SUPERHEATED MELT AT WEST CLEARWATER IMPACT STRUCTURE: EVIDENCE FROM CUBIC ZIRCONIA.

N.S. Chinchalkar[1], G.R. Osinski[1], T.M. Erickson[2], C. Cayron[3]. [1]Department of Earth Sciences, University of Western Ontario, London, N6A 5B7, Canada, [2]Jacobs JETS, ARES division, NASA Johnson Space Center, Mailcode XI3, Houston, TX, 77058, USA, [3]Laboratory of ThermoMechanical Metallurgy (LMTM), PX Group Chair, École Polytechnique Fédérale de Lausanne (EPFL), Rue de la Maladière 71b, 2000Neuchâtel, Switzerland

Introduction: The evolution and emplacement of impact melt in crater environments remains poorly constrained in terms of initial melt temperatures, melt transport, and thermal history. Recently, the role of accessory minerals as geothermobarometers has gained popularity in impact cratering studies due to the refractory nature of these minerals and their ability to record extreme temperature and pressure conditions [*e.g.*, 1, 2]. Research by [1] identified the former presence of cubic zirconia, an extreme temperature zirconia polymorph, in impact glass from Mistastin Lake impact structure. Further evidence of cubic zirconia at Mistastin Lake impact structure was reported by [3]. Stability of the different polymorphs of zirconia is dependent on the temperature and pressure conditions, for example, formation of cubic zirconia requires temperature above 2370℃ at atmospheric pressure, whereas tetragonal ZrO_2 is stable between 1200℃ – 1673℃, and baddeleyite, the monoclinic form, is stable below 1200℃ [*e.g.,* 1,3,4,5]. The phase heritage approach implemented by [1] allows for identification of the original parent cubic zirconia by quantifying crystallographic orientation relationships between parent/daughter zirconia polymorphs. To our knowledge, Mistastin Lake is the only terrestrial crater with known evidence for precursor cubic zirconia. In this work, we conducted *in situ* analyses on zircon grains in impact glass from the West Clearwater Lake impact structure, Canada. Here we report the first discovery of cubic zirconia, a high temperature polymorph of ZrO_2 that formed as a product of zircon dissociation in superheated impact melt from that site. We also document the first occurrence of former reidite in granular neoblasts (FRIGN) zircon in West Clearwater impact glass.

West Clearwater Lake impact structure: West Clearwater Lake impact structure is a ~36 km diameter [6] complex crater located in Quebec, Canada. The impact structure formed in target lithologies of the Archean Canadian Shield, mainly composed of granite, granodiorite and monzonite, with some minor mafic lithologies [6,7]. The impactite stratigraphy at West Clearwater Lake consists, from bottom to top, of fractured basement, monomict lithic breccia, impact melt bearing lithic breccia, clast rich fine grained impact melt, clast poor fine grained impact melt, and clast poor medium to coarse grained impact melt [8].

Methods: We investigated 5 thin sections total from 2 impact glass samples collected from the Tadpole islands in West Clearwater Lake. Electron microprobe analyses were conducted at the Earth and Planetary Materials lab included Backscattered electron (BSE) imaging and Energy Dispersive Spectroscopy (EDS) mapping of whole thin sections to locate the zircons in each thin section. Close up BSE imaging of individual zircons was done for analyzing zircon microtextures. Quantitative Wavelength Dispersive Spectroscopy (WDS) was applied for determining matrix composition of the glass. Crystallographic orientation maps and phase maps were obtained from Electron backscatter diffraction (EBSD) analyses conducted at the Astromaterials Research and Exploration Science division of Johnson Space Center.

Impact glass composition: The two samples are petrographically similar, with a clast content of up to 30% and dominant clast composition being quartz and feldspar crystals. The matrix of both the samples is holohyaline, and reaction rims around boundaries are common due to interaction of clasts with the surrounding melt. The samples are chemically homogenous, and their trachyandesitic compositions contain no significant differences between the two samples.

Zircon Microtextures: A total of 48 and 51 zircons were identified in each sample, respectively. Both glass samples contain a diverse array of zircon microstructures, including fully dissociated and partially dissociated zircons, granular zircons, and grains that do not display diagnostic shock features.

Cubic zirconia: One completely dissociated zircon grain in sample 1 (Fig. 1A) contained granules that indexed as monoclinic zirconia, i.e., baddeleyite in the EBSD phase map (Fig. 1B). The {100} pole figures of this grain (Fig. 1C) display evidence indicative of transformation of parent cubic ZrO_2 to daughter monoclinic ZrO_2, potentially by a two-stage transformative mechanism [1]. Reconstruction in ARPGE [9] generated parent cubic zirconia in the grain (Fig. 2A). We further confirmed the presence of this cubic precursor by comparing the theoretical parent-daughter orientation relationships constructed by GenOVa [10] to those observed in our grain (Figs. 2B, C). No evidence for a cubic precursor was identified in the other glass sample.

