A 4.43 Ga MINIMUM AGE FOR MARS-SHAPING IMPACT DEDUCED FROM MICROSTRUCTURAL GEOCHRONOLOGY OF METEORITIC ZIRCON AND BADDELEYITE.

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Introduction: Determining the age of planet-shaping impacts is the first step toward reconstructing the initial conditions of early crustal evolution and potential habitability. To this end the earliest mineral remnants of planetary crusts, specifically accessory and highly refractory phases such as zircon and baddeleyite, are of great value. These two U-Pb geochronometers have been shown to preserve a wealth of microstructural and isotopic information for reconstructing the impact and temperature evolution of crust on Earth [1] and Mars [2,3]. However, challenges to recovering such information from ancient (>4 Ga), nanostructurally complex zircon and baddeleyite in meteorites include small grain size (typically <20 µm) and overprinting shock metamorphic events including launch to Earth. Here we show how these have been overcome with a combination of correlative electron microscopy (e.g., electron backscatter diffraction, cathodoluminescence), targeted focused ion beam sampling of µm-size domains, and atom probe tomography. These techniques can reveal distinctive µm-scale to atom-scale structures created by far-field processes such as extreme thermal metamorphism [4,5]. In the case of Mars, the distinctive hemispheric dichotomy of southern highlands and northern plains is seen as the product of global melting and metamorphism due to an early collision with a moon-sized object [6,7]. Our premise is that a planet-shaping impact event would either destroy the accessory phases of the earliest crust through melting or vaporization, or impart a microstructural signature on survivor crystals. We have characterized such signatures by investigating zircon and baddeleyite from the crater floors beneath the melt sheets of some of the largest known Earth impacts (Vredefort, Sudbury) and then made comparison to a ~4.43 Ga suite of grains known from the martian breccia samples of the Rabt Sbayta family of stones [e.g., 8]. Our most detailed analyses have been on NWA 7475, a polymict breccia containing a mixture of igneous clasts and melt spherules [9].

Method: Correlative electron microscopy was performed at the Zircon and Accessory Phase Laboratory (ZAPLab) at the University of Western Ontario using a Hitachi SU-6600 FE-SEM. Sample preparation and atom probe tomography was carried out with LEAP 4000 and 5000 instruments at CAMECA laboratory in Madison, WI.

Results: Vredefort and Sudbury impact samples reveal nanoclustering of Pb in zircon and Fe in baddeleyite [10], respectively, along with dislocation loops decorated with trace elements (Figure 1). Impact-related Pb-loss can also be documented within nano-scale domains of the fractured crystals[10]. These characteristics as well as shock-related recrystallization are so far absent in ~4.43 Ga martian minerals from the Rabt Sbayta family of breccia samples such as NWA 7475, which instead show younger nanodomains with introduced Cl and Mg. The general absence of high temperature thermal and shock metamorphic effects in the early Mars grains indicates that very ancient, low-shock crustal domains persist in the modern highlands. Moreover, if thermal models of planet-shaping impact processes are correct then the preservation of essentially unshocked igneous zircon with concordant ~4.43Ga U-Pb age serves as a minimum age for the catastrophic event that created the Mars hemispheric dichotomy, consistent with the >4.25 Ga age estimated from crater counting [11]. This is one example of the new insights into planetary evolution offered by this relatively non-destructive approach to meteoritic accessory minerals.

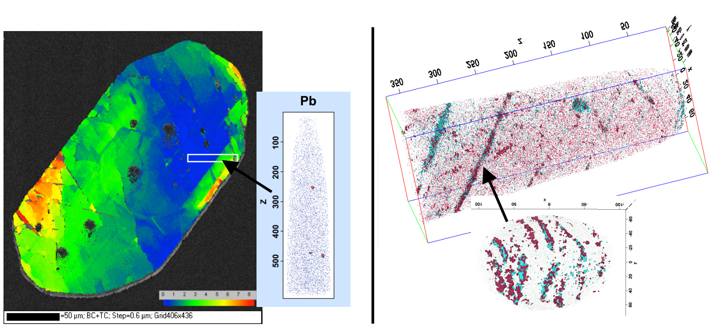

Figure 1. Earth examples of nanostructural features created by high-temperature shock metamorphism. Left; EBSD and atom probe (APT) analysis of a 200 µm zircon from the the Vredefort impact [1] showing Pb clustering. Right; Atom probe tomography of baddeleyite from the footwall of the Sudbury melt sheet [10], showing nanostructures of Fe (red) and Si (blue) in planar feature. Scale units of APT reconstructions are in nanometres.

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