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EDITORIAL

Coronene - A Potential Powerful Tool for Reconstructing Ancient Fire Records and Its Significance in a Geological Context

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Introduction

Major volcanic activities throughout geological times have significantly contributed to shaping the world we know today. These events often coincide with drastic changes in the Earth's environment, leading to the mass extinctions. As the environment recovers, new species emerge, and thus, the Earth's history of life has undergone several renewals. To understand these fluctuations in Earth's life history, it's crucial to comprehend when and how these large-scale volcanic activities occurred and the environmental changes they induced.

However, reconstructing these ancient volcanic activities poses challenges. Igneous rocks formed from massive volcanic eruptions may have eroded over the long span of Earth's history, leaving little evidence behind. Additionally, the vast geographical range of these volcanic activities makes it difficult to grasp their full extent. To address this, geologists have started utilizing tracers found in sedimentary rocks.

Among the polycyclic aromatic hydrocarbons (PAHs), coronene, alongside mercury, is emerging as a tracer for large-scale volcanic activities. Coronene is a PAH characterized by six condensed benzene rings. While PAHs in geological samples can form due to diagenesis or incomplete combustion of organic matter, larger PAHs aren't formed through diagenesis, making them indicators of incomplete combustion. Notably, coronene isn't typically formed in low-temperature combustion environments like forest fires. Its high relative abundance compared to other PAHs during events like massive volcanic activities or asteroid impacts suggests its formation requires high-energy combustion conditions, a notion supported by thermodynamic calculations.

The unique formation factors of coronene, combined with its stability and resistance to biodegradation, allow its preservation for hundreds of millions of years, offering opportunities to reconstruct past massive volcanic activities (Fig. 1). Coronene is formed during the high-temperature heating of organic matter in strata. When large-scale volcanic activities cause magma to intrude into these strata, significant amounts of coronene are released into the atmosphere. It is believed that this coronene then gets preserved in marine sediment layers. The intrusion of magma into strata not only results in the release of greenhouse gases due to the decomposition of organic matter but also produces harmful gases. Coronene serves as a marker, providing insights into the timing of the release of these environmentally destructive gases. Recently, significant spikes in coronene have been reported from strata recording events like the late Devonian, Guadalupian+Lopingian, Permian-Triassic, Triassic-Jurassic, and Cretaceous-Paleogene mass extinctions, enhancing its significance as an indicator. Moreover, mercury, which has traditionally been used as a tracer for volcanic activities, is often paired with coronene in these extinction events, further emphasizing the importance of these two compounds in understanding the history of volcanic activities and their environmental impacts.

Additionally, it is known that coronene is highly accumulated in hydrothermal fields driven by magma intrusion beneath the seafloor (Kawka and Simoneit, 1990). While the relationship between seafloor hydrothermal activity and coronene concentration in strata hasn't been verified, examining strata from periods or regions with active hydrothermal activity could provide insights about this relationship.

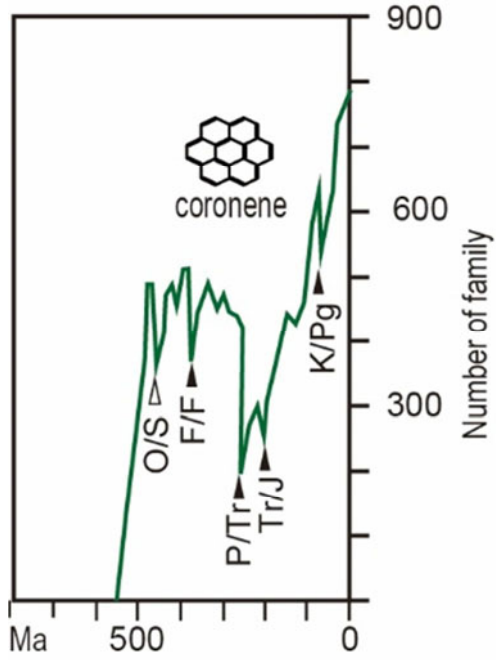

Fig. 1. Phanerozoic marine animal biodiversity represented by the number of family (Sepkoski, 1997). Open triangles denote mass extinction events where coronene spikes are not found, while filled triangles indicate events with detected coronene spikes. Key extinction events: O/S - Ordovician-Silurian, F-F - Frasnian-Famenian, P-Tr - Permian-Triassic, Tr/J - Triassic-Jurassic, K-Pg - end- Cretaceous.

