Atmosphere-interior exchange of nitrogen on the primitive Earth

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Despite its status as the most common element in Earth's atmosphere, nitrogen's long-term cycling between the surface and interior remains highly uncertain. Many geochemical studies over the last few decades have been conducted to provide constraints on the exchange of nitrogen between the mantle and surface over time. However, to date there has not been extensive theoretical investigation of the possible mechanisms for nitrogen exchange.

Here we examine a range of biotic and abiotic mechanisms that could have allowed efficient subduction of atmospheric nitrogen into the mantle at different times in Earth's history. We argue that if atmospheric N_2 levels were indeed close to present-day 3.0-3.5 Ga, as suggested by recent geochemical analyses, a biological explanation for the apparently large quantities of N in the present-day mantle is problematic. We therefore explore several abiotic mechanisms that may have operated at various points in Earth's early history. Through a combination of radiative and photothermochemical calculations, we show that nitrogen fixation via thermolysis under a transient early reducing atmosphere is possible, but requires surface temperatures of order 1000 K or greater, implying close to magma ocean conditions. We also discuss the likely importance of surface catalytic effects and trapping of N in reduced form in the mantle during accretion. Finally, we show that the nitrogen content of the atmosphere is coupled to the rate of planetary oxidation, because a low nitrogen partial pressure implies inefficient cold-trapping of H_2O and hence a route to rapid H_2O photolysis. This may have implications for Earth's oxidation rate in the Hadean, as well as for the climate evolution of many Earth-like exoplanets.