PETROGRAPHY AND MINERAL COMPOSITIONS OF 12013,165. S. N. North-Valencia and B. L. Jolliff, Dept. of Earth & Planetary Sciences, Washington University in St. Louis, MO, 63130, USA (snorth@levee.wustl.edu)

Introduction: Apollo sample 12013 was collected at the Apollo 12 landing site. It is an 82.3 g mingled breccia composed of black breccia and gray breccia components [1,2]. The relationship between the black breccia and the gray breccia remains unclear. The black breccia has a KREEP-basalt-like groundmass, with an REE pattern similar to KREEP. The felsic groundmass in the gray breccia also has elevated REE contents, with a bowl-shaped pattern, with a depletion of middle REE [3].

Some workers [4,5] have argued that SLI (silicate liquid immiscibility) was involved in the formation of 12013. Hess et al. (1975) argued that the granitic portion of 12013 formed as an immiscible liquid layer near the top of a fractionated igneous melt body, which later intruded into a brecciated basalt [4]. However, Quick et al. (1977) argued that the black breccia and gray breccia are compositionally related through SLI and once existed together as two silicate liquids that had unmixed [5]. Understanding the relationship between the black breccia and the gray breccia may be at the crux of our understanding of the formation of lunar granite.

12013 is a complex sample and there is significant variability among previously studied thin sections [2,5,6]. For this work, we requested new thin sections of 12013. The thin section discussed here, 12013,165, is ~35 vol.% black breccia and ~65 vol.% gray breccia (Fig. 1). Boundaries between the two are typically intermingled, and within each breccia type there is considerable lithologic variability including the occurrence of lithic clasts. Mineralogically, both lithologies in 12013 are dominated by pyroxene and feldspar. Minor and trace minerals in 12013,165 include zircon, troilite, tranquillityite, chromite, Fe-Ni metal, apatite, and merrillite.

Black Breccia: The black breccia has a globular appearance and is dominated by pyroxene and plagioclase. Throughout the black breccia, granitic material, which dominates the gray breccia, is uncommon, but present. Importantly, the black breccia contains felsic material as lithic and mineral clasts. Of the two large silica grains in the black breccia, one is surrounded by granitic material. This granitic material contains K-feldspar and acicular silica grains (possibly tridymite), similar in habit to those found throughout the gray breccia.

Pyroxene occurs as subhedral clasts in the black breccia. Grain size ranges from sub-micron to ~220 × 170 μm. Both high-Ca and low-Ca pyroxenes are present, indicating a slow cooling history. The augite has an average composition of $Wo_{40.2}En_{41.5}Fs_{18.3}$. The low-Ca pyroxenes have a wider composition range: from $Wo_{2.3}En_{80.2}Fs_{17.5}$ to $Wo_{9.0}En_{51.6}Fs_{39.4}$, and averaging $Wo_{3.6}En_{64.9}Fs_{31.5}$. Within the region of the breccia that is more magnesian, pyroxene grains are zoned with magnesian cores and slightly more iron-rich rims.

