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Middle Eocene to earliest Oligocene development in the eastern North Sea Basin: Biostratigraphy, magnetostratigraphy and palaeoenvironment of the Kysing-4 borehole, Denmark

Erik Thomsen [a,*], Niels Abrahamsen [a], Claus Heilmann-Clausen [a], Chris King [b], Ole Bjørslev Nielsen [a]

[a] Department of Geoscience, University of Aarhus, Building 1672, DK8000 Aarhus C, Denmark
[b] 16A Park Road, Bridport, DT6 5DA, UK

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ABSTRACT

The cored 154.5 m deep Kysing-4 borehole in central Jutland is unique for high northern latitudes because it comprises an almost complete Middle Eocene to lowermost Oligocene succession mostly in a highly calcareous facies with abundant well preserved microfossils and from an upper bathyal environment. It has therefore been possible to carry out biostratigraphical analyses of calcareous nannofossils, benthic and planktonic foraminifera as well as dinoflagellate cysts. In order to correlate the section to the geomagnetic polarity time scale a detailed palaeomagnetic analysis has been performed. The magnetobiostratigraphic calibration allowed a well constrained identification of nearly all magnetochrons between Chron C21n and Chron C13n. The Eocene deposits consist mostly of calcareous ooze (Søvind Marl Formation with three new members formally defined), whereas the Oligocene Viborg Formation consists of moderately calcareous mud. Overall, the lithology of the deposits is in agreement with previous interpretations of a British provenance for the Eocene deposits and a Scandinavian provenance for the Oligocene deposits. Cyclic shifts in the clay/carbonate content during the Middle Eocene (chrons C19–C17) are attributed to orbitally controlled climate shifts. Obliquity seems to have been the dominating factor, but intervals dominated by precession end eccentricity signals also occur. A 10 m thick hitherto unknown black mud (Moesgaard Member) of Scandinavian provenance and deposited very rapidly during the late Eocene Chron C16n.1n is interpreted as a precursor event to the Oligocene mode of sedimentation. Both the Moesgaard Member and the Lower Oligocene Viborg Formation are associated with sea-level falls.

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1. Introduction

The warm greenhouse climate of the late Mesozoic and early Cenozoic eras reached a maximum during the Early Eocene, when northwest Europe experienced a subtropical to tropical climate (Collinson and Hooker, 1987; Collinson, 1992; Prothero, 1994; Lindow and Dyke, 2006). During the Middle and Late Eocene the global temperatures slowly decreased although with considerable fluctuations (Zachos et al., 2001, 2008; Miller et al., 2005). This cooling trend culminated at the Eocene–Oligocene transition with an abrupt temperature fall. The climate on Earth thus changed from greenhouse to icehouse conditions. The temperature fall affected all parts of the Earth from the interior of continents to the deep sea. However, the scientific documentation of the deterioration is far from evenly distributed. In the marine realm most studies are from the deep sea of the southern hemisphere and from the tropical and subtropical zones (e.g., Zachos et al., 2001). Only a few studies are from high northern latitudes including the North Sea Basin and the Nordic seas despite the fact that marine Eocene and Oligocene deposits occur widespread along the northwest European margin (Ziegler, 1990).

The reason for the lack of northern studies is mainly of geological nature. Most climate proxies are based on biogenic calcareous material and Eocene and Oligocene carbonate-rich successions from high northern latitudes are predominantly from shallow water environments. They are usually intersected by numerous hiatuses or accessible only in relatively small isolated outcrops (Aubry, 1986; Köthe, 1986, 2009; Vandenberghe et al., 2003, 2004; King, 2006). More continuous sections representing deeper water environments are normally non-calcareous due to carbonate dissolution. Recent studies based on dinoflagellates from ODP cores have improved our knowledge of the palaeoenvironment in the nordic seas (Eldrett et al., 2004; Eldrett and Harding, 2009). However, the ODP material is non-calcareous and the biological and geochemical climate proxies are uninvestigated.

In the central and eastern North Sea Basin, the Eocene–Oligocene boundary is marked by a major change in depositional pattern comprising a shift in the source of siliciclastic material from west to northeast, viz. from the British Isles to Norway (Danielsen et al., 1997; Michelsen et al., 1998). The broad outline of the shift is well established, but details

* Corresponding author. Tel.: +45 8715 6443.
E-mail address: erik.thomsen@geo.au.dk (E. Thomsen).

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are few, and the actual cause, climate or tectonics, remains controversial (De Man et al., 2004; Vandenberghe et al., 2004; King, 2006; Nielsen et al., 2009, 2010; Chalmers et al., 2010; Knox et al., 2010).

The 154.5 m deep Kysing-4 research borehole investigated in this study is located in central Jutland in the eastern part of the North Sea Basin. Jutland is the only onshore area in the North Sea Basin where relatively deep-water Middle and Upper Eocene sediments are preserved in a calcareous facies (Heilmann-Clausen et al., 1985), and the borehole section comprises the most continuous succession known from this time period in any onshore area of northwest Europe.

The aim of the study was threefold: (1) to establish a bio-chronostratigraphic framework allowing for a more precise correlation of northwest European sections to records outside this area and to the geomagnetic polarity time scale, (2) to analyse the sedimentological and palaeoenvironmental changes in the eastern North Sea Basin with special reference to the lithologic shift at the Eocene–Oligocene transition, and (3) to investigate the climatic changes in the North Sea area during the Middle Eocene to the Early Oligocene interval. The present paper deals only with points (1) and (2). The age determinations are based on calcareous nannofossils integrated with a palaeomagnetic analysis and calibrated with foraminifera and dinoflagellates. The palaeoenvironmental investigations are based on numerous sedimentological parameters together with studies of planktonic and benthic foraminifera and palynology. Stable isotopes and other climate proxies are under investigation and will be published later.

