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Astronomical constraints on the duration of the Early Jurassic Pliensbachian Stage and global climatic fluctuations

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A B S T R A C T

The Early Jurassic was marked by multiple periods of major global climatic and palaeoceanographic change, biotic turnover and perturbed global geochemical cycles, commonly linked to large igneous province volcanism. This epoch was also characterised by the initial break-up of the super-continent Pangaea and the opening and formation of shallow-marine basins and ocean gateways, the timing of which are poorly constrained. Here, we show that the Pliensbachian Stage and the Sinemurian–Pliensbachian global carbon-cycle perturbation (marked by a negative shift in δ^{13}C of 2–4‰), have respective durations of ∼8.7 and ∼2 Myr. We astronomically tune the floating Pliensbachian time scale to the 405 Kyr eccentricity solution (La2010d), and propose a revised Early Jurassic time scale with a significantly shortened Sinemurian Stage duration of 6.9 ± 0.4 Myr. When calibrated against the new time scale, the existing Pliensbachian seawater ^{87}Sr/^{86}Sr record shows relatively stable values during the first ∼2 Myr of the Pliensbachian, superimposed on the long-term Early Jurassic decline in ^{87}Sr/^{86}Sr. This plateau in ^{87}Sr/^{86}Sr values coincides with the Sinemurian–Pliensbachian boundary carbon-cycle perturbation. It is possibly linked to a late phase of Central Atlantic Magmatic Province (CAMP) volcanism that induced enhanced global weathering of continental crustal materials, leading to an elevated radiogenic strontium flux to the global ocean.

1. Introduction

The Early Jurassic (201.4–174.1 Ma) is distinguished by the end-Triassic mass extinction and global warming event, climatic cooling in the Late Pliensbachian and subsequent greenhouse warming in the Early Toarcian (McElwain et al., 1999; Hesselbo et al., 2002; Ruhl et al., 2011; Gradstein et al., 2012; Wotzlaw et al., 2014; Gomez et al., 2015; Korte et al., 2015). Continental rifting and the break-up of Pangaea in the Early Jurassic led to the formation of continental and marine rift basins, which acted as major sites of organic carbon burial and led to the generation of hydrocarbon source rocks (Fleet et al., 1987; Olsen, 1997). The equatorial Tethys Ocean was connected in the Early Jurassic (Sinemurian) to Eastern Panthalassa via the Hispanic Corridor and to the high-latitude Boreal realm via the Viking Corridor, likely initiating changes in (global) ocean currents and planetary heat distribution (Fig. 1; Porter et al., 2013; Korte et al., 2015).

The Early Toarcian in particular was set apart by the global Toarcian Oceanic Anoxic Event (T-OAE), with possibly the largest exogenic carbon-cycle perturbation in the Mesozoic, and associated perturbations in other global geochemical cycles, palaeoclimate and the palaeoenvironment, linked to emplacement of a large igneous province (LIP) in the Karoo–Ferrar region (Jenkyns, 2010; Burgess et al., 2015; Percival et al., 2015). The Early Jurassic was also marked by multiple somewhat smaller scale fluctuations in the global exogenic carbon cycle (Riding et al., 2013; Jenkyns and Weedon, 2013), shifts between climatic warming and cooling on regional and global scales (Korte et al., 2009, 2015; Korte and Hesselbo, 2011), marine and continental extinction and origination events (Close et al., 2015), and fluctuations in regional and global sea-level (Hallam, 1997; Hesselbo et al., 2004; Hesselbo, 2008).

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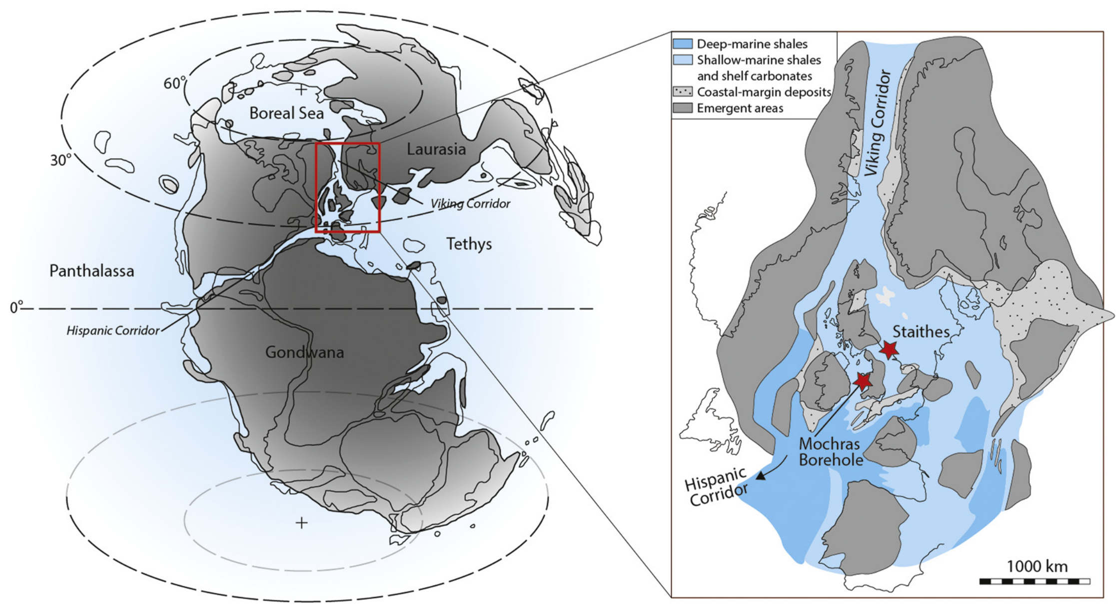

Fig. 1. Early Jurassic palaeogeography showing the Mochras (Cardigan Bay Basin) and Staithes (Cleveland Basin) localities (red stars) at the northwestern extremity of the Tethys Ocean. The figure is modified after Dera et al. (2011) and Korte et al. (2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The age, rate of change, and duration of these events are, however, poorly constrained and their inter-relationships only crudely appreciated.

