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Toarcian carbon isotope shifts and nutrient changes from the Northern margin of Gondwana (High Atlas, Morocco, Jurassic): Palaeoenvironmental implications

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ABSTRACT

The Early Toarcian is marked by a global perturbation of the carbon cycle and major marine biological changes. These coincide with a general decrease in calcium carbonate production and an increase in organic carbon burial, and culminate in the so-called Toarcian Oceanic Anoxic Event. It is believed that the environmental crisis was triggered by the activity of the Karoo–Ferrar large igneous province. In order to further document the Early Toarcian palaeoenvironmental perturbations, carbon isotope, total organic matter, calcareous nannofossils and phosphorus content of the Amellago section in the High Atlas rift basin of Morocco were investigated. This section is extremely expanded compared to the well-studied European sections. Its position along the northern margin of the Gondwana continent is of critical importance because it enables an assessment of changes of river nutrient input into the western Tethyan realm. The carbon isotope curve shows two negative excursions of equal thickness and amplitude, at the Pliensbachian–Toarcian boundary and at the transition from the Polymorphum to the Levisoni Zone. This confirms the supra-regional nature of these shifts and highlights the possible condensation of the first "boundary" shift in European sections. Phosphorus content is used to trace palaeo-nutrient changes and shows that the two negative carbon isotope shifts are associated with increased nutrient levels, confirming that these episodes are related to enhanced continental weathering, probably due to elevated greenhouse gases in the atmosphere. In the High Atlas Basin, the increase in nutrient levels at the Pliensbachian–Toarcian boundary is moreover likely to be the main factor responsible for the coeval demise of the Saharan carbonate platform. A middle Toarcian event, centered on the boundary between the Bifrons and Gradata Zones, characterized by a positive carbon isotope excursion and nutrient level rise, is documented in the Amellago section.

1. Introduction

The Early Toarcian is characterized by major marine biological changes (Little and Benton, 1995; Harries and Little, 1999; Cecca and Macchioni, 2004; Mattioli and Pittet, 2004; Wignall et al., 2005; Wignall and Bond, 2008; Dera et al., 2010) and a decrease in carbonate accumulation (Dromart et al., 1996; Blomeier and Reijmer, 1999; Erba, 2004; Mattioli et al., 2004; Tremolada et al., 2005). It is also noticeable for its widespread organic matter deposition occurring during the so-called Toarcian Oceanic Anoxic Event (T-OAE; Jenkyns, 1985, 1988; Baudin et al., 1989; but see also McArthur et al., 2008a) and the associated perturbation of the carbon cycle. This latter is marked by a pronounced negative carbon isotope shift recorded in marine carbonates and organic matter, brachiopods, biomarkers and fossil wood around the boundary of the Polymorphum and Levisoni Zones (Jenkyns and Clayton, 1997; Hesselbo et al., 2000; Schouten et al., 2000; Röhl et al., 2001; Schmid-Röhl et al., 2002; Van Breugel et al., 2006; Hesselbo et al., 2007; Suan et al., 2008a). It is however not observed in belemnite guards from England, Germany and Spain (Van de Schootbrugge et al., 2005; Gomez et al., 2008). The T-OAE is also marked by an increase in the $^{87}Sr/^{86}Sr$ ratio (McArthur et al., 2000) and a positive excursion of Os isotopes which are interpreted to document a substantial increase in continental weathering (Cohen et al., 2004). Oxygen isotope and Mg/Ca ratio recovered from belemnite guards indicate that the T-OAE is coeval with a 6–7 °C warming of seawater (McArthur et al., 2000; Bailey et al., 2003; Rosales et al., 2004; van de Schootbrugge et al., 2005; Gomez et al., 2008). This warming is also observed in southwestern Tethyan brachiopods (Suan et al., 2008a) and northwestern Tethyan fish teeth (Dera et al., 2009a). Finally, changes in phytoplankton assemblages point toward higher nutrient input and fertility prior to, or during the

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event (Erba, 2004; Mattioli and Pittet, 2004; Mattioli et al., 2004, 2008; Suan et al., 2008a).

The negative excursion associated with the T-OAE was originally explained by the upwelling of poorly oxygenated water enriched in isotopically light dissolved inorganic carbon (Küspert, 1982; see also Sælen et al., 1996). The accumulation of evidence that the negative isotopic excursion was global in nature and found to affect both the ocean and atmospheric reservoir, led Hesselbo et al. (2000) to propose a massive methane gas hydrate injection in the ocean-atmosphere system as the source of the isotopically light carbon (see also Kemp et al., 2005). Alternative models suggest that thermal metamorphism of carbon-rich sediments in the Karoo–Ferrar large igneous province provided the source of isotopically light carbon (McElwain et al., 2005; Svensen et al., 2007). Calculation of the timing of the excursion by spectral analysis (Suan et al., 2008b) supports this argument. Nevertheless, the global nature of the Early Toarcian negative carbon isotope excursion is challenged by isotopic records of belemnite rostra (van de Schootbrugge et al., 2005; Gomez et al., 2008), leading van de Schootbrugge et al. (2005) to favour the initial upwelling "Küspert" model. This model is however unable to explain the presence of the negative excursion in continental wood. The different models proposed so far have been discussed in details by Cohen et al. (2007, see also McArthur et al., 2008b). Apart from dismissing the belemnite record (e.g. Hesselbo et al., 2007; Suan et al., 2008b) or the continental record (van de Schootbrugge et al., 2005), no explanation is presently available to clarify this discrepancy.

