THE RESPONSE OF ZIRCON TO A LIGHTNING STRIKE: CHARACTERIZING NON-IMPACT-RELATED EXTREME PRESSURE–TEMPERATURE EXCURSIONS AT EARTH'S SURFACE

G. G. Kenny[1]*, M. A. Pasek[2]
[1]Department of Geosciences, Swedish Museum of Natural History, SE-104 05 Stockholm, Sweden. [2]School of Geosciences, University of South Florida, Tampa, FL 33620, USA.
*Corresponding author. Email: gkennyeire@gmail.com

Introduction: Hypervelocity impacts induce extreme pressures and temperatures that are not normally produced by endogenic geological processes. Features created in response to these conditions can thus be used to infer the occurrence of a bolide impact and confirm a suspected impact structure (planar deformation features, PDFs, in quartz are perhaps the best known of these [1]). The mineral zircon ($ZrSiO_4$) responds to extreme pressure–temperature (P–T) conditions in a variety of crystallographically controlled ways [2]. Given the use of zircon in studies of shock metamorphism, it is critical to understand which features in zircon are unique to hypervelocity impacts and which may form as a result of other extreme P–T excursions, such as lightning strikes. Additionally, analysis of deformation and phase transitions in zircon may shed light on the P–T conditions of such events. Previous studies of fulgurites (tubular bodies of glass and fused clasts that form in response to lightning) have noted zircon with rims of ZrO_2 [3,4] and one study documented a Zr-rich patch of glass interpreted to represent a melted zircon grain [4].

With the aim to recognize features that form in response to extreme P–T excursions but are not unique to hypervelocity impacts, and to understand better the P–T conditions of these events, we undertook imaging and microstructural analysis of zircon and baddeleyite (monoclinic ZrO_2) in a recently formed fulgurite. As an experimental control, we also imaged zircon from nearby soil and rock that was not exposed to the lightning strike.

Samples: The fulgurite sample studied here formed as lightning struck vegetated soil in York County, Pennsylvania, USA, in 2004. The rock control sample collected near the fulgurite is a phyllite, consistent with local bedrock being mapped as metasedimentary rocks of the late Proterozoic or early Cambrian Harpers Formation [5]. The soil control sample contains mm-scale clasts of phyllite, supporting a local provenance.

Methods: A portion of the fulgurite was mounted in epoxy and cut perpendicular to it exterior wall. This exposed an approximately circular cross-section 20 mm in diameter, which was polished with diamond suspension and colloidal silica. Imaging and microstructural characterization of zircon and baddeleyite by electron backscatter diffraction analysis were performed on an FEI Quanta FEG 650 scanning electron microscope. Microstructural data were processed in Oxford Instruments Channel 5 software and further data analysis was done in ARPGE software [6].

Results: Zircon grains from the control samples displayed a range of features, including xenotime rims and porosity. However, none displayed rims or inclusions of baddeleyite. Of the 91 Zr-rich grains identified in the fulgurite, five are composed entirely of vermicular baddeleyite. The other 86 are zircon grains, with 19 of these displaying granular baddeleyite and 29 having rims of vermicular baddeleyite. The abundance of baddeleyite in the zircon grains decreases with increasing distance from the fulgurite's central void, indicating that the baddeleyite formed in response to the lightning strike. Microstructural analysis of a rim of vermicular ZrO_2 on a zircon grain revealed that it is composed of systematically oriented clusters of baddeleyite, consistent with cubic to monoclinic transformation and the former presence of cubic ZrO_2 in the sample [7]. Cubic ZrO_2 is a high-temperature phase (forming at $T>2370°C$ at low pressure) and previously documented natural occurrences were associated with hypervelocity impacts [8-10].

Implications: Evidence for precursor cubic ZrO_2 in baddeleyite rims on zircon grains in a fulgurite indicate that cubic ZrO_2 – despite indicating extreme P–T conditions – is not unique to, or diagnostic of, hypervelocity impacts. Furthermore, the observation adds new constraints to the P–T conditions of lightning strikes. Comprehensive results and discussion are presented in [11].

Acknowledgments: This project received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie Individual Fellowship Grant Agreement No. 792030, supporting Kenny. We thank Cyril Cayron for helpful discussions and support with ARPGE software.

References: [1] French B. M. and Koeberl C. (2010) *Earth-Science Reviews* 98:123–170. [2] Timms N. E. et al. (2017) *Earth-Science Reviews* 165:185–202. [3] Essene E. J. and Fisher D. C. (1986) *Science* 234:189–193. [4] Pasek M. A. et al. (2012) *Contributions to Mineralogy and Petrology* 164:477–492. [5] Lloyd O. B. and Growitz D. J. (1977) *Pennsylvania Bureau of Topographic and Geologic Survey Atlas*, W 42, plate 1. [6] Cayron C. et al. (2007) *Journal of Applied Crystallography* 40:1183–1188. [7] Cayron C. et al. (2010) *Journal of the American Ceramic Society* 93:2541–2544. [8] Timms N. E. et al. (2017) *Earth and Planetary Science Letters* 477:52–58. [9] White L. F. et al. (2020) *Nature Astronomy* 4:974–978. [10] Tolometti G. D. et al. (2022) *Earth and Planetary Science Letters* 584:117523. [11] Kenny G. G. and Pasek M. A. (2021) *Scientific Reports* 11:1560.