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Carnian (Late Triassic) C-isotope excursions, environmental changes, and biotic turnover: a global perturbation of the Earth's surface system

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ABSTRACT

Here we present the second part of the special thematic issue on the Carnian Pluvial Episode (CPE). In this issue, two works on terrestrial sedimentological and floral changes linked to the CPE, and new carbon-isotope records from Oman and China are presented. The papers published in this issue complement those contained in the previous issue; they altogether give an almost complete vision of the state-of-the-art about the CPE, including the many conundrums.

An overview of the papers contained in the Carnian Pluvial Episode thematic set, in this issue and the previous November issue (volume 175, issue 6; Dal Corso et al., 2018a) of the Journal of the Geological Society, should convince the reader that major environmental, geochemical and biological changes happened in the early Late Triassic on land and in the ocean. Terrigenous influx into the shallow water settings of the Tethys realm is undoubted, as is the widespread crisis of the microbial carbonate platforms, a diversification of the dinosaurids, widespread amber preservation, and carbon and oxygen isotope excursions (Dal Corso et al., 2018b). Conundra are still apparent however, with the supposedly coeval deposition of Carnian halites and coals in the Arctic (Torskvik & Cocks, 2016), and lack of significant coarse clastic deposition that would be redolent of a 'pluvial' episode through much of the southern hemisphere on Gondwanaland. The evidence for climate change for the CPE is still debated, and a standing hypothesis is that sea-level change, instead of increased rainfall, could explain the preservation of plants in continental Europe (Franz et al., this issue). The location of main volcanic centres (either on Honglu-Pindos [Greece], Phasoula [Mamonia complex, Cyprus], or Wrangellia [North America]) is also still discussed. Indeed, the two may be not unrelated, as pre-CAMP rifting and associated igneous activity would open marine corridors, allow in marine organisms to the Pangaeian interior as well as salt-bearing waters and moisture-laden winds. Damp climate may thus be associated with marine transgression and volcanic activity during the CPE at least for some parts of Pangaea. Critical for our understanding of the CPE is the temporal and spatial distribution of its effects on sedimentation and the biosphere. The temporal progression of the CPE is exemplified in this thematic set: bed by bed measurement of changes through the episode, matched to global chrono- and or biostratigraphy, are provided. A full understanding of the spatial variability of environmental change through the CPE is still lacking, but significant work has been made in China (Sun et al., 2016, this issue; Shi et al., this issue; Xin et al., this issue), Oman (Sun et al., this issue), and the southern USA (Lucas & Tanner, 2018) that reaffirms earlier work and

extends the documentation of the CPE, further confirming that this is not only western Tethys change in biota and depositional environments, but a global event.

Visscher et al. (1994) proposed that the deposition of coal and plant debris in the Germanic Basin, attributed to the Carnian Pluvial Episode by Simms and Ruffell (1989), was an artifact of preservation in locally damp environments. The rejection of the CPE by Visscher et al. (1994) was based on observations, mostly of the palynofacies, in the Schilfsandstein in the Germanic Basin. After more than 20 years, the paleoclimatic significance of the Schilfsandstein is still a matter of debate. Most of the uncertainty is related to the ambiguity of the palynological record as a paleoclimatic indicator, if taken alone. Thus, the detailed interdisciplinary study of the Schilfsandstein in the Central European Basin by Franz et al. (this issue), that opens this second thematic set, comes as a long awaited novelty. Franz et al. present an impressive dataset of well and outcrop data from this endorheic basin, which include paleobotanical and palynological data, the modal composition of arenites, clay mineralogy and chemistry, a description of paleosols and a tightly constrained sequence stratigraphic interpretation of the basin. This study stands out as probably the one most complete works on the effects of the CPE on continental environments – and yet it leaves the debate open. Franz et al. documented a clear deviation of the clay chemistry and type of paleosols in the Schilfsandstein with respect to previous and subsequent units of the Central European Basin that could be explained, however, without changes of rainfall. This work should be compared with Barrenechea et al. (2018), Lucas and Tanner (2018) and Baranyi et al. (this issue), who studied similar continental successions and found evidence for climate change, albeit less intense than suggested by Simms and Ruffell (1989) and recorded in most marginal marine successions of Tethys. The debate is still open.