Here, we determine the age and duration of the Early Jurassic Pliensbachian Stage and ammonite zones and subzones in the hemipelagic marine sedimentary record of the Mochras Farm (Llanbedr) Borehole from west Wales (Cardigan Bay Basin). The Mochras Borehole represents ∼1300 m of possibly the most continuously deposited and stratigraphically expanded Lower Jurassic sedimentary archive known (Fig. 2; Hesselbo et al., 2013). High-resolution (sub-precession scale) element concentration data from this cored material are used to construct a floating astronomical time scale for the Early Jurassic Pliensbachian Stage. Combined with published astrochronological and radiometric constraints on the age of the Rhaetian–Hettangian (Triassic–Jurassic) and Pliensbachian–Toarcian Stage boundaries, and astrochronological constraints on the duration of the Hettangian and Toarcian Stages, we calculate the duration and age of the Pliensbachian Stage and its constituent zones. With these data, we then assess the duration and rate of change of the Sinemurian–Pliensbachian climatic and global carbon-cycle perturbations and the Late Pliensbachian climatic cooling cycles, and assess the rate of change of Pliensbachian seawater $^{87}Sr/^{86}Sr$.

2. The Mochras Farm (Llanbedr) Borehole

The Mochras Farm (Llanbedr) Borehole, hereafter referred to as Mochras, was drilled in 1968–1970 on the west coast of Wales (52°48′32″N, 4°08′44″W; Fig. 1; Woodland, 1971; Dobson and Whittington, 1987; Hesselbo et al., 2013; Copestake and Johnson, 2014). The borehole yielded, unexpectedly, a ∼1.3 km-thick (601.83–1906.78 m below surface), biostratigraphically complete succession of calcareous mudstone and clay-rich limestone, representing almost the complete Early Jurassic, an interval representing some 27 Myr of geological time.

The Early Jurassic age sedimentary record in the Mochras core is more than twice as thick as any other UK core or coastal outcrop, and it is over four times more expanded than the well-studied Sancerre–Couy core from the Paris Basin, France (Fig. 2; Tappin et al., 1994; Hesselbo et al., 2013; Boulila et al., 2014). The Hettangian and Sinemurian part of the Mochras core was largely broken up for ammonite biostratigraphy; hence only limited continuous core is preserved for these stages. Continuous core slabs are, however, preserved for the Pliensbachian and Toarcian parts of Mochras (Hesselbo et al., 2013).

3. Bio- and chemostratigraphy

Biostratigraphical zones, combined with high-resolution geochemical proxy records, provide the primary means for global correlation of Lower Jurassic marine and terrestrial sedimentary archives. The Pliensbachian Stage in northwest Europe is subdivided into five ammonite zones (and 15 ammonite subzones), which are all present and recognised in the Mochras core (Ivimey-Cook, 1971; Page, 2003; Copestake and Johnson, 2014). In this paper, these are referred to as zones and subzones, and are named by the index species name (e.g. *margaritatus* zone). Foraminifers provide further biostratigraphical constraints, and allow detailed correlation to records elsewhere (Copestake and Johnson, 2014).

The Pliensbachian is further marked by perturbations of global geochemical cycles and climate. A 2–4‰ negative shift in the carbon-isotope composition ($\delta^{13}C$) of skeletal (belemnite) calcite, bulk shallow-water carbonate, and organic matter is recognised at the Sinemurian–Pliensbachian boundary at Robin Hood's Bay (Yorkshire, UK), the Central Apennines and Trento Platform (Italy), in Portugal and Germany, and in the Mochras core (Jenkyns et al., 2002; Morettini et al., 2002; van de Schootbrugge et al., 2005; Woodfine et al., 2008; Korte and Hesselbo, 2011; Franceschi et al., 2014). This negative carbon-isotope excursion (CIE) likely represents a global carbon-cycle perturbation and associated climatic change, and allows detailed stratigraphical correlation, potentially at a resolution equivalent to, or even significantly higher than, ammonite zones. The Late Pliensbachian was marked by a major positive shift, of up to 5‰, in the $\delta^{13}C$ of wood ($\delta^{13}C_{WOOD}$), and up to 3‰ in the $\delta^{13}C$ of organic matter ($\delta^{13}C_{TOC}$; TOC: Total Organic Carbon) (Fig. 7; Suan et al., 2010; Korte and Hesselbo, 2011; Silva et al., 2011), reflecting enrichment of ^{13}C in the coupled ocean–atmosphere carbon pool, and thus a perturbation of the global carbon cycle. This