Fulgurites: "Paleo-Lightning" Remnants

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Originally published in
Meteorology 4990
Dr. William Beasley
December 4, 1992

ORIGINALLY PUBLISHED IN
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Introduction

A general description of a fulgurite is a vitreous tube and crust formed by the fusion of sand by lightning. There are two basic types of fulgurites that have been recognized. The most common, or at least commonly found, is a sand fulgurite, which fits the above general definition. The other type is called a rock fulgurite, as is formed when lightning strikes solid rock and creates a superficial coating of glass. The word 'fulgurite' comes from the Latin word 'fulgur' which means lightning.

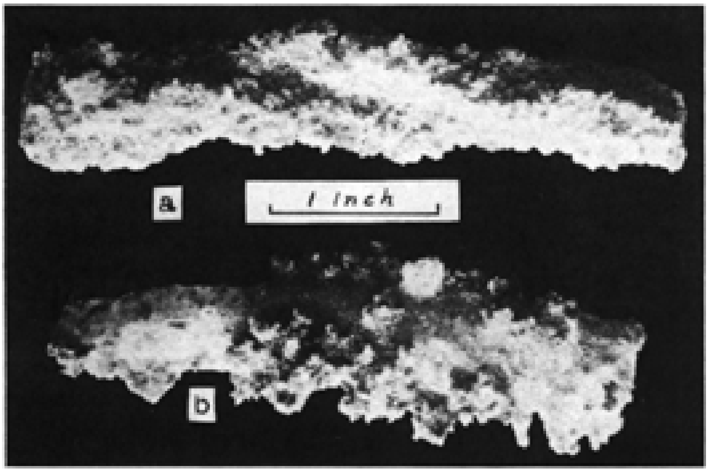

Figure 1: Fulgurites with ridged (a) and with spiny (b) surfaces. (Petty, 1936, p. 189)

Fulgurites are relatively rare occurring 'rocks' in nature. I use the term 'rocks' loosely because by definition, fulgurites fit, although they are formed from another force in nature from the under the Earth's surface or from forces on the surface. According to Plummer (1991), the definition of a rock is a "naturally formed, consolidated material composed of grains of one or more minerals." To go one step further, a mineral is a naturally occurring, inorganic crystalline solid with a definite chemical composition and characteristic physical properties.

If we think about how a fulgurite is formed, we would classify it as a metamorphic rock. Metamorphic rocks are derived from preexisting rocks and changed by heat and/or pressure. In this case extreme heat has changed the preexisting rock into a fulgurite in the immediate vicinity of the lightning strike.

Historical Accounts

The earliest recorded discovery of a fulgurites was in 1706 by Pastor David Hermann in Germany. In 1805, Dr. Hentzen was credited with recognizing the true character of the tubes found in the sand dunes of the Sennerheide near Padderborn, Germany (Petty, 1936 and Gailliot, 1980). The first compre-

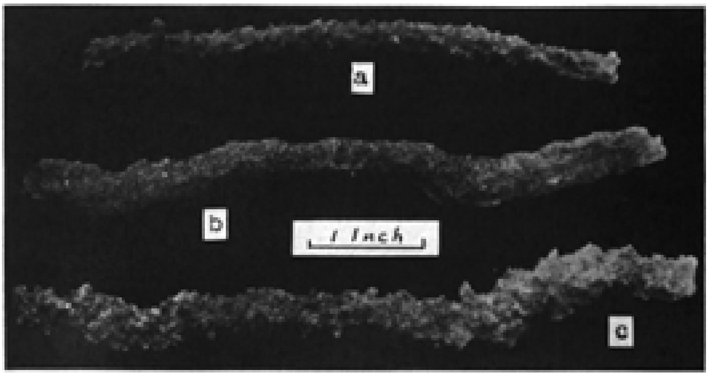

Figure 2: Fulgurites with a warty (a, c) and with a slightly ridged (b) surfaces. (Petty, 1936, p. 190)

hensive paper was written by a student at Gottingen named Fielder in 1817.

Fulgurites were first identified in the United States by Dr. A. Cobb of Montague, Massachusetts at Northfield Farms in 1910. He gave the fulgurite to Hitchcock, who described the discovery as "some kind of slag, more or less tubular, with cavities glazed on the inside and rough on the outside; looking externally somewhat like branched coral..." (Hitchcock, 1861). He went on to write that the specimens "...are obviously fulgurites."

