NEW ZIRCON SHOCK PHENOMENON FOR DATING AND RECONSTRUCTION OF LARGE IMPACT BASINS REVEALED BY ELECTRON NANOBEAM (EBSD, CL, EDS), U-Pb, AND (U-Th)/He ISOTOPIC ANALYSIS OF THE VREDEFORT DOME.

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Introduction: Refractory, U-bearing accessory phases such as zircon and monazite are excellent candidates for surviving metamorphism, and recording large-scale melting, produced by a period of Late Heavy Bombardment. Such early planetary residua are likely to be detrital [1], necessitating age and microstructural interpretations out of primary context. To improve our understanding of primary spatial relationships of zircon microstructure and U-Pb isotope response in large craters, we present new microstructural and ID-TIMS data on zircon microcrystals from bedrock across ~65 km radial distance of the deeply eroded collar and central uplift of the 2.020 Ga [2] Vredefort impact basin of South Africa, the largest recognized terrestrial impact basin.

Background: In order to explore the relationship between shock-induced microstructure, heating and Pb-loss, shocked zircon was analyzed from a pre-impact intrusion in the sedimentary collar of the Vredefort dome and from the high temperature post-impact granofels zone in its core; zones of relatively 'cool' and 'hot' impact heating of ~200K and 2000K, respectively [3]. The results reveal several mechanisms for impact-driven Pb-loss as well as important new shock-related features that may enable more accurate dating and reconstruction of cratering processes.

Methods: Electron beam analyses were collected with a Hitachi SU6600 variable pressure, analytical field emission gun SEM at the Zircon and Accessory Phase Laboratory (ZAPLab), University of Western Ontario. Colour Cathodoluminescence (visible + UV CL) images were collected with a customized Gatan ChromaCL detector system. Micro-structural data were collected with an Oxford Nordlys EBSD system with step sizes ranging from 50 nm to 600 nm. A dynamic EBSP noise reduction routine was executed with 7 frames, 4x4 binning, and a high gain. Post-analysis noise reduction processing was not applied to any of the datasets. Elemental identification and mapping was conducted by X-ray Energy Dispersive Spectrometry (EDS) with an Oxford X-Max 80mm^2 silicon drift detector.

Results and Discussion: Integrated microstructural (EBSD, CL) and isotopic measurements (U-Pb, (U-Th)/He) of zircon from the rim and center of the ~80 km central uplift of the 2020±3 Ma Vredefort impact basin reveal a microstructural progression corresponding to detailed stages in crater evolution. Shock microdeformation (≥20 GPa) failed to cause Pb-loss in granitoids (Schurwedraai-Baviaanskrantz), which are at a radial distance of 25 km, with single zircon ID-TIMS data extending between a primary age of 2077±11 Ma and a secondary Pb-loss event at 1.0 Ga. The latter reflects Kibaran igneous activity across the region based on new ages between 1.110 Ga and 1.021 Ga. Pervasive microstructures include planar fractures, some of which are twin lamellae in orientation of 65° about [110] (Fig. 1).

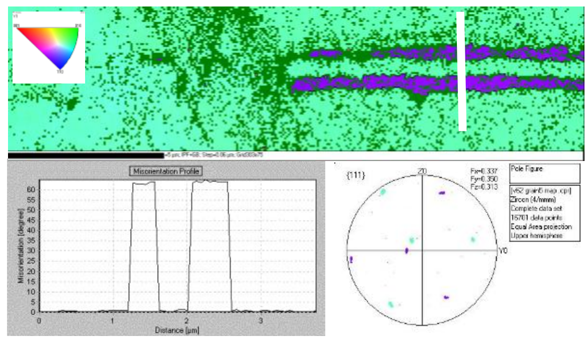

Figure 1: EBSD crystal orientation map of a 20 µm by 8 µm area of a zircon's planar feature from a collar zone syenite, which reveals a doublet of zircon lamellae (purple) in twin orientation relative to the main crystal (white vertical bar = misorientation profile location).

Archean zircons from the core granofels zone (ILG gneiss) also display planar fractures, curviplanar features, shock twin lamellae as well as amorphous inclusions of alkali aluminosilicate glass along planar features. The inclusions are interpreted to be partial melt of the host rock granitoid that was injected and trapped during shock. Shocked zircons entrained in impact melt bodies feature these same types of inclusions (Fig. 2).

The Archean zircons also contain impact-age crystallites in twin orientation relative to the host crystal (Fig. 2). Syn-impact Pb-loss mechanisms include thermal and melt-assisted diffusion aided by crystal plastic deformation and internal recrystallization during the crater modification phase. The onset of impact-driven Pb-loss lies 15 km from the center at present level of erosion and coincides with impact-elevated temperatures in the range 700°C to 900°C.

