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Dinoflagellate cyst biostratigraphy of Upper Cretaceous strata from two wells in the Norwegian Sea

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ABSTRACT

Rich assemblages of dinoflagellate cysts from two sections in the Norwegian Sea provide a solid basis for a palynostratigraphic framework for the upper Albian to upper Maastrichtian succession in this area. The framework is based on a unique composite section combining samples from the shallow stratigraphic core 6711/4-U-1 and core-samples from well 6707/10-1, the latter filling in data from the intervals represented by hiatuses in core 6711/4-U-1. Seven previously described, and one new palynostratigraphic zone, are recognised. These are based on the relative abundances of prominent taxa together with top and base occurrences of selected age-diagnostic dinoflagellate cyst taxa. The zones and their ages in ascending order from the oldest to youngest comprise: the intra late Albian to intra early Cenomanian *Subtilisphaera kalaalliti* Interval Zone sensu Nøhr-Hansen (1993a); the intra early Cenomanian to intra late Cenomanian *Palaeohystrichophora infusorioides*–*Palaeohystrichophora palaeoinfusa* Interval Zone sensu Radmacher et al. (2014b); the Turonian to ?intra early Coniacian *Heterosphaeridium difficile* Interval Zone sensu Nøhr-Hansen (2012); the ?intra early Coniacian to late Santonian *Dinopterygium alatum* Interval Zone sensu Radmacher et al. (2014b); the early Campanian *Palaeoglenodinium cretaceum* Interval Zone sensu Radmacher et al. (2014b); the new intra Campanian *Hystrichosphaeridium dowlingii*–*Heterosphaeridium* spp. Interval Zone; the intra late Campanian *Chatangiella bondarenkoi* Interval Zone sensu Radmacher et al. (2014b) and the intra late Maastrichtian *Wodehouseia spinata* Range Zone sensu Nøhr-Hansen (1996). Comparison of the palynological events with records in adjacent regions enables correlation across similar paleolatitudes in the Northern Hemisphere.
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1. Introduction

During the past decades, the Norwegian Sea has become increasingly important for the petroleum industry due to the recognition of Upper Cretaceous plays. A relatively large number of exploration wells have been drilled, and the need for a solid biostratigraphic framework is therefore increasingly important. The objectives of this study are therefore to identify and describe the distribution of dinoflagellate cyst assemblages from the Upper Cretaceous interval. Palynological analysis of a shallow stratigraphic core (6711/4-U-1) and exploration well (6707/10-1), and comparison to the south-western Barents Sea, has resulted in a detailed description useful for future dating of sections in this region. Since core material is extremely scarce from exploration wells, the samples on which this study is based, add valuable knowledge concerning the ranges of important taxa. Previous palynological studies of well 6707/10-1 include that of Williams et al. (2005), who investigated non-acid palynological preparation of dinoflagellate cysts. Setoyama et al. (2013) described the foraminiferal and palynological biostratigraphy of the Vøring Basin, focusing mainly on Santonian to Campanian foraminiferal biofacies of fan sub-environments recorded in well 6707/10-1 and comparing them to other Upper Cretaceous records from the south-western Barents Sea (Setoyama et al., 2011a, b). In addition, several non-palynological studies of exploration well 6707/10-1 have been conducted (Brekke et al., 1999; Kittilsen et al., 1999; Færseth and Lien, 2002; Ren et al., 2003; Lien, 2005; Martinsen et al., 2005; Morton et al., 2005b; Knaust, 2009).

