FIRST TEM CONFIRMATION OF ALKALI FELDPSAR CRYPTOPERTHITE IN LUNAR ROCKS: IMPLICATIONS FOR THE ORIGIN AND THERMAL HISTORY OF LUNAR FELSITES. R. Christoffersen[1], J. I. Simon[2], M. D. Mouser[3], and D. K Ross[1], [1]Jacobs-JETS Contract, NASA JSC, Mail Code XI3, Houston, TX 77058, USA (roy.christoffersen-1@nasa.gov), [2]Center for Isotope Cosmochemistry and Geochronology, ARES, NASA JSC, Houston, TX 77058, USA, [3]Dept. of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA.

Introduction: Although the Moon is often informally referred to as a "basaltic" planetary body, there are well-established findings from the Apollo alkali suite of rocks [1,2,3,4] and recent indirect evidence from remote sensing [5], that the Moon has found a number of still-enigmatic petrogenetic paths to make highly-evolved lithologies represented by true granite and other "felsites". In addition to containing a silica phase, all of these rocks are intrinsically defined by their significant-to-dominant modal content of alkali feldspar relative to plagioclase [1,2,3,4]. Simultaneous with our recent efforts to use trace H contents in lunar alkali feldspars to investigate how water and other volatiles accumulate/re-distribute during lunar crustal evolution [6,7], we have begun to revisit the major element compositional variations of alkali feldspars in a variety of lunar felsites [7,8]. This work has drawn our attention to the diverse unusual sub-population of lunar alkali feldspars, notably in Apollo 12 samples [3,4], whose compositions extend well inside the feldspar ternary miscibility gap or solvus (Fig. 1). Despite every expectation from feldspar phase equilibria that these grains should have exsolved on the sub-microscopic scale at a minimum during cooling [9,10], no studies using TEM or other techniques have been performed to see if this might be the case. We have now performed this work and report here what we believe to be the first TEM-based confirmation of the development of sub-microscopic alkali feldspar "cryptoperthite" in a lunar rock. Far from being a mineralogical curiosity, the TEM-scale exsolution microstructures are of a type known from terrestrial rocks to be thermal history indicators, raising the possibility of applying them to constrain cooling rates in lunar felsites containing suitable composition alkali feldspars.

Methods: Our on-going NanoSIMS measurements of lunar alkali feldspars use coordinated field-emission SEM, EPMA and TEM imaging to characterize and map the microstructures and compositions of host felsites prior to H analysis [6,7,8]. A JEOL 7600F analytical field-emission SEM (FE-SEM) with EDS element mapping capabilities is used for initial characterization, followed by quantitative spot analyses using a JEOL 8530F field-emission EPMA. A JEOL 2500SE field-emission scanning transmission electron microscope (FE-STEM) supported by an FEI Quanta dual-beam focused ion beam (FIB) instrument for sample preparation, is used to investigate sub-micron microstructural and compositional relations.

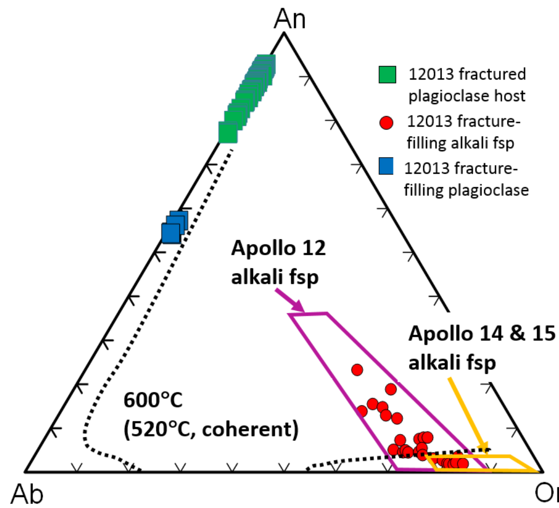

Fig. 1. Compositions of alkali feldspars in felsite fracture-filling assemblages in lunar breccia 12013 compared to other Apollo 12 felsites, and those in Apollo 14 & 15 [1,2,3,4]. Dashed line defines the approximate 600ºC ternary solvus for coexisting compositions in non-coherent feldspar exsolution intergrowths. The equivalent solvus for structurally coherent intergrowths occurs at ~80ºC lower temperature [10].

