Oligocene to Lower Pliocene deposits of the Norwegian continental shelf, with correlation to the Norwegian Sea, Greenland, Svalbard, Denmark and their relation to the uplift of Fennoscandia

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Acknowledgement: Tom Bugge, Det norske oljeselskap ASA and Morten Smelror, Geological Survey of Norway

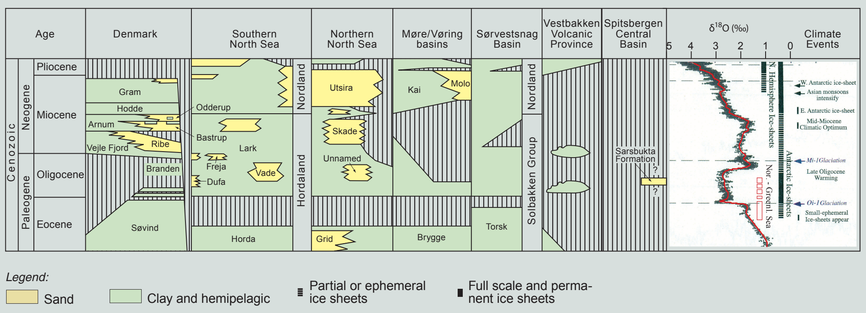


Fig. 1. General view of the Late Paleogene and Neogene lithostratigraphy in the investigated areas modified after Rassmussen et al. (2008) and Rundberg and Eidvin (2005). On the right hand side of the diagram there is added some paleoclimatic data including a global deep-sea oxygen curve and periods with ice-sheets in the Antarctica and northern hemisphere (after Zachos et al., 2001). Periods with deposition of IRD at ODP Site 913 (off East Greenland) are also indicated (from Eldrett et al., 2007).

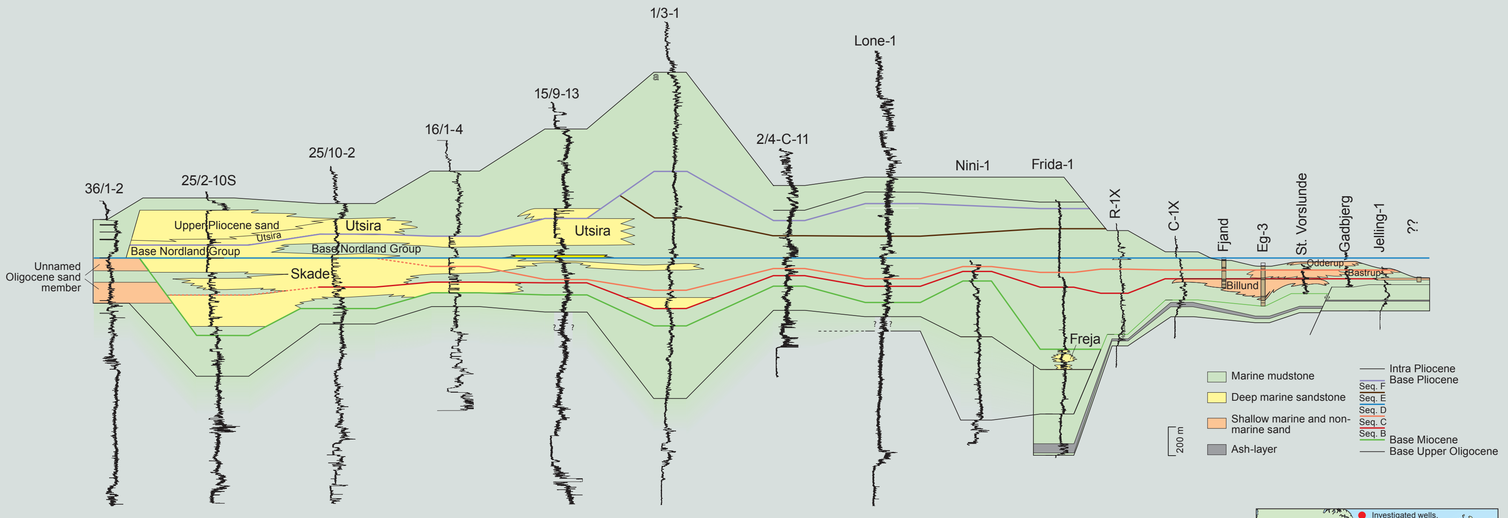


Fig. 2. Correlation panel of the Oligocene–Pliocene succession from central Jylland into the North Sea and northward to near Stad, west of Norway. The datum is the Mid Miocene unconformity. The Oligocene is dominated by marine mud. The most distinct incursion of sands is found in the 36/1-2 and Frida-1 wells. The sands laid down in the 36/1-2 area were deposited in a shallow marine depositional environments. In the Frida-1 well the sand was deposited at the base of slope in more than 500 m of water depth. The Miocene is characterised by marked sand deposition both in the Norwegian–Danish Basin and in the northern North Sea. The sand in the Norwegian–Danish Basin was sourced from Norway and central Sweden and the sand in the northern North Sea was mainly sourced from the Shetland Platform.

