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The Cenomanian–Turonian boundary mass extinction (Late Cretaceous): New insights from ammonoid biodiversity patterns of Europe, Tunisia and the Western Interior (North America)

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ABSTRACT

Major biological crises are attributed to a variety of factors, whose respective contributions and interactions are often difficult to disentangle. The Cenomanian–Turonian boundary was a period of high organic matter burial coupled with a high positive excursion in the carbon isotope record. This event has been widely recognized to reflect anoxic conditions (the Oceanic Anoxic Event 2) and is concomitant with one of the major mass extinctions of the Phanerozoic. It has been considered a typical example of global extinction caused by the spreading of anoxic waters. However, recent studies question this anoxia kill mechanism in Europe both from palaeontological and sedimentological arguments. Hence, this study analyzes the biodiversity patterns of ammonoids from three major areas (Europe, Tunisia, and the Western Interior) in order to better understand the relationships between ammonoid biodiversity patterns and abiotic factors during the Cenomanian–Turonian interval. The biodiversity patterns of ammonoids (species richness, origination/extinction, turnover, poly-cohort survivorship, and taxonomic distinctness) highlight that the mass extinction of the Cenomanian–Turonian boundary is restricted to Europe when considering only ammonoids. Only Europe documents an actual decrease of species richness during the late Cenomanian, which results mainly from decreasing origination. In Tunisia, where the onset of anoxic waters is synchronous with Europe, species richness increases during the late Cenomanian and reaches its highest values in the lower Turonian. The Western Interior records relatively high species richness during the late Cenomanian with only a single minor extinction event. Furthermore, major changes in biodiversity patterns of ammonoids occurred around the middle–upper Cenomanian boundary, i.e. ca. 0.75 myr before the onset of the OAE2. Although there is extensive evidence for widespread anoxia during the Cenomanian–Turonian boundary interval in deep sea environments, the biodiversity patterns of ammonoids in Europe, Tunisia, and the Western Interior rule out global anoxia as a direct causal mechanism for changes in ammonoid diversity. These biodiversity patterns also question the global scale character of the so-called Cenomanian–Turonian mass extinction. Observed biodiversity patterns of ammonoids strongly support the global warming of the late Cenomanian as evidenced by the northward migration of the Tethyan Realm. Changes in ammonoid diversity are compatible with the exceptional high sea level occurring at that time and with concomitant regional climate changes.

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1. Introduction

The Cenomanian–Turonian boundary witnessed one of the ten most severe biotic crises of life's history (Raup and Sepkoski, 1986) with the extinction of approximately 26% of marine animal genera. It is characterized by a worldwide diversity drop of a number of groups, such as benthic and planktonic foraminifers (Jarvis et al., 1988; Kaiho, 1994; Peryt and Lamolda, 1996; Tur, 1996; Groshény and Malartre, 1997), calcareous nannoplankton (Leckie et al., 2002), ostracods (Babinot et al., 1998), radiolarians (Erbacher and Thurow, 1997; O'Dogherty and Guex, 2002), aragonitic rudist bivalves (Johnson and Kauffman, 1990; Philip and Airaud-Crumière, 1991; Steuber and Löser, 2000), and ammonoids (Elder, 1989; Hirano et al., 2000). For example, in the Western Interior, Harries and Little (1999) reported the extinction of 79% of macro-invertebrate species and Elder (1989) of 74% of ammonoid species.

The description of several sections around the world highlighted the occurrence of many, more or less interwoven, abiotic events around this mass extinction (Fig. 1). The Cenomanian–Turonian boundary recorded the highest sea level of the Mesozoic (Haq et al., 1988), some of the highest atmospheric CO_2 concentrations (Berner, 1994; Bice and Norris, 2002), a global warming (Jenkyns et al., 1994; Clarke and Jenkyns, 1999; Huber et al., 2002), a global oceanic anoxic event (Jenkyns, 1980; Arthur et al., 1987; Schlanger et al., 1987), and a

