Goldschmidt 2025 Abstract
https://doi.org/10.7185/gold2025.28320

Connecting Rocky Planet Interiors and Atmospheres through Volatile Solubility Experiments and Numerical Tools

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Planetary science is entering an exciting new technological era with sample return missions and advanced spacecraft providing the most in-depth view of the rocky bodies in the Solar System. These efforts will allow us to place Earth in the wider context of planet formation and evolution. In preparation for these upcoming observations, we must develop a comprehensive understanding of the connection between rocky planet interiors and atmospheres. During the main stage of planet formation, the heat from accretion and impacts likely generates global magma oceans on planetary embryos and young planets. Because the atmospheres of these planets during the magma ocean stage are thought to be the result of chemical equilibrium with their interiors, their mass and composition are modulated by the solubilities of major gases in the magma. Therefore, we require a theoretical framework, informed by experimental data, to determine how volatile elements partition between the interior and atmosphere for diverse planetary compositions. However, there is limited experimental data on the solubilities of major atmosphere-forming gases in a range of silicate liquids which may be unlike that of the present-day Earth, including that of Earth's primitive mantle. To fill this gap, we performed new volatile (e.g., H, O, S) solubility experiments on planetary melt analogs at high temperatures (1400 - 2500 ℃) using a 1-bar H_2-CO_2 gas-mixing furnace and an aerodynamic laser levitation furnace coupled to an FTIR spectrometer. We incorporate these experimental results into a new Python package (*atmodeller*), which computes chemical equilibrium at the melt-atmosphere interface of rocky bodies. Given a set of planetary parameters (e.g., surface temperature, planetary mass, radius, mantle melt fraction) and volatile inventory, *atmodeller* uses experimentally calibrated solubility laws (including those determined from our experiments), together with free energy data for condensed and gas species, to determine how volatiles partition between the atmosphere and interior. Within the H-C-N-O-S-Cl system (along with noble gases), we investigate the atmospheric compositions and the impact of volatile dissolution into the interior for a set of plausible scenarios for early Earth, Venus and Mars during their magma ocean stage.