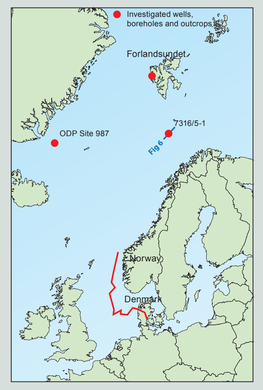
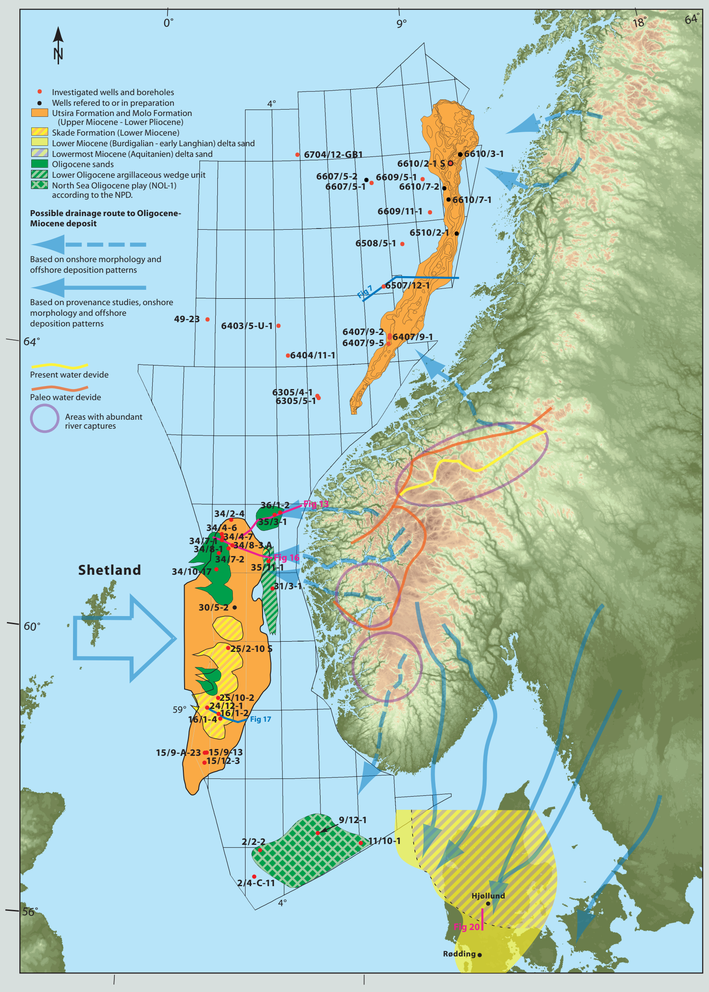


Fig. 3. Oligocene to Lower Pliocene well and borehole data base, seismic profiles and Oligocene to Lower Pliocene sandy deposits on the Norwegian Sea continental shelf, in the North Sea, the Norwegian-Danish Basin and Denmark. The extent of the Oligocene sands and wedge unit and the Utsira and Skade formations is according to Rundberg & Eidvin (2005). The extent of the Molo Formation is according to Bullimore et al. (2005). The extent of the North Sea Oligocene play (NOL-1) is according to the Norwegian Petroleum Directorate web page (www.npd.no). Provenance study is after Olivarius (2009). Topographic map is after Olesen et al. (in press).



Drainage pattern

One of the purposes of Fig. 3 is to correlate the locations of the described Oligocene to Lower Pliocene depocenters with the topography and present drainage of Scandinavia. In the topographic map, the shift from greenish to brownish colours takes place at about 800 m elevation. The highest peaks of the South Scandes Dome exceed 2000 m. Here, red lines show generalized water divides, separating major drainage systems. Extensive river capturing has taken place, in particular in the northern part of the dome, where the present water divide has moved to the SE (yellow line).

It is believed that the paleo-drainage to a large extent will control the present drainage, and one hypothesis for the significant movement of the water divide would be a late uplift of the South Scandes Dome.

The compilation shows that the Oligocene sediments in the Northern North Sea were sourced from the western part of the South Scandes Dome (blue arrows). In the northernmost North Sea, this sedimentation continued throughout the Oligocene. In that period, a much larger amount of clastic sediments was transported to the southernmost part of the Norwegian sector and to Denmark. This depositional patterns are consistent with a water divide located far to the NW and W on the South Scandes Dome. In the Early Miocene, all the clastic sediment transport was apparently directed towards the south, and mainly sourced from the east (blue arrows in SE Norway and Sweden).

The Utsira and Molo Formations postdate the Mid Miocene tectonism in the North Atlantic. The Molo Formation was derived from the mountains of Mid Norway, where the present drainage system seems to be controlled by longitudinal valleys and by Mesozoic fractures. At that time, the sediments eroded from the South Scandes Dome apparently were transported to the south, with the exception of the deltaic deposits in well 35/11-1. Large scale erosion and sediment progradation from the western part of the South Scandes Dome did not take place until the onset of glaciations in the Late Pliocene.

