

## Environmental perturbations at the mass-extinction events: What we can learn from isotope composition

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Environmental perturbations at mass extinction events are reviewed based on isotopic compositions of carbon and sulfur. Large negative excursions in marine-carbonate  $\delta^{13}\text{C}$  are commonly associated with mass extinctions [e.g., 1]. Although suppression of photosynthesis can induce reduction of a marine carbonate  $\delta^{13}\text{C}$ , this is not a single process to cause such negative excursions. For instance, an input of  $^{12}\text{C}$ -enriched carbon, such as methane from gas hydrate, into the ocean-atmosphere system was proposed to explain the negative  $\delta^{13}\text{C}$  excursion at the Permian-Triassic boundary [e.g., 2, 3].

Both two major events that can initiate mass extinctions, i.e., bolide impact and intense volcanic activity, should release sulfur-bearing gases into the atmosphere. Such gases should be converted to sulfate aerosol and, eventually, sulfuric acid rain, which raises sulfate concentration in freshwaters [e.g., 4]. Increase of sulfate concentration in freshwaters enhances accumulation of sulfide produced by sulfate-reducing bacteria. Actually, sulfide enrichments were observed in the sedimentary rocks from the terrestrial Cretaceous-Tertiary and Permian-Triassic boundary sections [5, 6].

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