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Editorial: How Large Igneous Provinces (LIPs) during the Triassic shaped modern-day ecosystems

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Editorial on the Research Topic
How Large Igneous Provinces (LIPs) during the Triassic shaped modern-day ecosystems

The Triassic (250–200 Ma) was an extremely intriguing period in Earth's history, marked by profound changes in ocean and land biota, which laid the foundations of modern-style ecosystems. Notably, the roots of *Homo sapiens* go back deep into the Triassic, when the first mammals appeared. The biological changes are marked by three major events. At the beginning and at the end of the Triassic, two of the five major known mass extinctions, also known as the "Big Five," occurred (Raup and Sepkoski, 1982). The Permian–Triassic boundary mass extinction (PTME) was by far the largest extinction of the Phanerozoic, "*when life nearly died*" (Benton, 2003), with the disappearance of 81%–94% of marine species and a massive turnover in terrestrial ecosystems (Erwin, 1993; Jin et al., 2000; Song et al., 2013; Stanley, 2016; Dal Corso et al., 2022). About 50 Myr later, the end-Triassic mass extinction (ETME) wiped out 60%–70% of marine species and severely perturbed terrestrial ecosystems (Raup and Sepkoski, 1982; Kiessling et al., 2007). Between these two major biological crises, other smaller extinctions took place. Amongst these, the "Carnian crisis" (234–232 Ma) is gaining increasing attention from the scientific community: a smaller extinction event, but apparently linked to a major diversification of important groups of animals and plants. This was the geological interval when dinosaurs rose to dominance and within which the first mammals' remains were found (Simms and Ruffell, 1989; Bernardi et al., 2018; Dal Corso et al., 2020). The rise of new groups had profound impacts on global biogeochemical cycles, such as calcifying nannoplankton, which since then have been major players in regulating global ocean chemistry (Ridgwell, 2005). The recent discovery of an Early Triassic lagerstätte (Guiyang biota, 1.08 Ma after the PTME; Dai et al., 2023) suggests that the PTME facilitated the replacement of the Paleozoic evolutionary fauna by the Modern evolutionary fauna in the oceans.

Three major Triassic global environmental crises, at the Permian–Triassic boundary, during the Carnian Pluvial Episode (CPE), and at the Triassic–Jurassic boundary, are coeval with the biological turnovers. The environmental perturbations included, e.g., global warming, ozone depletion, changes in the hydrological cycle, marine anoxia, ocean acidification, and acid rain (e.g., (Wignall, 2001)). The magnitudes of these changes differ from case to case and this could be the reason for different extinction rates between the events (e.g., (Song et al., 2021)). Nevertheless, they share similar triggers, as they are all temporally linked to the emplacement of large igneous provinces (LIPs), i.e., the Siberian Traps (STLIP) across the Permian–Triassic boundary (Burgess and Bowring, 2015; Burgess et al., 2017), the Wrangellia during the Carnian (Greene et al., 2010), and the Central Atlantic magmatic province (CAMP) during the end of the Triassic (Blackburn et al., 2013; Davies et al., 2017; Lindström et al., 2021). LIPs are volcanic provinces with areal extents of more than 0.1 million km^2 and volumes of more than 0.1 million km^3 that were emplaced in less than <1–5 Ma (e.g., (Ernst et al., 2021)). While ascending toward the surface intruding crustal rocks (intrusive activity) and erupting enormous volumes of magma (effusive and explosive activity), LIPs release large quantities of volcanic gases—namely CO_2, CH_4, SO_2, metals, and halogens—which can induce massive perturbations for the global climate and ecosystems. Vast input of volcanic CO_2 into the atmosphere could indeed result in global warming, ocean acidification, and extreme droughts and rainfall events. These environmental perturbations sound familiar today, when we are witnessing increasing atmospheric pCO_2 levels, global temperatures, ozone depletion, etc. Gaining a deep understanding of such events of the past is therefore crucial to understand future climate scenarios. Hence, this Research Topic of *Frontiers in Earth Science* and *Frontiers in Ecology and Evolution* aimed at gathering an article Research Topic of studies and reviews on the biological turnovers, environmental changes, and LIP eruptions that marked the latest Permian–earliest Jurassic interval.

