SHOCK-METAMORPHOSED ZIRCONS FROM THE ACRAMAN IMPACT STRUCTURE (SOUTH AUSTRALIA) - TRACERS OF MULTI-STAGE IMPACT CRATER EVOLUTION.

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Introduction: With an estimated original diameter of ~90 km [1], the deeply eroded Acraman impact structure (South Australia), set in ~1.6 Ga volcanics of the Gawler Ranges (mainly the Yardea Dacite), is one of Australia's largest impact structures. Distal impact ejecta in the Bunyeroo Formation exposed in the Flinders Ranges and the Dey Dey Mudstone in drill cores from the Officer Basin stratigraphically constrain the impact age to roughly ~580 Ma (Ediacaran) [1,2]. Compared to the extensive work on the ejecta layer, less work has been done on the autochthonous melt rock that occurs in the remote uplifted central part of the Acraman impact structure, although major uncertainties remain on the exact age of the impact [2,3]. The melt rock exhibits different transitional subtypes in terms of matrix crystal size and clast content. The main constituents of the rock are spinifex-textured albite, K-feldspar, quartz, matrix hematite, Ti-magnetite, vesicle-filling zeolites [2-4], and accessories (e.g., barite and zircon). $^{40}Ar/^{39}Ar$ dating of the melt rock yielded plateau alteration ages around 444 Ma [3,4].

Analytical Methods: After a field trip to Lake Acraman in April 2012, several hundred zircon grains were recovered from ~2 kg of the melt rock using Frantz magnetic and heavy mineral separation. Petrographic and preliminary geochemical studies on 3D and polished mineral mounts were performed using a VEGA3 TESCAN scanning electron microscope (SEM) equipped with a panchromatic cathodoluminescence (CL) detector and an X-Max 50 silicon drift EDS system at the Centre for Microscopy, Characterisation and Analysis (CMCA) at UWA. In addition, zircons were analyzed using a Sensitive High Resolution Ion Micro Probe (SHRIMP) II facility at the John de Laeter Centre at Curtin University in the quest for a first precise and accurate age for the Acraman impact.

Shock Metamorphism: Two major populations of zircons could be observed in the Acraman melt rock: firstly, smaller (~100 µm on average) and virtually crystal-clear zircon crystals with shock metamorphic planar microstructures; and secondly, larger (~200 µm on average) zircon grains partially to completely transformed into granular aggregates of zircon crystallites ~1 µm in size. Secondary electron and SEM-CL imaging reveals that the 'inherited' shocked magmatic zircons commonly show multiple sets of non-planar to planar microstructures and that these grains have largely retained their original internal zoning pattern (Fig. 1A-B). In contrast, the granular zircons have largely to completely lost their primary magmatic fabric, commonly lack planar microstructures, and rather appear as cryptocrystalline granular masses (Fig. 1C). Vesicles and globular domains of silica occur in some of the granular zircons, and transitional types still exhibit relict patches of their zoned magmatic progenitor grain (Fig. 1D). Similar shock features were earlier described in impactites from other terrestrial impact structures, such as Manicouagan and Sudbury [5], the Ries crater, Popigai, Chicxulub [6] and the related K/Pg boundary ejecta [5], Araguainha [7], and Vredefort [8,9].

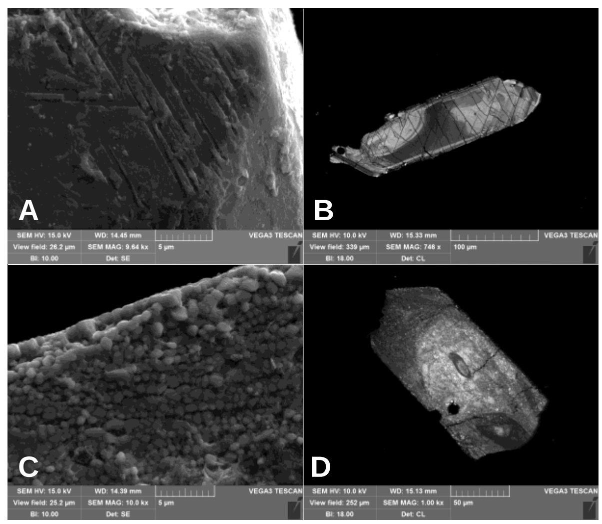

Fig. 1: Shock metamorphic features in the Acraman zircons. **A**: Grain domain with planar microstructures (secondary electron image; SEI); **B**: Shocked zircon with planar microstructures (SEM-CL); **C**: Granular-textured grain (SEI); **D**: Granular zircon with relict patches of magmatic zoning and vesicle (SEM-CL).

Associated 'Exotic' Phases: About one third of the impact-metamorphosed Acraman zircons exhibit small (≤10 µm) crystals locally intergrown with the host zircon and/or adherent to the mineral surface (Fig. 2A-D). SEM and preliminary EDS analyses suggest that these crystals represent exotic Co-Cr-Ni-Fe (~50-80 wt% in total) phases with elevated contents in Mo and Mn and a high reflectance under incident light (Fig. 2A-B); microcrystalline barite (Fig. 2C); micro-nuggets of native gold (Fig. 2D); and a cluster of crystallites of probably native tungsten.

