Lunar Phosphates Record Impact Cratering Events at Micro to Nano Scales

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The field of planetary mineralogy has greatly benefited from recent studies of accessory minerals that utilise µm- and nm-scale analytical techniques such as EBSD, APT, TEM and SIMS. Apatite and merrillite have been of particular interest, as they record vital information on the volatile content, U-Pb ages and trace-element composition of various planetary materials. However, the extent to which shock-deformation, pervasive among all planetary materials, affects the distribution of these valuable geochemical tracers is still poorly understood. Here we focus on exploring the U-Pb and Pb-Pb ages of apatite and merrillite in a set of variably shocked lunar rocks, building on previous nanostructural analyses of the phosphates.

We carried out U-Pb and Pb-Pb analyses of phosphates in Apollo 17 samples of the Mg-suite rocks (76535, 76335, 76255, 72255, 78235 and 78236) using the CAMECA 1280 ion microprobe at the NordSIMS facility (Stockholm). In addition, we applied a recently developed approach of conducting high-precision U-Pb and Pb-Pb analyses by ID-TIMS of extracted phosphate grains (Jack Satterly Lab, University of Toronto). For this purpose, individual ~50x50x30 µm crystals of apatite and merrillite were extracted directly from thin sections using a Xe+ plasma FIB.

As determined by SIMS, 207Pb/206Pb systematics of the unshocked or weakly shocked apatite in 76335 and 76335 is undisturbed, implying cooling of the rock below the closure temperature of Pb diffusion in apatite (~450°C) at ~4.2 Ga, ~100 Ma younger than what is interpreted as the rock’s crystallization age. Phosphates that experienced similar levels of deformation but were in proximity or in direct contact with the impact melt in samples 76255 and 72255 show almost complete age resetting (~3.92 Ga). The SIMS determined age of 16 phosphates in sample 76255 is 3922.2 ± 6.7 Ma (2σ) and agrees with the previously published 207Pb/206Pb phosphate ages of impact melt breccias found within the same boulder and was interpreted as the timing of the Imbrium impact. These recrystallized phosphates yield comparable TIMS Pb-Pb ages (3917.8 ± 1.8 Ma and 3921.0 ± 1.3 Ma, 2σ) with significantly lower internal uncertainties than that of the
individual SIMS measurements and may represent multiple impact-events close to the Imbrium event.

SIMS U-Pb analyses of highly shocked phosphates (78235 and 78236) reveal a discordia line with an upper intercept of ~4.2 Ga and a lower intercept of ~0.5 Ga. We interpret this new, younger age as a minor thermal event that reactivated existing shock-induced nm-scale grain boundaries, as visualised by APT, within the apatite population to allow for Pb-loss at ~0.5 Ga. We propose a small crater located near the Apollo 17 landing site as a possible source of this sample.

By correlating micro- to nanostructural characterization with in-situ age systematics we show that apatite and merrillite are powerful thermochronometers that provide a new approach to dating which has the potential to discriminate between temporally similar events. This can greatly aid in unravelling the bombardment record of solar system and be helpful when dealing with samples of limited availability (e.g. space return missions).