Thematic set:
The Mid-Carnian Episode

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The Carnian pluvial episode (Late Triassic): new insights into this important time of global environmental and biological change

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Abstract: In May 2017, in the delightful town of Delmenhorst (Lower Saxony, Germany), the first meeting on the Carnian Pluvial Episode (CPE) was hosted by the Hanse-Wissenschaftskolleg, Institute for Advanced Study. This was a milestone event. For the first time researchers from around the world met to discuss this still poorly known episode of early Late Triassic global environmental and biological change. This thematic set originates from discussions at this first meeting, and includes state-of-the-art research on the CPE, with the most recent discoveries on the complex phenomena that happened during this fascinating interval in Earth's history.

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The Carnian Pluvial Episode (CPE) is a global climate change that occurred in the early Late Triassic, a time of major biological turnovers between two of the largest mass extinctions, at the end of the Permian and at the end of the Triassic, respectively. It is marked by severe extinction among important marine groups such as ammonoids and conodonts, and rapid radiation of key taxa on land and in the ocean, e.g. dinosaurs and pelagic calcifiers (Bernardi *et al*. 2018; Ruffell *et al*. 2018). Abrupt sedimentological changes are observed in a number of geological successions worldwide, recording a multiphase climate change that impacted continental to deep-water settings (Dal Corso *et al*. 2018*a*). This appears to have been primarily a shift towards a more humid climate from the generally arid climate that globally is recorded before the CPE, and was marked by global warming as recorded by the $\delta^{18}O$ of conodont apatite. The CPE was coincident with repeated major carbon-cycle perturbations, evidenced by multiple sharp negative $\delta^{13}C$ shifts, which could have been triggered by intense contemporaneous volcanism, such as the emplacement of a Large Igneous Province (LIP; Dal Corso *et al*. 2012, 2018*a*; Sun *et al*. 2016).

A possible scenario emerges for the Carnian that is similar to other LIP-related climate changes: large quantities of volcanic greenhouse gases entering the reservoirs of the exogenic C-cycle, global warming, negative carbon-isotope excursions, intensification of the hydrological cycle, and biological turnover (e.g. Wignall 2001). Although being a good starting point that can broadly summarize the basic phenomena observed so far, this conceptual model remains, however, too simplistic to explain the complexities of the CPE. On the one hand, such a conceptual model does not go into the details of this specific event to account for features such as the multiphase nature of the CPE. On the other hand, due to a lack of sedimentological, palaeontological, stratigraphic and geochemical data from various geological settings and on a global scale (Dal Corso *et al*. 2018*b*), it is still unclear exactly what a model of the causes of the CPE should try to explain. Even the precise duration of the CPE is poorly known.

If the causes of the CPE are still unknown with sufficient detail, its consequences on biota and depositional environments are even less known. Several questions remain open. Was there really greater precipitation globally, and at all latitudes? Did the CPE have a similar impact on all depositional environments and at different latitudes? How do the phases of the CPE differ? What is the exact timing between the climate change and the biological turnover? What was the magnitude of the extinction and radiation, on land and in the sea?

The papers of this thematic set of the *Journal of the Geological Society, London* add crucial information to our growing comprehension of the CPE. The following six papers included in this issue represent the first part of the thematic set; the second part will be published in the next issue.

Mike Simms and Alastair Ruffell (Simms & Ruffell 2018) tell us how they first recognized the importance of the CPE as a global, major geological event (Simms & Ruffell 1989) and how the CPE struggled to conquer the hearts of the scientific community until recently. This opens philosophical questions on how scientific research develops and can take different paths. Indeed, in the 1960s, 1970s and 1980s many scientists were aware of the importance of the CPE as a major environmental change and biological turnover, a crucial event from an evolutionary perspective (Angermeier *et al*. 1963; Kozur 1972, 1975; Schlager & Schollnberger 1974; Tollmann 1976; Schröder 1977; Visscher & Van der Zwan 1981; Tucker & Benton 1982; Simms & Ruffell 1989). This first research was published in very important journals but since then the CPE has been utterly overshadowed by the much more famous end-Permian and end-Triassic mass extinction events. Through the research conducted by very few research groups, it took almost thirty years for the CPE to be reborn.

The following four papers present interesting new data and ideas about the impact of the CPE on terrestrial ecosystems. José Barrenechea and colleagues (2018) show new data from the Manuel Fm (Stable Meseta, Spain), where the CPE has been previously recognized (Arche & López-Gómez 2014). The authors provide important sedimentological, stratigraphic and mineralogical information to better define the nature of the CPE in this area. The detailed analysis of the most genuinely continental strata of Manuel Fm shows remarkable changes in the palaeosols that highlight an interval of wetter conditions, which is evidenced by waterlogging of the floodplain, with Fe-illuvial, gleying and kaolinite enrichment. In the same interval, river channels become larger, and the sedimentary structures are thicker and contain plant remains, again showing more humid conditions. The authors conclude that although the data do not show massive rainfall phenomena in the study area, they definitely show a time interval of higher humidity when compared to the generally drier conditions that were predominant before and after it.

