Monsoonal rainfall and natural recharge ‘stimulation’ drive seasonal $GeoH_2$ and CH_4 production

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I. Hypothesis

We hypothesize that in tropical monsoonal environments, rainfall amount and seasonality (wet and dry cycles) stimulate groundwater recharge, resulting in more significant i) water-rock interactions (during the wet season) and ii) $GeoH_2/CH_4$-rich dissolved phase during baseflow conditions (dry season).

II. Study Area

Active tropical serpentinization in the Santa Elena Ophiolite (known as SEO; 250 km² area and ~520 km³ rock volume), exposed along the North Pacific coast of Costa Rica, was discovered by Sánchez-Murillo and Gazel in 2013.

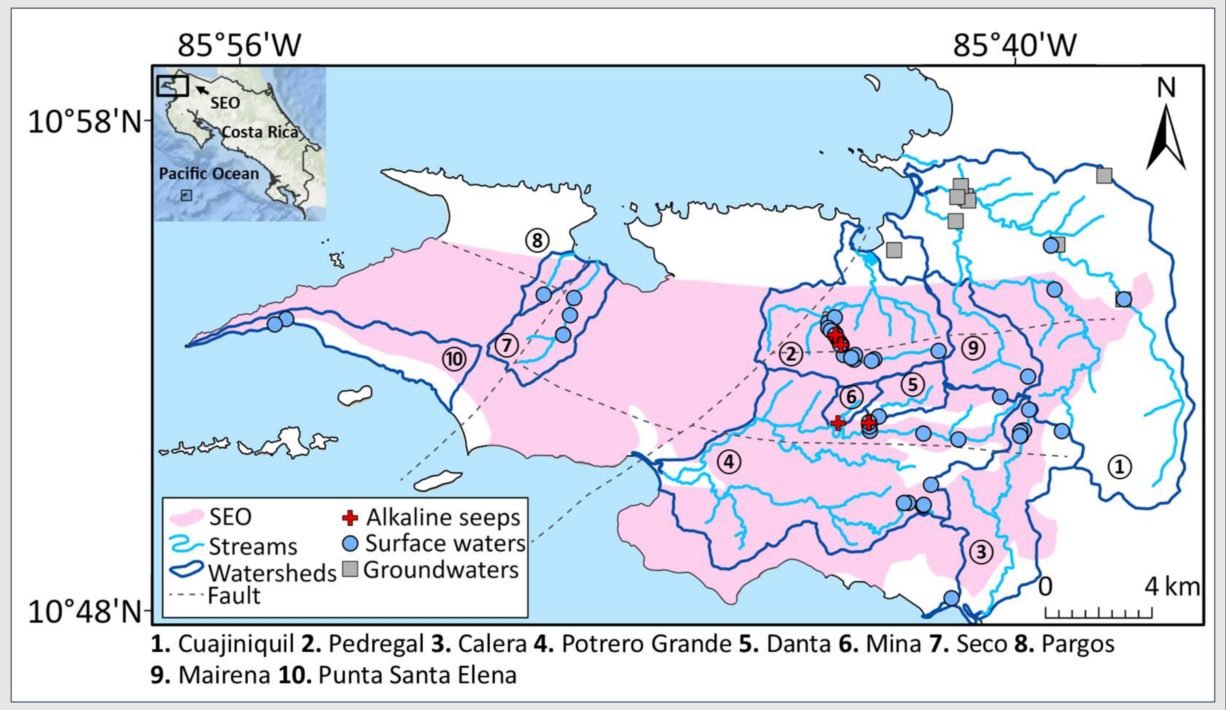


Figure 1. Map of the study area. The pink highlighted area denotes SEO’s boundary, dominated by ultramafic rocks.

