SPHERULES AND GLASSES IN LUNAITE SHIŞR 161 RECORD REWORKED REGOLITH AND A MAGNESIAN COMPONENT OF THE FELDSPATHIC HIGHLANDS TERRANE. Axel Wittmann[1], Randy L. Korotev[1], Bradley L. Jolliff[1], and Anthony J. Irving[2]. [1]Department of Earth & Planetary Sciences, Washington University Saint Louis, MO; [2]Department of Earth & Space Sciences, University of Washington, Seattle, WA.

Introduction: Petrologic models for the feldspathic highlands terrane invoke a global magma ocean with plagioclase accumulation in the crust [e.g., 1] variably modified early-on by intrusive activity [e.g., 2]. Some 4.4 Ga later, this surface is saturated with impact craters, their ejecta blankets, and regolith. Shişr 161, a 57.2 g lunaite, is a feldspathic, fragmental regolith breccia [3] and, thus, a recent sample from this surface. It's bulk rock composition indicates high MgO (8.17 wt%) relative to FeO (5.93 wt%) together with a low incompatible element content (TiO_2 0.34 wt%, Th 0.16 ppm) [4]. We explore its petrogenesis from bulk chemistry and petrography with a focus on melt spherules and glass shards.

Samples and Methods: Petrographic observations were made on a 5.5 cm^2 thin section area of Shişr 161. Compositions of 13 spherules and 12 glass shards were determined by electron microprobe analysis. Bulk chemical compositions of the spherules were approximated by modal recombination after the relative proportions of components were determined by image anlysis, using NIH's ImageJ software.

Results: In thin section, Shişr 161 is composed of a fine, clastic matrix that embeds lithic clasts. Clasts <0.5 mm make up 25 % of the thin section area (n=69): 18 % poikilitic melts, 26 % aphanitic melts, 31 % granulites, 13 % polymict breccias, ferroan anorthosites (FAn), plagioclase, Fe-rich Cpx, and 12 % basalt; agglutinates were not observed. The 12 glasses occupy ~0.05 % and the 12 spherules ~0.06 % of the thin section area.

Petrography: The 12 glasses are 0.1 to 0.4 mm long shards; 8 of these are holohyaline without inclusions. Two contain tiny blebs of (Fe,Ni)S. One has variably assimilated debris along its rim; another displays domains with acicular plagioclase crystals, and one is clast-rich with variably assimilated plagioclase, olivine, pyroxene, chromite, and minor, ~1 µm-size blebs of (Fe,Ni)S. Most glass particles are fused to dense portions of the matrix, suggesting reworking and emplacement as parts of polymict breccia clasts.

The 13 spherules are 50 to 480 µm in size and their degree of crystallization ranges from cryptocrystalline (3) to aphanites with tiny crystallites of plagioclase and/or pyroxene (2) to progressively coarser crystallized aphanites with plagioclase laths >5 µm (4); the most coarsely crystallized one has an ophitic texture of plagioclase, pyroxene and olivine with interstitial mesostasis that is enriched in Si, K, P, and Ti. Three spherules bear evidence for thermal metamorphism. One of them equilibrated with the surrounding matrix, presumably as part of a breccia-in-breccia clast; two metamorphosed spherules are components of breccia clasts. One of these belongs to an aphanitic, dark clast that contains abundant, partly assimilated plagioclase fragments in a mafic matrix that crystallized plagioclase laths. The other metamorphosed spherule is part of a more strongly crystalline clast composed of angular plagioclase crystals in a poikilitic olivine-pyroxene matrix (Fig. 1A). This spherule crystallized ~10 µm plagioclase laths that are enclosed in pyroxene. One cryptocrystalline spherule composed of fused droplets, is a component of a polymict breccia clast.

