NEW INSIGHTS INTO THE ORIGIN OF 14053 – THE ONLY BASALTIC ROCK RETURNED BY APOLLO 14.

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Introduction: The Apollo 14 Mission brought back a large number of lunar rocks, the majority of which were breccias [1]. Of the four rocks that were believed to be basaltic, 14310 and its pair, 14073, turned out to be our 'type specimens' of "melt rocks, at the time, a new concept for the lunar community. The remaining two, 14053 and its small-sized pair, 14072, are unique among the rocks in the lunar collection, in that they possess evidence for being the most reduced of all lunar basalts. It is to the origin of these unusual rocks to which this study is addressed.

The sample studied, 14053, has a mass of 251g and is commonly used as an example of a pristine high-Al basalt. Rb-Sr studies yielded a well-defined age of 3.92 ±0.04Ga [2]; however, when 14053 was reinvestigated by Snyder and Taylor [3], the Sm-Nd data were determined to be disturbed, indicating that some of the components formed before the 3.92 Ga, Rb-Sr age. This is highly unexpected as Rb-Sr isotope systematics are almost always more easily disturbed then those of the Sm-Nd system [4]. These results led to the hypothesis that 14053 and other Apollo 14 hi-Al basalts actually had an impact-melt origin, with the pre-4.0 Ga ages representing melt rocks that were not reset after impact [3]. Likewise, unique petrographically observed, reduction features also led to questions about its origin. We have revisited these unusual features as they relate to the origin of 14053.

Petrographic Description: As studied in thin section, 14053 has an ophitic texture and consists of predominantly pyroxene (50%) and plagioclase (40%). The remainder of the rock consists of ilmenite, chromite-ulvöspinel, silica, in the form of tridymite, FeNi metal, fayalite, troilite, K-Ba-rich glass, F-apatite, and baddeleyite. The rock contains typical basaltic mesostasis, consisting of fayalite, silica, glass, phosphates, and opaque minerals. Some of the fayalite shows reduction-breakdown to Fe metal and silica (Fig. 1). This rock also displays abundant examples of the extreme reduction of Cr-ulvöspinel to ilmenite, Ti-Al-chromite, and native Fe (Fig. 2). It is these reduction textures and mineral chemistry that are evidence for extreme reduction, the only lunar basalt with such assemblages.

Results: Electron microprobe analyses of the opaque minerals in a thin section of 14053 confirm the earlier findings [1]. The typical sub-solidus reduction of ulvöspinel to ilmenite + Fe, seen is most mare basalts, involves ulvöspinel with relatively minor Cr2O3. The fO2 conditions are usually not sufficient low to reduce spinel that has appreciable Cr2O3 (e.g., Cr-

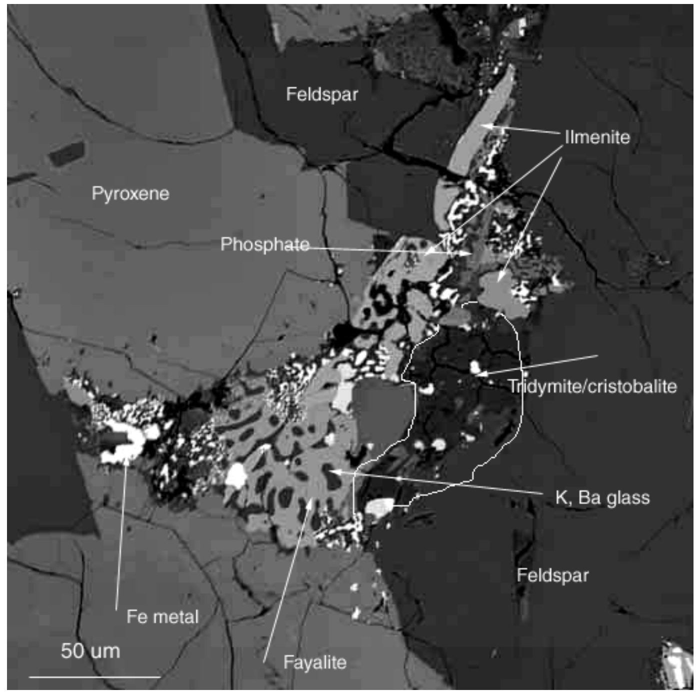

Figure 1: Mesostasis showing breakdown of fayalite.