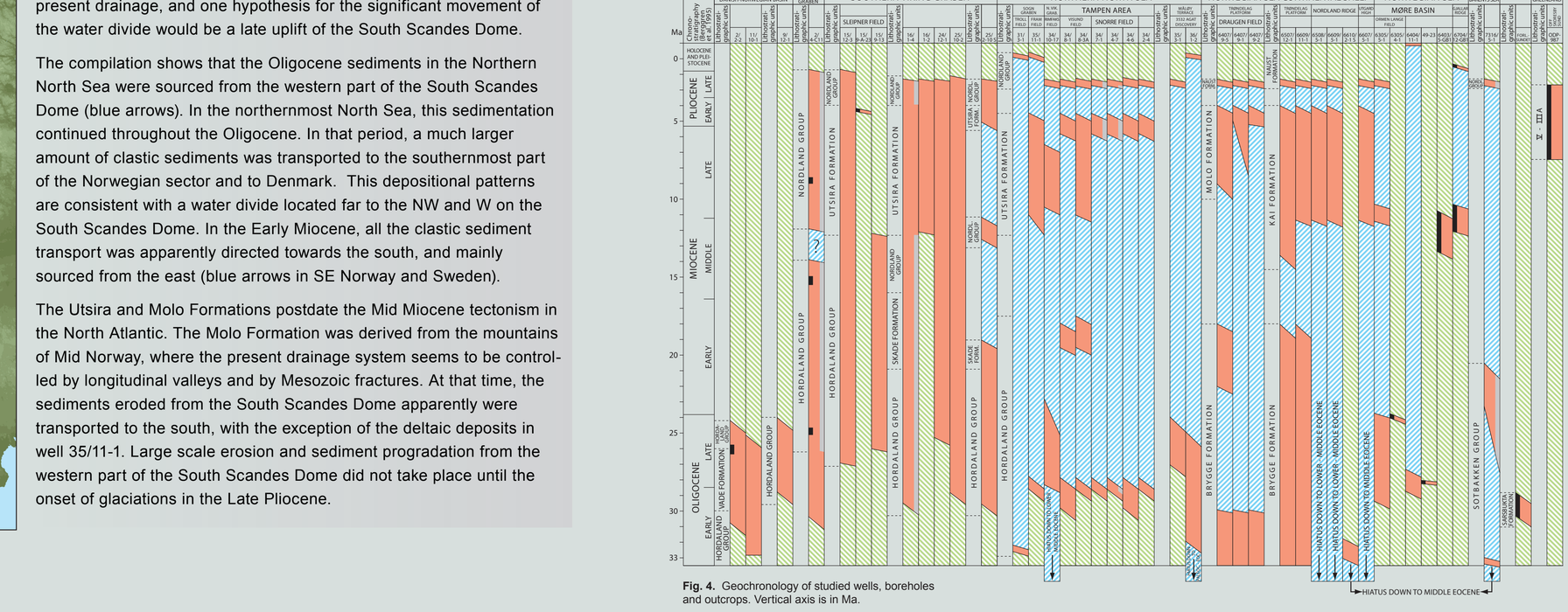
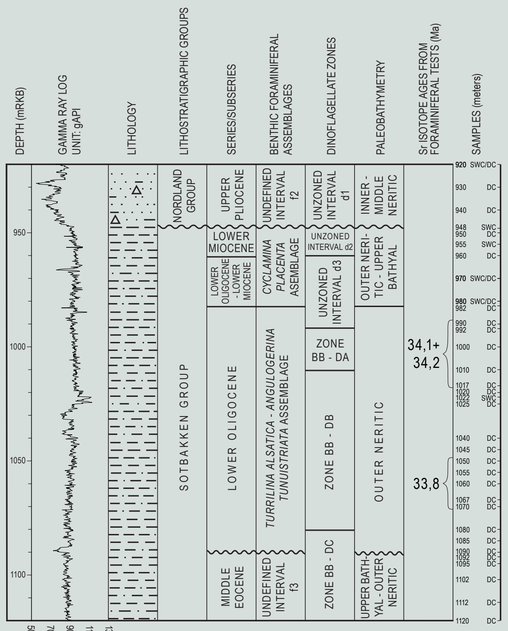


Fig. 4. Geochronology of studied wells, boreholes and outcrops. Vertical axis is in Ma.

WELL 7316/5–1



Sea floor = 473 meters below rig floor (mRKB)
gAPI = American Petroleum Institute gamma ray units
DC = Ditch cuttings
SWC = Side wall cores
△ = Ice rafted pebbles

Fig. 5. Dating of the Middle Eocene to Lower Miocene Sotbakken Group in well 7316/5-1. Location in the map in Fig. 2 (modified after Eidvin et al. 1998b).

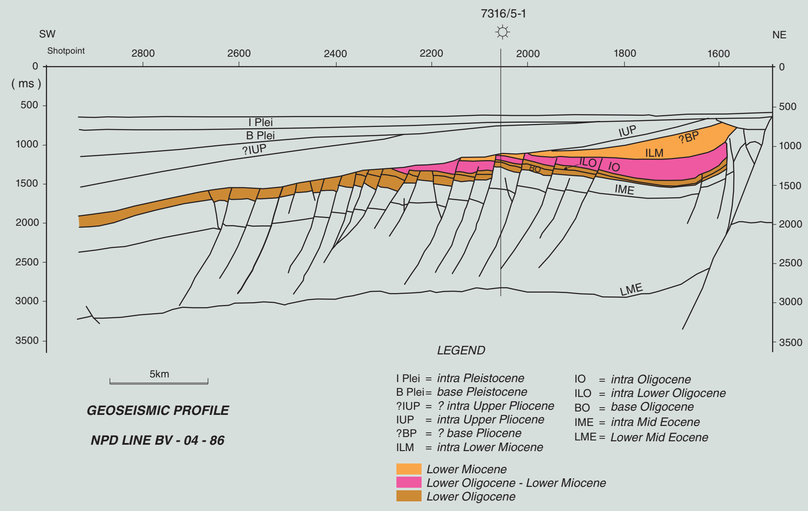


Fig. 6. Digitized seismic line NPD BV-04-86 through well 7316/5-1. Location in the map in Fig. 2 (modified after Eidvin et al. 1998b).

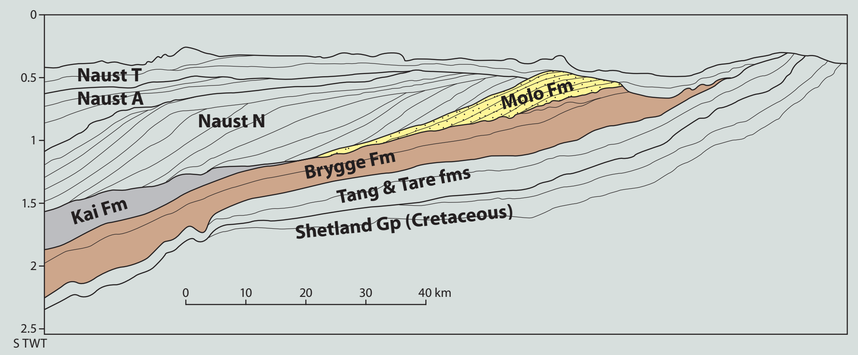


Fig. 7. Geoseismic section showing that the Molo and Kai formations are proximal and distal equivalents with respect to each other. The mid Miocene unconformity separates the Kai and Molo formations from the underlying Brygge Formation (location in Fig. 3; after Eidvin et al., 2007).

