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Latitudinal temperature trends in the northern hemisphere during the Early Cretaceous (Valanginian–Hauterivian)

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ABSTRACT

We present the first detailed stable isotope record ($\delta^{13}C$, $\delta^{18}O$) for the Valanginian (Lower Cretaceous) of the southern Boreal Realm. The observations are based on the geochemical analysis of 286 belemnite rostra from stratigraphically well-dated sections in northwest Germany. A major positive carbon isotope excursion (CIE) of ~2‰ in the early late Valanginian documents a perturbation of the carbon cycle. This positive CIE, which is well known as the 'Weissert Event' in the Tethys, is also displayed in composite carbon isotope records based on published and own data from three different palaeolatitudes (35°, 39°, 65° North). These findings suggest that the environmental changes indicated by the CIE in the early late Valanginian are synchronous, thereby pointing to a global control. The combined oxygen isotope data sets show long-term fluctuations of up to 7 °C with a cooling in the late Valanginian for both the southern and the arctic part of the Boreal Realm, whilst Tethyan data document only a ca. 1 °C cooling. Based on a reliable bio- and chemostratigraphic correlation between the different realms this study highlights the amplitude of the environmental perturbations in the Valanginian and supports the idea that a combination of regional and global factors caused such shifts.

1. Introduction

The Valanginian period was characterised by major environmental changes affecting both the oceans and the continents. A profound perturbation in the global carbon cycle is evidenced by a positive carbon isotope excursion (CIE) at the transition of the early to the late Valanginian. This 'Weissert' CIE (e.g. Erba et al., 2004), coincides with a demise of shallow-water carbonate platforms (Föllmi et al., 2006), a biocalcification crisis in calcareous nannofossils (Barbarin et al., 2012) and increased storage of organic matter on the continents (Westermann et al., 2010). The 'Weissert' CIE is recognised in the $\delta^{13}C$ record of marine bulk rock (e.g., Lini et al., 1992; Bornemann and Mutterlose, 2008; Gréselle et al., 2011), belemnites (Price and Mutterlose, 2004; McArthur et al., 2007b; Nunn et al., 2010), oysters (Aguirre-Urreta et al., 2008) and terrestrial sediments (Gröcke et al., 2005; Nunn et al., 2010).

The CIE can be traced globally (Fig. 1), thus being a distinctive chemo-stratigraphic marker. Interestingly, the occurrence of widespread organic carbon rich levels is very limited (Westermann et al., 2010) and, judging from organic geochemistry data, bottom waters were well oxygenated (Westermann et al., 2010; Kujau et al., 2012). At the same time Nunn et al. (2010) showed that the perturbation affected both the marine and the terrestrial domains.

A second intensively discussed aspect of the Valanginian is the concept of cool interludes, including even potential ice house phases, in the overall warm greenhouse world of the Cretaceous (e.g. Kemper, 1987; Miller et al., 2005). Physical evidence are the occurrences of glendonites (Kemper and Schmitz, 1981; Kemper, 1987; Price and Nunn, 2010; Rogov and Zakharov, 2010), tillites and dropstones (Frakes and Francis, 1988; Frakes et al., 1995) and glacial diamictite (Alley and Frakes, 2003) in sediments of Berriasian to Valanginian age at various places on the globe. A potential presence of ice is supported by a trend towards positive values (i.e. lower temperatures) in the $\delta^{18}O$ record of fish teeth enamels (Pucéat et al., 2003; Barbarin et al., 2012), and belemnites (Price and Mutterlose, 2004; McArthur et al., 2007b) during the early to late Valanginian. Independent palaeontological evidence for a Valanginian cold phase comes from bipolar distribution patterns of calcareous nannofossils (Mutterlose et al., 2003). A cooling trend is also evident in the clay mineral assemblages in sediments from southern France (Duchamp-Alphonse et al., 2007, 2011) and the occurrence of cool water indicating biomarkers (steryl ethers) in claystones of Valanginian age is documented from Shatsky Rise (Brassell, 2009). Rapid and repeated sea-level fluctuations as inferred from the upper Valanginian in southern France are seen as documents of glacio-eustacy (Gréselle and Pittet, 2010). Polar ice is also postulated by Price and Passey (2013), based on clumped isotope measurements of belemnites from Arctic Russia.

