Scientists make first observations of how a meteor-like shock turns silica into glass

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Credit: AI-generated image (disclaimer)

Studies at the Department of Energy's SLAC National Accelerator Laboratory have made the first real-time observations of how silica – an abundant material in the Earth's crust – easily transforms into a dense glass when hit with a massive shock wave like one generated from a meteor impact.

The results imply that meteors hitting Earth and other celestial objects are smaller than originally thought. This new information will be important for modeling planetary body formation and interpreting evidence of impacts on the ground.

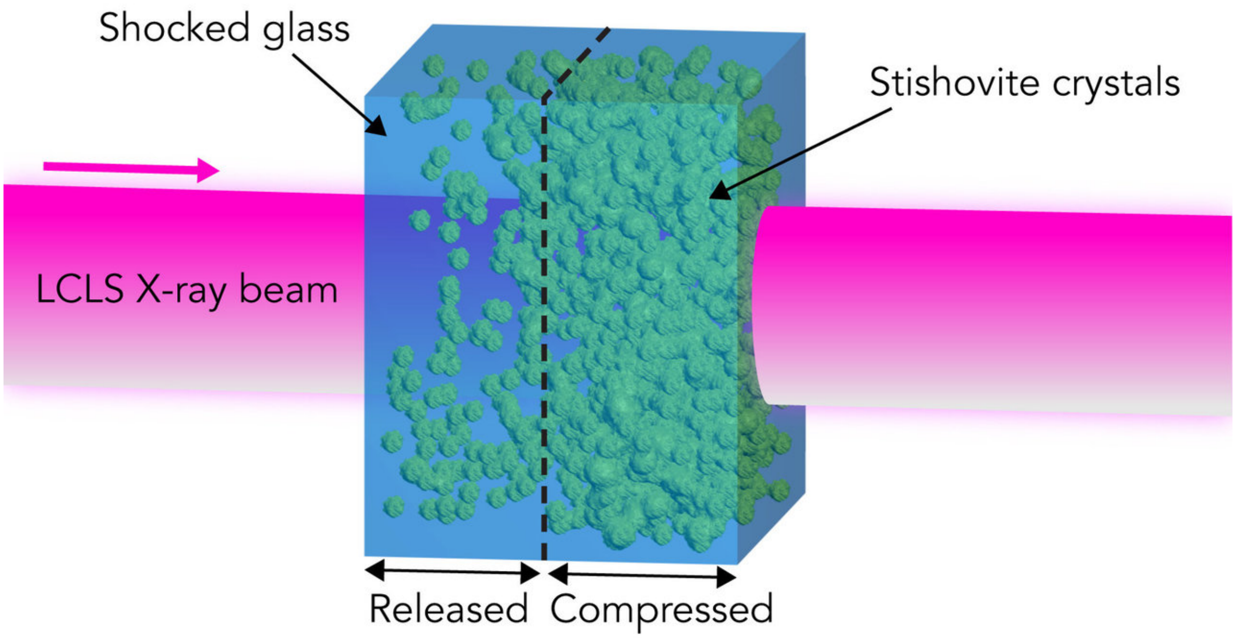
The experiments took place at SLAC's Linac Coherent Light Source (LCLS) X-ray laser, a DOE Office of Science User Facility whose ultrafast pulses can reveal processes taking place in millionths of a billionth of a second with atomic resolution.

"We were able for the first time to really visualize from start to finish what happens in a material that makes up a major portion of the Earth's crust," said Arianna Gleason of the DOE's Los Alamos National Laboratory (LANL), the principal investigator for the study, which was published Nov. 14 in *Nature Communications*.

How Does Shocked Glass Get That Way?

Scientists have long known that impacts from meteors convert silicates into a dense, amorphous phase known as shocked glass. The question is how this shocked glass forms.

In the past, scientists have tried to estimate the amount of pressure needed to cause this transformation by examining debris from meteor impacts and squeezing mineral samples in pressure cells in the lab, but they were unable to observe the process as it unfolded.



This drawing depicts the process that turns silica into shocked glass after it's hit with a shock wave like one from a meteor impact. At right, compression has transformed the silica into stishovite crystals. On the left, the compression has been released and the stishovite crystals have transformed into shocked glass. The LCLS X-ray laser beam recorded this process, which happens within 30 nanoseconds. Credit: A.E. Gleason et al., Nature Communications

At LCLS, researchers can use an intense laser beam to create a shock wave that compresses a silica sample, and then use the X-ray laser to examine its response on a timescale of nanoseconds, or billionths of a second.

A previous SLAC study, published in 2015, demonstrated that silica forms stishovite, a crystalline phase, within 10 nanoseconds of being hit by the initial laser pulse. That research showed that the transformation occurred much more rapidly than was previously believed. But the existence of debris from meteor impacts that is composed entirely of shocked glass suggests that stishovite may be a short-lived phase that can convert permanently to shocked glass after impact.

Overturning Assumptions

In the latest study, the scientists took advantage of the Matter in Extreme Conditions instrument at LCLS to generate shock waves that induced various peak pressures in silica samples. After sending the laser pulse, "We just watch what the silica does naturally," said Gleason, who is the LANL Fredrick Reines Postdoctoral Fellow.

Analysis of X-ray diffraction data taken at various intervals after peak pressure was reached showed that when the pressure is high enough, stishovite forms, but it then reverts to shocked glass. The diffraction data from the LCLS samples matched data from impact debris collected in the field.

Scientists have previously assumed that peak pressures of roughly 40 gigapascals – equivalent to 400,000 times the atmospheric pressure around us – are required to create shocked glass from silica. But the results from this study suggest that the threshold is about 25 percent lower than that, and that stishovite then reverts to the shocked glass state due to thermal instability rather than higher pressure.

"An impact event has a short timeline," said Gleason, "making LCLS an ideal instrument for understanding the fundamental thermodynamics of glasses formed by impacts." Gleason envisions using the MEC at LCLS to investigate other Earth-abundant minerals, such as feldspar, and to better understand the "rule book" for transformation processes.

Gleason's research is more broadly applicable to debris from other planets, such as meteorites from Mars that also contain shocked glass.

Martian meteorites often contain trapped volatile compounds, such as water vapor and methane. No one understands how these compounds become locked inside meteorites or why they don't escape, but continued work at LCLS could provide answers.

More information: A. E. Gleason et al. Time-resolved diffraction of shock-released SiO2 and diaplectic glass formation, *Nature Communications* (2017). DOI: 10.1038/s41467-017-01791-y

Provided by SLAC National Accelerator Laboratory

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