SLOWLY COOLED, HIGH-TITANIUM AND VERY-LOW TITANIUM BASALT CLASTS FROM APOLLO CORE 73001. Z. E. Wilbur[1], A. Tatsch[1], J. J. Barnes[1], A. C. Stadermann[2], S. A. Eckley[3], T. Erickson[3], J. Gross[2], C. K. Shearer[4], R. A. Zeigler[2], F. M. McCubbin[2], and the ANGSA Science Team[5]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721, USA (zewilbur@arizona.edu); [2]NASA Johnson Space Center, Houston, TX, 77058, USA; [3]Amentum- *JETS II*, NASA Johnson Space Center, Houston, TX, 77058, USA; [4]University of New Mexico, Albuquerque, NM, USA; [5]List of co-authors includes all members of the ANGSA Science Team (https://www.lpi.usra.edu/ ANGSA /teams/).

Introduction: The Apollo Next Generation Sample Analysis (ANGSA) program recently processed Apollo 17 double drive tube, 73002/1 [1,2]. The double drive tube is composed of two core samples: 73002 represents the top 35 cm, and 73001 represents the bottom 35 cm of the core [1]. During preliminary examination (PE) of 73001, ~220 clasts greater than 4 mm in size were identified and, of these, 31 clasts were initially characterized as basalt fragments [2]. Here, we employ a detailed 2D and 3D investigation of two basalt clasts initially identified during PE as a high-Ti basalt and a low-Ti basalt [2]. We seek to determine the petrogenesis of basalt clasts from the core and to compare them to previously characterized Apollo 17 basalts. Furthermore, the studied basalt clasts provide the opportunity to evaluate the diversity of lunar volcanism sampled at Station 3 during the Apollo 17 mission.

Recent work has highlighted the utility of coupling traditional 2D methods with 3D measurements to better understand the crystallization and degassing histories of lunar lava flows [3,4]. At the upcoming conference, we will present a detailed study of the mineralogy, petrology, microstructures, and 3D morphology of these basalt clasts to shed light on their magmatic, volcanic, and post-eruptive histories. We show that the samples represent a characteristic high-Ti basalt clast, and a new, very-low-Ti (VLT)-type basalt clast, and that both samples cooled slowly in their respective lava flows.

Samples: The two clasts examined in this study were extracted in pass 2 during PE of 73001. The high-Ti basalt clast (original mass of 0.785 g) is from interval 25, was denoted 73001,1095B for X-ray computed tomography (XCT) scanning, and was subsequently potted, cut, and polished into a thick section denoted 73001,531. The low-Ti basalt (original mass of 0.123 g) is from interval 62, was denoted 73001,1234B for XCT scanning, and was cut and polished into a thick section denoted 73001,538.

Methodology: For 3D study, bulk samples of 73001,1095B and 73001,1234B were scanned using XCT with the Nikon XTH 320 instrument in the Astromaterials Research and Exploration Science (ARES) Division at NASA's Johnson Space Center (JSC) to determine 3D mineralogy, fabrics, and vesiculation textures. The samples were scanned with a 180 kV transmission source without a filter using the following conditions: 90 kV, 33 μA, and a voxel size range of 4.07 μm for 73001,1234B and 6.71 μm for 73001,1095B. These scans were reconstructed using CT Agent Pro and visualized using Dragonfly™ software. Vesicles were separated and measured with Blob3D [5], following the methods of [3].

Polished thick sections were surveyed using a Keyence VHX 7000 Digital Optical Microscope in the Lunar and Planetary Laboratory (LPL) at the University of Arizona. X-ray elemental and backscattered electron (BSE) mapping of polished thick sections of 73001,531 and 73001,538 were performed using the JEOL 7900F scanning electron microscope (SEM) in the ARES division at NASA JSC. The chemistry of major (e.g., pyroxene and feldspar) minerals and accessory phases (e.g., apatite) within these samples was determined using the CAMECA SX100 electron microprobe analyzer at the University of Arizona's Kuiper-Arizona Laboratory for Astromaterials Analysis (K-ALFAA). 2D modal mineralogy was determined from the X-ray maps using *ImageJ* software.