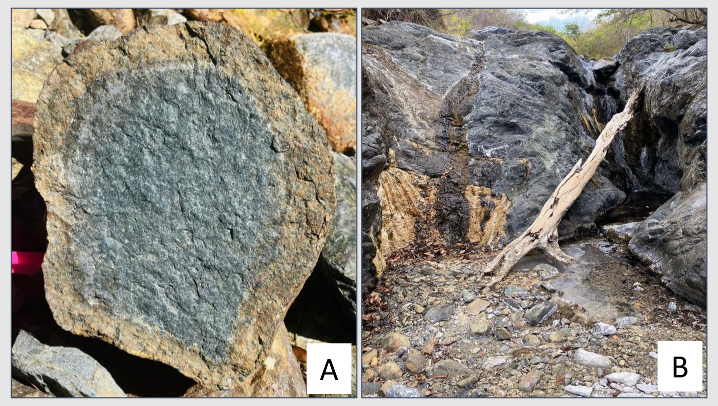


Figure 2. A) Partially serpentinized peridotite. **B)** Alkaline seepage from the Mina site. Travertine deposits and white supernatant crust (calcite/aragonite) are due to atmospheric CO_2 uptake.

III. Methods

III. Global Overview

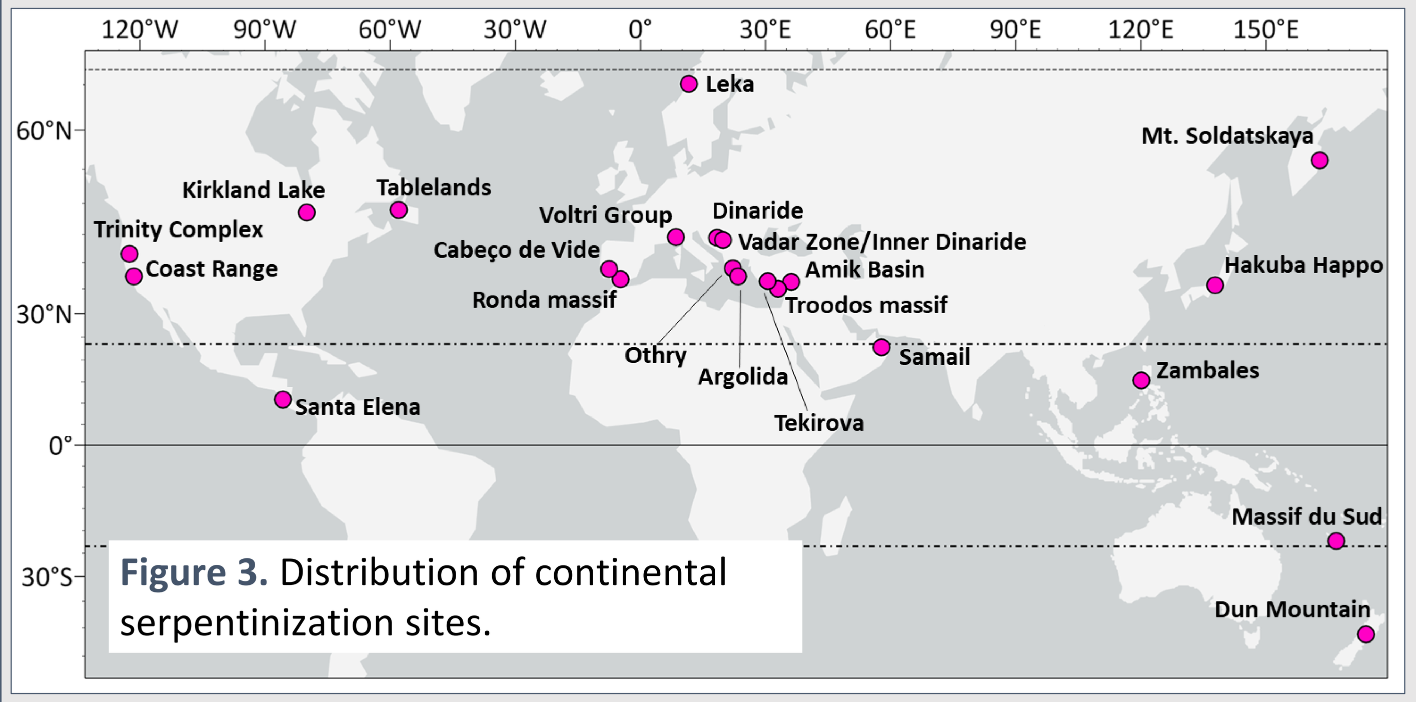


Figure 3. Distribution of continental serpentinization sites.

