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# Integrated stratigraphy of Lower Cretaceous sediments (Ryazanian–Hauterivian) from North-East Greenland

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ABSTRACT

The reconstruction of past climates and oceanography requires a solid stratigraphic framework ideally applicable on a global scale. The earliest Cretaceous, however, was a time of strong faunal provincialism, making supra-regional correlation of biostratigraphical zonations difficult. The step-by-step correlations between neighbouring provinces/subprovinces that are commonly utilized bear the risk of loosing accuracy in every step.

Here we present $^{87}Sr/^{86}Sr$- and stable isotope-data ($\delta^{13}C$, $\delta^{18}O$) from belemnite rostra of the Rødryggen section in North-East Greenland. The integrated stratigraphy based on Sr-isotope ratios, ammonite and calcareous nannofossil biostratigraphy offers the opportunity for a direct comparison of the different stratigraphic zonations. These are complemented by $\delta^{13}C_{bel}$-data recording the positive carbon isotope excursion of the Valanginian Weissert Event, which is a reliable stratigraphic event. The geochemical data furthermore allow a reliable correlation of Tethyan and Boreal strata.

The stratigraphic range of the Rødryggen section resulting from Sr-isotope stratigraphy (Ryazanian–Barremian) is in agreement with the biostratigraphic findings. Mismatches regarding stage/substage boundaries demand a reconsideration of the nannofossil biostratigraphy of the Boreal Lower Cretaceous. Our findings suggest stratigraphic ranges for two nannofossil index species (*Sollasites arcuatus*, *Micrantholithus speetonensis*) different from published ranges. The new observations imply changes in the Boreal Ryazanian–Valanginian nannofossil zonation scheme. Specifically the base of calcareous nannofossil zone BC3, originally defined as uppermost Ryazanian, is shifted to the lower Valanginian.

Based on these new stratigraphic interpretations a decrease in the abundance of nannoconids observed in the Rødryggen section can now be identified as the Valanginian nannoconid crises. This nannoconid decline has been observed in Tethyan sections along with the Weissert Event. A positive trend in the $\delta^{18}O_{bel}$-data agrees with a late Valanginian cooling that has been postulated based on independent proxies from the Boreal Realm and the Tethys.

## 1. Introduction

The earliest Cretaceous (Berriasian–Hauterivian) is an interval characterised by a distinctive provincialism of marine biota, causing the evolution of endemic floras and faunas in different parts of the world. The Indo-Pacific, the Tethys and the Boreal Realm show in parts geographically bound marine assemblages limited to these oceans (e.g. Remane, 1991; Wimbledon et al., 2011).

This situation applies for the Tethys (nowadays southern France, Switzerland, northern Italy) and the southern part of the Boreal Realm (northern Germany, Poland, North Sea, Great Britain). Both areas show close faunal links throughout the Early-Middle Jurassic and the Aptian–Campanian. A Late Jurassic–Early Cretaceous sea-level lowstand caused the closure of gateways, hampered thereby migration and resulted in biogeographic isolation (e. g. Haq et al., 1988; Michael, 1979; Scotese, 1991). This in turn led to the widespread evolution of endemic taxa. The biogeographic restrictions culminated in Tithonian–Berriasian times, an interval for which two different stage names are being used. The Berriasian stage, defined in the Tethys, corresponds to the upper Volgian and Ryazanian (Zakharov et al., 1996) in the northern parts of the Boreal Realm (Siberia, Greenland, Svalbard, in some cases also used in England). These biogeographic differences resulted in major problems for biostratigraphical correlations of the uppermost Jurassic and lowermost Cretaceous sedimentary sequences of both realms (Remane, 1991; Zakharov et al., 1996). Discussions regarding these problems have been going on for nearly 100 years (Mazenot, 1939; Wimbledon et al., 2011) without finding a practicable solution yet.

