

LIQUIDUS EQUILIBRIA OF LUNAR ANALOGS IN THE GARNET STABILITY FIELD. J. Longhi, Lamont-Doherty Earth Observatory, Palisades, NY 10964

New melting experiments have been performed in the range of 28 to 30 kbar on partially crystallized synthetic glasses in order to refine parameterizations of liquidus boundaries and crystal/liquid partition coefficients employed in polybaric fractional fusion (PFF) calculations (1,2). Results confirm that PFF of a low- $\text{Al}_2\text{O}_3$  (< 1.5 wt%), low- $\text{Mg}'$  (~0.80) source may yield composite melts similar in composition to the picritic green volcanic glasses (3): a) if pressure-release melting (~1%/kbar) begins very deep within the Moon (1200 km, ~40 kbar), b) if ~60% of the available melt effectively separates after each 1-2 % melting, and c) if there is some means of aggregating the melt produced over a range of depths. New results from high  $\text{Mg}'$  compositions also agree with predictions (4) that the clinopyroxene(cpx) coexisting with olivine(ol) + orthopyroxene(opx) ± garnet(gar) on the solidus of anhydrous planetary mantles in the garnet stability field is not only low in CaO (5-8 wt%), but is also supercritical.

Volcanic glasses with picritic compositions (3) have posed a thorny problem for petrologists: their compositions are multiply-saturated with olivine and orthopyroxene at pressures of 17.5 to 25 kbar (cf. 5) and traditionally the pressure of multiple saturation is interpreted as the minimum pressure of melt segregation, yet on the Moon these pressures translate to depths of 350 to more than 500 km.. The physics of transporting melt these distances through cracks without altering the melt composition have been modeled (6) and the possibility of such transport seems remote at a time in lunar history when the thickness of the elastic lithosphere was on the order of 50 to 100 km (7). Thus polybaric melting models analogous to those proposed for terrestrial midocean ridge basalts (8) provide attractive alternatives. Algorithms in the polybaric melting model proposed by the author (1) depended upon several extrapolations of phase equilibria and crystal/liquid partitioning from experiments at lower pressures on terrestrial compositions, so a series of melting experiments was initiated to provide data at high pressure with which to test and refine the model. The first round of experiments [(2) - partial results in Fig. 1a] produced melts with  $\text{Mg}'$  (0.40-0.45) lower than that appropriate for the green glasses. The new experiments (Fig. 1b and c) have multi-saturated melts with  $\text{Mg}'$  ranging from 0.50 to 0.78 — the lower end of the range are more appropriate to green glass source regions, whereas the higher values are appropriate to proposed bulk Moon compositions that are similar to the Earth's upper mantle (e.g., 9)

The new experiments also provide relevant data on partitioning and phase equilibria. There are dramatic increases in the molar partition coefficients ( $D^*$ ) for  $\text{Al}_2\text{O}_3$  for opx/liq and aug/liq from average values of ~0.1 and ~0.2, respectively, at low pressure to values of ~0.5 and ~0.7 at 30 to 40 kbar (Fig. 2). Although in both cases the strongest correlating factor is P/T, the aug/liq coefficient has several statistically significant compositional dependences including the wollastonite fraction in pyroxene ( $\text{WoPx}$ ). So an independent expression for  $\text{WoPx}$ , appropriate for augite at low pressures and supercritical cpx at high pressures, was obtained by linear regression (Fig. 2). The original model (1) employed constant values of  $D^*$  for opx/liq (0.35) and cpx/liq (0.44) at high pressure that are now obviously too low for pressures in the range of 30 to 40 kbar. A consequence of using a pressure-dependent  $D^*$  for Al is that now it is more difficult to deplete the source in  $\text{Al}_2\text{O}_3$  at high pressure and extraction of melt at each pressure must, therefore, be more efficient to produce a polybaric pooled melt with green glass composition. Consequently, permissible melt extraction efficiency is now more than 60% as compared to 40% originally.

Fig. 1 shows the approximate location of liquidus boundaries (dashed curves) projected from the olivine component at 30 kbar for low (a) and intermediate  $\text{Mg}'$  liquids (b) and at 28 kbar for high  $\text{Mg}'$  liquids (c). Experimental liquid compositions are shown as squares, crystal compositions as circles. Filled symbols indicate olivine and liquid coexisting with two other solid phases, open symbols indicate one other solid phase. Fig. 3a contrasts liquidus boundaries at 1 bar (light solid lines) and 30 kbar (dashed lines) for  $\text{Mg}'$  appropriate for mare basalts. Opx is not stable at 1 bar, but has a relatively large stability field at 30 kbar; the cpx that coexists with opx, gar, and ol is constrained to be low in CaO; minimum melts of garnet peridotite assemblages are tholeiitic; and the pseudoinvariant point is a peritectic with opx in reaction with liquid. The 30 kbar topology in Fig. 3b, which is appropriate to picritic compositions, is similar to that in 3a: the data here fix the position of the ol + opx + cpx liquidus boundary and definitively show opx in reaction with liquid. The bulk composition of the green glass source region used in the polybaric melting calculations (1) is shown as a cross. Because the cross is lower in Al than the pyroxenes coexisting with gar and liq, garnet is not stable on the solidus. The coverage of data in Figs. 3a and b is ambiguous as to whether both low- and high-Ca pyx are stable as separate phases. However, the data in Fig. 3c show that cpx solid solution is continuous in petrologically relevant compositions as predicted by Bertka and Holloway (4). Liquidus boundaries in Fig. 3c are shifted to higher Al than those in Figs. 3a and b. This shift is the result of higher  $\text{Mg}'$  and alkalis. The projection of primitive terrestrial upper mantle compositions (PUM - depleted and undepleted (9)) shows that

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garnet is on the solidus of terrestrial-like bulk Moon compositions (8). The considerable difference in Al contents between the PUM and model green glass source regions is not likely to be the result of differing degrees of basalt extraction — pyroxene accumulation seems to be essential to produce the low Al contents of the green glass source.

