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Isotope records (C-O-Sr) of late Pliensbachian-early Toarcian environmental perturbations in the westernmost Tethys (Majorca Island, Spain)

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ABSTRACT

The late Pliensbachian–early Toarcian (Early Jurassic) was a time of major environmental changes that culminated with the Early Toarcian Oceanic Anoxic Event (T-OAE, ca. ~183 Ma). This period is marked by significant disturbances in the carbon cycle and rapid climatic changes. To improve the understanding of the expression of these events in westernmost Tethyan domains, this study provides new belemnite and bulk carbonate C and O stable isotope records of a ~5 Myr upper Pliensbachian to middle Toarcian marine succession of the Balearic Basin (Es Cosconar section, Majorca). Time resolution has been improved by combination of biostratigraphic (ammonoids and brachiopods) and geochronologic ($^{87}Sr/^{86}Sr$) methods. Seawater paleotemperatures derived from $\delta^{18}O$ belemnite records reveal cooler paleotemperatures in the upper part of the *Spinatum* Zone. The uppermost *Spinatum* Zone is characterized by the onset of a warming event that crosses the Pliensbachian-Toarcian boundary, culminating with the warmer temperatures (up to ~10 °C of warming) for the *Serpentinum* Zone of the lower Toarcian. This warming event has been detected contemporaneously in many other European and Tethyan basins and is interpreted to represent generalized raised seawater temperatures linked to the T-OAE. Four significant $\delta^{13}C$ events have been recorded in belemnite and bulk carbonate records. The first is a negative carbon isotope excursion (CIE) around the Pliensbachian-Toarcian boundary, which is best represented in the belemnite record. Soon after, the bulk-carbonate record shows a positive shift in the lower *Tenuicostatum* Zone concomitant with a return to background values in the belemnite record, suggesting strong water stratification or decoupling probably related with export of neritic carbonate to the basin. The third is a negative CIE represented in bulk carbonate across the *Tenuicostatum-Serpentinum* zonal transition, which could be correlated with the negative excursion characterizing the onset of the T-OAE in other sections. The position of this excursion corresponds with a gap in the belemnite record. Finally, in the lower Toarcian, both the bulk carbonate and belemnite carbon isotope records show pronounced positive CIEs in the lower-middle part of the *Serpentinum* Zone. These CIEs testify the impact of the T-OAE in the Balearic basin.

1. Introduction

The Jurassic was a time of major paleoclimatic, paleogeographic and paleoceanographic changes, of which the Early Toarcian Oceanic Anoxic Event (T-OAE; ~183 Ma) is the only event recognized to date that is considered clearly global in its effects (e.g. Hesselbo et al., 2000; Jenkyns, 2010). It coincided with a period of major paleogeographic reorganization (Fig. 1), due to the opening of the Central Atlantic Ocean during the break up of Pangea, the formation of the Karoo-Ferrar large igneous province (LIP) in southern Gondwana (Pálfy and Smith, 2000; Jourdan et al., 2008), and the climax of a second-order eustatic transgression with rapid rise of sea level (Hallam, 1997). The confluence of these events triggered a significant paleoclimatic and paleoenvironmental change that resulted in conditions of oceanic warming and anoxia with widespread deposition of organic-rich shales and a dramatic impact on the marine environment, which led eventually to mass extinctions (Little and Benton, 1995; Hallam and Wignall, 1999; Harries and Little, 1999; Wignall et al., 2005; Dera et al., 2010; Gómez and Goy, 2011; García Joral et al., 2011). This event has been related also to significant perturbations in the global carbon cycle that gave rise to carbon isotopic excursions (CIEs) in all carbon reservoirs (Hesselbo et al., 2000, 2007). The CIEs were accompanied by