Baranyi et al. (this issue) continue the reliable tradition of studying Carnian palynofloras with an examination of the Mercia Mudstone Group (syn: Keuper facies) in southern England. New organic-carbon isotope data from outcrop material from Strangman's Cove (Devon) are also presented and integrate previous data from core material of the Mercia Mudstone Group (Miller et al., 2017). Their carbon-isotope record from Strangman's cove shows multiple bulk organic carbon-isotope excursions that match those found in the WP-1 core record (Mercia Mudstone Group, Devon, UK), previously published by Miller et al. (2017). Through quantitative analysis of the rich palynological data presented, they conclude that a simple increase in humidity is not tenable, due to the presence of xerophytic pollen assemblages, preferring instead to invoke preservation of this arid signal by locally damp conditions. Strong seasonality in precipitation and prevailing arid conditions in the hinterland of Pangaea would have prevented the expansion of a permanent hygrophytic flora. The authors suggest that in the lacustrine settings represented by the studied successions, the regional mainly xerophytic pollen from hinterland conifers would have been accumulated; this input of hinterland elements could have been enhanced by the increase in continental runoff that is generally observed during the CPE.

The last three papers of the thematic set are focused on the perturbations of the carbon-cycle that punctuated the CPE and present both carbonate and organic carbon-isotope data from Oman and China. This is particularly important, because the negative $\delta^{13}\text{C}$ shifts during the CPE interval have been so far detected mainly

through the analysis of bulk organic matter and biomarkers (leaf wax n-alkanes, and algae isoprenoid lipids and n-alkanes; e.g. Dal Corso et al., 2012, 2018b; Miller et al., 2017; Baranyi et al., this issue). In the reference sections of the Dolomites, the bulk carbonate carbon-isotopes record does not parallel the organic carbon-isotope record and does not record negative $\delta^{13}\text{C}$ shifts (Dal Corso et al., 2015). On the contrary, in the Nanpanjiang Basin, Guizhou (South China Block), bulk carbonate carbon-isotope data show three distinct negative shifts that can be correlated to the shifts detected in western Tethys sections, while the organic carbon-isotope record show only one long negative excursion in the Julian 2 – Tuvanian 2 interval (Sun et al., 2016; Dal Corso et al., 2018b).

The new isotopic records presented in this thematic set strengthen the evidence that the onset of the CPE was marked by a major change in the carbon-isotope composition of the reservoirs of the exogenic C-cycle.

Sun et al. (this issue) present new carbonate carbon-isotope data from Northern Oman and Southwest China. Both these records show a positive trend in the early Julian 1, which is a feature of many published carbonate and organic carbon-isotope curves for the same interval (e.g. Korte et al., 2005; Dal Corso et al., 2011, 2012, 2015, 2018b). This Middle – early Late Triassic isotopic trend seems a global signal and has been originally interpreted by Korte et al. (2005) as the result of the enhancement of organic carbon burial in coal swamps after the early Triassic “coal gap”, but an increase in primary productivity in the ocean is also proposed (Sun et al., this issue). The trend is interrupted by sharp negative $\delta^{13}\text{C}$ excursions in the Julian 2 substage in both the records studied by Sun et al. (this issue). $\delta^{13}\text{C}$ data from SW China (Yongyue section) show a negative excursion at the base of the Julian 2. In Wadi Mayhah (Oman), the $\delta^{13}\text{C}$ of bulk marine carbonates show two negative shifts: the first at the base of the Julian 2 followed by a second within the Julian 2. This is an extremely interesting finding. Indeed, a second negative carbon-isotope excursion within the Julian 2 has been recently found also in organic carbon from marine sections of northwestern Tethys realm (Italy and Hungary), and in succession from continental Pangea (Miller et al., 2017; Dal Corso et al., 2018b; Baranyi et al., this issue), as well as in carbonate carbon from a marine succession in Southwest China (Sun et al., 2016). During the Carnian Oman was located ca. 30°S, and these new data from the southern hemisphere add a precious tessera in our understanding of Carnian carbon-cycle changes. The $\delta^{13}\text{C}$ negative excursions in China and Oman presented in this study coincide with changes in sedimentation from limestone to shale, probably a consequence of the intensification of the hydrological cycle. Sun and colleagues conclude that a large quantity of isotopically light carbon was transferred into the ocean–atmosphere system during the CPE, confirming previous studies. The source of such ^{13}C -depleted carbon is still unknown but the coincidence with the emplacement of Wrangellia large igneous province and other volcanic centres suggests a causal relationship between the phenomena.

