GEOCHEMISTRY OF ANORTHOSITE CLASTS FROM 67016: EVOLUTION OF THE LUNAR CRUST AND THE COMPOSITION OF THE MOON M.D. Norman[1,2] and S.R. Taylor[2,3]
[1]Planetary Geosciences Div., Geol. & Geophys., SOEST, University of Hawaii, Honolulu, HI 96822, [2]Research School of Earth Sciences, Australian National University, Canberra, A.C.T. 2601, [3] Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058.

67016 is one of the feldspathic fragmental breccias (FFBs) collected from the rim of North Ray Crater, Station 13, Apollo 16. FFBs probably represent units similar to those exposed on the Kant Plateau and Descartes Highlands, and may represent ejecta from the Nectaris impact basin. If so, they are crucial samples from a poorly explored region of the Moon, and could yield important information about the composition and evolution of the lunar crust. 67016 contains abundant plutonic and granulitic anorthositic clasts from sources deep within the lunar crust [1,2]. We have analyzed a suite of these anorthositic clasts for major and trace element abundances to investigate the role of these rock types in lunar crustal evolution.

Three compositional groups of anorthositic clasts have been recognized (**Fig. 1**). One group is poor in mafic constituents (Al_2O_3 >30%, FeO and MgO <4%), with the low concentrations of incompatible elements and large positive Eu anomalies considered typical of lunar ferroan anorthosites. The other two groups are more mafic (Al_2O_3 ≤28%, MgO and FeO ≥5%) and are distinguished from each other by their FeO/MgO ratios (**Fig. 1**). Mafic-rich varieties have higher concentrations of incompatible trace elements at levels similar to that of the lunar crust [1]. Siderophile element contents are variable (Ni 6-360 ppm), but several clasts have <40 ppm Ni and probably would qualify as "pristine" igneous rocks.

Mafic-poor ferroan anorthosites are a well known igneous rock type in the lunar crust. Mafic-rich varieties have been predicted based on mixing models of polymict breccias [3], but have not been widely recognized in the lunar rock record. The clast population of 67016 may provide examples of these mafic-rich anorthosites, which have major and trace element compositions close to that of average lunar crust. An upper limit of 2-5% of a KREEP component can be calculated for the mafic-rich anorthositic clasts from their LREE, Nb, Hf, Zr, U, and Th abundances. Such a model, however, fails to account for the major element compositions of these clasts, the shape of their REE patterns, or their relatively high abundances of moderately incompatible elements (e.g., Sc, V) [1]. Li-Al_2O_3 variations in the 67016 clasts trend away from the impact mixing trend (**Fig. 2**), which is also inconsistent with a significant KREEP component in these clasts. Based on the textures and mineralogy of these clasts [2], the lack of KREEP and meteoritic contamination, and the coherent compositional variations between mafic-poor and mafic-rich varieties, we conclude that at least the ferroan anorthositic clasts in 67016 probably represent a co-genetic suite related by igneous differentiation. Magnesian clasts typically have higher concentrations of incompatible elements (e.g., Ce, Th) suggesting they are not related to the ferroan varieties by simple fractional crystallization.

Fig. 3 shows Li vs. Li/Yb variations for common lunar highland and mare rock types. Li is a potentially useful element which has received comparatively little attention in lunar studies. It is only moderately volatile, and appears to be moderately compatible into many rock-forming silicate minerals during igneous differentiation [4,5]. Crustal and mantle-derived lunar rocks show complementary fractionation trends consistent with global differentiation in a magma ocean. The most primitive crustal and mantle-derived lunar rocks have similar Li abundances and Li/Yb ratios, providing an estimate of the magma ocean (~bulk Moon) composition (**Fig. 3**). This estimate of the Moon's Li abundance is considerably higher than previous values (~3-5 ppm vs. 0.83 ppm [6]), but provides consistent Yb values (0.6-0.8 ppm) for the bulk Moon. This estimate of the Moon's Li/Yb is similar to that of the Earth's mantle as measured on peridotite nodules, and is considerably less than the CI value of 9.8 [7]. However, other classes of chondrites (i.e., CO, CV, and EL), several eucrites, and some of the SNC meteorites also have comparable Li/Yb ratios, precluding a unique match between the Earth and Moon.

[1] Norman M.D. and Taylor S.R. (1990) Lunar Planet. Sci. XXI, 899 [2] Norman M.D. (1981) Proc. Lunar Planet. Sci. Conf. 12, 235 [3] Korotev R.L. and Haskin L.A. (1988) Geochim. Cosmochim. Acta 52, 1795 [4] Ryan J.G. and Langmuir C.H. (1987) Geochim. Cosmochim. Acta 51, 1727 [5] Philpotts et al. (1972) Proc. Lunar. Sci. Conf. 3, 1293 [6] Taylor S.R. (1982) Planetary Science: A Lunar Perspective. LPI, 481 pp. [7] Wasson J.T and Kallemeyn G.W. (1988) Phil. Trans. R. Soc. Lond. A325, 535 [8] Lindstrom M.M. and Salpas P.A. (1983) Proc. Lunar Planet. Sci. Conf. 13, JGR 88, A671.

