

Cenozoic stratigraphy in the Danish North Sea Basin

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Abstract

This paper provides a concise review of investigations into the Cenozoic stratigraphy of the Danish North Sea Basin. In the Danish North Sea, mainly Pliocene and Pleistocene strata are found. Results of published seismic and sequence stratigraphic analyses are combined with biostratigraphic analyses and correlated to marine formations found onshore.

Keywords: Eastern North Sea, Neogene, Pleistocene, sequence stratigraphy

Introduction

Following the stratigraphic work by Deegan & Scull (1977) a stratigraphy for the Danish North Sea sector was established by a working group at the Danish geological survey (Kristoffersen & Bang, 1982). They subdivided the Cenozoic, excluding the Danian, into 6 informal units, where the unit CEN-5 comprises the Miocene above the mid-Miocene unconformity as well as the Pliocene, and the unit CEN-6 comprises the Pleistocene to Recent.

With the introduction of the sequence stratigraphic concept it was logical to apply it to the sediments of the Danish North Sea. In 1993, a manuscript was published (Michelsen et al., 1998) with a quite comprehensive study including interpretation of seismic data, petrophysical logs and lithology as well as biostratigraphy of the eastern North Sea, primarily the Danish North Sea sector. This study divided the post-Chalk succession into 7 informal 'Major Sequence Stratigraphic Units' (Michelsen, 1996). The major sequences were controlled by shifting sediment sources and available accommodation space in a more or less clock-wise direction (Huuse, 2002). The first 6 major sequences were primarily derived from Scandinavia and from Scotland. The uppermost 'Major Sequence Stratigraphic Unit', no. 7, comprises the 'Nordland Group' of Deegan & Scull (1979). Apparently, these sediments derive from Scandinavia and from Baltic rivers.

Miocene

Major Sequence Stratigraphic Unit 7 (Fig. 1) comprises the sediments found above the mid-Miocene unconformity. It was divided into 6 preliminary sequences, the four lower ones are of late Middle Miocene to Pliocene age and the two upper ones of Pleistocene age. The depocenter is located in the Central Graben area and the sequences are lenticular prograding clinoforms migrating towards the west (Sørensen & Michelsen, 1995). The unit makes up roughly half of the thickness of the post-Chalk succession of sediment in the area.

This Major Unit was later refined and divided into 31 sequences (Sørensen & Michelsen, 1995). Due to the existence of the Ringkøbing – Fyn High the sequences developed differently in the northern Norwegian-Danish Basin area and in the southern North German Basin area. The two basins were interconnected in the west in the Central Graben area. Apparently more hiatuses exist in the northern area, especially in the upper part. This phenomenon can possibly be caused by the quality of the conventional seismic data and by the lower thickness of the strata or these two causes in combination.

The mid-Miocene unconformity, that forms the base of Unit 7, is a conspicuously strong seismic reflector seen all over the eastern North Sea Basin (Cameron et al., 1993) and is recognised as a marked downlap surface migrating westward in the

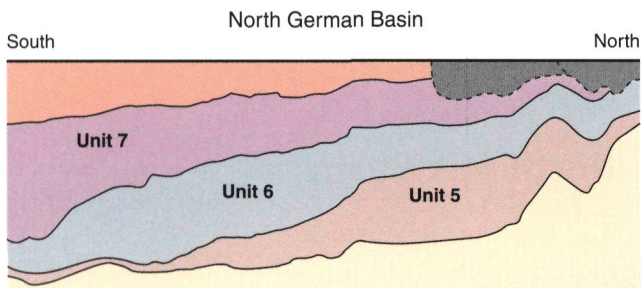


Fig. 1. Interpreted seismic reflection profile from the south to the north through the Horns Graben. Depth about 1 sec TWT and length about 100 km.

Central Graben area (Huuse & Clausen, 2001). The reflector is seen as an onlap surface migrating eastward in areas with Oligocene and Early Miocene strata on the Ringkøbing-Fyn High. In the gamma ray records it is characterised by one (or two) distinct peaks probably indicating starved sedimentation in the basin during a high-stand (Kristoffersen & Bang, 1982). It appears to correlate with the Middle Miocene Hodde transgression (Fig. 2), which led to the termination of peat formation in most northwest European lowlands (Huuse, 2002). Onshore Denmark, the marine conditions prevailed and continued in the Gram Formation of late Middle to Late Miocene age (Rasmussen, 1966). This is a coarsening-upward succession of clay and silt probably with sandy intercalations giving rise to a horizontally laminated seismic signature.

| CHRONO-STRAT. | | MAJOR SEQUENCE START. UNITS (Michelsen et al. 1998) | LITHOSTRATIGRAPHY ONSHORE DENMARK (Michelsen 1996, Michelsen et al. 1998) | |
|---------------|------------|---|---|------------|
| | | | WEST | EAST |
| CENOZOIC | QUATERNARY | 7 | QUATERNARY | QUATERNARY |
| | PLIOCENE | | U | SÆD Fm. |
| | | | L | |
| | MIOCENE | | U | GRAM Fm. |
| | | | M | HODDE Fm. |
| | | | 6 | |

Fig. 2. Stratigraphic table, with the Formations found in Jylland.

