Thematic set:
The Mid-Carnian Episode

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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 volume 175 issue 6; they altogether give an almost complete vision of the state-of-the-art about the CPE, including the many conundrums.

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An overview of the papers contained in the Mid-Carnian Episode thematic set, in this issue and the previous November issue (volume 175, issue 6; Dal Corso *et al.* 2018*a*) of the *Journal of the Geological Society*, *London,* 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.* 2018*b*). 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.* 2018). 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 related, as pre-CAMP rifting and associated igneous activity would open marine corridors, allowing marine organisms in to the Pangaean 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, 2018, Shi *et al.* 2018; Jin *et al.* 2018), Oman (Sun *et al.* 2018), 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 (CPE) by Simms & 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 Shilfsandstein in the Germanic Basin. After more than 20 years, the palaeoclimatic 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 palaeoclimatic indicator, if taken alone. Thus, the detailed interdisciplinary study of the Schilfsandstein in the Central European Basin by Franz *et al.* (2018), which opens the second half of this 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 palaeobotanical and palynological data, the modal composition of arenites, clay mineralogy and chemistry, a description of palaeosols and a tightly constrained sequence stratigraphic interpretation of the basin. This study stands out as probably the most complete work 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 palaeosols in the Shilfsandstein 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 & Tanner (2018) and Baranyi *et al.* (2018), who studied similar continental successions and found evidence for climate change, albeit less intense than suggested by Simms & Ruffell (1989) and recorded in most marginal marine successions of Tethys. The debate is still open.

Baranyi *et al.* (2018) 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 $\delta^{13}C$ 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, 2018*b*; Miller *et al.* 2017; Baranyi *et al.* 2018). In the reference sections of the Dolomites, the bulk carbonate carbon isotope record does not parallel the organic carbon isotope record and does not record negative $\delta^{13}C$ 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–Tuvalian 2 interval (Sun *et al.* 2016; Dal Corso *et al.* 2018*b*).

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.* (2018) 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, 2018*b*). 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.* 2018). The trend is interrupted by sharp negative $\delta^{13}C$ excursions in the Julian 2 substage in both the records studied by Sun *et al.* (2018). $\delta^{13}C$ data from SW China (Yongyue section) show a negative excursion at the base of the Julian 2. In Wadi Mayhah (Oman), the $\delta^{13}C$ 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 successions from continental Pangea (Miller *et al.* 2017; Baranyi *et al.* 2018; Dal Corso *et al.* 2018*b*), as well as in carbonate carbon from a marine succession in Southwest China (Sun *et al.* 2016). During the Carnian Oman was located *c.* 30°S, and these new data from the southern hemisphere add a precious tessera in our understanding of Carnian carbon cycle changes. The $\delta^{13}C$ 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.* (2018) report on the succession at Ma'antang in the northwest 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*b*) and continental Europe (Miller *et al.* 2017). The $\delta^{13}C$ 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 $\delta^{13}C$ 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.* (2018) 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 $\delta^{13}C$ perturbation is a character of the CPE throughout the basin: 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.* (2018) now provide a more comprehensive stratigraphic study of the Carnian in Sichuan that shows how the shift to siliciclastics is diachronous, and excludes it being related to the CPE. The Carnian-Norian transition is represented by a 12 m 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, 2018), Zhang *et al.* (2018), Jin *et al.* (2018) and Shi *et al.* (2017, 2018), 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.* 2018*a*, *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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