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Original article

The onset of anoxic conditions in the early Barremian of the Boreal Realm evidenced by benthic foraminifera

Installation des conditions anoxiques dans le Barrémien inférieur du domaine Boréal souligné par les foraminifères benthiques

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Abstract

The Frielingen clay pit, situated approximately 20 km northwest of Hannover (northern Germany) exposes sediments of Early Cretaceous age (Hauterivian, Barremian). Rhythmic alternations of dark mudstones and pale marls of late Hauterivian age (*Simbirskites discofalcatus* ammonite Zone) dominate the lithology. These bedding rhythms are overlain by laminated dark shales and lighter mudstones, assigned to the lowermost Barremian (*Praeoxyteuthis pugio* belemnite Zone). For this study 27 samples covering the Hauterivian/Barremian boundary interval were investigated with respect to their $CaCO_3$ and total organic contents (TOC), stable isotope composition ($\delta^{13}C_{org}$, $\delta^{13}C_{CaCO_3}$, $\delta^{18}O_{CaCO_3}$) and their micropalaeontology (foraminifera). The samples were analysed in order to better understand the onset of the Barremian anoxic conditions in the Boreal Realm. The data obtained show that shifts of the environmental parameters are reflected by the mudstone-marl alternation. The dark mudstones reflect cooler surface water temperatures and a lower oxygen content, while the pale marls were deposited under warm surface water conditions. These bedding rhythms are thought to be the result of climatic variations in the Milankovitch Band (10Ka–1Ma). This study further documents that the Hauterivian/Barremian transition is characterised by a deterioration of the living conditions for benthic organisms. This is indicated by the decline of several foraminiferal genera, by decreasing generic richness and by a coeval increase in the abundances of specific taxa. The TOC content and the isotopic composition of the organic carbon support these findings. A morphogroup analysis of the benthic foraminifera indicates changes of the habitats from mainly infaunal in the late Hauterivian to more epifaunal in the early Barremian. Due to this dramatic decline of infaunal forms in the laminated, TOC-rich mudstones of the lowermost Barremian, suboxic to anoxic conditions are postulated for these sediments. The bottom water must, however, have contained some oxygen at least, as is indicated by a few epifaunal genera that became very abundant (e.g. *Ammodiscus*). A major regression around the Hauterivian/Barremian boundary caused a closing of the seaway to the Tethys, resulting in a significantly reduced water exchange and the establishment of anoxic conditions.

Keywords: Benthic foraminifera; Hauterivian; Barremian; Black shales; Paleoecology; Boreal Realm

Résumé

La marnière de Frielingen, située approximativement à 20 km au Nord de Hanovre (Nord-Ouest de l'Allemagne) expose des sédiments d'âge Crétacé inférieur (Hauterivien, Barrémien). La lithologie des dépôts tardi-Hauterivien (zone d'ammonite à *Simbirskites discofalcatus)* est dominée par des alternances rythmiques d'argilites sombres et de marnes claires. Ces alternances sont recouvertes par des argilites laminées, riches en matières organiques, et des argilites plus clairs, attribués au Barrémien précoce (zone de bélemnites à *Praeoxyteuthis pugio*). Pour cette étude, 27 échantillons recouvrant l'intervalle de la limite Hauterivien-Barrémien ont été analysés pour leur contenu en $CaCO_3$ et en COT, leur composition en isotope stable ($\delta^{13}C_{org}$, $\delta^{13}C_{CaCO_3}$, $\delta^{18}O_{CaCO_3}$) et leur contenu micropaléontologique (foraminifères) afin de mieux comprendre l'installation des conditions anoxiques du Barrémien en domaine boréal. Les données obtenues montrent que les modifications de styles sédimentaires coïncident avec des changements environnementaux, reflétés par les variations rythmiques observées dans le Hauterivien et le Barrémien. Les marnes claires ont ainsi été déposées sous des eaux de surface chaudes, tandis que les argilites sont corrélés avec des eaux de surface plus froides et un taux d'oxygène moindre. Ces alternances sont probablement le résultat de variations climatiques rythmées par les cycles de Milankovitch. Les résultats obtenus montrent que la transition Hauterivien–Barrémien est caractérisée par la détérioration des conditions de vie des organismes benthiques. Cela est observable

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par le déclin de nombreux genres de foraminifères, par la décroissance de leurs diversités et par une croissance contemporaine de l'abondance de certains taxa. Le contenu en COT et la composition isotopique du carbone organique supportent ces observations. Une analyse morphologique groupée des foraminifères benthiques indique des changements dans leur style de vie, principalement endobiontes pendant l'Hauterivien tardif, a plus épibiontes pendant le Barrémien précoce. De part la forte décroissance des formes endobiontes dans les argilites laminées riches en COT du Barrémien inférieur, on peut émettre l'hypothèse de sédimentation sous conditions suboxiques à anoxiques. Les eaux de fonds doivent cependant avoir contenu une fraction réduite d'oxygène afin de rendre compte de la présence de quelques genres épibiontes qui peuvent être très abondants. L'établissement des conditions anoxiques est à relier à la régression du niveau marin autour de la limite Hauterivien/Barrémien, qui a causé la fermeture de corridors marins entre le domaine Boréal et le domaine Téthysien, et ainsi réduit de façon significative les échanges de masses d'eaux.

