Is orange hydrogen the new green? Exploring $GeoH_2$ generation in a serpentinization environment

Alexandra May[1] & Ricardo Sánchez-Murillo[1]

[1]Tracer Hydrology Group, Department of Earth and Environmental Sciences, University of Texas at Arlington, Arlington, TX, USA

I: Hypothesis

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 base flow period.

II: Study Area

Active tropical continental serpentinization in the Santa Elena Ophiolite (~250 km^2), exposed along the North Pacific coast of Costa Rica, was discovered by Sánchez-Murillo and Gazel in 2013.

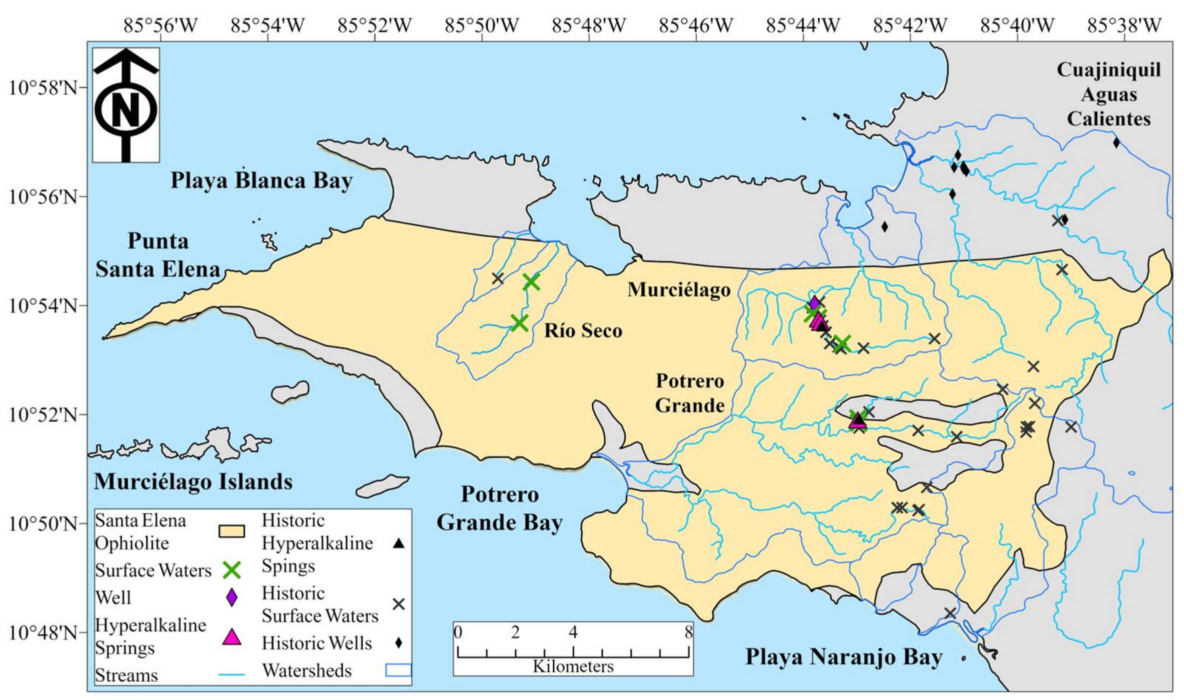


Figure 1: Map of the study area. The yellow highlighted area denotes the Santa Elena Ophiolite (SEO), dominated by ultramafic rocks.

