TERNARY FELDSPAR WITHIN FELSTE CLASTS FROM APOLLO IMPACT MELT BRECCIA 72255.

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Introduction: Granitic clasts with unique ternary feldspar compositions have been identified within samples of the layered impact melt breccia from Apollo 17 Station 2 Boulder 1 (72215, 72235, 72255 and 72275) [1], and in a felsite clast from station 3 (73215) [2,3]. These "ternary" compositions seemingly plot within the miscibility gap of the albite-anorthite-orthoclase (Ab-An-Or) system. Feldspars with these compositions have not been identified in terrestrial samples, and equilibrium feldspar compositions from laboratory experiments indicate they would not be thermodynamically stable [4,5]. Thus, the physiochemical processes involved in forming these unique ternary feldspars remain poorly understood.

To better constrain the formation of ternary feldspar within lunar breccias, we have undertaken a coordinated scanning electron microscope (SEM)-based coupled electron backscatter diffraction (EBSD) and energy dispersive spectrometry (EDS), electron microprobe analyzer (EPMA) wavelength dispersive spectrometry, and transmission electron microscopy (TEM) study. The goals of this study are twofold: 1) confirm whether ternary feldspar is present as coherent, single-crystals or sub-microscopic intergrowths of normal compositions, and 2) better constrain the formation conditions of clasts containing ternary feldspar.

Methods: Felsite clasts were identified within the matrix regions of three thin sections: 72255,94, 72255,95, and 72255,105. Full section EDS maps were collected using a JEOL 7900F field emission (FE) SEM in the ARES division, NASA JSC. Felsite clasts were then mapped by EBSD using an Oxford Instruments Symmetry™ detector and simultaneous EDS maps were collected with a 170 mm^2 SDD detector. The EBSD step size ranged from 0.4 – 0.1 µm. To index the diffraction patterns from the ternary feldspar we used match units based on triclinic anorthite [6] and monoclinic anorthoclase [7]. Ternary feldspar domains identified by EBSD microstructural data were analyzed with a JEOL 8530 FE-EPMA in ARES. Analyses were conducted with beam conditions of 15 kV, 20 nA current, and 2 µm diameter. A conventional peak-to-background standardization included diopside (Ca, Si), oligoclase (Na, Al), and orthoclase (K) standards. After EPMA analysis, an oriented ~15 µm electron transparent foil was extracted using a FEI Quanta focused ion beam (FIB) from a large ternary feldspar grain in a ~2 mm diameter felsite clast within 72255,105. The FIB foil was analyzed using a JEOL 2500 Analytical Field-Emission STEM (FE-STEM).

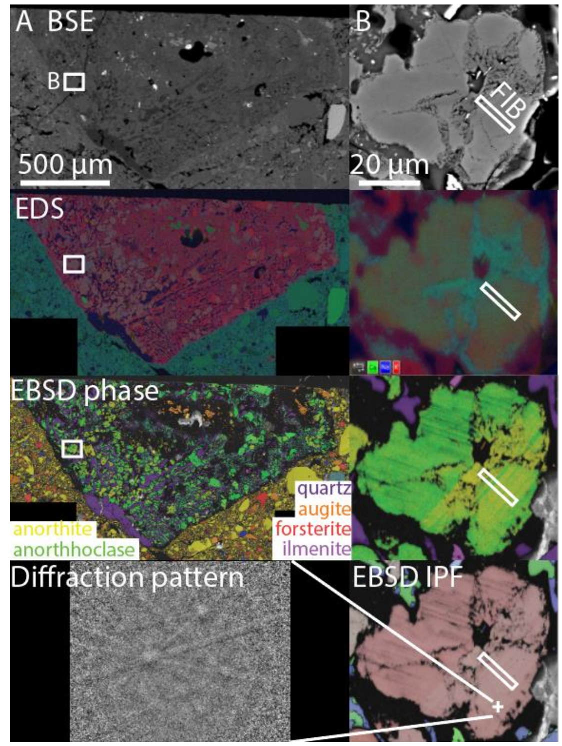

Figure 1. Backscatter electron (BSE), energy dispersive spectrometry (EDS) and electron backscatter diffraction (EBSD) phase and inverse pole figure (IPF) maps and diffraction pattern of ternary feldspar within a large clast from 72255,105.

Results: Felsite clasts were identified in all of the sections investigated. Clasts are 100s of µm in diameter, and the largest clast is ~ 2 mm in diameter [Fig. 1]. The 2 mm clast in 72255,105 is truncated by the edge of the section suggesting the original clast may be larger. Many of the clasts exhibit granophyric intergrowths of SiO_2 and alkali feldspar, EBSD indexing indicates a majority of the SiO_2 is quartz with minor tridymite.

Feldspars within felsite clasts from 72255 exhibit a wide range of compositions including endmember orthoclase ($Ab_{0.6}An_3Or_{97}$) with up to 1.6 wt.% BaO, and intermediate, ternary feldspars ($Ab_{17}An_{78}Or_5$ – $Ab_{19}An_{59}Or_{22}$) (Fig. 2). Ternary feldspar compositions are identical to those previously reported from 72255 [1]. Further, relatively Na-rich plagioclase compositions ($Ab_{17}An_{78}Or_5$) in 72255,94 and 72255,95 are consistent with zoned plagioclase compositions previously reported from felsite clasts in 72215, 72235, and 73215 [1,2].

