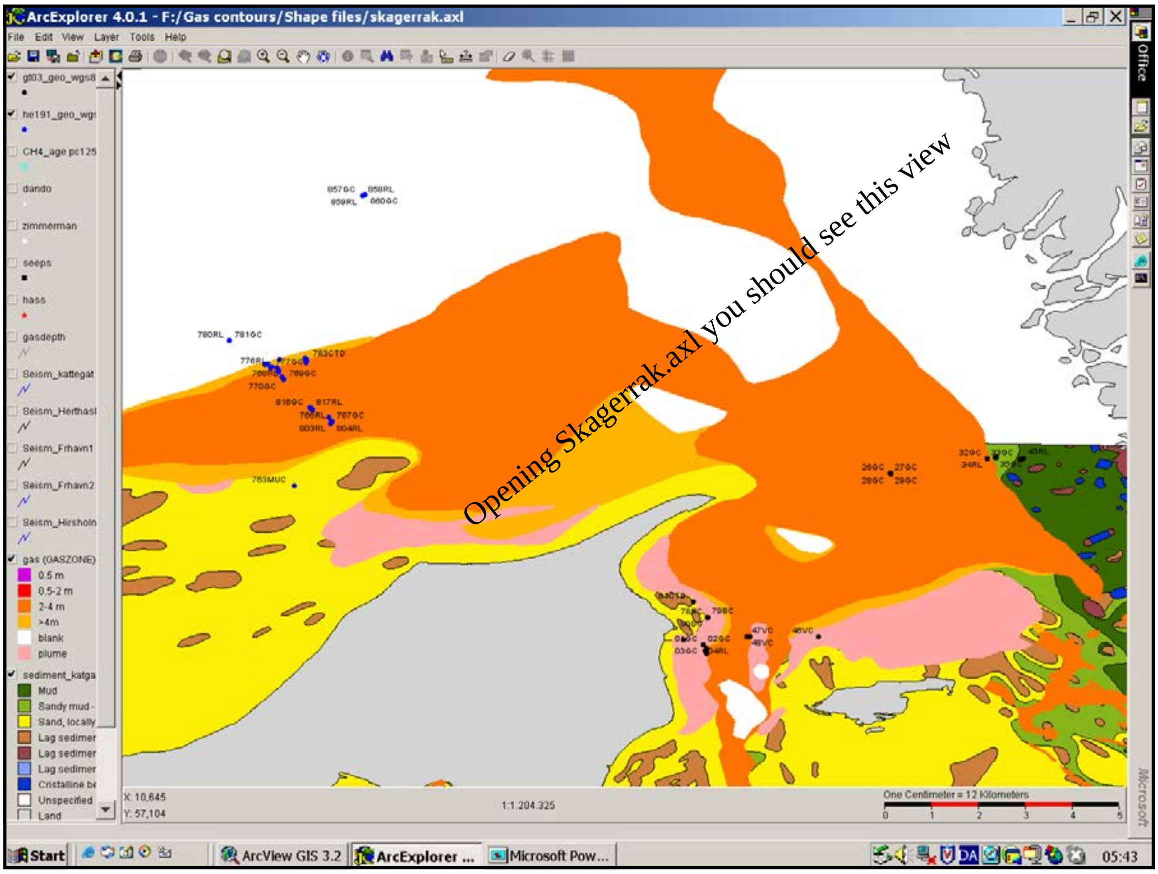

Jpg file of view inserted
335
1100
1250
1030
2500

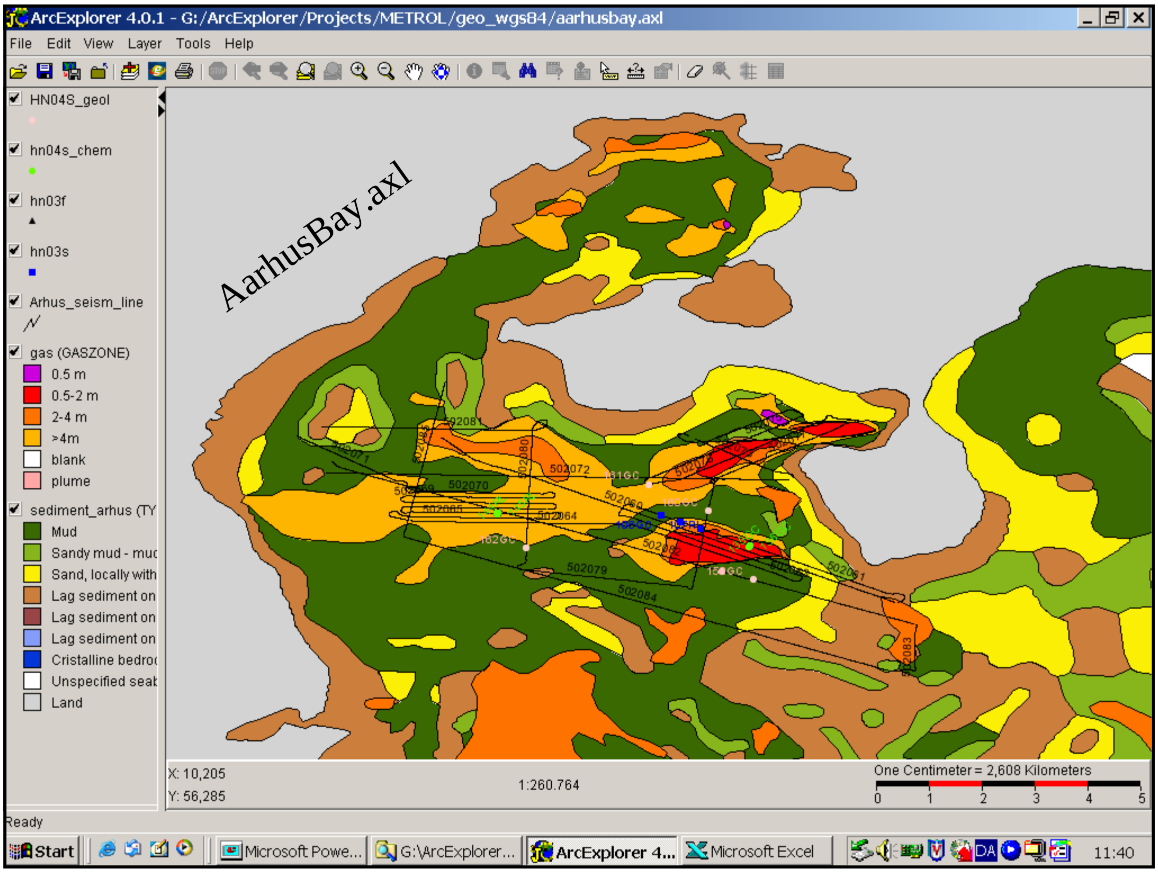

Using a licenced software ”ArcView” instead of freeware ”ArcExplorer” you can export view as a metafile which may then be edited as shown here
335
1100
1250
PC126
PC125
1030
2570
PC129
Sweden
Skagerrak
>40000
2570
Denmark
Kattegat
0
20 km
Free gas, metres below sea-floor
2-4
>4
Plumes/seeps
335 = age of gas