Late Cretaceous dinoflagellate cysts from other locations in the Vøring Basin and adjacent regions have also been studied by Gradstein et al. (1999, 2010a) who provided a foraminiferal zonation calibrated with dinoflagellate cysts, and Costa and Davey (1992) who included palynology from offshore Norway. Extensive work by Nøhr-Hansen (2012) provides valuable knowledge on the Late Cretaceous palynology from East Greenland, which during this time period was located close to the studied area (Fig. 1), and was a major source of sediment

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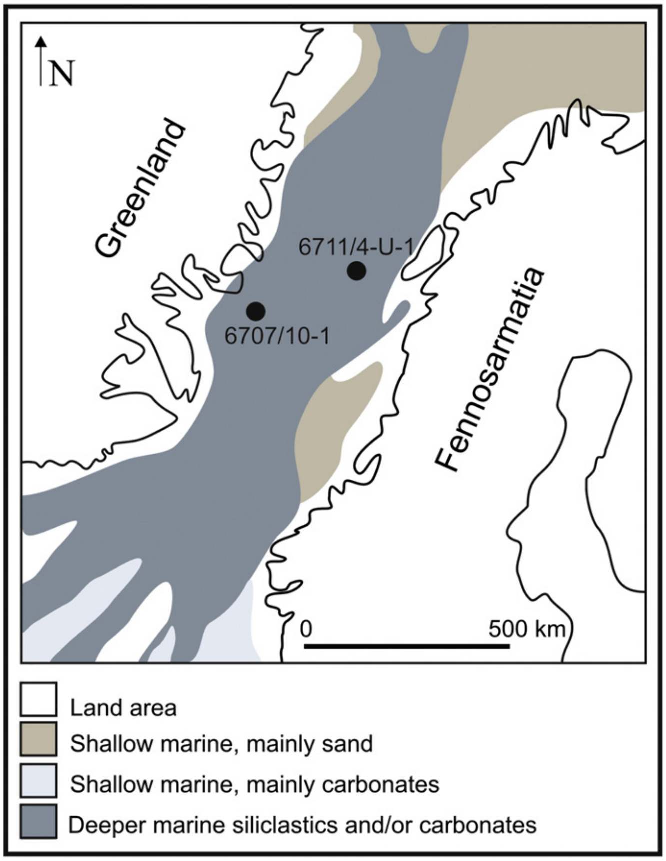

Fig. 1. Turonian–Campanian palaeogeographical reconstruction of the Norwegian–Greenland Seaway and surrounding areas (modified after Ziegler, 1988).

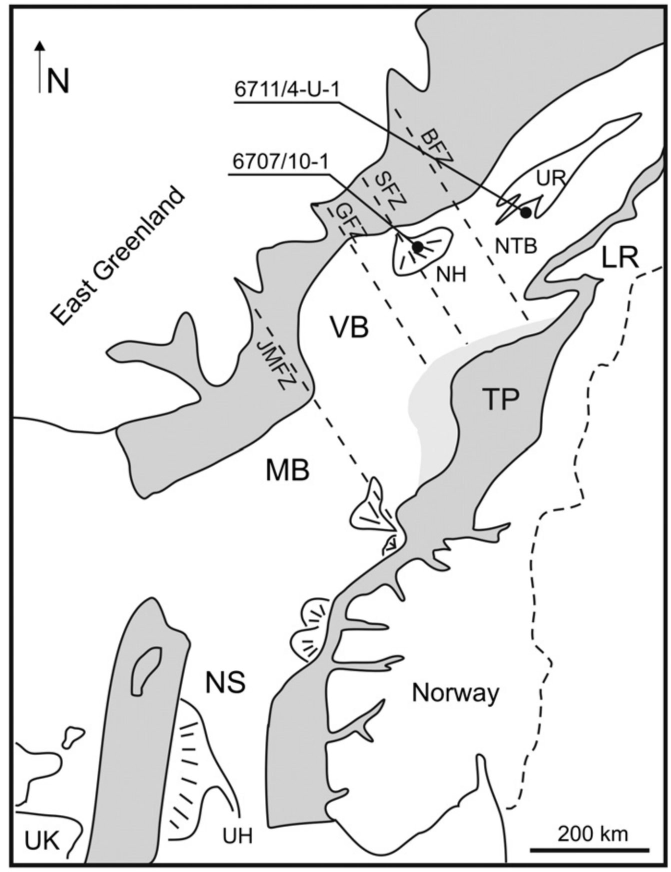

Fig. 2. Map of the Norwegian Sea with the location of wells 6707/10-1 and 6711/4-U-1, and with major structural features shown: NS: North Sea, VB: Vøring Basin, MB: Møre Basin, UH: Utsira High, NH: Nyk High, NTB: North Træna Basin, UR: Utrøst Ridge, TP: Trøndelag Platform, LR: Lofoten Ridge, JMFZ: Jan Mayen fracture zone, GFZ: Gleipne fracture zone, SFZ: Surt fracture zone, BFZ: Bivrost fracture zone. Shaded part indicates paleo-shelf areas. The map has been modified after Martinsen et al. (2005) and Hansen et al. (2012).

