Holocene sedimentation from chirp sonar data and IMAGES coring in northeastern Skagerrak

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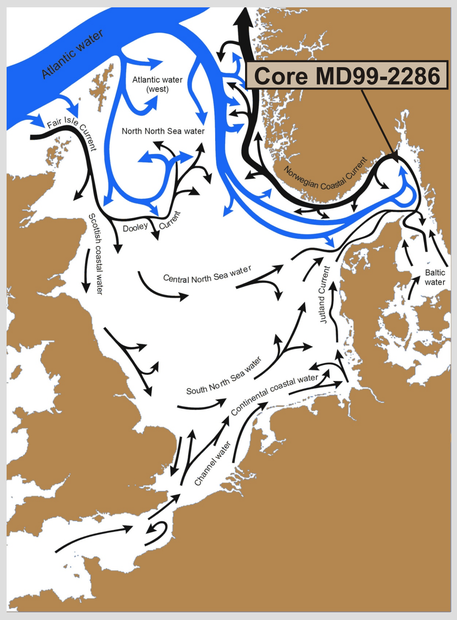
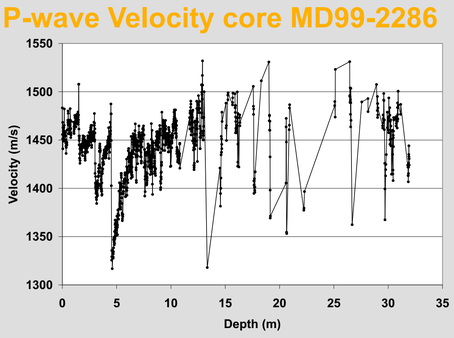
North Sea ocean circulation



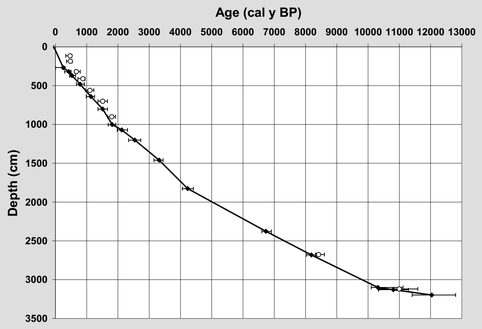
General circulation pattern in the North Sea and Skagerrak. The relative magnitude of volume transport is indicated by the width of the arrows. Blue arrows indicate water entering the Skagerrak more or less directly from the Atlantic and black arrows indicate indirect transport via the North Sea (redrawn from ref. 4).

P-wave Velocity core MD99-2286



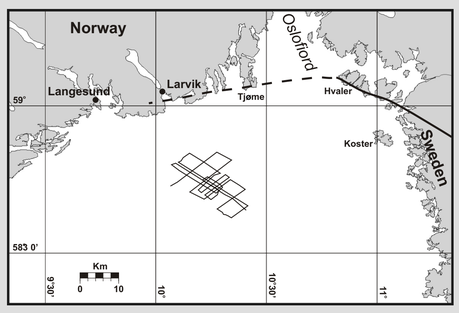
P-wave velocity in core MD99-2286, measured with 0.5-cm resolution using MSCL. The acoustic signal was lost due to insufficient coupling in the interval 10.8 11.7 m, and in virtually all measurements below 13 m. Abrupt changes in the core top are artefacts.

Age Model core MD99-2286



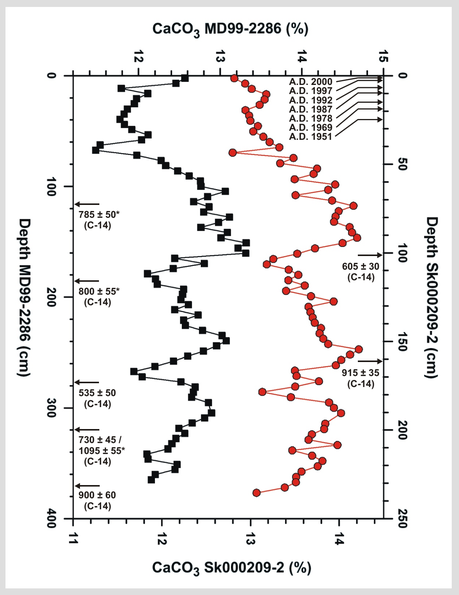
AMS C-14 dating of core MD99-2286. The age model is shown with line connected black diamonds. Open circles show age estimates excluded from the age model because of reworking. Error bars denote 2 calibrated age ranges.

