Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.34977

Sediment-Controlled Transport of Water into the Lower Mantle via Hydrous Aluminous Phase D

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Water strongly influences mantle dynamics, melting behaviour, and geochemical evolution of Earth's interior, yet the mechanism allowing H_2O transport into the lower mantle remains unresolved. Conventional models predict efficient dehydration of subducting slabs at the 660-km discontinuity because hydrous ringwoodite breaks down into nearly anhydrous bridgmanite and ferropericlase, preventing significant deep-water transport.

Here we present ultrahigh-pressure multi-anvil experiments in the Al_2O_3–SiO_2–H_2O system conducted at 18–50 GPa and up to ~3000 K, simulating conditions from the mantle transition zone to the lower mantle. Phase relations determined using Schreinemakers analysis demonstrate that hydrous aluminous phase D ($Al_2SiO_4(OH)_2$) possesses exceptional thermal stability compared with other hydrous aluminosilicates such as phase Egg and δ-AlOOH. Aluminous phase D remains stable along both normal mantle and plume geotherms and exhibits a steep positive Clapeyron slope of ~35 K/GPa. NanoSIMS measurements show that this phase incorporates ~10 wt% H_2O, an order of magnitude greater than hydrous stishovite.

Our results indicate that H_2O released from decomposing hydrous ringwoodite at the 660-km discontinuity can be captured by Al-rich sedimentary layers, where phase Egg progressively transforms into aluminous phase D with increasing pressure. This process consolidates slab-derived water into a thermally stable solid reservoir capable of transporting H_2O throughout the lower mantle.

Upon plume entrainment, breakdown of aluminous phase D generates hydrous melts, providing a potential source for the elevated water contents observed in ocean island basalts. These findings identify subducted sediments as a previously unrecognized control on deep Earth water cycling and establish a new solid-state pathway linking surface water recycling to deep mantle geochemistry.