Norwegian Sea continental shelf

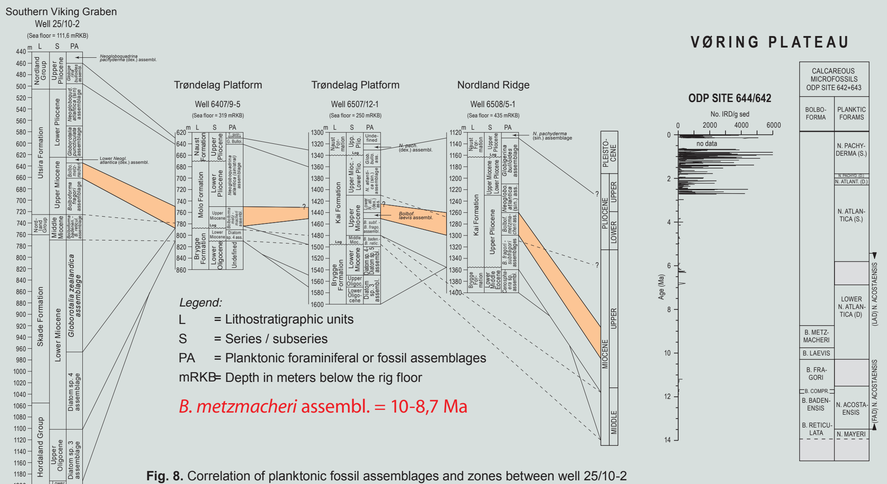
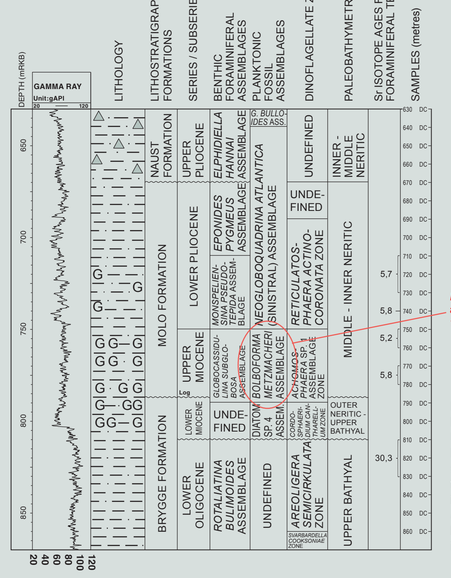


Fig. 8. Correlation of planktonic fossil assemblages and zones between well 25/10-2 (southern Viking Graben), 6407/9-5 (Trøndelag Platform), 6507/12-1 (Trøndelag Platform) and 6508/5-1 (Nordland Ridge) as well as from the wells to the fossil zonation of the ODP sites 642 and 643 on the Vøring Plateau (Spiegler & Jansen 1989, Müller & Spiegler 1993). The correlation lines for the *Bolboforma metzmacheri* assemblage are shown in yellow. The IRD curve is after Jansen & Sjøholm (1991) and Fronval & Jansen (1996) (after Eidvin et al. 2007).

WELL 6407/9–5



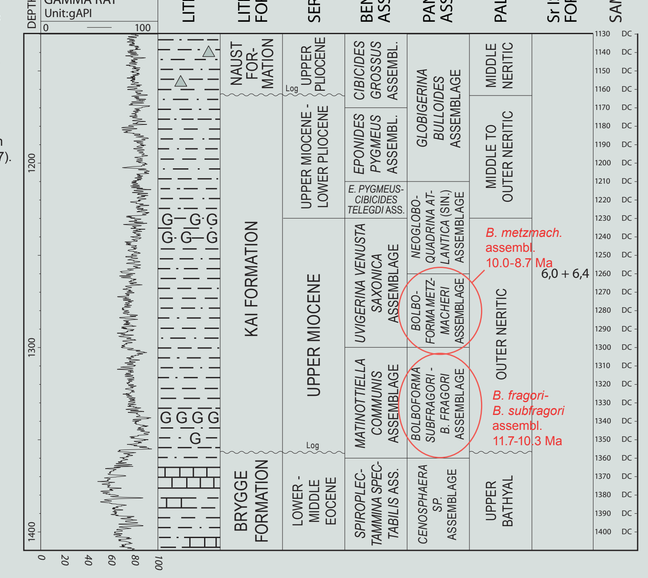
B. metzmach. assembl. 10.0-8.7 Ma

Fig. 9. Dating of the Lower Oligocene to Lower Pliocene sections including the Upper Miocene to Lower Pliocene Molo Formation in well 6407/9-5 based on analyses of benthic and planktonic foraminifera, *Bolboforma* and strontium isotopes. Note the *Bolboforma metchmacheri* assemblage (10.0-8.7 Ma) in the lower part of the Molo Formation. Location in Fig. 3 (modified after Eidvin et al. 2007).

Fig. 10. Dating of the Upper Miocene to Lower Pliocene Kai Formation in well 6508/5-1 based on analyses of benthic and planktonic foraminifera, *Bolboforma* and strontium isotopes. Note the *Bolboforma metchmacheri* assemblage (10.0-8.7 Ma) and *Bolboforma subfragori-B. fragori* assemblage(11.7-10.3 Ma) in the lower part of the Kai Formation. Location in Fig. 3 (modified after Eidvin et al. 2007).

