

APOLLO 16 EVOLVED LITHOLOGY SODIC FERROGABBRO. R. A. Zeigler¹, B. L. Jolliff², and R. L. Korotev².
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Introduction: Evolved lunar igneous lithologies, often referred to as the alkali suite, are a minor but important component of the lunar crust. These evolved samples are incompatible-element rich samples, and are, not surprisingly, most common in the Apollo sites in (or near) the incompatible-element rich region of the Moon known as the Procellarum KREEP Terrane (PKT; [1]). The most commonly occurring lithologies are granites (A12, A14, A15, A17), monzogabbro (A14, A15), alkali anorthosites (A12, A14), and KREEP basalts (A15, A17) [2 and references therein]. The Feldspathic Highlands Terrane is not entirely devoid of evolved lithologies, and rare clasts of alkali gabbroanorthite [3] and sodic ferrogabbro (SFG) have been identified in Apollo 16 station 11 breccias 67915 [4-6] and 67016 [7,8]. Curiously, nearly all pristine evolved lithologies have been found as small clasts or soil particles, exceptions being KREEP basalts 15382/6 and granitic sample 12013 (which is itself a breccia).

Here we reexamine the petrography and geochemistry of two SFG-like particles found in a survey of Apollo 16 2-4 mm particles [9,10] from the Cayley Plains 62283,7-15 and 62243,10-3 (hereafter 7-15 and 10-3 respectively). We will compare these to previously reported SFG samples, including recent analyses on the type specimen of SFG from lunar breccia 67915.

Methods: The petrography of the SFG lithology in 67915 was characterized on thin section 67915,190 using back-scattered electron (BSE) images, x-ray maps, and quantitative mineral compositions by wavelength dispersive x-ray spectroscopy (WDS) on the JEOL 8200 Electron microprobe (EMP) at Washington University in St. Louis (Fig. 1-2). The petrography of samples 7-15 and 10-3 was determined by WDS on the JEOL 733 (EMP) formerly at Washington University (Figs. 2-3). The bulk compositions of 7-15 and 10-3 were determined by instrumental neutron activation analysis [see 9,11 for more analytical details].

Petrography: The texture of 67915,190 is that of a monomict breccia (Fig. 1) composed primarily of relatively large sodic plagioclase (43% modal abundance) and Fe-rich pyroxene (35.5%) clasts up to ~0.7 mm in length, as well as smaller clasts/grains of silica (16%) and ilmenite (6%) up to ~0.3 mm in length. Trace

amounts of troilite, apatite, K-feldspar, and baddeleyite are also observed. Most plagioclase clasts fall in the

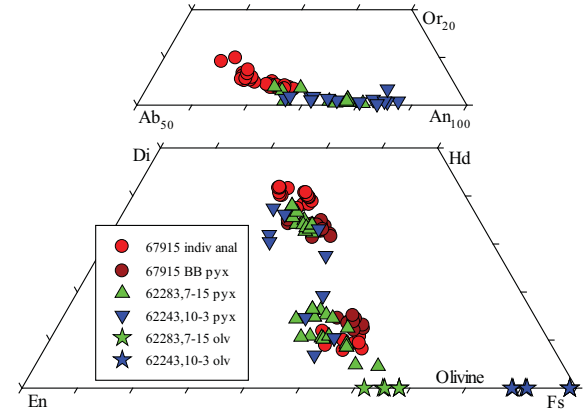


Figure 2: Plagioclase, pyroxene, and olivine compositions in the SFG samples reported here; for convenience, olivine compositions are projected on to the En-Fs join.

compositional range $An_{61-69}Or_{3.2-4.9}$; a subset of smaller grains has more alkali-rich compositions $An_{51-59}Or_{4.8-9.9}$, however. Exsolution in the pyroxene clasts is ubiquitous, typically <1-2 microns, with augite ($Fs_{30-33}Wo_{37-40}$) most commonly hosting pigeonite ($Fs_{50-57}Wo_{8-11}$), though the inverse is also observed. Silica grains contain minor Al_2O_3 (~1 wt%), K_2O (0.5 wt%) and TiO_2 (0.3 wt%) components, with trace amounts (<0.1 wt% of FeO and Na_2O) also present. Ilmenite is moderately enriched in MgO (up to 2 wt%).

