

LIGHTNING STRIKE GLASSES AS AN ANALOG FOR IMPACT GLASSES: ^{57}Fe MÖSSBAUER SPECTROSCOPY OF FULGURITES. A. A. Sheffer¹, M. D. Dyar², and E. C. Sklute². ¹Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721, abigailw@lpl.arizona.edu, ²Dept of Astronomy, Mount Holyoke College, South Hadley MA 01075.

Introduction: The process of lightning striking rock or sand is chemically very similar to impact events, especially micrometeorite impacts. Both processes cause a rapid rise in temperature followed by rapid isentropic cooling [1]. These processes result in glassy products such as fulgurites, tektites, and lunar regolith agglutinates that are often chemically reduced from their starting materials [2,3,4]. Because iron has more than one oxidation state, it is a good indicator of reduction ($\text{Fe}^{3+} \rightarrow \text{Fe}^{2+}$ or Fe^0). We chose to study fulgurites because of their abundance and the relative ease of obtaining the pre-melted “country rock” materials for comparison. We present the results of a ^{57}Fe Mössbauer spectroscopy study of eight fulgurites and trinitite (Trinity bomb test glass) as well as their unmelted starting materials.

Samples: Three samples were obtained from the Mineralogical Research Company: a basalt talus fulgurite from Cline Butte, OR; a sandstone fulgurite from the Cacapon River District, WV; and trinitite glass from White Sands Missile Range, NM. Sand samples from the Trinity bomb test site were provided by the White Sands Missile Range Public Affairs Office. Bruce and Miranda Jarnot generously provided a sand and basalt gravel fulgurite from Farmington, CT [5]. Four samples were obtained from the Smithsonian Institution: a sand and gravel fulgurite from Black Rock, UT; a rock fulgurite from Algeria; a rock fulgurite from Mt. Ararat, Turkey; and a sand fulgurite from Starke, FL. A. Sheffer collected the sand fulgurite from Monahans Sandhills, TX.

Method: The fulgurite glasses were initially studied using a Cameca SX50 electron microprobe with a voltage of 15 kV and a current of 20 nA to obtain backscattered electron images and point analyses.

Room temperature Mössbauer spectra were acquired to determine Fe^0 , Fe^{2+} and Fe^{3+} contents. Samples were prepared by gentle crushing under acetone (to avoid oxidation), and then by handpicking out pure glassy pieces. Roughly 40-300 mg of each sample, depending on Fe content, were powdered and mounted to obtain thin absorbers. A source of 100-30 mCi ^{57}Co in Rh was used on a WEB Research Co. model W100 spectrometer. Run times ranged from 1-6 days. Results were calibrated against a-Fe foil of 6 μm thickness and 99% purity.

Fitting methods employed quadrupole splitting distributions (QSDs) as described in [6]. Errors on $\%\text{Fe}^{3+}$ are roughly 3-5% absolute for samples with low Fe contents and 1-3% for higher Fe samples. Because there are no crystal chemical constraints imposed on Fe site occupancy or valence state in a glass, it must be noted that the glass (fulgurite) fits are especially highly non-unique and model-dependent.

Results: Microprobe analyses show a range of total Fe content in the glasses (Table 1). The fulgurites that have sand as the primary starting material are predictably low in iron content (0.07-0.18 wt. % Fe). The other samples have higher Fe contents reflecting the contribution from their country rock (basalt in the case of the Farmington, CT, Mt. Ararat, Algeria, and Cline Butte, OR, fulgurites).

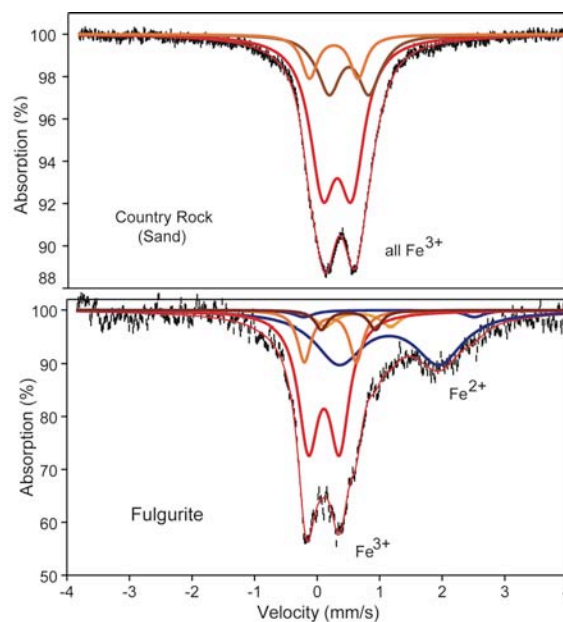


Figure 1: Mössbauer spectra of the Monahans, TX, sand (top) and fulgurite glass (bottom). Fe in the sand is entirely Fe^{3+} , but 43% of it has been reduced to Fe^{2+} in the fulgurite glass.

