ON FULGURITES.

By GEORGE P. MERRILL.

(With one plate.)

Numerous papers on this subject have from time to time appeared, the more recent being those of Wichmann,* Diller,† and Rutley,‡ the last two treating principally of fulgurites formed on solid rock while the first named describes both those formed on the solid rock and the tubular varieties formed in loose sand. The subject is by no means a new one. The earliest notices I am able to find relating to it are those given in the Transactions of the London Philosophical Society for 1790, and in the papers of Fiedler and Gilbert in the Annalen der Physik for 1817 and 1819. Since then periodic papers have appeared in various journals, not all of which I have had access to and concerning whose contents I have to judge from notices given of them in subsequent publications.

So far as I am able to learn the most extensive notices regarding the mode of occurrence of tubular fulgurites (those formed in loose sand) are those given by Fiedler,§ Gilbert, Darwin, and Roemer, while the chemical and microscopic side of the question, that relating to the composition and structure of the resultant glass, is most fully discussed by Gumbel, || Harting,** and Wichmann.††

Unfortunately none of these gentlemen made complete chemical analyses of the purely glassy portion of the fulgurite, and though their papers are full of interest as showing *something* of the actual composition and structure of the glass, none of them give any information regarding this composition relative to the sand in which they were formed.

The National Museum has recently received from Mr. Silas Stearns, of Pensacola, Florida, Messrs. E. L. and A. N. Abbott, of Union Grove, Whitesides County, Illinois, and Mr. C. T. Mason, of Sumter, South Carolina, some very interesting fulgurites of the tubular variety, formed by the lightning striking in loose sand. As these gentlemen furnished full notes regarding the localities and mode of occurrence of these, I have decided to publish in full what information I can glean from them, together with such notes on chemical tests as have been possible under the circumstances, even at the risk of duplicating in part the work of previous observers.

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* Zeit. der Deut. Geol. Gesell., XXXV, p. 487.

†Am. Jour. Sci., XXVIII, 1884, p. 252.

‡ Quar. Jour. Geol. Soc., May, 1885, p. 152.

§ See bibliography at end of this article.

‖ Zeit. der Deut. Geol. Gesell., 1882, p. 647.

**Ann. de Mines, vol. VIII, 1825, p. 200.

†† *Op. cit.*

The tubes received from Mr. Stearns were two in number, each some 50 mm in length and 10 mm in greatest diameter, tapering gradually toward one end. One of these was still in the form of a cylindrical tube, while the second was completely collapsed, so that its internal walls were in contact. Both were of very light gray color, with numerous slight corrugations on their outer surfaces, but, with all, smooth and glassy throughout, with no unfused particles sticking to their outer surfaces, as is commonly the case. The tube walls are about a half millimeter in thickness, and are pierced by numerous minute holes, the edges of which are rounded from fusion. Interiorly the tubes are brightly glazed, while exteriorly they are dull and somewhat rough. Under the microscope, as noted by Diller,* they appear, for the most part, of a perfectly clear and amorphous glass, with only here and there a faint brownish stain from the presence of an iron oxide in the sand. There are also a few remnants of unfused quartz grains embedded in the glass, but they are not abundant. Concerning the occurrence of these Mr. Stearns writes me as follows:

"I had been noticing fragments of this peculiar substance (the fulgurites) among the sand dunes of Santa Rosa Island in this vicinity for a long time, when in the fall of 1882 I discovered the solution of the problem. Near the center of the island, at a point about 35 miles from Pensacola, and on the side of a sand hill, stood a small pine tree that had not long before been shattered by lightning, and about 40 feet away, on a low, level, and moist area, was a crooked interrupted line of fulgurite. One viewing the fragments from a little distance could readily make out the path of the electric fluid as it came from the tree. Upon leaving the low basin for the dryer sandy slope beyond there were no traces of fulgurites to be found.