Sample 7-15 is a coarse-grained sample (up to ~2 mm) dominated by moderately sodic plagioclase (45%) and ferroan pyroxene (40%), with an area of recrystallized matrix (10%) and a SiO_2 /K-feldspar granophyre (5%), and minor to trace amounts of olivine, ilmenite,

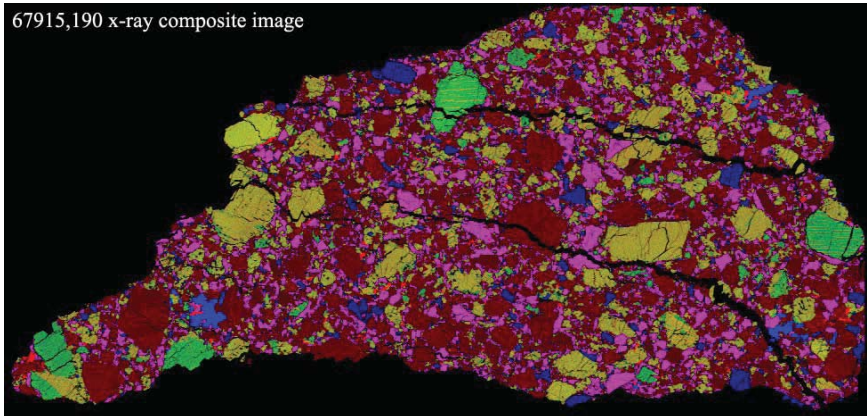


Figure 1: RGB x-ray composite image: Ca = red, Mg = green, and Fe = blue. Additionally, silica grains (which were otherwise black) were colored magenta and superimposed on the image. Phases are: dark red = plagioclase, bright red = apatite, yellow = augite, pigeonite = green, ilmenite = dark blue, troilite = bright blue, and silica = magenta. Field of view is 7 mm.

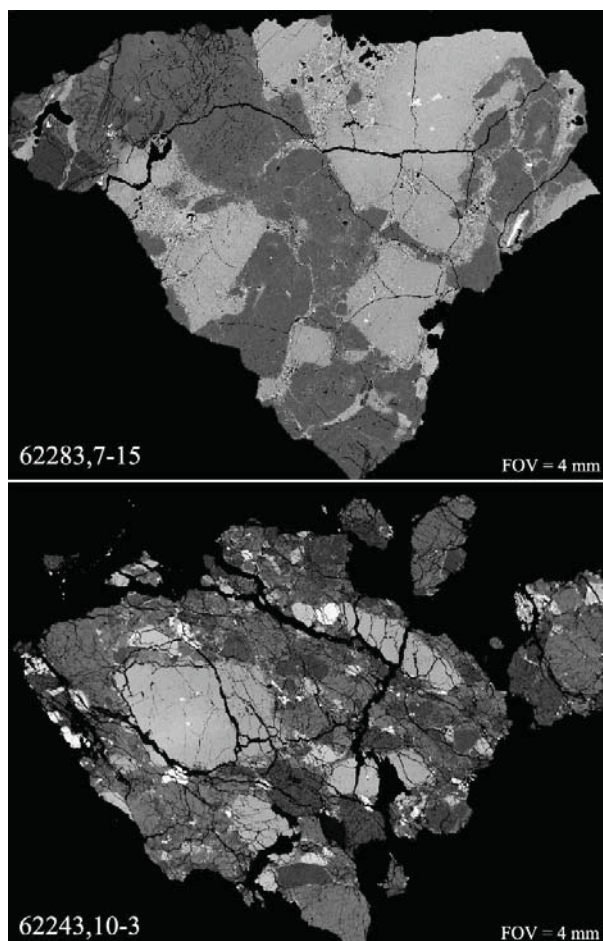


Figure 3: BSE images of SFG samples from the 2-4 mm size fraction of Apollo 16 station 2 soils. Olivine and ilmenite are white, pyroxene is light grey, plagioclase is medium grey, and silica is dark grey.

chromite, apatite, zirconolite, zircon, baddeleyite, and an unidentified REE rich aluminous phosphate (Fig. 3). Plagioclase composition are somewhat variable ($An_{63-73}Or_{0.5-3.8}$), but there is no systematic core to rim zoning. Pyroxene grains are uniformly augite ($Fs_{30-35}Wo_{34-38}$) with minor pigeonite exsolution ($Fs_{49-55}Wo_{8-11}$) up to ~ 1 micron in width; partially resorbed olivine (Fo_{35}) and chromite grains are contained within the pyroxene as well. The recrystallized matrix consists of <10 micron plagioclase laths and intersertal pyroxene and mafic glass.

