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High-temperature peridotite mylonites reveal deep organic carbon cycle at Oceanic Transform Faults

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Hydrothermal circulation and associated alteration of the oceanic lithosphere are the first order control on Earth's volatile cycles and have been proposed as a potential driver of the emergence of life on our planet. Constraining the extent of oceanic lithosphere's alteration, and its consequences on lithospheric composition, carbon budget including abiotic organic compound formation is thus key.

While these processes have been investigated at mid-ocean ridges (MOR), oceanic transform faults (OTFs), which regularly segment MOR, have received comparatively little attention. Recent studies, however, suggest that these plate boundaries can be the locus of deep mantle hydration by downward percolation of seawater-derived fluids (to depths of ~ 25-30 km on (ultra)slow spreading ridges; Prigent et al., 2020; Wang et al., 2022), as well as mantle carbonation by upward percolation of magmatic-derived carbon-rich fluids within the fault zone (Klein et al., 2024). Such fluid circulation is key in establishing chemical, particularly redox, disequilibria that influence carbon speciation. In addition, subduction of fracture zones, the fossilized portion of OTFs, is associated with higher slab seismicity and enriched geochemical signatures in overlying arc lavas (e.g. Paulatto et al., 2017). Together, these observations identify OTF as an important yet poorly constrained component of the Earth's volatile cycle, potentially influenced by both hydrothermal and magmatic processes.

This study focuses on constraining the deep volatile cycle on OTFs, with a particular emphasis on carbon. Using deformed and hydrated peridotites from two OTFs of the Southwest Indian Ridge, we characterized water bearing-components (e.g. amphibole, fluid inclusions) that formed during high temperature deformation (700-900℃).
Hydrated silicate phases (e.g. amphibole) serve as indicators of fluid-rock reactions. Trace element concentrations and enrichments in chlorine, boron and lithium suggest a hydrothermal origin for the fluids interacting with the studied mantle rocks, even at great depths.
Fluid inclusions (FIs), mainly hosted in olivine, occur as trails formed near the brittle-ductile transition of the host mineral. Some trails are associated with the formation of the high-temperature shear bands, suggesting syn-deformational fluid trapping. Raman spectroscopy and FIB-SEM analyses of FIs in olivine reveal various crystalline (including serpentine, brucite, magnetite) and gaseous phases (CH4 and H2) in FIs, suggesting intense fluid-olivine reactions during rock cooling. Carbon-bearing phases, including methane and carbonaceous compounds, also formed together with molecular hydrogen, which was likely produced during olivine serpentinization. Methane concentrations (25-136 ppm) and δ13C-CH4 values (-3.8 to -21.5‰), measured for the first time at OTFs, overlap those reported from SWIR gabbros and sediment-starved hydrothermal systems; more work is needed before making robust constraints on the carbon source.

Overall, our results highlight OTF as active sites of deep hydrogen and carbon cycling and emphasize their role in controlling volatile speciation during high-temperature deformation of the upper mantle.

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Paulatto et al. (2017). Nat Commun 8, 15980.
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PhD 2nd year

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