The provincialism ultimately resulted in two different ammonite zonation schemes used for subdividing the Tithonian–Early Cretaceous

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succession of the northern Tethys (Kilian, 1907–1913) and the Boreal Realm (Koenen, 1902, 1907). Even in more recent biostratigraphic zonation schemes (e.g. Thieuloy, 1977; Hoedemaeker, 1987, 1991; Rawson, 1995; Rawson et al., 1996, 1999) the correlation of the two realms is limited to rare phases of faunal exchange. Further refinement of the correlations is therefore needed.

Two different zonation schemes were established also for calcareous nannofossils, calibrated to the regional ammonite zonations. Most widely used for the Tethys are the nannofossil zonation schemes by Sissingh (1977, 1978) and Bralower et al. (1989). Two zonation schemes are available for the Boreal. The LK zonation (LK being derived from Lower and Kreide, German for Cretaceous) of Jeremiah (2001) is based mainly on boreholes from the Central North Sea Basin, England, the Netherlands and Germany. The BC (Boreal Cretaceous) zonation of Bown et al. (1998) compiles studies by Perch-Nielsen (1979), Jakubowski (1987), Crux (1989) and Mutterlose (1991). For the lowermost Cretaceous (Ryazanian–Hauterivian) the BC zonation is based on material from sections in northeast England, northwest Germany, North Sea cores (Moray Firth Basin, off northeast Scotland, offshore Norway) and the Barents Sea. The correlation with the Boreal ammonite zonation is provided by outcrops where both calcareous nannofossils and ammonites are available, particularly the Speeton section in northeast England and outcrops in northwest Germany.

Geochemical proxy data ($^{87}Sr/^{86}Sr$, $\delta^{13}C$) can be used to overcome the stratigraphic problems caused by geographically restricted index taxa, provided that an influence of regional processes on the isotope signature can be ruled out. The Sr-isotope ratio ($^{87}Sr/^{86}Sr$) is an efficient stratigraphic tool for correlating marine sediments on a global scale due to the long residence time of Sr in seawater (e. g. Elderfield, 1986; Peterman et al., 1970; Veizer, 1989). The varying $^{87}Sr/^{86}Sr$-signature of seawater as reflected in marine carbonates is not affected by fractionation during incorporation. It results from the input of heavy radiogenic Sr due to continental weathering, and the amount of light, non-radiogenic Sr released by hydrothermal activity associated with submarine volcanism (Veizer, 1989; Allègre et al., 2010).

Recently, Mutterlose et al. (2014) presented $^{87}Sr/^{86}Sr$-curves for the lowermost Cretaceous (Berriasian–Barremian), compiling data measured on belemnites from Tethyan (Vocontian Basin, Bodin et al., 2009; McArthur et al., 2007) and Boreal sections (Speeton, McArthur et al., 2004). All belemnites have been collected bed-by-bed, thus allowing a calibration with the existing regional ammonite zonation schemes.

In the current study, $^{87}Sr/^{86}Sr$-data are obtained from 28 belemnite specimens collected from the Lower Cretaceous (Ryazanian–Barremian) Rødryggen section on Wollaston Forland (North-East Greenland). The section has been studied with respect to its biostratigraphy. Alsen (2006) established an ammonite biostratigraphic zonation for the Valanginian of North-East Greenland. Pauly et al. (2012a) provided a detailed calcareous nannofossil zonation for Wollaston Forland. Using the Sr-isotope data a reliable correlation to the biostratigraphic zonation of the Tethys can be achieved. Further we present a high-resolution record of Ryazanian to Hauterivian stable isotope ratios ($\delta^{13}C_{bel}$, $\delta^{18}O_{bel}$) of 102 belemnite specimens covering the positive carbon isotope excursion interval (CIE) of the Valanginian “Weissert” Event (Erba et al., 2004).

The Weissert Event is well established in the Tethys (Lini et al., 1992; Channell et al., 1993; Weissert et al., 1998; Gréselle et al., 2011; Kujau et al., 2012), but has also been documented from the western Atlantic and the Pacific (Lini et al., 1992; Erba et al., 2004; Bornemann and Mutterlose, 2008), and from the European and Russian parts of the Boreal Realm (Meissner et al., 2015; Nunn et al., 2010; Price and Mutterlose, 2004,). The isotope anomaly is a stratigraphically well constrained isochronous event (Lini et al., 1992; Channell et al., 1993; Hennig et al., 1999; Weissert and Erba, 2004), which makes it a useful stratigraphic tool.

