Isotope record of abiotic nitrogen reduction in a Neoproterozoic continental hydrothermal system

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Modern nitrogen (N) fixation from Earth's surface reservoirs (e.g., the atmosphere and hydrosphere) to lithosphere is primarily mediated by biological processes. However, in the early Earth where biological activity was absent or limited, abiotic N reduction in hydrothermal systems is thought to be a key process to transform atmospheric N_2 and NOx to ammonium, an essential nutrient to support the emergence of life and also a form that can be incorporated into rocks. Surprisingly, evidence for abiotic N reduction in the rock record has not been clearly recognized.

In contrast to biological vestige in the early Earth records that can be easily altered by secondary processes, such as metamorphism under elevated temperature and pressure conditions, abiotic/geological signatures embedded in minerals can better survive metamorphic overprinting.

In this study, we reported anomalously low N isotope compositions ($\delta^{15}N$ values as low as -15.8‰) of mica samples in ultrahigh-pressure metamorphic rocks from the Donghai area in the Sulu orogenic belt, eastern China. Compared to mica samples with typical crustal $\delta^{15}N$ values in similar metamorphic rocks from the western Dabie orogen, the ^{15}N-depleted mica samples from the Sulu orogen are characterized by significant N enrichment and extreme ^{18}O depletion. These features can be best explained by assimilation of N from a source characterized by extremely low $\delta^{15}N$ values (less than ~ -16‰). The extremely low $\delta^{15}N$ value would be produced by abiotic N reduction during reaction of a meteoric-hydrothermal fluid with crustal rocks before the continental subduction. This observation provides a new clue to the occurrence of abiotic N reduction in continental supracrustal rocks, additional to the highly reduced rocks in the oceanic crust (e.g., peridotite and basalt). The abiotic N reduction process would have been widepread on the early Earth and provided a steady reduced N source for the origin of life.