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Potential of Fluid-Mantle Interactions for Abiotic Organic Synthesis on Oceanic Transform Faults

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Recent studies have highlighted the presence of aromatic amino acids (Ménez et al., 2018) and solid organic compounds (Sforna et al., 2018; Andreani et al., 2023) in mantle rocks exposed along the Mid-Atlantic Ridge. These organic compounds were formed abiotically - without the involvement of life - through the reduction of inorganic carbon (e.g., CO_2) by geogenic hydrogen (H_2) during fluid-rock interactions. As fundamental building blocks of more complex organic molecules, which are potential precursors to life, these organic compounds strengthen the hypothesis of a hydrothermal origin of life. In this context, the extent and the impact of lithospheric alteration on the associated carbon cycle and organic chemistry of prebiotic interest remain critical to understand. Interestingly, research on transform faults (OTFs), which are strike-slip faults that segment mid-ocean ridge segments, has revealed that these plate boundaries could be also hydrothermally active with deep hydration reaching depths of up to 25 km (Prigent et al., 2020) and percolation of C-rich fluids in the fault zone (Klein et al., 2024). These findings suggest that OTFs could also be favorable environments for abiotic organic synthesis of potential prebiotic interest on Earth. To assess this potential, petrological and geochemical analyses were conducted on peridotite mylonites from two OTFs on the ultraslow Southwest Indian Ridge, deformed and emplaced at the seafloor from very high temperature/depth on the fault zone (~1000℃).

Hydrated silicate phases (e.g., amphibole) are associated with deformation and serve as indicators of fluid-rock interactions. Trace element concentrations suggest that the fluids that inter acted with studied mantle rocks had a hydrothermal origin, even at great depths on the fault zone.

Fluid inclusions (FIs), which are micro-cavities that trapped a portion of the fluids circulating through fractures, also formed during deformation. The majority of these FIs have been observed in olivine. The formation of FIs is constrained to high temperatures, near the brittle-ductile transition of olivine (~800℃), which allows the mineral to fracture and then heal. These FIs were analyzed through Raman spectroscopy and FIB-SEM cross-sectioning. Results show that all the fluids within the inclusions had reacted with the surrounding mineral to form various crystalline and gaseous phases, among which many carbon-bearing phases with different speciation (e.g., carbonate, organic carbon, including methane, and carbonaceous compounds).

Our results thus indicate a complex carbon dynamics and the first evidence for endogenic organic carbon compounds in an OTF context formed during interaction of deforming mantle rocks with hydrothermal fluids at high temperature. Although these results are promising, questions still need to be addressed regarding the source of inorganic carbon, the composition of hydrothermal fluids percolating into the mantle of OTFs, their impact on the carbon cycle, the mechanisms of organic compound formation, and the roles of magmatism, hydrothermalism, deformation, and temperature in these processes.

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