An ~3.5 Ga Impact Recorded by Cubic Baddeleyite in Lunar Meteorite Northwest Africa 12593.

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Introduction: The formation of cubic zirconia (ZrO_2) requires temperatures exceeding 2370°C, which typical geologica settings do not reach [1]. The presence of cubic zirconia associated with the high-temperature breakdown of zircon in terrestrial impact settings has led to the conclusion that this microstructure foms in superheated impact melts [e.g., 1, 2]. Cubic zirconia has been identified in Apollo samples as a heritage phase within a large ~250 μm baddeleyite (monoclinic ZrO_2) [3] and as sub-micron inclusions within zircon grains [4]. The U-Pb age of the heritage phase cubic zirconia grain in troctolite 76535 from [3] provides evidence of crystallization in an impact melt sheet approximately 4330 million years ago.

We conducted a microstructural survey of baddeleyite grains in lunar meteorite Northwest Africa (NWA) 12593 and discovered multiple grains exhibiting evidence of heritage cubic zirconia structures. Additionally, initial $^{207}Pb/^{206}Pb$ geochronology suggests these grains have crystallization ages of ~3.5 Ga, potentially indicating a large impact during this period.

Sample: NWA 12593 is a fragmental lunar breccia containing numerous clasts, accessory phosphates, and zirconium-bearing phases. We previously presented the initial geochronology of phosphates within this sample, proposing a crystallization age near ~3.48 Ga with a subset of phosphates either having older ~4.33 Ga ages or requiring contributions of initial lead from a KREEP-like reservoir [5]. Some phosphates from this sample have demonstrated elevated $\delta^{37}Cl$ values, making it an intriguing specimen for investigating the volatile history of the Moon [6]. A petrologic study of this meteorite is ongoing, and results will be presented in this meeting by [7].

Methods: EBSD analyses were collected using a JEOL 7900F field emission Scanning Electron Microscopy with an Oxford Instruments Symmetry detector at NASA Johnson Space Center. The data were processed using AztecCrystal. U-Pb and $^{207}Pb/^{206}Pb$ geochronology were obtained using the Cameca ims1290 at the University of California, Los Angeles using the Hyperion II ion source. The analyses employed an O^{-3} primary beam and achieved spot sizes between ~ 5-10 microns. Reference material Phalabowra baddeleyite [8] was used to correct for instrumental fractionation of U and Pb.

Results Out of the 22 baddeleyite grains surveyed with EBSD, 4 grains exhibit complete evidence for phase heritage of a cubic structure in disorientation space (Fig. 1), while an additional 12 grains show either partial evidence for a cubic parent structure or a tetragonal parent. We conducted $^{207}Pb/^{206}Pb$ and U-Pb geochronology analyses for nine baddeleyites in NWA 12593, including the two grains with the best evidence for the phase heritage of cubic zirconia. Analyses of these two grains yield $^{204}Pb/^{206}Pb$ ratios $<10^{-4}$, suggesting no contributions from adjacent phases or inherited inial Pb. The ages of these two grains based on 204Pb/206Pb measurements show agreement within 2σ uncertainty and suggest a crystallization age around or just before 3.5 billion years ago.

Conclusions: The coordinated microstructural and geochronologic investigation of NWA 12593 suggests this sample records evidence of a superheated impact melt sheet ~3.5 Ga. The results of ongoing petrologic study of this lunar meteorite [7] will help better infer the significance of this impact age.

References: [1] Timms N. E. et al. 2017. *Earth and Planetary Science Letters* 477:52-58. [2] Tolometti G. D. et al. (2022) *Earth and Planetary Science Letters* 584:117523. [4] Author J. et al. (2002) *LPS XXXIII*, Abstract #1577. [3] White L. F. et al. (2020) *Nature Astronomy* 4:974-978. [4] Kusiak M. A. et al. (2022) *Contributions to Mineralogy and Petrology* 117:112. [5] Crow C. A. et al. (2022) *LPSC LIII* Abstract #2524. [6] Hayden T. S. et al. (2021) *LPSC LII* Abstract #1550. [7] Richards M. et al. (2023) *86th Meteoritical Society Meeting*. [8-Ref for Phalabowra]

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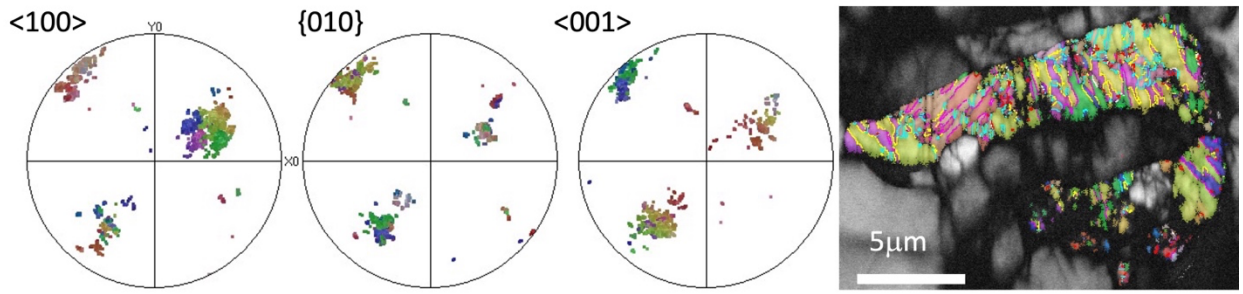

Fig 1. EBSD data for NWA 14259B Badd1 showing evidence of heritage cubic zirconia.