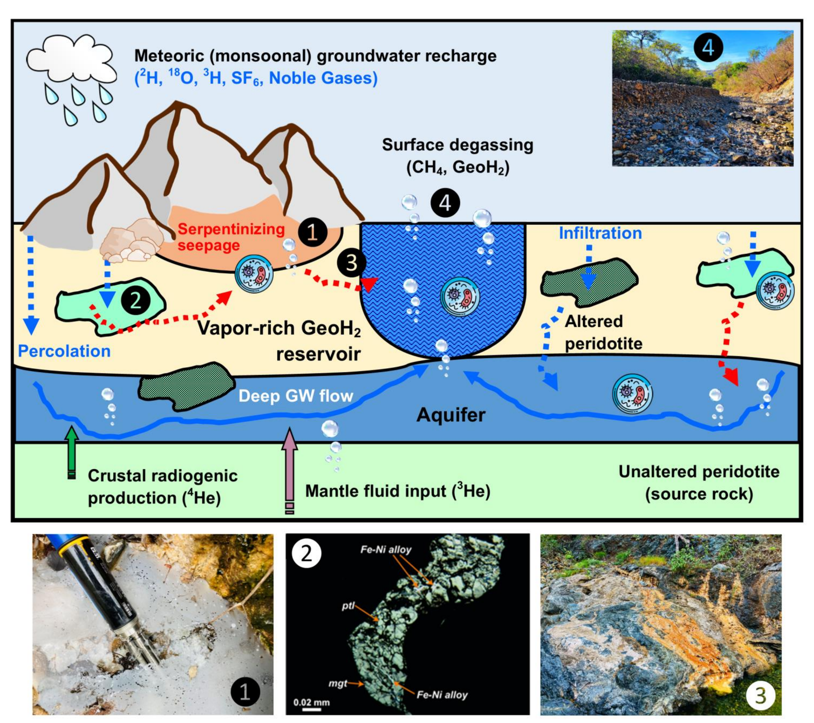
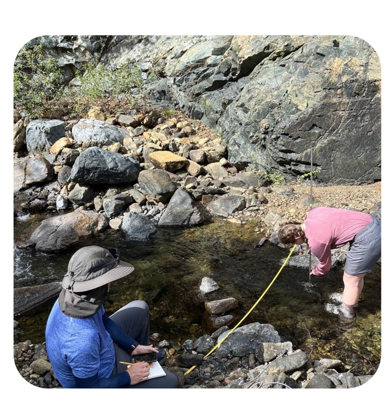


Figure 2: Conceptual diagram illustrating the main hydrogeological processes, fluid pathways, and potential $GeoH_2$ reservoir at SEO. Example photos show 1) Calcite precipitation in a hyperalkaline pool, 2) Fe-Ni alloys at SEO, 3) Hyperalkaline seepage, and 4) Stream cross-section.

III: Methods

Dissolved Geochemistry

Dissolved Gasses



Hydrometric Measurements

IV: Results

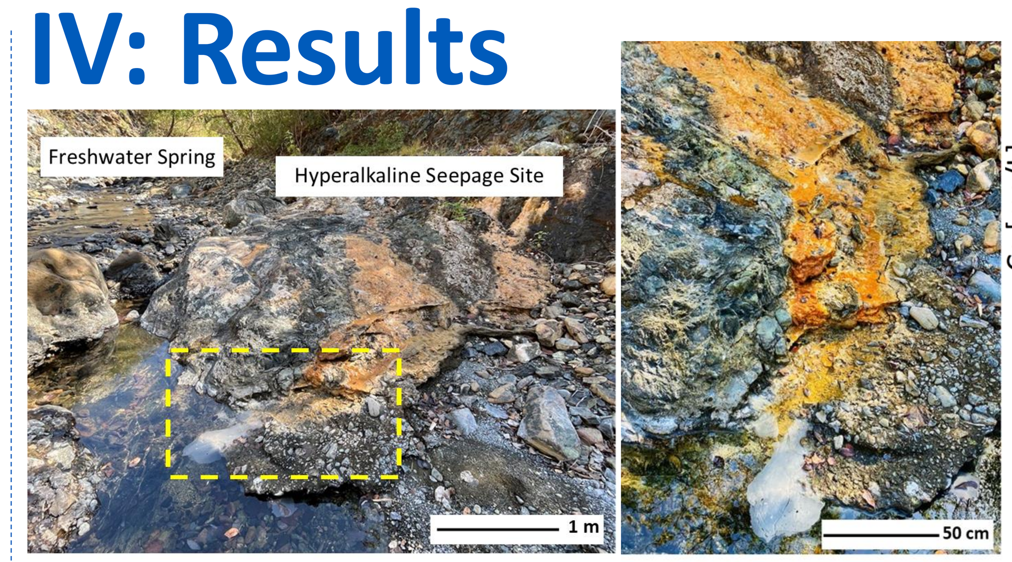


Figure 3: Right) Image of the hyperalkaline spring at Quebrada Danta site showing pool on the right spring bank with extensive yellow-brown precipitates. These precipitates form small travertine terraces. Left) Enlargement of yellow dashed area. Note that travertine deposits and white supernatant crust (calcite/aragonite) are due to atmospheric CO_2 uptake.

