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Research paper

The calcareous nannofossil crisis in Northern Spain (Asturias province) linked to the Early Toarcian warming-driven mass extinction

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ABSTRACT

Quantitative analysis of Late Pliensbachian–Early Toarcian calcareous nannofossil assemblages from the West Rodiles section (Asturias, Northern Spain) has been performed in order to interpret the paleoenvironmental changes that occurred during this time interval, characterized by a major extinction event, and especially around the Lower Toarcian Tenuicostatum/Serpentinum zonal and extinction boundary. Nannofossil data were statistically treated: the Shannon diversity index was calculated, and results were compared to the stable isotope data and the total organic carbon content. To determine the changes recorded in the entire nannofossil communities, a principal component analysis was applied. During the latest Pliensbachian, the nannofossil assemblages were dominated by *Schizosphaerella* sp. and *Tubirhabdus patulus*, followed by the dominance of *Calcivascularis jansae*, taxa that probably thrived in rather cold waters. The progressive decrease in the relative abundances of both *Schizosphaerella* sp. and *C. jansae* coincides with a progressive increase in paleotemperatures during the extinction interval, as indicated by the $\delta^{18}O$ values measured on diagenetically screened belemnite calcite. *Biscutum* spp. dominated the nannofossil assemblages during the Early Toarcian Tenuicostatum Ammonite Zone, when seawaters were warm. In the West Rodiles section, the extinction boundary coincides with the deposition of the laminated shales, where especially high relative abundances of *Calyculus* spp. were recorded. After the extinction boundary, *C. jansae* becomes extinct, the relative abundance of *Biscutum* spp. sharply decreases, and the nannofossil assemblages become dominated by the *Crepidolithus* and *Lotharingius* species, which have been interpreted as opportunistic taxa. The Shannon Index fluctuates throughout the studied section, although it is especially high after the extinction boundary. The covariance between the nannofossil crisis and the evolution of $\delta^{18}O_{bel}$-based seawater paleotemperatures, as well as the fact that none of the explanations proposed by other authors seems to explain our observations, suggest a clear relationship between the increase in paleotemperature and the changes recorded in our nannofossil assemblages. Nevertheless, we do not discard possible changes in other paleoenvironmental parameters related or not to warming.

1. Introduction

The Early Toarcian has often been described as an interval during which important changes in temperatures took place (e.g. Sælen et al., 1996; Jenkyns, 2003; Rosales et al., 2004; Gómez et al., 2008; Metodiev and Koleva-Rekalova, 2008; Suan et al., 2008; Dera et al., 2009; Gómez and Arias, 2010; Gómez and Goy, 2010, 2011; Suan et al., 2010; García Joral et al., 2011), coinciding with a significant transgressive peak (e.g. Hallam, 1961, 1981, 1997; Hallam and Wignall, 1999; Gómez and Goy, 2000, 2005; Gómez et al., 2008; Suan et al., 2008; Gómez and Arias, 2010; Suan et al., 2010). In the here studied West Rodiles section (Northern Spain) (Fig. 1) a progressive seawater warming, based on oxygen isotope values obtained from belemnite calcite ($\delta^{18}O_{bel}$), was recorded during the latest Pliensbachian–earliest Toarcian. It was followed by a pronounced increase in temperature of about 6 °C around the Tenuicostatum/Serpentinum Ammonite Zones (AZs) boundary, reaching an average seawater paleotemperature of 21 °C (Gómez et al., 2008).

During the Early Toarcian, major perturbations in the global carbon cycle have been inferred for different sub-basins, based on the presence of a pronounced negative Carbon isotope excursion (CIE) recorded in bulk rock carbonate, carbonate microfractions, marine organic matter, brachiopod calcite and continental fossil wood (e.g. Küspert, 1982; Jenkyns and Clayton, 1986; Jiménez et al., 1996; 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; Gómez et al., 2008; Suan et al., 2008, 2010; Hermoso et al., 2009; Caruthers et al., 2010; Izumi and Tanabe, 2010; Littler et al., 2010; Hesselbo and Pieñkowski, 2011), but this excursion has not been clearly recorded in belemnite calcite (McArthur et al., 2000; van de Schootbrugge et al., 2005;

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Wignall et al., 2005; McArthur, 2007; McArthur et al., 2007; Gómez et al., 2008; Gómez and Arias, 2010; Gómez and Goy, 2011).