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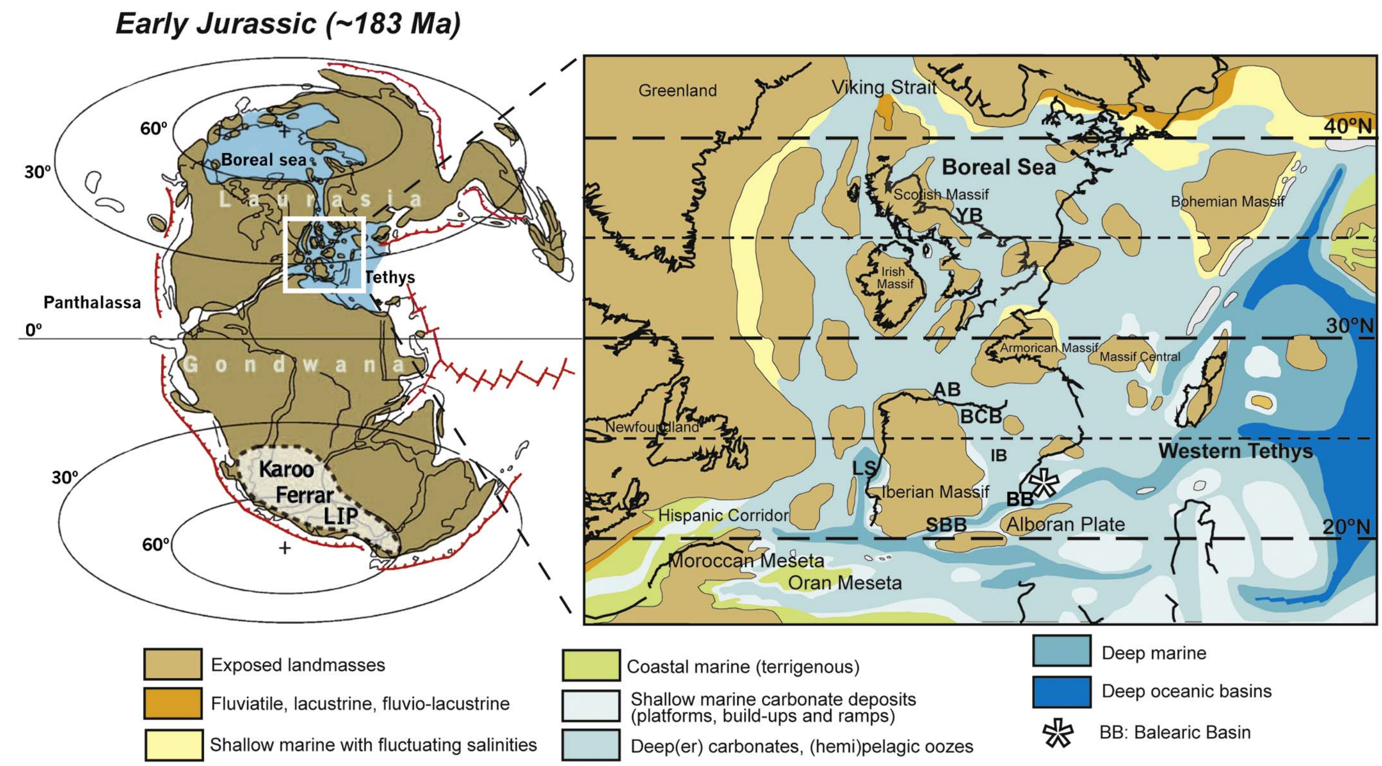

Fig. 1. General Pliensbachian-Toarcian (Early Jurassic) paleogeographical context of the study area at global scale and in the Western Tethyan realm. Modified from Dera et al. (2010) and Dercourt et al. (2000). Cited basins from North to South, YB: Yorkshire Basin, AB: Asturian Basin, BCB: Basque-Cantabrian Basin, IB: Iberian Basin, LS: Lusitanian Basin, BB: Balearic Basin, SBB: Sub-Betic Basin.

minimum Sr-isotope values (Jones et al., 1994; Jenkyns, 2010) and a negative oxygen isotope excursion, triggered presumably by global warming. All these geochemical anomalies have been reproduced in many lower Toarcian sections around the world, despite the regional presence or not of anoxic deposits.

