BIOGEOCHEMISTRY

Balancing the hydrogen books

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This energy source might fuel the evolution of life on other planets
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The small concentrations of H_2 in our atmosphere belie the large scales on which it is generated and consumed below the surface of our oceans. Without access to other reductants, microorganisms deep in the ocean turn to H_2 as an energy source. We suspect that a lot of microbial activity also takes place beneath the seafloor in the oceanic lithosphere — the crust and mantle just below the ocean — yet this is harder to probe. By combining what we know about abiotic processes here with new assumptions, Stacey Worman, Lincoln Pratson, Jeffrey Karson and William Schlesinger report in *Proceedings of the National Academy of Sciences* the net amount of H_2 available for microbial activity. The energy might well support a startling amount of life in this apparently inhospitable region.

When tectonic plates spread apart they can give rise to a mid-ocean ridge, a mountainous formation abundant in igneous rock less than

10 million years old — fresh on the geological timescale. Being relatively reduced, these materials are rich in Fe^{II} that can be oxidized by H_2O to give Fe^{III} with concomitant release of H_2 . If we first consider the top of the oceanic lithosphere, the youngest exposed rock forms when magma rises and contacts seawater, whence liquid FeO species convert into solid Fe_2O_3 and give $0.1 \text{ Tmol y}^{-1} H_2$. The team arrived at this value by assuming that the top 1 cm of lava reacts. The same H_2O -splitting reaction with FeO remaining in solidified rock is slower but had previously been estimated to produce H_2 on a larger scale of 1 Tmol y^{-1} . Related to these processes is weathering, which affords Fe_2O_3 as well as $FeOOH$ and $Fe(OH)_3$, all the while evolving 0.2 Tmol y^{-1} of H_2 . Aside from oxides, Fe^{II} in basalt can exist as the silicate Fe_2SiO_4 , which reacts with H_2O to give oxidized products Fe_3O_4 and SiO_2 , along with H_2 (0.06 Tmol y^{-1}). Moving to regions lower down, it becomes clear that most magma cools and crystallizes before touching seawater, such that FeO and dissolved H_2O convert into solid $FeO \cdot Fe_2O_3$ and release huge quantities of H_2 (3 Tmol y^{-1}). As if $1,200^\circ\text{C}$ molten Fe minerals were not reactive enough, magma also contains CH_4 that gives H_2 (0.7 Tmol y^{-1}) as magma degasses near the seabed, which the team estimated by considering gases trapped in ‘popping rocks’. Other sources of H_2 include H_2O radiolysis (0.5 Tmol y^{-1}), pyrite FeS_2 formation ($9 \times 10^{-7} \text{ Tmol y}^{-1}$) and fracturing (0.03 Tmol y^{-1}), whereby Si -dangling bonds at fresh surfaces cleave H_2O to give $Si-OH$ groups.

Having identified the abiotic H_2 sources, the team sought estimates for abiotic H_2 sinks. Although some H_2 is retained in crustal rocks and waters

(0.3 Tmol y^{-1}), a lot (3 Tmol y^{-1}) is released into the sea at hydrothermal vents and sustains microorganisms. The team considered a steady-state box model of H_2 in the lithosphere, and with $\sim 6 \text{ Tmol y}^{-1}$ and $\sim 4 \text{ Tmol y}^{-1}$ being abiotically produced and consumed, respectively, they found that at least $\sim 2 \text{ Tmol y}^{-1}$ would be left for microorganisms to grow here. “The hydrogen in this realm might be a source of energy for microbial communities, completely removed from photosynthesis at the oceans’ surface,” says Schlesinger. Such a quantity of H_2 , assuming a typical microbial metabolism, could sustain carbohydrate biomass (CH_2O)_n growth of $\sim 0.2 \text{ Tmol y}^{-1}$, although the real value may be substantially lower if growth is limited by other factors. Considering the whole planet, this H_2/CO_2 metabolism is dwarfed by the biomass formed by photosynthetic metabolism of H_2O/CO_2 , but the former nevertheless accounts for a large proportion of H_2 utilization.

Coming to a definitive estimate of microbial activity in the lithosphere will require direct measurement, which is challenging to do in a way that is globally representative. The elements near hydrothermal vents (Fe , Ni , S) have been implicated in the origin of life on Earth, and microorganisms that derive energy from H_2 are among the oldest known. The same might be the case elsewhere. “This energy source might fuel the evolution of life on other planets (or their moons) and allow extraterrestrial biospheres,” concludes Schlesinger.

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ORIGINAL ARTICLE Worman, S. L. et al. Abiotic hydrogen (H_2) sources and sinks near the mid-ocean ridge (MOR) with implications for the subsurface biosphere. *Proc. Natl Acad. Sci. USA* <https://doi.org/10.1073/pnas.2002619117> (2020)

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