

THE ORIGIN OF THE GREEN GLASS MAGMAS BY POLYBARIC PARTIAL MELTING: J. Longhi, Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964

One of the important unanswered questions in lunar petrology is how the picritic volcanic glasses (1) acquired and maintained their apparent high-pressure signature. Traditionally, lunar petrologists interpreted the point of olivine + pyroxene multiple saturation on the high-pressure liquidus of mare compositions, illustrated in Fig. 1, as the pressure of melt segregation (e.g., 2,3,4). In the case of the picritic glasses multiple saturation occurs between 17.5 and 25 kb (e.g., 4), implying depths of segregation of 350 to more than 500 km on the Moon. The major alternative to the multiple saturation hypothesis has been invoking relatively large degrees of partial melting at some low pressure that leaves behind a residuum consisting of only olivine. For a source with 2.0 wt% Al_2O_3 and 80% olivine, such a process would require approximately 30% melting to produce a green glass composition; sources with more Al_2O_3 or less olivine would require larger degrees of melting. The prospect of large degrees of melting of sources with small amounts of pyroxene has remained unpopular with petrologists even though they have not explained how a magma could retain its primary composition through transits of several hundred kilometers to the surface: kimberlitic eruptions from depth seem unlikely on the Moon.

In the 1980's terrestrial geophysicists developed quantitative models for melt migration by porous flow, segregation, and compaction of the crystalline residua in a convecting mantle (5,6,7). These models typically portray a pool of melt consisting of contributions from a range of pressures collected at the top of the ascending mantle column and often ponded at the base of the crust or lithosphere. These treatments have incorporated terms for trace elements with constant partition coefficients, but do not readily lend themselves to major elements whose partition coefficients typically depend on composition. Attempts to model major elements during polybaric porous flow approximated the process as one in which extraction of melt produced no change in the composition of the continuously melting source (8,9). However, given that some net separation of melt takes place, some net change in source composition must also take place, so these models should be regarded as endmembers.

Porous flow models may have some applicability to mare basalt petrogenesis. Mare basalts were produced by partial melting of low-Al mafic to ultramafic sources. During the time of mare petrogenesis the Moon had a thin, but growing elastic lithosphere that eventually supported the loading of mare basalts in the great basins to form mascons: stress modeling suggests elastic lithosphere thicknesses of ~ 50 km at 3.6-3.8 b.y., and increasing to ~ 100 km afterwards (10). A thermal lithosphere, probably of comparable thickness, extended the elastic lithosphere. Beneath the base of the lithosphere was the mare basalt source region, partially molten in places and probably convecting. In such a physical regime mare basalt magmas would pool at the base of the lithosphere and possibly would rise to the surface along fractures caused by impacts. A major test of the applicability of the porous flow model is its ability to generate composite melts ponded at ~100 km (5 kb) that appear to be multi-saturated at higher pressure and hence to be derived from greater depths. Fig. 2 illustrates this situation: the field of the picritic green volcanic glasses (1) sits astride the calculated 20 kb olivine + orthopyroxene liquidus boundary -- well below the position of the boundary at 5 kb.

To test the porous flow model, I have calculated numerous variations of polybaric partial melting of lunar mantle compositions designed to simulate porous flow and segregation, using parameterizations of liquidus boundaries based on the high-pressure data of (11). Some of the results are shown in Fig. 2. In each case melting begins at some initial pressure and proceeds in a series of steps at progressively decreasing pressure with the extracted melt pooling in a reservoir; the curved arrows in Fig. 2 show the chemical evolution of the melt pool. The source also becomes progressively depleted in response to melt extraction, but this change is not shown. In these calculations I employed the value of 1.2% melt/kb adopted by (8) and based upon the thermal modeling of (12); melting began at pressures indicated in Fig. 2 (25 or 40 kb); melt extraction began at 2.4% (a pressure drop of 2 kb) and continued in 2 kb steps until 4 kb. To simulate the porous flow process, some percentage of the melt generated in each step was retained in the source. To achieve a satisfactory fit of ponded melt to green glass composition, I derived the source composition (Table 1) by subtracting 15 wt% Highland Crust and 3% anorthite from Primitive Mantle (13, Table 8.4) and reducing Mg' from 0.85 to 0.80. More aluminous compositions shift the melt reservoir curves to the right; less aluminous and more ferroan compositions shift these curves to the left.

At first inspection results of these calculations (Table 1, Fig. 2) suggest that compositions similar to those of the green glasses may be generated by inefficient fractional fusion of an ascending low-Al source that began to melt at great depth (~ 1000 km) in the Moon. However, the physical aspects of the model need to be explored further. In particular, the model seems to require a discrete melt reservoir that ascends with the melt region. Whether this reservoir can be justified as part of a partially molten diapir or as a porosity wave (14) needs further investigation. Also, the temperature drops are not as steep as one would expect along "wet" adiabats (15).

If such polybaric models prove physically plausible, then remelting a differentiated source at great depths would imply an early "magma ocean" that involved nearly all of the Moon.

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TABLE 1 (wt%)

	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MgO	MnO	CaO	K ₂ O	Na ₂ O	Mg'
model mantle	44.2	0.26	1.87	0.70	15.6	35.1	0.17	2.05	0.003	0.03	0.80
pooled melt 40 kb /0.4	43.9	1.44	7.73	0.59	20.1	15.1	0.25	10.7	0.02	0.18	0.57
Ap 14 green glass (1)	44.1	0.97	6.71	0.56	23.1	16.6	0.28	7.94	0.05	0.19	0.56

FIGURE CAPTIONS

Fig. 1. Schematic high-pressure melting relations of low-Ti mare compositions. Fig. 2. Comparison of green glass compositions (1) and calculated polybaric, pooled melt compositions. Phase boundaries are appropriate for low pressure and compositional parameters shown in upper right: $Mg' = MgO/(MgO+FeO)$; NAB and NOR are albite and orthoclase fractions of the normative feldspar; QWo is the Wo coordinate of the Ol-Pl-Wo-Qtz system in mole units (15). Curved lines describe trace of cumulative pooled melt compositions. Numbers give the percentage of generated melt that is extracted in each cycle.