The CIE goes along with the drowning of carbonate platforms (Weissert et al., 1998; Wortmann and Weissert, 2000; Föllmi et al., 2006; Föllmi, 2012) and changes in calcareous nannofossil assemblages. Among these the dramatic decline of nannoconids is perhaps the most prominent (eg. Bersezio et al., 2002; Bornemann and Mutterlose, 2008; Channell et al., 1993; Erba and Tremolada, 2004; Barbarin et al., 2012).

## 2. Geological setting

In the Early Cretaceous the Greenland–Norwegian Seaway was part of a gateway between the Tethys in the south and the Arctic Ocean in the north (Fig. 1). It formed during a rifting event that started in the late Bajocian (Middle Jurassic) and culminated in the latest Jurassic to earliest Cretaceous (Surlyk, 1978, 2003). The Upper Jurassic and Lower Cretaceous sediments in North-East Greenland are represented by up to 3 km of siliciclastics. Conglomerates and pebbly sandstones are common in the near shore settings, and gradually finer grained sediments were deposited further off-shore (Surlyk, 1978, 2003; Pauly et al., 2012b). The fossiliferous mud- and marlstones of the Ryazanian–Hauterivian Albrechts Bugt Member and Rødryggen Member are the distal sediments of the late rifting phase. Due to a Ryazanian drowning event and a subsequent transgression they were deposited on top of the coarse clastics that represent the syn-rift deposits (Surlyk and Clemmensen, 1975; Surlyk, 1978, 2003).

## 3. Section

The 138 samples analysed here were collected in the Rødryggen section (Pal4/2001, locality 5 of Alsen (2006) and Alsen and Mutterlose

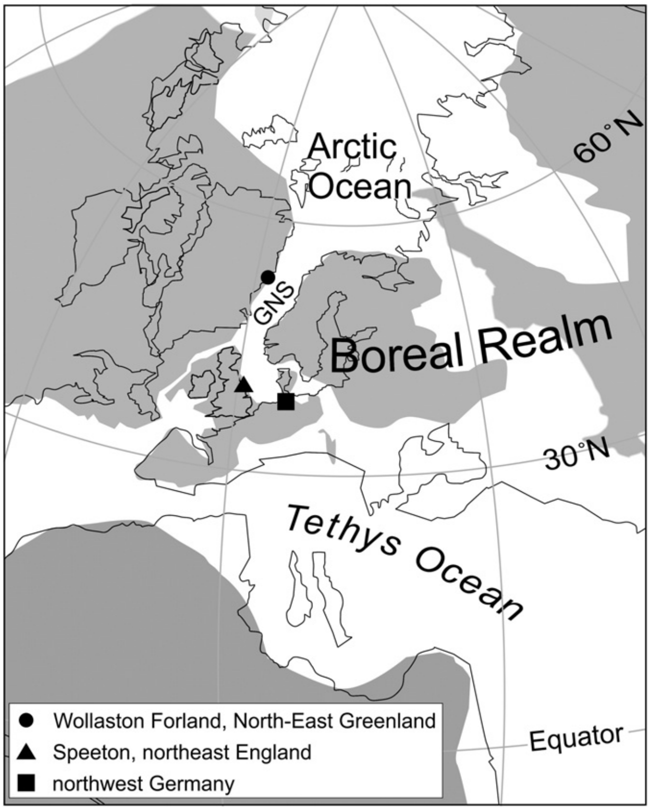

**Fig. 1.** Map of the Valanginian paleogeography, modified from Smith et al. (1994) showing the position of the Rødryggen section, Wollaston Forland, North-East Greenland. Indicated in grey are areas presumably above sea-level in the Valanginian; GNS = Greenland–Norwegian Seaway.