Contradicting temperature interpretations are based on TEX_{86} data (Littler et al., 2011). These document rather equable climatic conditions

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displayed by sea-surface temperatures of ~33–34 °C at a palaeolatitude of 15–20°N and ~25–28 °C at 53°S for the entire Valanginian.

A major shortcoming of these different palaeoclimatic interpretations is the bias of the biostratigraphic record. Ammonites, the classical index markers of the Cretaceous, show a distinctive provincialism during the Early Cretaceous. This complicates stratigraphic interpretation of proxy records (e.g. $\delta^{13}C$, $\delta^{18}O$, clay mineral assemblages) obtained at different sites, making it difficult to differentiate between regional and global causes for environmental change

In this study the current correlation of the ammonite zonation schemes of the Tethys and the Boreal Realm (Mutterlose et al., 2014) is modified by re-calibrating biostratigraphic and Sr-isotope data. An extensive $\delta^{13}C_{bel}$ curve from the Lower Saxony Basin (LSB; northwest Germany) is presented, documenting robust evidence for the Valanginian positive CIE in the southern Boreal Realm for the first time. These findings are compared with the $\delta^{13}C_{bel}$-excursions of two composite sections from different palaeolatitudes (35°N and 65°N respectively) to show regional modifications of the $\delta^{13}C$ curve. Finally, the oxygen isotope excursions will also be discussed with respect to the palaeolatitudinal setting.

2. Geological background and samples

2.1. Palaeobiogeography

During the Early Cretaceous the palaeogeographic setting of the northern hemisphere (Fig. 1) led to distinctive biogeographic distribution patterns of various groups of marine organisms (e.g. Michalik, 1992; Mutterlose, 1992a; Rawson, 1995). The Tethys and the Boreal Realm (e.g. Mutterlose, 1992a), are characterised by taxonomically different floral and faunal groups, including the stratigraphically important ammonites. Consequently, two different biostratigrapic ammonite schemes have been developed, based on the occurrence and abundance of regionally dominant taxa (e.g. Kemper et al., 1981).

The Lower Saxony Basin (LSB), a shallow epicontinental sea (depth of ~200 m), formed the southernmost extension of the Boreal Sea (Schott et al., 1969; Michael, 1979; Mutterlose, 1992a). Surrounded by large landmasses, water exchange to the Boreal Sea in the north and the Tethys in the south was limited to shallow straits, which only existed periodically (Kemper, 1979).

The definition of the Berriasian/Valanginian boundary has been a matter of intense debate for more than 20 years, here we follow a suggestion recently made by Mutterlose et al. (2014). According to this proposal the base of the Valanginian should be placed in the Tethys at the base of the *Tirnovella pertransiens* zone, an event that correlates in the southern Boreal Realm (LSB) with the first occurrence of the ammonite genus *Platylenticeras*. It should be noted here, however, that no official GSSP has been fixed yet for defining this boundary. In the course of the Valanginian transgression the Carpathian Seaway opened (Fig. 1), allowing a floral and faunal exchange between the Tethys and the Boreal Realm (Thieuloy, 1977; Kemper et al., 1981; Melinte and Mutterlose, 2001). These exchange patterns increased throughout the Valanginian and peaked in the early late Valanginian (Mutterlose, 1988a, 1992b).