Legend for fig. 9 and 10
Sea floor= 435 meters below rig floor (mRKB)
DC = Ditch cuttings
gAPI = American Petroleum Institute gamma ray units
G = Abundant glauconite
△ = Ice rafted pebbles
⊢⊣ = Limestone

WELL 6508/5–1



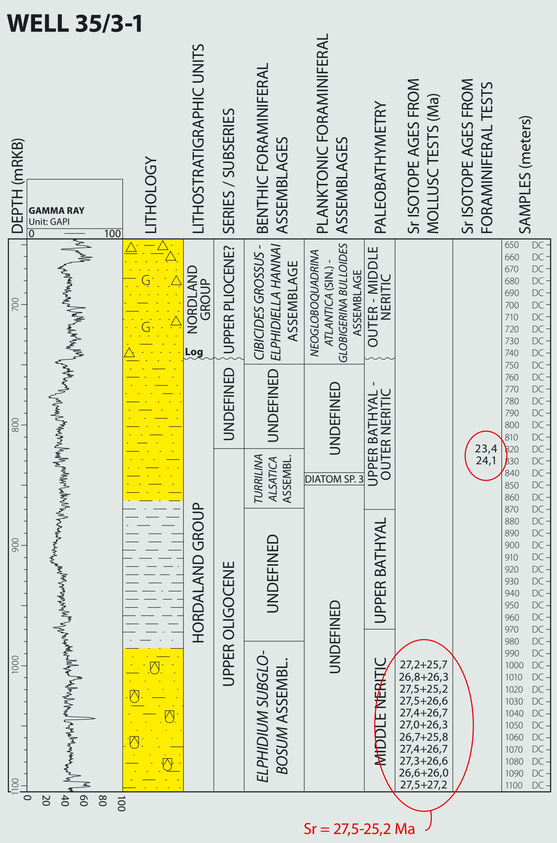


Fig. 11. Dating of the unnamed sandy Oligocene section in well 35/3-1 based on analyses of benthic foraminifera, diatoms and strontium isotopes. Note the large number of strontium isotope data from the lower part of the section. Location in Fig. 3.

Legend for fig. 11 and 12

Sea floor= 435 meters below rig floor (mRKB)

DC = Ditch cuttings

gAPI = American Petroleum Institute gamma ray units

= Abundant glauconite

= Ice rafted, angular pebbles

= Rounded or sub-angular pebbles

* = Caved

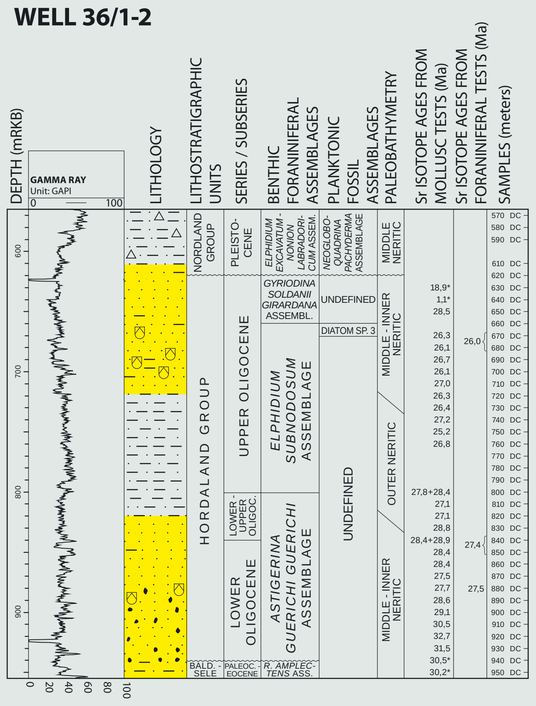


Fig. 12. Dating of the proximal part of the unnamed sandy Oligocene section in well 36/1-2 based on analyses of benthic foraminifera, diatoms and strontium isotopes. Note the coarse sediments in the lower part of the unit and the large number of strontium isotope data throughout. Location in Fig. 3.

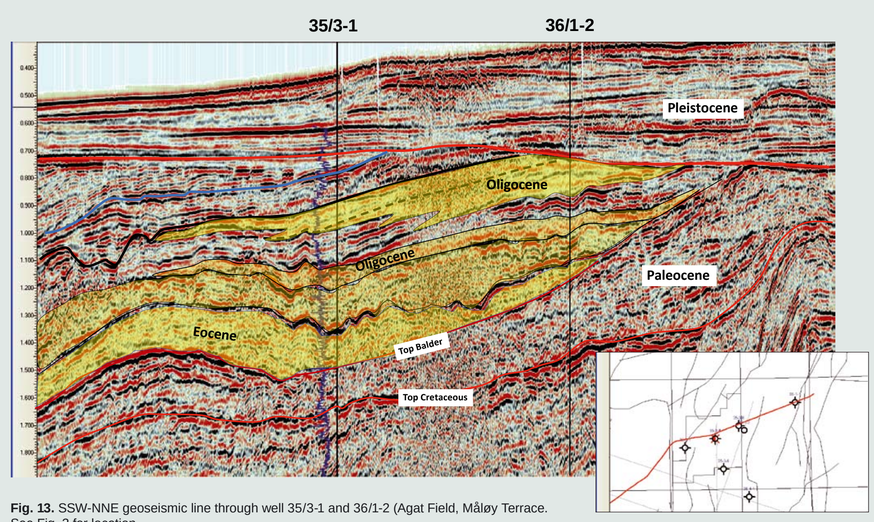


Fig. 13. SSW-NNE geoseismic line through well 35/3-1 and 36/1-2 (Agat Field, Måløy Terrace. See Fig. 3 for location.

