AN IMPROVED METHOD TO ESTIMATE THE MANTLE SOURCE PRESSURE AND TEMPERATURE OF LUNAR LOW-TI PICRITIC GLASS.

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Introduction: Lunar picritic glass erupted during ancient (3.3–3.7 Ga) volcanic fire-fountain events [1]. These glasses are widely accepted to have originated from low-degree partial melting of cumulate mantle sources, providing valuable insights into the physical and chemical nature of the lunar mantle [2]. The pressure-temperature conditions (P-Ts) of mantle sources for Apollo-returned picritic glasses have been precisely determined through high P-T melting experiments (e.g., [3]). In these experiments, the major-element compositions of primitive picritic glasses were used as starting materials. Source P-Ts were identified when the system reached multiple saturation with olivine and orthopyroxene on the liquidus during partial melting.

Beyond the Apollo collections, recent studies have identified significant quantities of picritic glasses with varying compositions in lunar regolith breccia meteorites (e.g., [4]). However, conducting high P-T melting experiments for these meteorite-derived glasses is often infeasible due to time and cost constraints. Alternative methods, such as Si-activity liquid thermobarometry and thermodynamic modeling of multiple saturation points (MSPs), have been applied to estimate their source P-Ts (e.g., [5]). These methods, however, were not rigorously calibrated for lunar picritic compositions, resulting in largely qualitative and uncertain estimations.

To address these limitations, we assessed the applicability of thermobarometers and thermodynamic modeling for lunar low-Ti picritic compositions. Our approach involves comparing modeled results with experimentally derived MSP P-Ts for Apollo low-Ti picritic glasses to improve calibration and reliability.

Methods: We applied two independent methods to establish a reliable relationship between picritic glass composition and its formation P-T: the Si-activity liquid thermobarometer proposed by [6] (Si-activity model) and thermodynamic modeling algorithm proposed by [7] (GeoPS model). For the GeoPS model, we used the "igneous set" ds633 thermodynamic database [8] and the a-X relations for olivine, pyroxene, plagioclase, spinel, and garnet from [9], focusing on the CFMAS (CaO-FeO-MgO-Al_2O_3-SiO_2) system. The magma H_2O content was set to zero, and the fO_2 was maintained at IW-1.

To evaluate the applicability of these models, we compared their predicted P-T conditions for MSPs with experimentally determined P-T values, which are considered accurate for primary melts. Starting compositions for this comparison were derived from Apollo-14 and Apollo-15 low-Ti picritic glasses, with experimental reference data obtained from [3, 10–11].

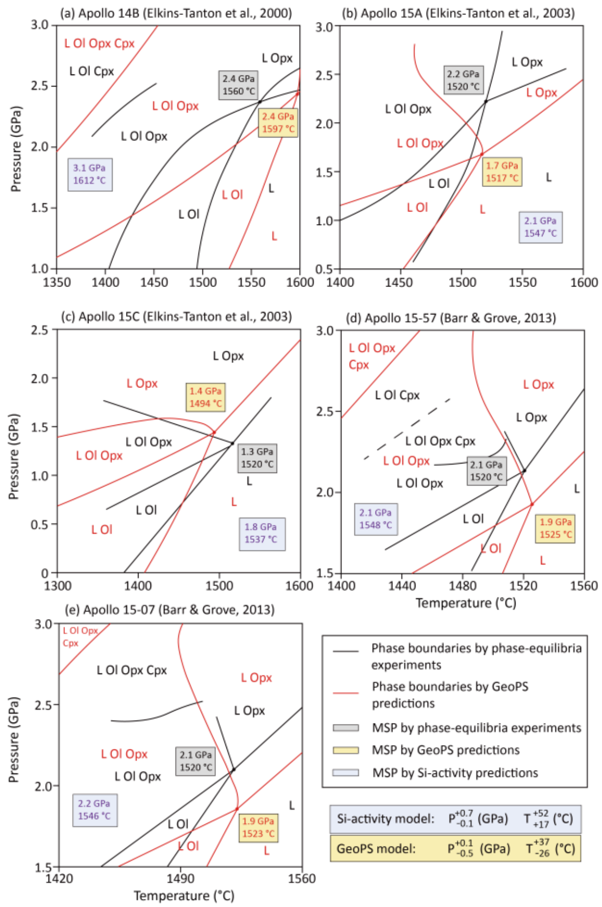

Figure 1. Phase diagrams P-Ts of MSPs, determined from experiments using lunar VLT picritic glasses as starting materials [3, 10–11], compared with predictions from Si-activity thermobarometer [6] and GeoPS thermodynamic model [7].

