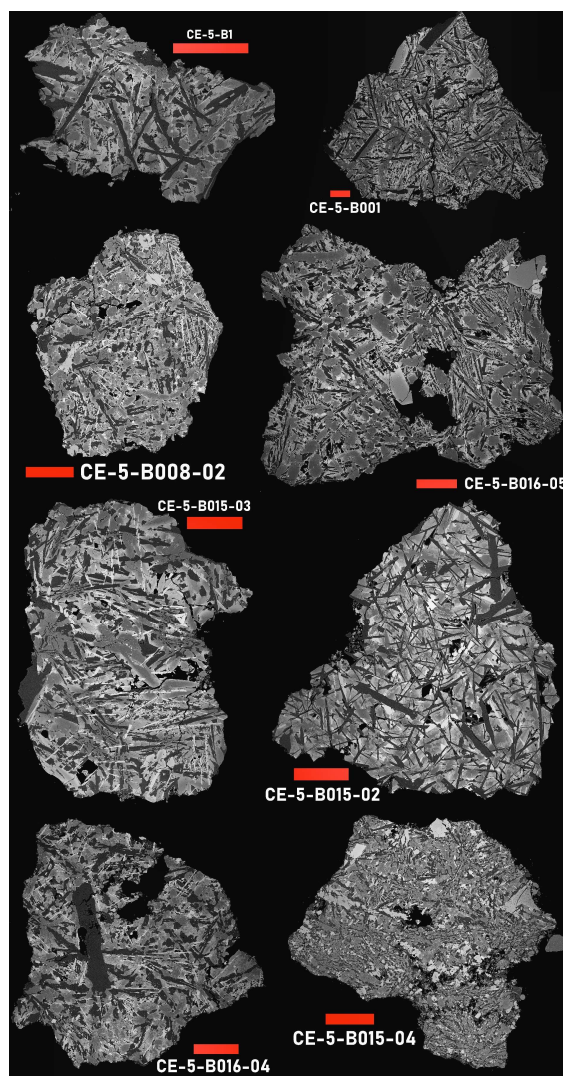


# CRYSTAL SIZE DISTRIBUTION OF PLAGIOCLASE IN BASALT FRAGMENTS FROM OCEANUS PROCELLARUM RECOVERED BY CHANG'E-5.

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**Introduction:** Crystal Size Distribution (CSD) data are valuable for evaluating the crystallization histories of igneous samples [1-3]. Plotting the CSD slope and y-intercept data for minerals from basalts yields information about crystallization history and cooling rate, as well as provides constraints on whether lunar basalts are volcanic or impact in origin [4]. For this study, we analyzed plagioclase CSDs from 8 basalt fragments (Fig. 1) returned by China's Chang'e-5 mission in 2020. The Chang'e-5 mission landed on basalt plains (Em4/P58) in northern Oceanus Procellarum near Rima Sharp [5]. These flows are younger than most other lunar volcanic basalts [6,7]. This study presents plagioclase CSDs on returned Chang'e-5 basalt fragments and another abstract in this meeting examines the ilmenite CSDs of these fragments [8].

**Methods:** CSD data for this study were collected similarly to that described in [4] with slight variations. Here, BackScattered Electron (BSE) images were used in conjunction with element maps to identify crystals (Fig. 1). Once the crystals were manually traced the BSE and false color images were removed from the background and the crystal traces were filled-in with a solid color. Those images were exported to *ImageJ*®, where the known scale of the images was used to determine the area, best-fit ellipse, and major/minor axis of each crystal and the sample area itself. These data were then input to *CSDSlice* [2] and *CSDCorrections* [3]. 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), and the slope and y-intercept data from these plots were used to compare the CSDs with Apollo mare basalt samples and Luna 16 basalt fragment samples (Fig. 3). The rule devised by [4] regarding omitting crystals below 0.3 mm in length was not followed in this study, because the BSE images were of higher resolution than typical photomicrographs of thin sections allowing crystals smaller than 0.3 mm to be included (Fig. 1). The BSE images allowed accurate determination of these smaller populations such that the remaining rules defined by [4] could be followed.



**Figure 1.** Backscattered Electron (BSE) images of the Chang'e-5 basalt fragments examined here. Red rectangle represents 0.2 mm in each image. The brightest crystals are ilmenite and the darkest crystals are plagioclase. Intermediate tones are usually pyroxene or olivine, but could also represent other phases.

**Results & Discussion:** The plagioclase CSDs of basalts B1 and B016-04 exhibit slopes that are less steep and y-intercept values that are lower than the other Chang'e-5 basalts studied here (Fig. 2). This is

consistent with fragments B1 and B016-04 being the coarsest-grained samples analyzed (Fig. 1) and they contain plagioclase crystals that have CSD relationships similar to those in endogenous Apollo 14 basalts (Fig. 3). The remaining CE5 basalt fragments studied here have plagioclase slopes and y-intercepts that fall on the “fast cooling” trend, similar to the Luna 16 samples (Fig. 3).