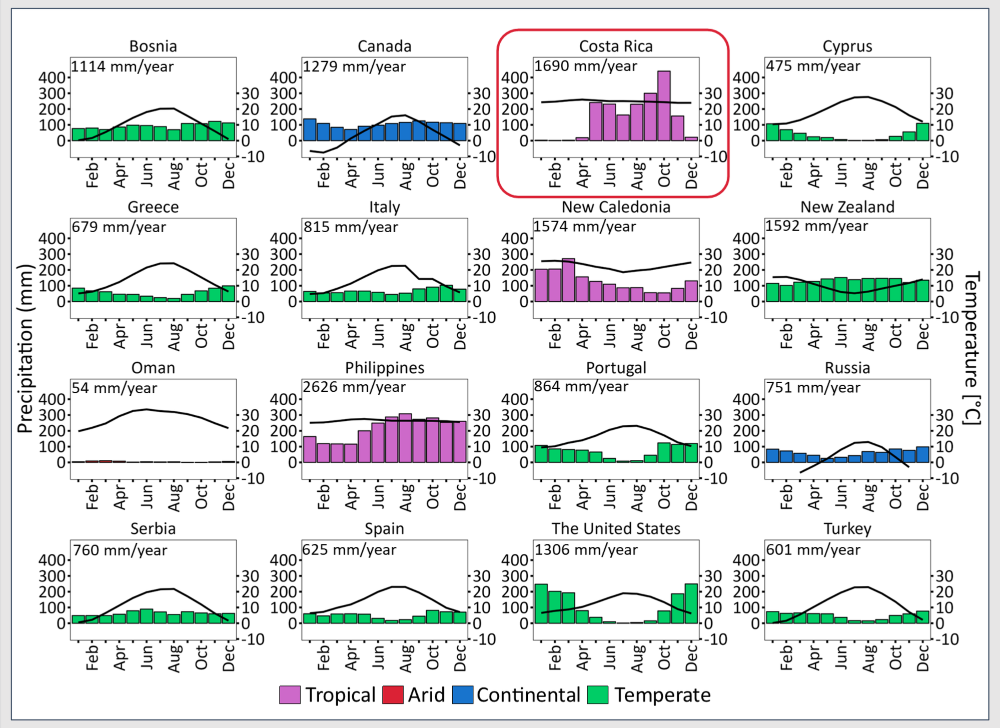


Figure 4. Climographs showing monthly and annual precipitation (mm) and air temperature (°C) seasonality in temperate (green), cold (blue), tropical (pink), and arid (red) serpentinization sites.

