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Early Cretaceous palaeoceanography of the Greenland–Norwegian Seaway evidenced by calcareous nannofossils

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ABSTRACT

Reconstructions of the palaeoclimate of the Early Cretaceous are controversial, varying from a warm-temperate greenhouse world to icehouse conditions. We studied calcareous nannofossil assemblages of sediments from North-East Greenland (Wollaston Forland and Kuhn Ø) of Late Ryazanian–Barremian age in order to better understand the palaeoclimate and palaeoceanography of the high latitudes. The calcareous nannofossil assemblages are characterized by abundant *Crucibiscutum* spp. and *Watznaueria* spp., *Biscutum constans* and other Boreal taxa. They show also influxes of Tethyan and low to mid latitudinal taxa like nannoconids (e.g. *Nannoconus bermudezii*, *Nannoconus dolomiticus*, *Nannoconus steinmannii*), pentaliths (*Micrantholithus hoschulzii*, *Micrantholithus obtusus*), conuspheres, *Speetonia colligata* and *Cruciellipsis cuvillieri* in the Upper Ryazanian and Lower Hauterivian. Reconstructed surface water conditions, indicated by fluctuations in the assemblage compositions, suggest cool conditions for the Late Ryazanian, a cold climate for the Valanginian, and warm climatic conditions for the Hauterivian–Barremian. High meridonial temperature gradients and cool–cold climatic conditions in the high latitudes caused supposedly the formation of deep water in the South Anyui Gulf in the Late Ryazanian–Valanginian. Palaeoceanographic changes, reflected in a counter-balanced ocean current system in the Greenland–Norwegian Seaway, allowed Tethyan biota to spread as far north as North-East Greenland during the Late Ryazanian.

1. Introduction

During the last decades the interpretations of the palaeoclimate and palaeoceanography of Late Jurassic and Early Cretaceous oceans varied from those of a uniform warm-temperate greenhouse world to icehouse world conditions. Studies of the late 1970's and early 1980's argue for warm tropical to subtropical conditions prevailing up to 45°N, possibly even up to 70°S (e.g. Frakes, 1979; Hallam, 1981, 1985). Palaeotemperature data ($\delta^{18}O$) from low latitude oceans (Douglas and Woodruff, 1981) indicate that the temperatures of Early Cretaceous oceans were only 2–4 °C lower than those of the Cenomanian, implying that warm and equable greenhouse conditions prevailed during the Cretaceous over the globe. More recent studies (e.g. Weissert and Lini, 1991; Mutterlose and Kessels, 2000) discuss a more varied climatic scenario with the formation of polar ice caps for the Valanginian and the Aptian/Albian. These cold snaps had a duration of a few thousand to two million years (e.g. Kemper, 1987; Frakes and Francis, 1988; Frakes et al., 1992; Ditchfield, 1997). Cool ocean temperatures have also been postulated by Pucéat et al. (2003) and Price and Mutterlose (2004). Price and Nunn (2010) propose cool temperatures for the high latitudes with transient glacial polar conditions. This interpretation of an Early Cretaceous ice-house world is opposed by Littler et al. (2011) and Jenkyns et al. (2011), who suggest a warm and stable climate for the Early Cretaceous with a lower meridonial temperature gradient than today.

Most studies, which tried to reconstruct the palaeoclimate of the Early Cretaceous, concentrated on low latitudinal tropical to subtropical sites, including the majority of the ODP/DSDP sites and Tethyan outcrops (Kollman and Zapfe, 1992; Mutterlose et al., 2003). These low latitudinal settings, however, were hardly affected by potential palaeoclimatic changes. Data from high latitudes, being more sensitive to temperature shifts, should supply clearer evidence for palaeoclimatic variations. A key area for understanding Early Cretaceous palaeoclimate and palaeoceanography is the Greenland–Norwegian Seaway. Lower Cretaceous sediments of high latitudinal affinities occur both in North-East Greenland and along the shelf area of Norway and Barents Sea (Mutterlose et al., 2003). In order to overcome the rarity of high latitudinal data we have studied and analyzed two sections of Ryazanian–Barremian age from North-East Greenland with respect to their calcareous nannofossil assemblages. Calcareous nannofossils can be used to reconstruct palaeoceanographic and palaeoclimatic changes (e.g. Roth and Krumbach, 1986; Erba, 1994; Mutterlose, 1996; Mutterlose and Kessels, 2000) for the Cretaceous period. The high-latitudinal calcareous nannofossil assemblages of the Lower Cretaceous of Greenland are well-preserved and should reflect autecological changes (temperature, nutrients, salinity).

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The objectives of this study are 1) to reconstruct potential changes of surface water conditions (temperature, nutrients) based on fluctuations of the calcareous nannofossil assemblages, 2) to observe possible influxes of Tethyan taxa, 3) to reconstruct the palaeoceanographic and palaeoclimatic conditions in the Boreal-Arctic province during the Early Cretaceous, and 4) to interpret the depositional environment of the Lower Cretaceous sediments.

