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Carbon cycle history through the Jurassic–Cretaceous boundary: A new global $\delta^{13}C$ stack

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ABSTRACT

We present new carbon and oxygen isotope curves from sections in the Bakony Mts. (Hungary), constrained by biostratigraphy and magnetostratigraphy in order to evaluate whether carbon isotopes can provide a tool to help establish and correlate the last system boundary remaining undefined in the Phanerozoic as well provide data to better understand the carbon cycle history and environmental drivers during the Jurassic–Cretaceous interval. We observe a gentle decrease in carbon isotope values through the Late Jurassic. A pronounced shift to more positive carbon isotope values does not occur until the Valanginian, corresponding to the Weissert event. In order to place the newly obtained stable isotope data into a global context, we compiled 31 published and stratigraphically constrained carbon isotope records from the Pacific, Tethyan, Atlantic, and Boreal realms, to produce a new global $\delta^{13}C$ stack for the Late Oxfordian through Early Hauterivian interval. Our new data from Hungary is consistent with the global $\delta^{13}C$ stack. The stack reveals a steady but slow decrease in carbon isotope values until the Early Valanginian. In comparison, the Late Jurassic–Early Cretaceous $\delta^{13}C$ curve in GTS 2012 shows no slope and little variation. Aside from the well-defined Valanginian positive excursion, chemostratigraphic correlation durSchning the Jurassic–Cretaceous boundary interval is difficult, due to relatively stable $\delta^{13}C$ values, compounded by a slope which is too slight. There is no clear isotopic marker event for the system boundary. The long-term gradual change towards more negative carbon isotope values through the Jurassic–Cretaceous transition has previously been explained by increasingly oligotrophic condition and lessened primary production. However, this contradicts the reported increase in $^{87}Sr/^{86}Sr$ ratios suggesting intensification of weathering (and a decreasing contribution of non-radiogenic hydrothermal Sr) and presumably a concomitant rise in nutrient input into the oceans. The concomitant rise of modern phytoplankton groups (dinoflagellates and coccolithophores) would have also led to increased primary productivity, making the negative carbon isotope trend even more notable. We suggest that gradual oceanographic changes, more effective connections and mixing between the Tethys, Atlantic and Pacific Oceans, would have promoted a shift towards enhanced burial of isotopically heavy carbonate carbon and effective recycling of isotopically light organic matter. These processes account for the observed long-term trend, interrupted only by the Weissert event in the Valanginian.

1. Introduction

The Jurassic–Cretaceous transition is a relatively poorly understood interval in the development of the Mesozoic greenhouse world (Föllmi, 2012; Price et al., 2013). This is, in part, due to the lack of an agreed upon, chronostratigraphic framework for the Jurassic–Cretaceous boundary (Zakharov et al., 1996; Wimbledon et al., 2011; Michalík and Reháková, 2011; Guzhikov et al., 2012; Shurygin and Dzyuba, 2015). It is a time of contentious biotic changes, for which opinions have ranged from proposal of a putative mass extinction (Raup and Sepkoski, 1984) or a regional event (Hallam, 1986) or non-event (Alroy, 2008; Rogov et al., 2010). Using large taxonomic occurrence databases, several recent studies (particularly of tetrapods) have re-examined the Jurassic–Cretaceous boundary, and note a sharp decline in diversity around the Jurassic–Cretaceous boundary (Barrett et al., 2009; Mannion et al., 2011; Upchurch et al., 2011; Tennant et al., 2016). Further, the boundary interval is characterised by elevated extinction and origination rates in calcareous nannoplankton (Bown, 2005) set against a background of several calpionellid diversification events (Remane, 1986; Michalík et al., 2009) and an evolutionary rise of the modern plankton groups, notably dinoflagellates and coccolithophores (Falkowski et al., 2004). The system boundary also presents persistent stratigraphic correlation problems, which explains why the Jurassic–Cretaceous boundary is the only