Ice Recession



Drawn black line/stippled line represents the location of the Hvaler/Tjøme/Trollhättan ice marginal zone, dated to 13 400-14 200 cal y BP (ref. 4, 12). The track lines of the chirp sonar profiles are also shown. The coring site of MD99-2286 was deglaciated sometimes between 14 500 and 13 600 cal y BP. Redrawn from ref. 12.

Core Correlation



A 2.4 meter long gravity core, Sk000209-2, was retrieved ca 800 m from core MD99-2286 in order to get full recovery of the surface sediments. The age model for core Sk000209-2 shows that the core top is of modern (zero) age, based on 7 ^{210}Pb-dates and 2 AMS C-14 dates. Age determinations for the two cores are indicated with arrows. A.D. age estimates refer to ^{210}Pb-dates, all other ages are reported in C-14 years BP. The three C-14 ages marked with asterisks (*) were excluded from the age model for core MD99-2286 because of reworking. Correlation between core MD99-2286 (black curve) and core Sk000209-2 (red curve) using carbonate content gives a correlation coefficient r = 0.67, significant with a confidence level of 99.9 %. Note the different depth scales. All data from core Sk000209-2 are from ref. 11.

Introduction

Skagerrak is the deepest part and the major sediment trap of the North Sea. The investigated area is characterised by intense water mass mixing and high sedimentation rates, up to 1 cm/year (ref. 1), as a branch of the North Atlantic Current turns anti-clockwise, slows down and becomes mixed with other waters to form the Norwegian Coastal Current. Present-day SSTs in Skagerrak are strongly linked to the NAO-index. This makes the Skagerrak a key area for our understanding of the late Quaternary oceanographic and climatic history of the North Sea region and adjacent land areas. Previous seismic studies in the Skagerrak (ref. 2, 3, 7, 9, 10, 12, 17, 18, 19) have demonstrated the presence of a prominent seismic reflector separating the upper relatively transparent units from the underlying stratified sequence. The age of this sharp reflector has previously been assumed to represent the Pleistocene/Holocene boundary (10 000 C-14 years BP = 11.5 ka cal y BP; informal working definition (ref. 6)).

The present poster provides a detailed view of the Holocene stratigraphy in northeastern Skagerrak by reconstructing a 3D stratigraphic model from high-resolution chirp sonar data, multibeam bathymetry data from the Geological Survey of Norway (ref. 8), and sediment physical properties of IMAGES core MD99-2286. The age model based on 25 radiocarbon dates shows that core MD992286 spans 12 000 calendar years, thus encompassing the entire Holocene and the latest Pleistocene. Information on the sedimentary environment obtained from this work also provides the spatial context necessary for interpreting measured sediment proxies in core MD99-2286.

Methods

Chirp Sonar Profiling

High-resolution seismoacoustic data was acquired from *R/V Skagerrak* with an X-Star chirp sonar system using the SB-512 tow-fish, with a 1.5-7.5 kHz 40 ms long chirp pulse. A hull-mounted Skipper GDS 101 echo sounding system with a 38 kHz transducer using a sound velocity of 1500 m/s provided depth measurements. Differential GPS was used for positioning.

Carbonate Content

The carbonate content in core MD99-2286 was measured on a UIC coulometrics coulometer at the Department of Geology and Geochemistry, Stockholm University, on 60-mg milled, freeze-dried bulk sediment samples.

