PARTITION COEFFICIENTS OF Hf, Zr, AND REE BETWEEN ZIRCON, APATITE, AND LIQUID AND THEIR INFERENCES TO LUNAR GRANITE PETROGENESIS.

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Lunar sample 12013 has been extensively studied by many lunar scientists as have the other nonmare samples (breccias) that contain "grey breccia or felsite (granitic material)". Discussions of the lunar granitic materials were mainly focused on the relationships between the granitic material and the surrounding "black" basaltic breccia [e.g., 1, 2]. Two probable and viable scenarios regarding the petrogenesis of lunar granite have been proposed: liquid immisibility [e.g., 3, 4] and fractional crystallization from highly evolved, incompatible element-enriched liquid [e.g., 5,]. In order to place better constraints on the origin of lunar granitic material, we determined the Hf, Zr, and REE partition coefficients between minor minerals that may crystallize from highly fractionated liquid and magma.

Minor minerals, like whitlockite, apatite, zircon, and zirconolite, must have played important roles in forming evolved lunar magma. Although neither whitlockite nor zirconolite were available for analysis, Hf, Zr, and REE partition coefficients between apatite, zircon, and liqud were determined by isotope dilution. Two zircon and one apatite separate from andesitic lavas and one zircon and one apatite separate from a granite were analyzed. For the granite sample, a whole-rock split with apatite and zircon removed was used as an approximation to the coexisting liquid. These data are shown in Figs. 1 and 2. MREE partition coefficients between apatite and liquid are larger than those of LREE and HREE. In contrast, Hf and Zr partition coefficients between apatite and liquid are much smaller than the HREE partition coefficients. HREE partition coefficients between zircon and liquid are very large (more than 100) and Hf partition coefficients are even larger. Whitlockite and zirconolite may have somewhat similar partition coefficient patterns to those for apatite and zircon, respectively.

In the following discussion, we assume that there were some genetic relationships between the lunar granitic material and the surrounding black basaltic breccias and/or KREEP. The lunar granitic materials have V-shaped REE patterns which are quite different from those of LREE-enriched basaltic breccias or KREEP. They are also less enriched in REE than the black basaltic materials or KREEP. An adequate amount of apatite/whitlockite fractionation can possibly explain the differences in REE patterns and concentrations by means of simple fractional crystallization because apatite/whitlockite have large (larger than 10 for all REE) and convex upward REE partition coefficient patterns. However, if also we take into account the fractionation of the other minerals required to produce the increase in the SiO_2 content, then an unreasonably large amount of apatite/whitlockite fractionation may be required.

Zircon/zirconolite fractionation can decrease the Hf and Zr concentrations in the residual liquid. However it also decreases HREE because the Hf, Zr, and HREE partition coefficients are large. Therefore, zircon/zirconolite fractionation cannot account for the V-shaped REE patterns of the granitic materials by means of fractional crystallization from the black basaltic materials or KREEP. The combined fractionation of apatite/whitlockite with zircon/zirconolite as well as major minerals will not explain the REE patterns of the granitic material unless apatite/whitlockite dominates the fractionation.

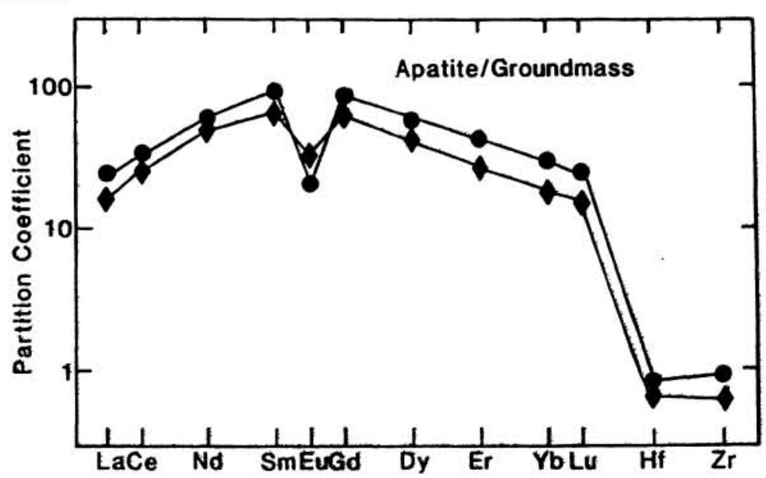

Fig. 1. Hf, Zr, and REE partition Coefficient patterns between apatite and liquid. Solid triangle: andesite, Solid circle: granite.

PARTITION COEFFICIENTS OF HF, ZR, AND REE

Fujimaki, H., et al.

In Fig. 3, the Lu-Hf features for the grey breccias, felsite, and black basaltic breccias are shown [data are from 2, 4, 6]. The black breccias are highly enriched in Hf and have almost the same Lu/Hf ratios as the KREEP basalts. In contrast, the granitic materials (grey breccias and felsite) are less enriched in Hf and they seem to have somewhat higher Lu/Hf ratios than those of black basaltic breccias and KREEP. These data show that the granitic materials lost more Hf than Lu if they were formed from the black basaltic materials or KREEP-like liquid. These tendencies appear to be most easily explained by the theory of liquid immisibility for the origin of the granitic materials because the highly charged cation (Hf+4) would be more strongly partitioned into Fe-rich liquid than the less highly charged cation (Lu+3).

