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Benthic ecosystem response to the deposition of lower Aptian black shales in an epicontinental sea

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ABSTRACT

Oceanic Anoxic Events (OAEs) of the Mesozoic are manifested globally by deposition of laminated, organic-rich sediments at depths ranging from the deep ocean to the shallow, epicontinental seas. In the deep ocean, the deposition of the OAE black shales is known to have been associated with the development of anoxic or dysoxic conditions. However, little is known about the oxygenations of shallower epicontinental seas, which may have served as refuge for benthic organisms. Here we present high resolution data on changes in diversity and abundance of benthic foraminifera from a continuous profile throughout the Fischschiefer, a lower Aptian black shale correlated with OAE 1a, located on the southern margin of the epicontinental Lower Saxony Basin. Benthic foraminiferal diversity and abundance decreased and reached minimum values prior to the deposition of the laminated black shale. The persistent occurrence of foraminifera throughout the Fischschiefer indicates that in the epicontinental setting of the studied basin, the sea floor remained habitable to at least some benthic life throughout the OAE. The impoverished foraminiferal content of the Fischschiefer was replaced by rich assemblages during two "interruption" events. These observations are consistent with the occurrence of other benthic and nektonic fossils in the studied profile, where ammonites indicate a well-oxygenated water column during parts of the OAE and benthic molluscs hint at short-term re-oxygenation events within the Fischschiefer horizon. Collectively, these data indicate that unlike the deep ocean, at least part of the water column of epicontinental seas remained habitable for planktic, nektic and benthic life throughout OAE 1a, facilitating subsequent rapid recolonisation of the European boreal seaways. Nevertheless, benthic foraminifera indicate a severe decline in diversity and abundance during OAE 1a.

1. Introduction

A significant portion of the mid-Cretaceous oceanic and epicontinental sedimentary record contains laminated organic-rich claystones, usually referred to as black shales. Due to their global distribution, their deposition has been linked to large scale reorganization of oceanic circulation associated with Oceanic Anoxic Events (OAE, Fozy et al., 2010; Schlanger and Jenkyns, 1976; Weissert et al., 2008).

Investigations of the response of fossil marine faunas to the environmental change associated with OAE1a, and its reconstruction based on fossil assemblages, is mainly focussed on micro- and nannofossils (e.g. Friedrich, 2010; Leckie et al., 2002). This kind of data is scarce for invertebrates (e.g. Monnet et al., 2005); for which essentially biostratigraphic information is available (e.g. Bréhéret, 1997; Gale et al., 2005; Lehmann, 1999). Mainly two sets of data on changes of macrofaunas at Cretaceous OAEs exist. First those relating occurrences of invertebrates to superordinate oceanographic change including eustatic cycles (e.g. Lehmann, 2000; Reboulet et al., 2005) and second those relating macrofaunistic occurrences to extinction-recovery phases assumably due to oxygen fluctuations (e.g. Hirano, 1993; Kurihara and Kawabe, 2003; Takahashi, 2005).

The first of the mid-Cretaceous OAEs (OAE 1a), took place during the early Aptian, expressed by the Selli Level in the Tethys and the Fischschiefer in the Lower Saxony Basin (LSB in the following) of the Boreal region.

The OAE 1a is associated with a globally occurring positive ^{13}C-excursion, preceded by a negative shift and widespread bottom water anoxia with anoxic to dysoxic water resulting in the deposition of organic-matter rich sediments (e.g. Ando et al., 2002; Arthur et al., 1990; Jenkyns, 2003, 2010; Leckie et al., 2002; Van Breugel et al., 2007). A few approaches have related individual black shale beds to fossil assemblage changes unequivocally

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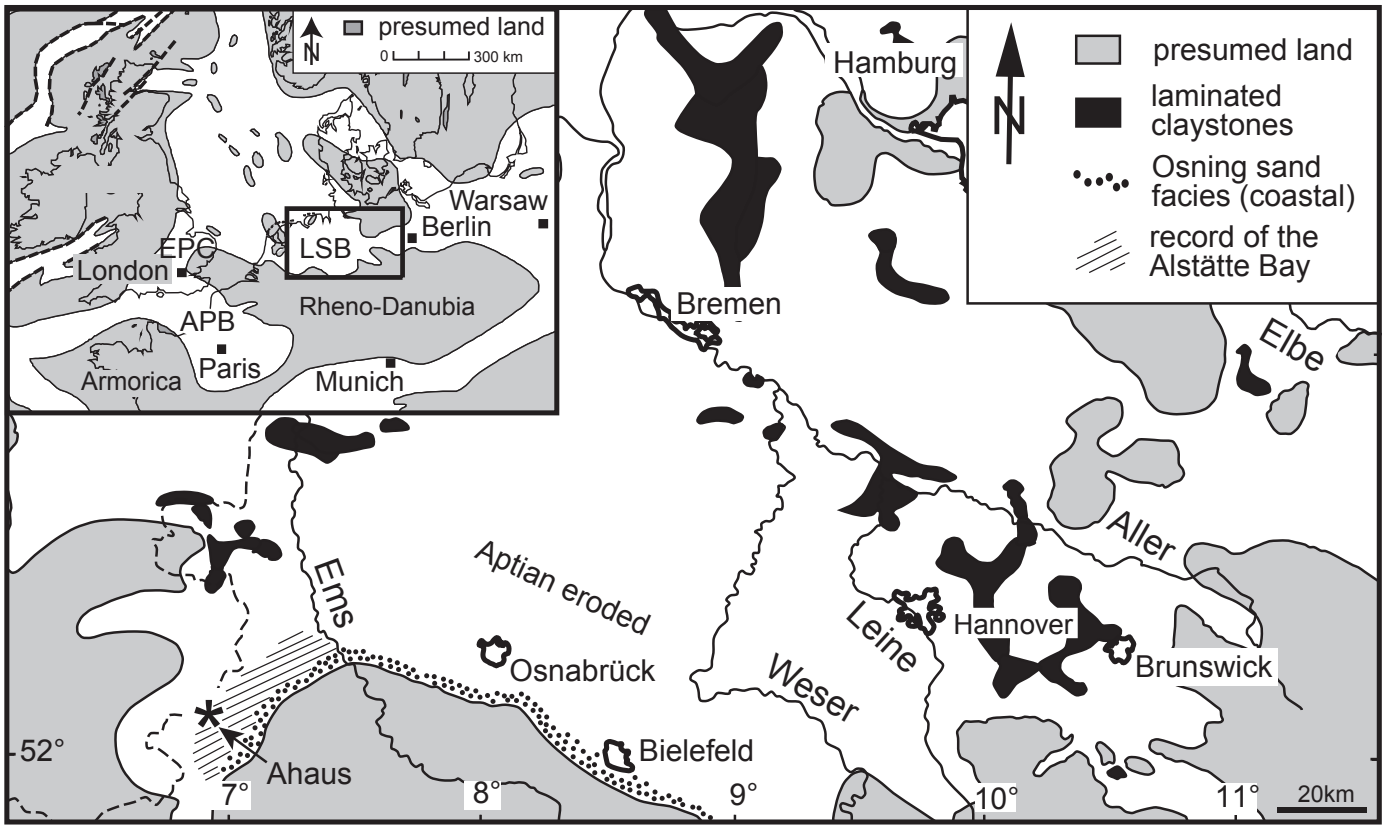