Results: Our larger study of lunar feldspar trace H contents has focused on lunar breccias 12013, 14303, 14321 and 15405 that are known hosts for granite/felsite lithic clasts [1,2,3,4,6,7]. Other previous EPMA studies along with ours have so far shown that only 12013 and other Apollo 12 rocks [3,4,6,7,8] contain alkali feldspars whose compositions are enriched enough in Ca and/or Na to lie along compositional trends penetrating into the feldspar ternary solvus region (Fig. 1). (The Apollo 14 and 15 granite/felsite clasts contain close to end-member K-feldspar, with some Ba-enrichment [1,2].) In 12013, the predominant felsite host for the ternary alkali feldspar compositions is the abundant patchy areas of fine-grained granophyre (microgranophyre) first described by [3]. Beyond the microgranophyre patches, however, we have also recently described complex felsic regions in 12013 where ternary feldspar, minor silica and intermediate plagioclase fill fracture networks and/or voids in coar-

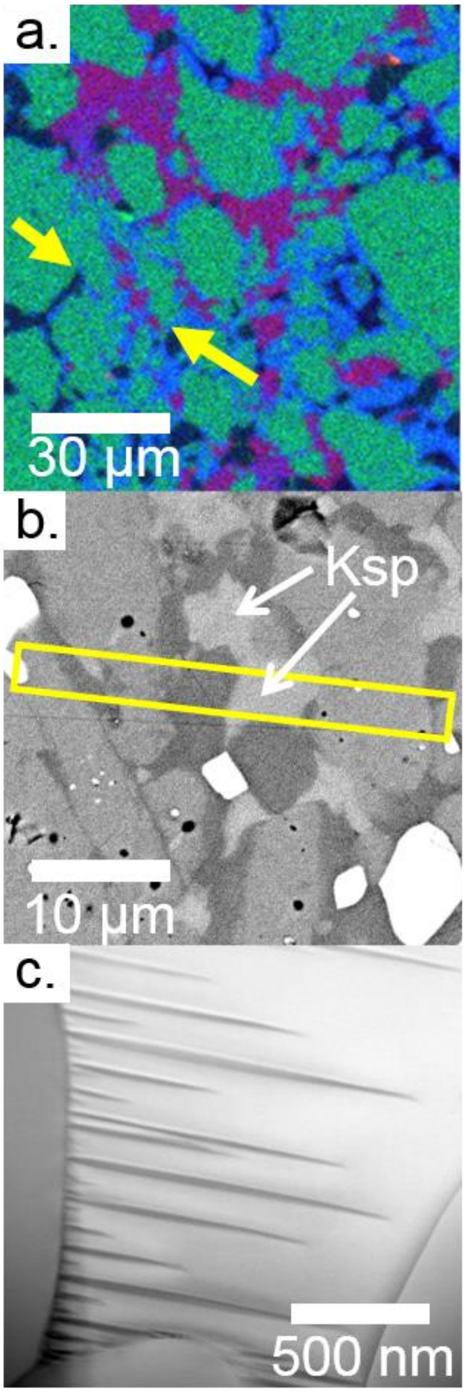

Fig. 2. (a) False-color EDS X-ray count element map showing relative distribution of K (red), Ca (green) and Na (blue) in 12013 felsite assemblage filling shock fractures in calcic (An_{80-90}) plagioclase. Arrows show FIB section transect. (b) Back-scattered electron image of fracture assemblage showing FIB section location. (c) Conventional TEM bright-field image of structurally-coherent exsolution lamellae in fracture assemblage alkali feldspar.

-ser calcic plagioclase fragmented by shock [7] (Figs. 1&2). A FIB cross-section of one of these fracture-filling assemblages revealed structurally coherent, sub-microscopic exsolution lamellae in one of the alkali feldspar grains (Fig. 2c). The lamellae are more extensively developed at the grain margins compared to the center (Fig. 2c). The fracture-filling alkali feldspars show significant inter- and intra-grain compositional variability along the trend shown in Fig. 1. The inhomogeneous development of the lamellae therefore most likely reflects controls that intra-grain compositional zoning exerts on the initiation of exsolution. FE-STEM compositional spectrum imaging is in progress to confirm this and measure the composition of the lamellae.

Discussion. Experimentally-determined kinetics for both the coarsening and compositional equilibration in cryptoperthite lamellae have previously been used to refine cooling rate models for terrestrial shallow intrusive (dikes and sills) and extrusive igneous bodies [9,10,11,12]. These bodies typically take between 0.5 to 3 yrs to traverse the temperature interval where cryptoperthite exsolution in the Ca-free, non-ternary system commences at 570-500ºC and closes kinetically at ~300ºC [10,11,12]. The kinetics in the Ca-bearing ternary system are less quantitatively defined, but become more sluggish once it is necessary to partition slowly-diffusing Si-Al between the lamellar phases [13]. The 12013 lunar felsite fracture-filling assemblage very likely formed from felsic melt that infiltrated the shock-fractured host plagioclase. For the cryptoperthite to have formed after this melt crystallized suggests emplacement in a thermal setting such as a several meter thick ejecta blanket analogous in cooling rate to shallow terrestrial intrusives and extrusive units, as opposed to a shallow loose pile of ejecta. The mobilization of water and other volatiles in such an environment, possibly with a contribution from a wet impactor, is an important consideration in interpreting the measured alkali feldspar H contents.

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