Textural Analysis of Pyroxene in Apollo 11 (A-11) High-Ti Basalts. L. E. Galien[1], C. R. Neal[1], [1]Department of Civil and Env. Eng. & Earth Sciences, University of Notre Dame, Notre Dame, IN 46556, USA [lgalien@nd.edu].

Introduction: A-11 basalts are classified texturally and compositionally into 6 groups: Groups A, B1, B2, B3, D, and uncharacterized Group U. Here, pyroxene (Px) textures were analyzed to understand the crystallization history in 14 A-11 basalts: 5 from Group A (10017,12; 10049,114; 10057,33; 10069,92; 10072,53); 3 from B1 (10044,41; 10047,9; 10058,253); one from B2 (10003,185); two from B3 (10020,58; 10092,9); and one from U (10062,45). Two A-11 Group D samples were analyzed: 10085,808 & 10002,121. This work aims to build on previous work [1] and investigate the cooling histories of A-11 basalts.

Crystal size distributions (CSDs) are a valuable non-destructive method for collecting quantitative data, which represents the cooling history of the mineral of interest in igneous rocks [2]. The gradient of a CSD slope represents the cooling rate, where steeper slopes indicate faster cooling. A linear trend indicates a singular cooling rate, whereas a kinked shape indicates two distinct cooling regimes. If a CSD is curved concave up, the sample may have undergone textural coarsening or crystal accumulation. Concave down CSDs indicate crystal fractionation [3]. The slope and intercept of CSD graphs for multiple minerals can be plotted to examine relative cooling rates between phases & samples [3].

Previous work [1] details the crystallization history of A-11 basalts where ilmenite crystallized immediately post-eruption in all samples, but also formed pre-eruption in the B1 basalts (kinked CSD profiles), and plagioclase crystallized only post-eruption at a single cooling rate [1]. This work examines Px in these basalts, which had a long crystallization history as evidenced by its mode representing ≥50% of the basalts (Table 1 and [4]). Pyroxene is usually intergranular to ophitic, often enclosing ilmenite & plagioclase [4]. Pyroxferroite breakdown textures (symplectite intergrowths of cristobalite, fayalite, and augite) are present in a number of lunar basalts, including A-11 samples [4-9]. The presence of pyroxferroite breakdown indicates a metastable crystallization followed by rapid cooling [10].

Methods: The CSD method is described in detail by [1, 11] and is summarized here. Photomicrographs of each sample were taken in both cross polarized light and plane polarized light and stitched together using *Microsoft Image Composite Editor* to create photomosaics. These images were imported into *Corel Paintshop Pro* and used to trace pyroxene crystal boundaries for 10 samples. Backscatter electron images were used for tracing of 4 finer grained samples. If two crystal boundaries were overlapping, they were traced in separate layers. A minimum of 250 crystals were traced per sample to ensure the data is statistically significant, except for 10047,9 and 10085,808, which contained 214 and 235 total pyroxene crystals within the sample. 10085,808 meets the requirements outlined in [11] for accepting CSDs with <250 crystals, but 10047,9 does not, and is not included. The crystal traces and the sample areas were filled and imported into *ImageJ* [12]. The crystals were analyzed using the best fit ellipse to determine the major & minor axes, degree of roundness, and the area of the crystals [11]. These data were imported into *CSDSlice* [13] to determine the 3-D shape of the traced crystals [12]. *CSDCorrections* [14] produced the final CSD: (ln) population density vs. the corrected crystal length.

Results & Discussion:

Table 1. *Px volume percentages and residence times.*

Sample	Group	% Px	Residence Time (years)
10017,12	A	66.3	6.15
10049,114	A	55.9	0.35
10057,33	A	46.1	0.31
10069,92	A	71.4	0.19
10072,53	A	54.5	1.12
10044,41	B1	56.3	0.39; 4.91
10058,253	B1	60.6	6.04
10003,185	B2	69.8	4.5
10020,58	B3	66.9	0.95
10092,9	B3	59.3	1.43
10002,121	D	55.1	1.54
10085,808	D	63.81	1.85
10062,45	U	47.1	1.25

6 Px CSDs have shallow slopes: one Group A-10017,12, both statistically significant B1 basalts (10044,41 & 10058,353), one B2-10003,185, one B3-10092,9, and one U-10062,45. 7 have steeper slopes: all other Group A basalts (10049,114, 10057,33, 10069,92, 10072,53), one B3-10020,58, and both Group D samples (10002,121, 10085,808). This indicates the former basalts cooled at a slower rate than the latter group (**Fig. 1**). Overall, Px in Groups A & D formed through faster cooling rates than Groups B1, B2, & U. 10069,92(A) has the steepest Px CSD slope & 10017,12(A) has the shallowest. All basalts demonstrate unkinked CSD profiles except for B1 basalt 10044,41 (**Fig. 1**), which contains two distinct slopes: from crystal lengths 0.03-0.08 mm and 0.08-0.8 mm. The CSD is consistent with two-stage cooling [3]. 10049,114(A), 10020,58(B3), & 10062,45(U) have concave upward Px CSDs, indicating textural coarsening during the cooling of the lava flow (**Fig. 1**). Some of these samples also displayed textural coarsening in ilmenite; 10062,45 (U), 10020,58(B3), 10092,9(B3), 10017,12(A), & 10072,53 (A) demonstrated textural coarsening in ilmenite and/or

plagioclase [1]. Px CSDs of all samples, except for Group B1 basalt 10044,41, indicate a single cooling rate consistent with only post-eruption crystallization based on their profiles.

