

ASSIMILATION IN LUNAR BASALTS AND VOLCANIC GLASSES: IMPLICATIONS FOR A HETEROGENEOUS MANTLE SOURCE REGION.

A.B. Finnila, P.C. Hess, and M.J. Rutherford. Department of Geological Sciences, Brown University Providence, RI 02912

Introduction: Several scientists have called on assimilation of anorthositic crustal material or KREEP compositions to explain various lunar lithologies (1-7). In order to address the practicality of such processes, we have outlined some techniques for calculating how much assimilation is possible in magma chambers and dikes based on thermal energy balances and simple fluid mechanical constraints. In a previous effort (8) we demonstrated that dissolution of plagioclase in an iron-free basalt was too slow to contaminate magmas, and that the energy cost of melting plagioclase-rich crustal material was prohibitive both in magma chambers and in dike conduits. In the present work we have extended this analysis to include dissolution rates in an orange glass composition and to quantitatively predict the maximum contamination possible due to assimilation of both lunar crustal material and KREEP (composition shown in Table I).

Experimental Work: Experiments to determine diffusion coefficients and saturation chemistry of anorthite in the basalt and picrite compositions shown in Table I were run at 1 atm at temperatures of 1290, 1340, and 1390 °C for durations between 20 and 240 minutes. The iron-free basalt powder was placed in a Pt crucible with a polished, annealed An₁₀₀ cylinder. The orange glass composition was placed in an anorthite glass capsule, wrapped in molybdenum foil and vacuum sealed in silica glass. The mafic glass in the charges was analyzed by microprobe in transects away from the melt/anorthite interface. Diffusion coefficients for Al₂O₃ from both melt compositions were 10⁻⁸ cm²/s at 1340°C and 10⁻⁷ cm²/s at 1390°C. Alumina saturation values are shown in Figure 1.

Potential Assimilation Values: Assimilation can occur either by partial to complete melting followed by mixing, or by dissolution. The dissolution rates of anorthite are too slow to significantly affect magma compositions in either magma chambers or dikes. Even if a magma chamber is vigorously convecting and is hot enough to avoid having chilled margins, a 10 cm nonconvecting boundary layer (9) would slow assimilation to only 0.02 cm/year at 1390°C, or a total of 2 meters of wall rock in ten thousand years. Due to the effects of chilled margins and the high melting temperature of norites and troctolites, melting of lunar crustal material by the picritic glasses is not likely (10). Using crustal temperatures between 700 - 900 °C and magma temperatures between 1300 - 1500 °C, maximum estimates are on the order of 6% contamination by the wall rock, assuming convection inside the magma chamber suppresses the formation of chilled margins (11). This would only increase the alumina content by 0.9 wt.%. If the lower crust is composed primarily of anorthosite which has a melting temperature near 1500 °C, no melting can be expected. Assimilation of KREEP is more favorable due to its low melting temperature of 1050 °C. Estimates extend up to 26% contamination of a magma chamber bounded by KREEP wall rock, but only by assuming the highest temperatures considered both for the magma and the KREEP (1500°C and 900°C respectively). Using the method of (12), the amount of crustal assimilation possible by low titanium mare basalt melts during their transit to the surface in vertical dikes is not expected to exceed 7%. The ascent mechanism for the negatively buoyant high titanium glasses reaching the surface is not understood well enough to make quantitative predictions about assimilation values.

Discussion: Because the volcanic lunar glasses would need 25% to 28% assimilation of noritic and troctolitic crustal compositions respectively, to explain the 5 wt.% aluminum variation in the most pristine lunar volcanic glass record, it is clear that assimilation is not responsible for the chemical variation among these glasses. When assimilation does occur, it is usually accompanied by fractional crystallization which provides the energy required by releasing latent heat of fusion. While assimilating KREEP material is energetically feasible, only the Apollo 14 high aluminum basalts and some groups from Apollo 15 and 17 of the common mare types show KREEP signatures. While isolation or actual removal of a KREEP

