FULGURITES: A LOOK AT TRANSIENT HIGH TEMPERATURE PROCESSES IN SILICATES

A. A. Wasserman, H. J. Melosh, and D. S. Lauretta
Lunar and Planetary Laboratory, University of Arizona

Introduction: Many high temperature processes result in very reduced products, such as fulgurites, impact melts, tektites, and chondrules. Previous work on fulgurites (the glassy products of the lightning strike fusion of sand, soil or rock) found silicon metal and iron-silicon alloys inside the silicate glass [1]. The mechanism for this extreme reduction is not yet understood. In this work we begin a study of several fulgurites as well as modeling the condensation of silicate liquid from a vapor. In previous work [2] we modeled the simplest silica system; here we investigate the effectiveness of carbon as an oxygen scavenger when added to the silica.

Thermodynamic Modeling: Thermodynamic calculations were performed using the equilibrium module in the HSC Chemistry package [3] to model the formation of fulgurite glass and investigate possible reduction mechanisms. All fulgurites contain silicate glass that cooled from a silicate liquid, so the simplest possible model is an entirely SiO_2 system, consisting of $SiO_{2(l)}$, $Si_{(l)}$, $SiO_{2(g)}$, $O_{(g)}$, and $O_{2(g)}$. Cooling of this assemblage from a vapor does not produce significant amounts of Si liquid unless some mechanism preferentially removes oxygen. Essene and Fisher [1] suggested that carbon produced from the charring of tree roots combined with oxygen in the vapor phase to leave the silicate liquid reduced. To test this theory, we added carbon to the model, in the form of $C_{(s)}$, $CO_{(g)}$, and $CO_{2(g)}$. Equilibrium compositions were determined in the temperature range from 1000 K to 5000 K, and at 1 bar pressure.

The modeling has shown that the addition of carbon to a silica system can produce Si metal liquid in a limited temperature range. The amount of Si produced is strongly dependent on the amount of C included in the system, but significant amounts of Si are produced even with only 0.05% carbon.

Petrographic Studies: Petrographic studies have begun on four fulgurites – a sand fulgurite from the Libyan Desert, Egypt; a sand fulgurite from the Pecos Plains, Texas; a basalt talus rock fulgurite from Cline Butte, Oregon; and a sandstone rock fulgurite from the Cacapon River District, West Virginia.

The preliminary microprobe analyses indicate obviously reduced phases in only one of the fulgurites – the West Virginia sandstone fulgurite. Two of other the fulgurites, the Egypt sand and the Oregon rock, have mottled areas of intergrown phases too small to be analyzed individually that may contain reduced metals.

The sandstone rock fulgurite consists of a heterogeneous glass with numerous vesicles and small metal droplets. Each droplet contains some or all of the following metallic phases: Fe_2Si, FeSi, FeSi2, FeTiSi2, and 99% Si. Smaller droplets (8-20 µm) consist of FeSi rimmed with Fe_2Si, while the larger droplets (100 µm) usually contain most of the metallic phases. The droplets contain overall less Fe than those studied in [1]. No obvious carbon phases have been found, although carbon may be present in the metal in small amounts.

With the exception of a few unmelted grains fused to the outside, the two sand fulgurites are very homogenous, with metallic phases generally occurring in the trapped grains. The silicate glass is on average 95% SiO_2. The basalt talus rock fulgurite is much more heterogeneous, containing many relict mineral grains in the glass. The areas around these grains shows flow features, and many grains have rapid-growth crystals on their edges. The glass in this fulgurite averages 60% SiO_2 with significant amounts of Na, K, Al, Mg, and Ti.

Discussion: For silicon metal to occur in the final cooled product, the system must reach its blocking temperature (at which the liquid can no longer equilibrate with the vapor) in the range where Si metal is present. The greater the amount of carbon present, the larger this temperature range becomes. Given estimated amounts of carbon and measured percentages of Si metal, these calculations could be used to closely constrain formation temperatures.

The previous report of Si metal found in a fulgurite [1] was for a sample that had been closely associated to charred tree roots. None of the four fulgurites examined here were associated with plant charring or other large sources of carbon, although the sandstone fulgurite is the only one that contains reduced phases. The hypothesis that the presence of carbon is an important parameter in the reduction of fulgurite glasses cannot be ruled out.

Thermodynamic modeling can be applied to other occurrences of the rapid heating and cooling of silicates, such as tektites, impact melts, and chondrules, with implications for the redox state of the moon in the giant impact scenario. Continuing work will extend the modeling to include Fe, Ti, and other phases to more accurately represent the composition of the fulgurites. Additional reduction mechanisms will also be modeled, such as the mechanical separation of solid and liquid from the gas.

References: [1] Essene E. J. and Fisher D. C. (1986) *Science, 234*, 189–193. [2] Wasserman A. A. and Melosh H. J. (2001) *LPS XXXII*, 2037. [3] Eriksson G. and Hack K. (1990) *Metall. Trans., 21B*, 1013-1023.

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