REFERENCES:
[1] Albee A.L., Burnett D.S., Chodos A.A., Haines E.L., Huneke J.C., Papanastassiou D.A., Podosek F.A., Russ G.P. and Wasserburg G.J. (1970), Earth Planet. Sci. Lett., 9, 137-163. [2] Wakita H. and Schmitt R.A. (1970), Earth Planet. Sci. Lett., 9, 169-176. [3] Rutherford M.J., Hess P.C., Ryerson F.J. Campbell H.W. and Dick P.A. (1976), Proc. Lunar Sci. Conf. 7th, 1723-1740. [4] Quick J.E., Albee A.L., Ma M.-S., Murali A.V. and Schmitt R.A. (1977), Proc. Lunar Sci. Conf. 8th, 2153-2189. [5] Ryder G., Stoeser D.B. Marvin U.B. and Bower J.F. (1975), Proc. Lunar Sci. Conf. 6th, 435-449. [6] Blanchard D.P., Jacobs J.W. and Brannon J.C.(1977), Proc. Lunar Sci. Conf. 8th, 2507-2524.

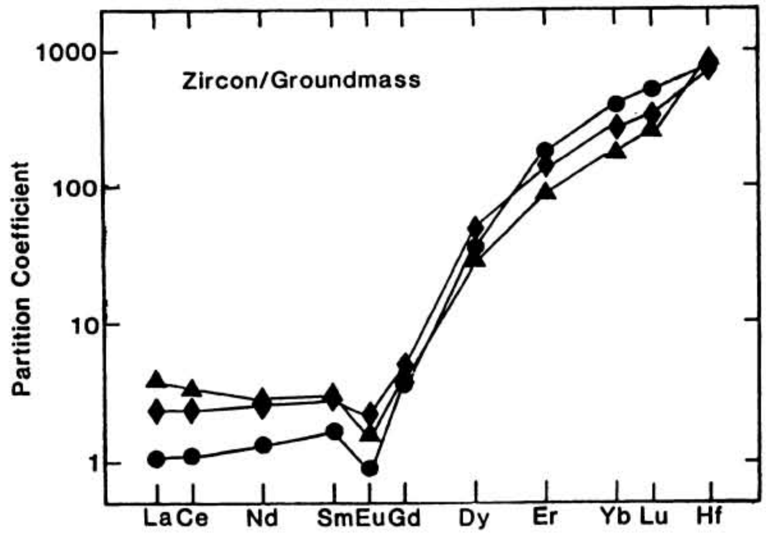

Fig. 2. Hf, Zr, and REE partition coefficient patterns between zircon and liquid. Solid triangle and diamond: andesites, Solid circle: granite.

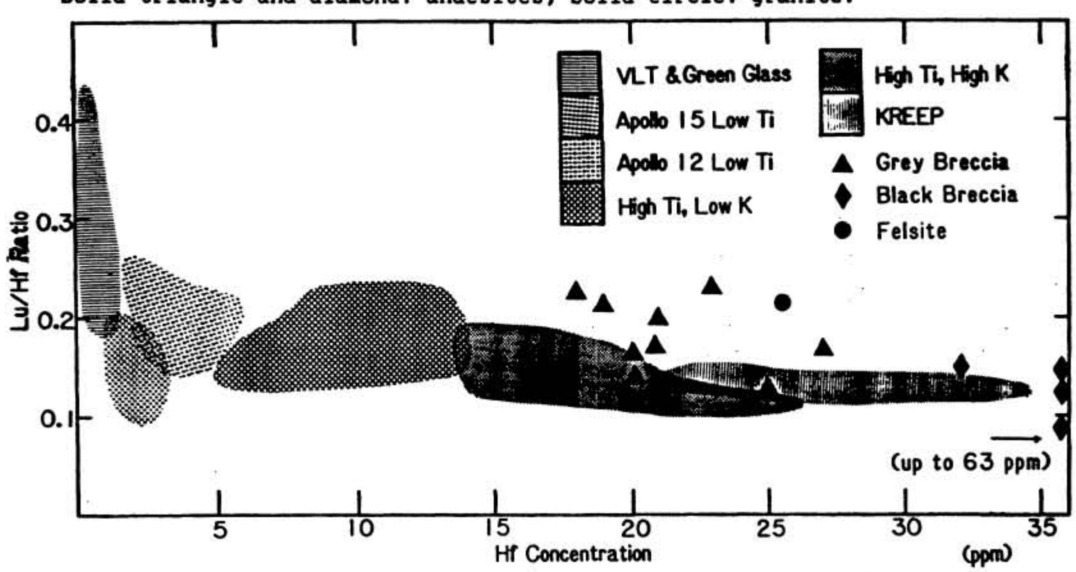

Fig. 3. Lu-Hf features for grey breccias, black breccias and felsite.