"The hill upon which the tree stood is a sand dune, formed, as usual, of the very finest white (siliceous) sand. It had been long built, and being somewhat protected from the winds by inner and outer rows of dunes, had gathered a considerable vegetation in the form of stunted trees, bushes, and coarse grass. The low part, or basin, was so situated between the hills that a strong draft of wind always drew over it, keeping the sand from filling it up. During the rainy season such places are covered by 6 or 12 inches of water, and even in the dry summer months they are rather damp, being very near the level of the sea. * * * As to the space occupied by this particular phenomenon, I would say that the pine was 35 feet in height, the distance from the tree to the first fragment of fulgurite was 40 feet, interrupted in one place by a knoll. A considerable quantity of the material was secured when discovered, but it seems all but the pieces forwarded have disappeared."

A series of over fifty fragments of tubes were received from Messrs. E. L. and A. N. Abbott, some of which present very interesting features.

* *Loc. cit.*, p. 253.

Like those from Santa Rosa, they were formed by the lightning striking in loose sand, but while the inner surface was glazed the outer was covered with a rough coat of grains of siliceous sand, iron oxides, and organic matter, rendering the tube entirely opaque instead of translucent, as in the case already mentioned. The surfaces were also very deeply corrugated, as will be noticed in the plate. With considerable difficulty there were prepared some cross-sections of these, which were submitted to microscopic examination. The tube wall was found to be 1 or 2 millimeters in thickness, the inner portion of which consisted of a true amophous glass, colorless or stained brownish in streaks, and inclosing innumerable bubbles and a few black opaque grains, which are probably iron oxides. Fully three-fourths of the tube wall is glass, with a narrow margin of sand grains adhering to the outer portion by means of the glassy cement. No such radial arrangement of elongate bubbles as described by Wichmann and Gumbel* could be seen, neither could I find such arrangement in a cross section prepared from other fulgurites received from Sumter, S. C.† The sand in which they were found was largely siliceous, with a few feldspathic grains and iron oxides, together with a little organic matter. The following in regard to the mode of occurrence of the specimen is from Mr. Abbott's letter:

"The locality is the top of a sand knoll, and includes in area a spot about 50 feet square. Besides the tubes there was found an irregular mass, fused together, which would weigh several ounces. This mass had no connection with anything else, for it had no broken edges. The largest tube was about 3½ inches in diameter, but the glassy lining was so thin and fragile that no sections could be removed. The next in size was about 2 inches across. This was convoluted and irregular in section, giving it an appearance not unlike the rough bark of a tree. * * * This fulgurite was traced into the sand 7 feet, increasing somewhat in size *from above downward*. In common with all others found, its course was nearly straight and vertical. On this and several other of the specimens were found small flat branches running horizontally for several feet. These were about one-fourth of an inch wide and half as thick, the greater diameter being horizontal, and the longitudinal hole being quite small and entirely absent toward the end, which terminated abruptly. Of a different nature was a short branch on the specimen, about the size and shape of a man's thumb; this was inclined slightly upward. A number of other fulgurites were found ranging in diameter down to a quarter of an inch, but having the same general features, except that they were more regular and cylindrical in section. * * * One peculiar fulgurite was found having bulb-like enlarge-

* *Op. cit.*, p. 852 and 648.

† The gift of Mr. C. T. Mason. These last were very thick and strong, and were stated by Mr. Mason to have been found while digging a well, at a depth of 20 feet below the surface. The thickness of the glassy lining was in one case nearly 2 mm. These lacked the wing-like corrugations shown in the plate, but had more the knotted appearance compared by Gumbel to that of stag-horns.

ments. The tube was about three-eighths of an inch in diameter and the enlargements about three-fourths of an inch in diameter (see Fig.—), and their distance apart about 4 inches. They corresponded to the stratification of the sand, and were without doubt caused by it." (See Fig. 2 of plate.)

To ascertain the comparative composition of the glass and sand a quantity of fragments were taken, and after pulverization and separation in the usual manner by the double iodide of mercury and potassium solution, the glass, together with a portion of the sand in which they were formed, was submitted to Professor Clarke, of the Geological Survey, for examination, with the results given below:

	Fulgurite glass.	Sand.
Ignition	.33	1.01
SiO_2	91.66	84.83
Fe_2O_3*Al_2O_3	6.69	9.88
CaO	.38	1.16
MgO	.12	.13
K_2O	.73	1.13
Na_2O	.77	1.50
	100.68	99.64

* Wichmann found the silica percentage of fulgurite glass from Senner Heide to be 96.44; from Elspect, 94.26; from Starczynon, 91.23. He does not give the composition of the sand in which they formed (*op. cit.*, p. 854).