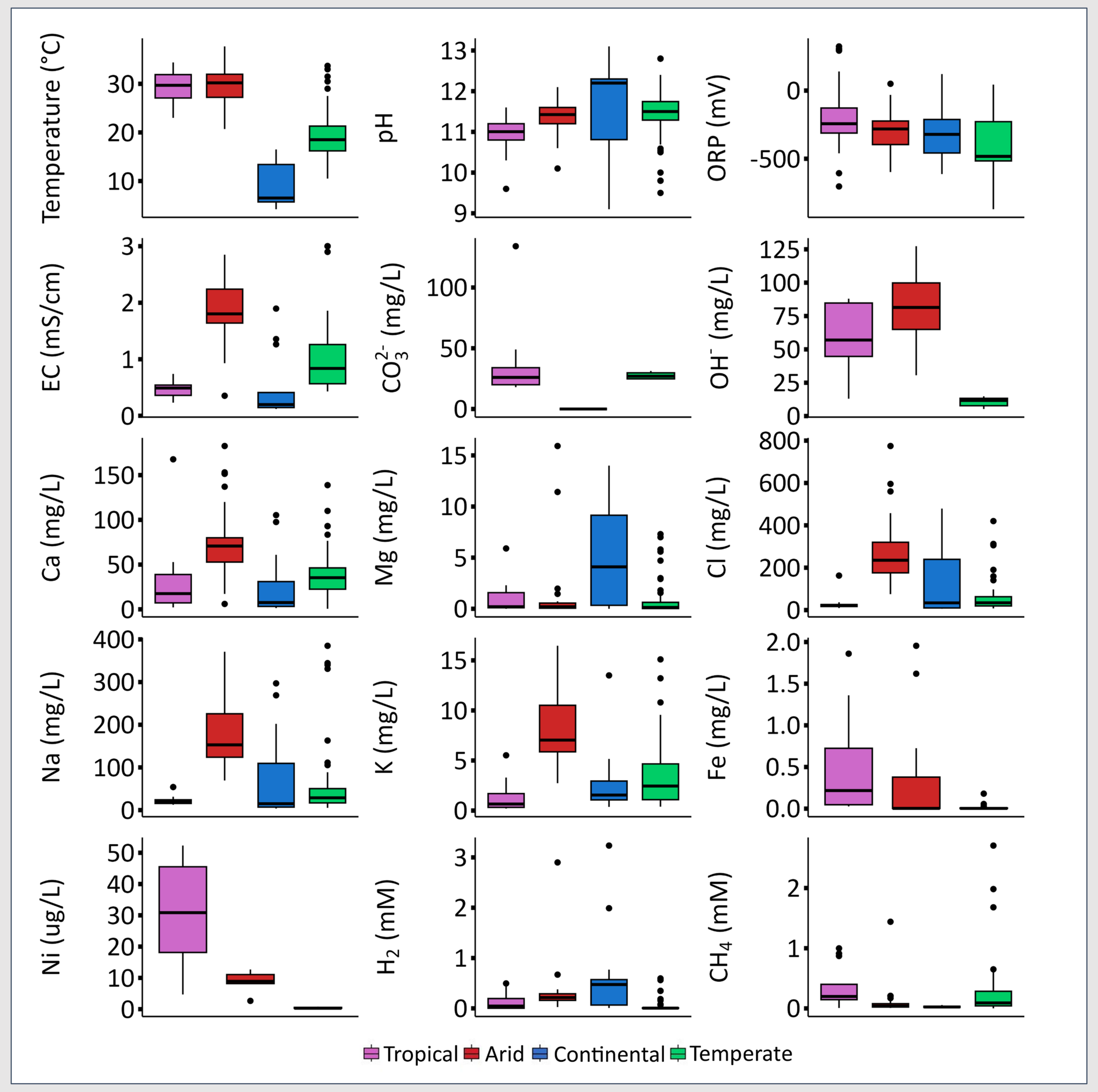


Figure 5. Global pH, alkalinity, major ions, and Fe-Ni compositions synthesis across serpentinization sites.

- **Costa Rica's annual rainfall** budget is, on average, **4.5 times greater than that of temperate sites and 30 times greater than that of Oman.**
- Our global assessment shows that there are **statistically significant differences between the alkaline systems across different climates.**
- While **$GeoH_2$ values in Costa Rica are lower** than those of other continental serpentinization sites, **CH_4 compositions are the highest reported**, with potential contributions from both biotic and abiotic processes.
- Reported **CH_4 concentrations reached up to ~500 µM**, except for relatively **high values in Costa Rica and two deep systems in Bosnia and Oman.**