TAMPEN AREA

SNORRE FIELD

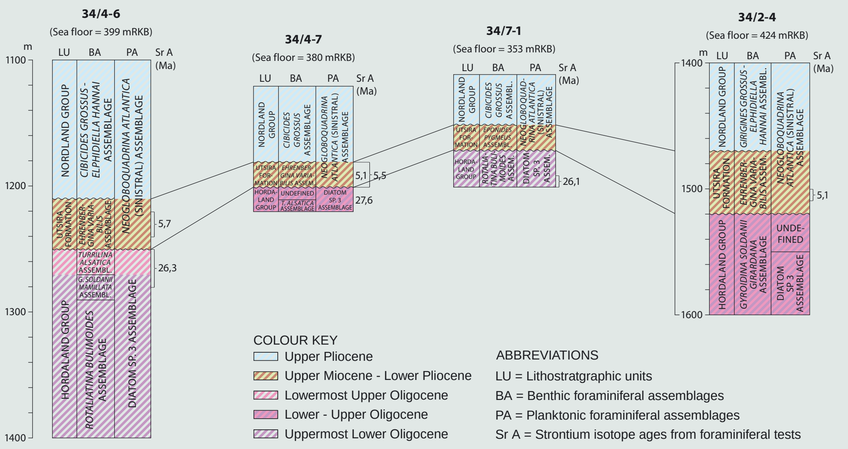


Fig. 14. Correlation of fossil assemblages between the wells studied from the Tampen area (Snorre Field, northern North Sea). Note that the strontium isotope analyses of calcareous index foraminifera from the glauconitic Utsira Formation give ages at about 5 Ma. The vertical axis is in metres below rig floor. Location in Fig. 3.

TAMPEN AREA

VISUND FIELD

SOGN GRABEN

FRAM FIELD

TROLL FIELD

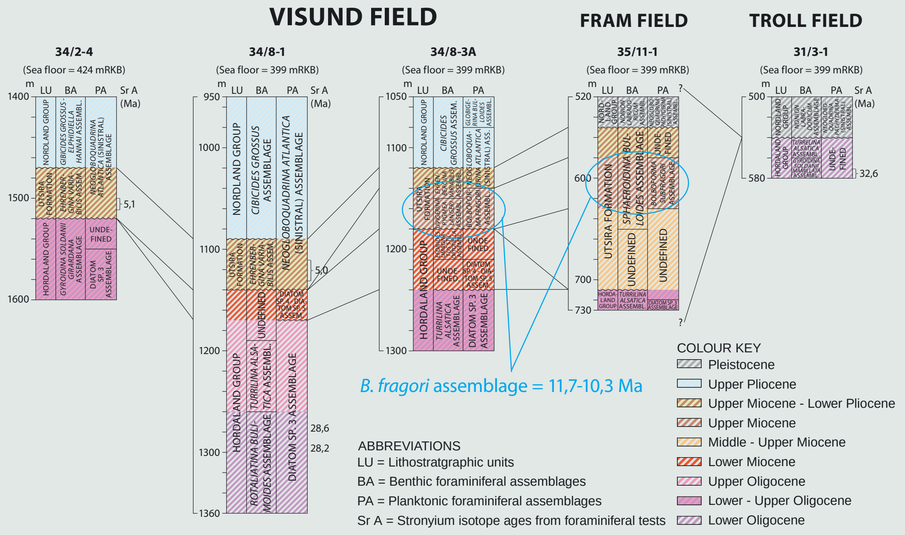


Fig. 15. Correlation of fossil assemblages between the wells studied from the Tampen area and Sogn Graben (Visund and Troll Field, northern North Sea). Note that the oldest part of the Utsira Formation is recorded from the two Eastern-most well 34/8-3A and 35/11-1 which include the *Bolboforma fragori* assemblage (11.7-10.3 Ma) known from the ODP Leg 104 boreholes on the Vøring Plateau (Norwegian Sea). The vertical axis is in metres below rig floor. Location in Fig. 3.

Northern Viking Graben - 61°N

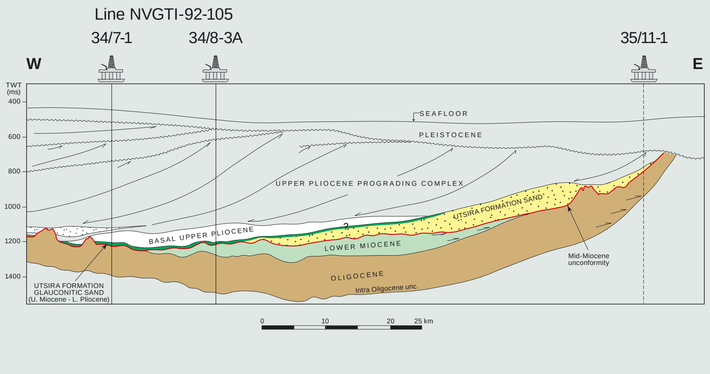


Fig. 16. East-West transect of the northern North Sea at about 61ºN (Tampen area) illustrating main sequences and sedimentary architecture of the post Eocene strata. Note that the Utsira Formation is represented by a thin glauconitic member in the western part (Snorre and Visund Field area). This member is thought to cap the main Utsira Formation sands to the East (modified after Eidvin & Rundberg, 2001 and Rundberg & Eidvin, 2005). Location in Fig. 3.

