

WHY MOLDAVITES ARE REDUCED. A. Sheffer and H. J. Melosh, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, abigailw@lpl.arizona.edu, jmelosh@lpl.arizona.edu

Introduction: Moldavite tektites are colored a bright bottle green by reduced Fe, despite the originating sediments being completely oxidized. The high temperature processing of silicates often results in very reduced products, such as Si-bearing Fe metal in type-1 chondrules [1], lunar regolith agglutinates [2], and multiple Si-Fe metal phases in fulgurites [3,4]. Previous work on silicate reduction has often focused on the need for reducing agents such as carbon or hydrogen; we show that for a moldavite composition these are not necessary. The isentropic cooling path is inherently reducing.

Shock Melting: The cooling path of rocks melted by hypervelocity impact is much different than for rocks melted at a constant pressure [5]. A strong shock causes the pressure and temperature both to jump to very high values. Since the shock compression is irreversible, the rock's entropy also jumps. Decompression is isentropic, thus cooling follows a specific P-T path. (Figure 1)

Modeling: The equilibrium module in the HSC Chemistry package [6] was used to model the Gibbs energy minimization. Equilibrium compositions were computed for the pressures 0.001, 0.01, 0.1, 1, 10, 100, 1000, and 10000 bars over the temperature range 2000-6000 K. Entropy calculations were performed in Excel. We used the composition of middle Miocene sands near the Ries crater from [7] as a starting composition. For simplicity, only the major elements Si, Al, Fe, and O were included in the model.

Results: We modeled the isentropic cooling paths for three entropies – 5000, 7500, and 10000 J/K-kg.

The ratio of moles of O to moles of Si, Al, and Fe is an indicator of oxygen enrichment. The higher the number, the more oxygen is available for bonding with the other elements. The starting material has a value of 1.9. (Figure 2)

$$\text{O} / (\text{Al} + \text{Si} + \text{Fe})$$

The vapor phase at these entropies always contains a higher ratio of oxygen to other elements than the liquid phase or the starting material. Higher entropy causes a larger difference between the liquid and vapor because fewer oxide phases are stable. Also, at the higher entropy the volume of liquid is much smaller than the vapor.

For this composition, an entropy of 10000 J/K-kg is too high for liquid to be stable anywhere in this temperature range. The oxygen ratio of the vapor remains constant at the value of the starting material,

1.9. For a liquid to form, the entropy of the vapor must first be decreased.

Discussion: Tektite material is both cooling rapidly and accelerating away from the crater. The condensing liquid will soon reach a blocking temperature where it can no longer equilibrate with the surrounding vapor. Since this vapor is enriched in oxygen relative to the liquid, it will leave the liquid reduced. Any further evaporation or degassing [5] of the tektite liquid will increase the amount of reduction.

Future work will include increasing the complexity of the model to investigate the addition of water to the system. We will also apply this model to lunar regolith compositions.

References: [1] Lauretta D. S. et al. (2001) *GCA*, 64:8, 1337-1353 [2] Anand M. et al. (2004) *PNAS*, 101, 6847-6851. [3] Essene E. J. and Fisher D. C. (1986) *Science*, 234, 189–193. [4] Wasserman et al. (2002) *LPS XXXIII*, 1308-1309. [5] Melosh H. J. and Artemieva N. (2004) *LPS XXXV*, Abstract #1732. [6] Eriksson G. and Hack K. (1990) *Metall. Trans.*, 21B, 1013-1023. [7] Engelhardt W. et al. (1987) *GCA*. 51, 1425-1443.

Acknowledgments: This work was supported by NASA grant NAG5-11493.