Harting gives the composition of the Elspect fulgurites (presumably both fused and unfused portions) as follows: SiO_2, 90.2 per cent.; Al_2O_3, 0.9 per cent.; Fe_2O_3, 0.7 per cent.; CaO, 0.1 per cent.; MgO, 0 5 per cent.; KO, 0.5 per cent.; NaO, 0.6 per cent; Insol.—HCl, 0.9 per cent.; carbonaceous matter, 5.6 per cent. In the Annual Record of Science and Industry for 1874, p. 228, it is stated that analyses of fulgurites made by Scholz showed them to consist essentially of "carbonates of the alkaline earths, about 85 per cent. being carbonate of lime and 11 per cent. carbonate of strontia." (?)

The results being somewhat different from what was anticipated, and fearing there had been some mistake, and that the sand was not the same as that in which the fulgurite formed, I wrote again to the Messrs. Abbott, one of whom kindly visited the locality a second time and obtained a further supply of material. He also visited another sand bank about 1 mile distant, and obtained there also samples of both sand and fulgurite. These last were very frail, about 1^{cm} in diameter, quite cylindrical, and free from corrugations. Mr. Abbott states he does not consider them "main tubes," but as branches; moreover, they did not pass perpendicularly into the sand, nor was their angle of dip constant, but varied from a few degrees from the perpendicular at the surface to within 10 or 15 degrees of the horizontal. The two branches were about 2 rods apart, one dipping to the southwest and the other almost to the east.

These branches were followed down to distances of 3 or 4 feet below the surface, and samples of both fulgurite and the inclosing sand forwarded to the Museum. Portions of these were pulverized as before and separations made. Some difficulty was experienced in getting a sufficient quantity of material for analysis, since, owing to the varying specific gravity of different portions of the glass caused by the included cavities, portions came down with the still unfused quartz kernels, while others floated to the very last. Two precipitations were made and laid

aside as of not sufficient purity, but the third was almost pure colorless glass with only rarely a stain from iron oxides. This had a specific gravity 2.197, and yielded Professor Clarke 95.91 per cent. of silica, while the sand gave but about 90 per cent.

The results shown by the two analyses are peculiar, and at first glance may seem difficult to account for. Had the lightning shown no selective power the resultant glass would possess the same composition as the sand in which it formed. Had it exercised such power one would naturally expect those minerals which are, under ordinary conditions, most fusible, *i. e.*, the feldspars and iron oxides, to be first acted upon, and hence that the glass would approach them in composition.*

In the case in hand the reverse of this *seems* to have taken place, the ordinarily infusible quartz having been most acted upon, while the other constituents in large part escaped,† thus yielding a glass from 5.91 to 6.83 per cent. richer in silica and relatively poorer in potash, soda, lime, iron, and alumina than the sand in which it formed. Conceding that the results obtained are correct, and that the composition of the sand examined is the same as when the fulgurites were formed, they may, perhaps, be accounted for as follows: When the lightning strikes a heterogeneous mass, as a bed of sand, the various grains or particles composing it will become unequally heated in proportion to their conducting powers, those substances which are the best conductors escaping with least injury while the poorer conductors present so strong a resistance as to become heated even to the point of fusion, hence the composition of the glass will depend upon the relative conductivity of the components of the sand, regardless of their fusibility.‡

Accepting the above as correct, it follows as a legitimate conclusion that the quartz grains composing the sand were poorer conductors of the electric fluid than either the iron oxides or the feldspar. The subject of the relative conductivity of minerals has, however, been too little investigated to afford reliable data for the confirmation or refutation of this.

