A FERROAN GABBRONORITE CLAST IN LUNAR METEORITE ALHA81005: MAJOR AND TRACE ELEMENT COMPOSITION, AND ORIGIN.

A. K. Maloy[1], A. H. Treiman[2], and C. K. Shearer Jr.[3].
[1]Department of Geology, Miami University, Oxford, OH 45056 (maloyak@cs.com), [2]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058 (treiman@lpi.usra.edu), [3]Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131 (cshearer@unm.edu).

Lunar ferroan anorthosites (FAN) are associated with rare ferroan mafic lithologies, the origins of which have been unclear [1,2]. We integrate optical and electron microscopy with EMP and SIMS chemical analyses to determine the bulk and trace element composition a ferroan gabbronorite clast in ALH84001. The clast is an impact melt, but is not a mixture of known lunar lithologies, nor a fractionate of known basalt types. By major and trace element chemistry, it is related to FAN.

Sample: We studied a granulitic ferroan gabbronorite clast, clast 2, in lunar meteorite ALHA81005 [3,4]. The clast is exposed in thin section ',48' and was described first by Goodrich et al. [5].

Methods: Major and minor element abundance in of mineral were obtained by EMP. Abundances of REE and other elements (V, Mn, Co, Ni, Y, Th) were measured with a Cameca ims 4f ion probe (Institute of Meteoritics, Uni. New Mexico) [6]. A primary beam of O^- ions, potential of 10.0 kV and 20 nA current, was focused to a 20 µm spot on the sample. Sputtered secondary ions were energy-filtered using a sample offset voltage of 105 V and an energy window of ±25V. Analyses involved repeated cycles of counting peaks and backgrounds. Element concentrations were calculated from empirical relationships of $Element^+/^{30}Si^+$ ratios (normalized to known SiO_2 content), based on multiple analyses of glass standards, calibrated daily.

To determine the mineral mode, X-ray maps for major elements were acquired by WDX (Cameca SX 100 EMP). The maps were classified to minerals with the image-processing program *Multispec* [7]. By combining the modal mineralogy of the clast the EMP compositions of its minerals, we calculated the clast's bulk composition, Table 1 (see [8]).

Results: Clast 2 is a ferroan gabbronorite (mg* = 56): 51% plagioclase $An_{95.6}$, 26% orthopyroxene, 22% augite, 1% ilmenite, 0.3% chromite, and traces of troilite and whitlockite [5]. Its bulk composition (Table 1) is like basalt + plagioclase; its mg* [=molar Mg/(Mg + Fe)] and the An content of its plagioclase are like FAN (Fig. 1). Its calculated bulk REE pattern (Fig. 2) is nearly flat at ~13xCI with a slight positive Eu anomaly. Ti/Sm and Al/Eu are at 0.8xCI.

Table 1.

SiO_2	47.13
TiO_2	0.74
Al_2O_3	19.09
Cr_2O_3	0.21
FeO	10.49
MnO	0.18
MgO	7.47
CaO	15.15
Na_2O	0.25
K_2O	0.03
P_2O_5	0.005
Sum	100.72

Clast 2 is probably not pristine. Its Co and Ni contents are ~0.03xCI ~0.02xCI respectively, far above the nominal cutoff for pristinity (0.0003xCI [18]). Clast 2 could be an impact melt with ~2.5% CI-equivalent contribution from the impactor.

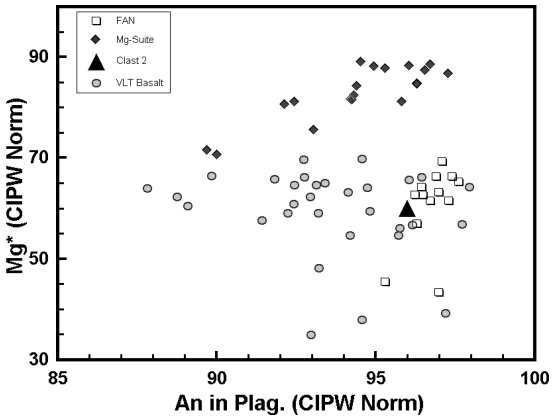

Figure 1. Normative plagioclase composition [An = molar Ca / (Ca + Na)] versus normative mg* [mg* = molar Mg / (Mg + Fe)] for ALHA81005,48 clast 2, and reference samples [9-17] of high pristinity [18].

