REDITE AND ZrO$_2$ IN MUONG NONG-TYPE AUSTRALASIAN TEKTITES AND THE SIGNIFICANCE OF GRANULAR ZIRCON IN SILICEOUS IMPACT MELT

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**Introduction:** The origin of Australasian tektites, enigmatic drops of siliceous impact melt found over an area of ~8,000 x ~13,000 km centered on Southeast Asia, has long been debated. The impact event occurred only 0.78 m.y. ago, yet the source crater remains undiscovered. While there is general consensus that Australasian tektites represent melted supracrustal material, their formation conditions and provenance remain poorly constrained. Here we present evidence of reidite and ZrO$_2$ in granular zircon within Muong Nong-type tektites from Thailand, providing new insights into their genesis.

**Background:** Tektites are drops of glassy impact melt found in areas called strewn fields. The Australasian field spans 1000s of km across the Indian, Southern, and western equatorial Pacific oceans, with on-land finds from Thailand to Antarctica. The mineralogy and geochemistry of tektites are consistent with derivation from a supracrustal source [2]; the presence of $^{10}$Be requires the source to be near-surface material [3,4].

**Muong Nong-type (MN-type) tektites:** MN-type tektites are high-silica glass (~80 wt. % SiO$_2$), have a layered structure, a high abundance of vesicles, high volatile and H$_2$O contents, and a variety of relict minerals [2]. Phases in Australasian MN-type tektites include lechatelierite, coesite, and stishovite; quartz, zircon, and other minerals with suspected shock damage have been identified via X-ray asterism [5]. The absence of baddeleyite, combined with geochemical and microstructural data, has been cited to infer that Australasian MN-type tektites represent lower temperature melts compared to other tektites [2].

**Samples:** Granular zircon grains in MN-type tektites from Thailand, previously analyzed for U-Pb age by secondary ion mass spectrometry (SIMS) [6], were characterized using backscattered electron (BSE), cathodoluminescence (CL) imaging, and electron backscatter diffraction (EBSD).

**Results:** Each zircon is polycrystalline with a 'granular' texture, with mean neoblast diameters of 1.1 μm. Some neoblasts are concentrically zoned in CL. Inclusions of ZrO$_2$ range up to ~1 μm across; most are located near neoblasts edges, rather than in cores. No other phases were observed. Neoblasts in each grain are systematically aligned in three crystallographic orientations (Fig. 1). Each grain comprises three distinct orientation clusters that are mutually perpendicular, with coincidence among (001) and {110} poles. High-angle misorientation axes (85-95°) show that neighbor-pair pixels in EBSD maps are systematically clustered, and align with poles to (001) and {110} of neoblasts. ZrO$_2$ inclusions index as zircon in the same orientation as the surrounding neoblast. The inclusions are likely poorly ordered, and appear electron transparent.

**Figure 1.** Map of granular zircon (top) showing variations in orientation using an inverse pole figure color scheme. Pole figures (bottom) show the zircon consists of three orthogonal domains with coincidence between (001) and {110} poles.
**Pressure constraints for MN-type tektites:** The orientation relationships described here for granular zircon are only known to result from transformation to, and reversion from, the high-pressure polymorph reidite [7,8,9]. Transformation of zircon to reidite results in alignment of [001]_zircon with <110> reidite, with a systematic dispersion of 10° about the axes [7-12]. Reversion of reidite to zircon follows the reverse transformation relationship, resulting in up to three orthogonal orientations of zircon [8,9]. The reversion from reidite produces additional systematic dispersion of ~10° about each axis, which manifests on pole figures as highly dispersed orientation domains with systematic misorientations. The former presence of reidite requires these tektites to have originated from within the 30 GPa isobar near ‘ground zero’ [10,13].

**Temperature constraints for MN-type tektites:** The presence of lechatelierite in MN-type tektites requires high temperatures [5], and our results provide additional evidence of high-temperature conditions. Most reported occurrences of reidite in other impact environments consist of lamellae in shocked zircon within rocks that have not melted [9,11,12,14]. In contrast, tektites are quenched impact melt, and contain shocked zircon grains that recrystallized to neoblasts after reidite. Granular zircon after reidite appears to be a product of super-heated impact melt [7-8,15], and is readily distinguished by orientation data from granular zircon in non-melted shocked bedrock [16]. The presence of ZrO₂ is additional evidence that the tektite samples experienced temperatures in excess of 1673 °C, at which zircon dissociates to tetragonal ZrO₂ and silica [8]. The suspected disordered character of the ZrO₂ inclusions, as well as their small volume, may explain why baddeleyite has not been detected in X-ray diffraction studies of Australasian tektites [5,6].

**Granular zircon in siliceous impact melt:** Granular zircon from impact melts with similar features offer new insight into the origin of tektites. We propose that siliceous impact melts are suitable analogues for tektite glass. Granular zircon grains in MN-type tektites possess the same characteristic microstructures described in zircon in impact melt from known craters. Granular zircon with orientation domains diagnostic of reverted reidite and ZrO₂ inclusions occur in siliceous impact melt at Meteor Crater, USA (~49 kyr old, ~1.1 km) [7]; and at the Acraman impact structure, Australia (~600 Myr old, ~40 km) [8,15]. Target rocks at both sites include siliceous zircon-bearing supracrustal rocks, such as Coconino sandstone at Meteor Crater [7] and Yarada dacite at Acraman [15], which locally experienced total fusion during impact. Physical conditions of impact melt as recorded in granular zircon at both sites, i.e., P> 30 GPa, T>1673 °C [7-8], are essentially identical to those derived from zircon in MN-type tektites here. At the deeply-eroded Acraman impact structure, the crater environment of the impact melt is uncertain; however its derivation from dacite [15] indicates an origin in siliceous supracrustal rock. Likewise, at Meteor Crater, shock-melted Coconino sandstone was excavated from only ~80 m [17], and thus is also a siliceous supracrustal rock. Our results establish unambiguously that unique microstructural features observed in MN-type tektites occur in impact melt derived from high-silica source rocks, and, therefore, support previous hypotheses for a siliceous supracrustal source for MN-type tektites [1-5]. Given that siliceous igneous rocks and sediments are rare on the Moon and Mars [18-19], tektites may be an impact product unique to Earth, as it is the only body in the Solar System with an evolved, silica-rich crust.