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# Secular environmental precursors to Early Toarcian (Jurassic) extreme climate changes

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ABSTRACT

The Early Toarcian Oceanic Anoxic Event (T-OAE), about 183 myr ago, was a global event of environmental and carbon cycle perturbations, which deeply affected both marine biota and carbonate production. Nevertheless, the long-term environmental conditions prevailing prior to the main phase of marine extinction and carbonate production crisis remain poorly understood. Here we present a ~8 myr-long record of Early Pliensbachian–Middle Toarcian environmental changes from the Lusitanian Basin, Portugal, in order to address the long-term paleoclimatic evolution that ultimately led to carbonate production and biotic crises during the T-OAE. Paleotemperature estimates derived from the oxygen isotope compositions of well-preserved brachiopod shells from two different sections reveal a pronounced ~5 °C cooling in the Late Pliensbachian (*margaritatus–spinatum* ammonite Zones boundary). This cooling event is followed by a marked ~7–10 °C seawater warming in the Early Toarcian that, after a second cooling event in the mid-*polymorphum* Zone, culminates during the T-OAE. Calcium carbonate ($CaCO_3$) contents, the amount of nannofossil calcite and the mean size of the major pelagic carbonate producer *Schizosphaerella*, all largely covary with paleotemperatures, indicating a coupling between climatic conditions and both pelagic and neritic $CaCO_3$ production. Furthermore, the cooling and warming episodes coincided with major marine regressions and transgressions, respectively, suggesting that the growth and decay of ice caps may have exerted a strong control on sea-level fluctuations throughout the studied time interval. This revised chronology of environmental changes shows important similarities with Neogene and Paleozoic episodes of deglacial black shale formation, and thus prompts the reevaluation of ice sheet dynamics as a possible agent of Mesozoic events of extinction and organic-rich sedimentation.



## 1. Introduction

Geochemical, sedimentological and paleontological data indicate that the Late Pliensbachian–Early Toarcian mass extinction event (~183 myr ago, Early Jurassic) was accompanied by severe environmental changes that included development of anoxic conditions, changes in the hydrological cycle, marked variations in seawater temperatures and changes in marine and terrestrial biota (Jenkyns, 1988; Philippe and Thévenard, 1996; Macchioni and Cecca, 2002; Bailey et al., 2003; Cohen et al., 2004; Wignall et al., 2005; Rosales et al., 2006; Suan et al., 2008a; Gómez et al., 2008). It has been suggested that these major environmental changes could have been triggered by massive releases of greenhouse gases, possibly involving the destabilization of marine gas hydrates or the thermal metamorphism of organic-rich sediments during the intrusive phase of the eruption of the Karoo–Ferrar large igneous province (Hesselbo et al., 2000; Cohen et al., 2007; Svensen et al., 2007). Shallow-water carbonate platforms and calcareous nannofossils, as well as benthic and pelagic invertebrates, were particularly affected by these major environmental changes, notably across the Pliensbachian–Toarcian boundary and during an episode of widespread organic-rich deposition defined as the Toarcian Oceanic Anoxic event (T-OAE) (Bassoullet and Baudin, 1994; Harries and Little, 1999; Cobianchi and Picotti, 2001; Macchioni and Cecca, 2002; Erba, 2004; Mattioli et al., 2004; Tremolada et al., 2005; Wignall et al., 2005; Mattioli et al., 2008; Suan et al., 2008a). Most studies relate these mass extinctions and biocalcification crises to pulses of $CO_2$-induced environmental changes, namely by enhanced nutrient input due to accelerated hydrological cycle, productivity-driven anoxia, rise in seawater temperatures and changes in the saturation state of the ocean with respect to calcite (Erba, 2004; Mattioli et al., 2004; Tremolada et al., 2005; Wignall et al., 2005; Mattioli et al., 2008; Gómez et al., 2008).

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Though many studies focused specifically on the Early Toarcian episode, the long-term environmental conditions that led to severe climatic and biotic perturbations remain poorly understood. In particular, a number of studies have suggested that the Late Pliensbachian was characterized by low seawater temperatures and cool atmospheric conditions, which may have been associated with the transient development of icehouse conditions prior to the T-OAE (Price, 1999; Cobianchi and Picotti, 2001; Guex et al., 2001; Bailey et al., 2003; van de Schootbrugge et al., 2005). Indeed, the temporal coincidence between this cooling episode and a major marine regression has been interpreted as possibly reflecting the growth of continental ice at high latitudes (Price, 1999; Cobianchi and Picotti, 2001; Guex et al., 2001; van de Schootbrugge et al., 2005). It has been proposed that these important environmental perturbations may have also contributed to platform carbonate production decline, and may as well have preconditioned the western epicontinental seas to water mass stratification during the T-OAE (Cobianchi and Picotti, 2001; Bailey et al., 2003). Nevertheless, the relative timing between this cooling episode, the decline of carbonate production and the sea-level fall remain poorly constrained, impeding integration of long- and short-term climate variability in our understanding of the Toarcian climatic and biotic events.