Spencer Lucas & Lawrence Tanner (2018) discuss the much-debated age of the non-marine Chinle Group, or Chinle Formation, depending on the different definitions given by different research groups, and provide evidence that the CPE is recorded in this succession. Despite recent radiometric ages of detrital zircons showing that most of the Chinle Group is younger than the Carnian (e.g. Ramezani *et al*. 2011), Lucas & Tanner (2018) review the set of palaeontological and sedimentological data available and conclude that the lowermost strata of the succession, namely the Shinarump Formation, records the CPE. The age of this interval is constrained by sporomorph, choncostracan and vertebrate biostratigraphy. The sedimentary record comprises major riverine and floodplain deposits containing kaolinitic gleyed to spodic palaeosols and local coal beds, which testify to more humid conditions and are similar to those observed in other non-marine settings in Spain and Germany (Barrenechea *et al*. 2018; Franz *et al*. 2018 second part of the thematic set).

Some 20 years ago, Gianolla *et al*. (1998) noted that amber occurs with exceptional abundance in Carnian deposits worldwide, and possibly in conjunction with an episode of climate change. The authors were referring then to the CPE, and in this thematic set, Seyfullah *et al*. (2018*a*) review the significance of amber occurrences associated with the CPE, based on a much larger literature foundation. The Carnian, along with the Cretaceous, Eocene, Oligocene and Miocene, is one of a few time slices in the Phanerozoic when resin production was prolific, and thus significant amber deposits are found. This is a relevant observation, as plants usually exude resin when they are subject to environmental stress (Seyfullah *et al*. 2018*b*). Seyfullah *et al*. (2018*a*) discuss the age of Carnian amber finds, the plants that most probably exuded resins that gave origin to amber, the organisms that are found entrapped in it and the possible reasons why Carnian amber is so abundant. The occurrence of a Carnian taphonomical window for amber is excluded and a link between resin production and the CPE is established. Plants were exuding more resin during the CPE either in response to wetter soil conditions, acid rain or wildfires triggered by an increased storminess.

Benton *et al*. (2018) build on Bernardi *et al*.'s (2018) depiction of the role of environmental change in the radiation of dinosaurs, and provide further statistical evidence that the rise of dinosaurs is coeval and causally related to the CPE. Recently, Bernardi *et al*. (2018) showed that although the origin of dinosaurs should be tracked back to the early or middle Triassic, this group of reptiles radiated dramatically in the Late Triassic. They baptized this radiation the 'dinosaur diversification event', or DDE. In this thematic set, Benton *et al*. (2018) use a broken-line regression model to identify break points in the fossil record of archosauria and tetrapod footprints with dinosaurian affinity. With the best available data, break points occur at the same age of the CPE, and mark abrupt changes in the abundance of major tetrapod groups. This reinforces the idea of a strict relationship between the CPE, the rise of dinosaurs and possibly the radiation of other terrestrial vertebrate groups, including mammals.

We move to marine environments with the paper by Zhang *et al*. (2018*a*), exploring another key biological event of the CPE, the extinction of conodonts. Conodonts are the teeth of an extinct marine vertebrate, and a major biostratigraphic tool in Paleozoic and early Mesozoic marine successions. Conodonts are known to experience a sharp turnover at the CPE (e.g. Simms & Ruffell 1989; Rigo *et al*. 2007). The geological record of Late Triassic conodonts has expanded sharply in the last years, as new Carnian successions from China were studied in detail and brought to the attention of the international scientific audience (e.g. Sun *et al*. 2016; Zhang *et al*. 2018*b*). For this thematic set, Zhang *et al*. (2018*a*) exploited a rich collection of conodonts from Chinese sections to explore a neglected facet of the evolution of conodonts during the Carnian, i.e. their body size. Conodonts are teeth and not the fossils of a complete animal; nevertheless, there is sufficient evidence in the literature for a correlation between conodont size and environmental stress, and conodont size has been considered representative for the conodont animal body size. In their study, Zhang *et al*. (2018*a*) found evidence for a significant decrease in diversity, overall biomass and body size of conodonts at the CPE. The loss of diversity observed in South China is completely independent from the extinction detected by earlier works, which were based largely on collections from western Tethyan localities. A remarkable reduction in conodont size is detected during the CPE, which is attributed to a rise in seawater temperature and, possibly, anoxia. Conodonts once again appear as one of the marine groups that suffered most the environmental changes related to the CPE.

A second part of this thematic set on the CPE will be published in the next issue of the *Journal of the Geological Society, London*, with more papers discussing the environmental changes on land and in shallow-marine environments, new palynological and palaeobotanical data across the climate change, and new carbon-isotope data.

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