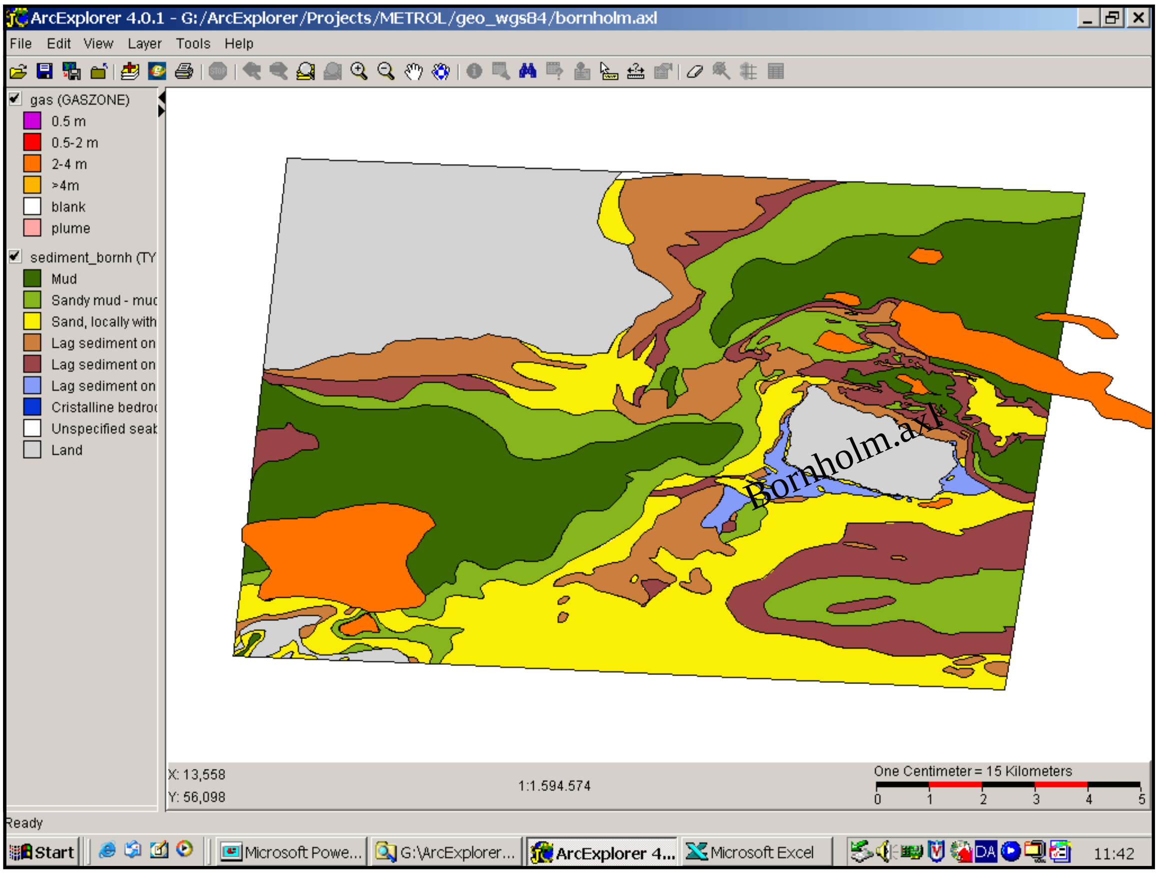
The shape files on sediment type included in the ”Shape Files” sub-directory only covers the METROL working areas

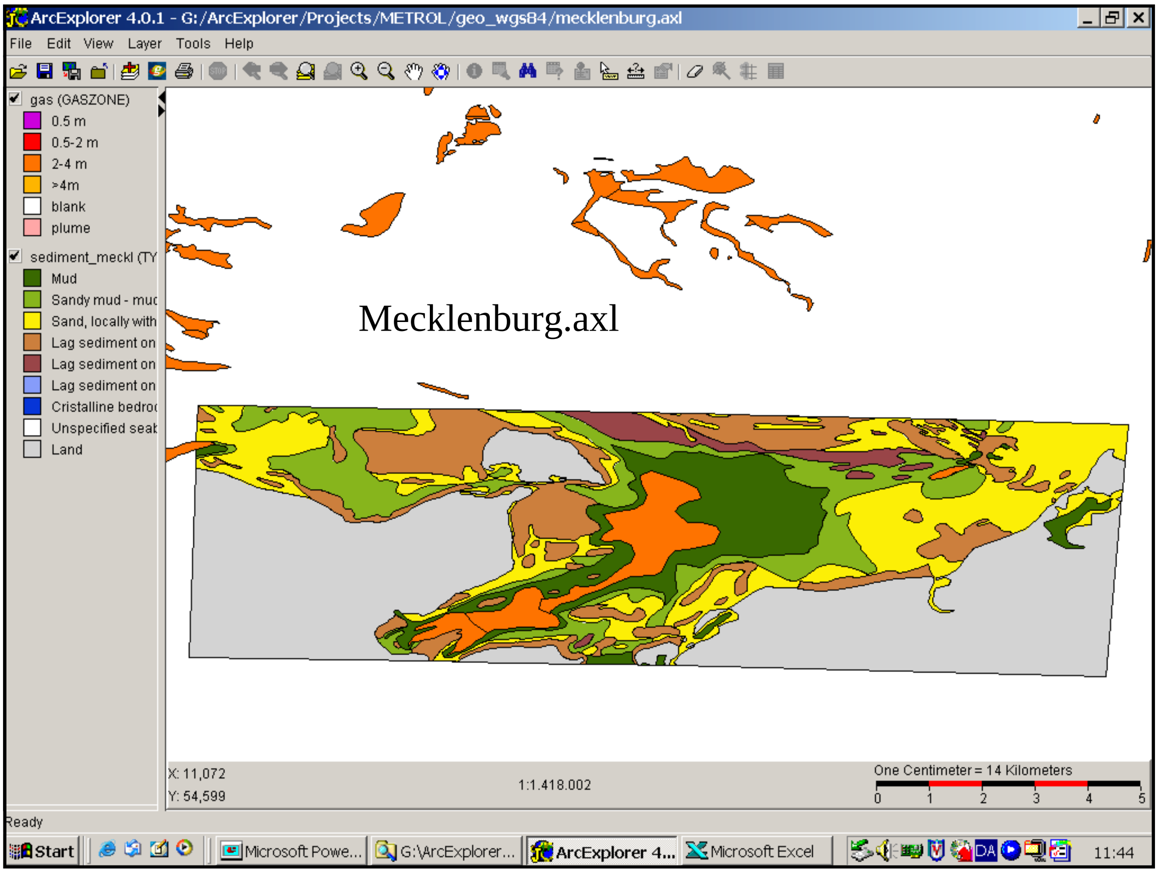
A sediment type map plus shape files covering all of the Danish waters may be obtained from the Geological Survey of Denmark and Greenland (GEUS).