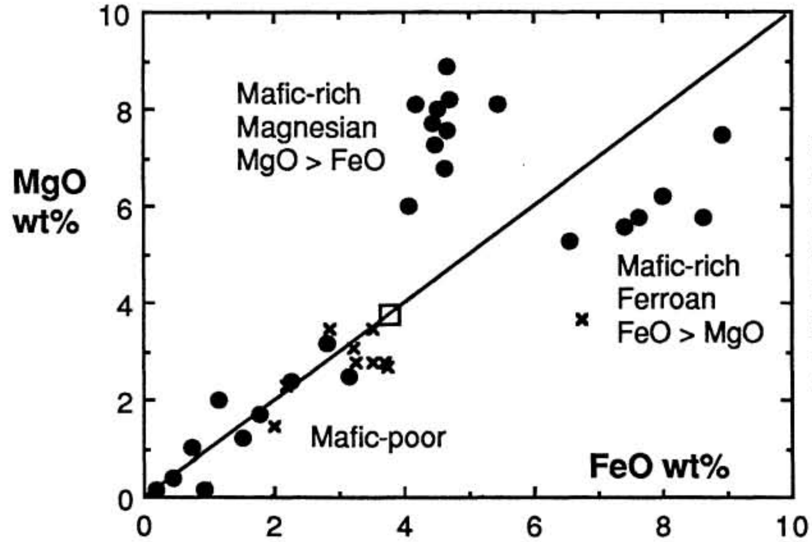

Fig. 1 FeO vs. MgO for splits of 67016. Black circles are anorthositic clasts, x's are melt breccia clasts, square is bulk breccia. The line represents FeO = MgO. Data from this study and [8].

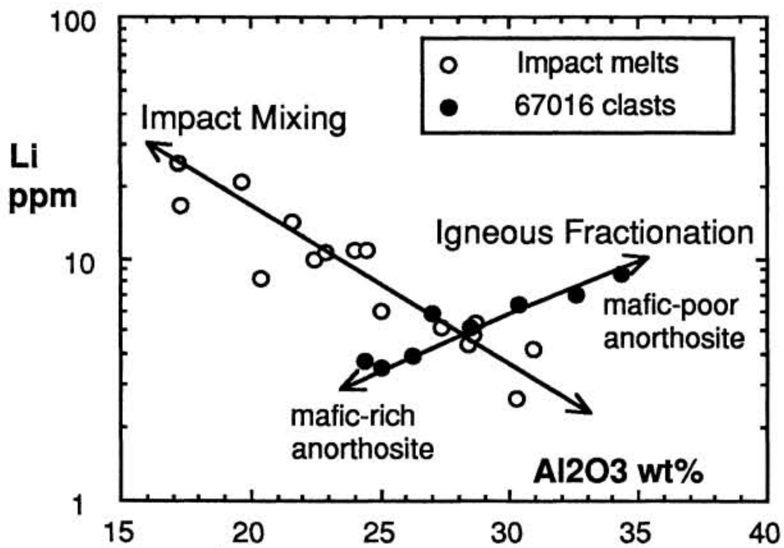

Fig. 2 Al2O3 vs. Li abundance for 67016 anorthositic clasts compared to those for Apollo 16 impact melts. If the impact melt trend results from mixing between a Li-poor anorthositic component and Li-rich KREEP, then the 67016 trend is unlikely to reflect the same process. 67016 data by ICP (our lab), impact melt Li data mostly by isotope dilution and radiochemical neutron activation, from the Lunar and Planetary Science Conference Proceedings.

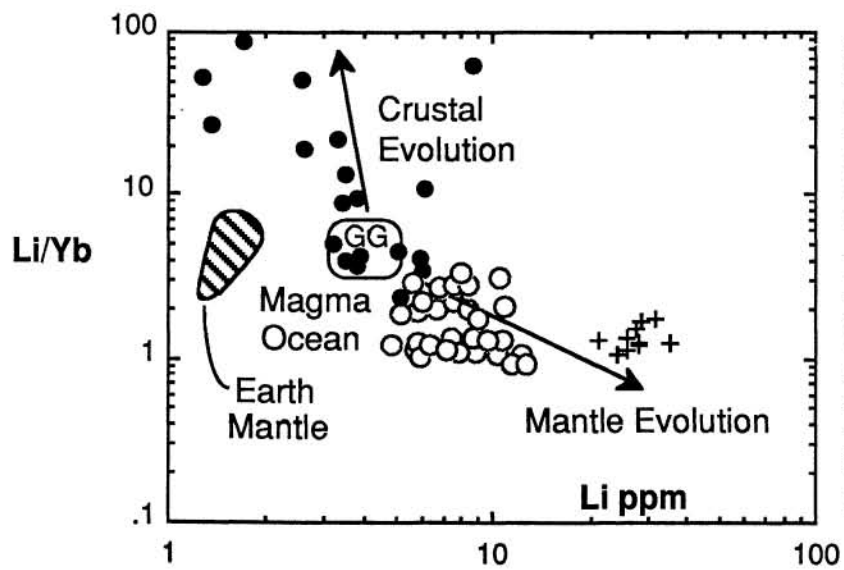

Fig. 3 Li abundance vs. Li/Yb ratio for common lunar rock types. Solid circles include anorthositic clasts from 67016 and other FFBs, GG is Apollo 15 Green Glass, open circles are low-Ti and high-Ti mare basalts, crosses are Apollo 14 KREEP-rich breccias. Literature data is mostly by ID and RNAA from the Proceedings.