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A DYNAMIC MELTING MODEL FOR THE ORIGIN OF APOLLO 15 OLIVINE-NORMATIVE AND QUARTZ-NORMATIVE MARE BASALTS.

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Early studies of mare basalts from the Apollo 15 site established that two distinct groups are represented: the olivine-normative basalts (ONB) and the quartz-normative basalts (QNB) [1-3]. The ONB and QNB suites are distinguished petrographically by their phenocryst assemblages (the ONBs are olivine-phyric, the QNBs are generally pyroxene-phyric) and chemically by their major element compositions: the QNBs are higher in SiO2 and MgO/FeO, and lower in FeO* and TiO2 than ONBs with similar MgO contents. Experimental data [2,4-7] show that the QNB suite is derived from a more magnesian, olivine-normative parent magma, a conclusion which is supported by the recent discovery of high-SiO2 olivine-normative basalt clasts in breccia 15498 [8]. The high-SiO2 ONBs fall on olivine control lines with primitive QNBs, and least-squares mixing calculations are consistent with the high-SiO2 ONBs being parental to the more evolved QNB suite [8]. We include these high-SiO2 ONBs as part of the "QNB suite" in this discussion. Our major element modeling results [8] also are consistent with the conclusions of earlier studies [2,3] which showed that the ONB and QNB suites cannot be related to one another by low pressure crystal fractionation. The combination of high Mg#, high SiO2, and low TiO2 in the QNB suite precludes a relationship to the ONB suite by simple removal of liquidus minerals (olivine and pigeonite).

Despite these significant differences in petrography and major element composition, both groups have nearly identical trace element concentrations and chondrite-normalized abundance patterns (Figure 1). The major question to be addressed by any petrogenetic model for Apollo 15 mare basalts is how to form mare basalt suites with distinctly different major element characteristics but nearly identical trace element compositions. The similarity in trace element concentrations imply compositionally similar source regions and similar percent melting, but these conclusions are not easily reconciled with the observed differences in major element compositions, which require sources with distinct mineralogies or large differences in percent melt.

PREVIOUS MODELS: The mare basalt source region has geochemical characteristics that are complementary to the highlands crust, and it is generally thought to comprise mafic cumulates from the magma ocean [9]. Early models of mare basalt petrogenesis, suggested that remelting of these cumulates at different depths resulted in the observed mare chemsitries [9]. Despite the appeal of this simple model, there is increasing evidence that more complex scenarios are required. More recent models of mare basalt petrogenesis have stressed two dominant themes: (1) the assimilation of crustal components, e.g., KREEP [10-15], and (2) melting of complex hybrid source regions [16,17].

Binder [10] suggests that all mare basalts have undergone modification by a KREEPy component, but this model has only been applied in detail to aluminous mare basalts from the Apollo 14 site [10-15]. A major problem with this type of model is that the assimilation of KREEP tends to both enrich the LREE and MREE relative to the HREE. KREEP assimilation models which succeed at Apollo 14 site will not work at Apollo 15 because the Apollo 15 basalts have LREE/MREE slopes <1. The Apollo 15 basalts also have low overall concentrations of incompatible elements which differ little between the two main suites present. These suites differ mainly in their major element chemistry (unlike the Apollo 14 basalts, which have nearly identical major element compositions). We have tried a variety of KREEP assimilation models on the Apollo 15 mare basalts and none have proved satisfactory.

Hughes et al. [17] have recently presented detailed, quantitative models that account for Apollo 15 ONBs by melting of hybrid source regions. These regions are complex mixtures of early magma ocean cumulates, late magma ocean cumulates, and trapped liquid. The trapped liquid component is late magma ocean with a KREEP-like composition, so these models are similar to the assimilation models in effect, but differ in concept. Hughes et al. [17] apply their model to Apollo 15 green glass, yellow-brown glass, and ONBs, but do not address the more subtle differences observed between the ONB and QNB suites.

DYNAMIC MELTING MODEL: We propose that the salient chemical characteristics of the Apollo 15 olivine normative and quartz normative mare basalt suites can be derived from a dynamic melting model without KREEP assimilation. In this model, melt extraction from the mantle source region is incomplete and 5-10% of the melt produced during each melting event is retained in the source region as dikes and veins [18]. During subsequent melting events, trace element concentrations are controlled by remelting of the dikes, whereas major elements are controlled by phase proportions and compositions in the refactory residuum. This model allows repeated melting of the same source region without total depletion of the incompatible trace elements. Because the refractory residuum is enriched in MgO and depleted in SiO2 during melting, subsequent melts derived from this region tend to be more mafic and silica-undersaturated.

