LARGE SCALE LUNAR MAGMATISM: INFERENCES FROM THE MOSCOVIENSE BASIN. H. Nekvasil[1], G. Ustunisik[1], and D. H. Lindsley [1]Dept. of Geosciences, Stony Brook University, Stony Brook, NY 11794-2100 Hanna.Nekvasil@stonybrook.edu

Introduction: One of the fundamental questions that have perplexed lunar petrologists since the Apollo days is how to constrain the composition of the magmas from which the primary crystalline lithologies of the lunar highlands formed. This has only become more complex as details of the lunar farside become available. However, this increased complexity is being offset by new information that may provide fresh insights into lunar magmatism in general, and into the origin of the distinct lunar terranes, in specific.

The Moscoviense Basin in the farside Feldspathic Highland Terrane is of particular petrologic interest because it exhibits a well-formed ring system [1] with an inner ring of material exposed from depths of ~7 km in a region purported to have a thin crust [2]. Based on data from the Moon Mineralogy Mapper (M3) onboard Chandrayaan-1, this material includes three primary rock units in close association, each characterized by the presence of abundant orthopyroxene, olivine, or Mg-hercynitic spinel [3]. [3] further indicated that the geologic context of the observed exposures suggests that these lithologies are genetically linked and sample several intrusions in close proximity or a single large layered intrusion. The possibility of a genetic link provides the potential to constrain parental magma compositions that may have characterized this region of the Moon. The implications of such constraints go beyond the local region as the general characteristics of these lithologies are not unique but are found in other lunar feldspathic terranes.

The model investigated: The model used for the assessment of a crystallization relation among the three pimary rock units and the anorthosite is one in which these lithologies were formed *in situ* by fractional crystallization of a single large magma body which produced layers of dense ferromagnesian minerals overlain by anorthitic flotation cumulates, thereby producing an apparent shallow "crust-mantle boundary". The computational investigation is being conducted to (a) constrain the compositional field of parental magmas, crystallizing at 0.05GPa, that could give rise to the observed lithologies, (b) evaluate the changes in residual melt composition and density and cumulate lithologies during fractionation, and (c) determine the change in Mg# of the equilibrium minerals assemblage with dropping temperature that can provide information for the interpretation of surface data.

It has been recognized since the early seventies that the system Ol-An-silica [4] at 1 bar provides a good first-order basis for understanding melt evolution of lunar magmas crystallizing anorthite, olivine, low Ca pyroxene, and spinel. Parental melt compositions in the spinel field can give rise to cumulates mimicking the spinel anorthosite, troctolite, and norite observed (e.g., [3]; (Fig. 1). This diagram indicates that magmas with compositions more anorthitic and less silica-rich than the spinel peritectic can produce the crystalline sequence of Figure 1.

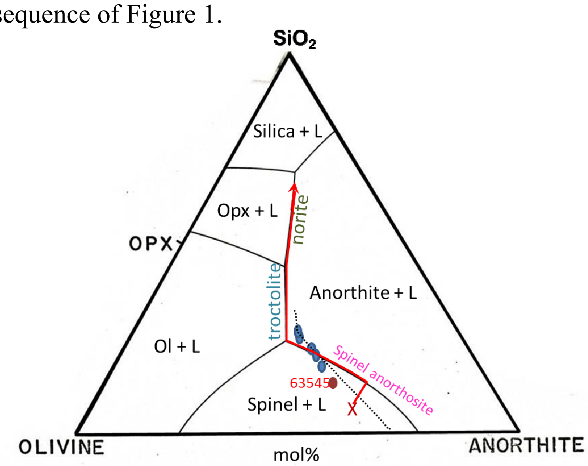

Figure 1. Projection at fixed Fe/Fe+Mg ratio of the system Fo-Fa-An-silica at 1 atm (from [4]). A parental magma composition at X (above the plane) evolves along the red arrow as it cools and undergoes fractional crystallization, producing sequentially spinel anorthosite, troctolite, and noritic crystalline assemblages. However, depending upon crystalline phase/melt density differences, the plagioclase produced at any stage may float while the ferromagnesian minerals sink, thereby leading to cumulate lithologies with higher concentrations of the separating phase. The red oval is the projected composition of Apollo 16 sample 63545; blue ovals are experimental residual liquids of [5] at 1 atm. Dotted black curve indicates phase boundaries projected from multicomponent space based on experimental assemblages of [5].

However, this diagram is limited in that it cannot constrain the abundances of other common melt constituents (e.g., TiO_2, K_2O), constituents that can affect factors such as density (and hence the possibility of plagioclase flotation) and the nature of late-stage felsic liquids (and the possible production of granitic lithologies). Experiments on multi-component parental liquids are needed to understand the behavior of natural lunar magmas. Experimentalists [e.g., 5] undertook early experiments on natural compositions to obtain a more comprehensive view of the crystallization behavior of lunar magmas. Experimental residual liquids during crystallization of a magma of composition 63545 (ovals in Fig. 1) follow the simple system in spite of leaving this isoplethal section.

