MEASUREMENTS OF THE VISCOSITIES AND DENSITIES OF SILICATE MELTS BY DYNAMIC NEUTRON IMAGING

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Introduction

Volcanic processes such as magma ascent and emplacement are governed to a large extent by the viscosities and densities of the magmas involved. The physical properties of magmas strongly depend on temperature and composition. For example, the viscosity decreases by 10 orders of magnitude when going from a pure silica (SiO_2) melt to a melt with diopside ($CaMgSi_2O_6$) composition at a constant temperature of 1500 K [1]. Other factors determining the viscosities of geologically relevant magmas are the amount of crystals in the melt, the concentration and size of bubbles formed during degassing and the amount of dissolved volatiles. While an understanding of the rheological behaviour of magmas is of fundamental importance in the Earth Sciences, the amount of reliable experimental data on physical properties of melts is limited and mostly restricted to homogenous melts. This severely constraints our ability to model volcanic processes. In order to provide more data on the physical properties of melts, we have developed a novel method for the simultaneous *in situ* determination of viscosities and densities of silicate melts which is accurate and can be used to investigate chemically inhomogeneous melts. In addition, rheological processes in magmas can be directly observed.

Method

We modify the well known falling sphere technique by using dynamic neutron imaging for a real-time, *in situ* observation of spheres falling in silicate melts. We use spheres of Gd, Er, Hf and Ta, which strongly absorb neutrons and are practically inert with respect to the melt, where the latter is essentially transparent for neutrons. The spheres have diameters between 2-5 mm, the sample height is typically 80 mm. The sample is illuminated by a parallel white neutron beam, and after transversing the sample and conversion to visible light, the transmitted intensity is recorded with a video camera.
A set of typical video frames is shown in figure 1.

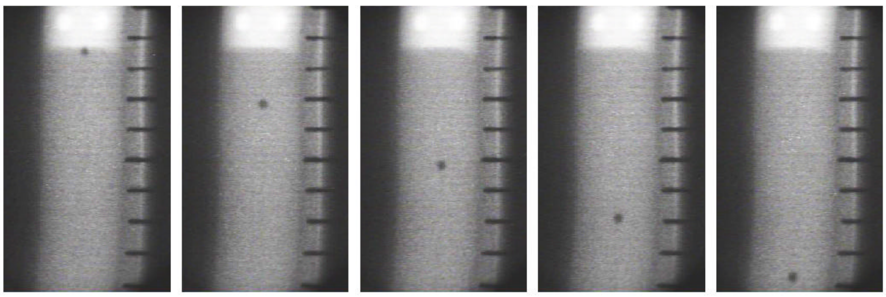

Figure 1: Frames from a video recording of a falling sphere experiment. The sphere has a diameter of 3 mm, the time between the first and last image is 30 min.

With software based on pattern recognition, the time-dependence of the position of the sphere is analysed. Typical data are shown in figure 2.

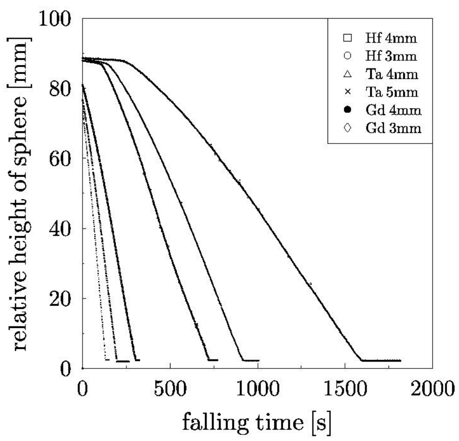

Figure 2: Plot of the relative height of spheres with different composition and diameter falling down in a melt as a function of time. The respective velocities are obtained from the slope of the lines.

The data analysis is based on Stokes' law. As we independently vary both sphere diameters and sphere densities, we can solve a set of equations at constant temperature and obtain the viscosity and density to within a few percent. This has been confirmed by comparison to standard samples. The high accuracy of this method is partially due to the absence of convection. This can be demonstrated by partially doping the melt, which is also the technique used to visualize rheological processes (see figure 3).

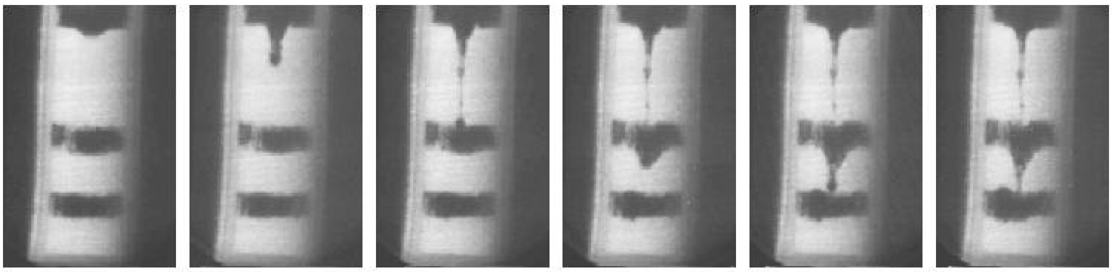

Figure 3: Real-time observation of a sphere falling through a silicate melt at 1050°C. The black and white layers are of equal density but the black ones are doped with gadolinium oxide. The boundaries between the layers stay sharp, indicating the absence of convection.

Summary and Outlook

Dynamic neutron imaging has been used to monitor spheres falling in silicate melts, thereby allowing an accurate *in situ* determination of melt viscosities and densities. In contrast to other methods, our approach does not require any calibration and can be used for partially crystalline melts. A new furnace designed for these experiments allows measurements at temperatures up to 2000^{o}C. An autoclave for high-pressure experiments of volatile-containing melts is currently being constructed. Furthermore, the direct observation of rheological processes is possible. This is currently used to investigate magma mingling.

[1] Stebbins J.F., McMillan P.F., Dingwell D.B. (eds): Structure, Dynamics and Properties of Silicate Melts, Reviews in Mineralogy, MSA, Vol.32.

Acknowledgement

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