CRYSTAL SIZE DISTRIBUTION OF ILMENITE IN CHANG'E 5 BASALT CLASTS

C.R. Neal[1], J.L. Valenciano[1], X. Che[2], Y. Shi[2], D. Liu[2], L. Tao[2], K. H. Joy[3], J.F. Snape[3], R. Tartèse[3], J. Head[4], B. Jolliff[5], A. Nemchin[2,6], M. D. Norman[7]. [1]Department of Civil & Environmental Engineering & Earth Sciences, University of Notre Dame, Notre Dame, IN 46556, USA [jvalenc2@nd.edu; cneal@nd.edu]; [2]Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China; [3]Dept. Earth & Envi. Sciences, University of Manchester, Manchester, M13 9PL, UK; [4]Dept. Earth, Env, & Planetary Sciences, Brown University, Providence 02912, USA; [5]Dept. Earth & Planetary Sciences, McDonnell Center for the Space Sciences, Washington University in St. Louis, St. Louis, MO, USA, [6]School of Earth & Planetary Sciences, Curtin University, Perth, WA 6845, Australia, [7]Research School of Earth Sciences, The Australian National University, Canberra ACT 2601 Australia.

Introduction: Chang'e 5 successfully returned 1731 g of lunar regolith samples from the Mons Rümker region of Oceanus Procellarum [1], and represents China's first lunar sample return. The site was chosen because it contains relatively young (~2 Ga) mare basalts, which has recently been confirmed [2,3]. Back-scattered electron (BSE) images (**Fig. 1**) and false color element maps were obtained and used to conduct quantitative textural analyses through creation of crystal size distributions (CSDs) of ilmenite. CSD profiles created using the plagioclase in each of these samples will also be presented in another abstract in this session [4].

Methods: CSDs are a quantitative, non-destructive method of analyzing crystallization histories of igneous samples [5,6]. The CSD data from this study uses a process similar to [7]. Here, BackScattered Electron (BSE) images were used in conjunction with element maps to identify crystals (Fig. 1). Ilmenite crystals in each sample were traced in *Paintshop Pro 2020* with an active stylus and touchscreen laptop computer. These traces, along with a trace of the perimeter of the sample itself, are filled with a solid color and then imported into *ImageJ* to determine the area, best-fit ellipse, and major and minor axis of each crystal and its sample by using a known scale. These data were then input to *CSDSlice* [6] and *CSDCorrections* [8]. This determined the overall shape and size distribution of the crystals. The resulting data were used to plot the natural log of population density versus the length of each crystal's major axis (**Fig. 2**). Any crystals that shared boundaries were traced on separate layers and incomplete crystals were omitted. In order to generate a statistically valid CSD a minimum of 250 crystals were traced on each sample [2].

Results & Discussion: These five basalt clasts show generally linear CSDs, which indicate the clasts underwent a constant cooling rate (**Fig. 2**). Steeper slopes represent a relatively faster cooling rate. Sample 329 possess a distinctly shallower slope when compared to the rest of the samples in this study, consistent with its significantly larger crystals and inferred slower cooling rate. The other samples have steeper slopes, with B015-04 possessing the steepest slope and, therefore, fastest cooling rate. The ilmenite CSD slopes and intercepts from the five CE5 basalt fragments are compared to high-Ti samples from Apollo 11, Apollo 17, and Luna 16 [9-11] (**Fig. 3**). It has been shown that presentation of ilmenite CSDs in this way allows two main cooling rates to be developed, that were termed simply "faster" and "slower" cooling by [9]. Ilmenite CSDs from basalts B015-02, B015-03, B015-04, and B016-04 all plot within the "faster" cooling trend samples that present fine-grained textures (**Fig. 1**), while basalt 329 plots

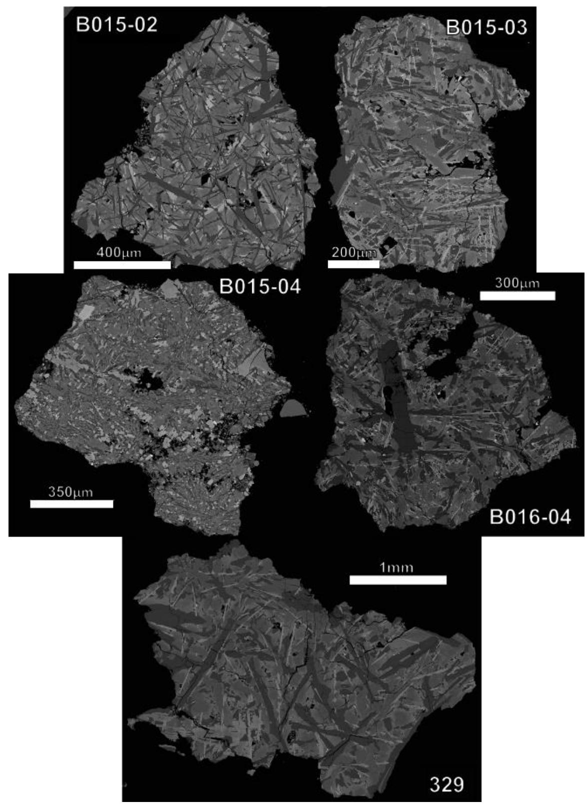

Figure 1: Back-scattered electron images of the samples analyzed in this study. There is armacolite surrounded by ilmenite present in B015-04.