Geochemistry: All glasses and all but two spherules exhibit atomic Mg/Al <1.5, and all glasses and 11 of 13 spherules have atomic Mg/Ca <1, which suggests an impact origin for all glasses and most spherules [5]. The 3 spherules that do not follow this trend belong to a group of 7 spherules containing FeNiS and/or FeNi inclusions, which are likely impactor components. One of them is a possible GASP (*gas-associated spheroidal precipitate* [6]; 0.17 wt% Al_2O_3,

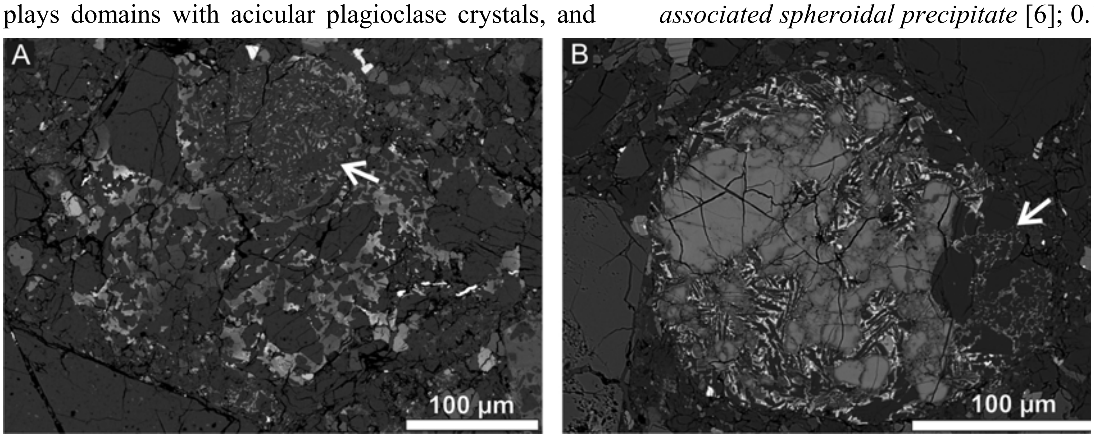

Fig 1. Shişr 161 back-scattered electron images. A – Metamorphosed spherule (arrow) in poikilitic clast. B – Olivine-rich spherule with accreted feldspathic melt (arrow).

64.4 wt% SiO_2, 28.7 wt% FeO), and another one accreted feldspathic melt (Fig. 1B). These characteristics suggest probable impact origins for all these glasses and spherules.

TiO_2 contents reach up to 4.3 wt% but are <0.5 wt% in 20 of the 25 particles analyzed. P_2O_5 concentrations are <0.1 wt% in 23 of the 25 particles and K_2O contents are mostly <0.1 wt%. One glass particle and one spherule are exceptions; they contain 0.8 and 1.1 wt% K_2O, and correlated high TiO_2 and P_2O_5 abundances, likely indicating KREEP components.

Compared with the normative anorthositic norite bulk composition of Shişr 161, normative mineralogies for the glasses and spherules reflect mainly plagioclase-rich precursor lithologies such as anorthosites (2), noritic anorthosites (8), troctolitic anorthosites (4), anorthositic norites (5) and anorthositic troctolites (1). However, two spherules indicate troctolitic normative compositions, a mafic glass, and one spherule have noritic normative compositions, and a possible GASP-particle has a pyroxenitic normative composition.

Comparison of the bulk chemical composition of Shişr 161 [4] with the 5-degree Lunar Prospector gamma-ray spectrometer data [7] points to three broad areas, where the average regional composition is similar: a) southern farside highlands, NW of Tsiolkovskiy crater; b) highlands between Smythii-Marginis, Mendeleev and Tsiolkovskiy; and c) highlands SE of Fecunditatis, between Furnerius and Australe.

Discussion: Although spherules are generally thought to represent distal ejecta, terrestrial examples of fallback debris near the center of the 10 km Ø Bosumtwi [8] and the 18 km Ø El'gygytgyn craters [9] show that such particles may form late fallback material on top of crater-fill impactites (*"microtektite-like spherules"*). In a lunar crater, spherule bearing fallback debris may, thus, blanket the surface of melt splashes and melt sheets, providing thin insulation layers that become thermally metamorphosed. Other interpretations of crystallized lunar spherules invoke prolonged residences in ejecta plumes of large craters [10,11]. Petrographic evidence (Fig. 1A), indicates post-depositional thermal metamorphism affected at least a subset of the crystallized spherules in Shişr 161. The large fraction of impact melts and granulites in Shişr 161 adds weight to the formation scenario as reworked fallback material of a large impact crater.

