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Extraterrestrial delivery of bio-essential metals as a possible driver of Archean biotic evolution and ecological expansion

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The Archean eon was marked by fundamental milestones in the innovation and evolution of early life. The emergence and proliferation of microbial metabolic pathways (e.g., methanogenesis, N–fixation) profoundly imprinted the parallel evolution of the oceans and atmosphere. These pathways are coupled closely to the bio-availabilities of crucial trace metals, such as Ni, Co, and Mo, that function as enzymatic co-factors. In the last decades, intense research has focused on trace metal inventories in Archean oceans as regulated by marine redox conditions and terrestrial sources. In contrast, the substantial delivery of extraterrestrial materials through relatively frequent impacts during the Archean and the biological responses have largely been ignored.

Archean impactors with carbonaceous or ordinary chondrite-like compositions contain high siderophile element concentrations (e.g., Ni, Co, and Mo) compared to terrestrial crustal rocks. In this work, we show that impact events and concomitant large-scale delivery of extraterrestrial materials during the Archean could have significantly enhanced the supplies of Ni and Co, thereby boosting microbial methanogenesis. The additional contribution to surficial reducing power induced by impactors, beyond direct delivery of element metals [1], amplified the extraterrestrial influence on early atmospheric-oceanic evolution. The potential elevation in seawater Mo concentrations could also have played a role in the development of Mo-based nitrogenases at a time of general Mo deficiencies in the oceans [2]. As the impactor fluxes declined later in the late Archean, in combination with declining terrestrial Ni sources [3], methane production would have correspondingly declined. The associated drop in methane buffering of atmospheric oxygen could have contributed to the onset of the Great Oxidation Event.

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