## REFERENCES

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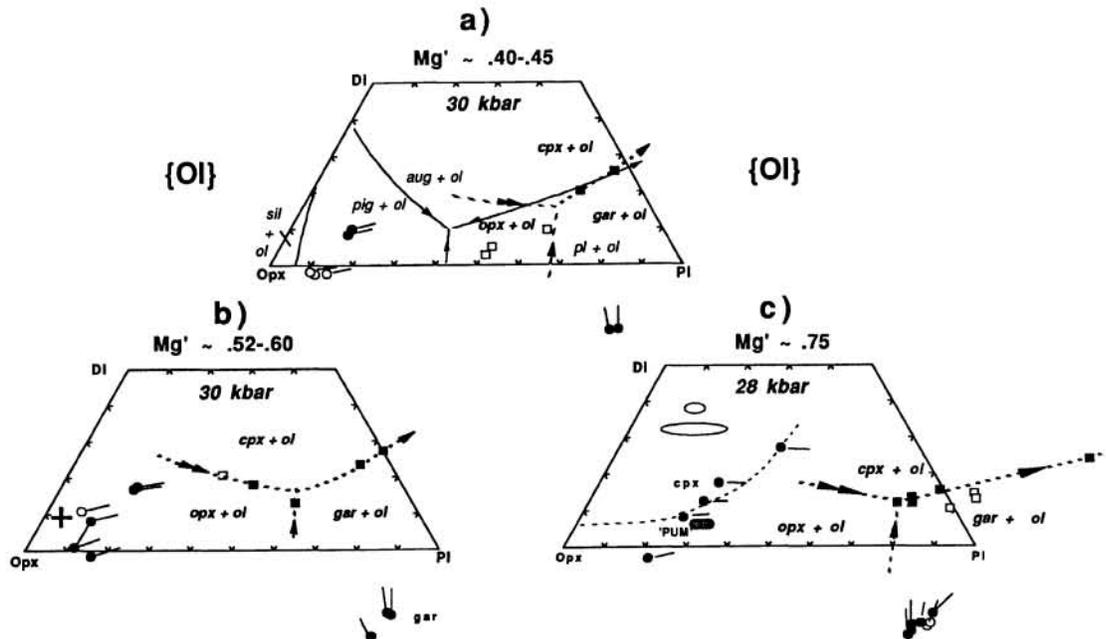


Fig. 1 Projections from Olivine component {Ol} onto a portion of the Wollastonite(Wo) - Orthopyroxene(Opx) - Plagioclase(Pl) plane. Symbols described in text. Arrows show direction of decreasing temperature; double arrows show reaction boundaries. Olivine coexists with all phases: a) f067-72, b) f075-80, c) f087-91. Large ellipses in c) show range in composition of liquid analyses (~30 micron raster of quench crystals); smaller ellipses show compositional ranges of pyroxene analyses (spot).

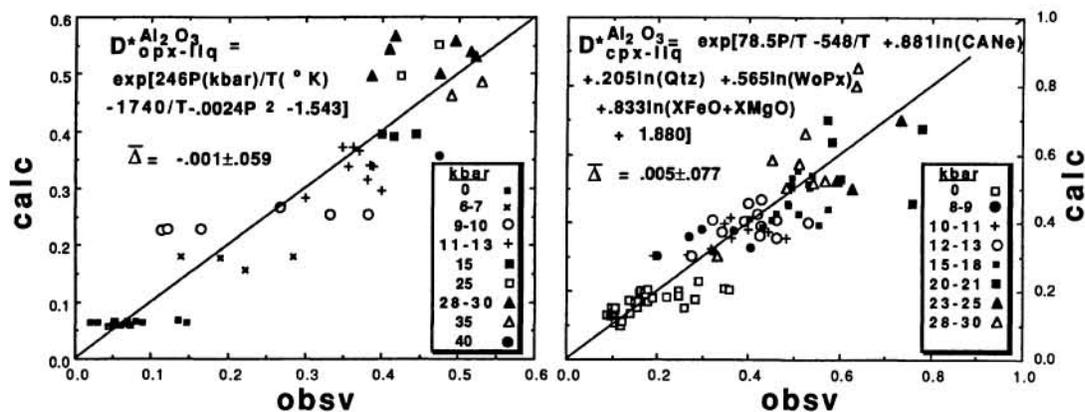


Fig. 2 Comparison of observed and calculated molar  $\text{Al}_2\text{O}_3$  partition coefficients ( $D^*$ ) for aug/liq and opx/liq.