The two columns of this Research Topic, i.e., Triassic biological turnovers and LIP volcanism, are presented by Benton and Wu and Boscaini et al. Benton and Wu describe the profound ecosystem revolution occurring in the Triassic as a recovery from the PTME, which started in the Early Triassic, but really peaked at the CPE. Also, the Mesozoic marine revolution may have started at the CPE, i.e., earlier than previously reported, contributing to the appreciation of the Carnian as a fundamental tipping point for life on Earth. Boscaini et al. reconstruct CO_2 emissions from the Siberian Traps, Wrangellia, and CAMP LIPs by using Nb concentration in magmas and melt inclusions as a proxy. The CO_2 load of these LIPs can vary significantly across magma units, and thermogenic gases mobilized by magma–sediment interaction contributed importantly to the total mass of volatiles released.

A relevant feature of this Research Topic is the attention dedicated to terrestrial ecosystem changes, which are often overlooked in mass extinction literature. Volcanically induced changes in rain patterns and conditions played a key role in shaping land plant biota. The effect of increasing humidity is portrayed in the contribution by Roghi et al. focused on conifer taxa preserved in amber from the Heiligkreuz Formation in the Dolomites (Italy). Here, and in other sections of the western Tethys realm, the CPE is recognized as the volcanic-driven stressor of conifers and lycophytes in a complex coastal and tidal setting. Mancuso et al. present a study of the terrestrial Carnian of the Ischigualasto-Villa Unión Basin in northwestern Argentina. Clay mineralogy and paleosol geochemistry are coupled with information on changes among terrestrial tetrapods and plants. The authors found that environmental change from warmer, drier conditions to more temperate humid conditions can explain pseudosuchian archosaur diversity and rhynchosaur relative abundance. Zeh et al. report new detrital zircon laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) U–Pb ages from the Carnian Stuttgart Formation (Schilfsandstein), revealing tephra fallout from the Olenekian to Carnian in the Central European Basin. The products of this volcanism were re-worked into the Stuttgart Formation and give a maximum LA-ICP-MS U-Pb depositional age for the Stuttgart Formation of 231.1 ± 1. 6 Ma, which is a very important unit representing the terrestrial CPE. Zhang et al. show how an increase in dry conditions and widespread wildfires can cause generic losses of up to 45% in land plants. They present a multi-proxy study of lacustrine deposits of the Jiyuan Basin (North China), which straddle the ETME interval. The turnovers can be attributed to CAMP volcanism, and associated mercury records evidence a distribution of volcanic activity in two major pulses. The palynological record from the Late Triassic–Early Jurassic sequence in the Danish Basin presented by Lindström shows two pulses of mass rarity in the coastal and near-coastal lowland mire vegetation during the ETME. These two pulses occur in correspondence to major environmental changes, including higher temperatures, sea-level fluctuations, wildfire activity, and soil erosion, which can be ascribed to the eruption of the coeval CAMP LIP.

Alongside changes in plant communities, Triassic climate changes affected animal evolution. Zhang et al. describe a new insect species (*Chauliodites tongchuanensis)* from the Middle Triassic Tongchuan Formation of Shaanxi, northwestern China. This finding combined with the occurrence of *Chauliodites* in the Lower and Middle Triassic of South China suggests that the bloom of *Chauliodites* is associated with low-productivity terrestrial ecosystems following the Permian–Triassic mass extinction. Langer and Cordoy studied the diversification and body size evolution of terrestrial pan-avians along the Triassic and Early Jurassic. Occurrence data show increased diversity, high diversification rates, and body size disparity of terrestrial pan-avians in the Carnian, supporting the hypothesis that the CPE played an important role in the early radiation of the group. Pan-avian macroevolution shows no marked shift across the Triassic–Jurassic boundary.

