AN *IN–SITU* STUDY OF REE ABUNDANCES IN THREE ANORTHOSITIC IMPACT MELT LUNAR HIGHLAND METEORITES.

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Introduction: Lunar meteorites may have sampled material more representative of the bulk lunar surface than the nearside regions sampled by Apollo and Luna missions. Lunar highland meteorites tend to be more anorthosite-rich, and poorer in the melt residue component (KREEP), than their Apollo analogues. For example, the Ni/Ir of most lunar meteorites is lower than for Apollo samples [1]. Here we report the REE composition of clasts from three lunar meteorites; model the original melt composition from which the clasts and relict crystals formed; and compare these results with previous work on the Apollo ferroan anorthosite (FAN) suite.

Samples and Techniques: *Dar Al Gani* (*DaG) 400* is a lunar highland regolith breccia, composed of melt fragments embedded in a poorly crystalline, dark matrix. The melt fragments are mostly composed of microcrystalline anorthite fragments intimately intergrown with pyroxene and (usually) minor olivine [2]. *Dhofar 081* is a fragmental breccia with a glass- and melt-rich matrix, and abundant vesicles. Clasts include anorthosite fragments, impact-melt breccias, and bimineralic fragments. Monolithic-plagioclase clasts, probably relict, are abundant [3]. *Northwest Africa* (*NWA) 482* is a light coloured anorthositic impact melt breccia composed of 80-90% plagioclase [1] including relict mm-scale plagioclase grains, with minor olivine and pyroxene, cross–cut by glassy impact melt veins.

Polished sections 200 µm thick were characterised by optical and scanning electron microscope. Trace element analysis was performed by laser ablation inductively coupled mass spectrometry (LA-ICP-MS), performed *in situ*, with a spatial resolution of ~50-100µm. Errors are approximately 10%, calculated from analyses of REE in standard basalt (BCR) measured as an unknown.

Major element abundances were determined by electron microprobe for a number of clasts and matrix of DaG 400. Of the clasts with REE data, three are ~95% plagioclase, 5% clinopyroxene (cpx); one is ~60% plagioclase, 25% cpx, 15% olivine; and one is ~50% plagioclase, 50% olivine (by mass). In all cases the plagioclase is extremely calcic (An_{95-97}). The plagioclase-olivine and plagioclase-cpx-olivine clasts are sufficiently coarse-grained to allow probe analysis of individual minerals. By contrast, the plagioclase-cpx clasts are much finer grained, consisting of micron to submicron crystals; their composition was determined by a model modal analysis of bulk measurements.

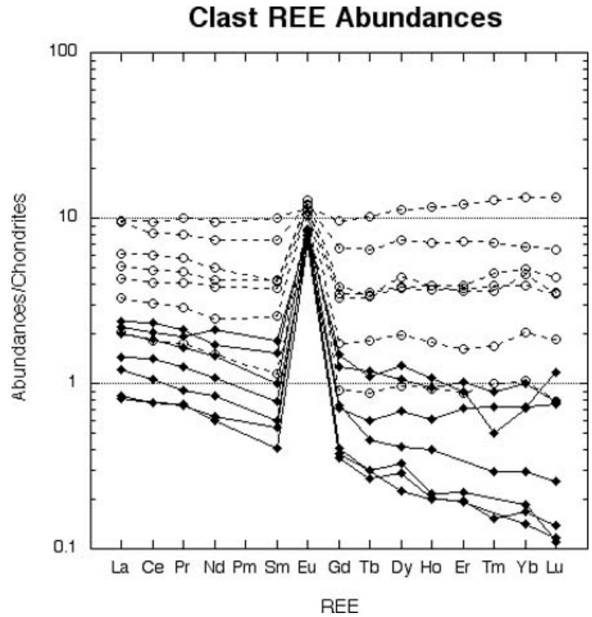

Figure 1: Clast REE measurements for NWA 482 (open, dashed line) and DAG 400 (closed, solid line).

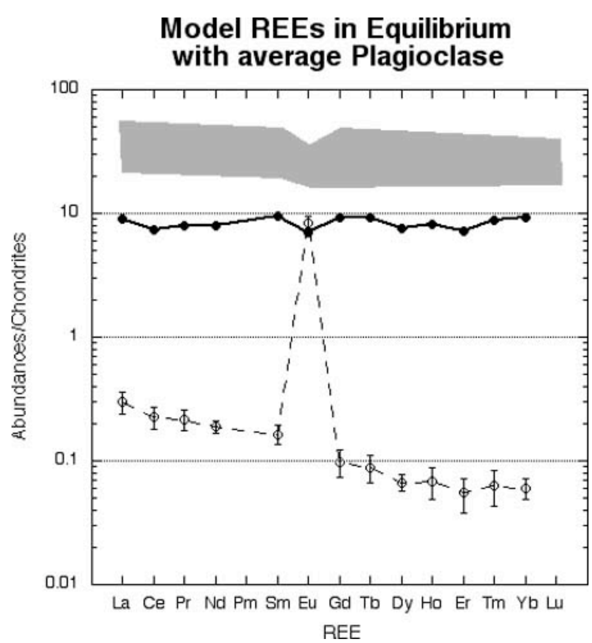

Figure 2: Average of pure relict anorthites in Dhofar 081 and NWA 482 (open, dashed; error bars are one-sigma of average) and the REE pattern in a model [4] equilibrium melt (solid line). Shaded area are model melts [5] for Apollo FANs.