P-wave Velocity

P-wave velocity measurements were carried out on split core halves in the department of Geology and Geochemistry, Stockholm University using a GeoTek Multi Sensor Core Logger (MSCL). Sampling resolution was 0.5 cm. The data was calibrated to on-site conditions (temp. = 7° C, salinity = 35 ‰, water depth = 225 m.)

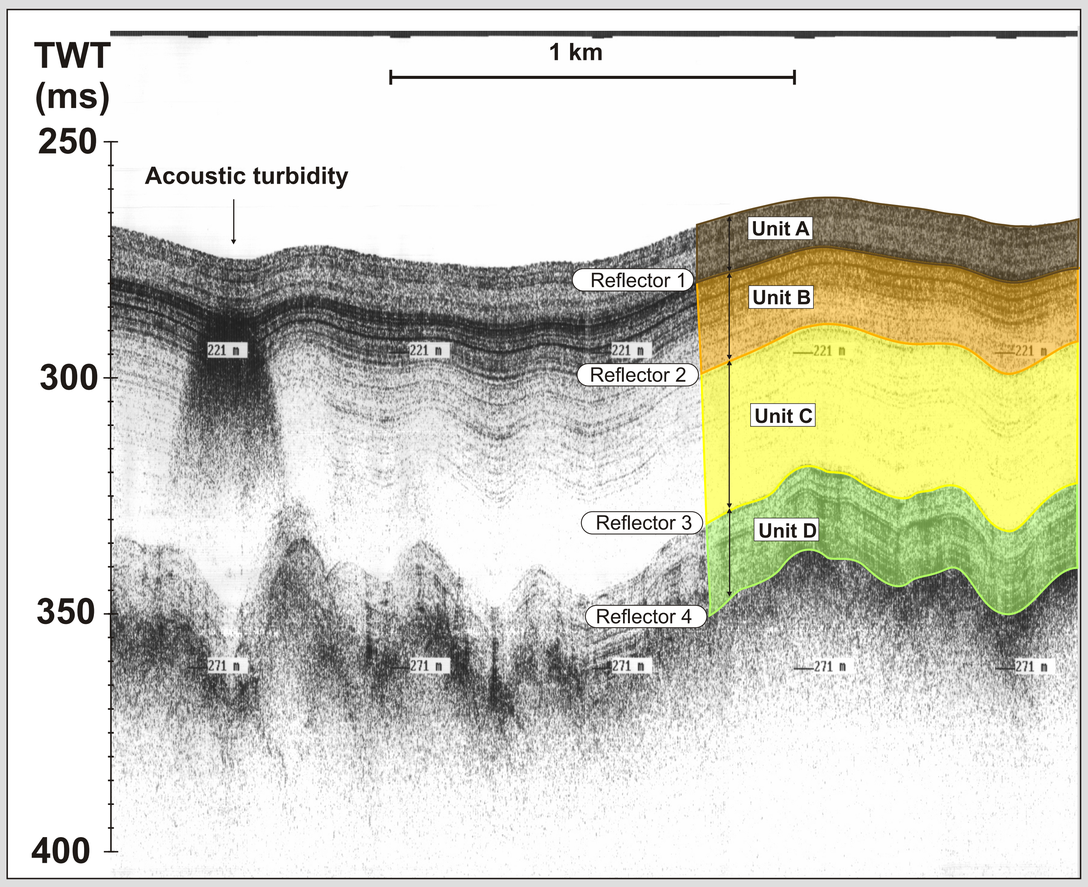
Dating

Twenty-five AMS C-14 dates for core MD99-2286 were performed on mixed foraminifera and species-determined shells by the institute of Particle Physics, ETH, Zürich, Switzerland. The radiocarbon dates were calibrated using the CALIB 4.3 software (ref. 12), with a R-value of -40 ± 25 C-14 years (ref. 11). The samples were assumed to consist of 100 % marine carbon, and the calibration data set MARINE98 was used (ref. 13).

