LUNAR METEORITE EET 96008, PART I. PETROLOGY & MINERAL CHEMISTRY: EVIDENCE OF LARGE-SCALE, LATE-STAGE FRACTIONATION

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The newly discovered lunar "basaltic breccia", EET 96008, is the most unique of the lunar samples yet analyzed, including Apollo and Luna samples and lunar meteorites. It contains a diversity of textures, clasts, and chemistry. Our mineral-chemical analyses and petrographic observations are inconsistent with its derivation as a simple "basaltic" breccia. This sample contains abundant evidence of large-scale, late-stage fractionation which may have included the onset of silicate liquid immiscibility (tridymite pods, hedenbergite-troilite phenocrysts, ferroan augite, fayalite phenocrysts, pyroxene-fayalite-silica segregations, whitlockite, and K-Si-rich glass). Many of these textures are similar to those reported for lunar meteorite EET 87521 [1,2]. Based upon these observations and trace-element chemistry [3] *we suggest that EET 96008 and EET 87521 should be paired.*

INTRODUCTION – During the 1995-1996 ANSMET field season, a 52.97 g (4.5 x 3.5 x 1.5 cm) chunk of the Moon, a lunar meteorite was collected, the 16th (14th if parings are considered). Preliminary investigation of the sample by Kathleen McBride (macroscopic) and Brian Mason (microscopic, mineral-chemical) did not indicate the unusual nature of this sample, which was classified as a "lunar basaltic breccia" [4].

We were allocated two probe mounts and three 151-172 mg splits of this sample [3] The diversity of this sample, even between the two probe mounts, is remarkable.

PETROGRAPHY & MINERAL CHEMISTRY -- The sample is a breccia, but a rather complex one consisting of some definite clasts, but also various minerals with bimodal mineral-chemical compositions. The sample is conspicuous in having no basaltic clasts. All material appears to be of highlands derivation. We were allocated two probe mounts which will be discussed in succession.

96008,38. This probe mount contains evidence of several generations of brecciation with phenocrysts and clasts contained within larger breccia clasts that are cross-cut by later glass "veins." This sub-sample contains several globular "silica" pods generally 100-200 μm and up to 600 μm across. These pods exhibit a "crackled" texture in reflected light indicative of tridymite. The sample is conspicuous by the presence of several "pockets" or clasts of ferroan augite ($Wo_{35-38}En_{16-18}Fs_{46-47}$), up to 900 μm in longest dimension, which enclose abundant (up to 30% of the clast) equigranular (20-50 μm) fayalite (Fo_{12-13}) and tridymite "intergrowths" (Fig. 1). In some of the clasts, the tridymite, and to a lesser extent the fayalite, is elongated into stringers or pods with aspect ratios of 3:1 to 7:1. A rare spinel grain from within one of these pyroxene-olivine-silica clasts contained 27.8 wt% TiO_2, 1.97 wt% Al_2O_3, and 7.05 wt% Cr_2O_3.