Lightning tubes, or fulgurites, have been reported worldwide. Sand fulgurites are where usually large quantities of loose, dry sand is present. Reports have come in from the Atlantic coast, the shores of Lake Michigan, Maine, New Jersey, California, Oregon, Florida, and even Oklahoma. Rock fulgurites are common on mountain peaks around the world, such as the Swiss Alps, the Rockies in Mexico and Oregon, the Pyrenees, and the Caucasus mountains.

General Description

As described above, fulgurites is the name given to glassy tubes produced by the fusion of sand or silicious soil by lightning and to superficial coatings of glass formed on rocks. The

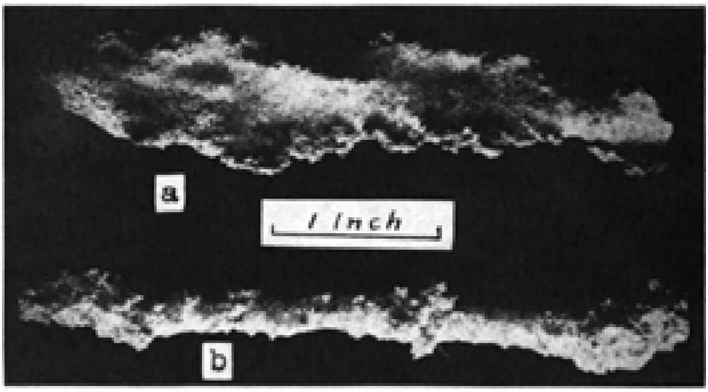

Figure 3: Fulgurites with winged projections (a) and with ring enlargements (b). (Petty, 1936, p. 190)

two types of fulgurites, sand and rock fulgurites, need to be described individually.

Sand fulgurites are externally characterized by a rough surface covered with partially fused grains of sand. The exterior color varies from yellow to light brown and a dull white (Myers and Peck, 1925) or a medium-gray color (Rogers, 1946). The coloring may be due to the ferric oxide in the sand, or other impurities and composition of the sand. The structure resembles a shriveled root, more or less hollow and somewhat branching. It appears as an irregular, cylindrical object composed of quartz sand grains. Sand, by definition, are sediment particles ranging from 1/16 to 2 millimeters in diameter. I interpret "sand" fulgurites as those forming from sand-sized grains, rather than strictly by a pure 'sand' (quartz) composition. Usually the fulgurites are found in a fairly clean, loose, dry sand.

The tubes found have been up to three inches or more in diameter and several inches in lengths with rare reports of lengths up to 30 feet (Petty, 1936). Petty collected tubes as much as 60 feet below the surface of the sand in a pit at Dixiana, South Carolina. Figures 1 through 6 depict several specimens of sand fulgurites. In cross-section, the fulgurite is usually elliptical or even jagged with three to five corners (Gailliot, 1980) with a hollow center. Some walls of the fulgurites have collapsed, thus sealing off the once-hollow center. The walls of fulgurites vary

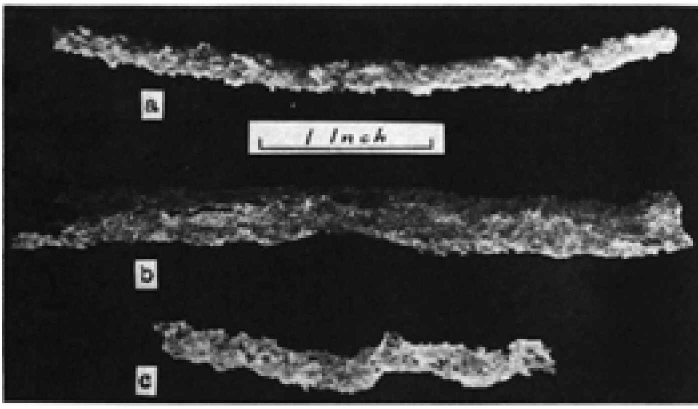

Figure 4: Fulgurites with lace-like walls (b, c). (Petty, 1936, p. 191)

in thickness from paper-thin to 2 millimeters. No relation seems to exist between the size of the tube or its bore and the thickness of the wall (Petty, 1936).

A downward tapering is reported in most of the fulgurites. Several excavated ones of 15 to 20 feet in length have not decreased in size with depth. Barrows reports a fulgurite tube running at an angle of ten degrees to the horizontal for the entire length recovered (Petty, 1936). Others have been found in a nearly vertical attitude.

