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The Origin and Deep Cycles of Life-essential Volatile Elements on Earth and Rocky Planets

RAJDEEP DASGUPTA, AINDRILA PAL, DEBJEET PATHAK AND ANNA JOHNSON

Rice University

Presenting Author: rajdeep.dasgupta@rice.edu

The habitability of Earth and rocky planetary surfaces and clement climate owes to a cocktail of gases in the planet's atmosphere to sustain the ocean-atmosphere systems. The necessary gaseous elements are also essential for life, and their bioavailability is tied to supply via a wide range of geochemical processes. While near-surface reservoirs and processes control the short-term fluctuations of life-essential volatile elements (LEVEs) on the planet's surfaces, the budgets and processes involving deep interiors dictate the long-term fluctuations.

The initial distribution of LEVEs on a planetary scale occurred during accretion and early metal-silicate-proto-atmospheric differentiation of planets and differentiated planetesimal building blocks. Therefore, here, we will first present a synthesis of laboratory constraints on the chemistry of dissolution, solubility, and partitioning of LEVEs (C, H, N, and S) in and between molten silicates and metals during the early differentiation of rocky bodies. We will discuss how the planet-scale distribution of LEVEs, emerging from the magma ocean stage, is expected to vary for Earth and other rocky planets in the solar system. We will also utilize the present-day bulk silicate Earth LEVE budget and discuss what such constraints suggest regarding terrestrial accretion and differentiation style.

Finally, we will discuss how mantle melting extracts and releases LEVEs, stabilizing and modulating their budgets at the near-surface reservoirs. We will show that there can be significant fractionation of the LEVEs in mantle-extracted melts, depending on the storage mechanism of the LEVEs in near-solidus conditions. Some LEVEs may be stored in nominally LEVE-free silicate minerals, whereas others in trace accessory phases. To this end, we will present and utilize new data on mineral-melt partitioning of nitrogen and sulfur to discuss the extraction of these LEVEs during mantle melting. In particular, for nitrogen, we will show how its partitioning during mantle melting may be strongly oxygen fugacity dependent and how a change in the oxidation state of the Earth's mantle may have been responsible for stabilizing a nitrogen-rich atmosphere for Earth.