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Coronene and the Permian-Triassic Boundary

The Permian-Triassic boundary marks one of the most significant mass extinctions in Earth's history, making it a crucial period for geological research. In Asian countries like India, Japan, Vietnam, and Thailand, PTr boundary strata are well-preserved. Particularly, the continuous and fossil-rich records in South China suggest frequent high-temperature combustion events during the mass extinction, possibly linked to the Siberian Traps or local volcanic activities near South China (Kaiho et al., 2021). These events, accompanied by global warming and other environmental deteriorations, are proposed as causes for the transition from the Permian to the Triassic. In details, Kaiho et al., (2021) employs paired coronene and mercury spikes as a refined proxy for Large Igeneous Province placement. From Permian-Triassic stratigraphic sections in south China and Italy, two sets of paired coronene-mercury spikes were identified. These spikes were accompanied by spikes in land plant biomarkers, followed by a rapid decline that aligned with terrestrial ecological disturbances and marine metazoan extinctions. Each of these short-term episodes is believed to be the result of high-temperature combustion of sedimentary hydrocarbons during the initial sill placement of the Siberian Traps LIP. The findings suggest that distinct volcanic eruptions at the latest Permian could have led to the terrestrial ecosystem crisis, followed by the marine ecosystem crisis in approximately 60,000 years. On the other hand, the data on coronene at the PTr boundary is limited to regions in the Northern Hemisphere. To investigate the geographical extent of the impact of large-scale volcanic activities, data from the Southern Hemisphere is essential. In this context, the PTr boundary from the Indian subcontinent could prove to be valuable (e.g., Aftabuzzaman et al., 2021)

Tracing the Deccan Traps

Alongside the asteroid impact in the Yucatán Peninsula, the Deccan Traps in west-central India, one of the largest volcanic provinces on Earth, are gaining attention as a potential cause for the Cretaceous-Paleogene mass extinction. The magma activity of the Deccan Traps peaked just a few tens of thousands of years before the mass extinction. Strata from the K-Pg boundary in India, located about ~1000 m from the Deccan Traps, suggest a link between the traps' activity and PAHs including coronene, although only one study has been conducted so far (Pal et al., 2023). In the Mahadeo-Cherrapunji road (MCR) section, the highest concentration of PAHs is found in the shaly transition layer of the K-Pg (Pal et al., 2023). These PAH variations align closely with major events of the time, including the Deccan volcanic activities and the merging of the Indian plate with both the Eurasian and Burmese plates. The unusual levels of these combustion-derived PAHs, combined with the evident fragmentation and dissolution of planktonic foraminifer shells, highlight marine biodiversity challenges and signs of biological distress. Analyzing more strata from India and other regions, especially for PAHs like coronene, could provide crucial insights into the causes of the Cretaceous-Paleogene mass extinction.

Future Prospects

While evidence is accumulating on the significance of coronene as an indicator of incomplete combustion in Earth's history, there's still much to explore. The conditions under which high concentrations of coronene are formed relative to other PAHs have not been experimentally constrained and therefore have not been found outside of the stratigraphic record. Future research should focus on experimentally determining the conditions under which coronene forms in abundance, understanding its spatiotemporal distribution during environmental upheavals such as large-scale volcanic activity, and making it a more robust indicator that can withstand and further enhance its usefulness as a paleoenvironmental indicator. Analyzing coronene records from strata near areas like the Deccan Traps holds potential for reconstructing the impacts of massive volcanic activities.

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