^{57}Fe Mössbauer spectroscopy shows that seven of the samples are reduced from their starting materials (Table 1, Figure 1): Black Rock, UT fulgurite; Monahans, TX fulgurite; Trinitite; Farmington, CT fulgurite; Mt. Ararat, Turkey; West Virginia; and

Algeria fulgurites. These samples either have a smaller percentage of Fe^{3+} in the glass than the country rock or have formed Fe metal. Fe metal was detected in the West Virginia; Algeria; and Black Rock, UT, fulgurites. In the Farmington, CT, fulgurite, iron metal droplets were found that were large enough to be removed from the glass before analysis.

Starke A, FL, is within the errors of the fitting method for the spectra. Its low total Fe content may have contributed to unusually high errors in the fit of the Mössbauer spectra. The Cline Butte, OR, fulgurite glass appears to be oxidized from its starting material.

Sample	Wt % Fe	% Fe^{3+}	% Fe^{2+}	% Fe^0
Starke A, FL glass	0.07	58	42	0
“ “ country rock		57	43	0
West Virginia glass	0.08	33	19	49
“ “ country rock		12	88	0
Black Rock, UT glass	0.14	37	15	48
“ “ country rock		54	20	27
Monahans, TX glass	0.18	57	43	0
“ “ sand		100	0	0
Trinitite glass	2.35	9	91	0
“ “ sand		75	25	0
Farmington, CT glass	3.13	3	97	0
“ “ country rock		16	84	0
Algeria glass	3.46	20	36	43
“ “ country rock		34	45	21
Cline Butte, OR glass	3.61	30	70	0
“ “ country rock		18	82	0
Mt Ararat glass	5.06	41	59	0
“ “ country rock		45	55	0

Table 1: Microprobe analyses of wt% Fe and Mössbauer spectroscopy results of fulgurite glasses and starting materials. Seven of the glasses are reduced (having lower % Fe^{3+} or forming Fe metal) from their starting materials, Starke A, FL, is within error of its starting material, and Cline Butte, OR, appears to be oxidized.

Discussion: The effects of shock on the redox state of Fe in materials have been studied for only a limited number of phases. For example, feldspar becomes significantly reduced when shocked to pressures above the transition to maskelynite [e.g., 7, 8]. Fe in diopside also appears to reduce when shocked [9], though other work on pyroxene that did not observe reduction may imply that the extent of the reduction is related to bulk composition [10, 11]. Based on these studies, the overall reducing trend observed in fulgurites is consistent. There is also an implication that variations in mineralogy and

composition of the country rock may affect the extent of reduction by lightning strikes.

The extent of reduction may also depend on other factors such as porosity, energy and entropy of the event, and the presence of reducing agents such as carbon. Our results do not show a clear correlation with wt% Fe or with any other element; however, fulgurite glass is often inhomogeneous, and the composition and degree of reduction can vary greatly throughout the sample. The areas that reached the highest temperature, most easily identified as the center of the tube in tubular fulgurites, are the most homogenous. The glass becomes less well-mixed towards the outside of the tube, often with partially melted and unmelted grains cemented into the glass. Evidence for carbon was only seen in the Farmington, CT, fulgurite, but it does not appear to have been a major contributor to the reduction.

Previous work modeling the chemistry of tektites found that their formation conditions are intrinsically reducing [4]. In the case of tektites, the starting material is strongly shocked, causing an irreversible jump in pressure and temperature that will then release along a constant entropy path. As the liquid cools, it reaches a blocking temperature where it can no longer equilibrate with the surrounding vapor. Excess oxygen in the vapor escapes and leaves the tektite liquid reduced.

The formation of fulgurites is similar. Although the pressure remains near atmospheric, electrical heating causes a rapid, irreversible jump in temperature. The fulgurite liquid also cools isentropically, and it rapidly quenches maintaining the high temperature equilibrium. The vapor escapes into the atmosphere. The Mössbauer spectroscopy results support this model, because the majority of the fulgurite glasses are reduced compared to their starting materials.

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