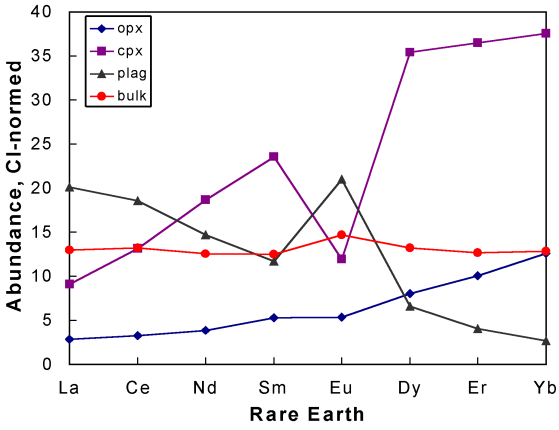

Figure 2. REE abundances in minerals of clast 2, and calculated bulk REE content – CI-normalized.

Origin: Clast 2 appears closely related to FAN although it is not anorthositic (Fig. 3a).

Fractionate from VLT basalt? ALHA81005 contains clasts of very-low-Ti (VLT) basalt [4], and clast 2 has mg* and An like some VLT (Fig 1). However, clast 2 cannot be derived from VLT because it is has much more feldspar and CaO than known VLT (Fig. 3a,c), and has a positive Eu anomaly (Fig. 2). Clast 2

cannot be a plagioclase-rich cumulate from VLT, as its Ti content is too high (Fig. 3b).

Fractionate from an Mg suite magma? Based on Ti vs. mg* (Fig. 3b), clast 2 could be a differentiate from an Mg-suite magma. However, the Mg-suite trend is inconsistent with the high CaO of clast 2 (Fig. 3c).

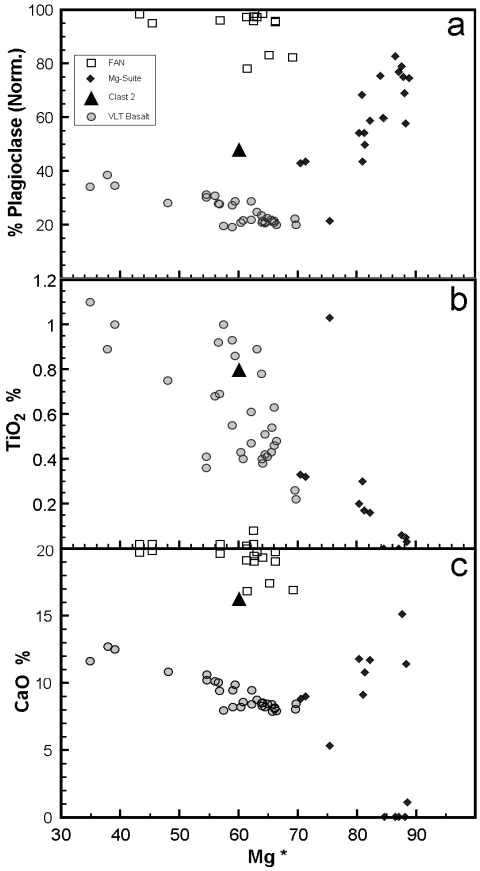

Figure 3. Normative Mg* versus several parameters for ALHA81005,48 clast 2 and reference samples (Fig 1).

Impact mixture of ALH81005 lithologies? ALH81005 contains FAN, Mg suite rock, and VLT, but the composition of clast 2 is not consistent with mixtures of these. Clast 2 matches FAN in mg* and An content (Fig. 1), but has a modal mineralogy like an Mg suite rock. Graphs of mg* versus normative feldspar and TiO_2 (Fig. 3a,b), show that mixing curves between FANs and Mg suite rocks do not pass near the clast 2 composition. So, clast 2 cannot represent a mixture of FAN and Mg suite rock.

