PETROLOGY AND CHEMISTRY OF AGGLUTINATES IN THE CHANG'E-5 SOIL. S. Xie[1], K. H. Joy[2*], A. Nemchin[3,1], B. Jolliff[7], X. Che[1], T. Long, Z. Li[4], M. D. Norman[5], R. Tartèse[2], J. Head[6], J. F. Snape[2], C. R. Neal[8], M. J. Whitehouse[9], R. Fan[1], C. Yang[1], Y. Shi[1], C. Wang[1], D. Liu[1,4*], [1]Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China (Corresponding authors: liudunyi@bjshrimp.cn), [2]Dept. of Earth & Environmental Sciences, The University of Manchester, Manchester, M13 9PL, UK (Corresponding author: katherine.joy@manchester.ac.uk), [3]School of Earth & Planetary Sciences, Curtin University, Perth, GPO Box U1987, WA 6845, Australia, [4]Shandong Institute of Geological Sciences, Jinan, Shandong 250013, China, [5]Research School of Earth Sciences, The Australian National University, Canberra ACT 2601 Australia, [6]Dept. of Earth, Environmental, & Planetary Sciences, Brown University, Providence 02912, USA, [7]Dept. of Earth & Planetary Sciences & The McDonnell Center for the Space Sciences, Washington University in St. Louis, One Brookings Drive, St. Louis, MO, USA, [8]Dept. of Civil Engineering & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA. [9]Dept. of Geosciences, Swedish Museum of Natural History, SE-104 05 Stockholm, Sweden.

Introduction: Agglutinates are an important glass-rich component of the lunar regolith, and are considered to be products of melting of lunar soil caused by micrometeorite bombardment [e.g., 1,2]. Determination of the detailed process of agglutinate formation can help us better understand space weathering effects on airless body processes. Some past studies of Apollo and Luna samples have suggested that agglutinitic glass forms preferentially by fusion of the finest soil fractions (<10 μm, known as the 'F3' model) [3,4], but some new results indicate that this model needs to be revised [e.g., 5].

Recently, lunar soil was collected by China's Chang'E-5 (CE-5) mission from a young ~2 Ga mare basaltic region of the Moon (geological unit Em4/P58) [6-8]. The new soil samples are finer and better sorted (smaller sorting value) than most Apollo and Luna soils [6]. In addition, CE-5 lunar soils show higher proportions of pyroxene (~42 vol%), and lower glass (~16.6 vol%) contents than Apollo soils [6]. Studies of agglutinates from CE-5 soil can provide new insights into their formation mechanism(s), and into the composition of the local regolith, including assessment of amount of exotic or non-mare components present at the sampling site. Here, we discuss the petrology and mineral and glass chemistry of agglutinates from CE-5 soil.

Samples: Ten agglutinates were picked out of a 1.5 g aliquot of the 2 g CE-5 lunar soil (sample CE5C0400). They were mounted in epoxy resin, together with terrestrial glass standards (BCR-2G, BHVO-2G, and NIST 610). The mineralogical and chemical characteristics of three of these agglutinate fragments, B004, B009-4, and B009-8, are reported here.

Methods: Electron probe microanalysis (EPMA) was carried out using Jeol JXA-8230 and JXA-8100 instruments at the Shandong Institute of Geological Sciences, Jinan, and the Institute of Geology, Chinese Academy of Geological Sciences, respectively. Analyses were done using a 15 kV accelerating voltage and a 20-30 nA beam current. Focused beam size was 1 μm for mafic minerals, ilmenite and troilite, 1-5 μm for feldspar, and 8-10 or 20 μm for agglutinitic glass.

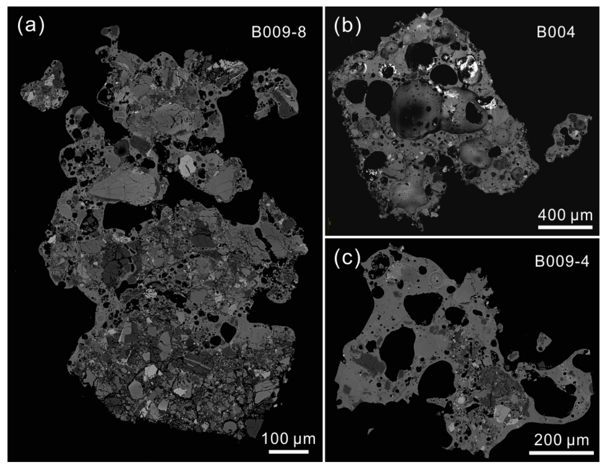

Figure 1. Backscattered electron (BSE) images of three agglutinates extracted from the CE-5 soil.