IV. Santa Elena Ophiolite

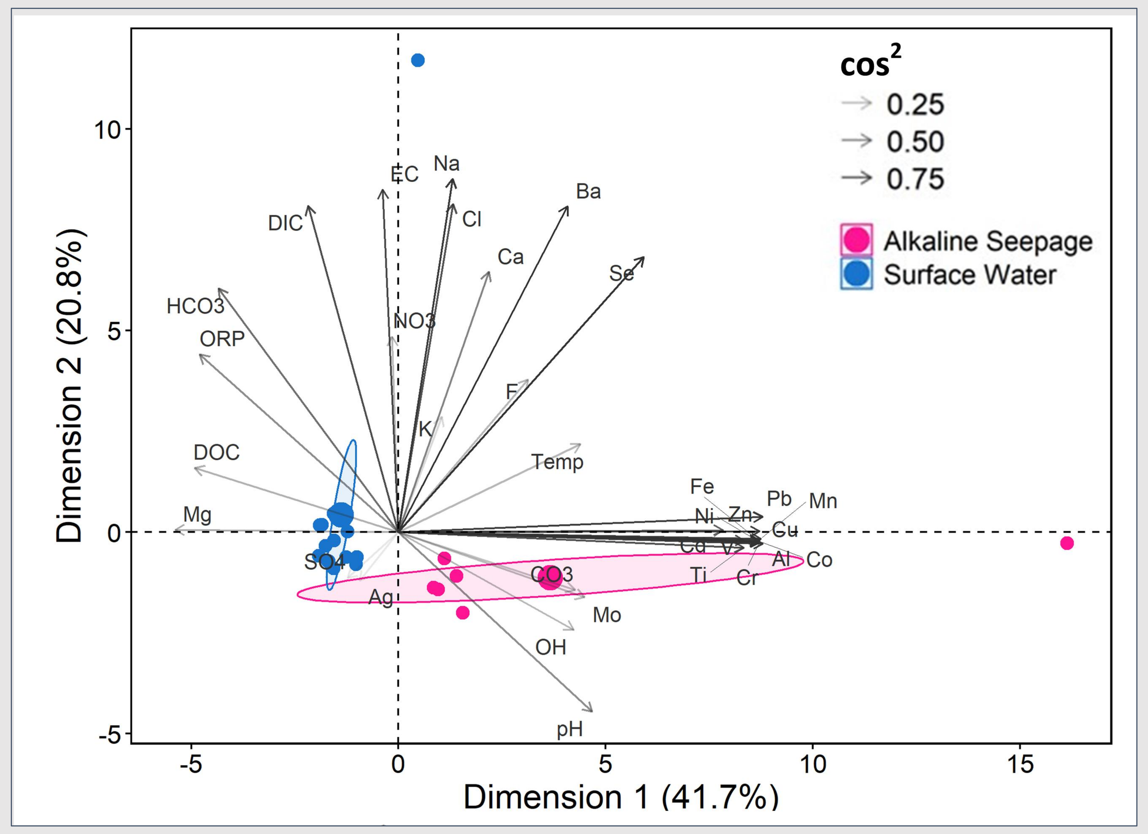


Figure 6. A PCA factor map, including SEO’s surface and alkaline geochemical data.

