

Biologically active soils and ecological prominence of primary producers on land during the Archean Eon

FRANTZ OSSA OSSA^{1,2}, OMAR ABDULRAHMAN
AHMED ALATTAS¹, EVA E. STÜEKEN³ AND AXEL
HOFMANN⁴

¹Khalifa University of Science and Technology

²Khalifa University

³University of St Andrews

⁴University of Johannesburg

The emergence and proliferation of photosynthetic organisms shaped the evolution of the biosphere and climate through Earth's history. However, the timing during which photoautotrophs became ecologically prominent on land remains poorly constrained. Here, we examine the contribution of microbial activity during Archean soil formation through clay mineralogy and clay mineral geochemistry, using two well preserved Archean paleosols of South Africa: 1) the Mesoarchean (~2.98 Ga) Denny Dalton paleosol of the Pongola Supergroup, which hosts the Earth's earliest glaciogenic deposits, and 2) the Late Neoarchean (~2.60 Ga) Lanseria paleosol from the Transvaal Supergroup, which records Paleoproterozoic (Huronian) glaciation. The data show that the occurrence of tobelite—ammonium-rich illite—characterized by illite/smectite mixed-layers with <5% of smectite, was controlled by the tobelitization of pedogenic smectite derived from organic matter-bearing soil during diagenesis. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of extracted clay minerals and their host paleosol, averaging -28‰ and $+2\text{‰}$, respectively, are consistent with autotrophy and nitrogen fixation by diazotrophs, which points to the presence of a soil biosphere involving photosynthetic bacteria. Our findings highlight the possibility of biologically-mediated silicate weathering on land, associated with high rates of clay mineral production and diversification. In so far as the Archean world was exposed to weaker solar radiation compared to modern days, enhanced concentration of reducing greenhouse gases (e.g., CO_2 , CH_4 , SO_2 , etc.) in the atmosphere likely served to mitigate the Faint Young Sun Paradox. But the stepwise increase and stabilization of continental crust during the Archean helped terrestrial ecosystems to become ecologically significant enough to enhance atmospheric CO_2 fixation and to decrease the coeval greenhouse effects. Decreasing atmospheric $p\text{CO}_2$, probably coupled with enhanced O_2 production, would also have contributed to significantly remove atmospheric methane, further limiting the greenhouse effect, which ultimately failed to offset the weaker solar luminescence and explains the development of Mesoarchean glacial events. As a result of faster growth of continental crust and further expansion of weatherable land areas at the Archean-Proterozoic transition, the climatic responses from biologically mediated silicate weathering became even more pronounced. This might have paved the way to the Huronian glaciation.