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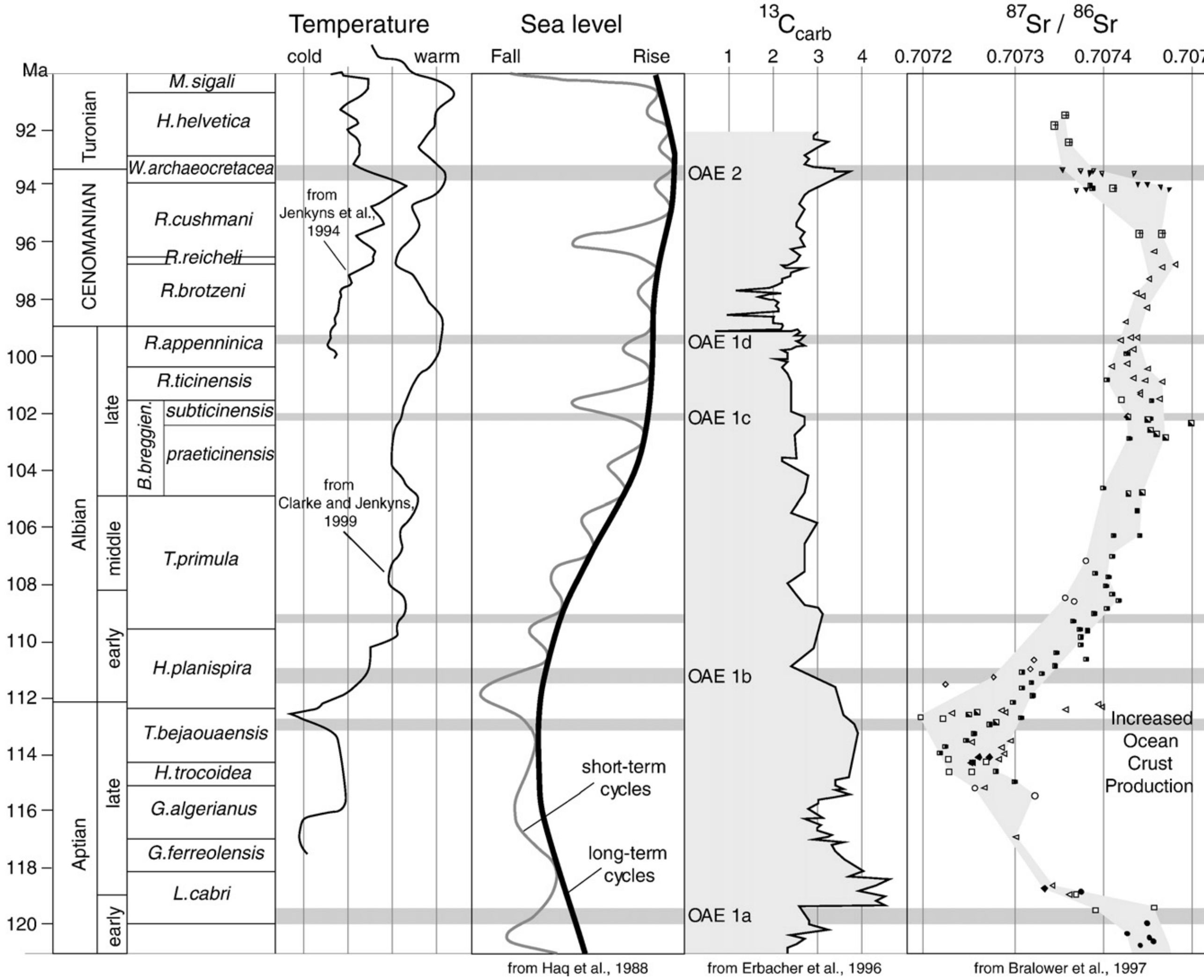

Fig. 1. Major environmental proxies during the Aptian–Turonian interval (Cretaceous).

global major positive $\delta^{13}C$ excursion (Scholle and Arthur, 1980; Accarie et al., 1996; Tsikos et al., 2004; Grosheny et al., 2006; Jarvis et al., 2006) coupled with massive deposition of organic-rich sediments (Herbin et al., 1986; Schlanger et al., 1987). Therefore, the Cenomanian–Turonian interval represents an ideal context to study the interactions between biotic and abiotic events.

The uppermost Cenomanian is characterized by the worldwide spreading of hypoxic/anoxic waters, the so-called Oceanic Anoxic Event 2 (OAE2). This event has been considered the major cause of the Cenomanian–Turonian boundary mass extinction and the killing-mechanism for numerous species (Kauffman and Hart, 1995). However, several authors questioned the existence of this mass extinction (Corfield et al., 1990; Banerjee and Boyajian, 1996; Gale et al., 2000; Smith et al., 2001). The goal of this study is to document the biodiversity patterns of ammonoids throughout the entire Cenomanian from three major areas (Europe, Tunisia, and the Western Interior) and to evaluate the relationships between ammonoid biodiversity patterns and abiotic factors during the Cenomanian–Turonian interval.

2. Data

2.1. Palaeogeography

The present study includes three major areas where ammonoid-bearing rocks of Cenomanian age are well exposed (Fig. 2A), namely Europe, Tunisia and the Western Interior (North America). These are all type regions (old stratotypes and recent boundary stratotypes) for the Cenomanian and Turonian stages (Juignet, 1980; Robaszynski et al., 1982; Robaszynski, 1984; Robaszynski et al., 1990; Kennedy and Cobban, 1991; Robaszynski et al., 1994; Gale et al., 1996; Kennedy et al., 2004, 2005; Caron et al., 2006).

Europe was located along the northern Tethyan margin at an approximate palaeolatitude of 35°N. The studied area includes three epicontinental basins: the Vocontian Basin (south-east France), the Münsterland Cretaceous Basin (north-west Germany) and the Anglo–Paris Basin (Fig. 2B). In its axial part, the Vocontian Basin consists of an irregular alternation of up to about 700 m of hemipelagic, more or less silty, marly limestones and marls interrupted by several organic-rich shales in the uppermost Cenomanian (the Thomel level; Crumière, 1989). The Münsterland and Anglo–Paris basins belonged to the north-European chalk sea and were mainly characterized by up to 170 m of chalk deposits interrupted by the Plenus Marls within the upper Cenomanian.

Tunisia, belonging to the southern Tethyan passive margin, was located at a palaeolatitude of about 15°N (Fig. 2B). In central Tunisia, the Cenomanian sediments consist mainly of about 650 m of grey to greenish marls (Fahdène Formation), with occasional calcisphere-rich limestone beds (see Robaszynski et al., 1990, 1994 for a detailed review of the basin for the Cenomanian–Turonian interval). The Cenomanian ends with black, laminated, and organic-rich limestones, called the Bahloul Formation (Burollet, 1956).

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