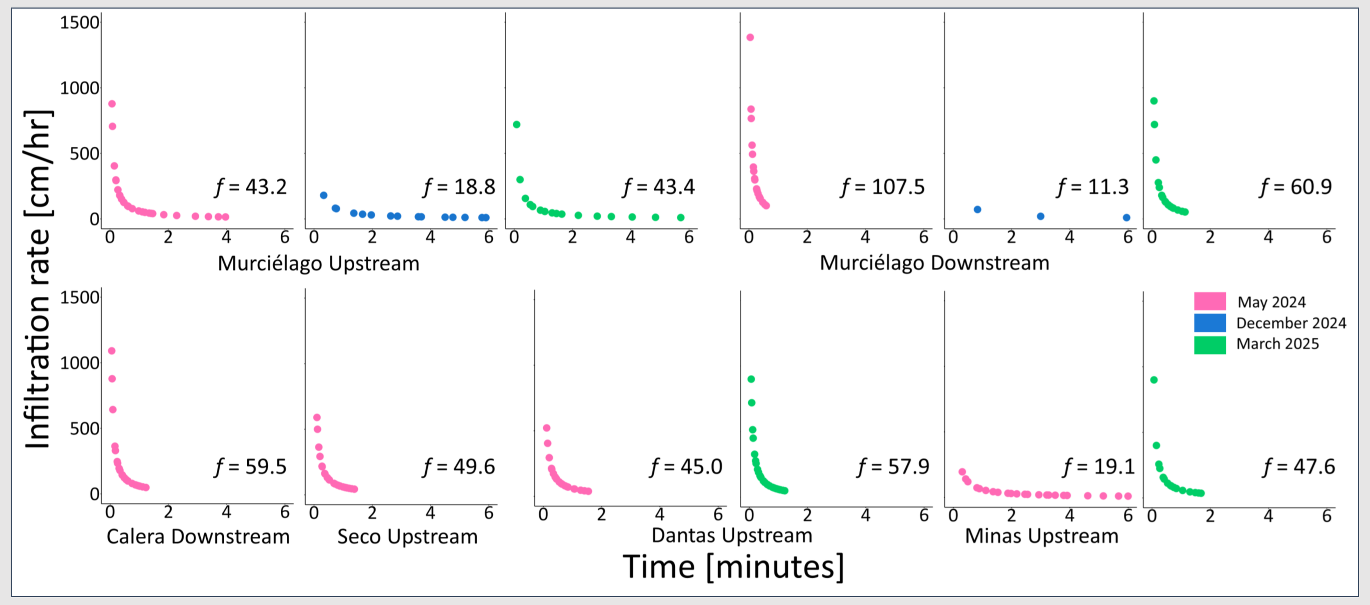


Figure 7. Spatial Infiltration tests across SEO watersheds.

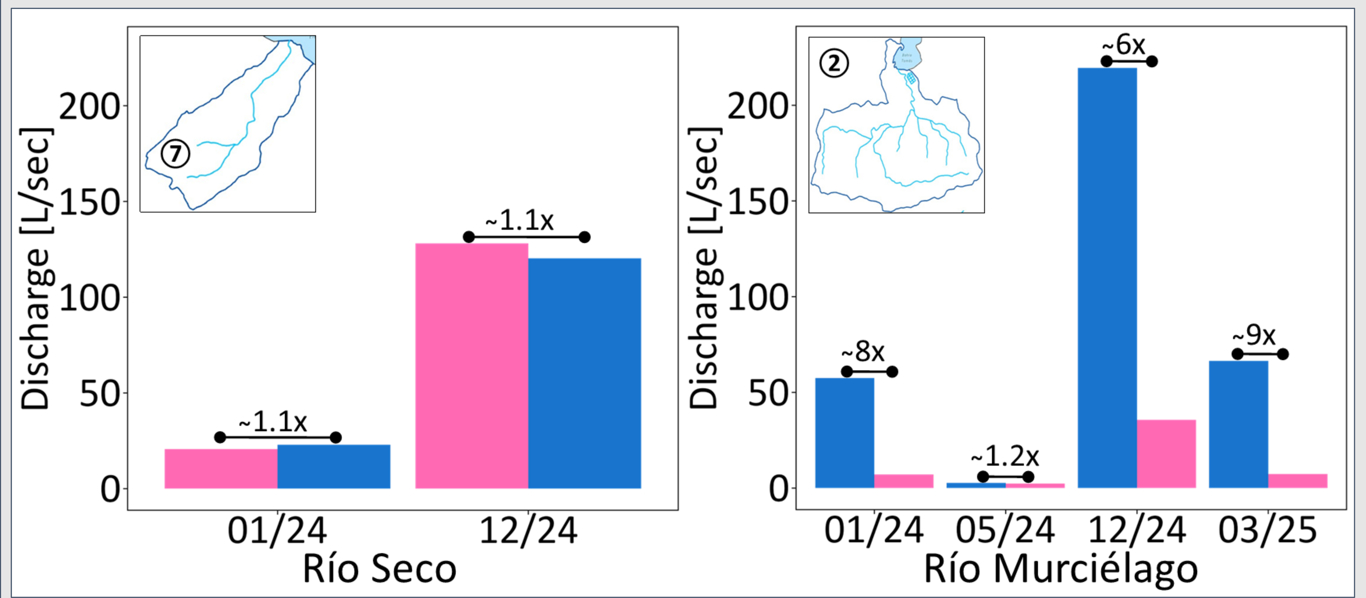
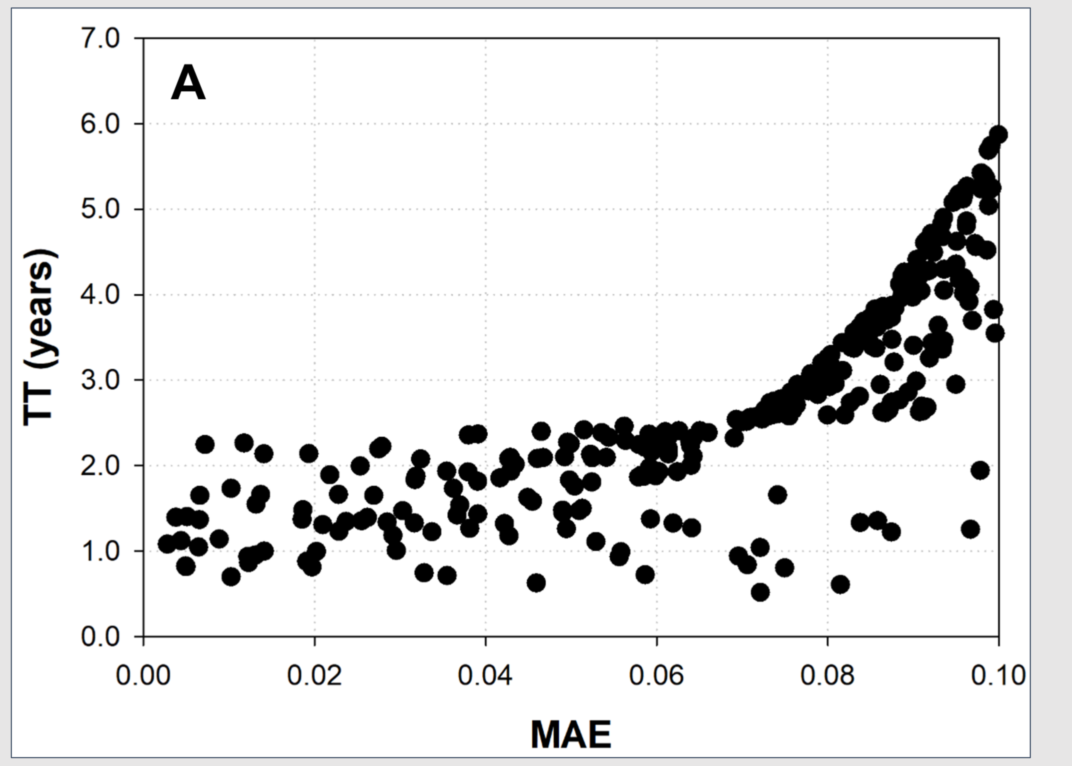


