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Mechanisms of the End-Permian Mass Extinction: Geochemical Evidence from South China Block Sections

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Abstract

The end-Permian mass extinction represents Earth's most severe biotic crisis, eliminating ~90% of marine species. Geochemical analysis of boundary sections from the South China Block reveals multiple volcanic episodes, ocean acidification, and anoxic conditions. Carbon isotope excursions indicate massive organic carbon burial disruption. Our integrated approach identifies volcanic CO2 emissions as the primary driver of environmental collapse.

Keywords: mass extinction, Permian-Triassic, environmental crisis, volcanic activity, ocean acidification

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1. Introduction

The end-Permian mass extinction (EPME), occurring approximately 252 million years ago, represents Earth's most severe biotic crisis, eliminating an estimated 81% of marine species and 70% of terrestrial vertebrate species. This catastrophic event fundamentally restructured global ecosystems and marks the boundary between the Paleozoic and Mesozoic eras. Understanding the mechanisms, timing, and ecological consequences of the EPME is crucial for assessing modern biodiversity loss and ecosystem resilience. The EPME coincided with the eruption of the Siberian Traps Large Igneous Province, one of the largest volcanic events in Earth's history. This volcanism released massive quantities of greenhouse gases, toxic compounds, and particulates into the atmosphere and oceans, triggering a cascade of environmental perturbations including global warming, ocean acidification, and marine anoxia. The precise causal relationships between volcanism and extinction, however, remain subjects of intense scientific debate. Recent advances in geochronology, geochemistry, and paleobiology have provided new insights into EPME dynamics. High-resolution uranium-lead dating has refined the timing of extinction relative to volcanic activity, while mercury anomalies provide direct evidence for volcanic impacts on marine ecosystems. Paleobiological analyses reveal complex patterns of selective extinction, with some groups showing gradual decline while others experienced rapid collapse. This study presents an integrated analysis of end-Permian extinction patterns and environmental changes recorded in marine carbonate sections from South China. Our research combines high-resolution biostratigraphic, geochemical, and sedimentological data to reconstruct the sequence of environmental deterioration and its relationship to biotic turnover. We focus on understanding the relative importance of different kill mechanisms and the factors controlling survival selectivity.

2. Materials and Methods

2.1 Stratigraphic Sections and Sampling Three well-exposed Permian-Triassic boundary sections were studied in detail: Meishan (Zhejiang Province), Shangsi (Sichuan Province), and Daijiagou (Chongqing Municipality). These sections represent different depositional environments from shallow platform (Meishan) to basinal settings (Daijiagou). Samples were collected at 10-20 cm intervals through the critical boundary interval. 2.2 Biostratigraphic Analysis Fossil abundance and diversity were quantified through systematic sampling of conodont, foraminifer, brachiopod, and ammonoid assemblages. Taxonomic identification followed established protocols with special attention to boundary taxa. Range data were compiled for statistical analysis of extinction patterns and timing. 2.3 Geochemical Analysis Carbon and oxygen isotope analysis was performed on both bulk carbonate and conodont apatite. Samples were analyzed using a Thermo Fisher Scientific MAT 253 mass spectrometer with precision better than 0.1‰. Mercury concentrations were determined by atomic absorption spectroscopy following acid digestion. Trace element analysis employed ICP-MS techniques. 2.4 Sedimentological and Petrographic Analysis Detailed petrographic analysis was conducted on thin sections to identify microfacies changes and diagenetic alterations. Cathodoluminescence microscopy was used to assess carbonate diagenesis. Scanning electron microscopy documented microbial structures and pyrite framboid morphology as indicators of redox conditions. 2.5 Statistical Analysis Extinction selectivity was analyzed using logistic regression models incorporating multiple ecological and morphological variables. Confidence intervals for extinction timing were calculated using biostratigraphic range data. Time series analysis of geochemical data employed spectral methods to identify cyclical patterns.

3. Results

Biostratigraphic analysis documents two-phase extinction pattern with initial diversity loss in latest Changhsingian followed by catastrophic collapse at the Permian-Triassic boundary. Carbon isotope values show dramatic negative excursion ($\delta^{13}C$ = -8‰) coincident with main extinction pulse. Mercury concentration spikes provide direct evidence for volcanic input. Microfacies analysis reveals rapid transition from normal marine to dysoxic/anoxic conditions.

4. Discussion

Extinction patterns indicate complex interplay between volcanic forcing and environmental deterioration. Initial warming and acidification weakened marine ecosystems, making them vulnerable to subsequent anoxic events. Selective extinction favored small, simple organisms with broad environmental tolerances. Recovery patterns suggest fundamental restructuring of marine ecosystem architecture.

5. Conclusions

End-Permian extinction represents a cascade of environmental perturbations triggered by Siberian Traps volcanism. Multi-phase extinction pattern reflects threshold responses to cumulative environmental stress. These findings provide crucial insights into ecosystem vulnerability and resilience during extreme environmental change.

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