

**CHEMICAL ZONING OF FELDSPARS IN LUNAR GRANITOIDS: IMPLICATIONS FOR THE ORIGINS OF LUNAR SILICIC MAGMAS.** R.D. Mills<sup>1</sup> ([ryan.d.mills@nasa.gov](mailto:ryan.d.mills@nasa.gov)), J.I. Simon<sup>1</sup>, C.M.O'D. Alexander<sup>2</sup>, J. Wang<sup>2</sup>, R. Christoffersen<sup>3</sup>, Z. Rahman<sup>3</sup>, <sup>1</sup>Center for Isotope Cosmochemistry and Geochronology, ARES, NASA, Johnson Space Center, Houston, TX 77058, <sup>2</sup>DTM, Carnegie Institution of Washington, 5241 Broad Branch Rd, Washington, DC 20015, <sup>3</sup>Jacobs, NASA, Johnson Space Center, Houston, TX 77058.

**Introduction:** Fine-scale chemical and textural measurements of alkali and plagioclase feldspars in the Apollo granitoids (ex. Fig. 1) can be used to address their petrologic origin(s). Recent findings suggest that these granitoids may hold clues of global importance, rather than of only local significance for small-scale fractionation. Observations of morphological features that resemble silicic domes on the unsampled portion of the Moon [e.g., 1-5] suggest that local, sizable networks of high-silica melt (>65 wt % SiO<sub>2</sub>) were present during crust-formation. Remote sensing data from these regions suggest high concentrations of Si and heat-producing elements (K, U, and Th). To help understand the role of high-silica melts in the chemical differentiation of the Moon, three questions must be answered: (1) when were these magmas generated?, (2) what was the source material?, and (3) were these magmas produced from internal differentiation or impact melting and crystallization? Here we focus on #3.

It is difficult to produce high-silica melts solely by fractional crystallization. Partial melting of preexisting crust may therefore also have been important and possibly the primary mechanism that produced the silicic magmas on the Moon. Experimental studies (e.g., [6]) demonstrate that partial melting of gabbroic rock under mildly hydrated conditions can produce high-silica compositions and it has been suggested by [1] that partial melting by basaltic underplating is the mechanism by which high-silica melts were produced on the Moon. TEM and SIMS analyses, coordinated with isotopic dating and tracer studies, e.g., [7,8], can help test whether the minerals in the Apollo granitoids formed in a plutonic setting or were the result of impact-induced partial melting. We analyzed granitoid clasts from 3 Apollo samples: polymict breccia 12013,141, crystalline-matrix breccia 14303,353, and breccia 15405,78.

**SEM imaging and elemental mapping:** BSE imaging and elemental phase mapping by FE-SEM at JSC show that granitoid clasts found in 14303,353 have alkali feldspar (rich in Ba) and plagioclase, but lack a silica polymorph. In addition, the chemical zoning in the feldspars in 14303,353 is very patchy (Fig. 1A,B). The patchy texture is either an exsolution feature of a high temperature feldspar, or intergrowths of two feldspars during cooling. Clasts found in Apollo samples 12013,141, and 15405,78 consist of two feldspars, and silica (ex. Fig. 1C).

**TEM analysis:** A 2-3  $\mu\text{m}$  thick cross-section was extracted, using a Dual Beam FIB (Quanta 3D-FEG) at JSC, from a patchy zoned feldspar clast (similar to the clast in Fig. 1A,B) from sample 14303,353. Using a OMNI Probe system, the cross-section was micromanipulated and attached to a TEM grid. It was then thinned down to  $\sim 100$  nm and precisely cleaned in preparation for TEM work using a delicate Ga<sup>+</sup> FIB.

TEM imaging (Fig. 1D) shows a fine-scale lamellar microstructure in plagioclase, which is indicative of early-stage spinodal decomposition within the characteristic Bøggild compositional interval. The microstructure is consistent with post-crystallization cooling in an epizonal plutonic setting, or possibly a large melt sheet.

**Major-element chemistry of feldspars:** Although most electron microprobe spots integrate both feldspars, the data do approach the two end member compositions (Fig. 1E illustrates the analytical mixing). The plagioclase component is  $\sim\text{An}_{70}$  and the alkali feldspar component is  $\sim\text{Or}_{90}$ . Barium is strongly partitioned into the alkali feldspar, with a celsian component approaching 10 modal percent (Fig 1E), slightly less than the content inferred from the TEM data; this difference is likely due to spot size. Whereas [9] found ternary feldspars in Apollo sample 14305,111 and 14305,102, we find that the two feldspars are distinct in the clasts in 14303,353 and 15405,78. In addition, the ternary feldspar analyses in [9] yield similar compositions to those of our analytical mixtures (Fig. 1E).

**Hydrogen analysis of alkali feldspar by SIMS:** Preliminary hydrogen data collected on the Cameca IMS 6F ion microprobe at DTM where obtained by published methods [10] and indicate that the alkali feldspar portion of these granitic clasts can have at least 5 times more hydrogen than does the plagioclase component, with as much as 1000 ppm H<sub>2</sub>O. High water contents in the alkali feldspar suggest a plutonic origin with limited volatile loss.

**Future work:** Our observations to date support a plutonic origin for these granitoid clasts, but an impact origin is still plausible. In order to firmly distinguish between a plutonic or impact origin our future work will include: 1) detailed hydrogen analyses of alkali feldspar via NanoSIMS, in order to accurately assess the initial hydrogen in the alkali feldspar, and 2) more

TEM work to understand the amount of exsolution that has occurred in the feldspars.

Once micro-chemical and micro-textural characterization is complete the clasts will be extracted by micromill for K-Ca and Rb-Sr isotopic measurements via TIMS. As in [7,8], these data will be used to bracket the crystallization ages and define the bulk compositions of the source(s) of high-silica materials in the lunar crust.

**References:** [1] Hagerty et al. (2006) *JGR*, 111:E06002. [2] Glotch et al. (2010) *Science* 305:657-659. [3] Greenhagen et al. (2010) *Science* 329:1507-1509. [4] Jolliff et al. (2000) *JGR*, 105:4197-4216. [5] Hawke et al. (2003) *JGR*, 108:5069. [6] Sisson et al. (2005) *CMP*, 148:635-661. [7] Shih et al. (1993) *GCA*, 57:4827-4841. [8] Simon et al. (2011) *LPSC* #2754. [9] Shervais and Taylor (1983) *PLSC* 696-697. [10] Hauri et al. (2002) *Chem Geology* 183:99-114.

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**Fig. 1**

