MODELING EQUILIBRIUM PARTIAL MELTING: IMPLICATIONS FOR EARLY LUNAR DIFFERENTIATION. John Longhi, Dept. of Geology and Geophysics, Yale Univ., P. O. Box 6666, New Haven, CT 06511.

Modifications of the fractional crystallization model employed by the author (1) have been made to allow the calculation of equilibrium crystallization sequences of olivine-normative lunar compositions in the range of 0-25 kb. Equilibrium partial melting may be viewed as the reverse of equilibrium crystallization. At low pressure the modifications involve merely a change in bookkeeping: the liquid remains in equilibrium with all of the phases crystallized throughout the calculations. At high pressure changes in phase boundaries and distribution coefficients are required. Due to the difficulty in performing high pressure experiments as compared to low pressure experiments there are relatively few reported experimental results to draw upon in constructing empirical models of high pressure. The existing data drawn in part from (2,3,4,5) allow the progression of liquidus phase boundaries to be depicted as in Figure 1. Due in part to compositional effects and in part to probable interlaboratory differences in pressure calibration, the precise relations between position of the phase boundaries and pressure cannot be defined. However, two important regimes can be identified and thus modeled. The first is in the pressure range 0-10 kb and is characterized by stable coexistence of olivine, plagioclase, low-Ca pyroxene and liquid (Fig. 1a and 1b); the second regime is in the range 15-25 kb and is characterized by the absence of plagioclase and the intersection of the olivine + low-Ca pyroxene and olivine + spinel saturation surfaces (Fig. 2a and 2b).

Modeling crystal-liquid equilibrium also requires some adjustment in distribution coefficients. To date only the coefficients for pyroxenes have been changed. Values employed for $K_{\text{px-L}}$, $K_{\text{OPX-L}}$, $K_{\text{P-L}}$ are 0.5, 0.35, 1.2; values for $K_{\text{Al}_2\text{O}_3}$, $K_{\text{TiO}_2}$, $K_{\text{Cr}_2\text{O}_3}$ are 0.5, 0.4, 2.2. These coefficients, which are defined as mole % crystal/mole % liquid, have been estimated from analyses given by (3 and 5). Errors in these numbers will basically affect only the proportions of phases along cotectic curves. Temperature is calculated by the olivine-equilibrium equations of (6) modified by an empirical gradient of the olivine liquidus of 5°C/kb taken from (2).

Results of the calculations in the 5-10 kb range are shown in Figures 1 (major elements) and Fig. 3a (trace elements); results in the 15-25 kb range are shown in Figures 2 and 3b. Two compositions were chosen to illustrate differentiation paths: the TB composition (7) is similar to other proposed whole moon compositions with chondritic proportions of the refractory elements; the R composition (5 - "outer portion of the moon") has sub-chondritic Ca/AI. In Figures 1, 2, and 3 the symbols represent the exhaustion of the indicated phase during partial melting; the numbers are the mole fraction of liquid and the liquid's Mg value $[\text{MgO}/(\text{MgO}+\text{Fe})]$, respectively; all liquids are saturated with olivine. In Figures 1 and 2 the low-pressure phase boundaries are shown in dotted lines for reference, so that the composition of a liquid produced at high pressure may be compared with its low-pressure crystallization sequence.

The primary constituents of the lunar crust are a series of plutonic igneous rocks free of meteoritic contamination ("pristine" - (8)). Current hypotheses suggest that the parental magmas of some (9) or all (10) of these rocks may be derived by partial melting of the lunar interior. Thus the results of the model calculations discussed above may be compared with the known compositional and mineralogical features of the pristine rocks to
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test the viability of these hypotheses. Some of the major features of the pristine, Mg-rich rocks are: pronounced depletions of Sc and Ti relative to the REE (11) and a crystallization sequence in which low-Ca pyroxene precedes high-Ca pyroxene (1). Figure 3 shows that partial melting (≤10%) at high pressure is an effective means of depleting Sc and Ti relative to the REE (Fig. 3). However, liquids thus produced would invariably crystallize high-Ca pyroxene before low-Ca pyroxene when intruded into the lunar crust. Larger degrees of partial melting at high pressure can produce liquids which will crystallize low-Ca pyroxene before high-Ca pyroxene at low pressure, but such liquids lack the requisite Sc and Ti depletions (Fig. 3).

The model calculations are consistent with earlier, more qualitative predictions (9, 11) that relatively unfractionated magmas assimilated or mixed with a highly fractionated Sc,Ti-depleted component prior to crystallization in the crust. If we consider the moon to have a composition similar to that of TB, then partial melting in excess of ~40 mole % at 5-10 kb and ~50 mole % at 20-25 kb is required to produce melts that will crystallize low-Ca before high-Ca pyroxene at low pressure. Recent models of slow accretion predict local rebounds in the lunar mantle of up to 100 km (10) following impacts of large projectiles. It is possible that the resultant 5 kb decompression could produce the large degrees of partial melting suggested by the phase equilibria if the mantle were already above the solidus. The cumulative effect of many such impacts might be to produce a partially molten, convecting zone in the outer part of the moon which had solidification and material transport features previously ascribed to a "magma ocean" (12).

REFERENCES


FIGURES. Figure 1. Liquidus phase boundaries (heavy dashed lines) at 5-10 kb. a) projection from wollastonite onto O1-An-SiO2 pseudoternary; b) projection from olivine onto Opx-An-Wo plane. Dotted lines are low pressure phase boundaries. Numbers are: mole fraction melted/MgO/(MgO + FeO)-molar. Symbols designate the exhaustion of a phase during partial melting: + - orthopyroxene, X - augite, □ - plagioclase, ♦ - spinel. Figure 2. Liquidus phase boundaries at 20-25 kb. Figure 3. Calculated concentrations of incompatible elements during high pressure partial melting.
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Figure 1

Figure 2

Figure 3

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