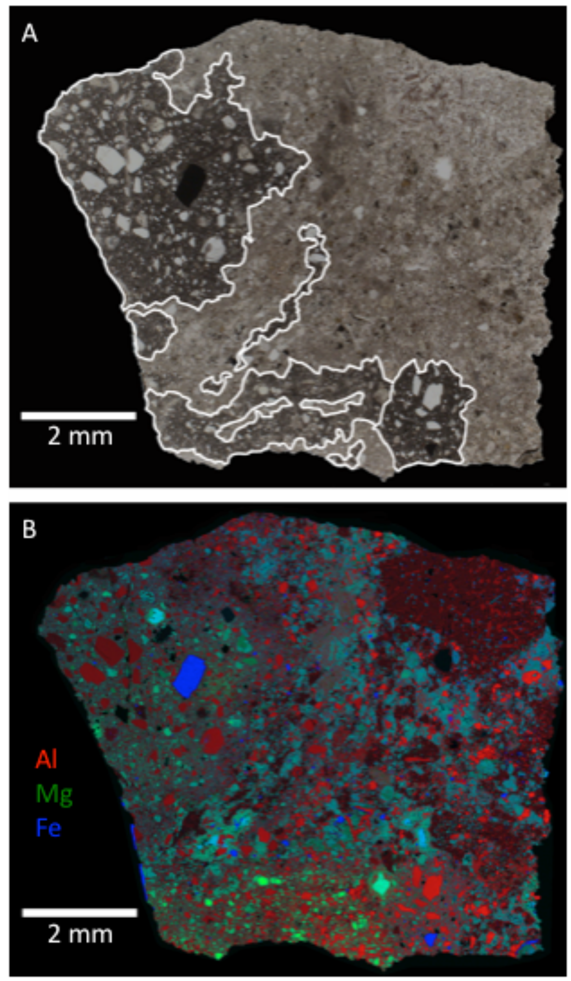

Figure 1. A. Transmitted light image of 12013,165, showing the mingled nature of the black and gray breccias. The black breccia clasts are outlined in white. B. RGB image of 12013,165. Al is in the red channel, Mg in the green and Fe in the blue. Feldspars appear red, ilmenite as bright blue, pyroxene and olivine as greens and teals, and silica and zircon as black. K-rich feldspars tend to be a deeper red than Ca-rich feldspars.

Plagioclase feldspar occurs as subhedral to anhedral clasts in the black breccia. The range of plagioclase compositions is $An_{50.7}Ab_{47.2}Or_{2.1}Cn_{0.0}$ to $An_{94.3}Ab_{5.4}Or_{0.2}Cn_{0.1}$ and an average of $An_{73.3}Ab_{25.5}Or_{1.1}Cn_{0.1}$. RGB color X-ray composite images show that alkali feldspar is rare in the black breccia, but a few grains are present (Fig. 1b). One alkali feldspar grain in the black breccia has a composition of $An_{15.2}Ab_{27.1}Or_{55.2}Cn_{2.5}$.

Olivine is rare in the black breccia. The largest olivine grain is ~260 × 260 µm. Olivine in the black breccia is generally more magnesian than olivine in the gray breccia. The black breccia olivine grains have an average composition of $Fo_{57.5}Fa_{42.5}$. One olivine grain in the black breccia contains very fine-grained Fe-Ni metal inclusions. Fe-Ni metal has also been found in Apollo 12 basalts [7]. This metal apparently formed by reduction from trapped melt in mineral grains, where Cr^{2+} and Ti^{3+} in the melt may have acted as the reductants [7]. It is possible that the olivine in 12013,165 that contains Fe-Ni metal is a basaltic clast that was incorporated into the breccia.

Minor minerals in the black breccia include chromite, phosphates, ilmenite, and zircon. Ilmenite is relatively common. Most ilmenite is very fine grained, but one ~650 × 380 µm clast occurs. This ilmenite clast contains a small amount of exsolved chromite. Zircon is found as a minor phase in the black breccia.

Gray Breccia: The gray breccia is a complex breccia composed of lithic and mineral fragments dominated by pyroxene and felsic minerals. Prominent clasts of granitic material are found throughout the breccia. Some of these clasts show an alignment around the largest portion of black breccia. This alignment may indicate flow or plastic deformation of the gray breccia around the black breccia.

One prominent granitic lithic clast is present with dimensions of ~ 2.6 × 1.4 mm (Fig 2). It is composed of alkali feldspar, silica, pyroxene, and trace ilmenite. The feldspar is coarsely crystalline. The silica and pyroxene are finer grained, and the silica is acicular.

Groundmass in the gray breccia is a complex mixture of several components. Most commonly, the groundmass is granitic material (alkali feldspar and silica grains) along with anhedral pyroxene. Portions of the groundmass are a fine-grained intergrowth of pyroxene and plagioclase with a symplectitic texture.