Numerous discoveries had a slightly spiral twist on the exterior of the fulgurite. A specimen from Illinois had corrugations on the outside running longitudinally. Another sample from Waterville, Maine had a straight spiral twist in the opposite direction on opposite sides of the tube (Figure 7). Bayley (1892) wrote that "these irregularities on the surfaces of sand fulgurites are due, not to the collapsing of the walls of the tube, ...but to the selective power of the electricity in directing its course through the sand." Other spiral fulgurites have been found in Wisconsin (Figure 8) indicating that this feature is not accidental, but due to the condition of the lightning discharge or by the influence of the earth's magnetic field upon the discharge.

Another interesting external surface feature on many fulgurites are the spiny projections which may be either solid or tu-

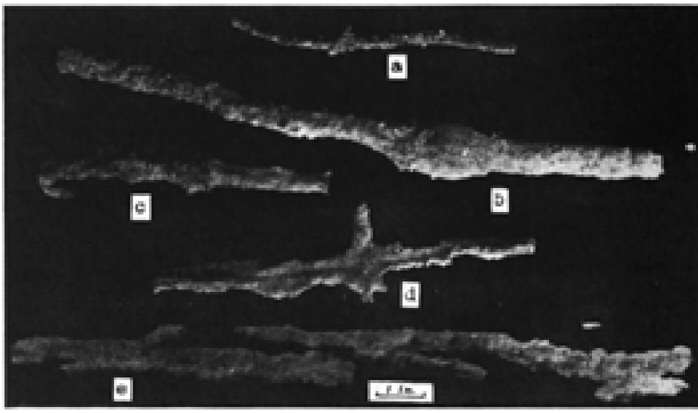

Figure 5: Fulgurites with tube enlargements (a, b, c, d) and a tube (e) which branches and the tubes reunite. (Petty, 1936, p. 191)

bular and extend outward as much as one inch (Figures 1-6). Overall, fulgurites have the same surface character for the entire length with only minor variations within short distances.

Occasionally, the sand contains amounts of feldspar, hornblende, and slate with the quartz grains. Other identified minerals of the sand are biotite, magnetite, zircon, and other igneous rock fragments (Rogers, 1946). This fulgurite composition would indicate that its source was from an igneous rock, granodiorite or one similar.

The interior of a fulgurite appears to be a glass with an inclusion of bubbles. The silica glass of sand fulgurites was named lechatelierite by Alfred Lacroix after Henry le Châtelier, a noted French chemist (Encyclopedia Britannica, 1968). The smooth and glassy interior varies from an opaque white to colorless, or slightly greenish or yellowish in tiny grains (Gailliot, 1980). The majority of the bubbles are concentrated in the outer sections of the walls and are generally arranged with their long axes pointing toward the center (Myers and Peck, 1925). However, Figure 9 depicts a cross-section of a fulgurite showing the general features magnified eight times Rogers (1925) "detected water, upon heating in a closed tube a fulgurite containing many bubbles, thus confirming (our) conclusion that the bubbles are due to entrapped steam." A more detailed explanation can be

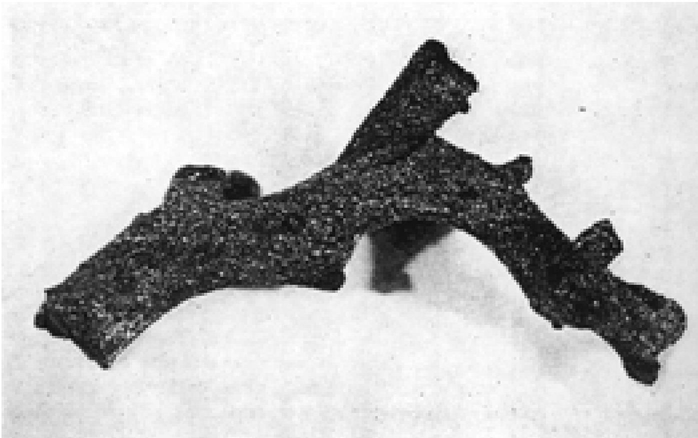

Figure 6: Sand fulgurite from the region around Indio, Riverside County, California. Natural size. (Rogers, 1946, p. 118)

found in Julien's paper (1901). Figures 10 and 11 from Julien's work illustrate both a cross-section and a lateral section of the same sand fulgurite from Poland.