(Fonneland et al., 2004; Morton et al., 2005a; Faleide et al., 2008). Additionally, palynofloras from West Greenland have been investigated by Nøhr-Hansen (1993a, b, 1994, 1996) as well as Nøhr-Hansen and Dam (1997). A formal zonation has recently been published from the south-western Barents Sea, (Radmacher et al., 2014b). In addition, the palynological significance of a new *Heterosphaeridium* species was described by Radmacher et al. (2014a). Palynological studies from other nearby regions include, for example, the Scotian Shelf (Fensome et al., 2008; Fensome et al., 2009), Great Britain (Pearce, 2010), offshore Norway (Costa and Davey, 1992), the North Sea (Schiøler and Wilson, 1993), Greenland (Nøhr-Hansen, 1993a, b, 1996, 2012), Northern Siberia (Lebedeva, 2006), in addition to a more global compilation by Williams et al. (2004).

2. Geological setting

The studied boreholes are located in the Norwegian Sea (Fig. 2), presently a part of the northeast Atlantic passive margin. Crustal separation between Europe and Greenland advanced during the Late Cretaceous, as a result of thermal subsidence following rifting in the late middle Jurassic–Early Cretaceous (Blystad et al., 1995; Brekke, 2000; Ren et al., 2003). At the onset of Cretaceous–Paleocene rifting, the region between Greenland and NW Europe was an epicontinental sea located in a zone of extensively weakened crust caused by earlier rift episodes (Ren et al., 2003; Faleide et al., 2008). The continuing break-up in the Paleocene–Eocene caused increased volcanism (Ziegler, 1990).

The shallow stratigraphic core 6711/4-U-1 was drilled in the North Træna Basin, south of the Utrøst Ridge (Fig. 2), where Cretaceous rocks subcrop below a thin Quaternary cover. Exploration well 6707/10-1 was drilled in the north-western part of the Vøring Basin, on the Nyk High. During the Late Cretaceous and Paleocene the Vøring Basin was an active rift basin. The main period of faulting occurred in the Campanian, resulting in the presence of a thick Campanian succession in the area (Ren et al., 2003). During the Paleocene late rift phase, regional uplift caused inversion structures such as the Nyk High, which became areas of erosion and redeposition (Knaust, 2009). The Late Cretaceous tectonic activity, which occurred prior to sea-floor spreading, led to increased sand supply from the west into the Vøring Basin (Fonneland et al., 2004; Morton et al., 2005a; Faleide et al., 2008). The southernmost part of the Vøring Basin was infilled by thick units of marine mud, whereas in the northern parts, thick Upper Cretaceous deep-water sandstones were deposited (Fjellanger et al., 2005; Lien, 2005).

The Late Cretaceous succession in the studied region is assigned to the Cromer Knoll and Shetland Groups (Fig. 3) following Worsley et al. (1988) and Gradstein et al. (2010a). The Langebarn Formation (Gradstein et al., 2010a) correlates with the lower part of the Lange Formation of Worsley et al. (1988) and is dated as of Aptian to Albian age. The overlying formations belong to the Shetland Group (Gradstein et al., 2010a) and are represented by the Cenomanian to Coniacian Blålange Formation, the Coniacian to Santonian Kvitnos Formation, the Nise Formation which may range from Santonian to Campanian, and the Springar Formation ranging from the Campanian to Maastrichtian (Worsley et al., 1988; Gradstein et al., 2010a). The various lithostratigraphical schemes are compiled in Figure 3.

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