Pyroxene in the gray breccia has a wide range of compositions (Mg# 64.2-42.4), which continues the trend of pyroxene in the black breccia but is more ferroan and shows limited overlap. Pyroxene compositions cluster around the 1000° isotherm, including both pigeonite and augite, with some intermediate compositions. The compositional range is $Wo_{4.0}En_{52.2}$ $Fs_{43.8}$ to $Wo_{35.6}En_{34.6}Fs_{29.8}$ with an average of $Wo_{18.1}En_{44.3}Fs_{37.6}$. Pyroxene textures are complex. Some pyroxene clasts have granular zoning, very fine lamellar exsolution or both. At least one clast is a mosaic of smaller grains, which was also reported in 12013,6 by [6].

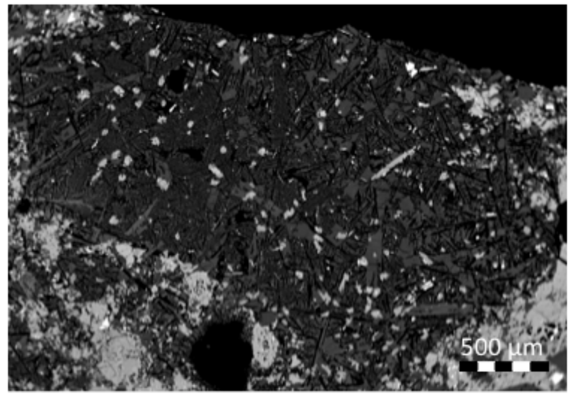

Figure 2. BSE image of the large granitic clast in the gray breccia of 12013,165. Phases in order of darkest to lightest: silica, alkali feldspar, pyroxene, ilmenite.

Feldspar occurs both as K-feldspar and plagioclase in the gray breccia. Alkali feldspar is nearly exclusively found in the gray breccia. The composition is from $An_{6.1}Ab_{20.7}Or_{70.7}Cn_{2.4}$ to $An_{17.3}Ab_{33.2}Or_{47.9}Cn_{1.5}$. Texturally, the alkali feldspar tends to be anhedral and is found both in the groundmass and within larger granitic clasts. Both anhedral and subhedral clasts of plagioclase are common in the gray breccia.

Minerals other than pyroxene and feldspar are relatively uncommon in the gray breccia. Ilmenite is the most common of the minor minerals. As in the black breccia, olivine is rare. Grains of olivine are anhedral to subhedral. The largest grain is ~ 335 × 100 µm. Olivine grains are slightly more Fe-rich than in the black breccia, with an average composition of $Fo_{51.1}Fa_{48.9}$.

Most silica in the gray breccia lithology occurs as needles intergrown with alkali feldspar in granitic clasts. However, one large silica grain (~420 × 280 µm) occurs, and is surrounded by granitic material that contains alkali feldspar and acicular silica grains.

Summary: Understanding the formation of 12013 is crucial for furthering our knowledge of igneous processes on the Moon. Having only two components in the breccia indicates that the black breccia and gray breccia precursors dominated the target region of the impact that produced the rock. Clues to the formation of 12013 may lie in the mineral compositions of the two breccias. The presence of granitic material in the black breccia (with similar composition to granitic material in the gray breccia) demonstrates that the formation of these two breccia must be linked.

References: [1] Meyer C. (2009) Lunar sample compendium, 12013. [2] Drake M. J. et al. (1970) *Earth and Plant. Sci. Letters, 9,* 103-123. [3] Quick J. E. et al. (1981) *Proc. Lunar Planet Sci., 12B*, 117-172. [4] Hess P. C. et al. (1975) *Proc. Lunar Sci. Conf. 6th,* 895-909. [5] Quick J. E. et al. (1977) *Proc. Lunar Sci. Conf. 8th,* 2153-2189. [6] James O. B. (1970) *USGS Interagency Report: Astrogeology, 23.* [7] Reid A. M. et al. (1970) *Earth and Plant. Sci. Letters, 9,* 1-5