Press Release

Publication information

- **Title of original paper**: *In situ* observation of the phase transition behavior of shocked baddeleyite

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High Energy Accelerator Research Organization (KEK)

University of Tsukuba

Kumamoto University

Exploring the scale of meteorite impact from minerals

Laboratory-based shock experiments on minerals

Key Points

- ○ Shock experiments were performed on baddeleyite (a zirconia mineral) in a laboratory, during which time its crystal structure dynamics were observed directly using a synchrotron X-ray.
- ○ The crystal structure changed upon compression before returning to its original state when released.
- ○ Geologists can use this information to estimate the scale of a past impact event using baddeleyite present in rocks.

Collisions of celestial bodies have formed and affected the evolution of planets. One well-known hypothesis is that an asteroid impact caused the mass extinction of dinosaurs on Earth ~65 million years ago. Understanding the scale of an impact event is essential to studying the evolution of a similar planet. Impact events cause shock metamorphism in rocks and minerals in the crust of a planet (see Fig. 1), and shock metamorphosed minerals can be used to identify and date impact events and as barometric indicators. Baddeleyite (ZrO_2) is one mineral that can be used as a shock-pressure barometer. The mineral is widespread on Earth, the Moon, Mars, and meteorites; it is also known to show traits of shock metamorphism.

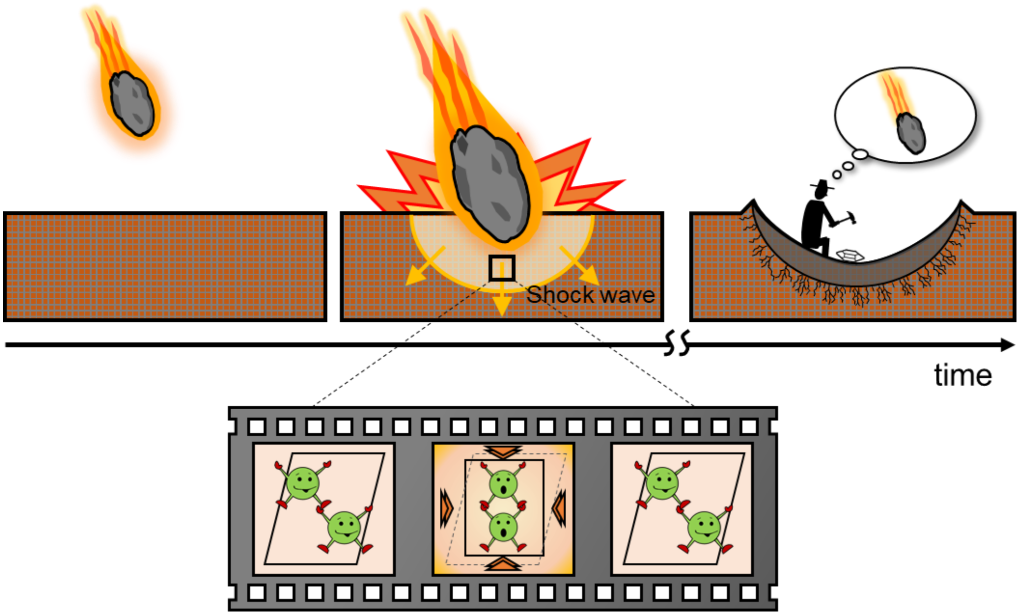

Figure 1. Meteorite impact produces shock compressions in rocks.

To date, our understanding of how minerals are affected by impact-induced shocks have been based on shock recovery experiments and the associated wave profile measurements in laboratories. However, shortcomings in temporal or spatial resolutions have made it impossible to determine a microscopic view of the conditions that a mineral underwent during an intense shock event. It was thought that the crystal structure of baddeleyite could change under shock compression conditions but the mineral did not retain its changed structure after the event. Therefore, direct observation of the response of the crystal structure during a shock is required to understand the effect of the latter on the mineral.

