

## Rapid change of atmosphere in the Hadean Earth: Beyond Habitable Trinity on a tightrope

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Surface environment of Hadean Earth is a key to bear life on the Earth or not. All of previous works assumed that high PCO<sub>2</sub> has been decreased to a few bars in the first a few hundreds millions of years (e.g., Zhanle et al., 2011). However, this process is not easy because of material and process barriers as shown below. Four barriers are present.

First, the ultra-acidic pH (<0.1) of 4.4Ga ocean prevented the precipitation of carbonates at mid-oceanic ridge or its pseudo-system through water-rock interaction after the birth of primordial ocean. To overcome this barrier, primordial (anorthosite + KREEP) continents must have been above sea-level to increase pH rapidly through hydrological process.

Second, major cap rocks on the Hadean oceanic crust must have been komatiite with minor basaltic rocks to precipitate carbonates through water-rock interaction and transport them into mantle through subduction at higher than the intermediate P/T geotherm on the Benioff plane. If not, carbonate minerals are all decarbonated at shallower depths than the Moho plane. Komatiite production depends on mantle potential temperature which must have been rapidly decreased to yield only Fe-enriched MORB by 3.8Ga.

Third, the primordial continents composed of anorthosite with subordinate amounts of KREEP basalts must have been annihilated until 4.0Ga to alter pH to be possible to precipitate carbonates by hydrothermal process. The value of PCO<sub>2</sub> must have been decreased down to a few bars from 35 bars at TSI (total surface irradiance) = 75% under the restricted time limit. If failed, the Earth must have been Venus state which is impossible to bear life on the planet.

Fourth is the role of tectonic erosion to destroy and transport the primordial continent of anorthosite into deep mantle by subduction. Anorthosite + KREEP was the mother's milk grow life on the Earth, but disappeared by 4.0Ga or even earlier, but alternatively granites were formed and accumulated on the Earth to supply nutrients for life. This is time-dependent process to increase new continents.

Fifth is the water content 3-5km thick, if the value was over, no way to bear life nor evolution afterwards.

After all, the Hadean Earth has passed the really naive tightrope processes to bear life. If any of above five conditions was lost, life has not been appeared.