Atomic Records of Inner Solar System Impact Processes from U-Pb Dating Phases

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Introduction: Time is of the essence in the reconstruction of planetary processes, and the extremely sluggish volume diffusion rates of elements such as U, Pb, O, Hf and trace elements in the geochronology minerals such as zircon and baddeleyite, together with their resistance to breakdown during shock metamorphism [1], make them ideal recorders of inner Solar System evolution. These micro-minerals, relatively common in planetary crusts and achondrites, can also preserve microstructures diagnostic of impact environments, with zircon sometimes capturing the entire shock loading and unloading sequence [2]. Here we present case studies from the Earth, Moon, Asteroid Belt and Mars illustrating the new records of shock metamorphic processes, ages and environments obtainable from U-Pb geochronology phases.

Methods: The advances we present are made possible by integration of electron nanobeam measurements of orientation and chemical microstructure with isotopic analyses, ideally using *in situ* techniques such as SIMS (UCLA), laser ablation ICPMS (Univ. of Houston), or the relatively new technique of Local Electrode Atom Probe (LEAP) Tomography (CAMECA). Electron nanobeam analyses were performed at the Zircon and Accessory Phase Laboratory (UWO ZAPLab) using a Hitachi SU6600 VP-FEG-SEM with cathodoluminescence (CL) , electron diffraction (EBSD), Energy Dispersive Spectroscopy (EDS) [2], and by atomic resolution STEM (CCEM).

EARTH: A natural laboratory for response of U-Pb and other isotopic systems to shock pressure and heating is the central uplift of the ~250 km diameter Vredefort impact basin of South Africa, where we can examine mineral response across a large shock-metamorphic pressure and thermal gradient from collar to center. Shock microtwins, first discovered in the collar, persist through extreme post-schock heating in the pyroxene hornfels post-impact thermal aureole, sometimes nucleating coarse granules of impact age. Crystallographically controlled planar and curviplanar features, impact melt glass, and pervasive crystal-plastic deformation track the sequence of shock loading, unloading and crater modification [2]. These records survive modern fluvial transport over hundreds of kilometers [3]. Monazite shock microstructures also vary radially from planar features to polycrystalline granular at center [4]. Impact-related Pb loss, age disturbance and plasticity are minor to absent in the outer zone of post-shock heating, and begins approximately at the 800°C isograd [2]. This is a useful template for reconstructing shock histories on other planets.

MOON: Micrograins of zircon and baddeleyite in lunar breccia NWA 2200 [5] exhibit a diversity of microstructures analogous to those in samples from the Vredefort and Ries craters. An example of polystage igneous and impact processes is evident in an anhedral zircon grain, in an apparently undeformed gabbro clast, exhibiting shock microtwin lamellae and crystal-plastic deformation. Our spatially correlated SIMS U-Pb dating are revealing a 400 million year window of early lunar processes.

ASTEROID BELT: Recent SIMS dating of eucrite zircon yield a 50 million year age range interpreted as protracted crystallization from 4.56 Ga [6]. We observe complex CL zoning in a 4.54±0.1 Ga eucrite zircon, as well as crystal-plastic deformation and low-angle grain boundaries, allowing that deformation-assisted Pb-loss could account for variations in U-Pb ratos in asteroidal material.

MARS:. Our microstructural analyses and SIMS dating of shocked, igneous micro-baddeleyites in the highly shocked basaltic shergottite NWA 5298 resolve a longstanding debate in martian geochronology. Our results demonstrate ‘young’ igneous activity on Mars at 187±33 Ma through melting of an ancient ~4 Ga reservoir, and subsequent shock-resetting of some baddeleyite grains during Earthward launch and growth of ‘ejectic’ zircon near quenched melt pockets [7]. Analysis of a recently discovered population of martian regolith zircon, baddeleyite and monazite is underway [8], and it is likely that documentation of their age and microstructure will reveal additional insight into impact phenomena and environments in the inner solar system.

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