THERMAL HISTORY OF CHICXULUB'S PEAK RING - CONSTRAINTS FROM ZIRCON U-Pb AND (U–Th)/He DOUBLE DATING. C. Rasmussen[1,2]; D. Stockli[2], R. Chatterjee[2]; A. E. Pickersgill[3,4], S. P. S. Gulick[1], M. Schmieder[5], D. A. Kring[5]; A. Wittmann[6]; C. Ross[2]; G. Christeson[1], S. Tikoo[7], L. Xiao[8]; J. V. Morgan[9], and the IODP Exp. 364 Science Party. [1]Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, 10100 Burnet Rd, Austin, Texas 78758 USA. [2]Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, 23 San Jacinto Blvd & E 23rd St, Austin, TX 78712; [3]School of Geographical & Earth Sciences, University of Glasgow, Gregory Building, Lilybank Gardens, Glasgow G12 8QQ, U.K.; [4]NERC Argon Isotope Facility, Scottish Universities Environmental Research Centre (SUERC), Rankine Avenue, East Kilbride G75 0QF, UK, [5]Center for Lunar Science and Exploration, Lunar and Planetary Institute, Universities Space Research Association, Houston TX 77058; [6]Eyring Materials Center, Arizona State University, 300 E University Drive, Tempe, AZ 85257-7205; [7]Department of Geophysics, Stanford University, 397 Panama Mall, Stanford, CA 94305 USA; [8]Planetary Science Institute, China University of Geosciences, Wuhan, China; [9]Department of Earth Science and Engineering, Imperial College London, SW7 2BP, UK. (crasmussen@utexas.edu).

Introduction: Disentangling the thermal evolution of impact craters and their targets is often challenging due to complex alteration histories that stem from multi-phase thermometamorphic activity, encompassing pre- and post-impact thermal events and the impact itself. Specifically, many impact craters (~70 out of 130 craters on Earth) hosted subsurface hydrothermal systems [1]. By introducing a heat source (such as the passage of the shock wave, impact-induced melting, and the uplift of rocks with higher temperatures) and the subsequent interaction of those heated materials with H_2O in the target allows for those systems to evolve [2]. Crater hydrothermal systems have received growing attention since it has been hypothesized that the impact-induced increase in porosity and permeability in combination with long-lasting (~1 to 2.3 Myr) hydrothermal activity at temperatures ~300–100 °C might facilitate pre-biotic chemical reactions or even the evolution of life [1-5].

In order to better understand the role of impact cratering for planetary surface evolution and habitats, it is imperative to improve our understanding of the thermal evolution of those structures. Zircon chronometers can reveal (partial) age information from multiple thermal events preserved within an individual crystal, including the time of crystallization and post-formation thermal episodes including impact events [6,7].

The large (~200 km wide) Chicxulub impact crater, associated with the K-Pg boundary and mass extinction event, also hosted a hydrothermal system [e.g., 4,5,8]. In 2016, the peak ring of the Chicxulub crater was drilled (Hole M0077A; 21.45°N, 89.95°W) by the International Ocean Discovery Program (IODP) – International Continental Scientific Drilling Program (ICDP) Exp. 364. A total of 829 meters of continuous core sections were recovered, including ~130 m of impactites (clast-poor melt sheet topped by reworked suevite), that overlay the predominantly granitoid basement (Fig. 1A) [8]. Hydrothermal alteration has been reported from samples of previous coring projects (Yucatán-6 and Yaxcopoil-1 (Yax-1) [e.g., 9,10]), but also from the Exp. 364 cores, from which minerals representing high-temperature (Calcium-Na and K-metasomatism) and low-temperature conditions (e.g., clay alteration and zeolites) have been described [5].

Building on previous work on the IODP Exp. 364 cores, we seek to further constrain the thermal evolution of Chicxulub impact crater by employing zircon multi-proxy chronometry, allowing us to account for the high- and low-temperature conditions within the peak ring via radioisotopic analyses.

Material and Methods: We extracted zircon from two samples from IODP Exp. 364 core, one suevite (89-R-1), and one melt-bearing breccia (45-R-1) (Fig. 1A). First, each crystal surface was imaged using a JEOL 6490LV scanning electron microscope in low vacuum mode and without carbon coating. Zircon crystals showing no apparent virtual disturbance and an adequate size (>50 μm diameter) were chosen for the radioisotopic analyses (Fig. 1B).