Sample 10-3 is a monomict breccia consisting principally of plagioclase and pyroxene clasts, with minor amounts of silica/K-feldspar granophyre, and trace amounts of fayalite ($Fo_{<10}$), ilmenite, RE-merrillite, and zircon observed (an exact mode has not yet been determined). Pyroxene clasts contain 1-2 micron exsolution, with augite ($Fs_{28-37}Wo_{33-38}$) commonly hosting pigeonite ($Fs_{49-51}Wo_{7-10}$), though the opposite is also observed. Plagioclase compositions ($An_{66-87}Or_{0.3-3.4}$) are similar to those observed in 7-15.

Geochemistry: The SFG samples in 67915 and 67016 are rich in Na_2O (~ 1 wt%) and K_2O (0.5 wt%), moderately rich in FeO (9-13 wt%) and incompatible trace elements (ITE) like Th (4 ppm) and Sm (12 ppm), with a REE pattern that lacks the light REE enrichment typical in most evolved lunar lithologies [6,8]. Sample 7-15 has comparable concentrations of FeO (9 wt%) and Sm (10 ppm), but higher concentrations of Na_2O (1.7 wt%), K_2O (1.5 wt%), and Th (15 ppm). Sample 10-3 has similar FeO and Na_2O (1 wt% each), but higher concentrations of K_2O (1.5 wt%), Sm (31 ppm), and Th (15 ppm). The REE patterns of both 7-15 (heavy REE enriched) and 10-3 (light REE enriched) are different than previous SFG samples.

Discussion: There are broad similarities in both petrography and geochemistry of previously described SFG samples and 7-15 and 10-3. The most notable exceptions are plagioclase compositions, silica and ilmenite abundance, and minor differences in accessory minerals. Similarly, there are minor differences in the bulk composition, particularly in the REE patterns and ITE abundances. Nevertheless, taken as a whole, the similarities outweigh the differences, particularly in light of how different 7-15 and 10-3 are compared to other Apollo 16 samples. Thus, we tentatively classify 7-15 and 10-3 as SFG samples, pending more detailed analyses (e.g., ion-probe analyses of individual mineral phases).

References: [1] Jolliff BL et al. (2000) *JGR*, **105**, 4197-4216. [2] Papike JJ et al. (1998) Lunar Samples in *Rev. in Min.*, **36**. [3] James OB (1987) *PLPSC*, **17**, E314-E330. [4] Roedder E and Weiblen PW (1974) *PLSC*, **5**, 303-318. [5] Taylor, GJ (1980) *Proc. Lunar High. Crust*, 339-352. [6] Marti K et al. (1983) *PLPSC*, **14**, B165-B175. [7] Norman MD (1981) *PLPSC*, **12**, 235-252. [8] Lindstrom MM and Salpas PA (1983) *PLPSC*, **13**, A671-A683. [9] Korotev R L (1997) *LPS XXVIII*, 753-754. [10] Zeigler RA et al. (2002) *LPS XXXIII*, #2038. [11] Zeigler RA et al. (2006) *MAPS*, **41**, 263-284.

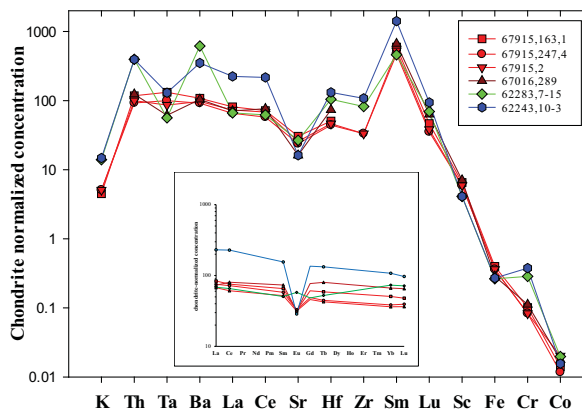


Figure 4: Spider diagram comparing the chondrite normalized concentrations of literature SFG [6,8], to 7-15 (green) and 10-3 (blue). The inset is a small REE plot highlighting the different slopes associated with each sample.