Several authors have interpreted this negative CIE as the result of a massive release of large quantities of isotopically light methane from the dissociation of gas hydrates buried in marine sediments (Hesselbo et al., 2000; Beerling et al., 2002; Cohen et al., 2004; Kemp et al., 2005; Hesselbo et al., 2007), but this hypothesis has been challenged by Beerling and Brentnall (2007). Some other papers support that the negative CIE is a consequence of the thermal metamorphism of carbon-rich sediments in the Karoo–Ferrar large igneous province (LIP) (McElwain et al., 2005; Svensen et al., 2007), but this last hypothesis has also been dismissed by Summons et al. (2008) and Gröcke et al. (2009).

Another important event that took place during the Early Toarcian was a mass extinction event, which affected many different groups of marine organisms over a wide geographic area, including ammonites from both the Boreal and the Tethyan domains (Little and Benton, 1995; Macchioni, 2002; Cecca and Macchioni, 2004; Bilotta et al., 2010; Dera et al., 2010); brachiopods from Central Spain (García-Joral and Goy, 2009; García Joral et al., 2011) and the UK (Little and Benton, 1995; Harries and Little, 1999); benthic foraminifera and ostracods from Central Spain (Arias et al., 1992; Arias, 2009; Gómez and Arias, 2010), UK (Little and Benton, 1995; Hallam, 1997; Harries and Little, 1999; Wignall, 2001; Wignall et al., 2005), Italy (Nocchi and Bartolini, 1994), France and NW Europe (Bassoullet and Baudin, 1994; Hylton and Hart, 2000; Hart et al., 2010), Portugal (Boomer et al., 1998) and Morocco (Bassoullet et al., 1991). Concomitant with the mass extinction, calcareous nannofossil assemblages experienced a drastic decrease in abundance of both *Schizosphaerella* (Bucefalo Palliani et al., 1998, 2002; Mattioli and Pittet, 2002; Erba, 2004; Mattioli and Pittet, 2004; Mattioli et al., 2004b; Tremolada et al., 2005; van de Schootbrugge et al., 2005; Mattioli et al., 2008; Suan et al., 2008; Mattioli et al., 2009) and *Calcivascularis jansae* ((*) See the appendix), which subsequently became extinct (Bucefalo Palliani and Mattioli, 1995; Bucefalo Palliani et al., 1998; Tremolada et al., 2005; Mattioli et al., 2008).

During the last two decades, the anoxia linked to the postulated Early Toarcian oceanic anoxic event (ETOAE), defined by Jenkyns (1988), have been inferred as the main cause of the mass extinction (e.g. Jenkyns, 1988; Bassoullet and Baudin, 1994; Nikitenko and Shurygin, 1994; Little and Benton, 1995; Harries and Little, 1999; Hesselbo et al., 2000; Hylton and Hart, 2000; Pálfy and Smith, 2000; Guex et al., 2001; Bucefalo Palliani et al., 2002; Macchioni, 2002; Vörös, 2002; Aberhan and Baumiller, 2003; Mattioli et al., 2004b; Tremolada et al., 2005; Wignall et al., 2005; Mailliot et al., 2006, 2009; Pearce et al., 2006; Mattioli et al., 2008, 2009; Bilotta et al., 2010; Hart et al., 2010). However, deposition of real black shales containing >5 wt.% total organic carbon (TOC) (Bates and Jackson, 1987; Kearey, 2001; McArthur et al., 2008) is mainly restricted to the Northwestern Europe Euxinic Basin (WEEB) (Gómez and Goy, 2011). Conversely, the time equivalent deposits in most European and Northern African sections are bioturbated, indicating well oxygenated conditions (Ruget, 1985; Alméras and Elmi, 1993; Arias, 2006, 2007). To indicate the event that generated the presence of the Early to Middle Toarcian black shale facies in the WEEB, the more appropriated name of Regional Anoxic Event (RAE) has been proposed by McArthur (2007) and McArthur et al. (2007). On the contrary, the Early Toarcian mass extinction has generally been considered a synchronous and global event, which has also been recorded in numerous areas showing evidences of well oxygenated bottom waters, where black shale deposits are absent (Arias et al., 1992; Monaco, 1995; Gómez, 2002a,b; Goy et al., 2006; Gómez et al., 2008; Arias, 2009; Gómez and Arias, 2010; Gómez and Goy, 2010, 2011; Rodríguez-Tovar and Uchman, 2010). Hence, a direct cause and effect relationship between the Early Toarcian anoxia and the mass extinction has not been established and, in fact, the main phase of deposition of black shales in the WEEB does not coincide with the extinction interval, but mainly with the repopulation interval (see below). Instead, on the basis of the strong covariance between the timing and patterns of the Early Toarcian mass extinction and the seawater paleotemperatures estimated, a warming event, probably of global extent, has recently been proposed as the main factor responsible for mass extinction (Gómez et al., 2008; García-Joral and Goy, 2009; Gómez and Arias, 2010; Gómez and Goy, 2010, 2011; García Joral et al., 2011).