However, these few available experiments still make it difficult to assess to what extent melt components outside of this simple system influence the phase assemblage. This assessment and its use in guiding future experiments are best done initially though computational methods.

Method: A computational investigation was undertaken using the CORBA MELTS routine of [6]. Initial computations were conducted on the bulk composition 63545 for pressure of 0.0001 GPa (at IW) to allow for comparison against the experiments of [5]. This lithology is a fine-grained crystalline rock consisting of pink spinel, plagioclase, olivine, and pyroxene, oxides and metallic Fe [5].

Results: Figure 2 shows the computed compositional evolution of residual melt, crystallization assemblages. The computed sequence differs from the experiments of [5] and the topologic constraints of the system Ol-An-silica [4] in that the computations indicate that olivine appears before plagioclase. However, the amount of olivine crystallized before plagioclase appears is vanishingly small and the computations and experiments agree very well in the temperature of first saturation of the melt with the three phases hercynitic spinel, plagioclase, and olivine. There is also excellent agreement with the extent of this field in temperature space.

The computations allow us to look in more detail at the evolution of minerals and melt for compositions like this. At low pressure, these results indicate that residual liquids (Fig. 2f), even with such an alumina-rich parent as 63545, evolve to compositions more typical of "high alumina" lunar highland basalts as they fractionate. According to the density difference of the minerals forming, olivine-rich and spinel-rich cumulate lithologies, as well as the more typical troctolite and norite can form. Of particular interest is the possibility of forming potassic granite from crystallization rather than from liquid immiscibility. These calculations also indicate that anorthitic plagioclase can float only within a well-defined temperature range; the density of the residual melt exceeds that of anorthitic plagioclase only from its first formation through the formation of noritic cumulate assemblages (Fig. 2).

Further calculations have explored the effect on phase stability and melt evolution if crystallization took place at 10 km depth. At 10km depth, there are major similarities in the type of lithologies that can be produced to those forming at 1 bar. However, the differences in melt composition enhance the density difference between liquid and plagioclase, thereby increasing the possibility of plagioclase flotation.

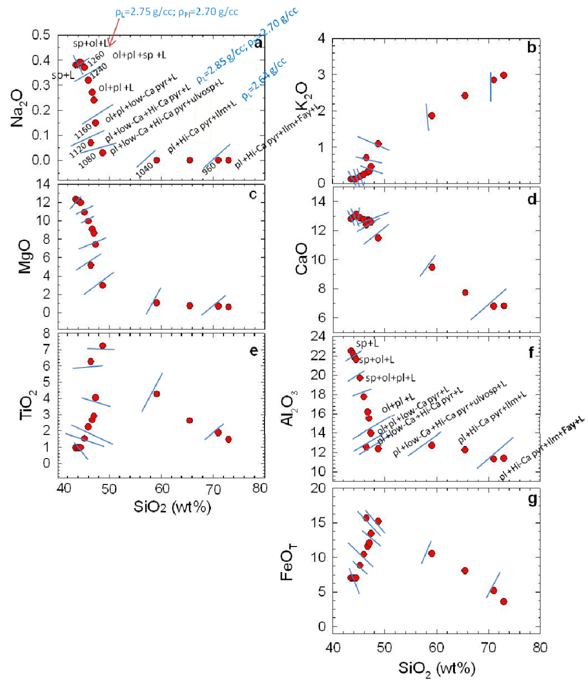

Figure 2. Harker variation diagrams based on CORBA MELTS calculation of phase equilibria during crystal fractionation of 63545 at 1 atm and IW. Selected temperatures are indicated. Changes in mineral assemblages are given by blue line segments. Phase assemblages in each region are indicated. Computed densities of liquid at several stages of melt evolution are shown for comparison with that of anorthite.

Conclusions: The lithologies observed at Moscoviense Basin are consistent with those that could be produced in a single magma chamber during shallow fractionation. The similarities of the assemblages to those commonly seen in Highlands lithologies suggest that this type of magmatism may be wide spread. Fractionation of a parental magma such as 63545 can produce cumulates enriched individually in olivine, spinel and plagioclase, in addition to the lithologies troctolite and norite. During fractionation, residual liquids are produced with similarities to high-Al alumina basalts, and at late stages, to potassic rhyolites. Efforts are ongoing to map out the compositional field of parental compositions that can produce these crystalline assemblages and predict the effects of dissolved volatiles on the melt evolution.

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