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Late Neogene dinoflagellate cyst and acritarch biostratigraphy for Ocean Drilling Program Hole 642B, Norwegian Sea

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ABSTRACT

The Arctic is a critical region in the current and past global climate system. One major challenge for investigating the geological history of the Arctic is the establishment of a rigorous chronology. To get better insights into the late Neogene history of oceanographic and climatic change in the region, well-calibrated ocean drill cores are essential. Nevertheless, detailed stratigraphy from (sub)Arctic ocean drill sites remains problematic due to the generally poor preservation of calcareous microfossils in high northern-latitude oceans. Here, organic-walled palynomorphs (dinoflagellate cysts and acritarchs) can compensate for the lack of calcareous microfossils because diverse and rich palynological assemblages can be recovered. We defined three magnetostratigraphically-calibrated dinoflagellate cyst and acritarch biozones in the Upper Miocene to Upper Pliocene of Norwegian Sea Ocean Drilling Program Hole 642B (Vøring Plateau) that show potential for correlation within the Nordic Seas. It is also noted that several bioevents in the Nordic Seas are strongly diachronous with the North Atlantic, highlighting the limitations of applying North Atlantic bioevents directly to the Nordic Seas. For each of the three interval biozones (VP1 to VP3) we use the highest occurrences of acritarch and dinoflagellate cyst species ("*Veriplicidium franklinii*" of Anstey 1992, *Reticulatosphaera actinocoronata*, and *Invertocysta lacrymosa*) that are relatively synchronous across the Nordic Seas and North Atlantic and thus show potential for a North Atlantic–Arctic reference stratigraphy.

1. Introduction

The Norwegian Sea links the high-latitude eastern North Atlantic with the Arctic Ocean and is today a critical component of the high-latitude ocean circulation and Arctic climate because of northward heat transport via the Norwegian Atlantic Current. Circulation in the Nordic Seas was different from the present during the earliest Pliocene (Jansen et al., 2000), with a modern-like circulation developing after 4.5 Ma in the Early Pliocene (Knies et al., 2014; De Schepper et al., 2015). In order to gain further understanding of the timing of oceanographic and climatic changes in the Arctic Ocean and Nordic Seas, detailed studies of chronostratigraphically well-calibrated successions are essential (e.g. Mattingsdal et al., 2013). The major challenge for a detailed stratigraphy at (sub)Arctic ocean drill sites remains the poor preservation of calcareous microfossils, or also simply their absence due to the harsh environmental conditions. Calcareous microfossils have not been recorded from the only existing Neogene Arctic Ocean sediment record (ACEX), and establishment of a reference stratigraphy for that region is further hampered by incomplete core recovery and the generally rare presence of organic-walled microfossils (e.g. Moran et al., 2006; Matthiessen et al., 2009a, 2009b). However, recently, at the margin of the Arctic Ocean, on the Yermak Plateau in the Fram Strait, an uppermost Miocene to Quaternary stratigraphic framework for the Atlantic–Arctic gateway was successfully established based on seismic correlation, magnetostratigraphy and biostratigraphy at Ocean Drilling Program (ODP) Sites 910, 911 and 912 (Mattingsdal et al., 2013). Based mainly on palynology and magnetostratigraphy, the base of ODP Hole 911A was placed in the lowermost Pliocene, with an age likely around 5.2 Ma (Mattingsdal et al., 2013; Grøsfjeld et al., 2014). Schreck et al. (2012) calibrated Neogene dinoflagellate cyst and acritarch bioevents to magnetostratigraphy at Iceland Sea ODP Hole 907A. These bioevents were successfully applied to dating a Central Artic Late Miocene interval (Stein et al., 2016), highlighting the potential of palynology in contributing to dating Arctic and Nordic Seas sediments and establishing an Arctic reference stratigraphy. In the Norwegian Sea, Mudie (1989) already documented a diverse late

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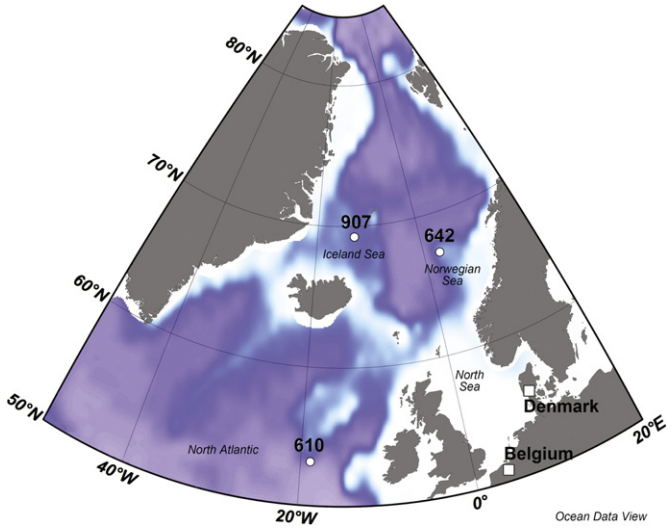

Fig. 1. Bathymetric map of the Nordic Seas showing the location of ODP Site 642 in the Norwegian Sea and the other locations in the Iceland Sea (ODP Site 907), the North Atlantic (DSDP Site 610) and the North Sea Basin discussed in the text.

Neogene dinoflagellate cyst flora, but a detailed and up-to-date record of dinoflagellate cyst stratigraphic events is currently required.

