

ELEMENT DISTRIBUTION OF SHOCK DEFORMED REGIONS IN ZIRCON AND IMPLICATIONS FOR ZIRCON CHRONOLOGY DURING THE IMPACT. J. W. Zhao¹, L. Xiao^{1*}, Q. He¹ and Z. Y. Xiao² and IODP 364 party.

¹State Key Laboratory of Geological Processes and Mineral Resources, Planetary Science Institute, School of Earth Sciences, China University of Geosciences, Wuhan, China (jiawei_zhao@cug.edu.cn, longxiao@cug.edu.cn). ² Planetary Environmental and Astrobiological Research Laboratory, School of Atmospheric Sciences, Sun Yat-sen University, Zhuhai, China (xiaozhiyong@mail.sysu.edu.cn)

Introduction: Zircon is ubiquitously used to nail down the geological events for both terrestrial and extraterrestrial materials. The U-Pb system and isomorphism matters in zircon plausibly remain stable and robust in normal metamorphic processes on Earth, while under the extremely shock condition, trace element behaviors in zircon could be unstable and differential due to the generated extraordinary deformations and thermal annealing [1]. Since the systematic deformations in zircon recovered from the Chicxulub impact structure, such as planar fractures (PFs), reidite and granular zircon [2, 3, 4], the phenomenon of partially or completely age resetting are discovered in zircons from impact melt, breccia, ejecta and meteorites [3]. In effect, element migration during the shock or post-shock setting is the most critical question, which may yield age resetting in nature. The enrichment of elements in shock-deformed zircon regions (PFs and reidite) are revealed, such as Y, Al, Ca, U, Th and Pb [5, 6]. Due to the limitation of resolution and lack of typical shock deformations, the straightforward correlations among deformations, element migration and chronology in zircon by traditional means have not been illustrated clearly so far. Here we systematically analyzed the correlations between shock deformations (from low to high degree: PFs, reidite and granular zircon) and element distribution in zircon by high-resolution Nano-SIMS mapping data. This can be used to interpret the chronology of shock products both from terrestrial and extraterrestrial bodies.

Samples and Methods: The zircon grains were separated from the impact melt-bearing breccia, impact melt rock and granitoid basement from the drill hole M0077A in the Chicxulub impact structure. Cathodoluminescence (CL) and backscattered electron (BSE) imaging, and analytical nano secondary ion mass spectrometry (Nano-SIMS) were used to map the trace elements (Y, Th, U, Pb, P, Ti) in shock deformed regions (PF, Reidite and Granular zircon region). ImageJ and its Plugin (OpenMIMS) were used to process the Nano-SIMS data.

Results:

In PF region: PF is one kind of shock products belonging to shock stage II [7]. Growth zonation in this

region of zircon correlates closely with the distribution of Y (from core to rim: 441–2984 ppm). The abundance of Y in PFs (~1 μm in width) increase significantly by 5–57%. The average concentration of Pb is 44 ppm.

In Reidite region: Reidite is the high-pressure phase of zircon, which belongs to shock stage III [7]. Growth zonation in this region of zircon correlates with the abundance of Y, which increases in reidite region (1–2 μm in width) by 20–40% (from core to rim: 970–1688 ppm). The content increase in this region for other elements such as Ti, Th, U are about 110–200%, 4–6%, and 8–12%, respectively. In contrast, the content of Pb decreases by 10–20% in reidite region (average content of Pb: 15 ppm) compared with the adjacent regions.

In Granular zircon region: The primitive zonation of granular zircon (shock stage III-IV, [7]) is ambiguous. The content of Y has significantly enhanced in some granules up to 7361–17698 ppm, while in the other adjacent granules, the content is about 798–1722 ppm. The average content of Pb in granular zircon is ~ 12 ppm.

