HOW DOES TEKTITE GLASS LOSE ITS WATER? H. J. Melosh[1] and Natalia Artemieva[2], [1]Lunar and Planetary Lab (University of Arizona, Tucson AZ 85721, jmelosh@lpl.arizona.edu). [2]Institute for the Dynamics of Geospheres (Russian Academy of Sciences, Leninsky Prospect 38/6, Moscow, Russia 117939. nata_art@mtu-net.ru).

Introduction: One of the enduring puzzles in the tektite story is the extreme dehydration exhibited by tektite glass. Whereas typical rhyolitic glass from volcanoes contains roughly 0.2 wt % of water, tektites typically possess only 0.01 to 0.005 wt % of water [1, 2, 3]. Although few scientists presently adhere to J. A. O'Keefe's [4] view that tektites originated on the moon, O'Keefe did highlight the still unsolved problem of just how the tektites lost their water [5]. Indeed, he argued persuasively that, at typical silicate melting temperatures, water diffusion takes so long that that it would be impossible for tektites to dehydrate in this fashion.

In the years since O'Keefe's original proposal, much has been learned about the mechanics of impact and the thermal history of glass ejected from terrestrial impact craters. A recent computation [6] convincingly demonstrated that the melts that became Moldavites were ejected from the Ries impact crater. These melts originated from the upper rock units exposed at the site at the time of the impact. The thermal history of these melts is very different from the approach to melting envisaged by O'Keefe, and may account for the rapid water loss in a natural way.

Shock Melt: Rocks melted by the shock of a hypervelocity impact follow a much different thermodynamic path than rocks melted at a constant pressure of 1 bar. When a shock strong enough to melt silicate rock (> 50 GPa for most rocks) engulfs a volume of rock, both the pressure and temperature jump to very high values. Shock compression is an irreversible process and so the rock's entropy jumps as well. The rock then decompresses isentropically, changing state as the pressure declines. If the entropy increase is large enough, then the rock will melt upon decompression.
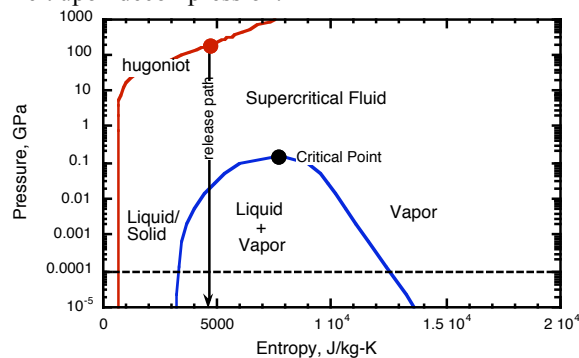

Figure 1. Phase plot for quartz in Pressure-Entropy coordinates. Note the typical shock release path.

Although this description seems elementary, Figure 1 shows that some interesting events occur along the path of decompression. The critical point of pure SiO_2 is approximately 0.45 GPa and 9600 K (using the hard-sphere method [7]). The Hugoniot curve lies well above this pressure, so that shock-melted rocks first decompress as a supercritical fluid. As the decompression curve reaches the liquid-vapor phase boundary the homogeneous fluid separates into a liquid plus vapor phase. At typical planetary impact velocities this occurs on the liquid side of the critical point, so that the silicate liquid begins to *boil* as it continues to decompress. The formerly homogeneous melt fills with vapor bubbles.

This thermodynamic path is much different than occurs for melting at constant pressure (the general experience in industrial glass making). In this case, heating adds entropy to the rock until melt appears. However, as the melting point is reached, the vapor pressure is generally very low. The result is a homogeneous melt phase that does not evolve vapor until the vapor pressure exceeds the environmental pressure.
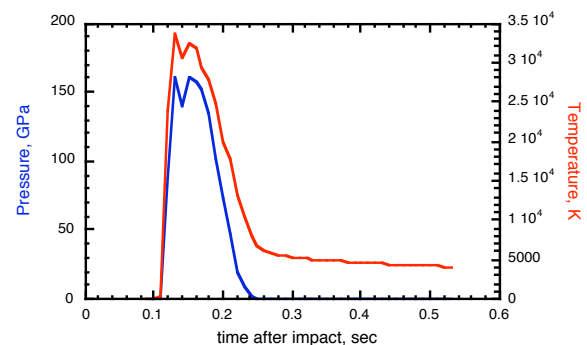

Figure 2. Pressure and Temperature vs. time for a tracer particle inserted in a computation of Moldavite formation in the Ries Crater [6]. This tracer began 10 m below the surface directly down range of the oblique impact.

Vapor Bubble Elimination: Vapor bubbles appear in the shocked melt at relatively high pressures, at a time when the melt is being actively accelerated out of the crater, as shown in Figures 2 and 3. In addition to the large acceleration, which approaches 50 g, the viscosity of the hot melt is

expected to be very low: Extrapolating the fit by [8], at a temperature of 9000 k a viscosity of only 7×10^{-6} Pa-s is expected. Under these conditions low-density vapor bubbles rapidly travel through the melt and burst at the tektite surface. It is reasonable to expect that these bubbles will strip water and other volatiles, such as Na and K, rapidly out of the glass. Indeed, bubbles 100 microns and larger will be eliminated from a 1 cm radius tektite in a few milliseconds down to temperatures of 4000 K. This is short compared to the tens of seconds during which acceleration is high.
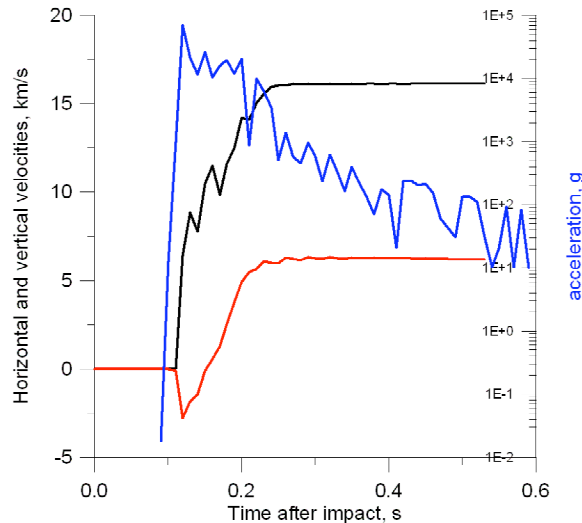

Figure 3. Acceleration and velocity of the tracer shown in Figure 2 for the first half second of flight. The large fluctuations may be due to turbulence in the cloud of melt and vapor as it travels downrange.

This bubble-stripping scenario also accords well with the otherwise puzzling observation that, despite the notable depletions of volatile elements from tektites, no tektite shows a diffusion-like profile, with high abundances of elements like Na and K in the center and lower ones on the outside (C. Koeberl, Personal Communication). However, if the volatiles were lost by diffusion to a large number of now-departed mobile bubbles, the low but uniform distribution of these elements becomes intelligible.

As the tektite continues to cool the bubbles become less mobile. Most will simply close up as the vapor pressure declines and disappear, but a few may remain late enough to be retained by the cooling and stiffening glass. Such remnant bubbles are commonly observed. At the present time they contain good vacuua [4], a consequence of cooling at very high altitude and the decrease of silicate vapor pressure with temperature.

Conclusion: Careful consideration of the thermodynamics and physical environment of tektite formation leads to a simple explanation of how water and other volatiles were removed from tektite glass in the short interval available for their formation in a large terrestrial impact event. J. A. O'Keefe had a valid concern over how this dehydration could occur, but our modern understanding of the impact process clears up the puzzles that he posed.

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