Shi et al. (this issue) report on the succession at Ma'antang in the north-west of the Sichuan Basin (China), where a negative carbon isotope excursion is recorded in the early part of the Carnian. The carbon isotope perturbation related to the CPE was only found in the organic carbon and, similarly to the Nanpanjiang Basin (Sun et al., 2016), only recorded one prolonged negative excursion instead of the multiple negative spikes of western Tethys (e.g., Dal Corso et al., 2018) and continental

Europe (Miller et al., 2017). The $\delta^{13}\text{C}$ shift occurs at the first terrigenous bed above a karstic surface. Further siliciclastic deposits are recorded above, but it is unclear whether these may represent the multiple phases of the CPE seen in Western Tethys. The work is the only record of the CPE carbon isotope trend in the Sichuan Basin, and is important in extending our palaeogeographic knowledge of Carnian depositional changes. It significantly extends the geographical documentation of the CPE to a region of China which is far from any previous occurrence of the CPE described so far. Moreover, the amalgamation of the multiple $\delta^{13}\text{C}$ perturbations of the CPE, which was observed so far in the Nanpanjiang Basin, seems to be a generalized phenomenon in South China, which still awaits explanation. In addition, Shi et al.'s record will no doubt generate further study of the succession in the area and at the locations recorded.

Jin et al. (this issue) take a novel look at the CPE, with an examination from three successions of what occurred following this period of dramatic change in the Sichuan Basin (South China). Hitherto, the change from oolitic limestones/sponge reef mounds to dark-coloured clays has not been well-dated in the successions they consider. Their carbon isotope data, placed accurately with new biostratigraphic observations demonstrate a late Carnian to earliest Norian age. They go further, with a comparison of the new dates to established magnetostratigraphy and thence the Astronomical time-scale. The studied successions in the Sichuan Basin only include the very last part of the broad CPE isotopic excursion. They could document that a long-lasting negative $\delta^{13}\text{C}$ perturbation is a character of the CPE throughout the basin. There were preliminary studies that proposed a higher position and a wider distribution of the CPE in the Sichuan Basin (Shi et al., 2009, 2017; Wang et al., 2015), corresponding to a sharp shift from carbonate to siliciclastic sedimentation. Jin et al. (this issue) now provides a more comprehensive stratigraphic study of the Carnian in Sichuan that shows how the shift to siliciclastics is diachronous, and excludes it could be related to the CPE. The Carnian-Norian transition is represented by a 12m section that shows the continuation of an upward trend in heavier carbon isotopes seen through the underlying Carnian.

Taken together, the two works of Shi et al. and Jin et al. presented in this issue contain important information on the Carnian of the Sichuan Basin. Until a few years ago, little was known of the effects of the CPE in China. As of now, the recent works of Sun et al. (2016; this issue), Zhang et al. (2018), Jin et al. (this issue) and Shi et al. (2017; this issue), the CPE in the South China Block became a hot research topic and shed a light on an area with its own special character and unique response to climate change, as compared with the better studied regions of continental Europe and western Tethys.

As discussed during the meeting on the Carnian that led to the publication of this special thematic set, the causes and consequences of the CPE are far from understood and need to be further explored. Also the geographic distribution of the CPE still needs to be better documented (Dal Corso et al., 2018a,b). However, the published data show the CPE was a global environmental and biological change that impacted both the marine and terrestrial realms, synchronous in time with sea-level changes and the emplacement of a LIP, and punctuated by multiple negative carbon-isotope excursions. The CPE can be therefore compared to other major volcanic-triggered Earth's surface system changes.

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