A jepg file showing sediment type for all Danish waters can be found on the PANGEA web page.




ArcExplorer 4.0.1 - G:/ArcExplorer/Projects/METROL/geo_wgs84/aarhusbay.axl
File Edit View Layer Tools Help
HN04S_geol
hn04s_chem
hn03f
hn03s
Arhus_seism_line
gas (GASZONE)
0.5 m
0.5-2 m
2-4 m
>4m
blank
plume
sediment_arhus (TY
Mud
Sandy mud - muc
Sand, locally with
Lag sediment on
Lag sediment on
Lag sediment on
Cristalline bedroc
Unspecified seat
Land
AarhusBay.axl
X: 10,205
Y: 56,285
1:260.764
One Centimeter = 2,608 Kilometers
0 1 2 3 4 5
Ready
Start
Microsoft Powe...
G:\ArcExplorer...
ArcExplorer 4...
Microsoft Excel
11:40


ArcExplorer 4.0.1 - G:/ArcExplorer/Projects/METROL/geo_wgs84/bornholm.axl
File Edit View Layer Tools Help
gas (GASZONE)
0.5 m
0.5-2 m
2-4 m
>4m
blank
plume
sediment_bornh (TY
Mud
Sandy mud - muc
Sand, locally with
Lag sediment on
Lag sediment on
Lag sediment on
Cristalline bedroc
Unspecified seat
Land
Bornholm.axl
X: 13,558
Y: 56,098
1:1.594.574
One Centimeter = 15 Kilometers
0 1 2 3 4 5
Ready
Start
Microsoft Powe...
G:\ArcExplorer...
ArcExplorer 4...
Microsoft Excel
11:42



List of shape files and their contents for the Skagerrak - Baltic Sea METROL study areas