The two clasts were analyzed by electron backscatter diffraction (EBSD) using the JEOL 7900F SEM in ARES at JSC, which is equipped with an Oxford Instruments Symmetry S2 detector. Analytical conditions included a 20 kV accelerating voltage, 4 nA beam current, ~20 mm working distance and a 70° sample tilt to the beam incidence following the methods outlined in [1]. Post-processing of the EBSD data was completed using Oxford Instruments Aztec Crystal software suite.

Results: High-Ti basalt 73001,531 is a plagioclase poikilitic basalt. Anorthite grains ($An_{95}Ab_5$) measure up to 1 mm in length and enclose zoned pyroxenes (Fig. 1a), and show a single crystallographic orientation based on EBSD-analysis. Modal mineralogy calculated for the polished section indicates the sample contains ~ 41.1 vol.% anorthite, 43.0 vol.% pyroxene, 13.8 vol.% oxides, 0.8 vol.% olivine, and trace amounts of phosphates, silica, glass, metal, and sulfide. The pyroxene grains in 73001,531 contain Mg- and Ca-rich cores and Fe-rich rims. The pyroxene grains span Ti/Al ratios from 0.5 to 0.8, and overlap ratios reported for Type IB basalts [6]. Angular, elongated ilmenite (up to 0.8 mm in length) contain inclusions of plagioclase, pyroxene, and glass. Rutile and ulvöspinel exsolution are present within the larger ilmenite grains, and the rutile presents a triple junction pattern with a topotaxial relationship (Fig. 1c). Olivine has a composition of Fo_{60}. The 3D study of clast 73001,1095B shows trace vugs (comprising 0.3 vol.% of the scanned volume; angular voids) throughout the sample that measure up to 0.5 mm.

Section 73001,538 primarily consists of pyroxene (56.6 vol.%), anorthite (40.2 vol.%), and trace phases including ilmenite, chromite, and Cr-ulvöspinel (combined 0.2 vol.%), and cristobalite and tridymite (combined 2.6 vol.%). 73001,538 contains zoned pyroxene phenocrysts measuring up to 2 mm in length (Fig. 1b). The pyroxene grains have Ca-rich cores (33% of the pyroxene) and Fe-rich rims (67% of the pyroxene), and grains contain coarse exsolution lamellae, of homogenous orientation, up to 4 µm in width (Fig. 1d,e). The pyroxene grains show a weak petrofabric, and some grains contain simple twin boundaries. The pyroxene grains span Ti/Al ratios from 0.1 to 0.7. The pyroxene Fe# (Fe/Fe+Mg) and Ti# (Ti/Ti +Cr) increase from core to rim in all the pyroxene grains. Anorthite ($An_{98}Ab_2$) laths (up to 1.8 mm in length) are subhedral and elongated. The 3D study of 73001,1234B shows vugs (1.8 vol.%) that measure up to 0.5 mm.

Discussion: We evaluate the representativeness of high-Ti mare basalt clast 73001,531 compared to other recently processed 73002/1 basalt clasts and the other basalts identified in the Apollo 17 collection. The low abundance of olivine (<1 vol.%) and its iron-rich composition (Fo_{60}), average pyroxene Ti/Al ratio of 0.5 [6], and the coarse-grained mineralogy compared to other Apollo basalts [7], are consistent with the chemical, mineralogical, and textural characteristics of high-Ti Type 1B basalts.