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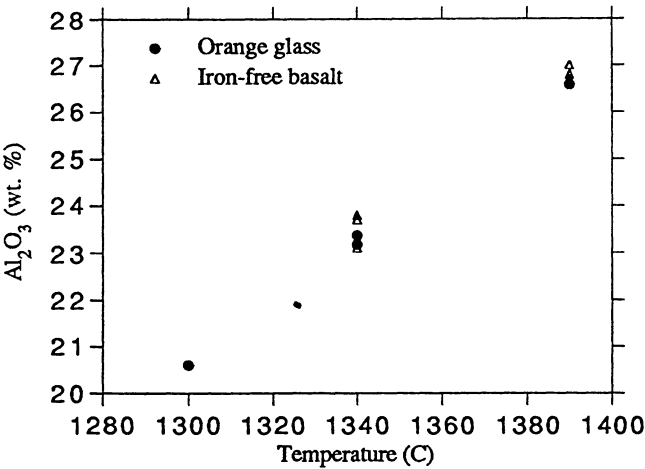
layer has been suggested to explain the selective contamination pattern (13), the thickening lunar lithosphere would prevent underplating of the crust after 3.9 b.y. Rising diapirs would tend to stall at the rheological trap at the base of the lithosphere. Even minor amounts of fractional crystallization would be apparent in the volcanic glass sample collection (14), the absence of which argues for little, if any, assimilation. Instead, as has been proposed for other reasons, most the chemical variation in the lunar basalts and volcanic glasses must be a result of distinct source regions in a heterogeneous lunar mantle.

The primary nature of these volcanic glasses has now been proposed by several lunar scientists. Hughes et al. (3) and others (15) argue for large-scale lateral and vertical heterogeneities in the lunar mantle based upon major and minor element chemistries. Hess (in this volume) argues for very deep source regions. This work shows how difficult it is to account for chemical variation using assimilative models and forces the conclusion that the lunar mantle must be extremely heterogeneous.

Table I:
Experimental compositions

Oxide Wt %	KREEP	Iron-Free Basalt	Orange Glass
SiO ₂	55.3	44.4	38.57
TiO ₂	3.0	11.7	8.81
Al ₂ O ₃	11.1	11.1	6.32
FeO	14.4	—	22.04
MgO	2.1	20.0	14.44
CaO	8.9	12.8	7.68
Na ₂ O	1.1	—	0.36
K ₂ O	2.1	—	0.09
Cr ₂ O ₃	0.0	—	0.75

Figure 1:
Alumina saturation
chemistry



References: (1) Warren (1986) *Proc. 16th Lunar Planet. Sci. Conf., J. Geophys. Res.*, 91, D331-D343; (2) Neal, Taylor, and Lindstrom (1988) *Proc. 18th Lunar Planet Sci.*, 139-153; (3) Hughes, Delano, and Schmitt (1990) *Proc. 20th Lunar Planet. Sci. Conf.*, 127-138; (4) Shervais, Taylor, Laul, Shih, and Nyquist (1985) *Proc. 16th Lunar Planet Sci. Conf., J. Geophys. Res.*, 90, D3-D18; (5) Goodrich, Taylor, Keil, Kallemeyn, and Warren (1986) *Proc. 16th Lunar Planet. Sci. Conf., J. Geophys. Res.*, 91, D305-D318, 1986; (6) Dasch, Shih, Bansal, Wiesmann, and Nyquist (1987) *Geochim. Cosmochim. Acta*, 51, 3241-3254; (7) Shih, and Nyquist (1989) *Lunar Planet. Sci. XX*, 1002-1003; (8) Finnila, Hess, and Rutherford (1992) *Lunar Planet. Sci. XXIII*, 359-360; (9) Zhang et al., *Contrib. Mineral Petrol*, 102, 492-513, 1989; (10) Marsh (1989) *Journal of Petrology*, 30, 479-530; (11) Huppert and Sparks (1988) *J. Fluid Mech.*, 188, 107-131; (12) Turcotte (1990) *Magma Transport and Storage*, ed. Ryan, 103-111; (13) Nyquist and Shih, (1992) *Geochim. Cosmochim. Acta*, 56, 2213-2234; (14) Longhi (1987) *Proc. 17th Lunar Planet. Sci. Conf.*, pp. E 349-E360; (15) Shearer, Papike, Galbreath, and Shimizu (1991) *Earth and Planet. Sci. Lett.*, 102, 134-147.