Each individual zircon crystal (15 total) was analyzed twice: (1.) with aid of Laser Ablation Inductively Coupled Plasma Mass Spectrometry using a Photon Machines 193 nm Analyte G2 excimer laser-ablation system with large-volume Helex sample cell, coupled to a Thermo Scientific Element2 HR-ICP-MS, we obtained U–Pb ages (shallow pit [continuous ablation for 15 sec.] and small pit [25 μm spot]); and (2.) by bulk grain analyses with aid of laser-heating and dissolution techniques, He ages were acquired. The zircon crystals were heated and degassed under ultra-high vacuum and total He concentration was measured on a quadrupole mass spectrometer. Completely degassed grains (99%) were dissolved with a combination of Hf and HNO_3. The dissolved samples were analyzed on a Thermo Scientific Element2 ICP-MS for absolute U, Th, and Sm concentrations. All analyses were conducted at the University of Texas at Austin (Electron Microbeam Laboratories & UTChron facility).

Results: Our analytical approach of 'double dating' reveals that the zircon U–Pb system preserves ages ranging from ~620 to 340 Ma, whereas the (U–Th)/He system yielded ages ranging from ~260 to 50 Ma (Fig. 1C). Measured Uranium concentrations for the individual crystals range from 70 to 595 ppm (Fig. 1D).

Discussion: Applying two different geochronometers to the same zircon crystal further constrains the crystallization and thermal history of the Chicxulub peak ring. The zircon U–Pb system records ages within a range that reflect mainly the age of the Yucatán basement (Maya block), possibly linked to the pan-African orogenic cycle [11]. One crystal yielded a Carboniferous U–Pb age. Similar ages were previously reported from the IODP Exp 364 core and seem to be linked to regional arc magmatism [12] (*see also Ross et al., (2019) this volume*). Therefore, in the case of our dataset, U–Pb ages were not reset by the impact but provide information about the time of crystallization allowing us to identify the provenance of those zircon crystals, while also demonstrating that the temperatures within the impactites overlying the peak ring did not exceed ~700 °C for a prolonged time (<1 Myr) [13].

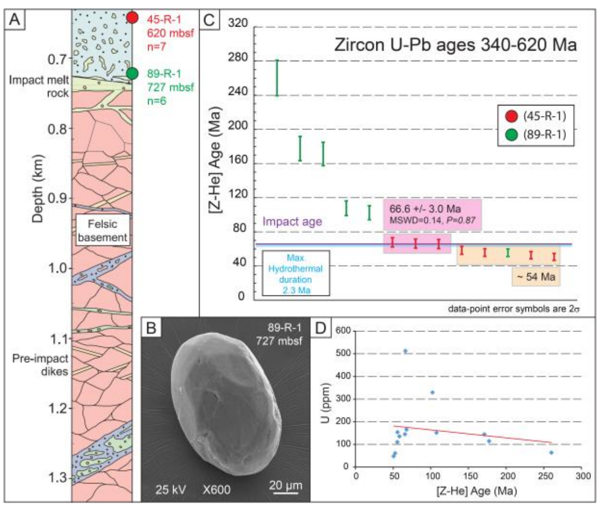

Figure 1: (A) Stratigraphic section of IODP Exp. 364 core (sample locations indicated) [8]; (B) Example of zircon crystal picked for 'double dating' approach; (C) Summary of U-Pb and (U-Th)/He results; and (D) (U-Th)/He) ages plotted vs. U concentration.

In contrast, the (U–Th)/He ages reflect the cooling history at temperatures of ~170 to 190 °C [7]. Several pre-impact ages are preserved that might be linked to the opening of the Gulf of Mexico [11] and/or to partial age resetting [6]. The Chicxulub impact age is well constrained (66.038 ± 0.098 Ma [14]) and three (U-Th)/He results form an age cluster possibly reflecting the time of impact (66 ± 3 Ma, Fig. 1C). Due to the relatively high analytical uncertainty associated with the (U–Th)/He method it cannot be resolved whether this age reflects the time of impact or post-impact hydrothermal overprint.

Based on radioisotopic analyses, the lifetime of hydrothermal activity in medium and large sized impact structures (e.g., Lappajärvi and Sudbury), may last for ~1 Myr [e.g., 15,16]. Numerical modeling suggested the Chicxulub hydrothermal system lasted for ~1.5 to 2.3 Myr [4]. In contrast, our (U–Th)/He ages indicate that the temperatures inside the peak ring remained elevated for a prolonged period of time, as indicated by ages clustering around 54 Ma (Fig. 1C). Prolonged hydrothermal fluid flow might facilitate pre-biotic chemistry or the habitability of crater subsurfaces (*see also Pickersgill et al., (2019) this volume*). However, post-impact resetting due to a currently unidentified thermal event cannot be ruled out and further low-temperature geochronology is necessary to constrain the post-impact thermal history.

Further, our data shows that, even within the same sample, variable ages can be obtained which might indicate that hydrothermal fluid flow was rather heterogeneous within the peak ring. In summary, the thermal history of the Chicxulub peak ring area is complex and our analytical approach allows us to unravel its thermal evolution.

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