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Phanerozoic system boundary for which a GSSP (Global Stratotype Section and Point) remains to be defined (Wimbledon, 2008; Wimbledon et al., 2011). The problems in global correlation of the Jurassic–Cretaceous boundary arise from the lack of an agreed upon biostratigraphical marker, in part related to general regression leading to marked provincialism in different fossil groups. The Tethyan based ammonite definition for the base of the Cretaceous has been the base of the Jacobi Zone (e.g., Hoedemaeker et al., 1993), although the base of which falls within the middle of relatively long sub-Boreal Preplicomphalus Zone and the Boreal Nodiger Zone. Other definitions of the Jurassic–Cretaceous boundary (see Grabowski, 2011; Wimbledon et al., 2011) include the base of Grandis ammonite Subzone, in the lower part of calpionellid Zone B, almost coinciding with the base of magnetozone M18r (Colloque sur la Crétacé inferieur, 1963) or the boundary between Grandis and Subalpina ammonite subzones, correlated with the middle part of calpionellid Zone B and the lower part of magnetozone M17r (Hoedemaeker, 1991). Due to scarcity of ammonites in many Tethyan Tithonian and Berriasian successions, calpionellids have been used as the main biostratigraphic tool in some studies (e.g., Horváth and Knauer, 1986; Blau and Grün, 1997; Houša et al., 2004; Boughdiri et al., 2006; Michalík et al., 2009; Grabowski et al., 2010a). The base of Calpionella Zone (B Zone) and the sudden appearance of a monospecific association of small, globular *Calpionella alpina* (referred to by authors as the *alpina* "acme", Remane 1985; Remane et al., 1986) is sometimes used as an indicator of the Jurassic–Cretaceous boundary. The base of reversed-polarity chron M18r has also been suggested as a convenient global correlation horizon near the clustering of these possible biostratigraphic-based boundaries (Ogg and Lowrie, 1986). The recognition of this magnetozone across provincial realms (e.g., Ogg et al., 1991; Houša et al., 2007; Grabowski et al., 2010a) has enabled inter-regional correlations. In the GTS2012, Ogg and Hinnov (2012a) utilize the base of chron M18r for assigning the numerical age (145.0 Ma) to the top of the Jurassic. Notably, the base of chron M18r which falls within the middle of the Berriasella jacobi Zone. Hence, Wimbledon et al. (2011), tentatively suggest that several markers have the potential to help define any putative Jurassic–Cretaceous boundary.

Carbon isotope stratigraphy is useful both to help understand past global environmental and biotic change that affected carbon cycle, and as a correlation tool. For example, the GSSP for the base of the Eocene Series is defined by a negative excursion in the carbon isotope curve (Aubry et al., 2007). To serve both purposes, Late Jurassic–Early Cretaceous carbon isotope stratigraphies have been developed extensively from pelagic sediments of the Tethys Ocean and Atlantic (e.g., Weissert and Channell, 1989; Bartolini et al., 1999; Katz et al., 2005; Tremolada et al., 2006; Michalík et al., 2009; Coimbra et al., 2009; Coimbra and Olóriz, 2012). Weissert and Channell (1989) documented how the Late Jurassic carbonate carbon isotopic composition shifts from $\delta^{13}C$ values of around 2.5‰ in the Kimmeridgian to values near 1.0‰ in the Late Tithonian–Early Berriasian. A change to lower $\delta^{13}C$ values was identified to occur within Magnetozones M18–M17 and within the B/C Calpionellid Zone (Weissert and Channell, 1989). The low $\delta^{13}C$ values of the earliest Cretaceous contrast with the more positive values obtained from the Valanginian (Lini et al., 1992; Hennig et al., 1999; Weissert et al., 1998; Duchamp-Alphonse et al., 2007; Főzy et al., 2010). Such variation has led to the idea that carbon isotopes may be useful in adding to the characterisation of the Jurassic–Cretaceous boundary (e.g., Michalík et al., 2009; Dzyuba et al., 2013; Shurygin and Dzyuba, 2015) although others (e.g., Ogg and Hinnov, 2012a) note the lack of significant geochemical markers. Changes in the Late Jurassic–Early Cretaceous carbon isotope record are interpreted to reflect decelerated global carbon cycling and ocean productivity (Weissert and Mohr, 1996) and have been variously linked to changes in sea level, aridity and temperature (e.g., Weissert and Channell, 1989; Ruffell et al., 2002a; Tremolada et al., 2006; Föllmi, 2012). Other carbon isotope records through the Jurassic–Cretaceous boundary show somewhat different trends. For example, Michalík et al. (2009) documented a minor (<0.5‰) negative excursion in the latest Jurassic (Late Tithonian), whilst some Boreal records (e.g., Zák et al., 2011) show negligible variation associated with the boundary. Dzyuba et al. (2013) reported a positive $\delta^{13}C$ shift immediately above the Jurassic–Cretaceous boundary. The significance of Jurassic–Cretaceous carbon isotope stratigraphies is underlined by correlation needs for the yet-to-be-defined GSSP.