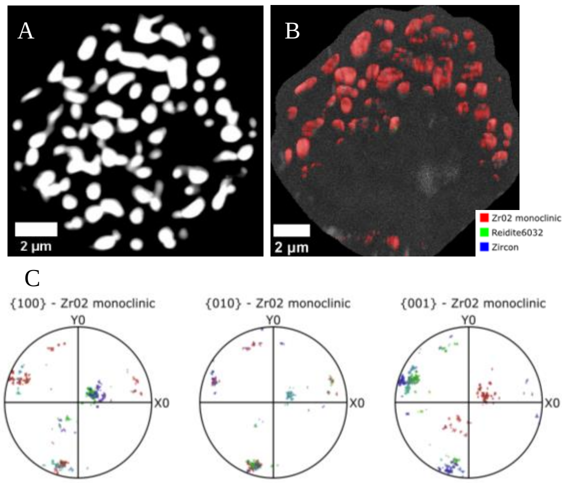

Fig. 1: A: BSE image of dissociated zircon grain in impact glass; B: EBSD phase map of the grain; C: Upper hemisphere pole figures.

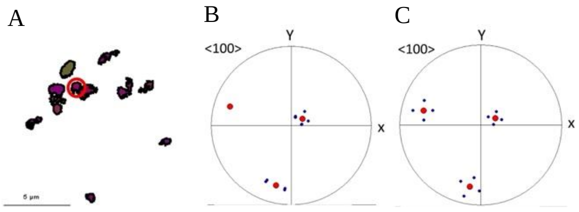

Fig. 2: A: Reconstructed parent cubic grains in the zircon in Fig. 1. B: Observed parent-daughter orientation relationships; C: theoretical parent daughter orientation relationships generated by GenOVa [10].

FRIGN zircon: Figure 3A shows a granular zircon with 90° misorientation about <110> (Fig. 3B), and alignment of dominant clusters between high angle misorientation plot with {110} pole figures (Figs. 3C and 3D). These orientation relationships are distinctive indicators of reversion of reidite to zircon [2]. A total of eight such FRIGN zircons (4 in each sample) were identified in this work.

Discussion: We have documented the first incidence of precursor cubic zirconia and FRIGN zircon at the West Clearwater Lake impact structure. Prior to our work, the presence of former cubic zirconia had only been documented in impact glass from Mistastin Lake impact structure [1]. Our report makes West Clearwater impact structure the second known terrestrial crater with evidence of cubic zirconia. These phases can be used to derive initial melt temperature and subsequent melt evolutionary pathways as the stability fields of zircon and zirconia have been constrained experimentally [9]. Formation of cubic ZrO_2 requires temperatures above 2370°C at ambient pressures [1] and the presence of FRIGN provides a shock pressure estimate of above 30 GPa, which is the minimum threshold for reidite formation.

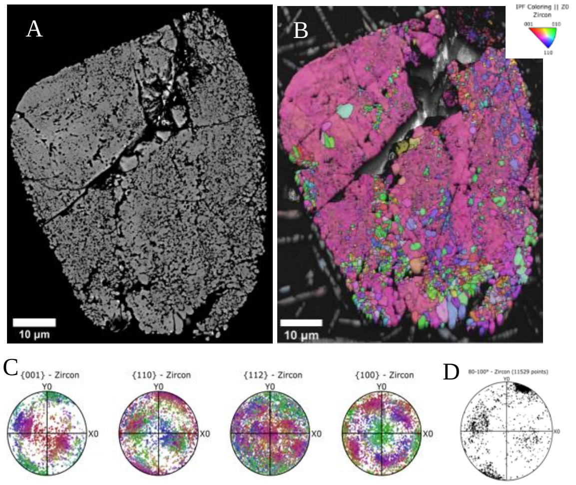

Fig. 3: FRIGN zircon. A: BSE image of granular zircon grain; B: EBSD crystallographic orientation maps of the zircon in inverse pole figure (IPF) colour scheme. C: Lower hemisphere pole figures; D: high angle misorientation plot.

Preservation of these extreme temperature/pressure indicators is facilitated by rapid cooling of the glass, as evidenced by the holohyaline matrix, since a longer residence time of the zircons in superheated melt would have erased the orientation relationships [*e.g.,* 3]. The occurrence of highly shocked and unshocked zircon grains in the glass samples underscores the complex nature of impact melt cargo in impact crater environments. We attribute the zircon microstructural diversity in the samples to entrainment of the grains in the melt at different times during the evolution of the transient cavity. Zircon grains showing high temperature dissociation, including the precursor cubic zirconia grain, would be the earliest to be entrained in the superheated melt, followed by the FRIGN zircons, and the unshocked zircons arriving in the later stages when the melt had cooled below 1678° C, the minimum temperature required for zircon dissociation [9]. Our work, along with previous reports on former cubic zirconia in impactites [1,3] suggests that evidence of impact melt superheating may be more pervasive than previously understood.

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