A cooperative research team of KEK, University of Tsukuba, and Kumamoto University conducted shock experiments on baddeleyite at the Photon Factory Advanced Ring (PF-AR) synchrotron facility, KEK, and reported their results. In their study, the shock condition was generated by a high-power laser, and the change in the crystal structure during the shock was observed using an X-ray pulse in the time-resolved X-ray beamline, NW14A (Fig. 2).

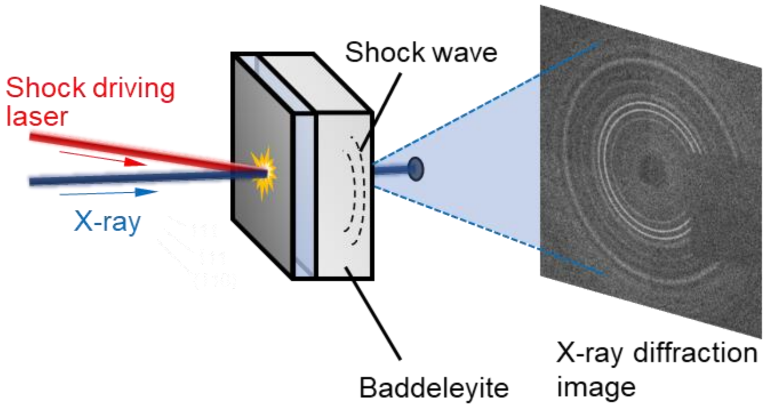

Figure 2. Experimental configuration of time-resolved X-ray diffraction measurement under laser-induced shock conditions.

The resulting X-ray diffraction image changes due to the effect of the shock compression (Fig. 3; upper), indicating that the latter was what changed the crystal structure of the baddeleyite. Figure 3 (upper) shows the new X-ray diffraction line that appeared between the two lines labeled “b” lines during a shock compression of 6.5‐15.4 nanoseconds (ns) but disappeared after the shock release (after 32.0 ns). This new line is attributed to the difference in the crystal structure shown in Fig. 3 (lower). In short, the crystal structure of baddeleyite changes during shock compression but immediately returns to its original state upon decompression. The pressure boundary at which the change occurred in the crystal structure was 3.3 gigapascal (= 33,000 atmospheric pressure; the prefix giga- = 10^9).