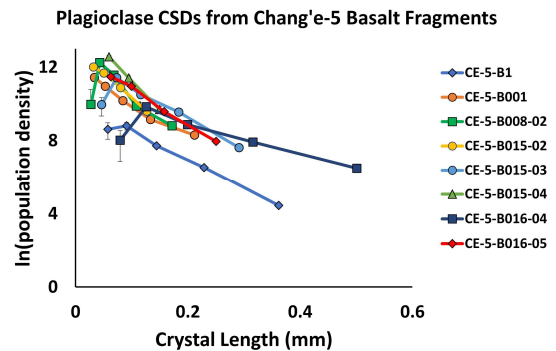
As with the Luna 16 samples [9], the BSE images allowed for accurate plagioclase CSD data to be acquired for crystals smaller than 0.3 mm. For the Chang’e-5 basalts, plagioclase crystals smaller than 0.1 mm were able to be traced, typically without any significant increase in the size of error bars until crystal length decreased below  $\sim 0.08$  mm.

The Luna 16 and Chang’e-5 basalt data define a “fast cooling” trend on a plot of CSD slopes vs. their corresponding y-intercept values (Fig. 3) and the data show that the Apollo 14 basalts are part of this trend. This relationship provides greater confidence that the apparent difference in cooling trends between the Luna 16 and Apollo samples that has been observed is not an artifact of using BSE images instead of photomicrographs in the CSD method, but a real phenomenon. The CSD data reported here (and the majority reported in [10]) are consistent with cooling rates of  $\sim 5^\circ\text{C/hr}$  or greater (cf. [11]). The CSDs for CE-5-B1 and CE-5-B016-04 have shallower profiles that are similar to Apollo 14 basalts (Fig. 3) and are consistent with a slightly slower cooling rate than the other basalt fragments in this study ( $1\text{--}3^\circ\text{C/hr}$ ), estimated from experimental work [11]. Lofgren et al. [11] noted that plagioclase morphology is related to the ratio of the Diffusion coefficient to the Growth rate. If  $D/G \geq 1$  (slower cooling, Fig. 3), tabular crystals form in an equilibrium crystallization environment, but if  $D/G < 1$ , disequilibrium quench textures form (faster cooling, Fig. 3). The basalts returned by Chang’e-5 were probably from the uppermost layers (just below the chilled zone) of lava flows, that underwent relatively rapid cooling. Flow emplacement models for Em4-P58/Rima Sharp [12] suggest two different cooling rates, one for the initial chilled upper part of the flow ( $10 \pm 5^\circ\text{C/hr}$ ) and one for final flow solidification ( $9 \pm 3^\circ\text{C/hr}$ ). Our results are consistent with these.

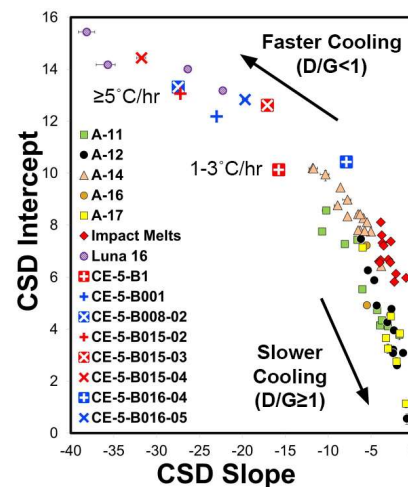
**Conclusions:** The majority of the Chang’e-5 basalts analyzed here contain plagioclase that experienced fast cooling that was  $\sim 5^\circ\text{C/hr}$ , similar to the previously reported Luna 16 samples [9,10]. Two of the samples studied here have larger plagioclase and CSDs similar to those reported for Apollo 14 basalts ( $1\text{--}3^\circ\text{C/hr}$ ). The textures measured here for the young Chang’e-5 basalt

fragments indicate that they most likely cooled quickly upon eruption and did not experience the same degree of slower cooling or textural coarsening that the coarsest Apollo samples did (Fig. 3).

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**Figure 2.** Plagioclase CSDs from this study. If error bars are not visible then they are within the area of the symbol. Sample B015-04's CSD exhibits the steepest slope, while sample B016-04's CSD is the least steep and indicates coarser grain sizes relative to the other samples in this study.



**Figure 3.** A plot of plagioclase CSD slope vs y-intercept [4]. If error bars are not visible then they are within the area of the symbol. The Luna 16 samples defined a faster cooling trend than the previously studied Apollo samples [9]. The CE5 samples plot near both the Luna 16 and Apollo 14 basalt samples at cooling rates of  $\geq 5^\circ\text{C/hr}$  &  $1\text{--}3^\circ\text{C/hr}$ , resp. [11].  $D$  = Diffusion coefficient;  $G$  = Growth rate [11].