PETROLOGY AND MINERALOGY OF CHANG'E-5 BRECCIAS. Y. Shi[1], K. H. Joy[2], W. Peng[1], Z. Bao[1], A. Nemchin[3,1], X. Che[1], Z. Li[4], M. D. Norman[5], R. Tartèse[2], J. Head[6], B. Jolliff[7], J. F. Snape[2], C. R. Neal[8], M. J. Whitehouse[9], R. Fan[1], S. Xie[1], P. Wang[1], Y. Kang[1], H. Sun[1], Z. Wang[1], W. Zhang[1], D. Liu[1,4], [1]Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China (shiyuruo@bjshrimp.cn), [2]Department of Earth and Environmental Sciences, The University of Manchester, Manchester, M13 9PL, UK (katherine.joy@manchester.ac.uk), [3]School of Earth and 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]Department of Earth, Environmental, and Planetary Sciences, Brown University, Providence 02912, USA, [7]Department of Earth and Planetary Sciences and The McDonnell Center for the Space Sciences, Washington University in St. Louis, One Brookings Drive, St. Louis, MO, USA, [8]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA. [9]Department of Geosciences, Swedish Museum of Natural History, SE-104 05 Stockholm, Sweden.

Introduction: China's Chang'E-5 (CE-5) mission landed on December 1st 2020, at 43.06°N, 51.92°W, about 170 km ENE of Mons Rümker, in northeastern Oceanus Procellarum. This is the highest latitude lunar sampling site to date, and the landing site is vital for testing key lunar and planetary science objectives such as duration and flux of lunar volcanism and petrogenesis of lunar basalt [1-3], Remote sensing data [3] indicate that the relatively young (ca. 1.6-1.7 Ga) basalt flows (designated as unit Em4/P58) exposed around the landing site cover an area of approximately 37000 km^2, with a mean thickness of 51 m; basalts in this unit are compositionally intermediate Ti with relatively high Th (5-8.5 ppm) concentrations.

The mission collected a total of 1731 g of core and scoop samples and returned them to Earth on December 16th 2020. 95% of the sample mass returned in the CE-5 lunar soil is distributed in the size range of 1.40-9.35 μm [4], and the rock fragments are classified into basaltic clasts, breccias (of various types), agglutinates, and glasses. At *ca*. 2.0 Ga, the basaltic clasts are the youngest known lunar volcanic samples [5, 6], and help constrain further lunar and Solar System impact chronology and the thermal evolution of the Moon post ~3 Ga. This contribution focuses on the petrology and mineralogy of the lunar breccias returned by CE-5 with emphasis on the regolith evolution at the landing site.

Samples: Sub-sample CE5C0000YJYX03501GP contained one breccia clast (~ 1.5×2.7 mm), CE-5-B3, which was mounted in a polished resin disc prepared by the National Astronomical Observatories, Chinese Academy of Sciences. Two additional breccia clasts, CE-5-B006 (~ 1.2×1.2 mm) and CE-5-B007 (~ 1.1×2.5 mm), were separated from sub-sample CE5C0400 (a 2 g lunar soil allocated to our group) and were mounted into an epoxy resin disc together with natural and synthetic terrestrial glass standards (BCR-2G, BHVO-2G, and NIST 610).

Methods: *Initial sample imaging.* The polished discs were carbon coated and mapped using the Zeiss Merlin Compact Scanning Electron Microscope (SEM) at the Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing, with a beam current of 6.6 nA and accelerating voltage of 20 kV.

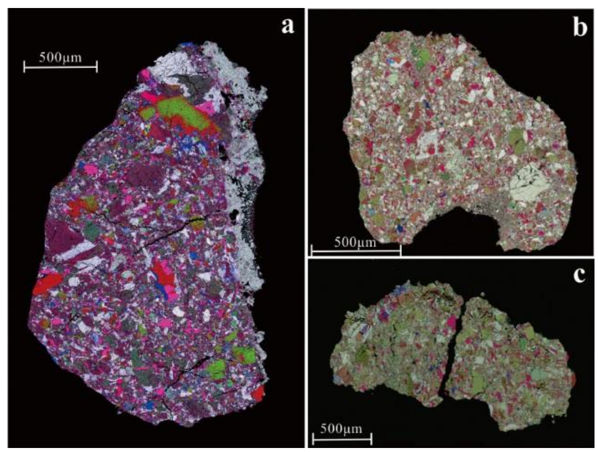

Figure 1. False color energy dispersive spectroscopy (EDS) element maps of the three CE-5 breccias studied, showing (a) CE-5-B3, (b) CE-5-B006, and (c) CE-5-B007. Qualitative concentration and distribution of different elements in both samples are represented by different colors: blue=silica, green=Mg, red=Fe, white=Al, yellow=Ca, pink=Ti, cyan=K.

The SEM system was coupled to an Oxford X-Max^N 150 Energy Dispersive Spectroscopy (EDS) AZtec software to derive <1 μm per pixel back-scatter electron (BSE) images and spatially-resolved element data (~0.38 μm per pixel). Element maps were normalized to the same brightness scale, colorised, and recombined to make qualitative false-color element maps (Fig.1) using the *ImageJ* software package.

