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Deep Serpentinization Processes: Insights into Hydrogen Generation and Fluid Chemistry from Drilling at the Atlantis Massif

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Hydrothermal systems influenced by serpentinization are of broad interest because they generate molecular hydrogen during water–rock reactions, promote carbon sequestration, drive abiotic carbon synthesis, and may have supported prebiotic chemistry on early Earth. These systems span a wide range of conditions, from high-temperature, metal-rich environments to lower-temperature, alkaline systems such as the Lost City Hydrothermal Field (LCHF). Understanding the primary controls on fluid geochemistry in serpentinized lithosphere remains challenging because ascending fluids commonly undergo mixing, microbial modification, mineral precipitation, and conductive cooling that obscure signatures of deep water–rock interaction.

International Ocean Discovery Program Expedition 399 drilled Hole U1601C to 1268 m below seafloor into serpentinized peridotite with gabbroic intrusions at the Atlantis Massif, ~800 m north of LCHF [1]. This borehole provides a rare direct window into active fluid circulation within ultramafic oceanic lithosphere. Post-drilling borehole waters reveal three-component mixing among drilling fluids, bottom seawater, and a zero-Mg, high-Ca formation water discharging into the base of the hole. The deepest samples contain up to 80% formation water enriched in Ca, Li, Rb, Cs, and radiogenic Sr, reflecting equilibration with peridotitic and gabbroic lithologies at elevated temperatures. These data provide insights into the controls on the deeper, higher-temperature fluids that likely contribute to LCHF fluids.

Dissolved volatile and single-carbon molecule concentrations and identify two interconnected hydrogeologic regimes [2]. The deep formation waters host elevated molecular hydrogen, methane, and micromolar ∑formate, with low dissolved inorganic carbon, similar to LCHF vent fluids. These waters likely represent channelized flow along faults and lithologic contacts. In addition, pervasive flow through serpentinized mesh textures and microfractures sustains micromolar H_2 and ∑formate throughout the borehole. In these waters, carbon monoxide was only present in deeper, hotter sections, and potentially associated with gabbroic intrusions into the peridotite host. Together, these observations demonstrate how deep high-temperature reactions and distributed serpentinization collectively regulate reduced carbon and hydrogen fluxes within ultramafic crust, linking subseafloor processes to hydrothermal vent chemistry.

References

[1] Lissenberg et al. (2024) Science 385: 623-629
[2] Lang et al. (2025) GCA 408: 84-104

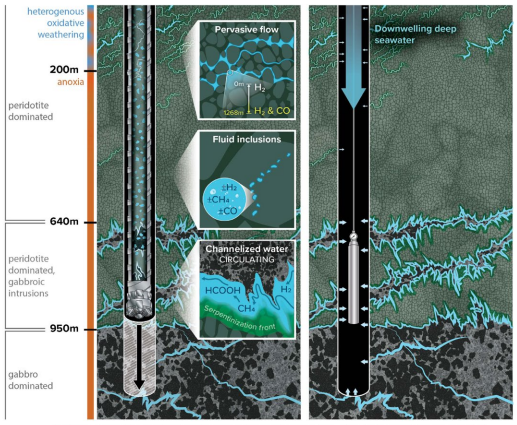

Figure 1. Pervasive and channelized flow can host elevated H_2, CH_4, CO, and formate. From [1]