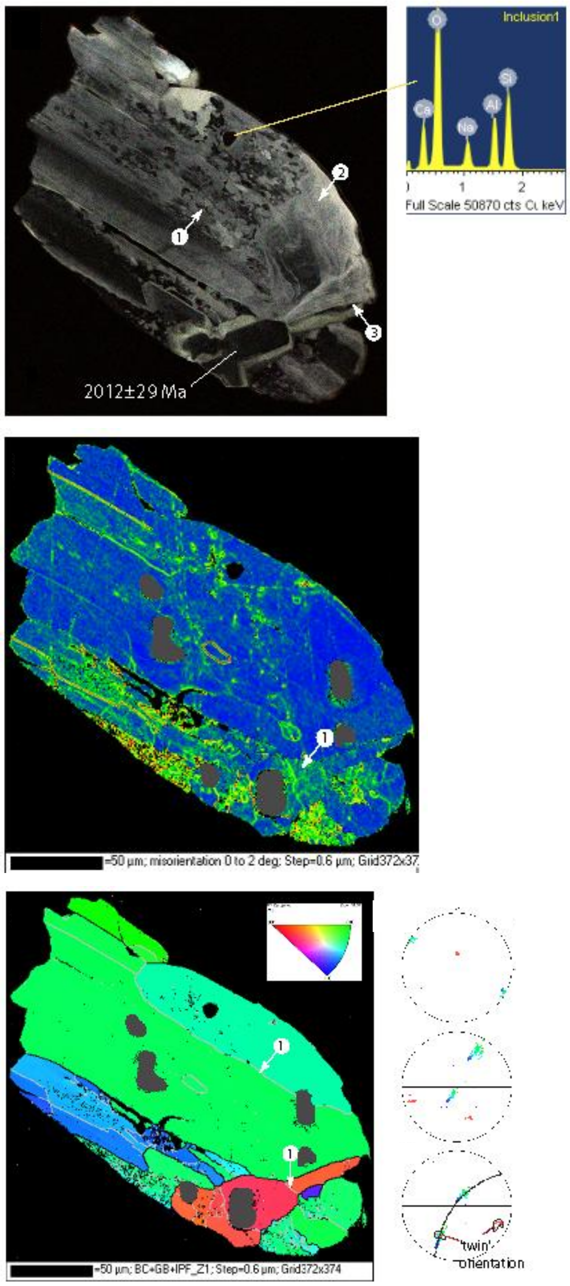

Figure 2: Polished section of a shocked zircon xenocryst in impact melt: Top, SEM-CL textures indicate relict primary zoning and pervasive secondary REE diffusion are spatially related to an unshocked crystallite. SHRIMP spot age indicates that the crystallite's age is equal to that of impact. EDS spectrum (right) of a glassy inclusion indicates a composition of Ca, Na, Al, Si and O; Middle, EBSD map showing local misorientation of > 2° based on comparison of 3x3 nearest neighbours. Networks of very low angle boundaries throughout the grain are interpreted to be the result of crater modification; Bottom, EBSD Inverse Pole Figure map and corresponding stereonet (right) showing c-axis of crystallites (red/orange) normal to the polished surface, whereas c-axis of the main grain lies in the plane of section. Note asterism of poles about the c-axis is likely due to glide during crater modification stage.

The shock metamorphic progression represented by zircon microfeatures across the central uplift is listed here in chronological order [4]: A) planar features in {100} and {102} orientation during initial compression, B) in the 'hot-shock' domain only, curviplanar features or 'shock veins' hosting glassy inclusions of partially melted host rock, C) twin lamellae in orientation of 65° about [110], synthetic twins (>40 GPa) attributed to shock wave rarefaction [5], D) crystallite nucleation on twins during post-shock heating, and E) crystal plastic deformation and crater modification in the partially melted core. Single igneous zircons from a 2019±2 Ma foliated norite in the central dome yield an average (U-Th)/He date of 922±61 Ma placing a limiting age for uplift and exposure of the present surface. This and the distribution of shock features suggest that crater size may be larger, or erosion level shallower, than current estimates.

Conclusions and Future Directions: New zircon shock features reported here include: high pressure twin lamellae in natural samples; the first recognized inclusions of partial melt of the crater floor entrapped along planar features – a powerful new tool for provenancing impact target compositions; twin-nucleated crystallites within zircon from superheated impact melt that may be a precursor to granular textures; and plastic deformation of pre-impact and impact-age crystallites reflecting subsolidus ductile adjustments of the central uplift during the crater modification stage. Impact-induced Pb-loss mechanisms are restricted to the 'hot shock' environment within 15 km of the crater's center and temperatures of between 700°C and 900°C depending on assumed level of erosion. The diverse microstructural features are robust throughout the stages of shock metamorphism and geographically correlated, making them valuable for crater reconstructions using similar techniques on detrital and meteoritic zircons.

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