In this study we report new carbon isotope data for the Late Jurassic–Early Cretaceous from two sections, Lókút Hill and Hárskút in Hungary (Figs. 2, 3). Both sections are well constrained by ammonite (Figs. 4, 5), belemnite (Vigh, 1984; Horváth and Knauer, 1986; Főzy, 1990) and calpionellid (Horváth and Knauer, 1986; Grabowski et al., 2010a) biostratigraphy. Magnetostratigraphy is also available for Lókút Hill (Grabowski et al., 2010a). The aim of this study is to assess whether a consistent pattern in carbon isotope variation can be established, particularly with respect to the Jurassic–Cretaceous boundary. To this end, we also developed a new global stack of carbonate $\delta^{13}C$ curves for the Jurassic–Cretaceous transition (from the Late Oxfordian to Early Hauterivian), based on the two newly obtained curves and a global compilation of 30 published curves from this interval. We use this global stack to evaluate the possible controls on carbon isotope variation (similar to the approach taken by Wendler (2013) for the Late Cretaceous) and the correlation potential of carbon isotope stratigraphy. Comparisons to a range of other climate proxies (including the oxygen isotopic composition of fossil belemnites derived from a range of low and mid Tethyan palaeolatitude sites) and environmental events is also made to help elucidate controls on the global $\delta^{13}C$ stack.

2. Geological setting

The studied Hungarian sections are situated ca. 6 km apart from each other in the southwestern part of the central Bakony Mountains (Fig. 1) that belongs to the Transdanubian Range, which in turn forms part of the Bakony Unit in the Austroalpine part of the AlCaPa terrane (Csontos and Vörös, 2004). This complex structural unit stretches from the Eastern Alps to the Western Carpathians. Its Mesozoic sedimentary succession is thought to have deposited on the southern passive margin of the Penninic ocean branch of the western Neotethys (Csontos and Vörös, 2004) (Fig. 1). In the lowermost part of the studied sections, the cherty Lókút Radiolarite Formation crops out (Figs. 2, 3). The overlying unit consists of red and yellowish, well-bedded nodular limestone (Pálihálás Limestone Formation), which passes gradually into light grey, less nodular, ammonite-rich facies (Szentivánhegy Limestone Formation). The uppermost part of both sections (Figs. 2, 3) are made up of white, thin-bedded, Biancone-type limestone (Mogyorósdomb Limestone Formation). The boundaries between these formations are gradational. A brief description of these lithostratigraphical units is given in Császár (1997). The studied section at Lókút (referred to as the hilltop section) ranges in age from the late Oxfordian to Berriasian, whereas at Hárskút (section HK-II) upper Kimmeridgian to Berriasian strata are exposed.

The entire Jurassic succession of Lókút Hill (exposed in three disjunct sections, of which the hilltop section is the youngest) is the most complete and thickest Hettangian to Tithonian succession of Transdanubian Range, deposited in a deep, pelagic environment (Galácz and Vörös, 1972). In the "horst and graben" palaeogeographic model proposed by Vörös and Galácz (1998), this locality represents a site of typical basinal deposition. The Upper Jurassic–lowermost Cretaceous strata (Fig. 2) are exposed on the southwestern edge of the top of Lókút Hill in an artificial trench (47° 12′ 17″ N, 17° 52′ 56″ E). The beds gently dip (20°) to the north. Biostratigraphic data from the Tithonian part of the section were first provided by Vigh (1984), later amended and complemented by late Oxfordian and Kimmeridgian cephalopod data by Főzy et al. (2011). In addition, Grabowski et al. (2010a) developed a calpionellid biostratigraphy and magnetostratigraphy for the Tithonian–Berriasian part of the section. Bed numbers of Grabowski et al. (2010a) are still visible, allowing correlation with these data and our isotope results.