The fulgurites from which the second silica tests were made were very thin walled and fragile, with scarcely a trace of the convolutions present in the larger forms. These also increased slightly in size from above downward, but grew correspondingly thinner and more fragile. This lack of corrugation even in so frail tubes I was at first inclined to

* "So far as observations have yet been made upon the production of fulgurite by the fusion of a heterogeneous rock it appears that the amount of melting experienced by each ingredient depends chiefly upon its degree of fusibility." (Diller, *op. cit.*, p. 258.)

† So at least it would appear to the writer, rather than as suggested by Mr. Abbott and others, that certain of the more basic substances had been volatilized by the extreme heat engenerated.

‡ The extraordinarily brief duration of the flash and consequent heat would, it seems to me, render it extremely improbable that any one mineral of comparative easy fusibility served as flux and thus aided in reducing the more refractory, as suggested by Wichmann and Harting.

believe to be due, as suggested by Mr. Abbott, to their having been formed at such a depth below the surface that the compactness of the sand prevented their collapsing. Further examination caused me to doubt this for reasons to be noted later.

Accompanying the tubes were several small irregularly rounded lumps of fulgurites without the tubular openings, resembling nothing more than as if a ladle of the molten matter had been poured out upon the ground and "spattered," as suggested by Mr. Abbott. The largest of these was some 2^{cm}. broad, and 5 to 6^{mm}. in thickness, and weighed about $2\frac{1}{2}$ grams. An average of four determinations on these blebs gave a specific gravity of 2.07.

A thin section of the largest sample showed it to be completely amorphous, with only here and there a small grain of sand adhering to its outer surface. This glass is nearly colorless, with occasionally a brownish or yellowish stain from iron oxides, and carries many bubbles. In a few instances what appears like fluidal structure was observed, but the appearance was not as if any considerable portion of the mass had moved, but rather as if the sudden expansion of a steam bubble had pushed the still fluid or plastic material to one side, causing a local development of very limited area. The size of this mass led me to look with considerable care for the presence of products of crystallization. None such, however, were observed, either in the isolated blebs or the glass of the tube walls, my own observations agreeing in this respect with those of Diller, Wichmann, and others.

The peculiar corrugations, or wing-like projections from the sides of the tubes, I cannot (in company with Wichmann) believe to be due in all cases to the partial collapsing of the tube through pressure from without, but rather to inequalities in the sand, together with, perhaps, unequal contraction due to rapid cooling. I cannot conceive how pressure, however applied, could give rise to such peculiar forms which have an appearance, as suggested by Darwin and Fiedler, closely resembling a shrunken vegetable stalk or the bark of the elm or cork tree (Figs. 1 and 3). The fact that these, although usually extending in a direction approximately parallel to the length of the tube, start out at any point in such a very irregular manner, and occasionally at very nearly right angles to the length of the tube, seems in itself a sufficient objection to this idea. Is it not more probable that they are formed by the lightning's following out the path of least resistance, causing the bore to be enlarged here and contracted there in accordance with the conductibility of those portions through which it passed (and the amount of moisture they contained), and that the small branches and wings, sometimes mere points, are lateral offshoots? The absolute contact, in some cases, of the inner walls of the wings, together with the fluidal structure extending from within outward, as noted by Wichmann, would, it seems to me, tend to prove that they are original structures, and in no way caused by a subsequent collapsing. I fail, moreover, to see that we have any grounds for expecting the bore of lightning to be evenly cylindrical,

although observations on this point are lacking. In this connection Fig. 4 is of interest, being an accurate representation, natural size, of the holes made by lightning in a hollow copper ball or globe that formerly surmounted a flag-staff on the Old Capitol Prison in this city, but is now in the collection of the National Museum. Four holes were made in all within a space of some 2 by 6 inches. Two considerably larger than the others and more nearly circular in outline, while the two smaller had the form shown in the cut. Their resemblance to the outline of a cross-section of some of the fulgurites is quite striking.*