Mots clés : Foraminifères benthiques ; Hauterivien ; Barrémien ; Argilites noires ; Paléoécologie ; Domaine Boréal

1. Introduction

The Lower Saxony Basin (LSB), one of the sedimentary basins of northern Europe during the Early Cretaceous, plays a key role in the understanding of Early Cretaceous marine settings. Its palaeogeographic position between the Boreal Realm in the north and the Tethys in the south made it exceptionally sensitive to changes in sea level, climate and palaeogeography. These shifts are documented by varying compositions of marine floras and faunas (Michael, 1979; Mutterlose, 1992).

In order to better understand these changes, several northwest German sections have been examined in the past for their floral and faunal content (Michael, 1967). Different fossil groups including calcareous nannofossils (Mutterlose et al., 1994) and foraminifera (Heinrich, 1991; Klein and Mutterlose, 1997) have been analyzed from the Frielingen section. These studies were restricted to the lower (upper Hauterivian) part of the exposed succession.

The objective of this study is to understand the environmental and depositional conditions of the Hauterivian/Barremian boundary interval, which is marked in the Frielingen succession by a remarkable shift from dark mudstone–pale marl bedding rhythms in the topmost Hauterivian to finely laminated black shales in the lowermost Barremian. Samples were analyzed with respect to their carbonate and total organic carbon contents (TOC), as well as for carbon and oxygen stable isotopes ($\delta^{13}C_{org}$, $\delta^{13}C_{CaCO_3}$, $\delta^{18}O_{CaCO_3}$). Given that benthic foraminifera have a great potential to unveil past paleoenvironments (Friedrich, 2010) the current study focuses on a micropalaeontological analysis of the foraminiferal faunas. Abundance and generic richness, the agglutinated/calcareous benthic foraminiferal ratio and the distribution pattern of 12 foraminiferal morphogroups have been used to reconstruct the palaeoenvironmental conditions of the Hauterivian/Barremian boundary interval.

2. Geological setting

During the Early Cretaceous, northwest Europe consisted of several sedimentary basins forming the southern extension of the Boreal-Arctic Sea. The LSB was the southernmost of these basins, with a length of 280 km in an east-west direction and a width of 80 km in a north-south direction. Due to continuous subsidence of the LSB, more than 2000 m of Lower Cretaceous sediments were deposited (Kemper, 1979; Mutterlose and Bornemann, 2000). During the Jurassic/Cretaceous boundary interval a strong global regression caused the separation of the Boreal Realm from the Tethys; sediments in southern England, northern France and northern Germany including the LSB were deposited under brackish–limnic conditions (Michael, 1979; Mutterlose and Bornemann, 2000). These siliciclastic sediments, which are attributed to the "Wealden" facies, span the Berriasian to lower Aptian interval in southern England. In the LSB the non-marine "Wealden" facies is only of Berriasian age.

The base of the Valanginian is marked by a major transgression leading to the return of marine conditions, which then prevailed throughout the remainder of the Cretaceous (Kemper, 1979; Mutterlose and Bornemann, 2000). In addition to a seaway towards the Boreal-Arctic area in the north, the Carpathian Seaway opened and connected the LSB via Poland with the Tethys (Fig. 1a). The Valanginian-Hauterivian biota are mainly of Boreal affinities, Tethyan forms are rare or absent. During short transgressive phases (early late Valanginian) distinctive short-termed influxes of Tethyan floras and faunas reached the LSB. The overall transgressive trend of the late Valanginian reached its maximum in the early Hauterivian (*Endemoceras amblygonium* ammonite Zone) and resulted in a widespread onlap of Hauterivian strata in the LSB. The dominant floras and faunas are of Boreal affinities, while Tethyan and endemic elements are rare (Michael, 1979; Mutterlose, 1992). Warm water ingressions during the late Hauterivian *Simbirskites discofalcatus* ammonite Zone are particularly documented by the occurrence of warm water foraminifera and bryozoans (Kemper, 1979; Michael, 1979; Mutterlose, 1992).

At the Hauterivian/Barremian boundary interval a strong regression resulted in major palaeogeographic changes (Fig. 1b). The Carpathian Seaway to the southeast closed and the coastal areas in southern and central Poland became brackish (Michael, 1979; Mutterlose, 1992). This new palaeogeographic situation also led to anoxic conditions in the centre of the LSB, documented by dark, laminated mudstones, known as "Blättertone" (Kemper and Zimmerle, 1978; Mutterlose et al., 2009). These mudstones are rich in organic matter and reflect the restricted conditions of the LSB. Further evidence for the establishment of an anoxic setting is the dwindling biodiversity of various benthic groups including foraminifera, bivalves and ostracods, as well as the almost complete disappearance of brachiopods. The establishment of a restricted environment supported the development of endemic forms, which evolved in the Barremian of the Boreal Realm. Tethyan forms were rare or absent during the