First archive of extensive N-fixation by volcanic lightning and implications for the prebiotic Earth

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On Earth, most of the nitrogen (N) accessible for life is trapped in dinitrogen (N₂), which is the most stable atmospheric molecule. In order to be metabolised by living organisms, N₂ has to be converted into assimilable forms, also called fixed N. Nowadays, nearly all the N-fixation is achieved through biological and anthropogenic processes. However, in early environments of the Earth, before the emergence of life, N-fixation must have occurred via natural abiotic processes. Electrical discharges, including from thunderstorms and also lightning associated with volcanic eruptions is one of the most invoked processes. The occurrence of volcanic lightning during explosive eruptions is frequent, and convincing laboratory experimentations support the role of this phenomenon, however no evidence of substantial N-fixation has been found in volcanic records.

Here we report on the discovery of large amounts of nitrates in volcanic deposits from Neogene caldera-forming eruptions, which are well correlated with the concentrations of species directly emitted by volcanoes such as sulphur and chlorine. The multi-isotopic composition (δ¹⁸O, Δ¹⁷O) of the nitrates reveals that they originate from the atmospheric oxidation of nitrogen oxides formed by volcanic lightning that occur during the eruption. According to these volcanic nitrate records, our first estimates suggest that about 60 Tg of N can be fixed during a large explosive event. Our findings hint at a unique role potentially played by subaerial explosive eruptions in supplying essential ingredients for the emergence of life on Earth.