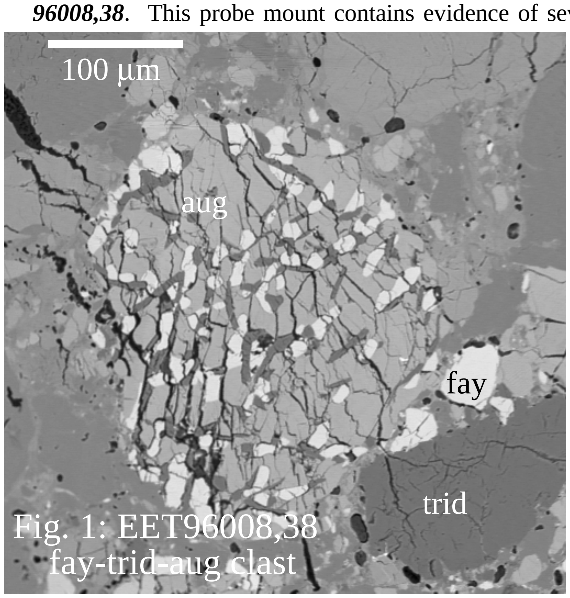

Fig. 1: EET96008,38 fay-trid-aug clast

Subhedral phenocrysts (xenocrysts?) of pyroxenes up to 2 mm in longest dimension occur throughout and show great inter-mineral (e.g., $Wo_{10-23}En_{55-62}Fs_{22-28}$) as well as intra-mineral chemical variation. Olivines are typically interstitial and much smaller (<100 μm). However, there is a single, large (1 mm), euhedral fayalite (Fo_{13-14}) grain which contains a central grain of euhedral ilmenite (140 x 200 μm) set at one end of a mass of glass (Fig. 2). The glass (69.7-74.9 wt% SiO_2; 1.06-2.61 wt% K_2O; 14.6-15.2 wt% Al_2O_3; 3.82-4.01 wt% Na_2O) also encloses 10-40 μm grains of whitlockite. Whitlockite (10-50 μm) also occurs along the contact of the glass with the fayalite host. An unusual 600 x 300 μm pyroxene phenocryst consists of nearly pure hedenbergite ($Wo_{42}En_{4-5}Fs_{53-54}$), enclosing elongated globules (60-70 μm) of troilite. Plagioclase generally occurs as anhedral masses with undulose extinction, although some

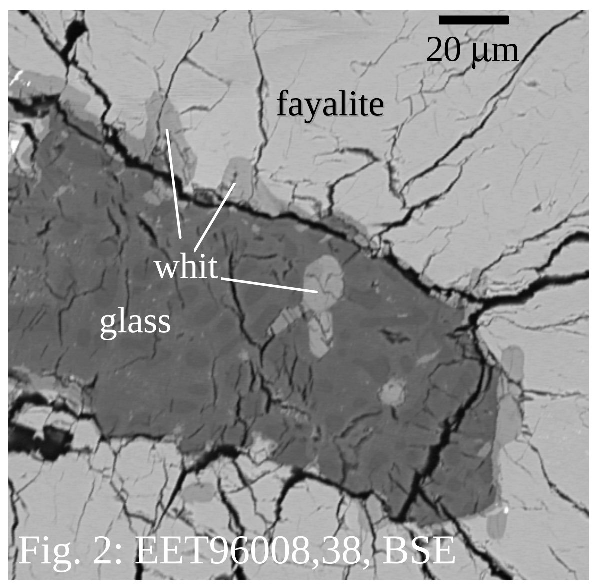

Fig. 2: EET96008,38, BSE

individual phenocrysts do maintain some of their original texture and twinning. One 600 µm feldspar grain contains a narrow range in chemistry, An_{94-95}. All of these clasts and xenocrysts are set in a fine-grained, devitrified glass matrix. A single chromite (40.6 wt% Cr_2O_3; 10.3 wt% TiO_2; 5.48 wt% Al_2O_3) grain from the matrix contained a minute (<5 µm) ilmenite grain, possibly formed by subsolidus reduction.

96008,39. The most conspicuous object in this section is a 1.8 x 1.5 mm clast that consists of mostly subhedral to euhedral, relatively fine-grained (100-300 µm) plagioclase (An_{77-89}; with an aspect ratio of 2:1 to 4:1) and approximately 5 modal% hedenbergite ($Wo_{38-42}En_{2-6}Fs_{54-59}$) (Fig. 3). However, one end of the clast contains a concentration

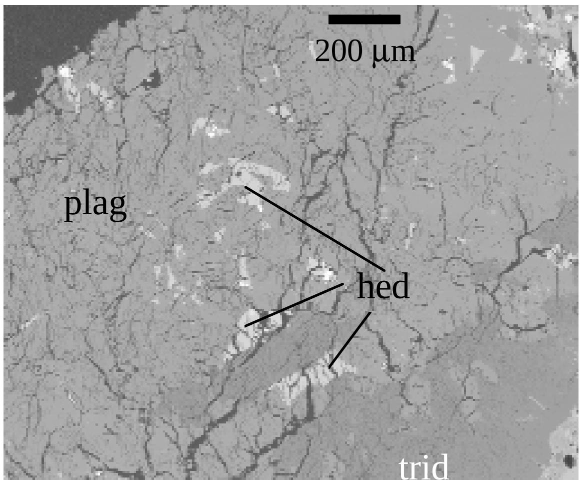

Fig. 3: EET 96008,39 Clast, BSE

of tridymite, which comprises ~20% of the total clast, intermingled with small amounts of plagioclase and pyroxene of similar habit to that in the remaining clast. Minute (<5 µm) ilmenite grains have also been identified within the clast. Besides this clast, the sub-sample seems to contain a lower proportion of tridymite than 96008,38.