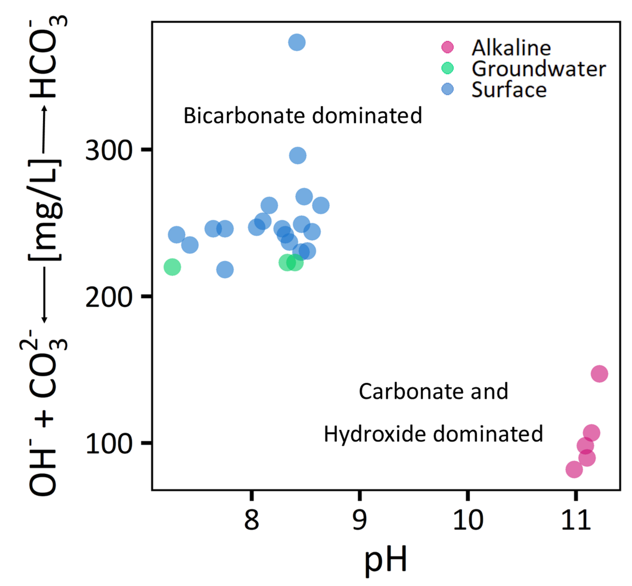


Figure 4: Comparative analysis of alkalinity levels in the SEO surface, alkaline, and groundwaters.

