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Late Maastrichtian warming in the Boreal Realm: Calcareous nannofossil evidence from Denmark

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ABSTRACT

The climate of the mid to Late Cretaceous was probably one of the warmest of the Phanerozoic, but by the late Maastrichtian distinctly cool high latitude regions had developed. Studies from low latitude sites have demonstrated that the late Maastrichtian cooling was punctuated by two pulses of warming, but the response of nannoplankton to climatic fluctuation in the mid to high northern latitudes is not well documented. A high-resolution nannofossil study was undertaken on subsurface chalk sections of Denmark which provide a stratigraphically complete record of late Maastrichtian sedimentation of nannofossil ooze in an extensive mid to high latitude carbonate province. The quantitative nannofossil data from cored sections through the upper Maastrichtian chalk reveal subtle but significant shifts in taxa interpreted as having been sensitive to temperature fluctuations (*Arkhangelskiella cymbiformis, Kamptnerius magnificus, Lucianorhabdus cayeuxii, Nephrolithus frequens,* and *Watznaueria barnesiae*), and indicate two late Maastrichtian warming events correlatable with those of low latitude records, and a decrease in surface water temperatures in the latest Maastrichtian.

1. Introduction

The climate of the Late Cretaceous was probably one of the warmest of the last 200 million years (Hay, 2008). However, climate cooling was initiated at least by the Campanian, and possibly earlier at high latitudes (Jenkyns et al., 2004). The Maastrichtian was characterised by a cooler but variable climate with two periods of warming in the late Maastrichtian inferred from microfossil and geochemical studies (e.g. Li and Keller, 1998). The response of planktonic foraminifers and calcareous nannoplankton to these palaeoclimatic changes has been documented from the Southern Hemisphere, tropical Pacific and equatorial regions (Pospichal and Wise, 1990; Huber and Watkins, 1992; Li and Keller, 1998; Lees, 2002; Thibault and Gardin, 2006, 2007, 2010). However, the response of nannoplankton to climatic fluctuation in the northern mid to high latitudes in the late Maastrichtian is not well documented.

The Maastrichtian chalks of the Danish Central Graben and Danish Basin are significant archives of latest Cretaceous mid to high latitude palaeoceanographic change leading up to the Cretaceous/Palaeogene (K–Pg) boundary. The results from a nannoplankton study of seven cores from the Danish sector of the North Sea and onshore eastern Denmark are presented here and correlated with studies (where available) of planktonic foraminifers (Rasmussen and Lassen, 2004; Lassen and Rasmussen, 2004). Using nannofossil abundance we have identified significant climate-driven trends which can be compared with microfossil and geochemical records from the lower latitudes and southern hemisphere.

2. Geological setting

The Danish Central Graben and the Danish Basin are adjacent Mesozoic–Cenozoic depocentres that were situated at a palaeolatitude of 44°–46° N in the Late Cretaceous (Smith et al., 1994) (Fig. 1a–c). Although both form part of the regional North Sea extensional basin system, they experienced different subsidence histories reflecting variation in the relative importance of rift-related and inversion tectonics (Andsbjerg et al., 2001).

The Danish sector of the North Sea intersects the Central Graben, a predominantly Mesozoic feature that experienced major rift events in the Triassic and Jurassic (Jacobsen, 1982; Koch et al., 1982). Rifting waned in the latest Jurassic–earliest Cretaceous whilst inversion was initiated in the Late Hauterivian (Vejbæk and Andersen, 2002) and was particularly important in the Late Cretaceous–Palaeogene (Fig. 1b). The southern part of the Danish Central Graben, relevant to this study, is known as the "Salt Dome Province" (Damtoft et al., 1992) which structurally is dominated by salt diapirs and inversion structures (Fig. 1b).