Area	Shape file	Subject	Source
Skagerrak-Baltic Sea	D500europa	Coast line Northern Europe 1:500,000	
Skagerrak-Baltic Sea	gas	Gas contours sub-seafloor depths	Obtained from existing acoustic data in GEUS and GEOMAR archives
Skagerrak-Baltic Sea	kyst	Coast line Denmark 1:25,000	
Aarhus Bay	Arhus_seism_line	track of seismic lines	METROL M/S Line Cruise 2-7 March 2003
Aarhus Bay	Arhus05lines	track of seismic lines	METROL Cruise on 8 March 2005
Aarhus Bay	gas_aarhus	gas contours from chirp profiles	METROL Cruise on 8 March 2005
Aarhus Bay	hn03s	Sample stations	METROL M/S Henry Cruise 10-14 March 2003
Aarhus Bay	hn03f	Sample stations	METROL M/S Henry Cruise autum 2003
Aarhus Bay	HN04S_chem	Sample stations for chemistry	METROL M/S Henry Cruise spring 2004
Aarhus Bay	HN04S_geol	Sample stations for geology	METROL M/S Henry Cruise spring 2004
Aarhus Bay	HN04W	Sample stations	METROL M/S Henry Cruise winter 2004
Aarhus Bay	HN05S	Sample stations	METROL M/S Henry Cruise spring 2005
Aarhus Bay	sediment_arhus	Sediment type map	Selected area from GEUS digital map
Bornholm	GT04Lgeo	track of seismic lines	METROL Gunnar Thorson cruise to Western Baltic 30 Sept.-10 Oct. 2004
Bornholm	GT04sta	Sample stations	METROL Gunnar Thorson cruise to Western Baltic 30 Sept.-10 Oct. 2004
Bornholm	sediment_bornh	Sediment type map	Selected area from GEUS digital map
Mecklenburg Bay	GT04Lgeo	track of seismic lines	METROL R/V Gunnar Thorson cruise 30 Sept.-10 Oct. 2004
Mecklenburg Bay	GT04sta	Sample stations	METROL R/V Gunnar Thorson cruise 30 Sept.-10 Oct. 2004
Mecklenburg Bay	sediment_meckl	Sediment type map	Selected area from GEUS digital map
Skagerrak-Kattegat	bgs91	area out-line of BGS deep towed boomer	BGS map with boomer tracks
Skagerrak-Kattegat	carbonate_crust	carbonate crust related to methane seeps	information collected from from fishermen and divers
Skagerrak-Kattegat	CH4_age pc125_29	radiocarbon age of methane	Data from Laier et al (1996)
Skagerrak-Kattegat	Dando	box corer positions in seep area	Digitized from figures in Dando et al (1994)
Skagerrak-Kattegat	gasdepth	detailed gas contours around seep area	Digitized from map based on BGS91 boomer data Marcus Cooper's MSc report (1997)
Skagerrak-Kattegat	gt03_geo_wgs84	Sample stations	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	hass	positions of 8 m long piston cores	Hass (1993)
Skagerrak-Kattegat	he191_geo_wgs84	Sample stations	METROL Heinke cruise 191 to the Skagerrak 12-22 June 2003
Skagerrak-Kattegat	Pos21lin	track of seismic lines	Digitized from maps of Poseidon cruise 21 in 1977 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos21poi	fix points of seismic lines	Digitized from maps of Poseidon cruise 21 in 1977 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos35lin	track of seismic lines	Digitized from maps of Poseidon cruise 35 in 1978 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos35poi	fix points of seismic lines	Digitized from maps of Poseidon cruise 35 in 1978 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos41lin	track of seismic lines	Digitized from maps of Poseidon cruise 41 in 1979 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos41poi	fix points of seismic lines	Digitized from maps of Poseidon cruise 41 in 1979 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos49lin	track of seismic lines	Digitized from maps of Poseidon cruise 49 in 1979 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos49poi	fix points of seismic lines	Digitized from maps of Poseidon cruise 49 in 1979 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos55lin	track of seismic lines	Digitized from maps of Poseidon cruise 55 in 1980 (by GEOMAR for METROL)
Skagerrak-Kattegat	Pos55poi	fix points of seismic lines	Digitized from maps of Poseidon cruise 55 in 1980 (by GEOMAR for METROL)
Skagerrak-Kattegat	sediment_katgat	Sediment type map	Selected area from GEUS digital map
Skagerrak-Kattegat	seeps	seep positions Skagerrak	box core observations reported by Dando et al (1994) and Zimmerman et al (1997)
Skagerrak-Kattegat	Seism_Frhavn1	track of seismic lines	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	seism_frhavn2	track of seismic lines	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	Seism_HerthasFlak	track of seismic lines	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	Seism_Hirsholm	track of seismic lines	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	Seism_Kattegat	track of seismic lines	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	Seism_Kolpen	track of seismic lines	METROL Gunnar Thorson cruise to the northen Kattegat 31 march - 11 April 2003
Skagerrak-Kattegat	Zimmerman	box corer positions in seep area	Digitized from figures in Zimmermann et al (1997)

References

Dando, P.R., Bussmann, I. Niven, S.J., O'Hara, S.C.M., Schmaljohann, R. and Taylor, L.J. (1994) A methane seep area in the Skagerrak, the habitat of the pogonophore Siboglinum poseidoni and the bivalve m

Hass, H.C. (1993) Depositional processes under changing climate: Upper Sub-atlantic granulometric records from the Skagerrak NE-North Sea. Marine Geology 111, 361-378.

Laier, T., Kuijpers A., Dennegård, B. and Heier-Nielsen, S. (1996) Origin of shallow gas in Skagerrak and Kattegat – evidence from stable isotope analyses and radiocarbon dating. Geological Survey of Norway

Novak, B. and Stoker, M.S. (2001) Late Weichselian glacimarine depositional processes in the southern Skagerrak revealed by high-resolution seismic facies analyses Marine Geology 178, 115-133.

Zimmermann, S., Hughes, R.G. and Flügel, H.J. (1997) The effect of methane seepages on the spatial distribution of oxygen and dissolved suphide within a muddy sediment. Marine Geology 137, 149-157.