Anomalous viscosity of basaltic melt at mantle conditions constraining the timescales of the early magma oceans

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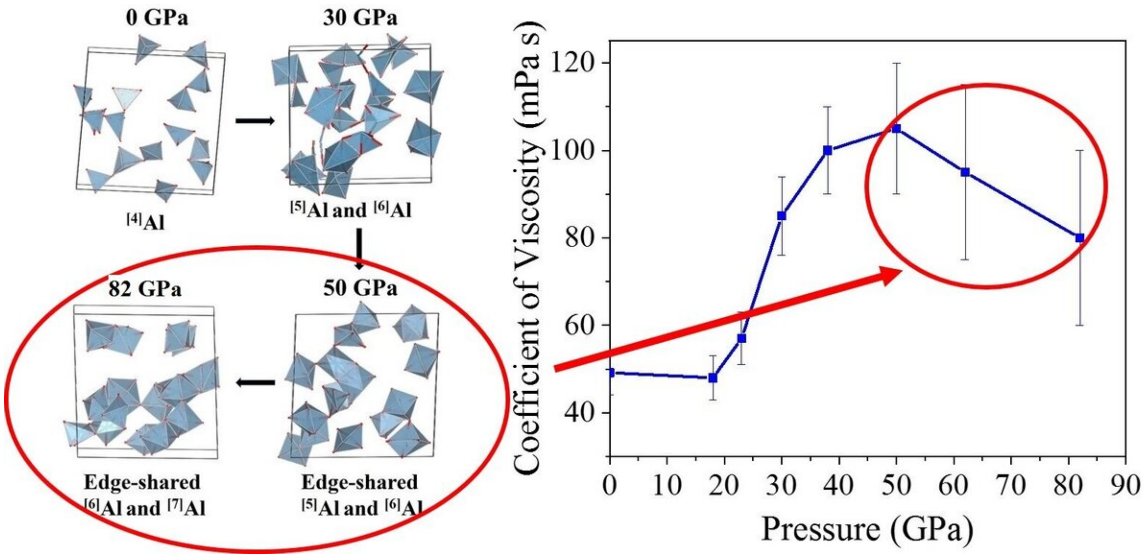

(Left) Polyhedra of Al–O linkages showing the transition from 0 to 82 GPa via 30 and 50 GPa at 2200 K. [4]Al, [5]Al, [6]Al and [7]Al are the four, five, six, and sevenfold coordinated Al atoms. (Right) Coefficient of viscosity of the model basaltic melt at 2200 K as a function of pressure. Credit: University of Saskatchewan

Researchers at the University of Saskatchewan, Canada, along with their collaborators at Zhejiang University of Technology, China, and RIKEN Center for Computational Science, Japan, made significant advances in constraining the age of the early Earth's magma oceans. The results were recently published in *Nature Communications*.

Transport properties like diffusivity and viscosity of melts dictated the evolution of the Earth's early magma oceans. In this work, the authors have explored the pressure evolution of the structures, densities, and transport properties of a realistic model basaltic melt. This model basaltic melt consisted of CaO, MgO, Al_2O_3, and SiO_2. The computations were performed using first-principle molecular dynamics simulations mimicking the pressure and temperature conditions of the mantle of the Earth. The research team led by Prof. John S. Tse from the Department of Physics and Engineering Physics at the University of Saskatchewan found anomalies in the form of reversal of the transport properties (diffusion and viscosity) under the lower mantle conditions. This reversal has been attributed to temporal atomic interactions at high pressure which are fluxional and fragile.

The silicon-oxygen and aluminum-oxygen bonds are decisive factors that led to the conclusions of the transport properties. In this work, the researchers observed that at pressures roughly above 50 GPa, the bonds become very fragile and keep breaking very frequently with time. There is extreme rapid interconversion between five, six, and seven-fold coordination of the silicon and aluminum atoms with respect to the oxygen atoms. This fluxional behavior of the bonds is expected to modify transport properties by enhancing diffusivity and reducing viscosity at that pressure range.

Viscosity is a very significant parameter that controlled virtually all the dynamic processes in the early Earth's magma oceans. Magma oceans are generally accepted to be responsible for the formation of the metallic core and the silicate mantle through differentiation as well as the atmosphere and hydrosphere through degassing. Previously, the timescales of magma ocean crystallization were suggested to vary from thousands to millions of years. This number depends on the viscosity of the magma. Earlier it was assumed that the viscosity was very high thus predicting timescales of ~100–200 million years for magma oceans. More recent studies using different assumptions have reduced the timescales of magma oceans to a few million years. Our calculations with the reversed trend at ~50–82 GPa predict the viscosity magnitudes of ~0.1 Pa s for basaltic melts under most lower mantle conditions. This provides support for the short timescales of magma oceans at a few million years.

"We have not only successfully constrained the short timescales of magma oceans at a few million years but also provided a tantalizing explanation for the horizontal deflections of superplumes at around 1000 km below the Earth's surface," said John S. Tse.

More information: Arnab Majumdar et al. Structural dynamics of basaltic melt at mantle conditions with implications for magma oceans and superplumes, *Nature Communications* (2020). DOI: 10.1038/s41467-020-18660-w

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