Hohn et al. and Todaro et al. present a marine perspective on Triassic biological and environmental changes. One of the major evolutionary innovations of the Triassic was the appearance of calcifying nannoplankton, which had a massive impact on ocean chemistry. Hohn et al. show that the rise of intracellular calcification was linked to cellular calcium metabolism and control of the accumulation of calcium in the cytoplasm. Gene-tree analysis indicates that ancestral non-calcifiers already possessed the physiological machinery to calcify, and modeling suggests that there is no difference in energy demands between calcifying and non-calcifying cells. Hence, calcifying nannoplankton could have appeared at any time, but only the peculiar environmental conditions of the Triassic, which still require further research to be fully understood, drove their rise. Todaro et al. use isotopic data of C, O, S, Zn, Pb, and Sr near the Triassic–Jurassic boundary at Mt Sparagio in north-western Sicily to link the marine ETME to the CAMP LIP. A warming event in the upper part of the Rhaetian beds coincided with the reduction in diversity and body size of the megalodontoids. The negative carbon isotope excursions suggest that ocean acidification affected the benthic community.

The theorized volcanic forcing on marine and terrestrial environments, and hence on biota, needs confirmation from studies of geochemical perturbations in the sedimentary record, and quantitative studies of volatile release from LIPs. Müller et al. test the effects of end-Permian global warming on the primary productivity, by investigating phosphorous speciation, sedimentary total organic carbon, and nickel concentrations in low-latitude Tethyan carbonate sections. They found that primary productivity collapsed 30 kyr before the main marine extinction pulse. Huang et al. present high-resolution carbon isotopic data in the microbialite formation across the Permian–Triassic boundary at Dajiang, South China. The results show a general decrease in $\delta^{13}C$ followed by an increase, suggesting that multiple sources of dissolved carbon are required to explain the carbon isotopic pattern in the microbialite profile. Cho et al. analyze a pelagic sequence of bedded chert encompassing the CPE from the Inuyama area (Japan). The new geochemical data show an increase in terrigenous supply to the deep-sea depositional environment around the Julian–Tuvalian boundary (i.e., the boundary between early and late Carnian). This terrigenous material was delivered to the site as aeolian dust and could indicate extensive aridification in the interior Pangea during the CPE interval, showing that the changes in the hydrological cycle during the event were likely highly heterogeneous.

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SC: Writing–original draft, Writing–review and editing. JC: Writing–original draft, Writing–review and editing. HS: Writing–original draft, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Benton, M. J. (2003). *When life nearly died: the greatest mass extinction of all time*. London, UK: Thames and Hudson.

Bernardi, M., Gianolla, P., Petti, F. M., Mietto, P., and Benton, M. J. (2018). Dinosaur diversification linked with the carnian pluvial episode. *Nat. Commun.* 9, 1499. doi:10.1038/s41467-018-03996-1

Blackburn, T. J., Olsen, P. E., Bowring, S. A., McLean, N. M., Kent, D. V., Puffer, J., et al. (2013). Zircon U-Pb geochronology links the end-triassic extinction with the central Atlantic magmatic province. *Science* 340, 941–945. doi:10.1126/science.1234204

Burgess, S. D., and Bowring, S. A. (2015). High-precision geochronology confirms voluminous magmatism before, during, and after Earth's most severe extinction. *Sci. Adv.* 1, e1500470. doi:10.1126/sciadv.1500470

Burgess, S. D., Muirhead, J. D., and Bowring, S. A. (2017). Initial pulse of Siberian Traps sills as the trigger of the end-Permian mass extinction. *Nat. Commun.* 8, 164. doi:10.1038/s41467-017-00083-9

Dai, X., Davies, J. H. F. L., Yuan, Z., Brayard, A., Ovtcharova, M., Xu, G., et al. (2023). A Mesozoic fossil lagerstätte from 250.8 million years ago shows a modern-type marine ecosystem. *Science* 379 (6632), 567–572. doi:10.1126/science.adf1622