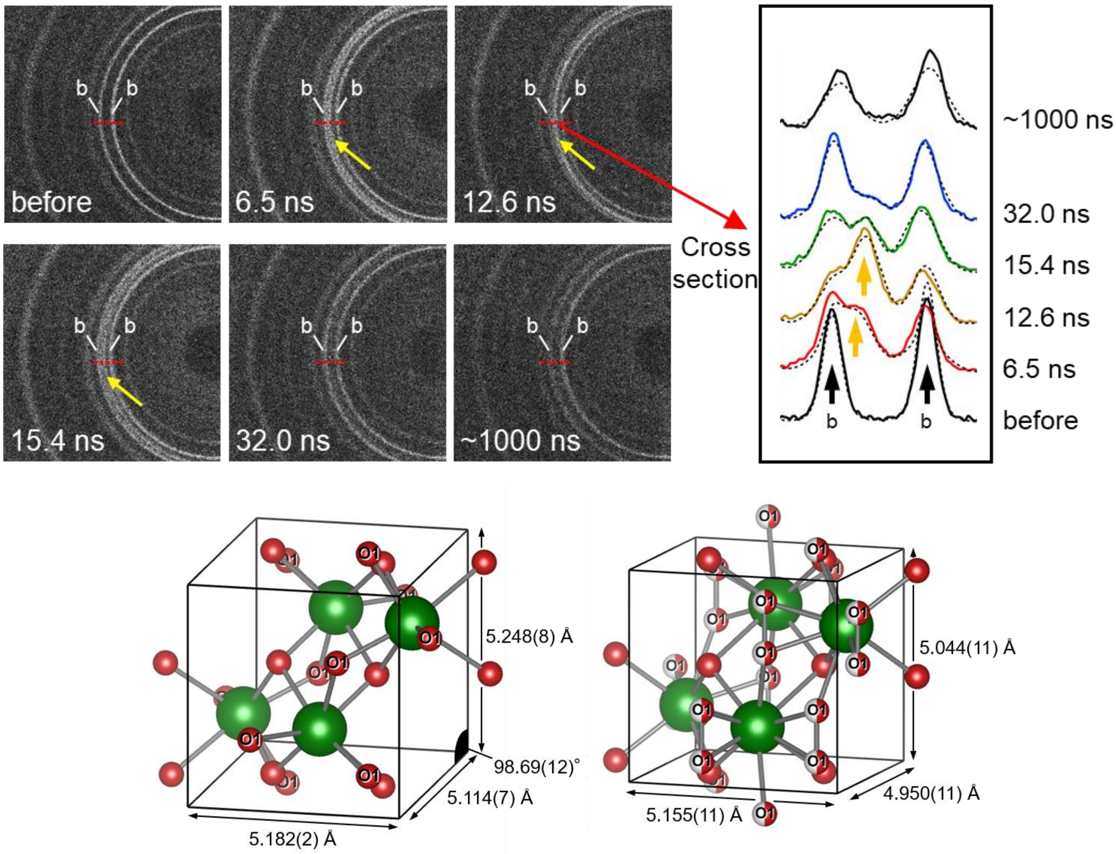

Figure 3. (Upper) Changes in X-ray diffraction images of baddeleyite taken under shock compression conditions. Two strong X-ray diffraction lines are indicated with ”b,” and the new line between them is indicated with a yellow arrow. ns stands for nanoseconds. (Lower) The crystal structure derived from X-ray diffraction. The structure on the left represents baddeleyite before the shock treatment while that on the right side represents the shock-induced mineral. Zr atoms are shown in green and O atoms are shown in red.

Geologists have reported that samples of natural baddeleyite at an impact crater site shows traces of changes in their crystal structure and that these can be used to determine the scale of the related impact. The behavior of the crystal structure and the shock pressure boundary of the change–as determined experimentally in this study–can be used to obtain a more accurate estimation of a planet’s bombardment history.

About High Energy Accelerator Research Organization (KEK)

KEK was established to promote various types of researches as a center of excellence for overall development of Japan’s accelerator science (particle and nuclear research using high energy accelerators, research on the structure/function of matter including living organisms, research on improving the accelerator performance, and related basic technologies). As the Inter-University Research Institute Corporation, KEK provides researchers across the country and abroad with opportunities for research. With the Tsukuba and Tokai campuses as centers for excellence, KEK joins international collaboration

experiments and developments. In addition, KEK, as a basic research organization under Graduate University for Advanced Studies, fosters scientists who will contribute to the promotion of accelerator science and advanced research fields.
https://www.kek.jp/en/

About University of Tsukuba

The University of Tsukuba is located in the suburbs of Tokyo and is at the heart of Tsukuba Science City —Japan's largest "science city," which has 29 national research institutes and about 150 private research organizations. The University operates on the principle that it is open to all.

The University of Tsukuba aims to cross the borders that separate a variety of organizations, such as those between nations, research institutions, and fields of study. The University's network is expanding globally. In particular, the University has entered into ten campus-in-campus arrangements with universities in eight countries and regions, thereby promoting close cooperative relationships between education and research. At present, the University hosts approximately 2,400 study abroad students from more than 110 countries and regions.
http://www.tsukuba.ac.jp/en/

About Kumamoto University

Kumamoto University (KU), in its current form, was established on the 31st of May 1949, but its origins can be traced as far back as the mid-18th century. Now it is a globally active research university with strong roots in the local community. With seven faculties and eleven graduate schools, KU aims to cultivate creative people and provide them with the tools to thrive in the information age. KU's research institutions and organizations strive to protect humankind's cultural heritage, produce cutting-edge academic research, and promote sustainable development to help create a better future for the generations to come.
https://ewww.kumamoto-u.ac.jp/en/