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In Situ Viscosity Measurements on Iron-Rich Silicate Melts under High Pressure: Evaluating the Solidification Regime of the Martian Magma Ocean

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One of the most intriguing discoveries of NASA's InSight mission is the identification of a thick basal magma layer (~150 km) atop the Martian core [1]. This layer could have profound implications for Mars' thermochemical evolution, significantly delaying deep cooling and influencing the planet's global properties. The solidification of the magma ocean at the beginning of Mars' accretion could have induced chemical fractionation, potentially giving rise to distinct geological reservoirs. However, current models of mantle thermal evolution and crustal extraction rely on limited knowledge of the physical properties of iron-rich Martian melts, particularly their viscosity under deep mantle conditions [2].

How did the Martian magma ocean crystallize and evolve over time? Could the recently discovered basal magma layer be the remnants of an ancient magma ocean? Answering these questions requires a better understanding of the viscosity of Martian melts. Viscosity is a key parameter that governs the extent of chemical equilibrium between silicates and metallic liquids forming the core, as well as the physics of crystal settling in a convecting magma. It also strongly influences the cooling rate of a primordial magma ocean and the timescales of planetary differentiation. To address this, we conducted high-pressure (~3–15 GPa) and high-temperature (~2500 K) viscosity measurements on iron-rich pyrolitic compositions using the falling-sphere technique in a multi-anvil press at DESY and SPring-8 synchrotrons. By tracking the terminal velocity of rhenium spheres falling through silicate melts via ultrafast X-ray imaging, we determined viscosity based on Stokes' law.

Our results contribute to developing a viscosity model for iron-rich silicate melts under Martian mantle conditions, integrating experimental data with theoretical frameworks [3]. This model aims to evaluate the role of iron in controlling melt viscosity and its implications for planetary differentiation and magma ocean longevity [4]. By improving our understanding of magma rheology in planetary interiors, this study provides new constraints on Mars' interior evolution, including its thermal history, and the potential longevity of a basal magma ocean.

1. Samuel et al., Nature 622, (2023).
2. Sanloup et al., Nature 503, (2013).
3. Monteux et al., Geophys J Int 221, (2020).
4. Bower et al., Planetary Science Journal 3, (2022).