Dal Corso, J., Bernardi, M., Sun, Y., Song, H., Seyfullah, L. J., Preto, N., et al. (2020). Extinction and dawn of the modern world in the carnian (late triassic). *Sci. Adv.* 6, eaba0099. doi:10.1126/sciadv.aba0099

Dal Corso, J., Song, H., Callegaro, S., Chu, D., Sun, Y., Hilton, J., et al. (2022). Environmental crises at the Permian–Triassic mass extinction. *Nat. Rev. Earth Environ.* 3, 197–214. doi:10.1038/s43017-021-00259-4

Davies, J. H. F. L., Marzoli, A., Bertrand, H., Youbi, N., Ernesto, M., and Schaltegger, U. (2017). End-Triassic mass extinction started by intrusive CAMP activity. *Nat. Commun.* 8, 15596. doi:10.1038/ncomms15596

Ernst, R. E., Dickson, A. J., and Bekker, A. (2021). *Large igneous provinces: a driver of global environmental and biotic changes*. Cambridge, MA, USA: MIT Press.

Erwin, D. H. (1993). *The great paleozoic crisis: life and death in the permian*. New York, NY, USA: Columbia University Press.

Greene, A. R., Scoates, J. S., Weis, D., Katvala, E. C., Israel, S., and Nixon, G. T. (2010). The architecture of oceanic plateaus revealed by the volcanic stratigraphy of the accreted Wrangellia oceanic plateau. *Geosphere* 6, 47–73. doi:10.1130/GES00212.1

Jin, Y. G., Wang, Y., Wang, W., Shang, Q. H., Cao, C. Q., and Erwin, D. H. (2000). Pattern of marine mass extinction near the Permian-Triassic boundary in South China. *Science* 289, 432–436. doi:10.1126/science.289.5478.432

Kiessling, W., Aberhan, M., Brenneis, B., and Wagner, P. J. (2007). Extinction trajectories of benthic organisms across the Triassic-Jurassic boundary. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 244, 201–222. doi:10.1016/j.palaeo.2006.06.029

Lindström, S., Callegaro, S., Davies, J., Tegner, C., van de Schootbrugge, B., Pedersen, G. K., et al. (2021). Tracing volcanic emissions from the central atlantic magmatic province in the sedimentary record. *Earth Sci. Rev.* 212, 103444. doi:10.1016/j.earscirev.2020.103444

Raup, D. M., and Sepkoski, J. J. (1982). Mass extinctions in the marine fossil record. *Science* 215, 1501–1503. doi:10.1126/science.215.4539.1501

Ridgwell, A. (2005). A Mid Mesozoic Revolution in the regulation of ocean chemistry. *Mar. Geol.* 217, 339–357. doi:10.1016/j.margeo.2004.10.036

Simms, M. J., and Ruffell, A. H. (1989). Synchroneity of climatic change and extinctions in the Late Triassic. *Geology* 17, 265–268. doi:10.1130/0091-7613(1989)017<0265:SOCCAE>2.3.CO;2

Song, H., Kemp, D. B., Tian, L., Chu, D., Song, H., and Dai, X. (2021). Thresholds of temperature change for mass extinctions. *Nat. Commun.* 12, 4694. doi:10.1038/s41467-021-25019-2

Song, H., Wignall, P. B., Tong, J., and Yin, H. (2013). Two pulses of extinction during the Permian-Triassic crisis. *Nat. Geosci.* 6, 52–56. doi:10.1038/ngeo1649

Stanley, S. M. (2016). Estimates of the magnitudes of major marine mass extinctions in earth history. *Proc. Natl. Acad. Sci. U. S. A.* 113, E6325–E6334. doi:10.1073/pnas.1613094113

Wignall, P. B. (2001). Large igneous provinces and mass extinctions. *Earth Sci. Rev.* 53, 1–33. doi:10.1016/S0012-8252(00)00037-4