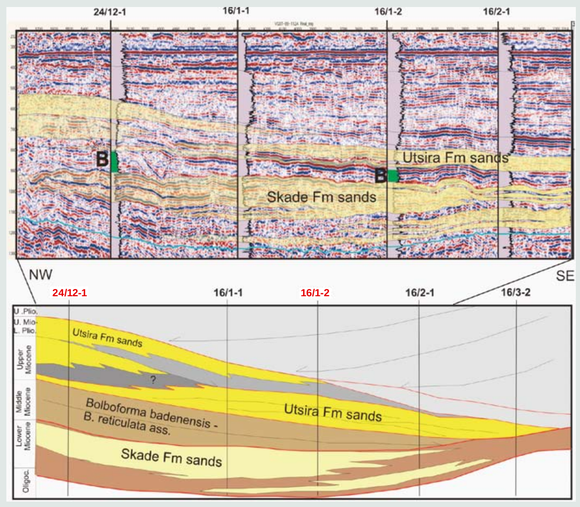


Fig. 17. Seismic line through wells 24/12-1, 16-1-1, 16/1-2 and 16/2-1 across southern Viking Graben showing Skade and Utsira formations. Green-coloured part of the GR-logs denotes Middle Miocene *Bolboforma badenensis* and *Bolboforma reticulata* assemblages. These index fossils are known from deposits with an age slightly older than 14 to 12.3 Ma in the ODP Leg 104 boreholes on the Vøring Plateau (Norwegian Sea; location in Fig. 3; after Rundberg & Eidvin, 2005). The Utsira Formation is a potential storage magazine for greenhouse gases.

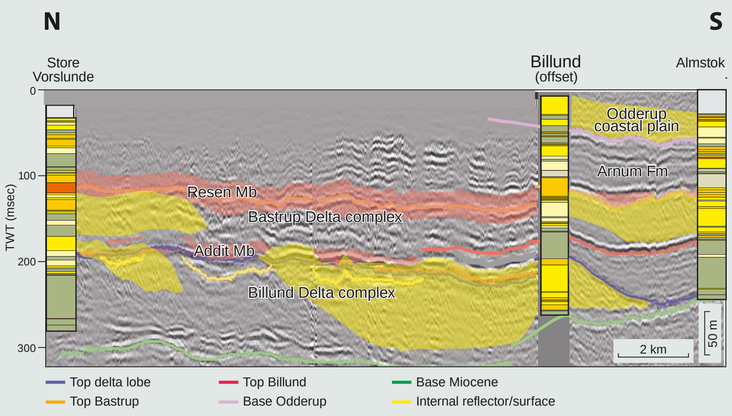


Fig. 20. North–south trending seismic section from central Jylland showing alternating delta progradation and marine deposits. Note the sand-rich delta lobe deposited indicated in yellow. Fluvial incised valley fill is shown in orange. This pattern characterised the Norwegian–Danish Basin during the Early Miocene. The Middle–Late Miocene was dominated by marine shelf deposits.

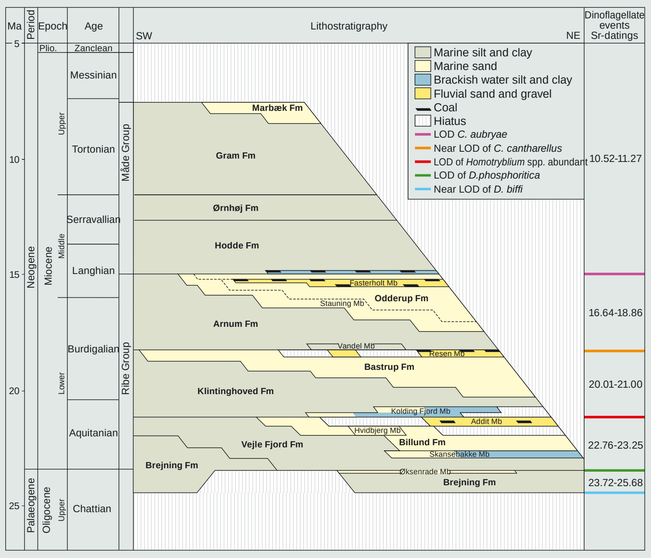


Fig. 21. Lithostratigraphy of the Danish Miocene. The Miocene of Denmark is relatively complete and is characterised by alternating fluvio-deltaic and marine deposits. Three major deltaic units (Billund, Bastrup and Odderup Formations) prograded from the north and northeast into the North Sea basin during the Early – early Middle Miocene. The delta progradation was punctuated by deposition of marine clay and silt associated with minor transgressive events (Vejle Fjord, Klintinghoved and Arnum Formations). During the Middle-Late Miocene, marine depositional conditions dominated (Hodde, Ørnhøj and Gram Formations). A fourth and final progradation (Marbæk Formation) commenced in the latest Late Miocene and present day Denmark including the North Sea sector became land. The deposition of sand-rich delta system in the Early Miocene was associated with inversion tectonics in the North Sea and Norwegian–Danish Basin. The shift to dominantly deposition of marine mud in the Middle and Late Miocene was coincident with the Mid Miocene tectonism. Palynological datings of Dypkjær and Piasecki (2008) are supported by strontium isotope datings of mollusc tests from outcrops and borehole cores.

WELL 16/1-4

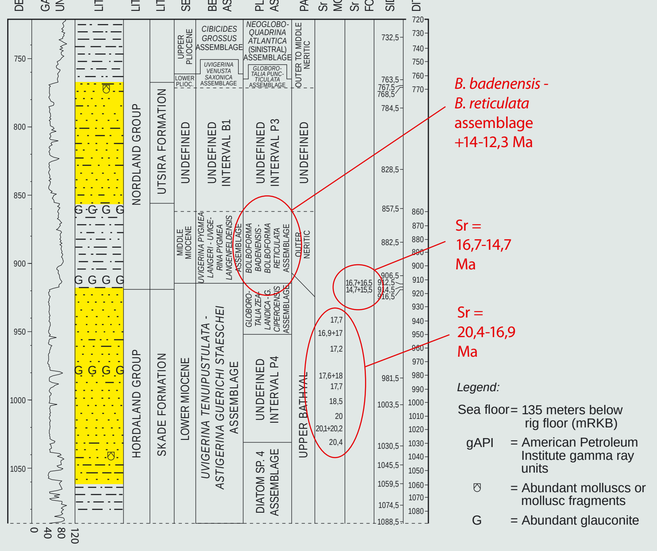


Fig. 18. Dating of the Lower Miocene to Lower Pliocene sections in well 16/1-4 including the Lower Miocene Skade Formation based on analyses of benthic and planktonic foraminifera, *Bolboforma* and strontium isotopes. Note the large number of strontium isotope data from the Skade Formation and the *Bolboforma badenensis-B. reticulata* assemblage (slightly older than 14 to 12.3 Ma) between the Skade and Utsira formations. (Location in Fig. 3; modified after Eidvin & Rundberg, 2007).