On the whole, it appears to the writer that the irregularity in outline of the tubes near the surface is due to the exceeding energetic action of the current during the first part of its course and the lack of homogeneity in the conducting material. At greater depths, where the force has been to some extent reduced and the sand is more compact and homogeneous, the tube is therefore more nearly cylindrical. In Fig. 1 it will be noticed the tube at the very top is about 12^{mm} in diameter, but almost immediately enlarges to about 35^{mm}, whence it again gradually tapers off to a diameter (not including the wings) of about 10^{mm}. This enlargement is not merely superficial, but the tube walls remain approximately of a thickness throughout. In Fig. 2 the bulb-like enlargement, which Mr. Abbott says corresponds to the stratification of the sand, I find to be filled with a firm nearly white quartz sand, with but a small hole or rift on one side, through which a portion of the electric fluid seems to have passed without fusion, while the whole inner wall of the bulb itself is glazed like the rest of the tube. Another interesting fragment is 3^{cm} long and about as broad, and only about 1^{cm} in thickness. In this there is a single orifice at the top and two at each corner of the bottom, the one at the lower left-hand corner being the largest. Held to the light the fragment is found to be riddled with small holes as though made by the point of a pin.

Aside from the interest on account of the peculiar form of the fulgurites and the composition of the glass, the case is remarkable on account of the number of specimens occurring in so limited an area, Mr. Abbott stating that he found "several pairs or couples (of tubes) situated only a few inches apart." Concerning a similar occurrence at Maldonado, Darwin expressed the opinion that the flash for some unknown reason was divided into several branches prior to striking the sand, rather than that the several bores were caused by distinct flashes. Facts given concerning the Whitesides County tubes would seem to show that while the closely adjoining ones may have been formed by a single flash, yet throughout the region examined there were at least three independent sets of tubes that must have required as many distinct discharges for their production.

* In each of these cases the fused copper has run back upon the outer surface of the globe, and the appearance of the hole itself is as though no other agency than that of heat had been employed in their production.

The cause of this frequent striking of lightning in similar situations has been discussed by Dr. Fiedler and others in the papers noted below.

SUPPLEMENTARY NOTE.—Since the above was written we have received from Mr. S. T. Walker, Milton, Florida, two fragments of fulgurite from that place. These are each some 65^{mm} in length by 10^{mm} in greatest diameter, being both somewhat flattened. Exteriorly they resemble those from Sumter, South Carolina, lacking the deep corrugations or wings, but being very rough and scoriaceous. The color varies from gray to dull ferruginous red, while the glassy lining, which in some places is 5^{mm} in thickness, is a dull lusterless black. Under the microscope this lining displays the properties of a true glass beautifully streaked with deep smoky brown. The many steam cavities show no definite order of arrangement, though the smaller ones are often grouped in dense aggregates, while the larger ones, often 1^{mm} across, are usually single. These show a peculiar corona of brownish streaks and clouds as if the coloring matter had been suddenly injected into the glass by the development and bursting of the bubble. The glass, with the exception of a few very minute faintly polarizing specks, is entirely black between crossed nicols and shows no colors such as might be produced by stain or partial crystallization.

The following is the bibliography of fulgurites so far as I have been able to gather it from available literature:

WITHERING, WILLIAM. [On Fulgurites.]

Trans. Philos. Soc. Lond., 1790, p. 293.

Gives an account of the fusion of quartz pebbles by lightning at Aylesford, England.

FIEDLER, Dr. K. G.

Ueber Blitzröhren und ihre Entstehung. Ann. der Physik, vol. 55, 1817, p. 121–164. With two plates.

(Ein Nachtrag zu seinem Aufsatze über Blitzröhren in dieser Annalen J. 1817, S. 2, od. B. 55, S 121). *Ibid.*, pp. 235 to 248, and one plate.

Gives a very full account of the occurrence and description of fulgurites at Senner Heide, Nietleben, bei Halle, Drigg, and Aylesford, England. Discusses their origin and composition.

Gives an account of fulgurites found at Rheine, and further discusses their origin. Mentions also the finding of fulgurites on the sand hills near Blankenburg, in the Harz, and near Bahia, in Brazil.

GILBERT, Dr. L.

Noch einiges von den Blitzröhren. Ann. der Physik, vol. 61, 1819, pp. 249–262.