Recently, Hesselbo et al. (2007) and Littler et al. (2010) have identified an earlier large-amplitude negative carbon isotope excursion in bulk carbonate, bulk organic matter and macroscopic fossil wood, near the Pliensbachian–Toarcian boundary in Portugal and England. This "boundary" excursion is also documented in brachiopod calcite in the Peniche section (Suan et al., 2008a) where the negative shift is less than 2 m thick but of the same amplitude as the T-OAE negative shift in the Peniche section (i.e. both show a 2‰ drop in carbon isotope values but the T-OAE negative shift is recorded within a 15 m interval in that section). Oxygen isotope records from brachiopods indicate that an almost identical warming to the one reported from the T-OAE moreover accompanies the "boundary" excursion (Suan et al., 2008a). This discovery leads to several questions about the significance of the events and their causes!

In order to further document the palaeoenvironmental changes occurring during the Early Toarcian, the Amellago section, situated in the High Atlas rift basin of Morocco (Fig. 1) was investigated. This study provides the first documentation of the Early Toarcian carbon isotope curve for the Northern Gondwana margin (most previous studies were located in the European domain). This is of critical importance for an assessment of the extent of the carbon cycle perturbation. The Early Jurassic sedimentation rate in this part of the High Atlas Basin was very high (the Toarcian being more than 600 m thick; Pierre, 2006; Bourillot et al., 2008), minimizing the likelihood of problems with condensation and stratigraphic gaps. Despite its position at the western end of the Tethys Ocean along the northern margin of the Gondwana continent, only a few studies have been undertaken to try to document the impact of palaeoenvironmental changes on Lower Toarcian sediments in the High Atlas. The previous investigations mainly focused on the platform drowning event that is observed in the High Atlas Basin at the Pliensbachian–Toarcian boundary (Blomeier and Reijmer, 1999; Lachkar et al., 2009). Dera et al. (2009b) documented clay mineral assemblage during the Pliensbachian–Toarcian in the western Tethyan realm, including the High Atlas of Morocco, to trace palaeoclimatic changes. However, the absence of kaolinite throughout the entire studied interval did not allow these authors to discuss such changes in the High Atlas.

This study presents a latest Pliensbachian–middle Toarcian dataset of stable carbon and oxygen isotopes, total organic and phosphorus content from the Amellago section. The carbon isotope record is used to document changes in the ocean-atmosphere carbon reservoir. Bulk-rock phosphorus content is used to assess nutrient changes in the ocean. The implications of our findings for the palaeoenvironmental changes during the Early Toarcian are discussed and a potential middle Toarcian event is introduced.

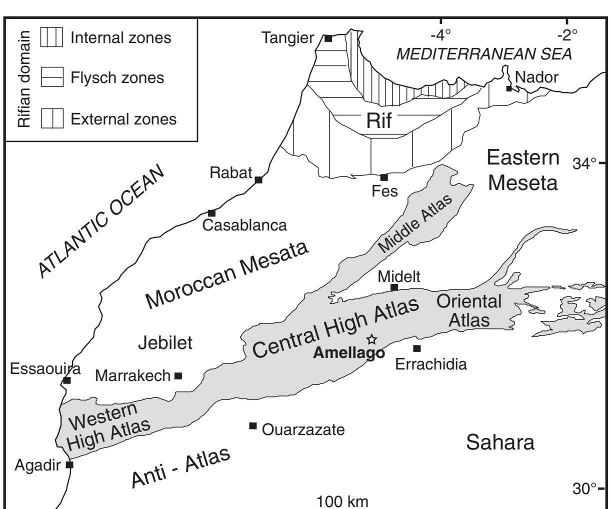

Fig. 1. Simplified structural map of Morocco and position of the Amellago section (modified after Lachkar et al., 2009). The Atlas range is shown in grey.

2. Geological setting of the High Atlas

The post-Hercynian geological history of Morocco was influenced by two significant events: (1) the opening of the northern Atlantic and western Tethys during the early Mesozoic and (2) the collision of Africa and Europe during the middle Cenozoic (Michard, 1976; Jacobshagen, 1988). These two events formed the Atlas System as well as the Rif Mountains. The Atlasic rift, which is associated with the first tectonic event, formed during two separated periods (Laville et al., 2004). Initial extension lasted from the Carnian to the earliest Jurassic, and this was followed by renewed subsidence from Toarcian times. Together, these lead to the formation of the fault-bounded Middle and High Atlas troughs, which are made up of several smaller depocenters, separated by synsedimentary highs (Studer and Du Dresnay, 1980).

The general palaeogeographic pattern of the central High Atlas region during the Early Jurassic was described as relatively deep marine in the centre and shallowing towards the northern and southern basin margins (Du Dresnay, 1971; Souhel et al., 2000; Fig. 2). However, a carbonate facies mosaic controlled by fault blocks developed during the Sinemurian and Pliensbachian, with a complex pattern of deep- and shallow-marine deposits throughout the central and eastern High Atlas. The Pliensbachian–Toarcian boundary is associated with an abrupt change from limestone-marl alternation to ubiquitous marl sedimentation in all the High Atlas depocentres (El Kamar et al., 1997–1998; Souhel et al., 1998; Fedan, 1999; Ettaki and Chellai, 2005). This feature was associated with sea-level rise interpreted as eustatic in origin by Warme (1988). It could however also be related to the drowning of the High Atlas carbonate platforms during the Early Toarcian (Blomeier and Reijmer, 1999; Wilmsen and Neuweiler, 2008; Lachkar et al., 2009), which would have lead to a halt in the shedding of carbonate platform ooze, which is responsible in some cases for limestone-marl alternation in epicontinental basins (Mattioli and Pittet, 2002; Reboulet et al., 2003). The thickness of the Toarcian marls and the intercalated shallow-marine deposits vary across the area.