In the Nordic Seas, organic-walled palynomorphs (dinoflagellate cysts and acritarchs) can compensate for the absence of calcareous microfossils since their assemblages are known to be diverse, rich and well preserved. Furthermore, our knowledge of late Neogene dinoflagellate cysts and acritarchs has increased steadily since the 1990s following major taxonomic advances and the formal description of numerous new dinoflagellate cyst and acritarch taxa (e.g. Head, 1993, 1996, 1997; Head and Norris, 2003; De Schepper et al., 2004; De Schepper and Head, 2008a, 2014; Schreck et al., 2012; Verhoeven et al., 2014; Versteegh and Zevenboom, 1995). Dinoflagellate cysts have been successfully applied for establishing a detailed late Neogene stratigraphy in the eastern North Atlantic (De Schepper and Head, 2008b, 2009), Iceland Sea (Verhoeven et al., 2011; Schreck et al., 2012) and the North Sea Basin (Louwye et al., 2004; De Schepper et al., 2009; Dybkjær and Piasecki, 2010), suggesting that this should also be achievable in the Norwegian Sea.

Because of the oceanographic and climatic importance of the Norwegian Sea in the Arctic region, we have reinvestigated the palynology of ODP Site 642 with the help of advances in dinoflagellate cyst and acritarch taxonomy. ODP Site 642 (Fig. 1) located on the Vøring Plateau is currently influenced by Atlantic waters via the Norwegian Atlantic Current, yet is situated at a latitude comparable to that of the Iceland Sea ODP Site 907, where Schreck et al. (2012) documented Miocene to Pliocene dinoflagellate cyst assemblages. The aim of this study is to establish a new, detailed palynostratigraphy for the Upper Miocene to Pliocene succession in the Norwegian Sea, which may represent a benchmark biozonation that can interlink the North Atlantic, Norwegian Sea, and Arctic Ocean.

2. Materials and methods

2.1. Ocean Drilling Program Hole 642B: lithology and samples

ODP Hole 642B (67°13.5′N, 2°55.7′E; water depth 1268 m, core recovery of 97.5%) located on the outer Vøring Plateau, was drilled with an advanced hydraulic piston corer in 1985 as a part of the ODP Leg 104 (Shipboard Scientific Party, 1987) (Fig. 1). The drill hole reached a depth of 221.1 meters below sea floor (mbsf), with a total core recovery of 215.6 m, and penetrated predominantly pelagic to hemipelagic sediments of Holocene through Early Miocene age.

The 40 samples investigated in this study were collected from the lower part of lithological Unit I, Subunit IIA and the upper part of IIB (Fig. 2). Unit I (0–65.7 mbsf) consists of repeated alternations of dark, carbonate-poor glacial mud and light, carbonate-rich interglacial sandy mud. Bioturbation and the presence of dropstones are common throughout. Subunit IIA (65.7–90.4 mbsf) consists predominantly of nannofossil oozes, with minor diatom-nannofossil oozes and muds. This subunit is moderately to heavily bioturbated. Subunit IIB (90.4–107.2 mbsf) consists of siliceous oozes and siliceous muds, one short interval of nannofossil ooze and several minor volcanic ash layers, which have been moderately to heavily bioturbated.

2.2. Palynological preparation

Samples were first wet sieved at 150 and 63 μm for measurements of foraminiferal stable isotopes (Risebrobakken et al., 2016). Consequently, the <63 μm sediment fraction was dried and processed to extract organic-walled palynomorphs at Palynological Laboratory Services Ltd. (Holyhead, UK) following a slightly modified procedure described in De Schepper and Head (2008a). A weighed quantity of each sample (Table 1) was disintegrated and placed into a 1 l Tripour beaker. One *Lycopodium clavatum* spore tablet (Batch no. 483.216, n = 18,583 ± 1708 spores per tablet) was added prior to chemical degradation. Calcium carbonate was removed by slowly adding 50% hydrochloric acid (HCl) until the sample had stopped reacting. Subsequently, the beaker was topped up fully with water, stirred and allowed to settle. The diluted supernatant liquid was then sieved through a 10-μm sieve cloth, and the collected residue returned to the beaker. To remove silicate, 100 ml of 60% hydrofluoric acid (HF) was added and left for two days with periodic stirring. The sample was then topped up with water for dilution and the entire residue sieved through a 10-μm sieve cloth and collected, before it was placed in a 250 ml Pyrex glass. Oxidation was carried out on four samples (642B-9H5, 100–101 cm, 642B-10H2, 40–41 cm, 642B-10H2, 100–101 cm, 642B-10H3, 102–103 cm) before mounting by adding 50% cold nitric acid (HNO_3) to the residue in the beaker (in 25 ml of water) and left for some time, depending on the preservation of the residue present. A short ultrasonic treatment then preceded the sieving as before using water. Before mounting, the residue was mixed with a 1% solution of polyvinyl alcohol (PVA) to prevent clumping, and stained with Safranin-O if necessary. It was then pipetted onto a 32 × 22 mm cover slip on a low temperature drying plate and allowed to dry. Once dry, the coverslip was mounted onto the glass microscope slide using glycerine jelly optical adhesive.

2.3. Counting, photography and data storage

The focus of this study was the dinoflagellate cyst assemblage, but also acritarchs and terrestrial palynomorphs were identified. At least 250 dinoflagellate cysts were counted in each slide along non-overlapping traverses at 400× magnification using a transmitted light microscope (Zeiss Axiophot and AxioImager.A2). During this regular count, all encountered acritarchs, spores, pollen and fresh water algae were also enumerated. The remainder of the slide was scanned at 200× magnification to identify rare taxa not seen during the regular count. Broken palynomorphs were counted as one unit when more than half of the original form was present.

Photographs of selected dinoflagellate cysts and acritarchs (see Plates I–VI) were taken using a Zeiss Axiocam 506 Color on a Zeiss AxioImager.A2 microscope.

All raw data are available at http://doi.pangaea.de/10.1594/PANGAEA.846838.

2.4. Taxonomy and nomenclature

Some taxa were grouped due to problematic taxonomy and/or limited stratigraphic value. This includes most *Spiniferites* and