Libyan Desert Glass: New evidence for an extremely high-pressure-temperature impact event from nanostructural study

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Abstract

The origin of Libyan Desert Glass (LDG) found in the western parts of Egypt close to the Libyan border is debated in planetary science. Two major theories of its formation are currently competing: (1) melting by airburst and (2) formation by impact-related melting. While mineralogical and textural evidence for a high-temperature event responsible for the LDG formation is abundant and convincing, minerals and textures indicating high shock pressure have been scarce. This paper provides a nanostructural study of the LDG, showing new evidence of its high-pressure and high-temperature origin. We mainly focused on the investigation of Zr-bearing and phosphate aggregates enclosed within LDG. Micro- and nanostructural evidence obtained with transmission electron microscopy (TEM) are spherical inclusions of cubic, tetragonal, and orthorhombic (Pnma or OII) zirconia after zircon, which indicate high-pressure, high-temperature decomposition of zircon and possibly, melting of ZrO2. Inclusions of amorphous silica and amorphous Al-phosphate with berlinite composition (AlPO4) within mosaicos whitlockite and monazite aggregates point at decomposition and melting of phosphates, which formed an emulsion with SiO2 melt. The estimated temperature of the LDG melts was above 2750 °C, approaching the point of SiO2 boiling. The variety of textures with different degrees of quenching immediately next to each other suggests an extreme thermal gradient that existed in LDG through radiation cooling. Additionally, the presence of quenched orthorhombic OII ZrO2 provides direct evidence of high-pressure (>13.5 GPa) conditions, confirming theory 2, the hypervelocity impact origin of the LDG.

Keywords: Granular textures, transmission electron microscopy, zircon, phosphates, zirconium oxide, orthorhombic zirconia OII, cubic zirconia, immiscibility

Introduction

Libyan Desert Glass (LDG) is an enigmatic rock formation known to geologists for almost 90 years, whose origin is still debated. In the past, various processes were suggested for the origin of the LDG: such as a lightning strike that would make it fulgurite (Baker 1959), meteorite collision (Kleinmann 1968), hydrothermal sol-gel process (Jux 1983; Feller 1997), sedimentary origin (Feller 1997), and a lunar volcanic source (Futrell and O’Keefe 1997). The occurrence of lechatelierite, α- and β-cristobalite, mullite, and possible tridymite enclosed in silica glass matrix provides evidence for high-temperature impact conditions (e.g., Urey 1957; Barnes and Underwood 1976; Kleimann et al. 2001; Greshake et al. 2010; Greshake et al. 2018) and/or high-pressure (Cavosie et al. 2019) melting by a meteorite impact. Arguments for hypothesis 1, airburst-related melting, were the absence of both the related impact crater and shock effects in the LDG. These led to a suggestion that LDG might be a product of a low-altitude atmospheric airburst that caused a high-temperature fusion of surface material (Wasson 2003; Svetsov and Watson 2007; Boslough and Crawford 2008).

Evidence for hypothesis 2, impact-related melting, has been presented in a series of papers (Kleinmann 1968; Koebel 1997, 2000; Pratesi et al. 2002; Greshake et al. 2010, 2018), where the LDG is suggested to be the product of a high-temperature impact process. The occurrence of lechatelierite, α- and β-cristobalite, mullite, and possible tridymite enclosed in silica glass matrix provides evidence for high-temperature impact conditions (e.g., Urey 1957; Barnes and Underwood 1976; Greshake et al. 2018; Cavosie et al. 2022). Lechatelierite and α-cristobalite indicate heating of the source rock to at least 1550 °C followed by rapid cooling (Greshake et al. 2010). The observed complete breakdown of euhedral zircon grains resulting in baddeleyite and...