Upon further microscopic observations, other minerals such as cristobalite and mullite have been formed from conversion of quartz. These "cristobalite pseudomorphs or rims of cristobalite may be present around the quartz grains" (Gailliot, 1980). "A few areas of parallel needles possessing high index, parallel extinction," (features observed using a polarized microscope), "and positive elongation were found to be present in places. These are probably mullite of Rowen" (Myers and Peck, 1925). They went on to write that the presence of mullite is due to the shot time the mass was liquid, thus giving the alumina of the clay insufficient opportunity to be thoroughly disseminated through the silica glass for complete solution. This would yield a high concentration of alumina of which mullite is comprised.

Four specimens of sand fulgurites were analyzed by Frondel (1962) and are summarized in Table 1. The four were located in Germany, New Jersey, Illinois, and Holland. As expected, the majority of the fulgurite is silica (SiO_2). The remaining composition is ferric oxide, alumina oxide (mullite), and other oxides with calcium, magnesium, sodium and potassium.

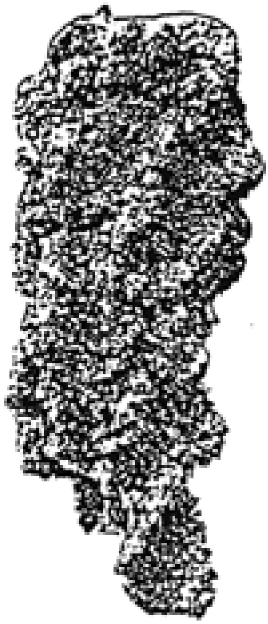

Figure 7: Corregations with a spiral twist on a fulgurite speciman from Waterville, Maine. (Bayley, 1892, p. 328)

Fulgurites found in rocks are very different than the more common sand fulgurites. Accounts from around the world have been recorded in a variety of solid rocks. Fulgurites have been found in igneous rocks such as gabbro, augite-andesite, basalt, and serpentinized peridotites. Others were in metamorphic rocks of gneiss, mica schist, and hornblende schist.

Nearly all of the rock fulgurite is either superficial or confined to the lining of preexisting cavities within a rock body (Figure 12). A wider variety of colors is exhibited in the rock fulgurites, probably due to the composition of the host rock. Many samples are dulled by weathering of the rock, thus making analysis difficult.

A rock fulgurite crust on gneiss has been produced almost entirely by fusion of surfaces of feldspar grains, rather than quartz (Julien, 1901). The bubbles were formed chiefly to expansion of air, but some water was most likely trapped in the weathered rock surface. This sample also showed partial devitrification. Other specimens of rock fulgurite exhibit formation along preexisting cavities as in the one found in an augite-andesite in Armenia. This would serve as a path of least resistance for the light-

	1	2	3	4
SiO_2	93.8	99.0	91.66	90.2
Fe_2O_3	3.8	0.3	6.69	0.7
Al_2O_3		0.7		0.9
CaO	0.6		0.38	0.1
MgO			0.12	0.5
Na_2O			0.77	0.6
K_2O			0.73	0.5
Rem.			0.33	6.5
Total	98.2	100.2	100.68	100.5

1. Germany 2. New Jersey 3. Illinois 4. Holland

Table 1: Analysis of Fulgurites (Froundel, 1962)

Figure 8: Spiral fulgurite from Cutler, Wisconsin, showing opposite sides. The units in the scale are inches. a,a,a in the figure on the left, horn-like protuberances terminating the fulgurite. b of the same portion of the figure, corrugateds broken open open and exhibiting thin-walled tubes. a in figure at the right, point of emergence

ning discharge. Table 2 summarizes the chemical composition of a fulgurite and its host augite-andesite groundmass (Diller, 1884).

A small portion of a rock fulgurite from Oregon seemed to have been produced within the adjoining compact rock by fusing the groundmass (Diller, 1884). The heat produced by the lightning in the rock is very brief. "The high temperature of any individual crystal within the heterogeneous path of the current may depend chiefly upon the resistance which that mineral offers" (Diller, 1884).