Results: The Si-activity model exhibited a pressure error range of $^{+0.7}_{-0.1}$ GPa and a temperature error of $^{+52}_{-17}$ °C, with an average overestimation of pressure by 6 kbar and temperature by 30 °C (Fig. 1). In contrast, the GeoPS model showed a pressure error range of $^{+0.1}_{-0.5}$ GPa and a temperature error range of $^{+37}_{-26}$ °C, generally underestimating pressure by 4 kbar while providing temperature estimates accurate to within ±40 °C (Fig. 1). These findings indicate that the Si-activity model tends to overestimate the formation P-T conditions of lunar low-Ti picritic glasses, while the GeoPS model often underestimates formation pressure but yields more reliable temperature estimates. We recommend using the Si-activity model to define the upper pressure bounds and the GeoPS model for the lower pressure bounds of mantle source regions. The GeoPS model is also preferred for constraining temperature estimates.

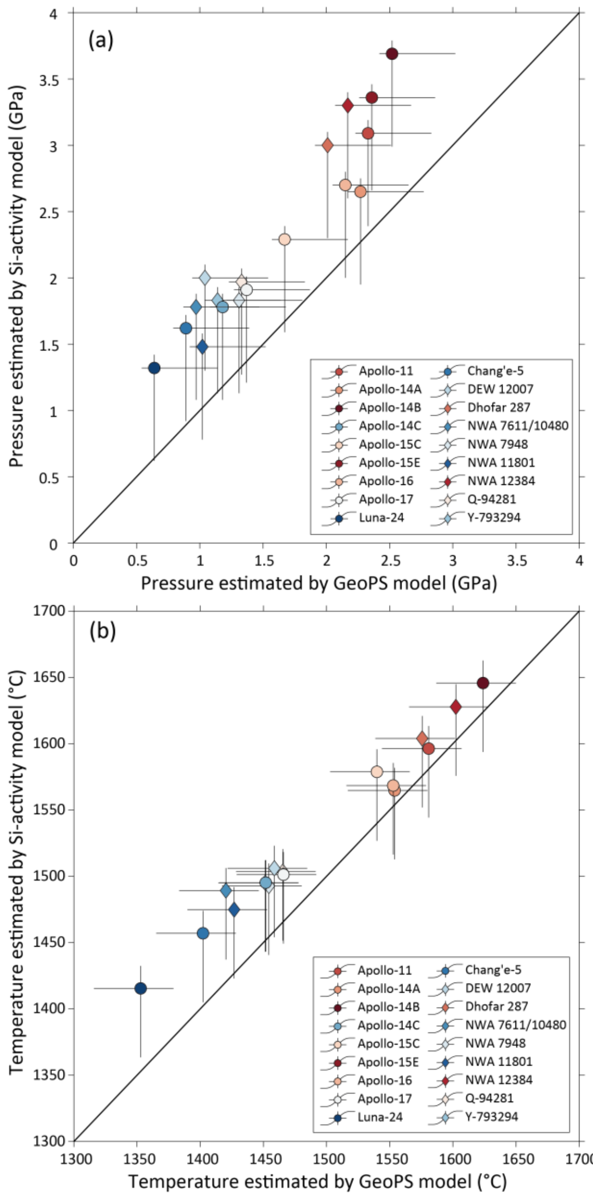

Figure 2. Comparative diagrams showing predicted pressures (a) and temperatures (b) of low-Ti picritic primary magmas derived from both returned lunar samples and meteorites. The predictions are based on two different modeling approaches: the Si-activity model and the GeoPS model. The compositional data of these picritic glass were collected from literatures.

Discussion: We further applied the Si-activity and GeoPS models to estimate the P-T conditions of previously reported low-Ti picritic glasses. Prior to estimation, we reconstructed the primary magma compositions for each glass group by incrementally adding olivine to the picritic glass using the meltPT program [12], until the magma was in equilibrium with the most primitive olivine in each glass group.

The P-T estimations revealed a strong positive linear correlation between the results of the Si-activity model and the GeoPS model (Fig. 2). The comparison indicates that the Si-activity model consistently predicts higher pressures than the thermodynamic model, whereas temperature estimates from both models align closely within the stated error range. These results are consistent with aforementioned experimental validations, confirming the reliability of these models under lunar conditions. Furthermore, the positive linear correlation between the predictions from the two models demonstrates that observed variations in P-T among different samples reflect intrinsic properties of the magmas, rather than artifacts of the modeling methods.

Conclusions: We recommend using the Si-activity model [6] to estimate the upper pressure limits and the GeoPS model [7] to determine the lower pressure limits for the mantle source regions of lunar low-Ti picritic glasses. For temperature estimations, the GeoPS model provides reliable constraints with an error range of ±40 °C.

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