Results: Samples B004, B009-4, and B009-8 have irregular shapes and are ~1.9×2.7 mm, ~0.7×0.8 mm, and ~0.7×1.0 mm in size, respectively (Fig. 1). Agglutinates B004 and B009-4 have similar structures, with well-developed vesicles ranging in size from < 50 to 500 μm in B004 and to 100-150 μm in B009-4 (Fig. 1). In addition, B004 and B009-4 contain ~65 vol% and ~35 vol%, respectively, of mineral and lithic clasts surrounded by glass (Fig. 1). In contrast, B009-8 contains a higher proportion of mineral clasts (~80 vol%), and ~20 vol% glass mainly distributed along the edge of the sample (Fig. 1). The glass is heterogeneous, sometimes displaying schlieren (flow) textures, and sometimes containing micron to sub-micron sized blebs of Fe-metal

Glass chemistry: Geochemical compositions of agglutinitic glass in the samples are variable (Fig. 2): B004 glass has relatively elevated average SiO_2, CaO and MgO contents compared with the other two fragments. Glass in B009-4 is more compositionally homogeneous. The chemical compositions of glass in B009-

8 are highly heterogeneous compared with the other two agglutinates, as indicated by larger standard deviations on average abundances (Fig. 2).

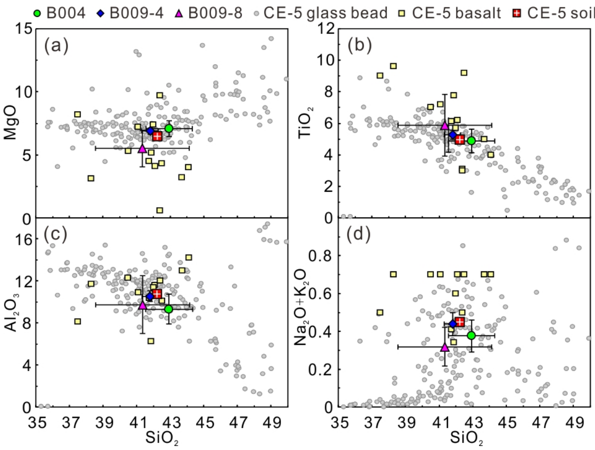

Figure 2. Chemical variation diagrams for average CE-5 agglutinitic glass per fragment compared with the local CE-5 bulk soil [6] and basalt [7, 10] compositions. Composition of glass spherules found in the CE-5 soil [Long et al., unpublished data] are also shown for comparison. Error bars represent 1SD on the average.

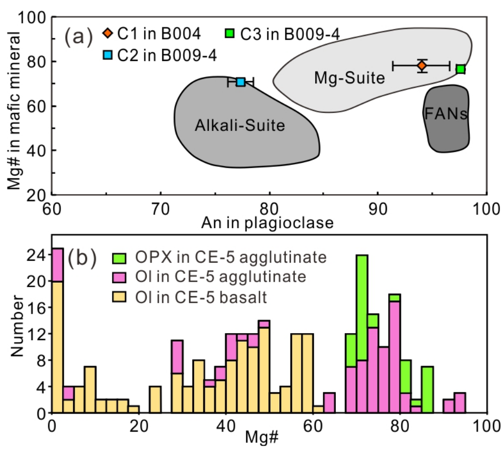

Figure 3. (a) Mafic mineral Mg# vs. plagioclase An# discriminant diagram of lunar highland lithologies (after [9]). (b) Histogram of Mg# in olivine and pyroxene from CE-5 samples, data for CE-5 basalts from [7, 10].

Clast components: A lithic clast (C1) in B004 has Mg-rich olivine ($Fo_{77.9 \pm 2.0}$) and high-Ca plagioclase ($An_{94.0\pm2.6}Ab_{5.0\pm2.0}Or_{1.0\pm0.8}$). Similarly, a lithic clast (C3) in B009-4 also has Mg-rich olivine ($Fo_{76.7\pm0.2}$) and anorthitic plagioclase ($An_{97.6\pm0.4}Ab_{2.2\pm0.3}Or_{0.2\pm0.2}$). These clasts have mineral chemistries comparable to rocks more similar to the Apollo Mg-Suite than the FAN suite (Fig. 3a). A lithic clast (C2) in B009-4 has orthopyroxene ($Wo_{4.9\pm1.4}En_{66.9\pm1.3}Fs_{28.1\pm0.7}$) with average Mg# = 70.6 ± 0.9, and plagioclase with $An_{77.4\pm1.2}Ab_{20.7\pm1.0}Or_{1.9\pm0.3}$, which is consistent with rocks from the Apollo Alkali Suite (Fig. 3a). Other lithic clasts and mineral fragments hosted within the agglutinates have similar chemical compositions to the CE5 young mare basalts.

Discussion:

Formation mechanism: The proportions of agglutinitic glass in the samples studied here are distinct and have different levels of homogeneity (Fig. 1). Although, chemically glass analyses in all three fragments show similarity to the bulk soil sample and Chang'e 5 basalts (Fig. 2), glass in B009-8 is least abundant and most heterogeneous compared to B004 and B009-4, implying variable degrees of melting of the starting soil/protolith(s).

Composition of the local CE5 regolith: The CE-5 soil was thought to be formed by accumulating weathered material from the local underlying mare basalt geological unit [6]. The abundance of basaltic fragments in CE-5 lunar soils [6-7, 10], and the observation that many of the agglutinate mineral fragments analyzed here (Fig. 3b) have mineral and chemical compositions similar to mare basalts, support this conclusion. Interestingly, three lithic clasts hosted within the agglutinates plot in Mg-Suite or Alkali-Suite fields (Fig. 3a). These lithic and mineral results provide an evidence for existence of uncommon 'exotic' non-mare components at the CE-5 landing site.

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