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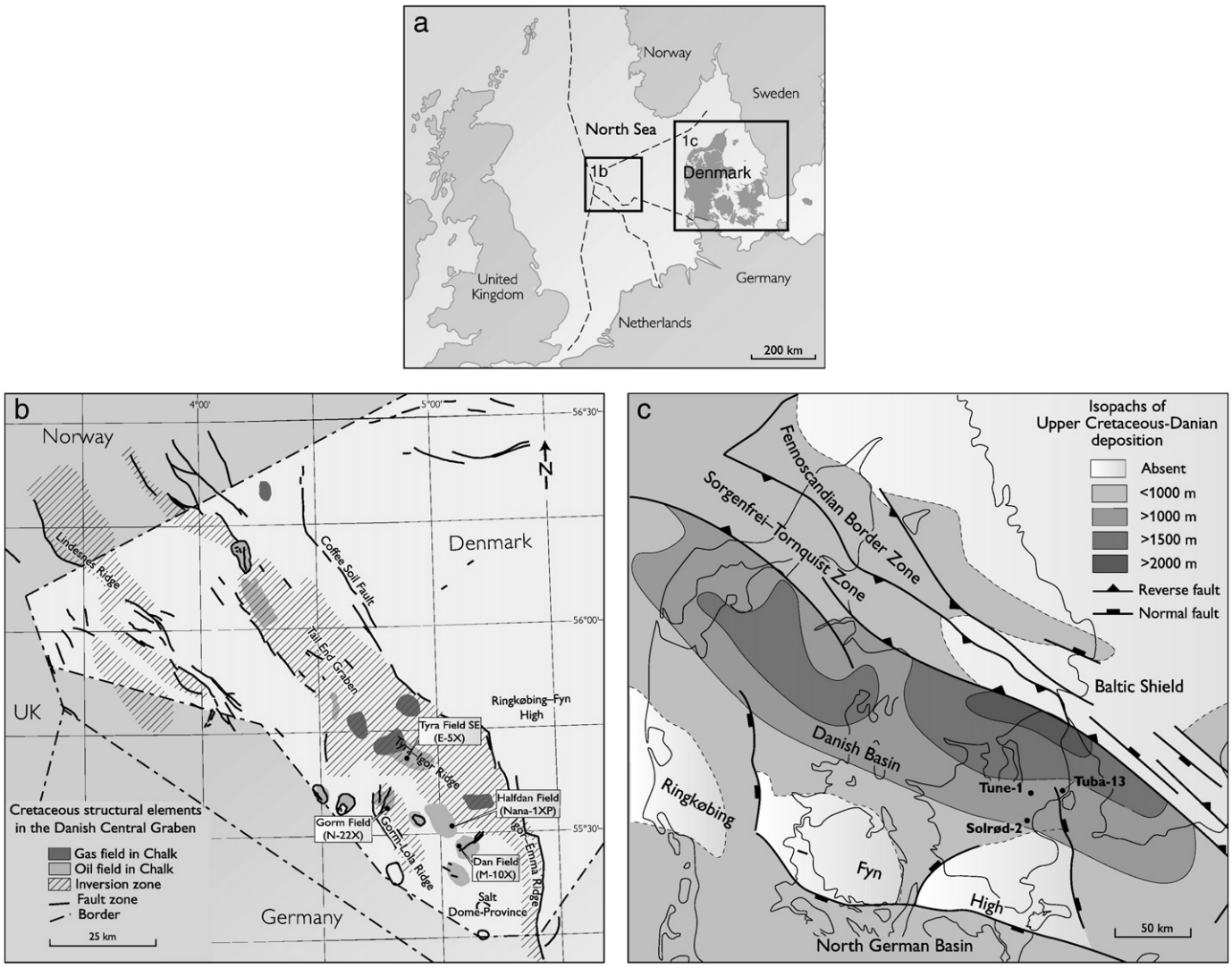

Fig. 1. Location maps. a, Northern Europe showing study area. b, Map showing the location of the Danish Central Graben wells relative to the important Maastrichtian structural elements. c, Structural map of the Danish Basin and surrounding areas with well localities (from Surlyk, 1997).

Further to the east, the Danish Basin is a NW–SE trending depression bordered to the NE by the Sorgenfrei–Tornquist Zone and to the SW by the Ringkøbing–Fyn High (Fig. 1c). Uplift and inversion of the Sorgenfrei–Tornquist Zone took place during the Late Cretaceous–Palaeogene (Vejbæk and Andersen, 2002).

3. Stratigraphy

The Cenomanian to Danian Chalk Group (Deegan and Scull, 1977) is widely distributed in NW Europe, and is over 1500 m thick in the Central Graben. It is fossiliferous and comprises very fine-grained, pure chalk and limestone, marly chalk, marl and calcareous shale, with flint nodules present at some levels.

The Maastrichtian part in the Danish area is known as the Tor Formation (nannofossil Zones UC17–20, Fritsen, 1999) and is 150–250 m thick (Surlyk et al., 2003). The Tor Formation is typically a homogenous, clay-poor, bioturbated chalk unit but in detail a range of facies can be recognised (Damholt and Surlyk, 2004; Ineson et al., 2004; Anderskouv et al., 2007). Although redeposited chalks are a common feature of the Tor Formation in the Central Graben of the North Sea, such facies are rare in the southern Danish sector (the study area). In the Danish Central Graben, the upper boundary of the formation is marked by a mature hardground (at the top of nannofossil subzone UC20d^{BP}) defining a marked hiatus that spans the K–Pg boundary (Ineson, 2004; Sheldon, 2006). The hardground level is characterised by an upper Maastrichtian nannofossil flora with burrowed Danian nannofossils, and is termed the "mixed-interval" in this study.

The Kjølby Gaard Marl (Troelsen, 1955; Ekdale and Bromley, 1983), a light grey-brown marl, approximately 35 cm thick, has been widely recognised in Danish Basin wells where it represents an important upper Maastrichtian (in UC20d^{BP}) marker bed. A marly chalk unit has been identified at a comparable stratigraphic level in a number of Danish Central Graben wells, providing a further lithostratigraphic correlation between the Danish Basin and the Central Graben.

4. Palaeoenvironment

The Late Cretaceous was characterised by a high sea-level which resulted in a vast, relatively deep epicontinental sea covering most of the low-lying, peneplaned land of NW Europe. This sea connected the Tethyan, Boreal and Atlantic seas during the Late Cretaceous–Early Paleocene highstand, and connectivity between the three basins was relatively good (Ziegler, 1990; Esmerode et al., 2008). Using foraminiferal data, Hart (2007) showed that a late Maastrichtian water mass flowed from the Atlantic, through the Faeroe–Shetland Basin into the Viking Graben and into the North Sea from the north.