Frenzel wrote of several discoveries in Europe. Many of these rock fulgurite specimens were enriched in silica and weakly en-

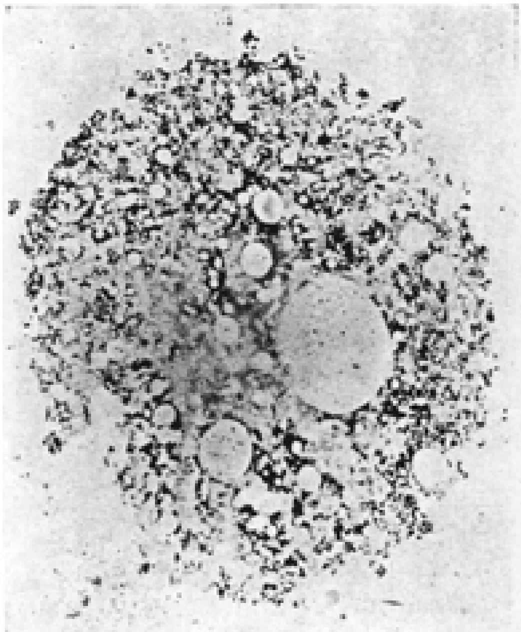

Figure 9: Cross-section of sand fulgurite showing general features. X8. (Rogers, 1946, p. 119)

riched alkalis, especially potassium. The calcium content was reduced, and the concentrations of iron and manganese were low when compared to the peridotite parent rock (Frenzel and Stahl, 1982). Rapid partial melting and volatilization of the quartz in other samples yielded the same general results. Lechatelierite was identified at the rims, as in the sand fulgurites (Frenzel, Irouschek-Zumthor, and Stahle, 1989).

There is considerable variation in the characteristics of rock fulgurites. Julien (1901) outlined two probable causes: “the variation in the electric current, in regard to volume, intensity, duration, and a probable series of

	Fulgurite	Groundmass
Silica (SiO_2)	55.04	55.85
Alumina (Al_2O_3)	28.99	22.95
Ferric oxide (Fe_2O_3)		4.59
Lime (CaO)	7.86	8.41
Magnesia (MgO)	5.85	3.08
Potash (K_2O)		2.67
Soda (Na_2O)		2.16
Loss by ignition	1.11	0.52
	98.85	100.23

Table 2: Fulgurite and groundmass chemical composition from Oregon. (Diller, 1884, p. 257)

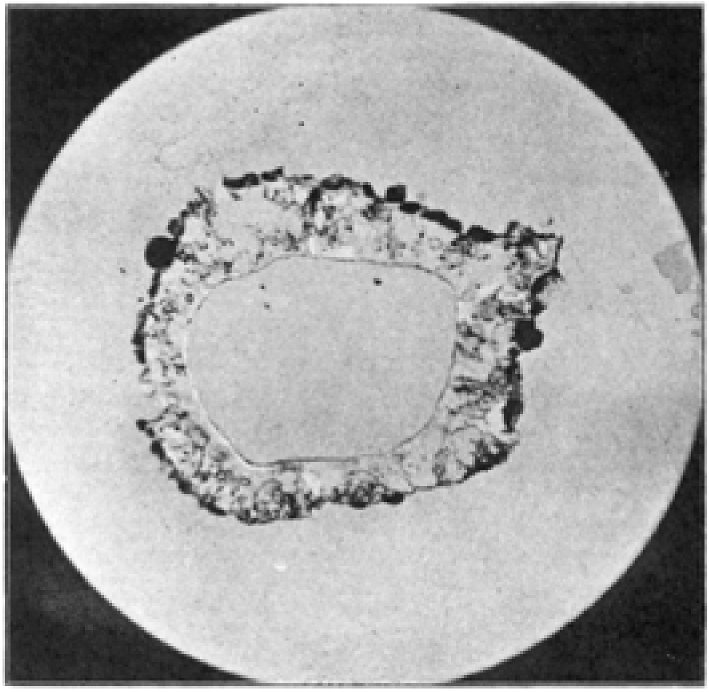

Figure 10: Sand-Fulgurite, Poland. X10. Photomicrograph of cross-section. (Julien, 1901, p. 674)

successive discharges, in some cases, within the same fulgurite; and the difference of the rock material" in the various rock fulgurites.

