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Water-dominated CO_2 diffusivity in silicate melts: a unified experimental dataset

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As the second most abundant magmatic volatile after water, carbon dioxide (CO_2) plays a critical role in eruption dynamics. Due to its lower solubility compared to H_2O, CO_2 is the first species to exsolve during magma ascent, acting as a driving force for bubble nucleation at depth. The rate of bubble growth is limited by the transport properties of these volatiles within the melt. Slow CO_2 diffusion relative to H_2O often leads to disequilibrium degassing and high degrees of supersaturation, providing the energy for highly explosive eruptions. However, experimental constraints on CO_2 mobility in hydrous magmas remain sparse. This study fills that gap by providing a comprehensive, internally consistent set of CO_2 diffusion coefficients (D_{CO2}) covering the basalt-to-rhyolite spectrum as a function of dissolved H_2O.

Diffusion couple experiments were conducted at 200–300 MPa and 775–1315 °C using rapid-quench internally heated and cold-seal pressure vessels. Symmetrical CO_2 concentration profiles, measured via FTIR micro-spectroscopy, were fitted with error functions to derive individual D_{CO2} values.

Our results align with and extend existing Arrhenius relationships across all investigated systems. Anhydrous compositions exhibit steeper Arrhenius slopes for basalt compared to felsic melts, reflecting higher activation energies (Ea) and greater temperature sensitivity in depolymerized mafic systems. Despite these differing slopes, total CO_2 diffusivity displays a remarkable near-constancy across the entire compositional range at high temperatures (>1200 °C), confirming that D_{CO2} is largely insensitive to anhydrous bulk chemistry. In contrast, dissolved H_2O exerts a dominant control on transport, accelerating D_{CO2} by approximately one order of magnitude with the addition of ~4 wt% H_2O (e.g., from log D_{CO2} ≈ −11.26 to −10.45 at 1250 °C in basalt) while simultaneously lowering the activation energy, in agreement with previous studies [1–2]. These results indicate that CO_2 transport is primarily governed by temperature and hydration state rather than melt structure. By providing a unified and high-resolution dataset, this work enables more accurate modeling of CO_2 degassing dynamics during the ascent of hydrous magmas.

[1] Watson E. B. (1991). *Geochimica et Cosmochimica Acta* 55, 1897–1902.

[2] Koch L. and Schmidt B. C. (2023). *European Journal of Mineralogy* 35, 117–132.