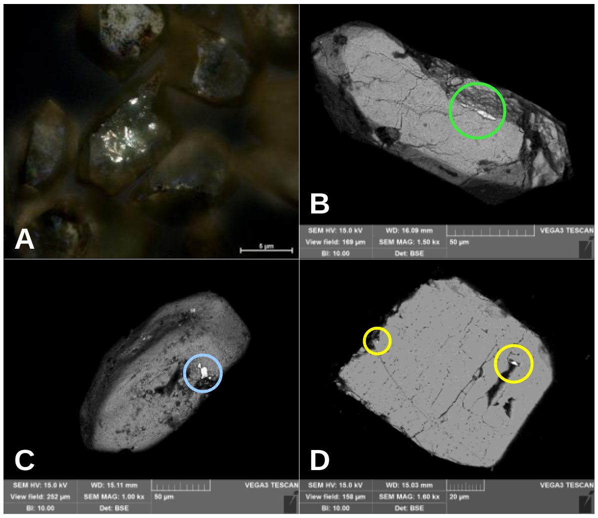

Fig. 2: Exotics in the Acraman zircons. **A**: Co-Cr-Ni-Fe phases (bright; reflected light); **B**: Co-Cr-Ni-Fe phase (green circle) growing on the zircon surface (backscattered electon image; BEI); **C**: barite (blue circle; BEI); **D**: tiny gold nuggets (~5 µm) inside a granular zircon fracture (yellow circles; BEI of polished mount).

U/Pb Systematics: Recent SHRIMP dating of both the 'crystalline' and granular Acraman zircons yielded a complex age dataset (Fig. 3), with a discordant array of U/Pb apparent ages within a range between ~1.6 Ga (inherited Yardea Dacite crystallization age) for most of the moderately shocked zircon crystals and apparent ages as young as ~330-470 Ma for the intensely shocked, granular, zircons. Only a few of the older magmatic zircon grains yielded concordance. Due to a likely post-impact thermal event [3,4] as a potential trigger for Pb loss, the array does not define a statistically robust discordia line and lower intercept 'impact age' value and is, therefore, difficult to interpret reliably in terms of U/Pb geochronology.

Discussion and Conclusions: The Acraman zircons display the typical structural features generated during different levels of progressive shock metamorphism, ranging from the lower and intermediate degrees of shock that produced subplanar microcracks and single and multiple sets of planar microstructures to the complete transformation of the proto-crystal into granular grains. Further micro-XRD analyses in search for impact-generated baddeleyite and reidite in the zircons (e.g., [6]) are envisaged.

The nature of the rather abundant but exotic Co-Cr-Ni-Fe-rich microcrystals inside and adherent to the zircons (Fig. 2A-B) is still enigmatic. As the impact-metamorphosed zircons were probably floating as solid 'seed crystals' in the hot Acraman impact melt, we hypothesize that these exotic phases, notably rich in siderophiles and chromium, might carry – partially or entirely – a distinct extraterrestrial component inherited from the Acraman impactor, probably a chondrite [10]. If true, this process could be considered as an early-stage, syn-impact, phenomenon. This hypothesis is supported by Co, Cr, and Ni contents that are only in the lower ppm range for the shocked and unshocked Yardea Dacite [2] and the difficulty of precipitating these types of phases by magmatic fractional crystallization alone. On the other hand, zeolites in melt rock vesicles, groundmass hematite [3], barite, particles of gold in fractures of the shocked zircons (Fig. 3C-D), as well as resolvable amounts of molybdenum in the Co-Cr-Ni-Fe phases, suggest an underexplored impact-induced hydrothermal system [11] at Acraman and the remobilization of target-hosted metals. Strong remobilization and K-metasomatism is indicated by a high content (~16 wt%) in K_2O in the melt rock matrix [3], as opposed to ~4-7 wt% K_2O in the Yardea Dacite [2].

The anomalous young ~330-470 Ma U/Pb ages for the granular zircons suggest that at least these strongly shocked zircon grains were reset by the Acraman impact. However, their apparent ages are in conflict with the impact stratigraphic age constaint (~580 Ma) [1] and they were obviously affected by an additional unknown thermal event as the cause for Pb loss in post-impact time (compare $^{40}Ar/^{39}Ar$ data in [3,4]). The sequence of multiple events recorded in the Acraman zircons highlights the complex syn- to post-impact evolution of this large impact structure and underlines the versatility of zircon in impact research.

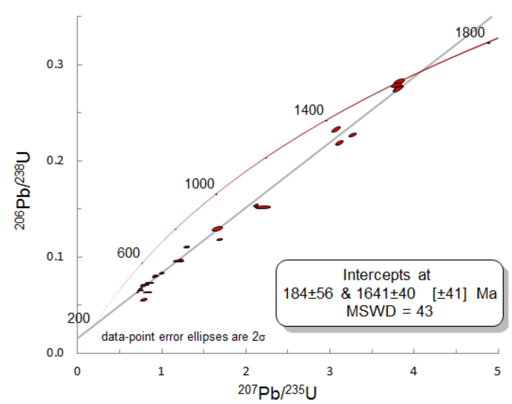

Fig. 3: SHRIMP U/Pb data obtained for the Acraman zircons.

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