Discussions:

Different behaviors of trace elements: The behaviors of trace elements are quite different according to the heterogeneous enrichment in deformed regions. Obviously, the elements such as Pb, Ti and Y have higher mobility than the other elements (U and Th), which has been confirmed according to the different closure temperatures of trace elements in zircon [Fig. 1]. The diffusivity and compatibility in zircon are determined by the radius divergence between trace element and Zr⁴⁺ or Si⁴⁺ [8]. Due to the high mobility of Pb, some regions show the Pb loss or low concentration of Pb. In addition, the zonation could affect the trace element content in deformed region, eg., the reidite in high-Y zonation enriches more Y than that in low-Y zonation. More importantly, the highly deformed zircon (granular zircon) locally have more element enrichment such as Y than that in the less deformed zircon (reidite/ PFs region).

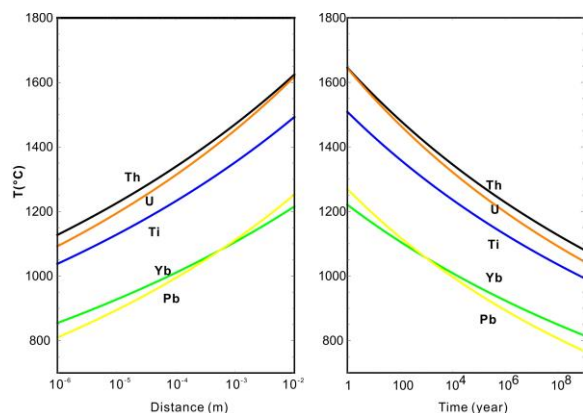


Fig 1. The closure temperature of typical trace elements in zircon and the diffusion rate in a radius of 2 μm in zircon [8].

Mechanisms of element migration: The primary mechanism of element migration related to the extremely shock conditions exhibit in two aspects: 1) the volume diffusion induced by high temperature ($>1200^\circ\text{C}$), e.g. granular zircon, whose age is totally reset [9]. 2) the pipe diffusion induced by the crystal boundary formed in shock, such as angle crystal boundary (low and high angle grain boundary), which provides high speed pathways for the diffusion of some substituted elements [10]. The effects of these two mechanisms on element migration and divergences of element behavior have been depicted by simulation models, which further shed light on the deformations and element re-distributions.

Effects on zircon chronology: The change of Pb/U value gradually breaks the U-Pb system in deformed zircon regions in theory, due to the different levels of the loss of Pb and the enrichment of U in PFs, reidite and granule regions. The highly deformed zircon (granular zircon) has a relatively low content of Pb than zircon with PFs and reidite, indicating a more intensive process of Pb loss. Additionally, the Pb/U value in shocked zircon with PFs is also affected, which means the possibility of partial resetting or discordance in zircon ages.

Conclusions

The zonation, element mobility and deformations collectively affect the re-distribution of trace elements in shocked zircon. Trace elements in typical deformation regions (PFs, reidite and granular zircon) are redistributed during the impact process, driving by the temperature and deformations in zircon.

References:

- [1] Timms N. E. et al. (2017) *ESR*, 165, 185–202.
- [2] Zhao J. W. et al. (2021) *GEOLOGY*, in press.
- [3] Rasmussen C. et al (2019) *CHEM GEOL*, 525, 356-367.
- [4] Cox M. A. et al. (2020) *Meteoritics & Planet. Sci.*, 55, 1715-1733.

- [5] Montalvo S. N. et al (2019) *CHEM GEOL*, 507, 85-95.
- [6] Kovaleva E. et al (2017) *AM MINERAL*, 102, 1311-1327.
- [7] Wittmann A. et al. (2006) *Meteoritics & Planet. Sci.*, 41, 433-454.
- [8] Cherniak D. J. and Watson E. B. (2003) *REV MINERAL GEOCHEM*, 53, 113-143.
- [9] Bohor B. F. et al (1993) *SCIENCE*, 119, 419-424.
- [10] Reddy S. N. et al (2007) *CONTRIB MINERAL PETR*, 153, 625-645.