Gives a history of the finding of fulgurites by Pastor Hermann at Massel in Silesia, in 1706 and 1707. Credits Hentzen with having first pointed out their probable origin, and Fiedler with having first *proven* this in a satisfactory manner. Also further describes the fulgurites from Bahia, Brazil, already noted by Fiedler, and makes remarks on their origin. Describes also the fulgurites found on elevated peaks of the Mexican Cordilleras by Humboldt.

Nachtrag zu dem Aufsatze von den Blitzröhren, S. 262. *Ibid.*, pp. 315, 316.

Brief note on the Mexican fulgurites before mentioned.

Sur des tubes vitreux qui paraissent produits par des coups de foudre. Ann. de chimie et de physique, vol. xxi, 1821, pp. 290–303.

A résumé of the subject up to 1821. Compiled mainly from the papers of Fiedler and Gilbert.

DARWIN, CHARLES. [Fulgurites from Maldonado, South America.

Voyage of H. M. S. Beagle, 1833, p. 53, 54.

Gives a detailed account of the occurrence and appearance of fulgurites found by himself at Maldonado, South America.

FIEDLER, K. G.

Comptes Rendus, vol. 17, 1843.

Describes briefly a fulgurite found in a vineyard on the right bank of the river Elbe.

COBB. [Fulgurite from Northfield Farms, Mass.]

Am. Jour. Sci., vol. xxxi, 1861, p. 302.

A brief notice of a fulgurite found by a Dr. Cobb, at Northfield Farms, Mass.

SAINTER. [Fulgurite from Macclesfield, England.]

Geol. Mag., vol. ii, 1865, p. 368.

Describes briefly a fulgurite found in a bed of dry sand at Macclesfield, England.

HARTING.

Soc. Batav. Amsterdam, 1873, p. 13.*

ROSE, G.

Zeit. der Deutschen Geol. Gesellschaft, vol. lxv, 1873, p. 112.

A brief note on the fulgurites from Little Ararat, in Armenia, and Nevado de Toluca, in Mexico.

Composition of fulgurites, Ann. Record of Sci. and Ind., 1874, p. 228. Gives a note of the chemical composition of fulgurite. Taken from the Polytechnisches Journal, ccxi, 408.

HARTING.

Ann. de Mines, vol. viii, 1875, p. 700.

Gives a description and the chemical composition of fulgurite formed at Elspeet in 1872, and a brief résumé of the subject up to date.

ROEMER, F.

Ueber ein Vorkommen von Blitzröhren, oder Fulguriten, bei Starczynow, unweit Olkutz, in Königreich Prussia. Neues Jahrbuch für Mineralogie, &c., 1876, p. 33.

Describes the occurrence and appearance of fulgurites found at Starczynow.

GÜMBEL.

Ueber die Bildung der Stylolithen und über Fulgurite.

Zeit. der Deutschen Geol. Gesellschaft, xxxiv, 1882, p. 642.

Describes fulgurites from the Libyan desert between Dachel and the Ammon Oasis, and considers them to be a true quartz glass.

WICHMANN, A. Ueber Fulgurite.

Zeit. der Deutschen Geol. Gesellschaft, xxxv, 1883, pp. 849–859. One plate.

Discusses the conclusions of Gümbel regarding the composition of fulgurites, and proves by analysis that those of Senner Heide, Starczynow, and Elspeet are not true quartz glass. Describes the microscopic structure of fulgurites formed in the sand and on rock. One plate, with four figures.

DILLER, J. S. On Fulgurite from Mt. Thielson, Oregon.

Am. Jour. Sci., vol. xxviii, 1884, pp. 252–258.

Describes in detail the structure, both micro- and macroscopically, of fulgurites from the above locality, and gives results of complete chemical analysis. Also mentions fulgurites formed in loose sand at Santa Rosa Island, Florida. Five figures, showing microscopic structure.

RUTLEY, F. On Fulgurites from Mt. Blanc.

Quar. Jour. Geol. Soc., xli, 1885, p. 152.

Describes the micro- and macroscopic structure and pyrognostic properties of fulgurites as above. One plate and five figures, illustrating microscopic structure.

* I have not seen this paper.