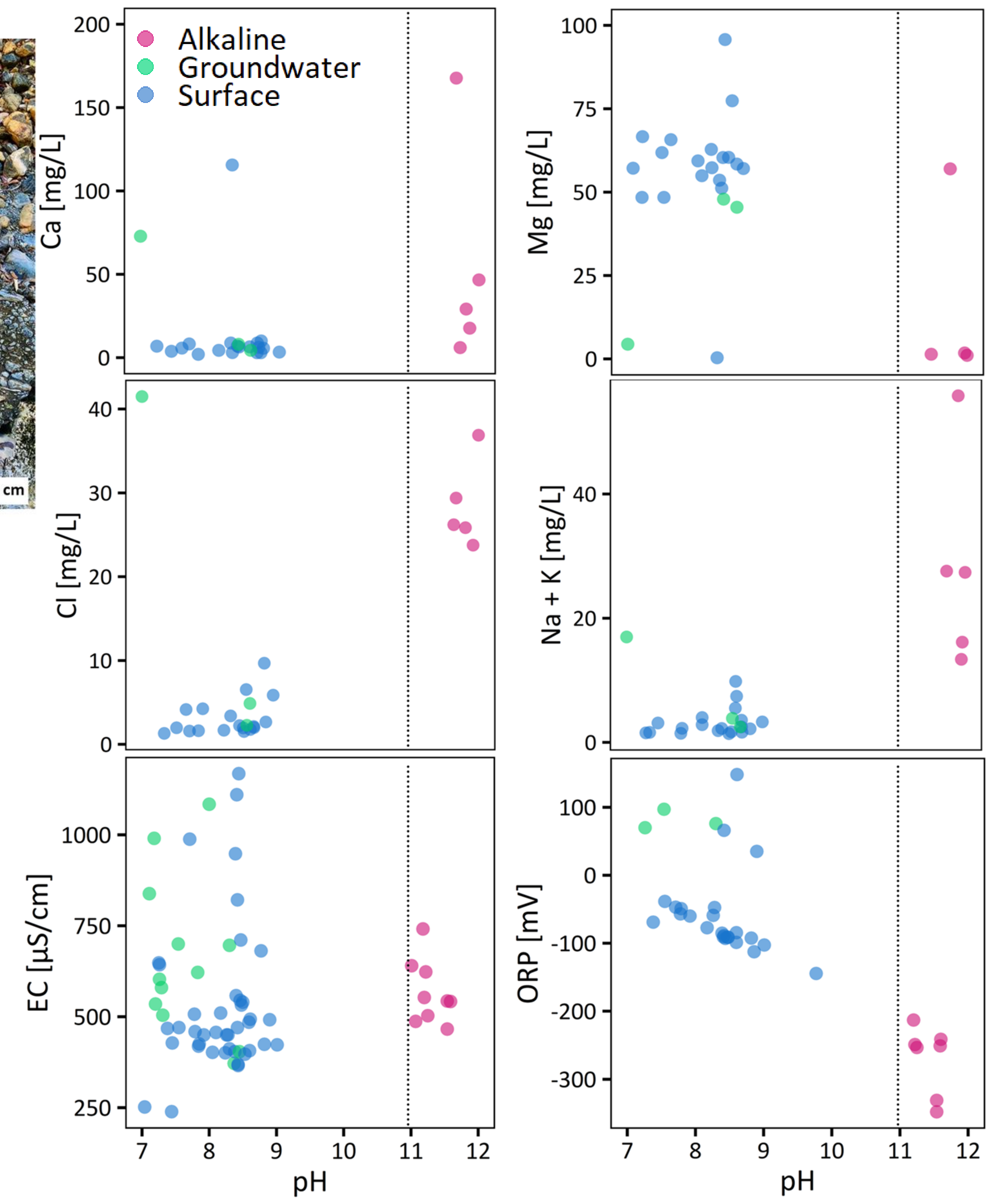
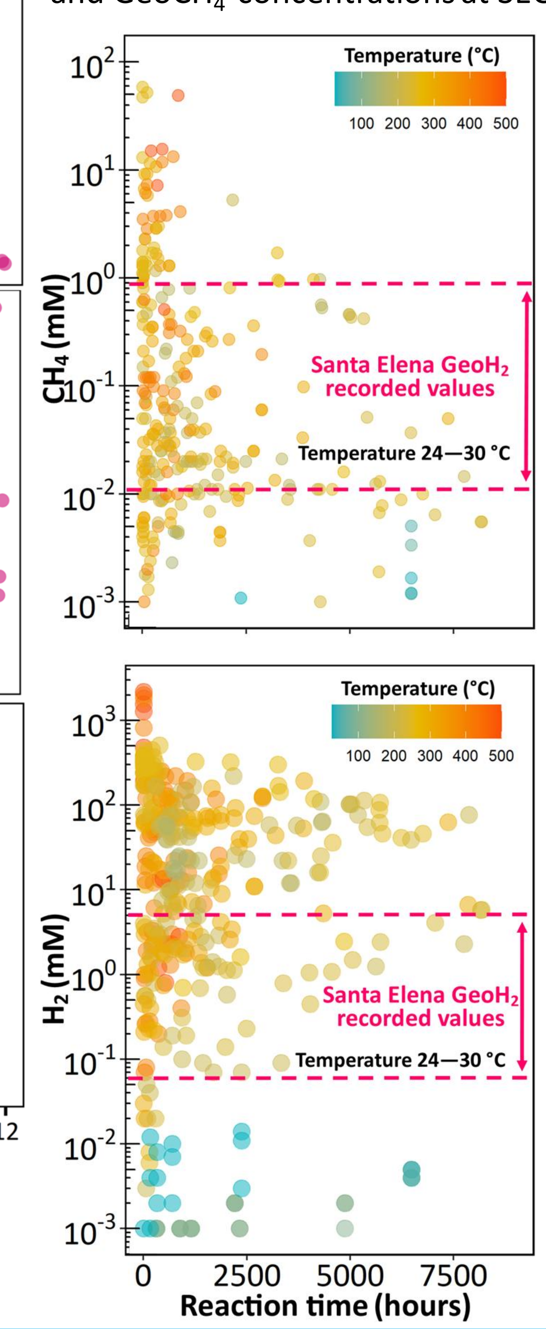


Figure 5: Santa Elena aqueous geochemistry characteristics. Grey dashed line represents pH = 11.