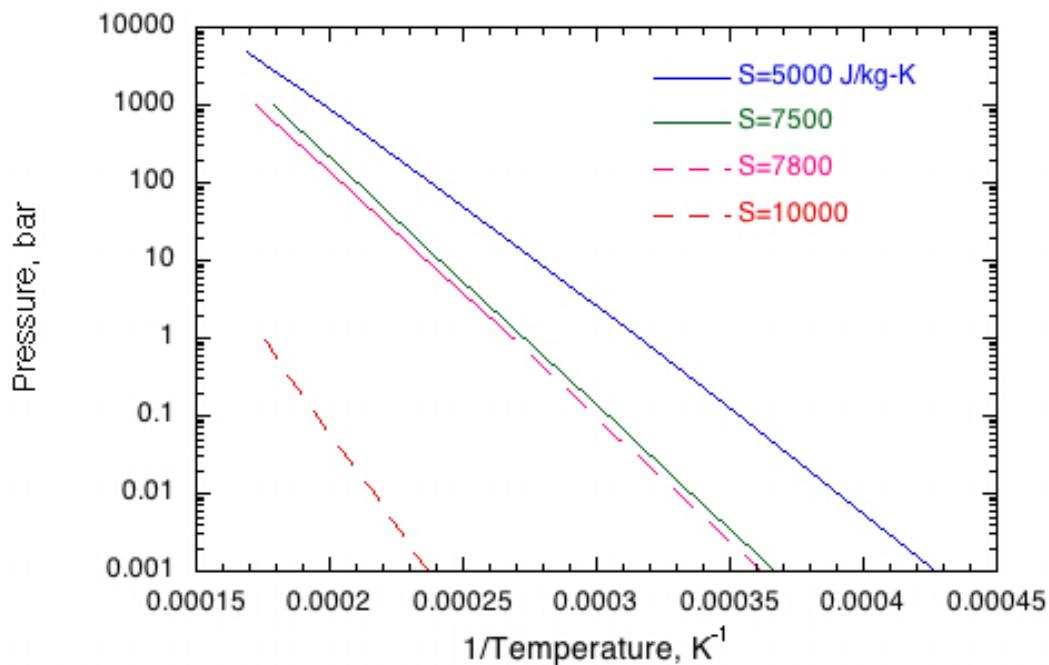


Figure 1: Isentropic cooling paths for middle Miocene sands near the Ries crater. Solid lines indicate the presence of a stable liquid, while regions with dashed lines have no stable liquid.

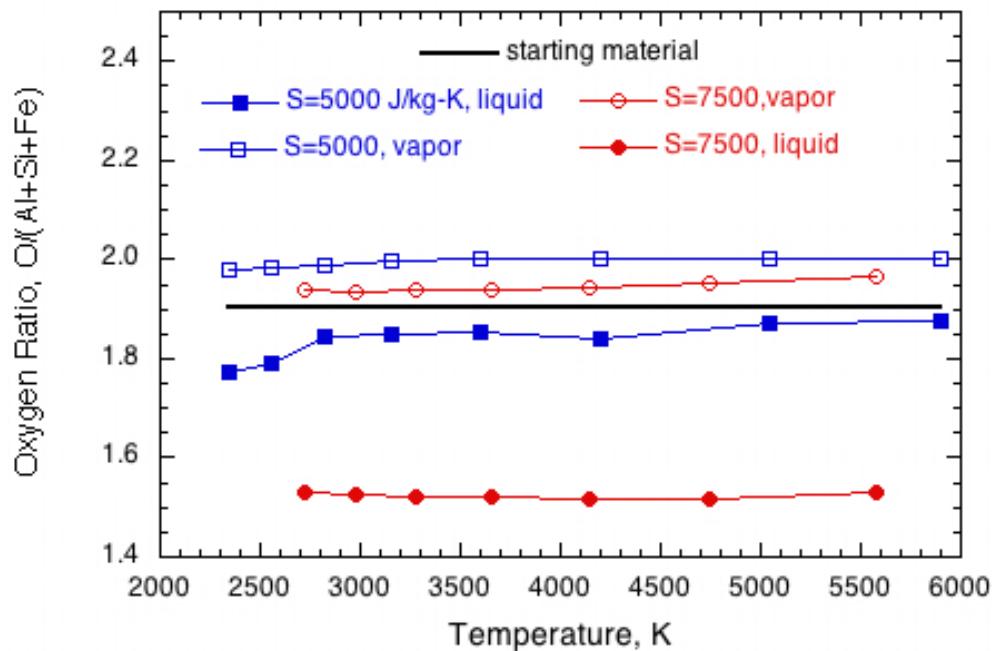


Figure 2: Oxygen ratios for liquid and vapor phases at 5000 and 7500 J/K-kg. Note the enrichment of oxygen in the vapor and the depletion in the liquid. For $S=10000$ J/K-kg, no liquid is stable, and the value of the oxygen ratio in the vapor stays at the starting composition.