

PRELIMINARY HIGH PRESSURE PHASE RELATIONS OF APOLLO 15 GREEN C GLASS: ASSESSMENT OF THE ROLE OF GARNET. D. S. Draper, S. A. DuFrane, and C. K. Shearer, Institute of Meteoritics, 1 University of New Mexico, MSC03-2050, Albuquerque, NM 87131, david@draper.name

Introduction: Pristine lunar glasses constitute unique probes of the interior of the Moon, because they were delivered to the lunar surface directly from their source regions. In conjunction with inferences drawn from compositions of selected mare basalts, their origins can help shed light on the mineralogy of the deep lunar mantle and thus on interpretations of the internal structure of the Moon.

Recently, Neal [1] argued that trace element and Lu-Hf isotopic features [2] of several pristine glasses and some mare basalts require the presence of garnet in their source regions. We therefore set out to test this hypothesis experimentally, and the project outlined here is part of a combined experimental and analytical approach to elucidating processes in the deep lunar interior, as reported last year [3]. In this contribution we report preliminary near-liquidus phase relations of Apollo 15 green glass C (A15C hereafter) at 2.5 to 4.5 GPa. It has the highest Mg#, lowest TiO₂ content, and lowest REE abundances of all the pristine lunar glasses. Although A15C is not among the candidate glasses identified by Neal [1] as reflecting garnet involvement (e. g. Zr/Y and chondrite-normalized Sm/Yb above those for KREEP while having low Sc/Sm), it remains of interest because it constitutes one endmember of the pristine lunar glass suite. Similar experimentation on pristine glasses from Apollo 14 (green A), 17 (74220 type), and 12 (red) is planned as part of this ongoing investigation.

Experimental procedures: Experiments on A15C were performed in the High Pressure Laboratory at the Institute of Meteoritics using a Walker-style multianvil press with cell assemblies and run procedures identical to those described in [4]. Major- and trace-element compositions of A15C were reported by Delano [5] and Shearer and Papike [6] respectively. Our starting material was the same powdered glass of A15C composition used in the experiments of [7], kindly provided by Dr. L. Elkins-Tanton, eliminating any compositional discrepancy between those lower-pressure results and the data reported here. All experiments were performed in unsealed graphite capsules under nominally anhydrous conditions.

Several experiments reported here (run numbers A57 and above) were performed on A15C glass doped with Sr, Ba, Nd, Sm, Dy, Y, Yb, Sc, Hf, Zr, and Th at ~50-100 times chondritic abundances, suitable for ion microprobe analysis. This suite of 2+, 3+, and 4+ cations will permit the successful application to the data of the lattice strain partitioning model of Blundy

and Wood [8], as we have done recently for garnets grown in an ordinary chondrite bulk composition [9]. At the time of writing, these run products have not yet been analyzed by ion probe; we anticipate that these (and subsequent runs using the doped starting material) will have been analyzed by the time of the conference, and we will report those results at that time.

Results: Table 1 lists experimental conditions and resultant assemblages. Figure 1 shows provisional phase relations and includes those from lower pressures determined by Elkins-Tanton et al. [7].

Run no.	P, GPa	T, °C	Assemblage
A41	2.5	1675	Liq, gt, px
A67	3.0	1775	Liq, gt
A42	3.0	1750	Liq, gt, px
A38	3.0	1725 </td <td>Liq, gt, px</td>	Liq, gt, px
A57	3.5	1800	Liq, gt, px
A37	4.5	1800	Liq, gt, px

Table 1. Results on Apollo 15 green C. *Liq* = liquid, *gt* = garnet, *px* = pyroxene.

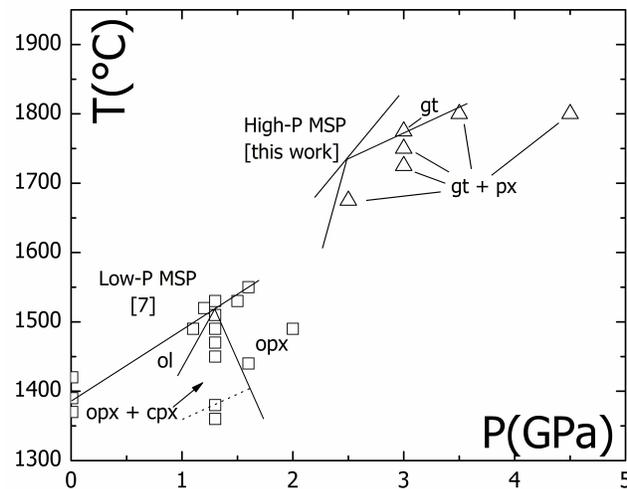


Figure 1. P-T phase relations of Apollo 15 green C glass. Results at 2 GPa and below from [7]. Provisional phase relations at 2.5 GPa and above from this study. *MSP* = multiple saturation point. *Gt* = garnet, *opx* = orthopyroxene, *cpx* = clinopyroxene, *px* = single-phase pyroxene (see text). *MSP* at ~2.5 GPa is preliminary.

Phase assemblages. Table 1 and Figure 1 show that garnet is the liquidus phase for A15C at ~3 GPa, 1775°C. Figure 2 shows a backscattered electron photomicrograph of run A67 in which only garnet coexists with liquid. The phase fields on Figure 1 are clearly provisional at this stage; ongoing experimentation will

flesh out these relations. In particular, the location of the multiple saturation point (MSP on Figure 1) at ~2.5 GPa is likely to shift as more experiments are performed. It seems clear, in any case, that there is likely to be a MSP between liquid, garnet, and pyroxene in a P-T range of 2.5-3.0 GPa and 1700-1800°C; we consider it as only an approximation in the Discussion below. It is also apparent from Figure 1 that the slope of the liquidus surface of A15C will probably change at some pressure between 2.0 and 2.5 GPa. This “kink” is consistent with the effect of the appearance of garnet on and near the liquidus, as has been shown in many previous experimental studies on a wide variety of primitive compositions.