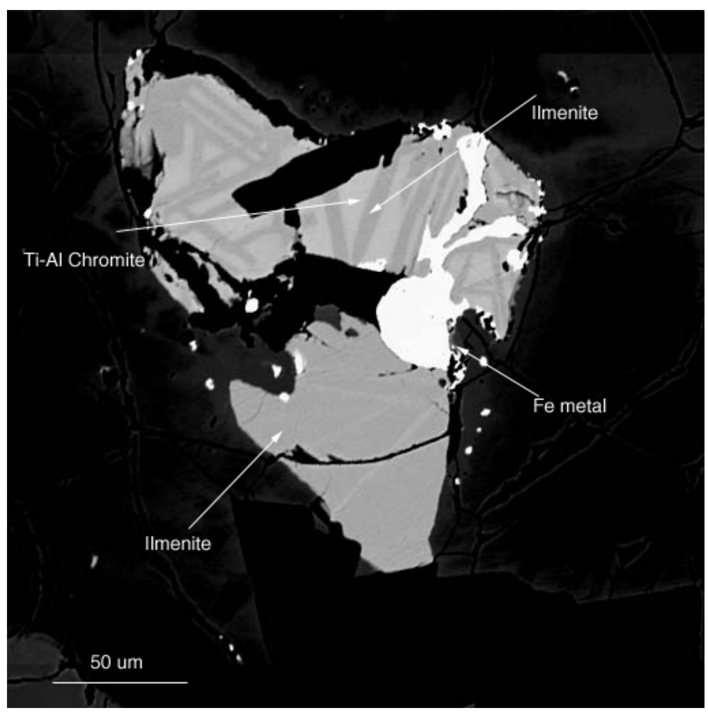

Figure 2: Reduction of Ulvospinel

ulvöspinel, Ti-chromite). However, in 14053, even the Ti-chromites are reduced, evidence for lower fO2 conditions than experienced by any other lunar basalt.

Most mare basalts, including 14053, contain evidence for extreme melt fractionation present as a mesostasis of fayalite, containing a swiss-cheese texture with K-Ba-rich glass as the holes (Fig. 1), ilmenite, silica (tridymite), and phosphate, usually present as F-apatite. In 14053, and its pair 14072, this late-stage fayalite that has been reduced to silica + native Fe. It is important to note that not all of the fayalite has been reduced, only about 50%. Likewise, not all of the Cr-ulvöspinel has been reduced. This presence of only selected reduction can be interpreted to indicate that there was a lack of reducant. This would be possible if the reducant were introduced from the outside of the rock. In such a situation, the "plumbing system" – i.e., cracks, grain boundaries – was not sufficient to permit homogeneous permeability of the reducant. The reduced assemblages discussed above formed at subsolidus temperatures.

Discussion: The major question raised by the reduction textures is the source of the reducant. *Is 14053 an impact-melt rock with solar-wind implanted hydrogen being the source of the extreme reduction?* Basalt 14310 is a sample known to have formed by impact-melt processes, yet it does not contain evidence for any unusual reduction [1,5]. Indeed, it would appear that most of the solar-wind hydrogen was lost upon melting, since this basalt is quite similar to other igneous basalts, albeit with its haystack texture. Basalt 14053 does not have an impact-melt texture (cf., 14310). Therefore, it is reasonable to assume that the reducant, possibly solar-wind hydrogen, was added to 14053 late in the rocks history – i.e., while it was sitting on the lunar surface.

We propose that 14043 was crystallized as a normal basalt; during its residence in the lunar regolith, it received solar-wind implanted hydrogen; subsequently, it was thermally metamorphosed to high, albeit subsolidus temperatures, where the solar-wind hydrogen facilitated the reduction; the ability of the hydrogen to permeate the rock was limited. In summary, the reactions, although subsolidus, would have required an input of heat and a reducing agent. If such a scenario is correct, the minerals in the center of rock 14053 should show lesser amounts of this extreme reduction, perhaps none. This remains to be determined. The best that can be determined from the "data packs" is that our thin section is from the exterior of the rock.

The scenario proposed above is supported by crystallographic studies [6] of the M1-M2 site distribution of Mg and Fe^{+2} in 14053 pigeonites. It was determined that exsolution lamellae, textures, and grain size indicate a relatively slow cooling rate for, but the distribution of Mg and Fe between the M1 and M2 cation sites appears to indicate just the opposite – i.e., rapid cooling. This evidence can be interpreted to indicate initial slow cooling from a melt forming the observed exsolution, et cetera, followed by subsequent reheating to temperatures of 800-900 ^{o}C, with rapid cooling. This substantiates our hypothesis.

Further Work: In order to test the hypothesis that the fayalite and Cr-ulvöspinel reduction observed in 14053 and 14072 may be due to secondary heating and the presence of solar-wind hydrogen, further studies are warranted. It seems reasonable to suggest that the hydrogen would not be able to permeate the entire sample, thereby reducing the exterior portions of the rocks more than those in the interior. Examining sections taken from known positions throughout 14053 and noting where the larger amounts of reduction take place could analyze the effects of such a process.

The hypothesis presented here does not explain the discrepancies described in the isotopic data, but it does explain the extreme reduction products without requiring an impact-melt origin for 14053. The proposed secondary heating event may have been responsible for some of the radiogenic isotope adjustments.

References: [1] El Goresy A. et al (1971) *Earth and Planetary Science Letters, 13,* 121-129. [2] Papanastassiou D. and Wasserburg G.J. (1971) *Earth Planetary Science Letters, 12*, 36-48. [3] Snyder G.A. and Taylor L.A. (2001) *64th Meteoritic Society Meeting,* Abstract #5107 [4] Gilleti B.J. (1991) *Geochimica Cosmochimica Acta, 55*, 1331-1343. [5] Heiken G.H. et al (1991) *The Lunar Sourcebook: a user's guide to the moon.* Cambridge University Press [6] Schürmann K. and Hafner S.S. (1972) *Proceedings of the Third Lunar Science Conference,* 493-506.