with the "slower" cooling trend. The general concave-upward profile presented by the ilmenite CSD of basalts 329 is consistent with crystal accumulation and/or textural coarsening that was arrested as the temperature of the lava dropped [12]. These faster cooling samples, along with some basalt fragments from Luna 16 [9] and Apollo 11 [11], help further characterize the faster-cooling trend. It is possible that 329 is from the interior of a flow with other samples closer to the chilled margin. B015-04 also shows armacolite surrounded by ilmenite, which was included in the ilmenite CSD. The ilmenite CSD for B015-04 has a distinct kink in it, suggesting two distinct crystal populations formed at two distinct cooling rates (the larger crystals forming at a slower cooling rate, maybe in a subsurface magma chamber prior to eruption). The shallower slope of the larger crystal size in the B015-04 ilmenite CSD is subparallel to the slope of the CSD for basalt 329.

A semi-quantitative estimation of cooling rates was obtained by comparing the similarities of textures in these fragments to textures shown in [13,14]. B015-04 (smaller crystals and steeper part of the CSD in Fig. 2) and B016-04 both show textures that approximate to samples that cooled at a rate of 86°C/hr. Images in [13,14] suggest the cooling rate of 329 could be around 2-7°C/hr. Using the results from Usselman et al. [13,14] we can broadly define the faster cooling rate to indicate temperature changes >2˚C/hr and the slower cooling rate to be <1˚C/hr. The cross over between the two trends is 1-2˚C/hr.

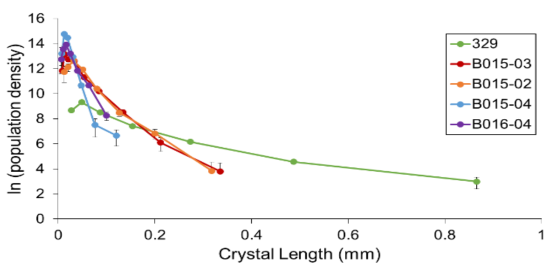

Figure 2: Ilmenite CSD profiles of these basalt fragments. Any error bars that are not visible are within the symbol.

Conclusion: Ilmenite CSDs from the five CE5 basalts studied here indicate that they cooled quickly, although subsurface cooling and potential textural coarsening/crystal accumulation occurred in at least two samples (B015-04 and 329). Comparison with cooling rate experimental results indicates that four of the CE5 basalts experience a range of cooling rates that were relatively rapid, akin to the Luna 16 basalts and two Apollo 11 high-Ti basalts, but unlike those from Apollo 17 (Fig. 3). Only CE5 basalt 329 has a texture similar to the Apollo 17 basalts and experienced the slowest cooling rate of the CE5 basalts studied here

Future Work: This could include conducting cooling rate experiments on high-Ti basalt compositions and constructing ilmenite CSDs on the run products to calibrate Figure 3 more quantitatively such that the cooling rate can be determined for a given sample simply through construction of an ilmenite CSD.

Acknowledgements: We thank the China National Space Administration who approved the sample request of our Beijing colleagues. We also thank the Chinese Academy of Geological Sciences for supplying their input and data. No NASA funding was used to support this research.

References: [1] Qian Y. et al. (2021) *EPSL 561*, article 116855; [2] Che X. et al. (2021) *Science 374*, 887–890 [3] Li Q-L. et al. (2021) Nature 600, 54-58; [4] Webb S. et al., (2022) *LPSC53*; [5] Marsh, B. D., (1998) *J Petrol 39 (4)*, 553-599. [6] Morgan D. J., & Jerram D.A. (2006) *JVGR 154*, 1-7. [7] Neal et al. (2015) *GCA 146*, 62-80. [8] Higgins M. D. (2000) *Amer. Min.*, 1105-1116. [9] Valenciano J. L. et al., (2021) *LPSC 52*, #1750; [10] Donohue P.H & Neal C.R. (2015) *GCA 149*, 115-130; [11] Xue Z. et al. (2021) *MaPS 56*, 221- 2229. [12] Higgins M.D. (1998) J. *Pet. 39*, 1307-1323; [13] Usselman et al. (1975) *PLSC 6*, 997-1020 [14] Usselman T. M. & Lofgren G. E., (1976) *PLSC 7*, 1345-1363.

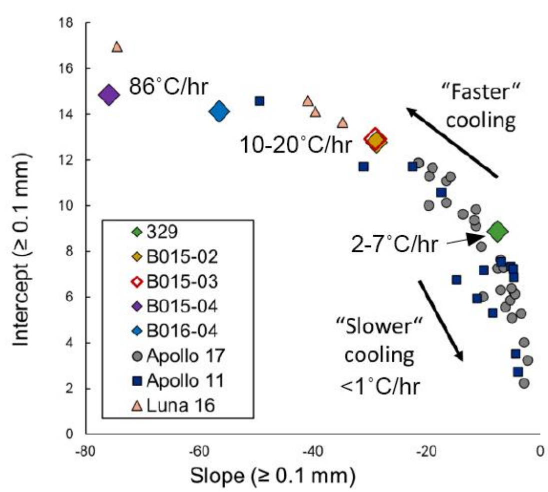

Figure 3: A comparison of the ilmenite CSD slopes and intercepts from this study and previously studied Luna 16 [9], Apollo 11 [11] and Apollo 17 [10] ilmenite-rich basalts, with the cooling rates estimated from experimental work [13,14]