Occurrence

Sand and rock fulgurites are found in very different environments. Sand fulgurites are usually found where the sand has not been too disturbed, due to their fragile nature. The sands are generally fine to course in texture, primarily composed of quartz, and often cross-bedded. The process of erosion assists in removing the overlying soil, and leaves the tubes projecting or lying on the surface. Sand fulgurites are usually found in relatively dry sand and extend down to the water table or other wet layer. This groundwater table or wet stratum determines

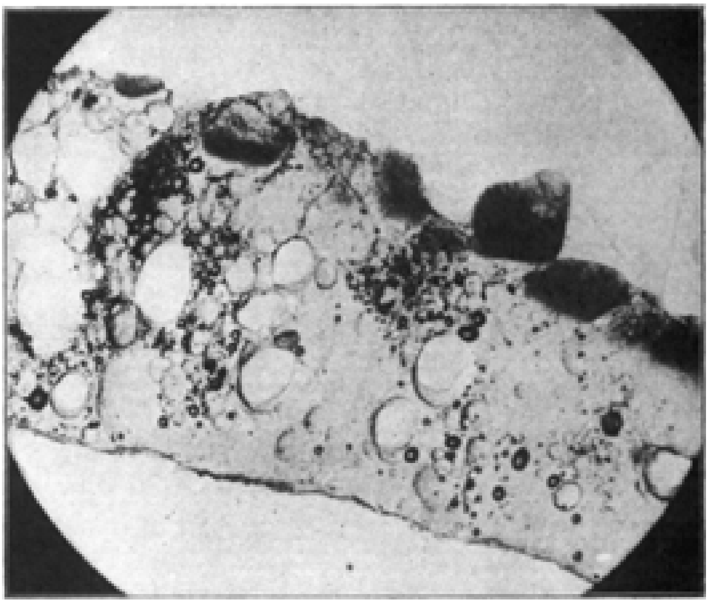

Figure 11: The same. X50. Part of wall. (Julien, 1901, p. 676)

the downward limit of the fulgurite (Petty, 1936). Inclined bedding may divert the fulgurite's course. The length of the tubes depends on the intensity of the lightning's discharge and the thickness of the sand layer according to Petty (1936).

Rock fulgurites are more common on mountain peaks or other high points relative to the surrounding land. Rocks rich in iron minerals may attract lightning with greater frequency.

Origin

Fulgurite formation is due to the expansion of air and what little moisture is present for a tubular sand fulgurite to form. The amount of sand melted to form the tube depends on the energy expended in the form of heat. The melted material making a cylindrical shape due to surface tension according to Petty (1936). Some tubes collapse before solidification of the glass is complete and may be related to the length of time of the discharge (Petty, 1936).

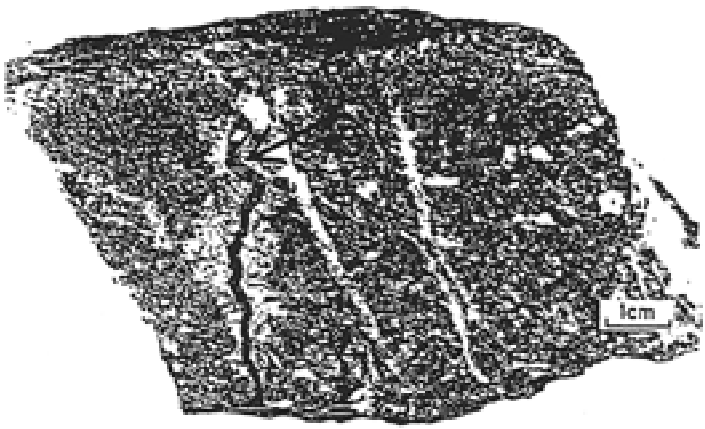

Figure 12: Fulgurite from Switzerland. (Frenzel and Stahl, 1984, p. 19)

The temperature of the lightning would cool as it entered the lower temperature sand or rock. The temperature to melt sand is about 1400 to 1800° C. Lightning may reach temperatures much greater than this, and therefore melts the surrounding quartz grains within 100 microseconds. Variation in temperature is evidently due to differences in electrical resistance from point to point (Rogers, 1946). As in some igneous rocks, which are formed from molten material, fulgurites have a glassy interior texture due to the sudden cooling. When liquid or molten material is cooled very rapidly, the atoms do not have time to arrange themselves in a very orderly atomic arrangement. The result is a glass, often containing bubbles as in many sand fulgurites.

Artificial Fulgurites

In 1868, experiments were seriously conducted by Rollman, although experiments had been made as early as 1828 (Petty, 1936). Artificial fulgurites were made by passing an electrical current into a ground pail of quartz sand containing some feldspar (Figure 13). Petty (1936) wrote that occasionally when high tension wires are grounded conditions are favorable for the production of artificial fulgurites.

Figure 13: Artificial fulgurite made by passing electric current into grounded ten-quart pail of sand. (Courtesy General Electrical Company, Pittsfield, Mass.) (Petty, 1936, p. 197)

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THE EVENT

Petrified Lightning from Central Florida

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