WELL 24/12-1

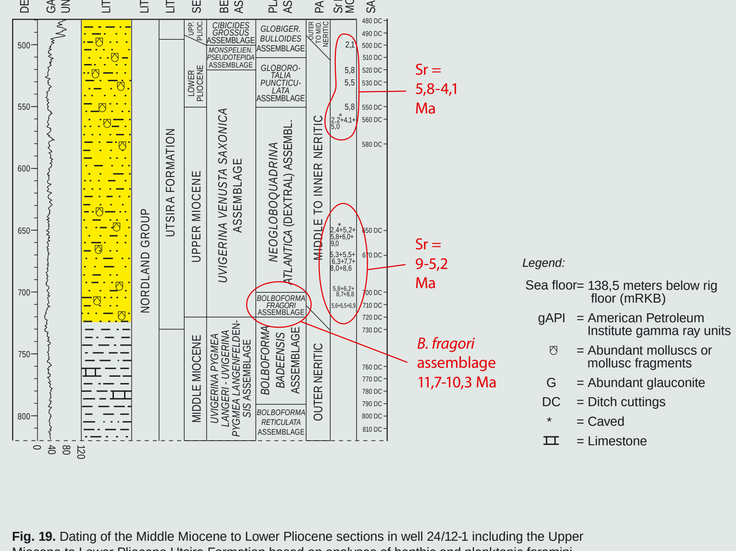


Fig. 19. Dating of the Middle Miocene to Lower Pliocene sections in well 24/12-1 including the Upper Miocene to Lower Pliocene Utsira Formation based on analyses of benthic and planktonic foraminifera, *Bolboforma* and strontium isotopes. Note the large number of strontium isotope data from the Utsira Formation and the *Bolboforma fragori* assemblage (11.7 to 10.3 Ma) in the lower part of the Utsira Formation (just as in the lower part of the Utsira Formation in well 34/8-3A in the Tampen area to the North). Location in Fig. 3 (modified after Eidvin & Runberg, 2007).

Summary

This poster synthesises biostratigrapic and strontium isotopic data from 39 wells and boreholes from the Norwegian shelf, supplemented with one outcrop from north-western Svalbard, one ODP borehole off east Greenland and borehole data and outcrop data from Denmark. Emphasis has been placed on investigations of sandy deposits. Most wells and boreholes have been integrated with wire-line log and seismic data. We present an improved stratigraphy and depositional history for the Oligocene to Early Pliocene for the study area with correlations to North-Western Europe.

Regional seismic interpretation indicates that offshore West and Mid Norway and along the western Barents Sea margin, progradation of Paleocene-Eocene sediments terminated in the early Oligocene, and the Eocene clinoforms are onlapped by Oligocene shales. Late in the early Oligocene a possible shift in the drainage divide of West Norway caused a transport of Oligocene coarser clastics mainly towards the Norwegian-Danish basin. Prograding deltaic complexes developed in the Danish-Norwegian Basin (Vade Formation and Freja Member). In the northern North Sea gravity-flow sandstones were sourced from the Shetland Platform and some minor input from Fennoscandia. Coarse clastic sediments were deposited in north-western Svalbard, while argillaceous sedimentation prevailed elsewhere, except for the deep-water Norwegian Sea where mainly siliceous ooze accumulated until the Early Pliocene.

During the Early Miocene, delta complexes (Ribe Group) prograded southwards into the south-eastern North Sea. In the western part of the Viking Graben sand-rich gravity deposits of the Skade Formation were sourced from the Shetland Platform. To the east, in the central part of the basin north of 60ºN and in the Central Graben fine-grained sedimentation occurred.

Extensive mid Miocene tectonism started at the transition from the Early - to Middle Miocene and major compressional features were formed in the Norwegian Sea, while many major faults were reactivated in the study area. Erosional features are observed in the northern North Sea, Norwegian Sea continental shelf and possibly in the Barents Sea margin. The southern North Sea and the Danish-Norwegian Basin subsided and hiatuses are minor or absent in the southern Viking and Central grabens.

In the Late Miocene, a marked relief of the Fennoscandian Shield, accompanied by continued uplift, colder climate and a low global sea level, resulted in a pronounced out-building of coastal plains and deltas all along the inner Norwegian Sea continental shelf (Molo Formation). During the same period the northern North Sea formed a narrow seaway between deeper water in the Møre Basin and the central North Sea. The strait received large amount of coarse clastics (Utsira Formation) mainly from the East Shetland Platform in the west, but also from the Sognefjorden area in the east. Offshore West Norway further to the south, only thin and shaly sections are recorded, while deposition continued towards Denmark and the Norwegian Sea, probably using the drainage systems which were established in the Oligocene. This situation lasted trough the Early Pliocene when the global temperature and sea level temporarily rose.

The investigation of the large sediment wedge off the Scoresby Sund fjord system shows that the build-up of substantial continental ice on Greenland started in Late Miocene at approximately 7.5 Ma.