2.2. Material

During extensive field studies about three thousand belemnites have been collected bed-by-bed from outcrops exposing Valanginian–Hauterivian strata in northwest Germany by Grade et al. (1969) and Mutterlose (1973, 1984, 1988b, 1992b). These exposures reflect a palaeolatitude of 39°N. From these sites a total of 286 rostra were studied with respect to their stable isotope patterns ($\delta^{13}C$, $\delta^{18}O$) and trace element content (Ca, Mg, Sr, Fe, Mn). The material used consists of five specimens of *Hibolithes* (4 *Hibolithes jaculoides* and 1 *Hibolithes* sp.) and of 283 specimens of *Acroteuthis* (59 *A.* (*A.*) *paracmonoides paracmonoides*, 29 *A.* (*A.*) *paracmonoides arctica*, 3 *A.* (*A.*) *lateralis*, 72 *A.* (*A.*) *explanatoides*, 3 *A.* (*A.*) *elegans*, 14 *A.* (*A.*) *acrei*, 89 *A.* (*A.*) *acmonoides* and 12 *Acroteuthis* sp.).

2.3. Sections and stratigraphy

The rostra are derived from 19 different sections covering the interval from the lower Valanginian (*Platylenticeras robustum* Zone) to the mid lower Hauterivian (*Endemoceras noricum* Zone). The stratigraphy used here is based on two different schemes. For nine outcrops (Kuhlmann, Ottensen, Diepenau, Varlheide, Bückeburg, Möller, Lindhorst, Jetenburg, Sachsenhagen) micropalaeontological data are available following the scheme of Bartenstein and Brand (1951). This high resolution zonation, which is based on benthic foraminifera and ostracods, has been calibrated with the Boreal standard ammonite zonation. The age assignment of the other 10 exposures studied here (Hasslage, Wiedenbrügge, Engelbostel, Hollwede, Suddendorf, Münchehagen, Twiehausen, Pollhagen, Rusbend, Müsingen) is directly based on the standard Boreal ammonite scheme.

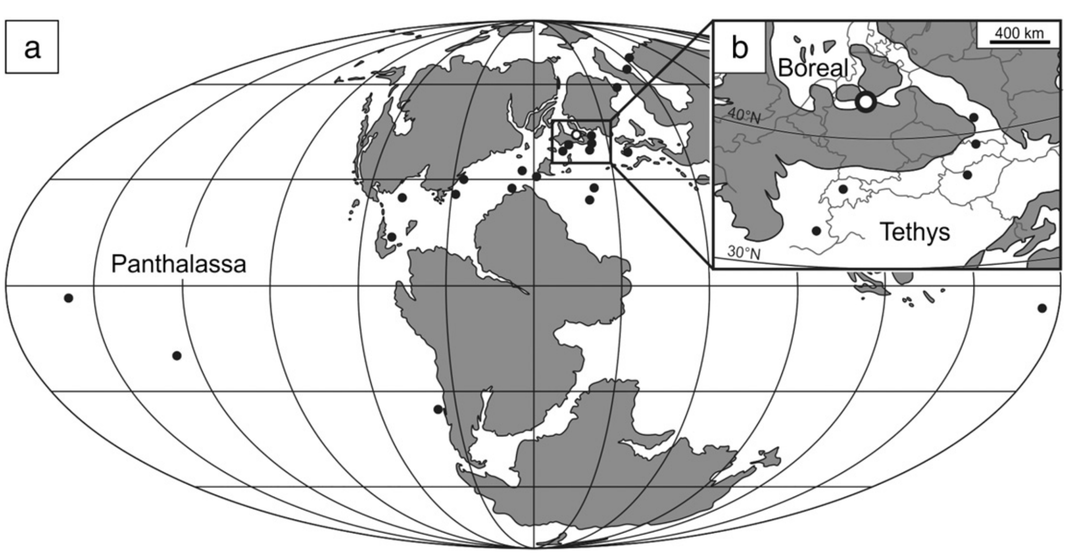

Fig. 1. Palaeogeographic setting of the Valanginian (A) showing sites from which evidence for the 'Weissert Event' is known (black circles). A close-up view (B) shows the palaeogeographic map of the study area (white circle) (modified after cpgeosystems.com).