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A Nanoscale Record of Impact-Induced Pb Mobility in Lunar Zircon

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Lunar and terrestrial zircon grains record the early evolution of the Earth-Moon system, and by association, dynamic processes within the early inner solar system. Zircon dates, which provide a lower limit on the age of the Moon [1], can be combined with zircon trace elements and isotope ratios to better understand the initiation, duration, spatial extent and composition of lunar magmatism [2-4]. While zircon remains one of the most robust phases for studying the Moon, debate persists concerning the magnitude, prevalence, and driving forces for Pb mobility in the lunar environment [5].

Atom probe tomography (APT) represents a novel means to characterize elemental and isotopic compositions of minerals on the scale of tens of nanometers. In terrestrial zircons, nanoscale clustering of Pb within single zircons has been linked to transient thermal episodes. When combined with micron-scale U-Pb analysis from secondary ion mass spectrometry (SIMS), Pb isotopes in nano-clusters record the timing of Pb clustering [7,8]. This work applies APT and SIMS to the study of zircon 17B-4, an isolated zircon within the matrix of lunar sample 73235,87. Sample 73235 is a clast-rich aphanitic breccia collected from "light mantle" material on the south side of the Taurus-Littrow Valley during Apollo 17 [9]. The light mantle material is interpreted as landslide deposits from the adjacent South Massif [9,10], and the ^{40}Ar/^{39}Ar plateau age of 3946 ± 95 Ma (2σ) of the breccia matrix [11] (here recalculated using modern decay constants and monitor mineral ages) and has been interpreted to reflect the timing of the Serenitatis basin-forming impact.

SIMS U-Pb analyses on 17B-4 yield ^{207}Pb/^{206}Pb ages between 4338 ± 12 and 4392 ± 12 Ma (2σ); the oldest and most concordant U-Pb analysis (4392 ± 12 Ma, 99% concordant) is interpreted to reflect primary crystallization. The [U] and [Th] range from 156-200 μg/g and 81-115 μg/g, respectively. A series of needle-shaped specimens for APT analysis were prepared from a single FIB (focused ion beam) lift-out taken adjacent to the oldest SIMS analysis (Fig. 1). APT data sets contain a small number of Pb-rich clusters, between 5-10 nm in diameter. The ^{207}Pb/^{206}Pb ratio within individual clusters are statistically identical, with a combined ratio of 1.42 ± 0.07. Using a simple clustering model [7,8], this places Pb cluster formation at 3850 +150/-170 Ma (2σ). This cluster formation age overlaps the ^{40}Ar/^{39}Ar age for the host breccia, and links cluster formation to the Serenitatis impact event.

The in-depth characterization of zircon 17B-4 provides a high degree of confidence that the ^{207}Pb/^{206}Pb age of 4392 ± 12 Ma records primary crystallization, making 17B-4 one of the oldest reliably dated lunar zircons. APT data document the first known occurrence of nanoscale Pb clustering in lunar zircon, and the first ever correlation of Pb clustering to impact processes. This multi-scale characterization of U-Pb systematics represents a novel means to study magmatic and impact processes during early lunar evolution.

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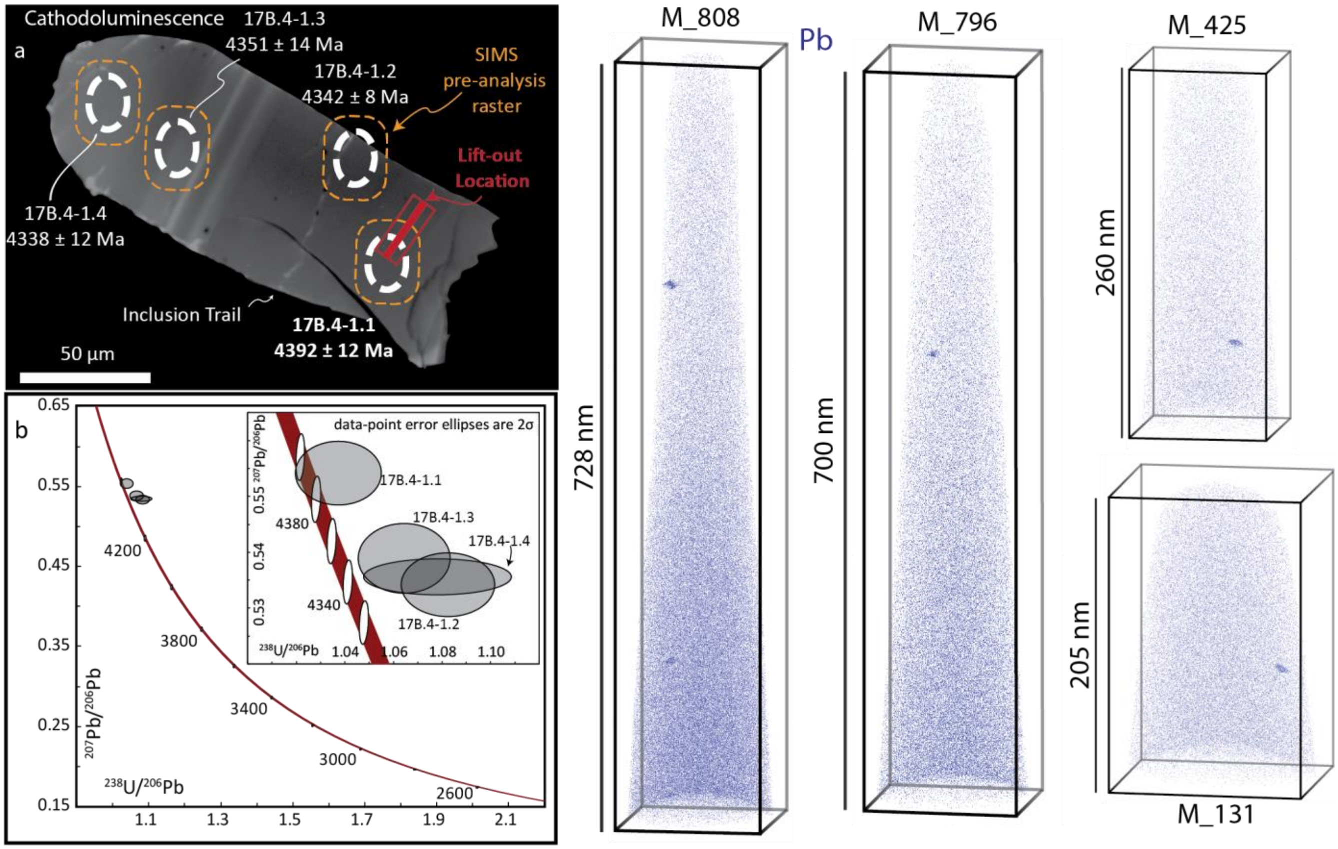

Figure 1: Summary of SIMS U-Pb data, and Pb distributions from APT analyses. (a) Cathodoluminescence image of zircon 17B-4 showing the location of SHRIMP U-Pb analyses, and ^{207}Pb/^{206}Pb ages. (b) Tera-Wasserburg diagram for SHRIMP U-Pb data. (On right): reconstructed APT data sets showing the distribution of individual Pb atoms.