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From ridge to subduction: fluid inclusions, micro-factories of abiotic organic compounds in the oceanic lithosphere

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Understanding how simple abiotic carbon compounds evolve toward molecular complexity is central to evaluating prebiotic pathways on early Earth. Serpentinization produces H_2 and establishes strongly reducing conditions that thermodynamically favor abiotic organic synthesis, highlighting hydrothermal systems as potential key environments for prebiotic chemistry. Recent work has shown that when COH fluids are trapped in olivine-hosted fluid inclusions, progressive fluid–host reactions during cooling can generate not only key fluid species (H_2, CH_4), but also complex condensed abiotic organic compounds. Here we present a systematic study of multiphase inclusions from the Atlantis Massif (30°N MAR), spanning the entire oceanic lithospheric section, from shallow serpentinized peridotites to deeper troctolites and gabbros drilled during IODP Expedition 304–305. Across all rock types, inclusions contain serpentinization-derived mineral assemblages, key gases (H_2, CH_4, N_2, CH_3SH, C_3H_8), and structurally diverse, heteroatom-rich condensed organics. These observations demonstrate that post-entrapment fluid–host reactions generate diverse carbon-bearing species from shallow to deep lithospheric levels. Serpentinization-driven reactions induce progressive H_2 production, CO_2 reduction, fluid drying, carbon supersaturation, and ultimately the condensation of chemically complex organic material within inclusions. Extending these observations to exhumed subduction rocks, we show that even in the absence of olivine, COH fluids trapped in Fe-bearing minerals along the deep plate interface undergo similar redox reactions with their hosts, likewise leading to condensed organic formation. Fluid inclusions thus act as confined micro-reactors throughout the life cycle of oceanic lithosphere, from ridge to subduction, systematically promoting abiotic organic synthesis. Upon exhumation to life-compatible conditions, subsequent alteration may open these inclusions, releasing organics that are out of equilibrium with their surroundings and potentially capable of further chemical evolution toward increasingly complex, biotically or prebiotically relevant molecules.