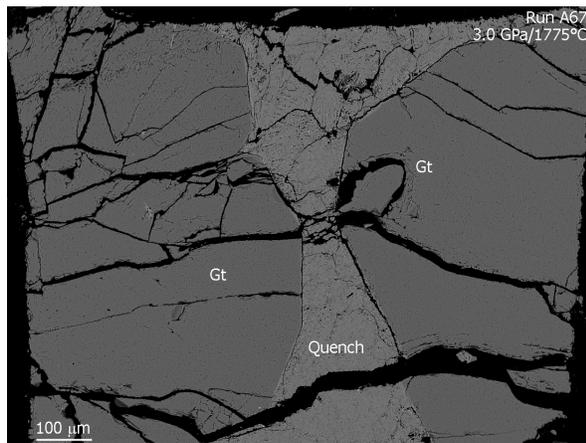


Figure 2. Backscattered electron photomicrograph of run A67 showing large, well formed garnet coexisting with liquid. Dark lines are decompression fractures.

Phase compositions. Garnets in our experiments have compositions of $\text{Py}_{55-65}\text{Alm}_{22-33}\text{Gr}_{12-14}$. In addition, garnets show a slight but distinct majorite component even at 2.5 GPa, where Si and Al per 12-oxygen formula unit are ~3.05 and 1.87, respectively, ranging to 3.12 Si and 1.70 Al per formula unit at 4.5 GPa (ideal pyrope would have exactly 3.0 and 2.0 Si and Al per 12-oxygen formula unit, respectively). The appearance of a measureable majorite component in garnets grown in this Fe-rich bulk composition is consistent with the formation mechanism of majoritic garnet we proposed in our recent L-chondrite experiments [9]. We anticipate that these garnet compositions will significantly affect the partitioning of trace elements, as we reported in that study. In addition, van Westrenen et al. [10] and Pertermann et al. [11] have documented the strong effects of Ca and Ti contents, respectively, on garnet-melt element partitioning, and results from this ongoing study will permit the assessment of these effects as well (e.g. as Ti-rich lunar glasses are investigated).

Pyroxenes in our experiments differ markedly from those formed at lower pressures [7]. We find single-phase pyroxene having a compositional range $\text{En}_{69}\text{Fs}_{17}\text{Wo}_{14}$ at 2.5 GPa to $\text{En}_{54}\text{Fs}_{23}\text{Wo}_{22}$ at 4.5 GPa. In contrast, Elkins-Tanton et al. [7] found multiple saturation of A15C with olivine, low-Ca pyroxene, and sub-calcic augite at ~1.3 GPa (Figure 1). We infer that in their runs, 200-300°C cooler than ours, crystallization drives pyroxenes to the limbs of the solvus, forming both cpx and opx, whereas at our higher temperatures (and pressures), pyroxene is above the solvus and so can form a single, intermediate composition. This inference is supported by high-pressure experiments by Lindsley [12] in the enstatite-diopside system, which show the solvus at 4 GPa to have a maximum temperature of ~1600°C, well below the temperatures in our experiments. Also, our pyroxenes are quite similar to those reported by Chen et al. [13] on A14 VLT glass at 1-2 GPa.

Discussion: MSPs have possible interpretations ranging from the conditions of melt extraction from a protolith's residua (which may have melted extensively enough to exhaust an originally present phase) to an average depth of melting in a series of polybaric processes. Elkins-Tanton et al. [7] invoked a model of episodic recharge combined with assimilation to explain the A15A-C compositional trend, and noted the problematic nature of accounting for the Al_2O_3 contents of these glasses (7-8 wt%). For example, pyroxene in the source would be completely consumed to produce these amounts [14], and spinel is not a liquidus phase for green glasses [15]. If the P-T range of our provisional high-pressure MSP for A15C in fact reflects a deeper origin for A15C or a precursor liquid, it could imply the existence of a garnet-bearing pyroxene-rich protolith at ~500 km depth in the Moon. Such material could represent both a source of Al_2O_3 and a remnant of primitive, unprocessed lunar mantle as suggested by Neal [1]. Measured trace element partitioning in our run products should help distinguish among these competing interpretations.

References: [1] Neal, C. R. (2001) JG, 106, 27865 [2] Beard, B. L., et al. (1998) GCA, 62, 525 [3] Shearer, C. K., et al. (2003) XXXIV LPSC, 1456 [4] Agee, C. B., et al. (1995) JGR 100, 17 [5] Delano, J. W. (1986) XVI LPSC, D201. [6] Shearer, C. K., et al. (1993) GCA, 57, 4785 [7] Elkins Tanton, L. T., et al. (2003) MAPS, 38, 515 [8] Blundy, J., et al. (1994) Nature, 372, 452 [9] Draper, D. S., et al. (2003) PEPI, 139, 149 [10] van Westrenen, W., et al. (2001) G-Cubed, 2, 2000GC000133 [11] Pertermann, M., et al. (In press 2004) G-Cubed [12] Lindsley, D. H. (1980) Rev Mineralogy, 7, 289 [13] Chen, H. K., et al. (1982) XIII LPSC, A171. [14] Longhi, J. (1992) XXII LPSC, 343 [15] Seifert, S., et al. (1988) Earth, Moon, and Planets, 40, 45