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Origin of β-cristobalite in Libyan Desert Glass: The hottest naturally occurring silica polymorph?

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Abstract

Identifying and determining the origin of β-cristobalite, a high-temperature silica polymorph, in natural samples is challenging as it is rarely, if ever, preserved due to polymorphic transformation to α-cristobalite at low temperature. Formation mechanisms for β-cristobalite in high-silica rocks are difficult to discern, as superheating, supercooling, bulk composition, and trace element abundance all influence whether cristobalite crystallizes from melt or by devitrification. Here we report a study of α-cristobalite in Libyan Desert Glass (LDG), a nearly pure silica natural glass of impact origin found in western Egypt, using electron microprobe analysis (EMPA), laser ablation inductively coupled mass spectrometry (LA-ICP-MS), time-of-flight secondary ion mass spectrometry (ToF-SIMS), scanning electron microscopy (SEM), and electron backscatter diffraction (EBSD). The studied grains are mostly 250 μm in diameter and consist of ~150 μm wide cores surrounded by ~50 μm wide dendritic rims. Compositional layering in LDG continues across cristobalite grains and mostly corresponds to variations in Al content. However, layering is disrupted in cores of cristobalite grains, where Al distribution records oscillatory growth zoning, whereas in rims the high Al occurs along grain boundaries. Cristobalite cores thus nucleated within layered LDG at conditions that allowed mobility of Al into crystallographically controlled growth zones, whereas rims grew when Al was less mobile. Analysis of 37 elements indicates little evidence of preferential partitioning; both LDG and cristobalite are variably depleted relative to the upper continental crust, and abundance variations correlate to layering in LDG. Orientation analysis of {112} twin systematics in cristobalite by EBSD confirms that cores were formerly single β-cristobalite crystals. Combined with published experimental data, these results provide evidence for high-temperature (>1350 °C) magmatic crystallization of oscillatory zoned β-cristobalite in LDG. Dendritic rims suggest growth across the glass transition by devitrification, driven by undercooling, with transformation to α-cristobalite at low temperature. This result represents the highest formation temperature estimate for naturally occurring cristobalite, which is attributed to the near pure silica composition of LDG and anomalously high temperatures generated during melting by meteorite impact processes.

Keywords: Cristobalite, silica, Libyan Desert Glass, EBSD, meteorite impact