Three general situations were tested using this approach: (1) Cpx-rich cumulate source in equilibrium with late lunar magma ocean (LMO)(La = 30 x chondrite), (2) Olivine ± Opx-rich cumulate with 20% Cpx in equilibrium with late LMO (La = 30 x chondrite), and (3) Olivine/Opx/Cpx cumulate in equilibrium with an early LMO (La = 10 x chondrite). All of our models share the following

characteristics: (1) Nine trace elements were included in the calculations (five REE, Ba, Th, Sc, Ti); (2) Following Nyquist et al. [19], a fractionated LMO was used (La/Lu = 2x chondrite); (3) Non-modal melting dominated by pyroxene; (4) We assume that 2-10% of the first stage melt was retained in the source as dikes/veins; (5) The high-SiO2 ONBs are taken to be parental to the more evolved QNB suite; (6) In each case, the QNB parent magma (= high-SiO2 ONB) is assumed to be the first melt extracted from the source, and the normal low-SiO2 ONBs are generated by re-melting of the refractory source region.

Figure 2 shows the results of our modeling compared to observed Apollo 15 mare basalt suites. Model 1 (Cpx-rich source with late LMO) produces observed trace element concentrations in the QNB parent magma after 25% melting. Remelting of the refractory residue (plus 10% dikes) produces the relative trace element concentrations of the ONB suite after 20% melting; matching the absolute concentrations requires about 25% fractional crystallization. Model 2 (olivine-rich source with late LMO) matches the QNB parent magma after 5% to 7% melting. Primitive ONBs are produced by an additional 5-7% melting of the residue (plus 5-9% dikes). Model 3 (olivine-rich source with early LMO) produces the overall shape of the trace element patterns after 4% melting, but the absolute abundances are too low; approximately 50% fractional crystallization is required to produce the correct absolute abundances. Re-melting of this mantle residuum (plus 5% dikes) can produce the ONB suite pattern, but up to 50% fractional crystallization is required to match the observed concentrations (Figure 2b).

Our results show that the dynamic melting model can be applied over a wide range of mantle compositions to successfully model mare basalt suites which have similar trace element abundances. It seems clear that model 1 is the most robust because the amount of melting significantly exceeds the amount of trapped/retained magma in the source, so we are not merely remelting the retained magma. However, Nyquist et al [19] have suggested that the Rb/Sr systematics of Apollo 15 ONBs require a source with only 20% Cpx. This constraint favors models 2 and 3 -- which differ mainly in their LMO component. Model 3 may be applicable to a non-hybrid, magma ocean cumulate source region, whereas models 1 and 2 will probably require some hybridization to match the major element characteristics of these basalts. We are currently attempting to model major element variations during partial melting of the LMO cumulates to further constrain these calculations.

REFERENCES [1] Rhodes J.M. and Hubbard N.J. (1973) Proc. Lunar Planet Sci. Conf., 4th, 1127-1148; [2] Chappell B.W. and Green D.H. (1973) EPSL,18,237-246; [3] Dowty E., et al.(1973) Proc. Lunar Planet. Sci. Conf.,4th, 423-444; [4] Humphries et al.,(1972) The Apollo 15 Lunar Samples, 103-107; [5] Lofgren (1975) Lunar Science VI, 515-517; [6] Longhi et al (1972) The Apollo 15 Lunar Samples, 131-134; [7] Grove T. and Walker D. (1977) Proc. Lunar Sci. Conf. 8th 1501-1520; [8] Vetter et al. (1988) Proc. Lunar Planet. Sci. Conf. 18th, 255-271; [9] Taylor, S.R. and Jakes, P. (1974) Proc.Lunar Sci. Conf. 5th, 1287-1305; [10] Binder, A.B. (1985) Proc. Lunar Planet. Sci Conf. 16th, D19-D30; [11] Shervais J. et al,(1985) Jour.Geophys. Res., 90, C375-C395; [12] Shervais J. et al,(1985) Jour.Geophys. Res., 90, D3-D18; [13] Shih, C-Y.et al, (1986) Proc. Lunar Planet. Sci. Conf. 16th, J. Geophys. Res., 91, D214-D228; [14] Dickinson, T.et al, (1985) Proc. Lunar Planet. Sci. Conf. 15th, 90, C365-C374; [15] Neal C.R., et al (1988) Proc. Lunar Planet. Sci. Conf. 18th, 121-137; [16] Ringwood A. and Kesson S. (1976) Proc. Lunar Sci. Conf. 7th, 1697-1772; [17] Hughes et al. (1989) submitted Geochim. Acta Chem.; [18] Langmuir C. et al. (1977) EPSL 36, 133-156; [19] Nyquist L. et al. (1977) Proc. Lunar Sci. Conf. 8th 1383-1415.
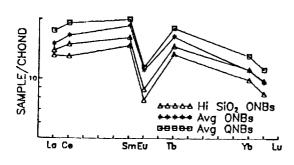

FIGURE 1 (above): Observed range in Apollo 15 mare basalts.

FIGURE 2. (a) Model results compared to observed primitive QNBs. (b) Model results compared to observed ONBs.