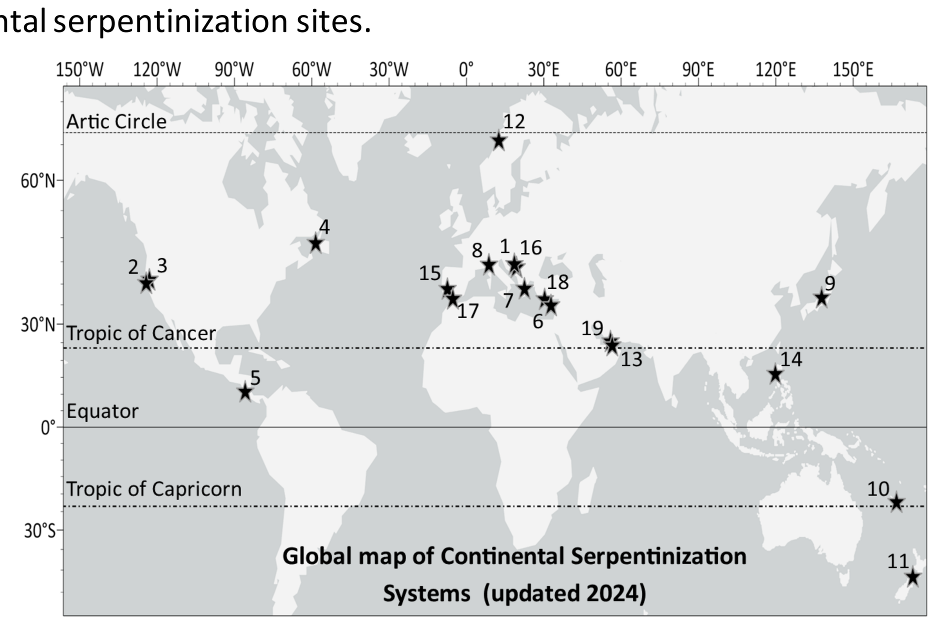
Figure 6: Laboratory-based H_2 and CH_4 production[1], including $GeoH_2$ and $GeoCH_4$-concentrations at SEO.



- **Murciélago and Potrero Grande springs exhibit Ca^{2+}-OH^- type waters, while surface and groundwater exhibit Mg^{2+}-HCO_3^- type waters.**
- **Relatively high concentrations of dissolved Ni (up to 69.9 µg/L) and Fe (up to 1,860 µg/L).**
- **$GeoH_2$ and methane-derived concentrations at Santa Elena (<30 °C) are within the range of concentrations reported in controlled lab-reactor experiments at high temperatures (>200°C).**

Global Comparison

Figure 7: Global map illustrating the distribution of the 19 identified continental serpentinization sites.



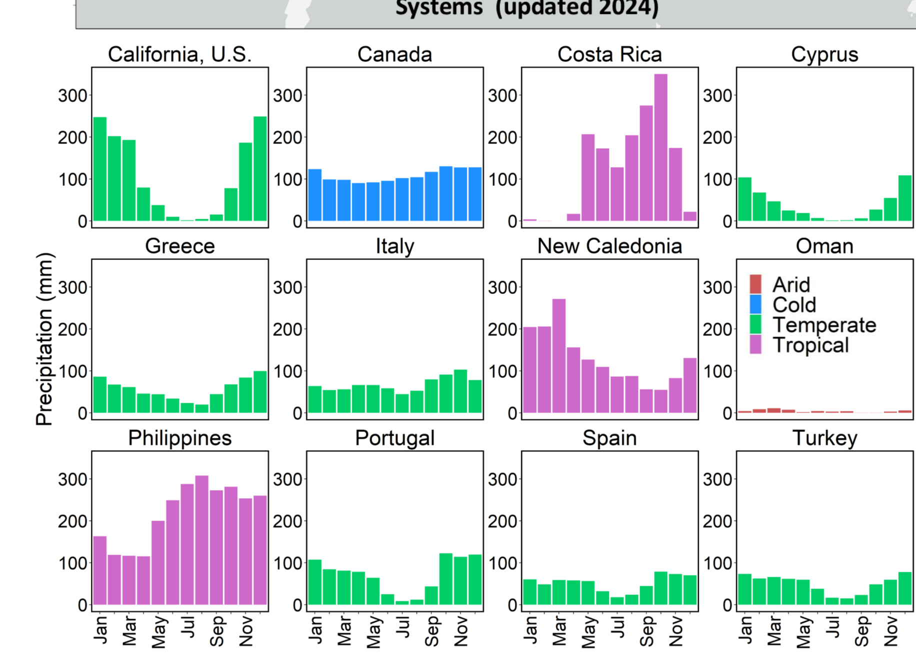


Figure 8: Monthly average precipitation (mm) by site.

