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Nanoconfinement Effects on the Geochemistry of Lithospheric Fluids

ALIREZA CHOGANI[1], HELEN E. KING[1,2], BENJAMIN M. TUTOLO[3], ALEKSANDAR ZIVKOVIC[4] AND **PROF. OLIVER PLÜMPER**[1,2]

[1]Utrecht University
[2]University of Bremen and MARUM
[3]University of Calgary
[4]University of Kiel

Water, as a major component of Earth's fluid systems, plays a pivotal role in governing both geochemical and geodynamic processes through its interactions with rocks. These fluid–rock interactions are essential for managing key resources, from subsurface energy extraction and storage to the regulation of the deep carbon cycle and the formation of critical metal deposits. Traditionally, it has been assumed that fluids travel through the lithosphere without being affected by the unique behaviours emerging at the nanoscale. In our study, electron microscopy and neutron scattering reveal that a wide variety of lithospheric rocks, including sandstones, peridotites, and serpentinites, consistently exhibit nanoporosity, with most pores measuring less than 100 nanometres. Moreover, molecular dynamics simulations show that water's dielectric permittivity, a fundamental property that influences its geochemical interactions, deviates significantly under nanoconfinement compared to its bulk state, across conditions ranging from ambient to extremes of 700 °C and 5 GPa. Our geochemical modelling further suggests that this confinement-induced alteration in permittivity leads to reduced mineral solubility, a factor not yet accounted for in conventional fluid–rock interaction models. Given the strong connection between dielectric permittivity and ion speciation, these pore-size-dependent effects are likely to have a major influence on rock reactivity and the overall geochemical evolution of fluids during fluid–rock interactions.

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