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Temperature-induced densification in compressed basaltic glass revealed by in-situ ultrasonic measurements

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Abstract

Acoustic velocities of a model basalt glass (64 mol% $CaMgSi_2O_6$ + 36 mol% $CaAl_2Si_2O_8$) were measured along different pressure-temperature (*P*-*T*) paths. One set of experiments involved isothermal compression-decompression cycles, performed at temperatures of 300, 641, 823, and 1006 K and pressures up to 12.2 GPa. The other set of experiments involved constant-load heating-cooling cycles at temperatures up to 823 K and pressures up to 7.5 GPa. Both sets of experiments were performed in a multi-anvil apparatus using a synchrotron-based ultrasonic technique. Our results show that the glass compressed isothermally at 300 K (cold-compression) displays anomalously decreasing compressional (V_P) and shear (V_S) wave velocities with increasing pressure until ~8 GPa. Beyond 8 GPa, both V_P and V_S start to increase sharply with pressure and irreversible densification of the glass occurred, producing large hysteresis loops of velocities upon decompression. However, for the glass compressed isothermally at increasingly higher temperatures (hot-compression), the velocity minima gradually shift to lower pressures. At temperature close to the glass transition temperature T_g, the velocity minima disappear completely, displaying a monotonic increase of velocities during compression and higher V_P and V_S during decompression. In addition, constant-load heating-cooling experiments show that velocities generally decrease slightly with increasing temperature, but start to increase once heated above a threshold temperature (~650 K). During cooling the velocities increase almost linearly with decreasing temperature, resulting in higher velocities (~1.5–2.5% higher) when returned to 300 K. This implies that a temperature-induced densification may have occurred in the glass at high pressures. Raman spectra on recovered samples show that the hot-compressed and high-*P* heated glasses contain distinctly densified and depolymerized structural signatures compared to the initial glass and the cold-compressed glass below the velocity transition pressure P_T (~8 GPa). Such densification may be attributed to the breaking of bridging oxygen bonds and compaction in the intermediate-range structure. Our results demonstrate that temperature can facilitate glass densification at high pressures and point out the importance of *P*-*T* history in understanding the elastic properties of silicate glasses. Comparison with melt velocity suggests that hot-compressed glasses may better resemble the pressure dependence of velocity of silicate melts than cold-compressed glasses, but still show significantly higher velocities than melts. If the abnormal acoustic behaviors of cold-compressed glasses were used to constrain melt fractions in the mantle low-velocity regions, the melt fractions needed to explain a given velocity reduction would be significantly underestimated at high pressures.

Keywords: Silicate glass, acoustic velocity, high pressure and high temperature, intermediate-range structure, low-velocity regions