Prior to the examination of soils within the Apollo 17 drill core segments 70007 to 70009, mare basalts were thought to comprise the low-Ti (1.5 wt.% TiO_2) and the high-Ti (>13 wt.% TiO_2) suites. Examination by [8] of the >0.02 mm soil fraction from the Apollo 17 drill core segments 70007 to 70009 showed a new mare basalt type with <0.5 wt.% TiO_2, so-called the very-low Ti (VLT) suite. Section 73001,538 contains <0.2 vol.% ilmenite. We calculated the bulk chemistry of this basalt to determine its affinity for either the low-Ti or VLT basalt suites. We determine a bulk TiO_2 value of 0.5 wt.%, making it a VLT basalt. Additionally, the average modal and chemical analyses of 73001,538 are similar to Apollo 17 VLT basalts from [8].

Based on the coarse-grained mineralogy, complex exsolution features, and low vesicularity observed in 3D data within both clasts, we infer these basalts cooled slowly in the cores of their respective lava flows.

Acknowledgments: We thank the AARB and NASA's Curation Office for the loan and allocation of samples to this project. Ken Domanik is thanked for EPMA assistance. This work is funded by NASA Grant 80NSSC19K0803.

References: [1] Shearer C. K. et al. (2024) *Space Science Reviews* 220(6). [2] Gross J. et al. Accepted *Journal of Geophysical Research- Planets* [3] Wilbur Z. E. et al. (2023) *Met. & Plan. Sci.* 58(11), 1600-1628. [4] Wilbur Z. E. et al. (In Press) *Geochim. Cosmochim. Acta.* [5] Ketcham R. (2005) *Journal of Structural Geology*, 2 (1217–1228). [6] Brown G. et al. (1975) 6th Lunar Science Conference. [7] Meyer C. (2011) Lunar Sample Compendium. [8] Vaniman D. T. and Papike J. J. (1977) *LPSC Proceedings*, *2*, 1443-1471.

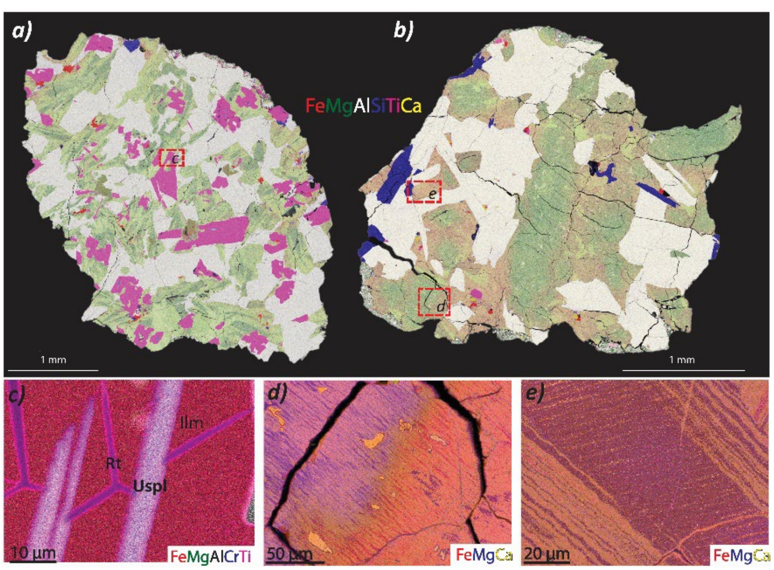

Figure 1. Mineralogy and textures of 73001, 531 and ,538. *Elemental composites of **a)** 73001,531 and **b)** 73001,538. Elemental composites include Fe (red), Mg (green), Al (white), Si (blue), Ti (magenta), Ca (yellow). The following phases can be identified: pyroxene (green), plagioclase (white), ilmenite (pink), metals/sulfides (red), and silica (blue). **c)** Elemental map of rutile and ulvöspinel exsolution present in ilmenite in 73001,531 with Fe (red), Mg (green), Al (white), Cr (blue), and Ti (magenta). **d)** and **e)** Coarse exsolution lamellae present in pyroxene in 73001,538 with Fe (red), Mg (blue), and Ca (yellow).*