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Organic Compounds as Messengers of Subsurface Habitability

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The search for life in the solar system requires the investigation of subsurface environments that are difficult to sample directly. For example, icy ocean worlds like Enceladus and Europa harbor subsurface oceans that are obscured by shells of ice kilometers in thickness, a major obstacle for assessing their habitability. However, volatile chemical species are escaping these worlds that bear signatures of processes occurring in their interiors (Matson et al., 2007; Villanueva et al., 2023).

Here we demonstrate that volatile organic compounds can be used as tracers of geochemical conditions such as temperature, pressure, pH, and redox state. We present a theoretical framework based on thermodynamic calculations along with laboratory validation through aqueous organic chemistry experiments (Robinson et al., 2023; 2024). We show that certain compounds in organic reaction systems approach abundances that are systematically controlled by reaction conditions in a predictable way. More specifically, we observed alcohols, alkenes, ethers, amines, carboxylic acids, amides, and associated reaction products approach metastable equilibrium abundances across wide ranges of experimental conditions (150-325°C, pH 1-10). The results provide strong evidence that concentration measurements of chemical species alone can be used to infer their source conditions.

In addition to their application to icy ocean world exploration, these methods are highly transferrable and could be used to investigate Earth's subsurface as well as ancient conditions in organic materials preserved in primordial rocks, including carbon-bearing meteorites that contain clues about the early solar system.

References

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