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Exploring natural $GeoH_2$ generation in a monsoonal serpentinization environment

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Global demand for H_2 is increasing and is anticipated to reach 500 Mt/year by 2050. In this regard, the discovery of natural $GeoH_2$ seepages offers enormous potential for C-free energy solutions. Low temperature serpentinization is one of the major pathways of $GeoH_2$ production. We hypothesize that in tropical, monsoonal serpentinization settings, rainfall amounts may enhance groundwater recharge, subsurface fracturing, and water flow pathways, resulting in greater water-rock interaction during the wet season and a $GeoH_2$-rich vapor phase throughout the baseflow period. Here, we present results from a unique tropical serpentinization environment within the Santa Elena Peninsula, Costa Rica (SEO; 250 km^2 area and ~520 km^3 rock volume). This site is characterized by hyperalkaline springs (pH=11.01-11.59 and ORP up to -348 mV) with low Mg^{2+} and relatively high Ca^{2+}, and low temperature (<30°C), which leads to precipitation of extensive carbonate deposits that entrain atmospheric CO_2. $GeoH_2$ and CH_4 concentrations (10^{-2} to 10^1 mM and 10^{-2} to 10^0 mM, respectively) are within the range of reported values in controlled lab-reactor experiments (at >200°C). As these conditions are within the range of habitability, microbial activities that consume these fuels are also an important consideration in terms of the usability and environmental impact of $GeoH_2$ emissions. Discharge measurements indicate a large groundwater input to the stream network, resulting in a ~8x discharge increase from the headwaters to the watershed outlet (7.1 to 57.5 L/s). Our spatial, geochemical, and hydrometric surveys indicate that the mechanisms controlling $GeoH_2$ and CH_4 emissions may be a net result of 'natural recharge stimulation' (annual rainfall: 1,500-3,000 mm) and sustained baseflow conditions, which in turn enhance water-rock ratios potentially catalyzed by trace Fe-Ni alloys (up to 1,860 and 69.9 ug/L, respectively) rather than high temperatures. Water isotope ratios consistently indicate high connectivity between rainfall, groundwater, and seepage manifestations. By integrating hydrometric, geochemical, and microbiological techniques, we aim to elucidate the key drivers controlling the relatively rapid and in-situ production of subsurface $GeoH_2$ and CH_4 in tropical serpentinization environments favored by wet-dry monsoonal cycles. Improving the understanding of natural $GeoH_2$ generation could help to accelerate and scale up cleaner $GeoH_2$ production.