Clast 2 is like the most feldspathic VLT basalts in mg* and An, but it cannot be a mixture of VLT and FAN. Element by element, mixes VLT and FAN can match clast 2 (Figs. 1,3), but every element requires a different proportion of FAN and VLT. Nor can clast 2 be a mixture of VLT and Mg-suite rock, because they cannot yield CaO high enough (Fig. 3d).

Nor is clast 2 like the complex impact mixture LKFM [12], although they have similar high Al_2O_3. Compared to LKFM, clast 2 has high CaO, low mg*, and very low REE contents.

Related to FAN? Clast 2 has many geochemical similarities to FAN, like other rare noritic and gabbroic clasts in FAN [1,2,8,19]. Clast 2 plots with FAN on mg* vs. An [5] (Fig. 1), and is consistent with FAN by abundances and ratios of elements held principally in mafics (e.g., Fe/Ti, Cr/Ti, Ti/Sm [17]) or in plagiolcase (e.g., Al/Eu [8]). REE in clast 2 are nearly identical to those calculated for parent magma of FAN [2]

Conclusions: The chemical composition of clast 2 cannot be replicated as a derivative of lunar basalt or Mg-suite magmas, nor as a mixture of highland and/or mare lithologies. It is closely related to FAN.

Mafic FAN-related rocks are known in the Apollo collections [1,2,8,19-21], with several possible origins suggested. Clast 2's flat REE pattern and similar CI-normalized abundances of Al, Ti, and Ca are consistent with it being nearly a magma composition [2] rather than being a melted cumulate rock [1]. In fact, the REE pattern of clast 2 (Fig. 2) is close to that of an inferred parent magma for ferroan anorthosite [2].

Acknowledgements: This line of research was suggested by R. Korotev. V. Lauer, G. Robinson, C. Schwandt, and J. Haggerty assisted with chemical analyses. We appreciate the insights of L. Borg and R. Korotev. This work was part of an LPI Summer Internship to AKM, advised by AHT. Support from the LPI and NASA Cosmochem. Grant NG-12771.

References

[1] Warren P.H. & Wasson J.T. (1978) *PLPSC 9*, 185. [2] Jolliff B.L. & Haskin L.A. (1995) *GCA*, 59, 11, 2345. [3] Korotev R.L. et al. (1983) *Geophys. Res. Lett*., 10, 9, 829. [4] Treiman A.H. & Drake M.J. (1983) *Geophys. Res. Lett*., 10, 783. [5] Goodrich C.A. et al. (1984) *PLPSC 15*, C87. [6] Papike J.J. et al. (1994) *Am. Mineral*. 79, 796. [7] Landgrebe D. & Biehl L. (2003) *MultiSpec©: A Multispectral Image Data Analysis System*. website. [8] Norman M.D. et al. (1995) *GCA* 59, 831. [10] Taylor S.R. (1982) *Planetary Science: A Lunar Perspective.* [11] Ryder G. & Norman M. (1979) *Curatorial Publication 14565/603.* [12] Ryder G. & Norman M. (1980) *Curatorial Publication 52-JSC16904.* [13] Ryder G. (1985) *Curatorial Publication 29787.* [14] Warren P.H. & Wasson J.T. (1979) *PLPSC 10*, 583. [15] Warren P.H. et al. (1987) *PLPSC 17,* 303. [16] Warren P.H. et al. (1990) *PLPSC 20*, 31. [17] Papike J.J. (1998) *Reviews in Mineralogy*, 36, ch. 5. [18] Warren P.H. (1993) *Am. Min*., 78, 360. [19] Norman M. (1981) *PLPSC 12B*, 235. [20] McGee J. (1987) *PLPSC 18*, 21. [21] Warren P.H. (1990) *Am. Min*., 75, 46.