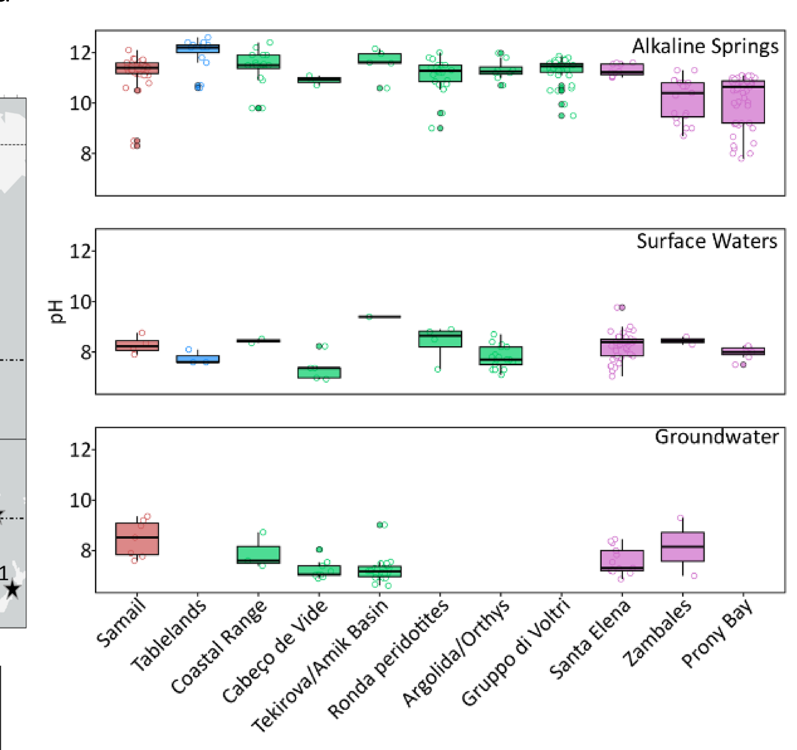


Figure 9: pH variability in hyperalkaline seepages, surface waters, and groundwaters in global serpentinization sites.

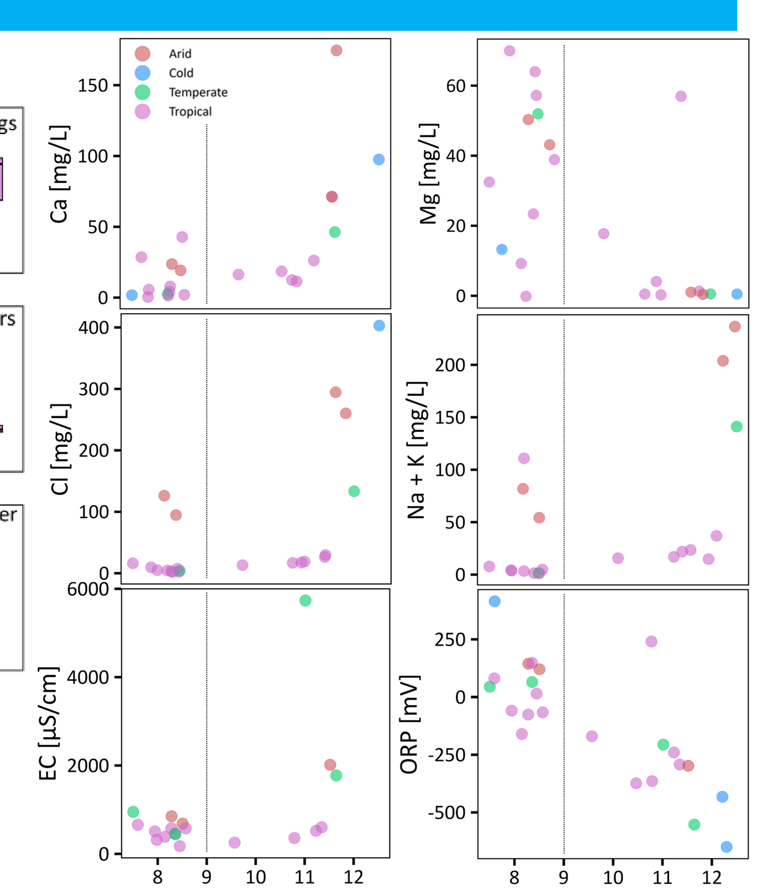


Figure 10: Global aqueous geochemistry. Grey dashed line represents pH = 9.