Electron probe microanalysis (EPMA). Mineral and glass chemical compositions were analyzed using a Jeol JXA-8230 electron microprobe at the Shandong Institute of Geological Sciences, Jinan. Peak counting times were 10 to 40 s, and backgrounds were counted for half the duration of peak counting time. The compositions of synthetic and natural glasses were used to monitor accuracy and precision.

Results: Fragment CE-5-B3 is a lithic (fragmental) polymict breccia, which contains a diverse range of basaltic clasts and basaltic mineral fragments, rare enstatitite and olivine (with compositions broadly similar to those found in Mg-suite cumulates). No glass spherules have been found in this fragmental breccia (Fig. 1a). CE-5-B006 is a predominantly basaltic regolith breccia, which is composed of basaltic fragments, vitrophyric clasts, rare Mg-suite lithic fragments, and glass spherules set in a matrix of predominantly glassy material (Fig. 1b). CE-5-B007 is also a basaltic regolith breccia, which is mostly composed of basaltic clasts and fragments (Fig. 1c). The maximum clast size in these breccias is ~500 µm (Fig. 1).

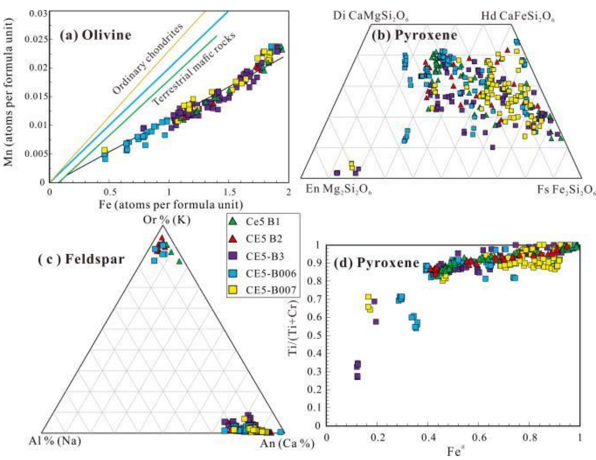

Figure 2. (a) Mn vs. Fe atoms per formula unit in olivine. (b) Pyroxene compositions. (c) Feldspar compositions. (d) Diagram of atomic Ti/(Ti+Cr) vs. atomic Fe# Fe/(Fe+Mg) of pyroxene in the CE-5-B3, CE-5-B006, CE-5-B007 fragments. Data are compared with Chang'E-5 basalts B1 and B2 (data from [5]).

Fe/Mn ratios of olivine in the breccias are consistent with the lunar sample mafic mineral Fe/Mn trend (Fig. 2a). Compared with other Chang'E-5 basalts [5], the basaltic fragments show similar pyroxene and feldspar chemistry (Fig. 2b, c, and d) with some textural variability. The glass spherules and matrix glass also exhibit compositional similarities to the glass beads and agglutinatic glass found in other Chang'E-5 samples (Fig. 3). Glass beads in CE-5-B006 have higher TiO_2, lower Al_2O_3, and are more ferroan than in the other two breccia fragments (Fig. 3).

Summary: The fragmental (CE-5-B3) and regolith breccia (CE-5-B006 and CE-5-007) clasts contain similar components to other Chang'E-5 basalt fragments and glasses extracted from the bulk soil sample (Figs. 2, and 3). This suggests that the breccias are mostly composed of material that has been sourced from the underlying basaltic units and well-mixed within the local regolith, with minor added highlands (i.e., feldspathic and Mg-suite) rock and mineral components.

Impact melt breccias are rare in all the breccias we have studied so far, suggesting that the regolith at the site is characterized by poorly sampled lithic material created by small local impact cratering events.

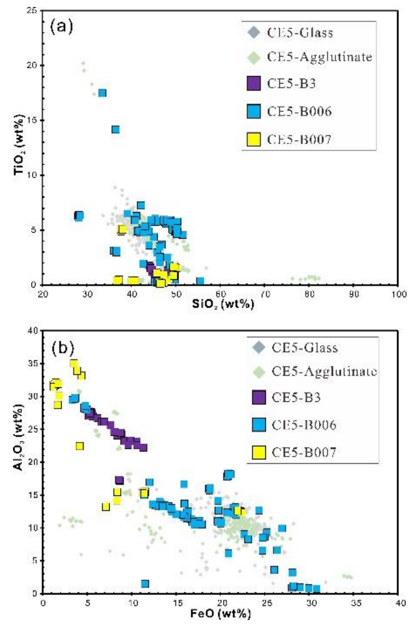

Figure 3. Diagrams of (a) TiO_2 vs. SiO_2 and (b) Al_2O_3 vs. FeO of the glass beads and other glass components found in the CE-5-B3, CE-5-B006, CE-5-B007 breccias. Glass data are compared with other CE-5 glass beads (data from Long et al., LPSC, 2022) and agglutinates (data from Xie et al., LPSC, 2022).

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