Dynamic 3D-Visualisation

All data in this study (i.e. chirp sonar, bathymetry, and core data) was brought into Interactive Visualisation System's (IVS) dynamic 3D-visualisation software Fledermaus. Grey-scale raster images were prepared from the processed chirp sonar data using an average sound speed of 1500 m/s and displayed geo-referenced as "hanging curtains".

General Seismic Stratigraphy



Chirp record showing the general stratigraphy of the survey area in northeastern Skagerrak. The defined seismic reflectors 1-4 and units A-D are indicated. A small patch of acoustic turbidity is marked with an arrow. Depth labels indicate approximate depth from the tow-fish in metres based on a sound velocity of 1500 m/s. Average towing depth for the chirp sonar tow-fish was ca 15 m below sea level. Chirp section located at N58°43.9', E10°14.6'.

Summary: The Pleistocene/Holocene Boundary

- Core MD99-2286 is 32.0 m long, and spans 12 040 calendar years
- The depth to reflector 3, previously interpreted as the Pleistocene/Holocene boundary (11 500 cal y BP), occurs at about 25 ms, corresponding to 37.5 m based on a sound velocity of 1500 m/s.
- If the previous interpretation of the P/H boundary in the seismic stratigraphy is correct, the core must penetrate through reflector 3. This requires a sound velocity of about 1200 m/s in the sediment, which is far below the measured values in the core of ca 1400-1500 m/s (see P-wave velocity plot).
- It follows that the sharp boundary between unit C and unit D, reflector 3, cannot represent the base of the Holocene as interpreted in earlier investigations (ref. 2, 3, 6, 8, 9, 11, 16, 17, 18).
- There is no sharp boundary at the inferred depth of the Pleistocene/Holocene transition (11 500 cal y BP) in the chirp sonar profiles, nor any obvious lithological changes in core MD99-2286.

