THE MOST REDUCED ROCK FROM THE MOON – APOLLO 14 BASALT 14053: EXTREME REDUCTION ENTIRELY FROM A RE-HEATING EVENT.

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Introduction: With the return of the Apollo 14 rocks and soil, the Preliminary Examination Team reported that the majority of the rocks were breccias. Only four rocks were believed to be basaltic: a) 14310, and its smaller-sized pair, 14073, later became the type specimens for "melt rocks," a somewhat surprising finding at the time, but logical in retrospect; and b) 14053 and its smaller pair, 14072, are unique among lunar rocks, in that they possess evidence for being the most reduced of all lunar basalts. It is the origin of these unusual rocks that is addressed herein.

Basalt 14053 is a fine-grained, holocrystalline, equigranular hi-Al mare-type basalt. Based upon the disturbed Sm-Nd and well-defined Rb-Sr age of 3.92 ±0.04Ga [1], Snyder & Taylor [2] speculated that the hi-Al Apollo 14 basalts actually had an impact-melt origin. Likewise, unique reduction features also led to questions about its origin. We have revisited these unusual features as they relate to the origin of 14053 textures and chemistry.

Basalt 14053 has an ophitic texture and consists of pyroxene (~50%) and plagioclase (~40%), as shown in Table 1. The rock contains typical basaltic mesostasis, consisting of fayalite, silica, glass, phosphates, and opaque minerals. In this mesostasis occurs evidence for a reduction reaction unique to all lunar rocks, the breakdown texture of fayalite to Fe metal and silica: $\boldsymbol{Fe_2SiO_4 \rightarrow 2Fe + SiO_2 + O_2}$ (Fig. 1-2). This rock also displays extreme reduction of Cr-ulvöspinel to ilmenite, Ti-Al-chromite, and native Fe (Fig. 2). It is these breakdown textures (1 = fayalite; 2 = ulvöspinel) that are evidence for extreme reduction, the only lunar basalt with such assemblages.

In our LPSC Abstract last year [3] in addressing these reduction textures, we proposed that 14053 originally crystallized as a normal basalt; however, during its residence in the lunar regolith, it received solar-wind implanted hydrogen. It was subsequently thermally metamorphosed, probably in an impact blanket, whereby the solar-wind hydrogen facilitated the reduction, with a limited amount of hydrogen – i.e., incomplete reduction. Support for this theory comes from crystallographic studies, Finger et al. [4] and Schürmann and Hafner [5], of the M1-M2 site

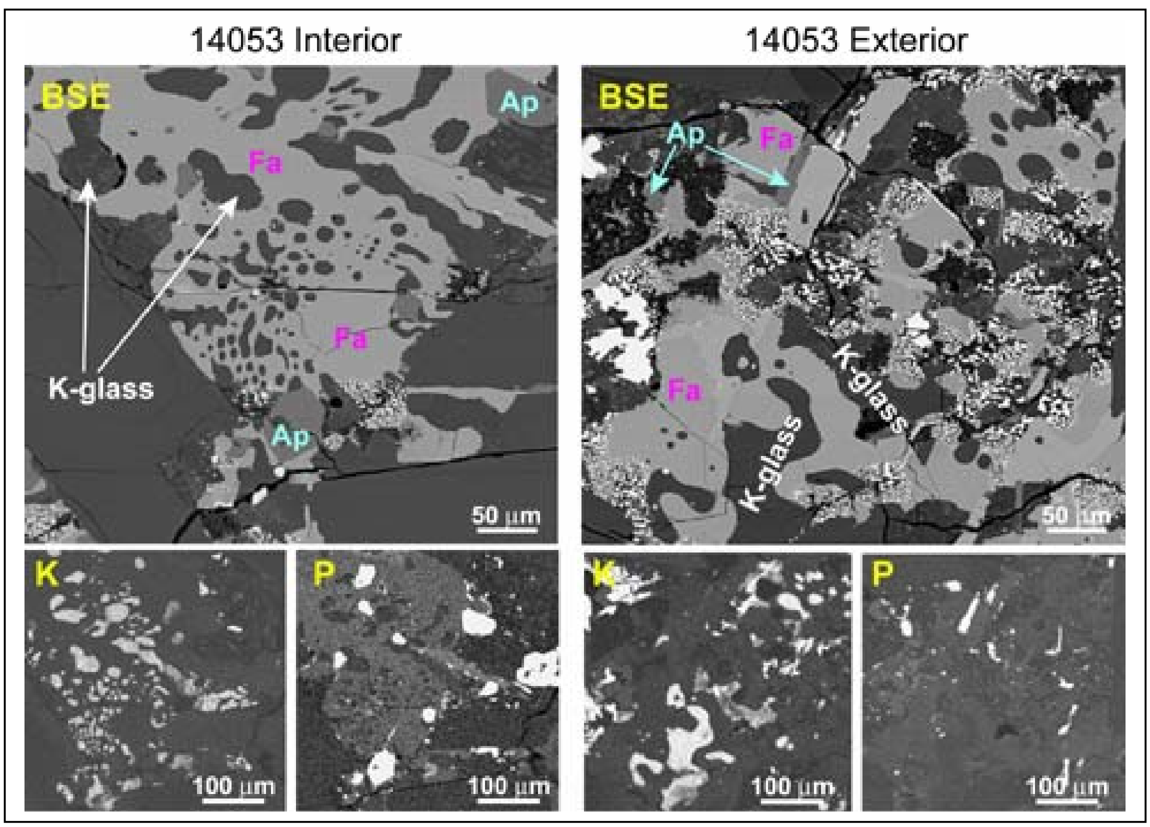

Figure 1. Mesostasis of basalt 14053, showing the late stage reduction of fayalite.

