Evolution of the water cycle since the Archean as constrained by hydrogen isotopes

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Hydrogen isotope (D/H) composition is useful to constrain the global cycle and evolution of water on Earth, as it varies depending on the origin of the water and fractionates through planetary processes. Whereas many analytical and experimental studies on D/H have been performed (e.g., [1-3]), the theoretical modeling of the global D/H cycle is limited [3,4]. The models have suggested possible mantle/ocean processes resulting in non-steady-state water mass [4] and isotopic composition [3].

We constructed a global water-cycle model taking the D/H compositions into account. Oceans, crust, and mantle exchange water through seafloor hydrothermal alteration, slab subduction, and degassing at mid-ocean ridges, ocean islands, and arcs. Hydrogen loss to space from photolysis of methane is also considered to have occured on early Earth. Exploring ranges of volumes, fluxes, and fractionation factors of water, we constrain the water cycle on present-day Earth and consider implications for that of the Archean.

Given the sea level variation since the Archean (<500 m, [5]), our model reproduced the observed difference in D/H ratios of the ocean and mantle on present-day Earth (~−60‰, [1]) as a balance between the outgassing and ingassing of water where the fractionation resulted from seafloor hydrothermal alteration and slab dehydration, showing that the D/H compositions are consistent with a steady state.

Combining our model with a low D/H ratio in the 3.8 Ga seawater (~−25‰, [2]) showed that the difference between the Archean and present-day D/H in oceans cannot be explained by hydrogen loss only and it is likely to be a signature of the Archean water cycle. We suggest two possibilities: i) the present-day water cycle had been just established and had not reached steady state yet, or ii) the Archean Earth had a different style of the water cycle.

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