Figure 8. Discharge comparison of downstream and upstream of each Murciélago and Seco watersheds in January, March, and May.

- At the end of the wet season, infiltration rates range from **10 to 20 cm/hour**, suggesting that the soils can still absorb water after the rainy season.
- During the dry season, infiltration rates increase significantly, ranging from **20 to 100 cm/hour**, indicating a high potential for water absorption in the dry soils.
- In the **early dry season**, Q increases **~8x** downstream (over ~1.2 km), aligning with **higher $GeoH_2$ and CH_4** values.
- By late May, after six months without rain, Q increases only **1.2x** downstream.
- A consistent **increase in discharge downstream** in watersheds containing alkaline manifestations.
- Subsurface storage provides sustained flow through **intermittent stream sections.**

V. Groundwater Age



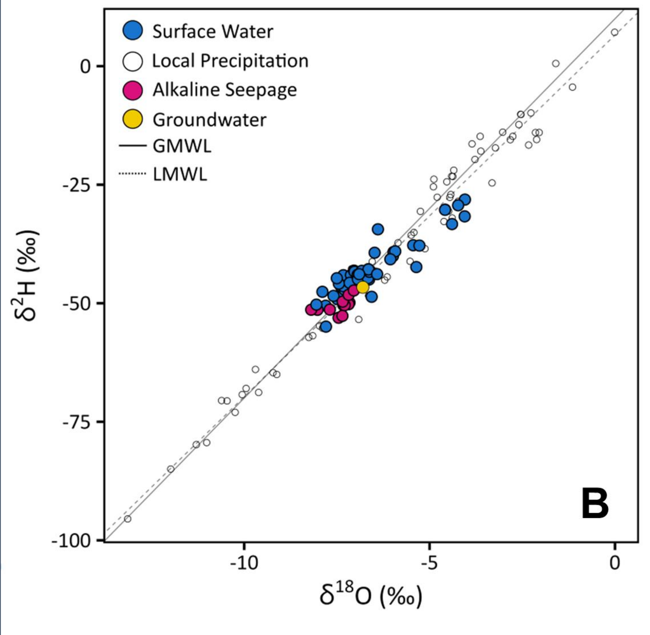


Figure 9. A) Tritium age distribution at SEO using a gamma distribution (with decay) as a transfer function with 10^5 Monte Carlos simulations. The best 327 runs were retained below 0.1 MAE. **B)** A dual water isotope plot for local rainfall, alkaline seepages, surface waters, and mean groundwater composition.

