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A general theory of mass extinctions

THOMAS ALGEO[1] AND JUN SHEN[2]

[1]University of Cincinnati
[2]State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan)

Presenting Author: Thomas.Algeo@uc.edu

Theory regarding the causation of mass extinctions is in need of systematization. Every mass extinction has both an ultimate cause, i.e., the trigger that leads to various climato-environmental changes, and one or more proximate cause(s), i.e., the specific climato-environmental changes that result in elevated biotic mortality. With regard to ultimate causes, strong cases can be made that bolide impacts, large igneous province eruptions, and bioevolutionary events have each triggered one or more of the Phanerozoic Big Five mass extinctions, whereas other proposed mechanisms (e.g., tectonic forcing, solar flares, gamma bursts, and supernova explosions) remain entirely in the realm of speculation. With regard to proximate mechanisms, most extinctions can be clearly categorized as either carbon-release or carbon-burial events, the former associated with a nexus of climato-environmental changes that include warming, ocean acidification, reduced productivity, and lower carbonate $d^{13}C$ values (Fig. 1), whereas the latter are associated with cooling, increased productivity, and higher carbonate $d^{13}C$ values (Fig. 2). Mass extinction causation can be usefully classified using a matrix of ultimate and proximate factors, in which the end-Cretaceous bolide impact and end-Permian plus end-Triassic large igneous eruptions were carbon-release events, and the Late Ordovician and Late Devonian were carbon-burial events with bioevolutionary triggers (i.e., the spread of non-vascular and vascular land plants, respectively). The Paleoproterozoic and Neoproterozoic also experienced major carbon-burial episodes with bioevolutionary triggers (i.e., spread of oxygenic cyanobacteria and early metazoans, respectively), possibly accompanied by extinctions among existing biotic communities. The impending Sixth Mass Extinction of the Anthropocene will be a carbon-release event with a bioevolutionary trigger (i.e., human technology), thus representing a new type of biocrisis. Broadly speaking, studies of mass extinction causation have suffered from insufficiently critical thinking: (1) claims of a common ultimate cause for all mass extinctions are suspect given the lack of evidence for bolide impacts and LIP eruptions for several of them, and by fundamentally different patterns of proximate climato-environmental causation and durations among them; and (2) the hypothesis that Phanerozoic mass extinctions were periodic depended critically on the now-discredited idea that they shared a common extrinsic mechanism (i.e., bolide impacts).

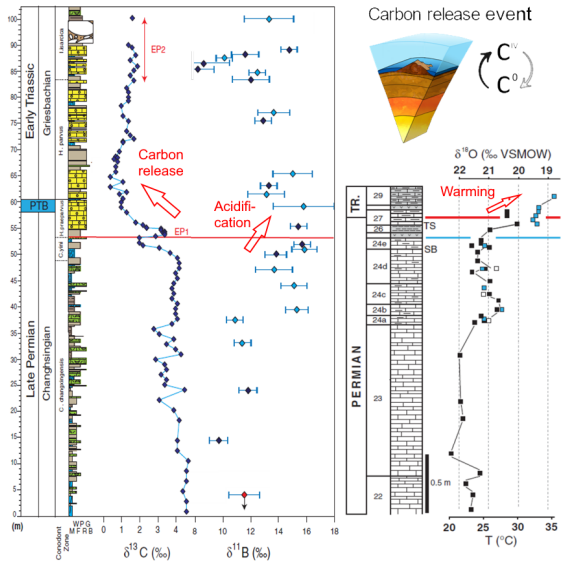

Fig. 1. The end-Permian crisis as an example of a carbon-release event, characterized by negative marine carbonate $\delta^{13}C$ excursions, ocean acidification, and climatic warming. Images from Joachimski et al. (2012) [right] and Clarkson et al. (2015) [left].

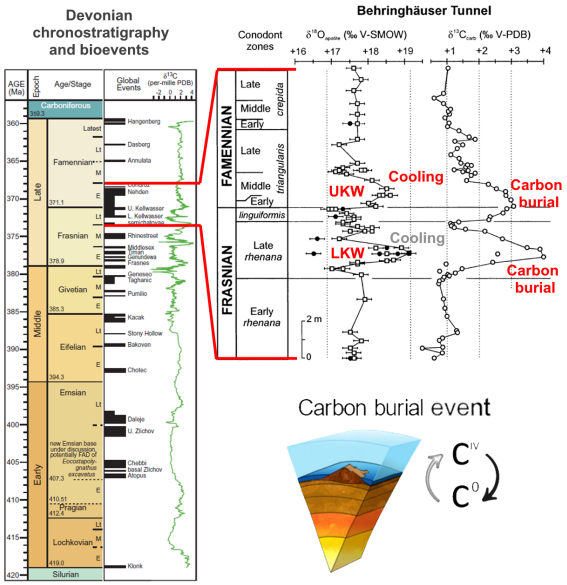

Fig. 2. The Frasnian-Famennian boundary crisis as an example of a carbon-burial event, characterized by positive marine carbonate $\delta^{13}C$ excursions and climatic cooling. Images from Joachimski and Buggisch (2002) [right] and Becker et al. (2020) [left].