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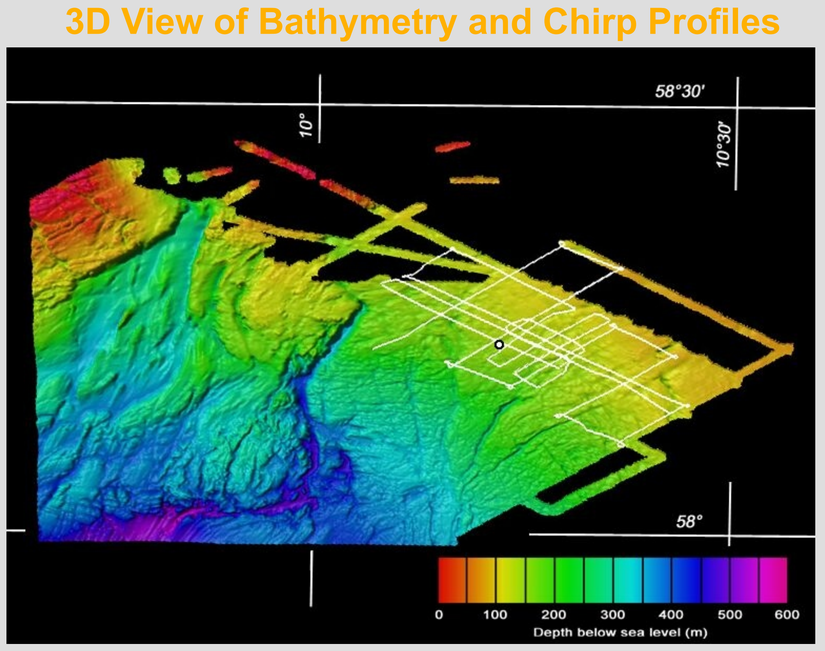
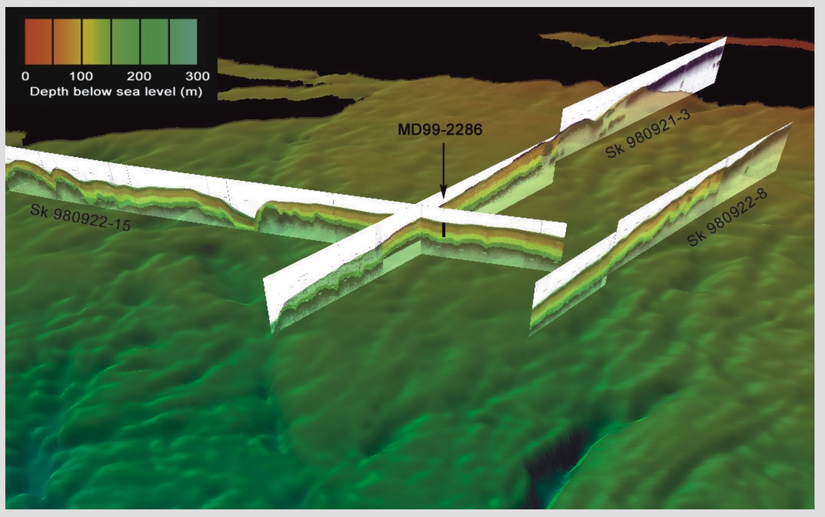
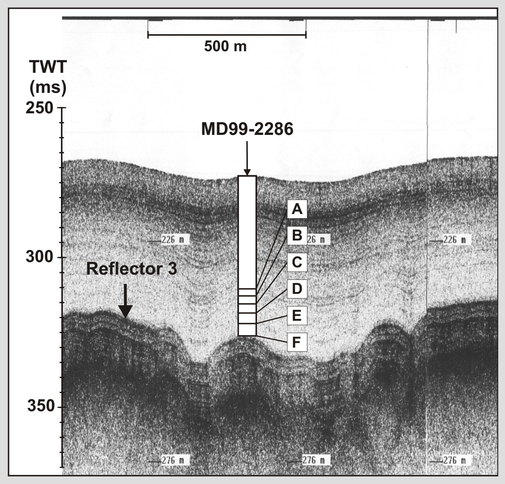
3D View of Bathymetry and Chirp Profiles



Three-dimensional shadow relief model of bathymetry in northeastern Skagerrak. Chirp sonar profiles are shown as white lines, and core MD99-2286 is indicated with a circle. Multibeam bathymetry data from the Norwegian Hydrographic Service (Ref. 8).



Oblique view of multibeam bathymetry and chirp sonar profiles around the coring location of MD99-2286. The chirp profile names are indicated, and the core MD99-2286 is marked with a black bar below the arrow. The bathymetric terrain model is made partly transparent in order to make the chirp profiles visible. Colours on the chirp profiles mark interpreted seismic units. Multibeam bathymetry from Norwegian Hydrographic Service (ref. 8).



Core Penetration

Calculated penetration depth of core MD99-2286 in the closest located chirp sonar profile, based on different theoretical sound velocities, where
A = 1700,
B = 1600,
C = 1500,
D = 1400,
E = 1300,
F = 1200 (m/s). Reflector 3 is marked with an arrow. Chirp section located at N58°43.9', E10°12.7'.

Conclusions

- Core MD99-2286 represents a continuous high-resolution record of Holocene and uppermost Pleistocene sediments Unit D is interpreted as glacial marine sediments rapidly deposited close to a calving shelf ice
- Reflector 3, separating the topmost relatively transparent sequence (units A+B+C) from the underlying stratified unit (D) is proposed to be older than the Pleistocene/Holocene boundary
- The change to Holocene conditions (lower unit C) is interpreted to have occurred during a continuous process of increasingly normal marine deposition, which gradually replaced the distal glacial marine sedimentation
- Unit C is interpreted as distal glacial marine sediments gradually changing to postglacial marine sediments deposited during latest Pleistocene to early Holocene times
- The uppermost units (A+B) represent marine Holocene sediments deposited in a more or less modern oceanographic environment

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