

CARBON IN LUNAR MAGMAS: ABUNDANCE, SPECIATION AND ROLE IN MAGMATIC PROCESSES. D. Wetzel¹, M.J. Rutherford¹, E.H. Hauri², and A.E. Saal¹. ¹Dept. of Geological Sciences, Brown University, Providence RI 02912 (Diane_Wetzel@brown.edu), ²DTM Carnegie Institute of Washington, DC 20015 (hauri@DTM.ciw.edu).

Introduction: Carbon has been proposed as the element responsible for the generation of the gas phase that drove lunar fire-fountain eruptions [1, 2] and produced vesicles in lunar basalts [3]. The gas phase is generated by the oxidation of C carried in the magma from depth [4]. Carbon has been previously identified both in and on lunar glasses volcanic glasses [5, 6, 7], but a lunar magmatic origin was not demonstrated. Recently Saal et al. [8] identified residual diffusion-loss profiles of H₂O, F, Cl, and S for a range of picritic glasses, indicating the volatiles were being lost from the beads during the eruption. They also found that the core abundance correlated with non-volatile trace element abundances, indicating the volatiles are characteristic of the melt and originated with the melt in the lunar interior. With new SIMS detection limits of 0.13 ppm C, Saal et al. [9] determined that picritic glass beads contained from 0-10 ppm C. Earlier studies [2] predicted that very little dissolved C would be expected in the beads because of the CO-rich nature of the gas and the low pressure of first gas formation. The role of graphite in forming the gas in lunar magmas has been confirmed by experiments [10] that show graphite in a graphite-saturated A17 orange glass (OG) magma oxidizes to form a CO-rich gas at 40 MPa (8.5 km depth) during ascent. This paper describes the results of SIMS and RAMAN analyses on previous experiments and the results of new graphite-saturated experiments for both the A17 orange and A15 green glass compositions. The study was designed to (1) determine the abundance and speciation of C in graphite-saturated picritic lunar magmas at lunar oxidation state conditions and (2) investigate how the pressure of graphite oxidation varies with magma composition in the picritic magmas.

Experimental and analytical methods: Experiments on synthetic A15 green and A17 orange glass compositions were carried out in an IHPV on pellets of powder reduced to an fO_2 equivalent to IW. Samples were run with excess graphite in sealed Pt tubes as described by Nicholis and Rutherford [10]. Temperatures were 1350°C for the orange glass and 1465°C, or about 15°C above the liquidus T, for the green glass. Pressures ranged from 30-150 MPa. Samples were quenched to a glass and analyzed by EMP, SIMS and Raman spectroscopy.

Results: Experiments at 1350°C for the A17 orange glass composition with the sample pre-set at

IW and enclosed in graphite contained a glass with no sign of an excess gas phase at pressures >40 MPa [10]. At pressures below 40 MPa, successively larger amounts of Fe-metal were present in melts (glasses) with lower FeO. Gas bubbles were also present (Fig.1).

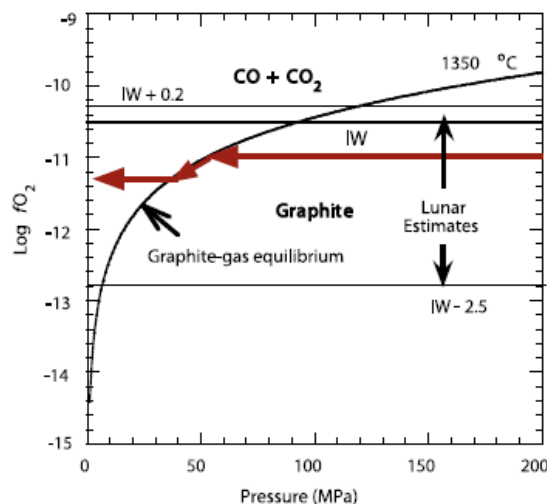


Fig. 1. Log fO_2 vs. pressure plot illustrating the calculated graphite-CO (GCO) surface at 1350°C [10]. The oxygen fugacity range of IW +0.2 to -2.5 for lunar interior is referenced to IW buffer at 1350°C [2]. CO-rich gas is generated where the melt (arrow path) intersects the GCO surface, and reduction of the melt produces Fe-metal with the oxidation of graphite.

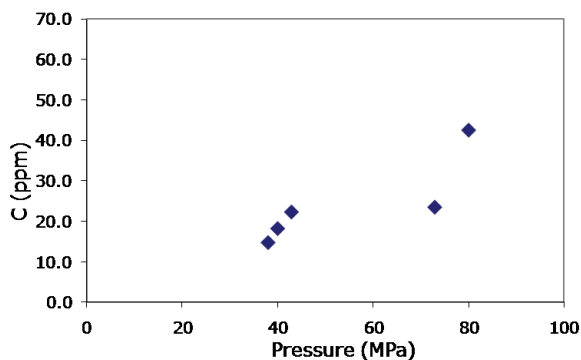


Fig. 2. C content vs. pressure for orange glass experimental samples [10], determined by SIMS with a C detection limit of 0.13 ppm C. Variation within a sample is all within the size of the spot. Four highest pressure experiments contain glass and graphite only; 38 MPa experiment also contains Fe-metal plus a CO-rich gas.

Five of the OG experimental samples have been analyzed by SIMS and found to contain from 15 to 50 ppm dissolved C (Fig. 2). Raman spectra of these samples show a small 784 cm^{-1} shoulder on the 754 cm^{-1} peak that we interpret to be a C-Si feature. We make this interpretation because there is no C-O Raman peak identified in the spectra, and the presence of C in the melt is clearly seen from the SIMS data, given the detection limit (0.13 ppm). Previous work [11] at very high pressures has suggested that C-Si bonds were present in mafic glass produced in equilibrium with Fe-metal. It is not certain that the SIMS C abundances (Fig. 2) represent a good approach to equilibrium since the experiments were of relatively short duration (2 hrs). Longer duration experiments have been done, but not yet analyzed to explore this possibility. The existing data (Fig. 2) involves three experiments at 38-43 MPa with similar but progressively higher C with increasing pressure. The two experiments above 40 MPa have no associated gas phase and no Fe-metal. Together these data suggest the C content of these melts (glasses) is probably close to the equilibrium value.

Experiments on the A15 Green Glass "C" composition [12] were all at 1465°C , just above the 1440°C liquidus temperature. Samples of these experiments have yet to be analyzed by SIMS or Raman, but the data show that graphite oxidation for this composition occurs at the same 35-40 MPa pressure as for the OG composition.

Discussion and Conclusions: Analyses of the natural picritic lunar glasses and experimentally produced samples of A17 orange and A15 green glasses appear to confirm the model of gas formation by C-oxidation in lunar magmas as they ascend through a depth of about 8 km below the lunar surface. This process of gas formation begins with the oxidation of graphite and/or C dissolved in the silicate melt. The speciation of C in the graphite-saturated mafic melt at fO_2 's representative of the lunar interior appears to be with Si. If the mafic melt was not saturated with graphite (activity of C < 1), the C oxidation reaction should begin at somewhat shallower depths for melt at the same oxidation state. Experiments with Ni present have not yet been done, and the results could be significant since Fe-metal in the orange glass beads contains ~14 wt % Ni. Theoretically, the presence of Ni would also tend to push the C-oxidation reaction to lower pressures (shallower depths) in the Moon. Experiments involving Ni and volatiles, such as F, Cl, and H_2O , clearly will be important in attempts to better understand where lunar volcanic gasses were generated and in evaluating the volatile contents of the natural lunar glasses.

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