- **Santa Elena has a unique climate, with two distinct dry and wet seasons.**
- **Surface and groundwaters exhibit similarities, with notable exceptions in extreme cold or arid climates.**
- **Alkaline springs display highly varied aqueous geochemistry.**

V: Hydrometric Analysis

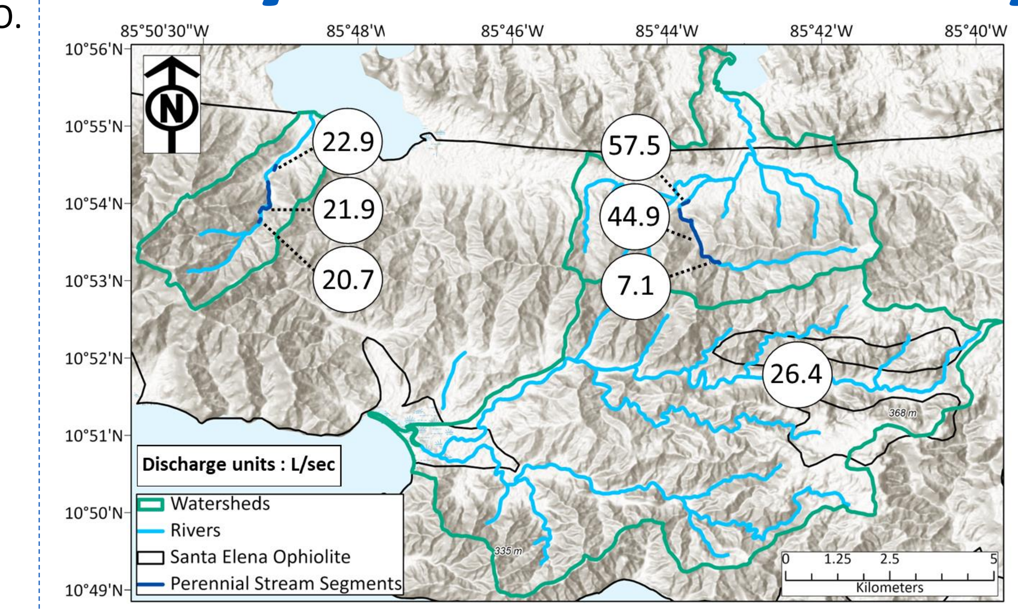


Figure 11: SEO's river segments with associated hydrometric measurements.

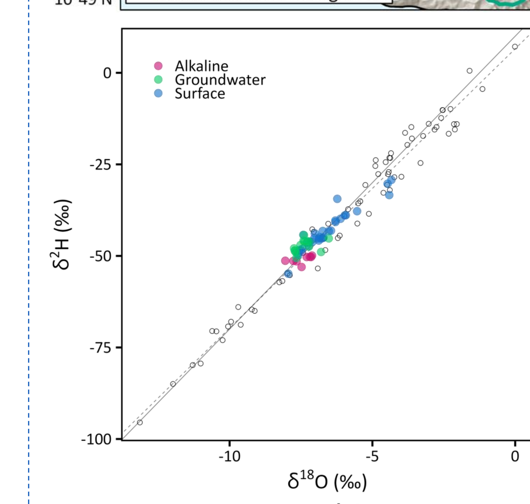


Figure 12: Dual-isotope plot: surface, alkaline, and groundwaters.

- **Discharge at Río Seco is consistent across the river network.**
- **At Río Murciélago, there is evidence of increasing discharge (8x) with distance downstream, suggesting groundwater inputs.**
- **Water isotope ratios consistently indicate high connectivity between groundwater reservoirs, surface water, and seepage manifestations (local meteoric origin).**

VI: Conclusions

Our results through spatial, geochemical, and hydrometric surveys suggest that:

- $GeoH_2$ and methane high concentrations may stem from a phenomenon called "natural recharge stimulation".
- This process is likely influenced by the annual rainfall (1,500-3,000 mm, occurring from May to November) and the persistent baseflow conditions during the dry season (December-April).
- These conditions promote increased water-rock interactions, potentially facilitated by trace Fe-Ni alloys rather than solely by high temperatures.

VII: Next research steps

- **Determination of groundwater apparent age in seepage manifestations.**
- **Identification of the effects of the related microorganisms on the serpentinization process and hydrogen consumption.**
- **Analysis of hydrological drivers controlling $GeoH_2$ production.**

VIII: Acknowledgements

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Reference cited:

[1]Barbier, S., Huang, F., Andreani, M., et al. (2020). A Review of H_2, CH_4, and Hydrocarbon Formation in Experimental Serpentinization Using Network Analysis. Frontiers in Earth Science.

Alexandra May
Alexandra.may@uta.edu