The EBSD results show that the ternary feldspars are electron diffracting and index as homogenous single crystals (Fig. 1). Due to poor pattern matching between the ternary feldspar and anorthite/anorthoclase, both match units give solutions for different orientations of the crystal structure. Lamellae cross-cutting the ternary felspar appear unrelated to chemistry and rather reflect albitic, baveno, or pericline twin laws. Near grain boundaries and adjacent to melt, the ternary feldspar exhibit increased plagioclase content, but these domains share the same crystallographic orientation as ternary feldspar, indicating partial replacement possibly driven by interaction with the evolving parent melt.

An electron transparent FIB foil was extracted perpendicular to the lamellae evident in the EBSD maps and extending into a small domain (~4 µm-wide) of the polycrystalline portion (Fig. 1). The main portion of the foil (~10 µm wide) is a contiguous single crystal, as evidenced by selected area electron diffraction (SAED) patterns and TEM diffraction contrast images acquired by FE-STEM. Minor twinning and slightly misoriented sub-grains were also identified (Fig. 3). The SAED patterns obtained from the single-crystalline portion of the foil index with the feldspar reciprocal lattice, as do the direct-space HRTEM images (Fig. 4). Quantitative EDS compositions from TEM are consistent with

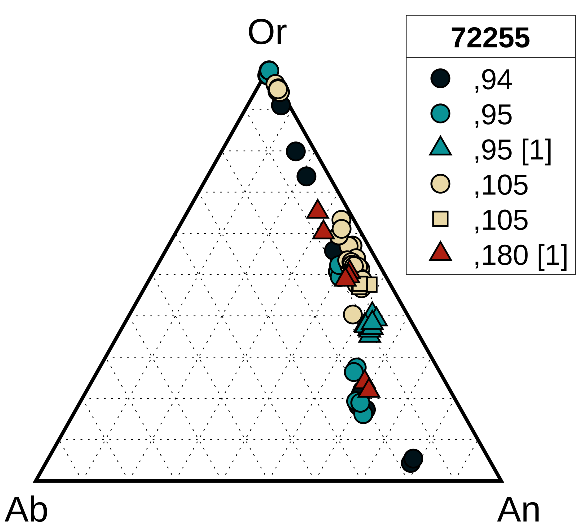

Figure 2. Compositional range of feldspars in felsite clasts within Apollo impact melt breccia 72255. EPMA data (circles) and TEM EDS data (squares) from this study, with compositions from [1] (triangles).

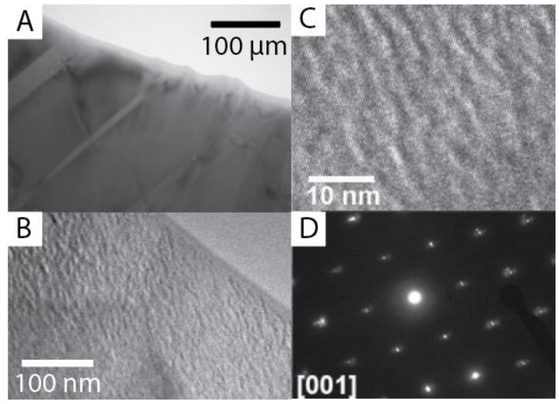

Figure 3. A. Conventional diffraction contrast TEM image of single-crystalline feldspar region (with twins) from FIB section shown in Fig. 1. B. Conventional TEM diffraction contrast and C. HRTEM image of ternary feldspar FIB section viewed along [001] as shown in D.

feldspar stoichiometry and our EPMA analyses (Fig. 2). All data confirm the grain is structurally coherent feldspar, however conventional and HRTEM [001] images also show a wavy contrast modulation in [001] images characteristic of spinodal (exsolution) microstructures observed in other feldspars [8]. The modulation orientation does not match those seen in alkali felspar cryptoperthites but is suggestive of Boggild- or Huttenlocher-type modulations observed in slowly cooled intermediate plagioclase samples [9].

Conclusions: These data provide diagnostic evidence for ternary composition feldspar in impact melt breccias from the Apollo 17 landing site. The ternary felspar are homogenous crystals containing growth twins and sub-microscopic (< 10 nm) spinodal decomposition textures. While felspar of these compositions are unknown from terrestrial samples and classical crystallization experiments, their existence in impact melt breccias may point to their origin. A potential mechanism for ternary felspar formation is entrainment of intermediate plagioclase in a high-temperature (superheated) K-rich impact melt. Under high-T conditions Na may be replaced by K faster than the parent crystal is consumed by the melt. The grains are then undercooled, enabling preservation of the otherwise metastable composition.

References: [1] Ryder et al. (1975) Proc. Lunar Sci. Conf. 435-449. [2] James & Hammarstrom (1977) Proc. Lunar Sci. Conf. 2459-2494. [3] Nord & James (1977) Proc. Lunar Sci. Conf. 2495-2506. [4] Schairer & Bowen (1947), Soc. Géol. Finlande Bull., 20, 67-87. [5] Ghiorso (1984) Contrib. Min. Pet. 87, 282-296. [6] Foit & Peacor (1973) Am. Min. 58, 665-675. [7] Harlow (1982) Am. Min. 67, 975-996. [8] Kroll et al. (1986) Am. Min. 71, 1-16. [9] Grove et al. (1983) Am. Min. 86, 41-59.