The aim of this study is to address the long-term evolution of climatic conditions and pelagic and neritic carbonate production during the Pliensbachian–Early Toarcian using a multi-proxy approach based on geochemical data and nannofossil abundance and biometry. Our study is based on data acquired in the Lusitanian Basin, and in particular from the reference section of Peniche, Portugal (Pliensbachian–Toarcian boundary GSSP candidate). The succession provides a continuous exposure of biostratigraphically well-constrained marine hemipelagic sediments of Late Sinemurian to Middle Toarcian age (Duarte and Soares, 2002; Duarte, 2007), and thus represents an ideal stratigraphic framework for such a study. To reconstruct the evolution of both the pelagic and neritic carbonate production, we present $CaCO_3$ contents and a quantification of nannofossil abundance and size for the Upper Pliensbachian. We use new carbon and oxygen isotope data of brachiopod shells sampled from the same section in order to access to concomitant changes in carbon cycling and paleotemperatures. We also present an additional carbon and oxygen isotope record of brachiopod shells sampled in a shallow marine environment succession of the Lusitanian Basin (Tomar) to further assess the environmental significance of the stable-isotope signal acquired in Peniche.

## 2. Geological setting and stratigraphy

### 2.1. Peniche

The Peniche section in Portugal (Fig. 1) presents a complete succession of marine hemipelagic marls and limestones of Late Sinemurian to Middle–Late Toarcian age (Duarte and Soares, 2002) that were deposited in one of deepest part of the Lusitanian Basin (Duarte, 1998, 2007). The ammonite biostratigraphy of the section is well established at the zonal level and refers to the studies of Mouterde (1955), Elmi et al. (1996) and Elmi (2006). The middle part of the Pliensbachian (top of *ibex* to *margaritatus* ammonite zones) displays several organic matter-rich levels generally poor in benthic macrofauna that may contain as much as 15% of organic carbon (Oliveira et al., 2006). The uppermost Pliensbachian (*spinatum* Zone) is characterized by thick carbonate-rich marl limestone alternations rich in belemnite rostra and brachiopod shells. Lithostratigraphy, stable-isotope data, nannofossil abundance and size, and cyclostratigraphic framework for the uppermost Pliensbachian and Lower Toarcian were documented by Hesselbo et al. (2007), Suan et al. (2008a,b) and Mattioli et al. (2008). In this study, we have extended the previously existing record (Suan et al., 2008a) by generating new measurements of the carbon and oxygen isotope compositions of brachiopod shells, $CaCO_3$ contents and size of the main pelagic

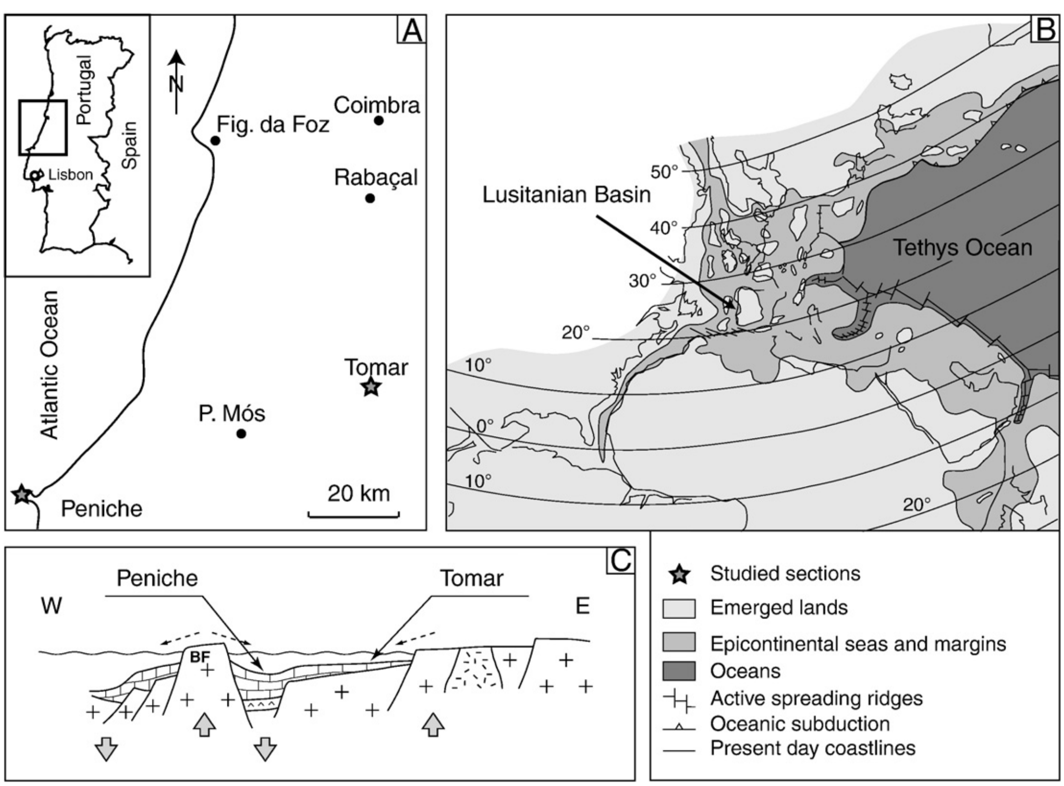


**Fig. 1.** (A) Location of the studied sections; (B), paleogeography of the western margin of the Tethys Ocean during the Early Jurassic and location of the Lusitanian Basin; (C) position of the studied sections relative to the morphology and structure of the Lusitanian Basin during the Early Toarcian (modified after Vanney and Mougenot, 1981). BF: Berlanga–Farilhões horst.