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Nuclear-blast induced nanotextures in quartz and zircon within Trinitite

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Abstract

The intense heat and pressure resulting from the detonation of the world's first nuclear device in the New Mexico desert, July 16, 1945, severely altered the arkosic sand, producing the fused, glassy material referred to as Trinitite. The study of Trinitite is key to the development of nuclear forensic techniques that can provide crucial information about a nuclear event, such as device composition and radionuclide distribution. Moreover, nuclear blasts are often considered analogs to catastrophic natural events such as meteorite impacts, and it is well-documented that with increasing impact severity, zircon and quartz grains deform systematically. In Trinitite, a sufficient number of primary quartz and zircon grains remain identifiable. Here, a multi-technique approach (focused ion beam, scanning electron microscopy, transmission electron microscopy, and micro-Raman spectroscopy) is employed to study the micrometer-to-nanometer-scale deformation features in altered grains of zircon and quartz to constrain blast pressure and temperature conditions. Trinitite zircon grains consistently show an outer halo of fibrous baddeleyite, radiating from a relatively unaltered core; HRTEM images show complex twinning, likely originating from an intermediate, tetragonal zirconia precursor. Trinitite quartz grains show various states of melting that appear to vary predictably with depth below the surface of the desert sand. Grains occurring deeper than ~1.5 cm are crystalline, with occasional planar fractures at the optical scale. At shallower depths, a systematic increase in quartz vitrification is observed. Considered together, these data suggest maximal temperatures in excess of 1500 °C and pressures of <10 GPa, the latter being considerably less than for any natural impact event. Taken in a broader context, the implications of this work extend toward exploiting the use of advanced imaging techniques to improve our understanding of mineral processes in extreme, non-equilibrium environments at the near-atomic scale.

Keywords: Trinitite, zircon, martensitic twins, baddeleyite, focused-ion beam, transmission electron microscopy, micro-Raman spectroscopy