Fig. 1. Small inlay (top left) illustrates the lower Aptian palaeogeography in Europe with position of the study area (rectangle). APB = Anglo-Paris Basin, LSB = Lower Saxony Basin, EPC = English Proto-Channel. After Schott et al., 1969; Ziegler, 1990. Large map indicates the depositional setting in the southern LSB with the position of the Alstätte locality near Ahaus (asterisk). Stippled lines: German-Dutch border. Modified after Kemper (1973) and Mutterlose & Böckel (1998).

representing oxygen depleted sediments. Bréhéret and Delamette (1989) found no benthic organisms and very scarce ammonites in the Goguel black shale layer in SE-France (local representative of OAE 1a), indicating a low bioproductivity. Based on benthic foraminifera, the deep-sea environment of OAE 1a is assumed to have been hostile to benthic life (Friedrich, 2010). Well studied areas are the Umbria-Marche Basin in Italy (e.g. Premoli Silva et al., 1999) and the Vocontian Basin in south-East France (e.g. Bréhéret, 1997). Other regions are less well-represented, e.g. outcrops in Tunisia (Elkhazri et al., 2009; Elkhazri et al., 2013) and Slovakia (Michalík et al., 2008). In many cases, the sampling strategy has been insufficient to provide a record of a continuous history of the OAE 1a event (e.g. Kemper, 1995a). Many studies assumed a complete lack, or at least the disappearance of benthic foraminifera during the OAE 1a (e.g. Michalík et al., 2008; Patruno et al., 2011; Takashima et al., 2004) and thus laminated claystones were not sampled or studied by insufficient methods. In deep-sea deposits during the OAE 1a impoverished benthic foraminifera assemblages were recorded (e.g. Cobianchi et al., 1999; Luciani et al., 2006; Moullade et al., 2000), but either quantitative data have not been obtained or few samples have been studied only from the OAE 1a (Elkhazri et al., 2009; Elkhazri et al., 2013).

Since a high resolution record of fossils across the OAE 1a black shales is missing hitherto, we do not know how the benthic ecosystem reacted to the sequence of events associated with the onset, deposition and termination of the OAE1a facies and in which way these responses may differ between various locations.

In this study we provide the first high-resolution data set on benthic foraminifera throughout the OAE 1a in an epicontinental basin. We investigate a lower Aptian section at Alstätte, near Ahaus in NW-Germany (Fig. 1), including the Fischschiefer that is believed to be the regional representative of OAE 1a (e.g. Bottini and Mutterlose, 2012; Malkoc et al., 2010; Pauly et al., 2013). Additionally to the microfossil data we provide macrofaunal data for some benthic and nektic groups. Our aim is to reconstruct the benthic ecosystem response to changes in oxygenation of the bottom water, focussing mainly on the well preserved and diverse benthic foraminiferal fossil assemblage of the Alstätte section.

2. Geological framework and palaeogeography

The configuration and properties of Barremian to Turonian shelf seas in Central and Western Europe were significantly affected by a long-term sea level rise, with prominent short-term fluctuations in the early Aptian (Hardenbol et al., 1998; Ruffell, 1991), and a tectonic rearrangement mainly during the late Barremian and early Aptian (Kemper, 1995b). As a result, the individual epicontinental basins became connected and although the Atlantic Ocean was still in its initial phase of opening, the flooding resulted in the development of a large continuous water body. The oceanic character of this region was further strengthened during the early Aptian OAE 1a, with a maximum flooding interval documented also for the Western Tethys and Central Atlantic (Erbacher and Thurow, 1997), but the palaeogeographic situation in Central and Western Europe did not change significantly until the late early Aptian, with the opening of the English Proto-Channel that allowed an exchange of Tethyan faunas (Fig. 1; Mutterlose, 1998; Rawson, 1992).

In contrast to deep sea records epicontinental settings represent a greater variation among microhabitats and therefore are suitable for diverse and specimen-rich microfaunas. Additionally, an