(Bio)geochemical cycles of S, C, Fe, and O on the hotter Archean Earth

H. OHMOTO[1*], U.M. GRAHJAM[2], Y. WATANABE[3], J.L. BRAINARD[1], A. CHORNEY[1], H. HAMASAKI[1], Y. TSUKAMOTO[3], Z-K. LIU[1]

[1]The Pennsylvania State University, PA, USA
[2]University of Kentucky, Lexington, KY, USA
[3]Tohoku University, Sendai, Japan
[*]hohmoto@psu.edu

Compared to the younger Earth, the Archean Earth was most likely characterized by: (1) a hotter and more reduced mantle; (2) frequent asteroid impacts, contributing to the creation of large igneous provinces; and (3) much smaller land surfaces. These characteristics created: (4) volcanism and hydrothermal activity being scarse on land but extensively occuring in the oceans; (5) higher atmospheric pCO_2 and warmer surface environments; and (6) the degassing of S as H_2S, not SO_2, if (1)-(4) had been true. Then, the currently popular model linking MIF-S in Archean sedimentary rocks to the UV photolysis of volcanic SO_2 and to an anoxic atmosphere would become invalid. Furthermore, the geochemical cycles of redox-sensitive- and bio-essential elements would have been controlled mostly by (bio)chemical reactions between seawater and submarine volcanic rocks.

Recently, we have discovered the abundance of two types of organic matter (OM) and Fe-oxides (FeOx) in the 3.46 Ga-old Marble Bar Chert in Pilbara, Western Australia. The first type was formed by aerobic chemolithotrophic benthic Fe-oxidizing bacteria and associated microbes in a deep (>2 km) ocean; thus indicating that the 3.46 Ga oceans and atmosphere were fully oxygenated. The second type, produced by hydrothermal reactions, consisted of aggregates of sub-nanometer-sized particles of OM and FeOx. Both types of OM-FeOx syntheses utilized Fe^{2+} from hydrothermal fluids and CO_2 and O_2 from the deep ocean water: $CO_2 + 6Fe^{2+} + 0.5O_2 + 7H_2O \rightarrow CH_2O + 3Fe_2O_3 + 12H^+$. Compared to the younger oceans, this reaction would have been far more important in the Archean oceans due to higher fluxes of CO_2, Fe^{2+}, and heat. The second type of OM-FeOx assemblage would have been much more reactive in (bio)chemical reactions than the first type; its abundance was key in the creation of a flourishing biosphere, leading to higher production rates of O_2 by cyanobacteria, which contributed to increased consumption rates of reduced volcanic gases, creating O_2- and SO_4^{2-}-rich and Fe^{2+}-poor oceans. BIFs formed in local anoxic basins. The isotopic compositions of S ($\Delta^{33}S$, $\Delta^{36}S$, and $\Delta^{34}S$), C and other redox-sensitive elements of the Archean sedimentary rocks, therefore, reflect the characteristics (1) - (6) of the early Earth.