DATING PLANETARY PROCESSES AND IMPACT EVENTS USING ACCESSORY MINERALS: PROGRESS AND CHALLENGES. J. R. Darling[1], D. Moser[2] and L.F. White[1], [1]University of Portsmouth, School of Earth and Environmental Sciences, UK (james.darling@port.ac.uk), [2]University of Western Ontario, Department of Earth Sciences, Canada.

Introduction: The accurate dating of Solar System events has been hampered by limited knowledge of how shock metamorphism affects mineral and whole-rock isotopic systems used for geochronology. This has led to large uncertainties in the interpretation of isotopic dates from Martian and Lunar rocks in particular, limiting our ability to place absolute age constraints on lithospheric and impact processes. The implications for our understanding of planetary evolution can be huge. In the case of shergottites, basaltic meteorites from Mars, debate over the effects of shock metamorphism on different isotopic systems used for dating has led to interpreted crystallization ages of individual meteorites that vary by as much as 4 billion years (Gyr; e.g. [1], [2], [3]); a reflection of our inability to resolve, by geochemical methods alone, the severity of mineral age resetting by impact events.

Uranium and thorium bearing accessory minerals have great potential to date these processes. These minerals include zircon ($ZrSiO_4$), baddeleyite (monoclinic ZrO_2) and phosphates (apatite and merrilite). Baddeleyite is a mineral chronometer of particularly great potential due to its widespread occurrence in meteorites (unlike zircon) and sluggish volume diffusion rates for U and Pb, but there is currently little understanding of shock-effects on this phase.

Here we report on recent advances in understanding the micro- to nano-scale effects of shock metamorphism on these phases, particularly for baddeleyite, and their linkage with isotopic disturbance. This has been achieved by combining nanostructural analyses with in-situ isotopic measurements.

Materials and Methods: We are investigating shock effects in a range of planetary, terrestrial and experimental materials, including: (a) the highly shocked shergottite NWA 5298; (b) Lunar anorthositic breccia NWA 2200; (c) variably shocked baddeleyite and zircon bearing samples from the 1.85 Ga Sudbury impact structure, Ontario; (d) experimentally shocked samples incorporating a two-stage light gas gun. This diverse sample set records bulk shock pressures ranging from <2 GPa to >20 GPa, providing a tremendous opportunity to study accessory minerals over a wide-range of shock metamorphic pressure and post-shock temperature conditions.

Our analytical approach combines microstructural tools such as electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM), with in-situ U-Pb isotope analyses by secondary ion mass spectrometry (SIMS) or laser ablation ICP-MS (LA-ICP-MS).

Findings: We have identified a range of new shock-phenomena in baddeleyite, including crystal-plastic deformation, amorphization, fracturing and granulation. In both NWA 5298 (shergottite) and NWA 2200 (Lunar anorthositic breccia), baddeleyite grains from individual polished thin-sections show a wide array of these deformation features, reflecting local variations in shock pressures and waste heat.

SIMS U-Pb isotope analyses reveals variable degrees of age resetting in both samples. For NWA 5298, variable Pb loss (as high as 80 %) can be directly correlated with observed microstructures and with the extent of post-shock zircon rims that are linked to release of Si-rich fluids during quenching of shock melt pockets during transit to space.

These findings, contrary to the results of shock loading experiments [4], indicate that baddeleyite U-Pb ages can be reset under certain shock metamorphic pathways. Furthermore, launch generated zircon rims offer new opportunities to directly date impact events. The combined microstructural and U-Pb data therefore provide a powerful tool for determining both the primary age of the meteorite assemblages and bracketing the time of impact events.

Remaining Questions and Ways Forward: While our findings suggest a predictable linkage between shock micro/nanostructure and U-Pb age resetting in baddeleyite, there are a number of areas for further work that require an interdisciplinary approach: including expertise from materials sciences, experimental shock and isotope geochemistry. These include a proper evaluation of hitherto speculative linkage between transformation and reversion to high pressure phases on the diffusion of U and Pb in ZrO_2, zircon and phosphates, and whether relict micro- to nano-structures from these transformations are preserved. Furthermore, new developments in high-precision, small-volume isotope geochemistry are being explored to capitalize on the opportunity to directly date impact events using launch-generated zircon.

References: [1] Bouvier et al. (2009), *EPSL* 280, 285–295. [2] Nyquist et al. (2001), *Space Sci. Rev.* 96, 105–164. [3] Moser et al. (2013), *Nature* 499, 454–457. [4] Niihara et al. (2012), *EPSL* 341-344, 195–210