Three main phases were distinguished by Kauffman and Erwin (1995) in mass extinction events, on the basis of the relation between extinction (E) and origination (O) rates: 1) the extinction interval, 2) the extinction boundary and 3) the repopulation interval, which includes the survival and the recovery intervals. During the extinction interval, E is higher than O and the diversity of the community decreases drastically. At the extinction boundary, E reaches the highest value and O shows a minimum. Finally, during the repopulation interval, O progressively increases with respect to E, and the assemblages are dominated by surviving taxa and newly evolved species. In this work, the extinction interval includes the uppermost Spinatum AZ of the Upper Pliensbachian and the Tenuicostatum AZ of the Lower Toarcian, and the extinction boundary is located around the Tenuicostatum/Serpentinum (=Falciferum) AZs boundary, as several authors pointed out (e.g. Arias et al., 1992; Little and Benton, 1995; Harries and Little, 1999; Cecca and Macchioni, 2004; Wignall et al., 2005; Gómez et al., 2008; Gómez and Arias, 2010; Gómez and Goy, 2010; García Joral et al., 2011). The repopulation interval starts above the extinction boundary and extends beyond the top of the studied part of the section.

The West Rodiles section provides a continuous and superbly exposed Upper Pliensbachian–Lower Toarcian sedimentary succession, well-calibrated to the standard ammonite zones and subzones (ASzs) and with good preservation of coccoliths. Moreover, the work of Gómez et al. (2008) presents detailed isotopic, TOC, and stratigraphic data for the studied section; some additional new isotopic data are presented here. The aim of this study is to determine the response of calcareous nannofossils to the paleoenvironmental changes that occurred in the West Rodiles section (Asturias, N Spain) during the Late Pliensbachian–Early Toarcian time interval, with special emphasis on the Early Toarcian mass extinction event. For this purpose, the abundance and diversity of nannofossils were quantified, treated by statistical analysis, and compared with the paleoenvironmental changes revealed by geochemical data.

2. Materials and methods

2.1. Location and lithostratigraphy of the West Rodiles section

The West Rodiles section (5° 22′ 31″ W; 43° 32′ 27″ N) crops out in a coastal cliff on the west side of the Punta de Rodiles (Fig. 1), in Eastern Asturias (Northern Spain). This section belongs to the Jurassic succession of Asturias, which is formed of two depositional megasequences separated by an unconformity related to extensional tectonic pulses (Borrego et al., 1996). The lower megasequence, the Villaviciosa Group (Valenzuela, 1988), is mainly calcareous, and ranges in age from Hettangian to Lower Bajocian. It includes the Gijón and the Rodiles formations. The upper megasequence, the Ribadesella Group, is Upper Jurassic in age, and is mainly composed of siliciclastics (Valenzuela, 1988). The samples analyzed in this study belong to the Santa Mera Member of the Rodiles Formation that is characterized by an alternation of limestone and marl. These sediments are thought to have been deposited on a carbonate ramp at varying depths, generally below the storm wave base (Valenzuela et al., 1986).

The continuous and well-dated West Rodiles section, spans from the Upper Pliensbachian Apyrenum ASz (Spinatum AZ) to the Lower Toarcian Falciferum ASz (Serpentinum AZ) and is made up of a 14 m thick alternation of marls and limestones with a one-meter thick intercalation of laminated calcareous marls, which coincides with a