The Px modal & calculated using CSDs are either consistent with, or higher than, Px modes calculated via point counting [15]. Px residence times calculated using CSD slopes and an estimated average growth rate [16] are consistent with plagioclase residence times [1].

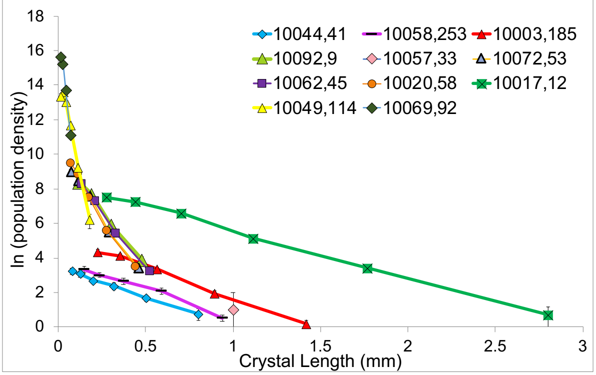

Figure 1: Px CSDs from thirteen A-11 samples.

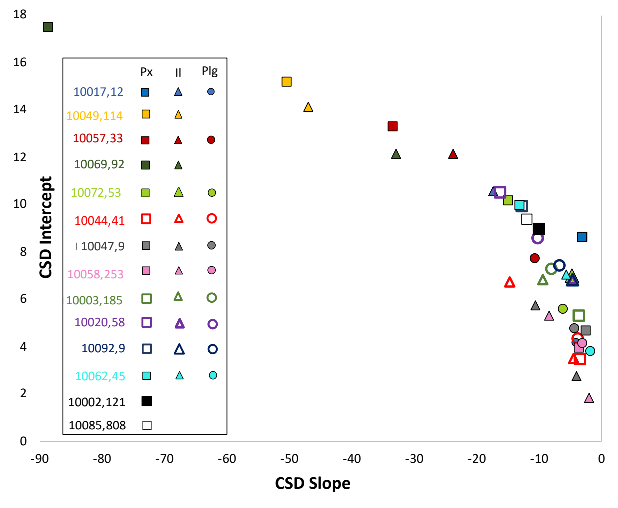

Figure 2: Slope vs. intercept plot of Px (□), ilmenite (Δ), & plagioclase (O) CSDs. Faster cooled samples plot to the upper left corner, with a steeper slope and higher intercept.

The slope & y-intercept data [11] for the CSDs from [1] & this study provides a complete picture of the cooling history of A-11 basalts (**Fig. 2**). If the CSDs plot higher and to the left, the mineral crystallized faster than samples plotting to the bottom right. The cooling rate of Px has some correlation with chemical group: pyroxene cooled faster than ilmenite & plagioclase in 4 of the Group A basalts and both Group B3 basalts, & pyroxene cooled at a similar rate to plagioclase in both B1 basalts.

As discussed in [1], ilmenite began to crystallize pre-eruption due to subsurface cooling in the B1 basalts, continuing post eruption. Px in the B1 basalts crystallized post-eruption with plagioclase & ilmenite in all samples, but 10044,41 contains two Px populations, one of which plots near the first ilmenite population, indicating they both began crystallizing pre-eruption at a slower rate (**Fig. 2**) [3,11]. 10044,41 shows a large range of Px compositions, indicating, along with the higher percentage of pyroxene (56%), that pyroxene was crystallizing for a long period of time: pre-eruption with ilmenite, and post eruption with ilmenite and plagioclase [15,17]. The presence of pyroxferroite breakdown textures in B1 basalts confirms that pyroxene was on the liquidus for an extended period to produce highly Fe-rich compositions.

Group A basalts have Px as the fastest cooling phase in all samples except 10017,12, in which ilmenite cooled the fastest. 10017,12 showed the longest residence time of the Group A basalts, with a maximum residence time of 99.7 cm/yr using the minimum growth rate from [15]. Pyroxene may have crystallized later in this sample with insulation from prior formed crystals reducing the cooling rate. 10049,114 has a steep concave up CSD, implying textural coarsening, but may represent disequilibrium quench cooling that produced a high abundance of smaller crystals. Other phases cooled quickly [1] supporting the latter interpretation. Pyroxene in the Group B2 basalt cooled slower than other phases post-eruption but has a linear profile and a high modal % (**Table 1**), indicating that pyroxene was on the liquidus for an extended period of time. Group B3 basalts likely cooled faster in a thinner flow because pyroxene was the fastest cooling phase. The two Group D CSDs are linear, with intermediate slopes and intercepts within the pyroxene slope-intercept range. CSDs of plagioclase and ilmenite for these samples are under construction. The one Group U slope intercept plot shows pyroxene was the fastest cooling phase in 10062,45. The concave up CSD is interpreted as textural coarsening, consistent with its coarse-grain size, which was also observed in ilmenite [1].

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