The issue of the T-OAE duration is complicated by different definitions of the T-OAE and of associated CIEs. Most authors use the presence of a negative CIE in marine sediments, recorded during the upper *Tenuicostatum* to lowermost *Falciferum/Serpentinum* zones in both organic and carbonate carbon, as the geochemical expression that defines the T-OAE. These authors give several estimates for the duration of the negative CIE, ranging the most recent publications between 0.6 Myr (Huang and Hesselbo, 2014; Ruebsam et al., 2014) and 0.3 to 0.5 Myr (Boulila and Hinnov, 2017), based on astronomical chronology and cyclostratigraphy. It should be noted, however, that these studies use different definitions for the negative CIE interval. Using the definition of Boulila and Hinnov (2017) and the time scale of Huang and Hesselbo (2014), the CIE may have lasted more that 1.4 Myr. Other studies define the duration of T-OAE as an interval that begins with the negative CIE at the *Tenuicostatum* Zone and follows with a pronounced positive CIE in the middle/upper part of the *Falciferum* Zone (equivalent to the *Serpentinum* or *Levisoni* zones in the Tethyan schemes) (e.g. Hesselbo et al., 2000; Jenkyns et al., 2002). The later is best identifiable in the dataset presented here, like in other records of Spain (Rosales et al., 2004a, 2004b, 2006; Gómez et al., 2016a, 2016b). This T-OAE interval is preceded in some sections by a negative shift during the Pliensbachian-Toarcian transition (Pl-To transition). The interval between the Pl-To transition and the highest carbon isotope values marking the positive CIE has an estimated duration ranging between < 1 Myr (Boulila and Hinnov, 2017) and up to 2.5 Myr (Huang and Hesselbo, 2014).

The mechanisms and the local versus global origin of the negative isotopic excursion at the onset of the T-OAE are still under debate. Although many authors now accept that it was global and synchronous worldwide and that affected to all the carbon reservoirs (Hesselbo et al., 2007; Hermoso et al., 2009, 2012; Littler et al., 2010; Suan et al., 2011), other studies have questioned its global nature because some profiles, especially those based on belemnite calcites, do not seem to record clearly the negative shift (van de Schootbrugge et al., 2005a; Rosales et al., 2006; Gómez et al., 2008; Metodiev and Koleva-Rekalova, 2008).

Oxygen isotope data indicate that the T-OAE was also a thermal event characterized by a global rapid rise in seawater paleotemperatures of about 5–7 °C in average (e.g. Bailey et al., 2003; Rosales et al., 2004a; Gómez and Goy, 2011; Korte et al., 2015; Gómez et al., 2016a). This temperature maximum succeeded a cooling phase (late Pliensbachian Cooling Event), evidenced by a shift to more positive $\delta^{18}O$ values, which appears to have occurred also synchronously in many basins during the late Pliensbachian *Spinatum* Zone (Rosales et al., 2001, 2004a, 2004b, 2006; Bailey et al., 2003; Gómez et al., 2008; Suan et al., 2010; Dera et al., 2011; Korte et al., 2015; Gómez et al., 2016a). These cooling and warming episodes may correlate respectively with second order regressive and transgressive sea-level phases (e.g. Quesada et al., 2005; Rosales et al., 2006; Suan et al., 2010), suggesting probably glacio-eustatic or supraregional tectonic controls on the isotopic and sedimentary records around the Pliensbachian–Toarcian transition (Korte et al., 2015).

An amount of the data supporting these interpretations come from epicontinental basins of Boreal, sub-Boreal or sub-Mediterranean seas (Fig. 1), but these epicontinental records may reflect strong regional overprint upon the C and O isotope records, because these basins likely became intermittently salinity stratified and developed strong haloclines and thermoclines (e.g. Podlaha et al., 1998; Rosales et al., 2004b; Harazim et al., 2012). Thus, more archives from other regions representative of different water masses are needed. In order to improve the understanding of the expression of these events in other paleogeographic regions, this study aims to reconstruct the long-term evolution of paleoclimatic changes and major perturbations of the geochemical cycles during the late Pliensbachian–middle Toarcian interval (~5 Myr)