THE POTENTIAL FOR HIGH FLUXES OF BOTH OXYGEN AND HYDROGEN IN THE EUROPA SYSTEM. S. D. Vance (svance@jpl.nasa.gov), K. P. Hand, R.T. Pappalardo, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.

Many icy worlds in the solar system likely contain inventories of liquid water comparable to Earth's [1,2]. This meets only one planetary habitability requirement; less is known about whether icy world oceans permit the needed chemical disequilibria for powering life [3,4]. Evidence for sustained internal heat and abundant water on Jupiter's moon Europa suggest life would have had the perceived time needed to develop there, but sources of electron donors and acceptors critical for habitability have been difficult to assess.

Past investigations have assumed hydrogen production at the rock-ocean interface scales with the heat input to the rocky interior [5], and that subsurface weathering and alteration are inconsequentiall [6]. However, estimates of hydrogen production rates on Earth show that low-temperature hydration of crustal olivine produces substantial hydrogen, on the order of 10^{11} moles yr^{-1} [7,8], comparable to the flux from Earth's volcanic activity.

We estimate global average rates of water-rock reaction on Earth, Mars, and icy worlds in the solar system using the pressure- and temperature-dependent physics of microfracturing in olivine. We predict hydrogen production within Europa's oceanic crust—also potentially applicable to other icy worlds—that are higher than those on Earth, even in the absence of contemporary high-temperature hydrothermal activity. Radiogenic cooling exposes unweathered rocky material progressively over time to ever greater depths [2]. Shallower gradients in pressure and temperature in objects smaller than Earth expose new unaltered rock to depths that scale with the inverse of gravity, as much as 100x deeper than on Earth. Alteration of exposed material, mainly by serpentinization, releases heat and hydrogen, which are necessary for life.

We hypothesize that Europa's ocean could have become reducing during geologically brief periods when hydrogen flux from rapid reweathering far exceeded oxidant flux, due to a thermal-orbital resonance some time after Europa's accretion in response to oscillations in mantle heating rate. Europa's present day hydrogen production is substantial, estimated on the order of 10^{10} moles yr^{-1}, whether from serpentinization or volcanic activity. Evidence for active chaos [11] and subduction-like behavior [12] in Europa's ice suggest that radiolytic oxidant flux to its ocean could be at the high end of the previously estimated range ($5 \times 10^9 - 4 \times 10^{11}$ moles yr^{-1}) [13]. These factors may make Europa unique among icy worlds for having an oxidizing ocean with a high flux of reductants. Europa is thus a prime candidate for hosting life.

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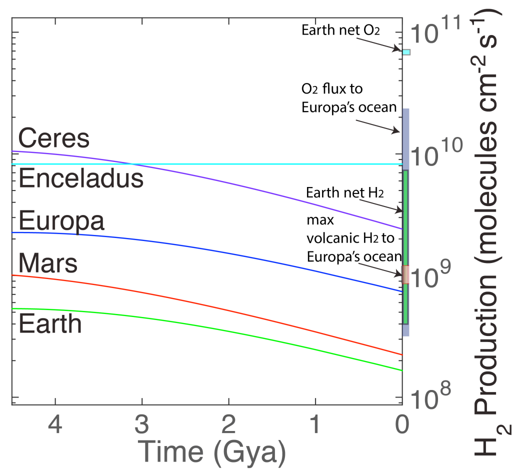

Figure 1. Hydrogen production (per unit area) in wet and rocky worlds, calculated from progressive microfracturing, compares favorably with net production on present-day Earth (green shaded region). Earth's predicted production from hydration alone (green line) is consistent with recent estimates [8]. Europa's production is in the range of estimates for oxygen delivery to its ocean (purple shaded region). Oxygen delivery may be at the high end of the estimated range [11,12], consistent with a Europa system with redox fluxes comparable to Earth's.