2. Geological setting

The Kysing-4 borehole is located centrally in the Danish Basin, a sub-basin located in the eastern part of the North Sea Basin bounded by the Fennoscandian Border Zone to the northeast and the submerged Ringkøbing-Fyn High to the south (Fig. 1a). The Middle Eocene to Lower Oligocene sediments in the eastern part of the

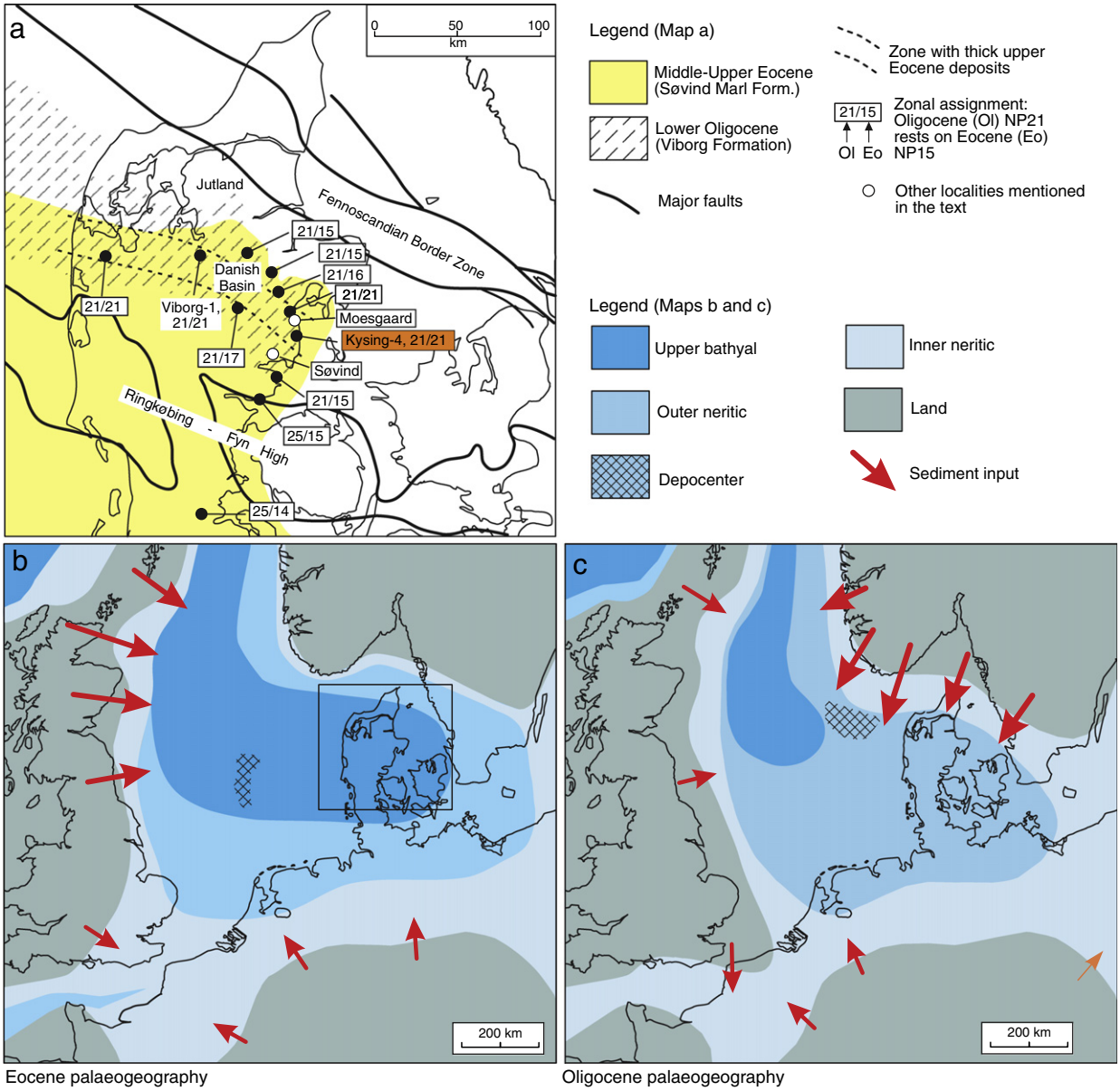

Fig. 1. (a) Map showing present day distribution of the Middle to Upper Eocene Søvind Marl Formation and the lowermost Oligocene Viborg Formation in Denmark. Position of the Kysing-4 borehole and three other Eocene localities discussed in the text (Viborg-1 borehole, Moesgaard and Søvind outcrops) are indicated. With respect to the Eocene–Oligocene boundary sections, the NP zones of the uppermost Eocene and the lowermost Oligocene deposits are given. Note that biostratigraphically continuous boundary sections are confined to the central part of the basin. (b) Eocene palaeogeography. Main sediment input to the North Sea Basin was from the British Isles. (c) Oligocene palaeogeography. Main sediment input was from Scandinavia. Palaeogeography modified from Ziegler (1990) with position of depocenters from Michelsen et al. (1998).

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