PETROGENESIS OF APOLLO 14 HIGH ALUMINA (HA) PARENTAL BASALTIC MAGMA.
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Petrologic studies of basalt clasts in Apollo 14 samples, especially consortium breccia 14321, revealed high-alumina (HA) varieties with a wide range in major and trace element abundances [1-3]. Whereas initial studies [1-2] suggested separate HA basalt groups possibly derived from multiple sources, subsequent research [3-4] indicated a general continuum of compositions derived from "primitive" (High MG#, low SiO_2, low LILE) parental magma. The observed range in HA basalt composition implies the combined effects KREEP assimilation and fractional crystallization (AFC) during crustal evolution [3]. Crustal AFC Processes, also demonstrated for petrogenesis of Apollo 14 VHK (very high K) basalts [4], indicate that these compositions can be derived from three parental (primitive, intermediate, and evolved) HA basaltic magmas. These studies support the hypothesis [5-6] that VHK basalt petrogenesis is inextricably linked to crustal assimilation by HA basaltic magma. Apollo 14 HA and VHK basalt evolution is, therefore, inherent in the definition and petrogenesis of parental HA basaltic magma. Constraints placed on possible sources for parent magma will demonstrate hybridization [e.g. 7] in mantle source regions of mare magma generation.

Parental HA Basalt. Vitrophyric basalt 14321,1422, was assumed to represent the most primitive composition from which the HA series evolved [3]. Compositions having positive REE slopes ($LA_N/LU_N<1$), low incompatible elements (e.g. Rb, K, Th, LREE), high MgO, and high compatible elements (e.g. Sc, Cr) are reported in [1-2] (corresponding to group 5 or [1]). The most likely parental HA basaltic composition is represented by the average of similar primitive compositions obtained in recent detailed studies [1-3]:

Major Oxides (%)		Trace Elements (ppm)			
SiO_2	= 44.7	Rb	= 0.9	Sm	= 2.18
TiO_2	= 2.67	K	= 431	Eu	= 0.62
Al_2O_3	= 11.8	Sr	= 87	Tb	= 0.66
FeO	= 18.2	Ba	= 31	Dy	= 4.39
MnO	= 0.26	Th	= 0.23	Yb	= 2.93
MgO	= 11.7	La	= 3.13	Lu	= 0.44
CaO	= 9.9	Ce	= 8.8	Sc	= 64
Na_2O	= 0.44	Nd	= 5.9	Hf	= 1.85

Geochemical Modeling. A model that describes a potential source for magma having the above composition was derived using a multifaceted approach. A series of "required sources", calculated for the trace element pattern shown normalized to bulk moon values [8] in Fig. 1, was tested according to [9] against potential mixing models of three lunar magma ocean (LMO) components: early cumulate ol + opx, late cumulate cpx + pig + plg + ilm, and trapped LMO liquid. The best fit without regard to major element concentrations yielded F = 0.10 and residual mineralogy consisting of only olivine, i.e. all late stage components were depleted during the melting event. Late-stage hybridizing components were in equilibrium with LMO liquid after 98 percent crystallization. Proportions of LMO components in this unconstrained model would not be suitable unless they match melting proportions required to yield the major element composition of parental HA magma.

Two additional models, using non-proportional parameters (F, LMO evolutionary stage and residual mineralogy) determined in the initial model, were based on CIPW normative composition of the HA parental magma and calculation of major element compositions of individual cumulate phases in equilibrium with the LMO. Proportions of these phases, required to reproduce the HA parent, were then assumed to represent melting proportions from the hybridized source. Neither model initially included a LMO trapped liquid component and, hence yielded trace element compositions far below (~0.1X) the level of abundances required to reproduce the observed composition. A trapped liquid (KREEP-like) component was included to minimize the difference in La contents between required and modeled sources. Proportions in all three models (Fig. 1) are summarized as follows:

LMO Phase	MODEL BASED ON: Unconstrained	Norm. Mineralogy	Equil. Min. Comp.
Early			
Ol:	96.5	91.1	92.9
Late			
Cpx:	1.44	1.6	2.0
Pig:	0.47	2.8	0.77
Plg:	0.91	3.3	3.1
Ilm:	0.41	0.51	0.51
T.L:	0.18(KREEP)	0.76 (LMO-98)	0.76 (LMO-98)

The model based on mineral compositions satisfies major element constraints and yields a close approximation (within limits of partition coefficients, etc.) of a source to produce average HA parental magma. These models do not address the possibility of more primitive HA compositions than the assumed parental magma; however, it is apparent that the HA source likely required hybridization of LMO components including KREEP-like trapped liquid.

References: [1] T. Dickinson, G.J. Taylor, K. Keil, R.A. Schmitt, S.S. Hughes, and M.R. Smith (1985) P.L.P.S.C. 15th, C365-C374; [2] J.W. Shervais, L.A. Taylor, and M.M. Lindstrom (1985) P.L.P.S.C. 15th, C375-C395; [3] C.R. Neal, L.A. Taylor, and M.M. Lindstrom (1988) P.L.P.S.C. 18th, 139-153; [4] C.R. Neal, L.A. Taylor, R.A. Schmitt, S.S. Hughes, and M.M. Lindstrom (1989) P.L.P.S.C. 19th, 147-161; [5] J.W. Shervais, L.A. Taylor, J.C. Laul, C.-Y. Shih, and L.E. Nyquist (1985) P.L.P.S.C. 16th, D3-D18; [6[C.-Y. Shih, L.E. Nyquist, D.D. Bogard, B.M. Bansal, H. Weismann, P. Johnson, J.W. Shervais, and L.A. Taylor (1986) P.L.P.S.C. 16th, D214-D228; [7] S.S. Hughes, J:W. Delano, and R.A. Schmitt (1990) P.L.P.S.C. 20th, (in press); [8] S.R. Taylor (1982) Planetary Science: A Lunar Perspective, L.P.I, 481 pp; [9] S.S. Hughes, J.W. Delano, and R.A. Schmitt (1988) G.C.A. 52, 2379-2391.

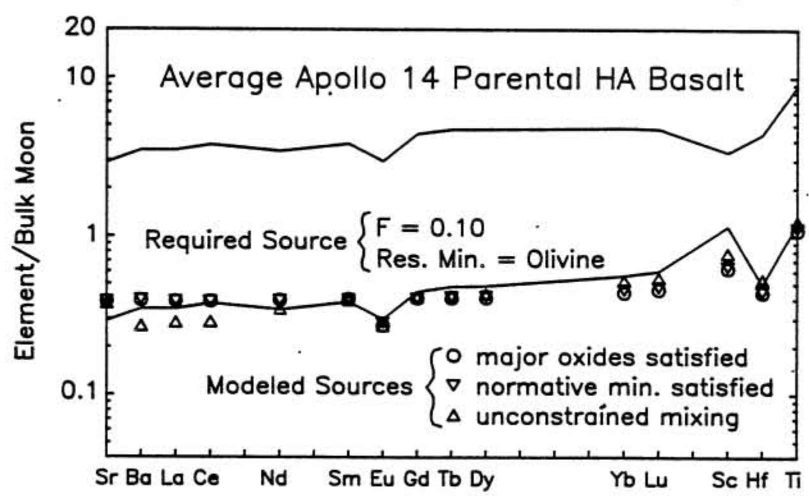

Figure 1.