Results: The REE vary systematically from meteorite to meteorite. Melt clast REEs from NWA 482 (2-10 x CI) are consistently higher than in DaG 400 (0.1-2 x CI), with some overlap (Fig 1). The anorthite crystal REEs in Dhofar 081 and NWA 482 are indistinguishable; their equilibrium melt model REEs are flat at 8 x CI (Fig 2).

The shock melt in NWA 482 has an REE pattern similar to, but higher than, the dark matrix of DaG 400. The REE (except Eu) in DAG 400 matrix matches that in the Dhofar 081 matrix.

The majority of the clasts in DAG 400 were anorthosites dominated by anorthite with a few percent cpx. The REE in a melt in equilibrium with these clasts would have had abundances of 20 to 30 x CI, like the anorthositic subgroup of the Apollo FAN suite, but with a significantly larger negative Eu anomaly and a different fractionation trend for both the LREE and HREE patterns. The olivine-bearing clasts' melt model predicts REEs at 100 x CI; the melt in equilibrium with the average matrix mineralogy lies between the anorthositic clasts and the olivine-bearing clasts, also with a strong negative europium anomaly (Fig 3).

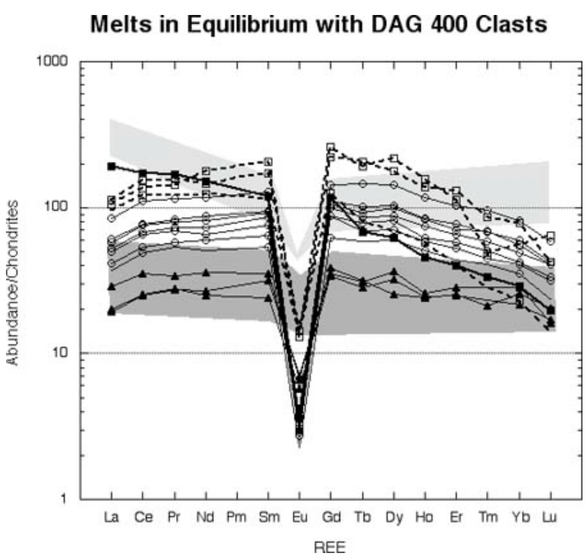

Figure 3: Model [4] equilibrium melts for DAG 400 clasts: plag-cpx-olivine clast (filled squares); plag-olivine clast (open squares, dashed); matrix (open circles); and plag-cpx clasts (closed triangles). Shaded regions are literature [5] calculated melt abundances for Apollo mafic ferroan (light gray) and anorthositic ferroan (dark gray) samples.

Discussion: The REE of the *anorthite crystals* may represent an equilibrium between crystals and melt pre-dating the shock event that led to the formation of the matrix and mixed clasts. The melt from which they crystallized, containing unfractionated REEs with abundances ~8xCI, are unlike those from Apollo lunar highland samples. Apollo anorthositic ferroan samples typically contain anorthites that formed from more evolved melts, calculated to contain REEs at levels of ~20-40 x CI [5].

The wide range of REE patterns seen in the *melt clasts* indicates that they experienced a more complex history. The Eu abundance remains remarkably constant at about 10 times chondritic in virtually all the clasts, even though the abundances of the other REEs vary by a factor of ten and the slope of the REE patterns shift from LEE-depleted to flat with increasing REE content. This suggests that the REE patterns in the clasts represent a continuum of mixing between a material like the most highly fractionated REE patterns seen in DAG 400, and material with a flat REE pattern typical of a trapped melt or of the most REE rich NWA 482 clasts.

Reproducing the REE patterns in the *matrix* as mixtures of other components seen in these meteorites is much more difficult; no one end-member can reproduce the Eu abundances in all the different matrix samples even within a given meteorite, much less given the very different Eu abundances between DAG 400 and Dhofar 081 matrices.

The *shocked melt veins* of NWA 482 show REE abundances that are virtually indistinguishable from the NWA 482 clasts. This suggests that the heating event which formed the veins occurred so quickly that the REEs were not redistributed over the ~50μm scale of the shock veins.

We conclude that all but a few relict anorthite grains were either partially or completely melted by the shock events experienced by these rocks. Depending on the initial mineralogy and textures, the shock events produced either clast material (some of which was transformed completely into the shock melt) or completely melted the material that became the matrix. The sample then cooled so quickly that no trace element equilibration between any of these phases (or the relict anorthites) could take place.

Thus it appears that the matrix, the clasts, and the anorthite grains represent at least three distinct components from the original rocks whose crystal structure was destroyed in the shock events, but whose trace element chemistry otherwise remains essentially unaltered.

References: [1] Warren and Kallemeyn, 2002, *MAPS* **36** A220 [2] Bischoff et al., 1988, *MAPS* **33**, 1243-1257; Zipfel et al., 1988, *MAPS 33*, A171 [3] Cahill et al., 2002, *LPSC XXXIII*, 1351; Warren and Taylor, 2001, *LPSC XXXII* [4] Phinney and Morrison, 1990, *GCA* **54**, 1639-1654; Weill, McKay 1975, *Proc. LSC 6th*, 1143-1158 [5] Floss et al., 1988, *LPSC XXII*, 391-392; Floss et al., 1998, *GCA* **62** 1255.