distribution of Mg and Fe^{+2} in 14053 pigeonites. It was concluded that the original cooling rate of 14053 was very slow, and that the rock had been reheated, at some later time, to a temperature >840 ^{0}C. This substantiates our hypothesis. Permeability of the hydrogen, from the surface of the rock inward, may have been a factor here. If such a scenario is correct, the minerals in the center of rock 14053 should show lesser amounts of this extreme reduction. Alas, the Lunar Sample Curtor has provided two new samples taken from the most-interior portion and the exterior of 14053, the basis for this study.

TABLE 1. Modal analyses of 14053.

	Interior 14305	Exterior 14305
# of Pts	296,285	353,509
Plag	42 %	39
Olivine	1.6	3.9
Pyroxene	48	48
SiO2	2.4	2.6
FeS	0.2	0.2
Mesostasis		
K-Glass	**0.9**	**0.9**
Phosphate	**0.3**	**0.3**
Fayalite	**0.9**	**0.3**
Spinel		
Chromite	**0.1**	**0.5**
Ulvöspinel	**0.3**	**0.2**
Ilmenite	**2.3**	**4.3**
Fe metal	**0.09**	**0.3**

Results: Electron microprobe analyses of the opaque minerals in a thin section of 14053 confirm earlier findings [6]. The typical sub-solidus reduction of ulvöspinel to ilmenite + Fe, seen is most mare basalts, involves ulvöspinel with relatively minor amounts of Cr_2O_3. The *f*O2 conditions are usually not sufficiently low to reduce spinel that has appreciable Cr_2O_3 (e.g., Cr-rich ulvöspinel, Ti-chromite). However, in 14053, even the Ti-chromites are reduced, evidence for lower *f*O2 conditions than experienced by any other lunar basalt – i.e.,

Usp/Ti-Chr $\rightarrow$ ***Chr***$_2$ ***+ Ilm + Fe + O***$_2$. Detailed analyses in both samples of the chromite resulting from Ulvö-spinel and Ti-chromite breakdown have shown that ***the spinel in the exterior sample has been reduced considerably further towards chromite,*** such that it contains lesser TiO_2. This would be possible if the reducant (H_2) were most abundant at the exterior of the rock.

The modal analyses reported in Table 1 were performed according to the method of Taylor et al. [7]. The amounts of K-rich glass and phosphate phases are identical in both samples – i.e., the amounts of mesostasis are equal. However, as is apparent in Figure 1 and 2, ***the amount of fayalite that has been reduced is far greater in the exterior sample – i.e., less residual fayalite***. In general, the fayalite of the interior sample has been reduced only 10-20% versus the 50-80% of the exterior sample. The modes also demonstrate that the exterior PM also contains more chromite, a result of greater reduction of the spinel, as discussed above. The higher native Fe and ilmenite on the exterior is also from more extensive reduction.

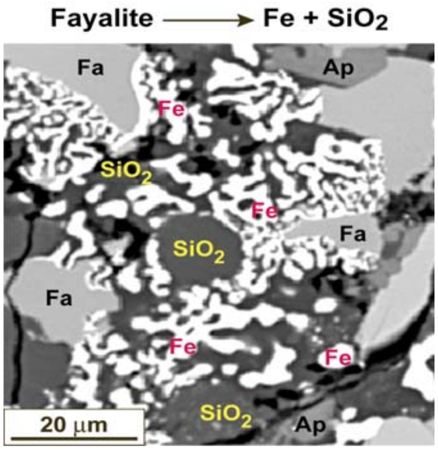

Figure 2. Fayalite reduction caused by introduction of H_2 during a reheating event.

Conclusions: The major question raised by the presence of these extreme reduction textures is the source of the reducant. From the evidence given above, it is concluded that **Apollo 14 rocks 14053, and its pair 14072, are normal hi-Al basalts that have undergone post-crystallization exposure at the surface of the Moon, so as to gather solar-wind implanted protons. A subsequent heating event permitted the solar-wind hydrogen to partially reduce the fayalite and spinels.** It is possible that this might have affected the radiogenic isotopes (Rb-Sr, and Sm-Nd).

References: [1] D. Papanastassiou & G. Wasserburg (1971) EPSL 12, 36-48; [2] G. Snyder & L.A. Taylor (2001) 64th Met Soc Mtg, Abstr #5107; [3] R. Mayne & L.A. Taylor (2003) LPSC XXXIV, CD-ROM #1604; [4] L. Finger et al. (1972) Lunar Sci. III, 259-261; [5] H. Schürmann & S. Hafner (1972) PLSC 3rd, 493-506; [6] A. El Goresy et al. (1971) EPSL 13, 121-129; [7] L.A. Taylor et al. (1996) Icarus 124, 500-512;