Pliocene

The existence of Pliocene deposits onshore Denmark is still debated as the so-called Sæd Clay (Fig. 2) is definitely of latest Miocene age (Rasmussen, 1966). In the Central Graben progradational wedges are ascribed to the Pliocene (Huuse 2002). Biostratigraphic investigations in wells in the northern part of the Danish sector (Konradi, 1995, 1996) indicate that the most complete section appears to be found in the Central Graben area. Here in the Kim-1 well only fluctuations in water depth and a possible hiatus between the Early and the Late Pliocene are identified. Outside this area several hiatuses are also biostratigraphically identified in the Late Miocene, in the Early as well as in the Late Pliocene and at the Plio-Pleistocene boundary.

The Plio-Pleistocene boundary has been mapped and indicates a generally westward dipping surface (Huuse & Lykke-Andersen, 2000). In most places the boundary is seen as a discordance, probably an erosional discordance after regression caused by the first Northern Hemisphere glaciation (Figure 1). The maximum thickness of the Pleistocene in the Central Graben area is over 1000 m. Here the boundary is also difficult to recognise in biostratigraphic analysis of the KIM-1 well (Konradi, 1995) and it is only indicated by the last occurrence of the foraminifer species *Cibicides grossus* generally said to belong in the Pliocene. The foraminifer species *Elphidium oregonense* characterises the first biostratigraphic zone in the Pleistocene (King, 1983, 1989). However, this species that belongs to the outer littoral facies has probably not been identified in the present well because of an unfavourable environmental setting in deep water. The species is found in several wells further south in the Danish sector (Pedersen, 1995) and onshore in the Netherlands (Van Voorthuysen, 1952).

Pleistocene and Holocene

The information on the Pleistocene is partly extracted from industrial reports from the hydrocarbon industry. These reports are concerned with the western-central part of the Danish sector. Seismically the Pleistocene consists of laterally continuous, sub-horizontal reflectors interpreted to be interbedded clay and sand sequences. Still, in a scientific borehole in the central-eastern part of the Danish sector, chiefly sands were identified. In these reports also several conspicuous reflectors are mentioned indicating several sedimentation events probably separated by erosion events (Konradi, 2002b).

Often the base of the Quaternary demonstrates the existence of valleys cut into that surface, caused by channelling, and most often repeated channelling in the Pleistocene. Part of these channels were mapped by conventional seismic techniques (Salomonsen, 1995), but other parts were mapped by high-resolution multichannel reflection seismic showing a general north-south trend (Huuse & Lykke-Andersen, 2000). Part of the deeper seated channels are expected to correlate with the multiple channelling seen in the Central British sector (Stoker et al., 1985), even though the individual formations have not been identified in the Danish sector. Some of the upper channelling events in the western-central Danish sector have been biostratigraphically dated to the Late Pleistocene (Salomonsen & Jensen, 1994) and correlated with nearby biostratigraphically dated boreholes.

Biostratigraphic analysis of boreholes in the Danish sector and adjacent British and Norwegian sectors indicate the existence of marine deposits with a temperate fauna. These can be ascribed to four interglacials (Sejrup & Knudsen, 1993). The same applies to marine deposits identified onshore Denmark (Sejrup & Knudsen, 1999) where these deposits are often found in depressions in the Quaternary subsurface.

Only limited investigations are concerned specifically with the Holocene. In a scientific borehole located in an erosional channel, identified in seismic data beneath the outer Heligoland Channel (Konradi, 2000), a Holocene succession has been identified biostratigraphically. An account of the environmental development of the 'Elbe Urstromtal' and of the Heligoland Channel area in the eastern North Sea is also given. In cores from the above mentioned industrial reports on site survey investigations several Holocene formations were identified and tentatively correlated with the lithostratigraphy in the Dutch and British southern North Sea (Konradi, 2002a, 2003; Konradi & Czakò, 2002a,b,c). Sediments correlatable with the late Pleistocene Twente Formation, the early Holocene Elbow Formation and the recent Nieuw Zeeland Gronden Formations were identified.

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