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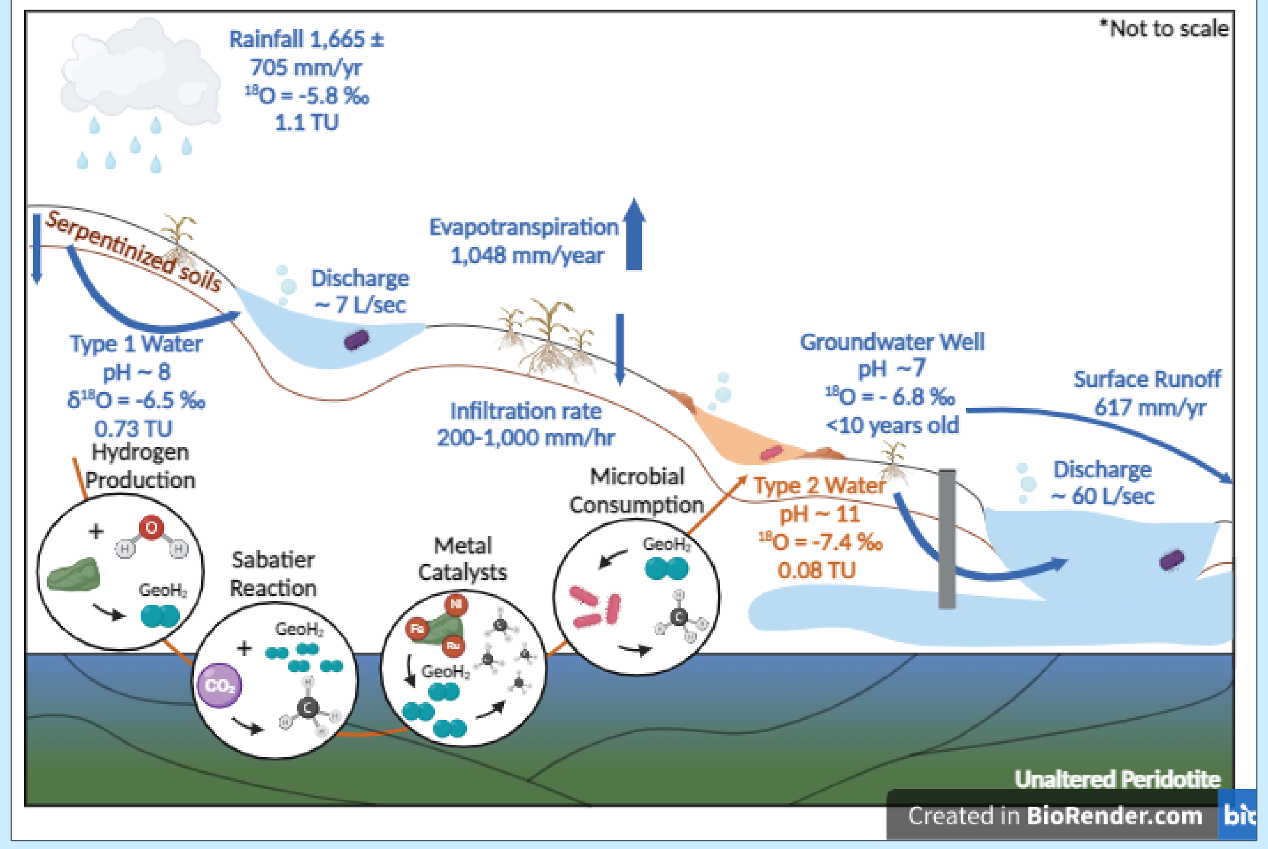

Figure 10. Conceptual diagram highlighting the key processes occurring during the low-temperature serpentinization process.

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