June 21, 2021

Earth & Space

How life on Earth almost ended once

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doi.org/10.25250/thescbr.brk557

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This Break was edited by Ayala Sela, Associate Editor - TheScienceBreaker

About 252 million years ago, more than 95% of marine and 70% of terrestrial species perished within a geological blink of an eye. Our study reveals how Earth's largest mass extinction occurred.

The onset of the Permian-Triassic mass extinction based on Jurikova et al. (2020)
Image credits: Dawid Adam Iurino (PaleoFactory, Sapienza University of Rome)

Life on Earth has never been so close to an end as during the environmental catastrophe that marked the Permian-Triassic boundary - 252 million years ago. Scientists have long speculated what could have triggered the sudden disappearance of so many organism groups- more than 95% of marine and 70% of terrestrial species went extinct. Among the favoured hypotheses have been large-scale volcanism, methane release from hydrate mounds on the seafloor, and an asteroid impact similar to that which ended the reign of the dinosaurs 66 million years ago. The latter has been, however, largely rejected in the recent years as no reliable evidence, direct or indirect, of the impact has been found.

Rock record holds a testimony of the extinction. Across the world, layers of sediment spanning the Permian-Triassic boundary show a dramatic disappearance of fossils. Chemical markers preserved in the sediments, such as carbon isotopes, indicate a large change in the carbon isotope composition of the oceans and the atmosphere at the time. This has led scientists to hypothesize that release of carbon-containing greenhouse gases such as carbon dioxide (CO_2) or methane (CH_4) could have been involved in the extinction. While volcanism could qualify as a source of CO_2 and gas hydrates as a source of methane, compelling questions exist about how they could trigger an extinction of the given magnitude.

The remnants of the ancient volcanic activity can be found in today's Siberia and are a smoking gun of the extinction, but also pose a mysterious puzzle: how could have volcanic activity lasting several millions of years initiated a sudden and rapid extinction? Recent data suggest that the onset of the extinction could have been as quick as few thousands to ten thousands of years - a geological blink of an eye!

To illuminate the causes and consequences of the extinction, we used an innovative approach to reconstruct the seawater pH (acidity) from boron isotope measurements in well-preserved fossil brachiopod shells. Seawater pH is a critical parameter; first, because it has direct implications for marine life. Second, because the ocean and the atmosphere are closely coupled and CO_2 is readily exchanged between them, we can use data on ocean pH to directly reconstruct the atmospheric CO_2 levels. We paired our pH data with the global carbon isotope records, and assimilated it into a model that quantified both the source and volume of CO_2 over the extinction period.

Our results showed that the extinction was initiated by an unprecedented pulse of CO_2 to the atmosphere, the result of organic-rich sediments combusted by volcanic intrusions. It was hence not the CO_2 released directly by the volcanic activity from magma degassing, for this would have been likely insufficient to produce such a rapid and deadly mass extinction. It was when the magma reached and started burning extensive ancient coal deposits that a sudden and immense amount of CO_2 was released. Our estimated total emissions amount is more than 40 times the amount of carbon available in modern fossil fuel reserves, including that already burned since the industrial revolution. This is likely the biggest event of carbon release since the evolution of animal life.

To further understand how the CO_2 release led to the extinction, we studied its feedbacks in the model and reconstructed a scenario that integrated our data with available geological, geochemical and palaeontological evidence. Our results showed that the CO_2 release led to a strong greenhouse effect on the marine environment. This severe heating and acidification of the oceans wiped-out shallow-water organisms in the initial stage of the extinction. Hot climate and high atmospheric CO_2 levels also had a dramatic effect on chemical weathering on land – the process of decomposition of minerals and rocks. As a result, over thousands of years more and more nutrients reached the oceans. This allowed plankton communities to thrive and accumulate, which also aided to remove a large part of the CO_2 excess from the atmosphere. However, dying and sinking plankton decomposed at depth consuming oxygen from the oceans. This subsequently killed-off deeper dwelling organisms.

Why was the extinction so deadly? It was the combination of the different environmental stressors that led to conditions too inhospitable to most of life in the oceans and the collapse of marine ecosystems.