2. Geological setting

2.1. Sediments

The Late Ryazanian–Hauterivian sediments of North-East Greenland were deposited at the end and shortly after a major Late Jurassic–earliest Cretaceous rifting event (Vischer, 1943; Maync, 1947, 1949; Surlyk, 2003). The uppermost Jurassic–lowermost Cretaceous in the Wollaston Forland–Kuhn Ø area is characterized by an up to three kilometre thick succession of coarse clastic sediments accumulated in submarine fans along fault scarps in westward-tilted half-grabens during rift-climax in the middle Volgian–late Ryazanian (Surlyk, 1978, 2003) (Fig. 1). In distal direction the Lower Cretaceous sediments rapidly wedge out and are finer grained. The early post-rift time was associated with a transgression, draping the syn-rift deposits with a thin cover of Ryazanian–Hauterivian marine sediments, represented by fossiliferous mud- and marlstones of the Albrechts Bugt and Rødryggen Members (Surlyk and Clemmensen, 1975; Surlyk, 1978), which are object of the calcareous nannofossil study described in this paper. At the Rødryggen and Perisphinctes Ravine sections, the Albrechts Bugt Member consists of 22–34 m thick calcareous mudstones. The overlying 3.5–5 m thick Rødryggen Member, composed of claret-coloured calcareous mudstones, has everywhere an unconformable upper boundary. These calcareous mudstones have commonly been referred to as the time of the first limestone deposition in Greenland since the Late Permian (Maync, 1949). The units are sandwiched within a kilometre-thick succession of Jurassic and Barremian black mudstones. The Upper Ryazanian–Hauterivian calcareous sediments thus reflect a relatively short interval of significant palaeoceanographic changes in an otherwise black mudstone dominated environment (Alsen, 2006).

2.2. Palaeoceanography of the Greenland–Norwegian Seaway

During the Early Cretaceous, the Greenland–Norwegian Seaway served as a gateway between the Arctic Ocean in the north and the Tethys in the south (Fig. 2). After non marine conditions, prevailing throughout the Bajocian–early Bathonian, the late Bathonian–Kimmeridgian saw an overall transgressive trend establishing stepwise the Greenland–Norwegian Seaway with a maximum sea-level in the late Kimmeridgian (e.g. Surlyk, 1990; Doré, 1991).

An arid setting, which is documented for the Volgian at the mid latitudes (36°N palaeolatitude) of southern England, northern Germany (by evaporites, Ruffel and Rawson, 1994) and for the southern North Sea (Abbink et al., 2001), caused deep saline waters flowing north, counterbalanced by a southward flow of cooler surface waters (e.g. Abbink et al., 2001). These current patterns, which prevailed throughout the late Oxfordian–Volgian, may explain the southward expansion of Boreal marine faunas at the beginning of the Tithonian described by Schudack (1999) for ostracods or by Atrops et al. (1993) for ammonites. A global sea-level fall across the Jurassic–Cretaceous boundary, initiated by low spreading rates (Haq et al., 1988; Ziegler, 1990; Hardenbol et al., 1998), resulted in an almost complete separation of the Boreal Realm and the Tethys causing a distinctive provincialism of marine floras and faunas.

The Late Ryazanian–Hauterivian saw the drowning of North-East Greenland, transgressive conditions (Rawson and Riley, 1982; Haq et al., 1988; Ziegler, 1990) and a change of ocean current patterns. The occurrence of Tethyan derived plankton (calcareous nannofossils), nekton (belemnites, ammonites) (Alsen, 2006; Alsen and Mutterlose, 2009) and benthos (brachiopods) (Owen, 1973; Harper et al., 2005) in North-East Greenland suggests a northward flow of surface water currents in the Late Ryazanian–Hauterivian, preventing simultaneously a southward migration of Boreal-Arctic elements. The Greenland–Norwegian Seaway thus served as a conduit for heat transport between the low latitudes and Polar Regions, where Atlantic water masses affected the sediments of North-East Greenland and the Barents Sea. A potential cooler subsurface or bottom counter current, flowing perhaps further east in the central part of the seaway may have compensated the northward flow (Alsen, 2006).

Subsequent deposition of Barremian–Aptian black mudstones in Greenland implies a shift of the oceanic regime towards stagnant conditions. During this phase the seaway was around 500 km wide and partly of bathyal water depth with dysaerobic bottom water conditions (Gradstein et al., 1999).

2.3. Chronostratigraphy

Integrated calcareous nannofossil and ammonite data from North-East Greenland allow a biostratigraphic zonation scheme for the Early Cretaceous Boreal-Arctic Province of the Boreal Realm. Pauly et al.

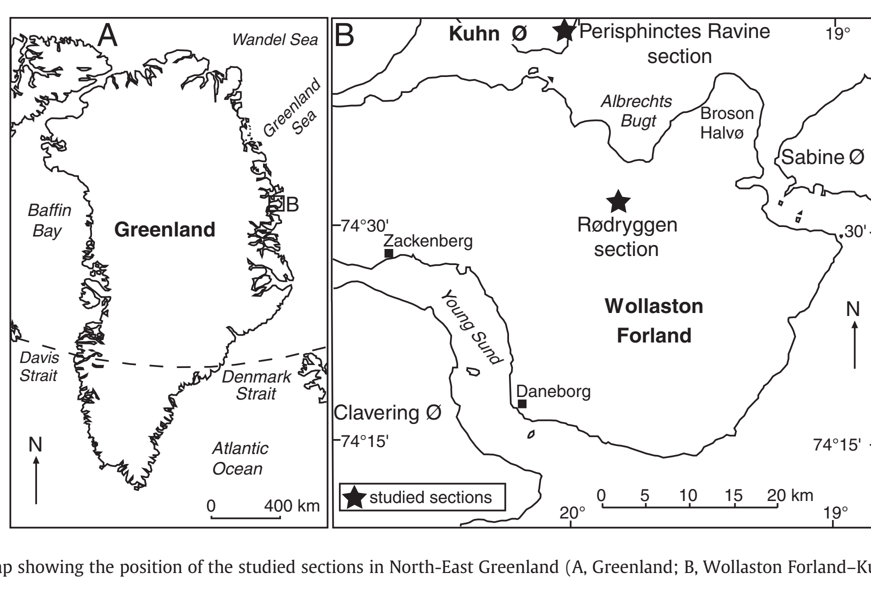

Fig. 1. Map showing the position of the studied sections in North-East Greenland (A, Greenland; B, Wollaston Forland–Kuhn Ø area).