
Knowledge of the densities of silicate liquids can provide important constraints on our understanding of magma transport processes and differentiation within planetary interiors. To date, silicate liquid densities have been reported on a range of compositions at pressures up to about 20 kbar using the "falling sphere" technique (e.g., 1), but data from higher pressures have been lacking. Attempts have been made to calculate densities of silicate liquids at higher than atmospheric pressure using measured 1 atm densities and compressibilities together with assumptions about the pressure and temperature dependence of compressibility, but these calculations are speculative (2,3). Although these calculations are consistent with the experimental data available, they are poorly constrained at higher pressures where many important magmatic processes occur. We have developed an experiment for measuring silicate liquid densities using shock wave techniques and report here preliminary results on a model basaltic composition.

The sample configuration during the experiment is depicted in Fig. 1. A silicate sample (10 mm diameter, 3 mm thick) is sealed into a cylindrical molybdenum capsule assembly, the rear surfaces of which are polished to a mirror finish. The sample is hung and aligned in the impact tank and heated under vacuum to the requisite temperature with a water-cooled copper induction coil powered by a 10 kW Lepel High Frequency Induction Heating Generator. A Pt-Rh thermocouple located in a well in the molybdenum capsule is used to measure the sample temperature. Impact of the heated sample assembly is accomplished by a flyer plate-bearing projectile and the shock velocity through the sample material is measured using reflected light techniques that have been adapted to our 40 mm gun apparatus (4).

The material chosen for initial experiments is the 1 atm eutectic composition in the system anorthite-diopside, An_{36}Dio_{64}. A low melting point (1275°C), low viscosity (≈40 poises at 1400°C; 5), and a composition that differs from natural basalts mainly in the absence of iron and alkalis make this an attractive material for preliminary experiments. In addition, measured ultrasonic velocities in the system anorthite-diopside (6,7), enable a good estimation of the 1 atm compressibility of this composition.

Fig. 1. Diagram of shock experiment for molten silicate target. Projectile velocity prior to impact is measured via laser obscuration and double flash x-ray radiograph. Temperature of sample, measured with Pt-Rh thermocouple, determines initial molten silicate sample density (calculated using liquid silicate partial molar volumes; 6). Shock velocity is measured by determining the time difference between the shock arriving at planes A and B. Shock propagation time through Mo cover plate must be subtracted from sample plus cover plate travel time introducing an error of only 0.3% in the measured shock velocity. Ceramic shutter shadows expendable mirror until ~1 sec before shot.
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Results of the first shock wave experiments on liquid silicates are shown as the two data points in Fig. 2. A theoretical Hugoniot is also shown in Fig. 2. Shock temperatures ($T_h$) have been estimated along this theoretical Hugoniot using standard methods (9). The calculated Hugoniot temperatures lie below the probable liquidus temperatures above about 15 kbar in the pressure range considered in Fig. 2. At 60 kbar $T_h \approx 1530^\circ$C. Obvious features in the shock wave data, that would imply a sudden collapse to a more dense structure or crystallization into a the solid phase assemblage, are absent. This leads us to suggest that the data points represent a smoothly compressible liquid at high pressure.

The density of a solid of composition $An_{0.86}Di_{0.14}$ at 1400°C has been calculated as a function of pressure, and is also shown in Fig. 2. At low pressures, this solid assemblage is metastable at 1400°C. At pressures above 30 kb the phase assemblage is assumed to be diopside+kyanite+grossular+quartz/coesite. This yields a maximum estimate of density as consideration of a CaAl$_2$SiO$_4$ component in the diopside would reduce the density further. Because anorthite breaks down at 30 kbar, the density contrast between liquid and solid actually increases at this point. However, at higher pressures, the greater compressibility of the liquid relative to the solid phases leads to a reduction of density contrast.

Based on the comparison with the calculated Hugoniot (Fig. 2) our preliminary results suggest that $K'$ may be nearer to 4 than to the previously speculated values of 6-7 (2,3). Calculations for basaltic melt using similar values of $K_o$ and $K'$ ($K_o=228$, $K'=4$) lead to the expectation that such a melt will approach the density of its host mantle at 80-100 kbar.