The section contains a variety of clasts and phenocrysts, including a fragment of a regolith breccia (900 µm in longest dimension) and a bimineralic chunk of "norite" (600 µm). Pyroxene phenocrysts range broadly in composition from enstatite ($Wo_{4-11}En_{51-69}Fs_{22-42}$) to pigeonite ($Wo_{16-22}En_{28-58}Fs_{30-54}$) to augite ($Wo_{24-42}En_{22-58}Fs_{24-58}$). Anhedral olivine phenocrysts are typically smaller (100-200 µm) than pyroxene phenocrysts and display distinctly bimodal composition modes (Fo_{7-12} and Fo_{60-61}). However, adjacent to the large plagioclase-tridymite-hedenbergite clast, fine-grained (50-100 µm) fayalite (Fo_{2-3}) is associated with globular tridymite as stringers. Plagioclase is less abundant in this sub-sample, but typically occurs as more distinct, individual (300-600 µm), blocky, anhedral grains (An_{91-97}). Interstitial, fine-grained plagioclase associated with matrix. K-Si-rich glass (SiO_2 = 71.2-76.1 wt%; K_2O = 4.57-7.64 wt%; Al_2O_3 = 11.9-15.6 wt%; Na_2O = 1.13-3.22 wt%) and more mafic glasses (SiO2 = 44.5-48.4 wt%; Al_2O_3 = 10.9-34.2 wt%; CaO = 12.4-18.5 wt%; MgO = 1.82-10.8 wt%; FeO = 1.51-21.3 wt%) has a much lower Ca content (An_{69-70}). Various fine-grained spinels occur throughout, ranging in compositions from ulvöspinel to chromite. Small ilmenite grains are also found scattered throughout the matrix.

INTERPRETATION – Many of the characteristics of this "new" lunar meteorite suggest derivation from a mostly highlands suite. However, the possibility cannot be ruled out that this sample represents an evolved segregration from within a basalt flow. Studies of the meteorite with which it is paired, EET 87521, have led others to postulate a mostly mare basalt derivation for that sample [1,2].

The bimodal distribution of phenocryst compositions, calcic-plagioclase phenocrysts, presence of a regolith breccia fragment, and lack of both minerals with compositions typical of basalts and basaltic fragments, lead to the conclusion that this meteorite contains a substantial amount of material of highlands affinity. Furthermore, the abundance of tridymite globules, high K-Si glass, and fayalite-augite-tridymite pods are suggestive of an extreme late-stage fractionate. The hedenbergite phenocryst which encloses troilite blobs may be due to breakdown of pyroxferroite and subsequent sulfurization. The single large fayalite grain which encloses an ilmenite grain engulfed by K-Si-rich glass + whitlockite is suggestive of late-stage fractionation with the onset of silicate liquid immiscibility: K-frac represented by the glass and REEP-frac represented by the fayalite, ilmenite, and whitlockite.

The abundant fayalite-augite-tridymite pods could be due to the natural breadown of large pyroxferroite grains or aggregates [5]. However, pyroxferroite in lunar rocks usually occurs only as thin rims on augites or as tiny grains in mesostasis. The suggestion that this sample originally contained abundant pyroxferroite may indicate either that the sample came from a depth coinciding with a pressure > 10 kb [5] and/or that this sample represents large-scale, late-stage fractionation and immiscibility in the lunar crust. The total lack of FeNi metal in this sample may reflect an increased oxygen fugacity environment during crystallization of certain components of this breccia; this may also have lead to the extreme Fe enrichment seen in this sample.

REFERENCES: [1] Warren, P.H. & Kallemeyn, G.W. (1989) *GCA 53*, 3323-3330; [2] Takeda, H., Mori, H., Saito, J, & Miyamoto, M. (1992) *PLPS 22*, 355-364; [3] Snyder, G.A. et al., LPSC XXX, this volume; [4] Antarctic Meteorite Newsletter, vol. 21, February, 1998; [5] Lindsley, D.H., Papike, J.J., and Bence, A.E. (1972) *Lunar Science III*, 483-485.