The compositional variability of spherules and impact glasses in Shişr 161 reflect heterogeneities in their precursors. These include rare KREEP and FeO-rich components, and dominant anorthositic-, FAn- and magnesian-like components. The resulting bulk composition of Shişr 161 suggests a mixture between anorthositic, mare, KREEP-bearing, and magnesian components (Fig. 2). Magnesian granulites and a hypothetical peridotitc component were recently advocated as components for similar feldspathic meteorites [13]. Troctolite clasts in Dhofar 305, 306, 307, olivine pyroxenite clasts in Dhofar 305, dunite clasts in Dhofar 307 [14] and spinel pyroxenites and dunites in Dhofar 310 [15] may represent other endogeneous ultramafic components of the lower highlands crust that contributed to the magnesian character of Shişr 161. Conceivably, admixture of ultramafic impactor material could also account for a magnesian component.

Conclusions: Variably crystallized spherules in lunaite Shişr 161 could record formation as metamorphosed fallback ejecta in a highlands impact crater. Compositions of glasses and spherules suggest larger variability among their precursor rocks than expected from the bulk rock composition [4]. They comprise minor KREEP and mare basalt, dominant anorthitic and poorly defined magnesian lithologies.

References: [1] Wood J. A. et al. (1970) *Proc. Apollo 11 Lunar Sci. Conf.*, 965-988. [2] Shearer C. K. et al. (2006) *RiMG 60,* 365-518. [3] Foreman A. B. et al. *LPSC XL*, abstr. # 2304. [4] Korotev R. L. (submitted) *MAPS.* [5] Joy K. H. et al. (2011) *GCA 75*, 2420-2452. [6] Warren P. H. (2008) *GCA 72*, 3562-3585. [7] Prettyman T. H. et al. (2006) *JGR 111*, E12007. [8] Koeberl C. et al. (2007) *MAPS 42*, 709-729. [9] Wittmann A. et al. (submitted) *MAPS.* [10] Ivanov A. V. et al. (1976) *Proc. Lunar Sci. Conf. 7th*, 743-757. [11] Symes J. K. et al. (1998) *MAPS 33*, 13-29. [12] Korotev R. L. et al. (2003) *GCA 67*, 4895-4923. [13] Treiman A. H. et al. (2010) *MAPS 45*, 163-180. [14] Demidova S. I. et al. (2003) *LPSC XXXIV*, abstract #1285. [15] Demidova S. I. et al. (2003) *66th Ann. Met. Soc. Meeting*, abstr. #5046.

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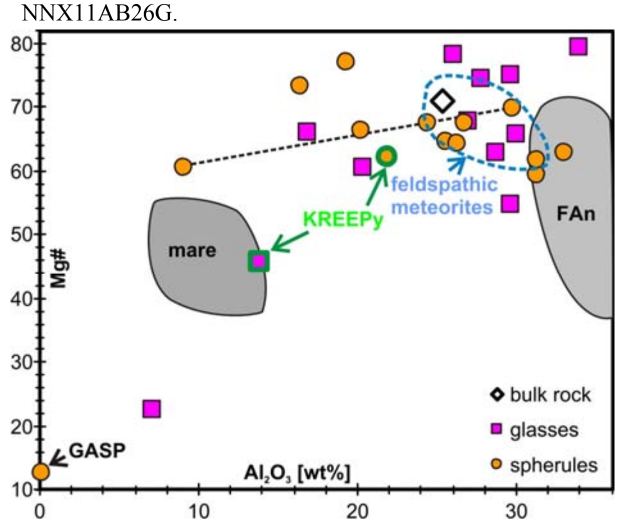

Fig. 2 Variation of Mg# [mole% Mg/(Mg+Fe)] with Al_2O_3 in Shişr 161 bulk rock, glasses and spherules; diagram after [12]. Dotted line connects feldspathic and mafic portions of spherule in Fig. 1B.