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Fulgurites are natural glasses formed where lightning strikes bare rock or sand. They are the result of a very large electrical discharge between the earth and clouds.

The potential difference necessary for such a discharge results when minute droplets of water condense on dust particles in the atmosphere. These droplets grow until the limit of cohesion is exceeded (when the drop has a diameter of about 4mm), after which they are torn apart by rapidly ascending air currents. The smaller, lighter fragments are carried to the top of the cloud, losing electrons as the result of friction. Thus the upper portion of the cloud becomes positively charged, and the lower portion negatively charged, and an electrical potential difference exists between the top and bottom of the cloud. The earth itself becomes charged by induction and the electrons in the earth become concentrated on any protuberances on the surface.

If the electrical potential difference between oppositely charged portions of the cloud or between the cloud and the earth become great enough, discharge occurs in the form of an immense spark. The critical potential difference is generally in the range of 20 to 30 million volts. It has recently been ascertained that these discharges occur in 10 microseconds or less (Orville, 1966). High-speed photographs reveal that the stroke starts as a thin leader passing between different parts of the cloud or between cloud and earth. Immediately after the leader a return stroke occurs, traveling in the opposite direction. This is usually followed by a number of discharges and return strokes, all taking place within a few microseconds. To the eye these appear as a single stroke, and during this brief discharge a current of 60,000 to 100,000 amperes may flow. The intense heat of the discharge creates an instantaneous and explosive expansion of the atmosphere along its path. The audible result of this expansion is thunder.

Approximately two-thirds of all lightning strokes occur between different parts of clouds. The remaining one-third occurs between clouds and the earth. Many of the cloud-to-earth discharges strike high buildings, trees, and in the United States about 200 unlucky people each year, but some strike barren rock or sand.

Where lightning strikes loose sand it fuses the sand grains to glass, creating a glass-lined tubular hole protruding several inches into the sand, These structures have been given the name “lightning-tubes” (Blitzröhren). Often these tubes branch irregularly downward, and are decorated with wispy threads of glass. Some tubes, while in the molten stage, cannot withstand the pressure of the surrounding sand and are found in various stages of collapse. The fused material has a glazed appearance; it is translucent and colorless to faintly colored. Under the microscope the glass is seen to contain numerous small gas bubbles and occasional unfused remnants of quartz grains. Lightning tubes are most abundant in sand dunes, and if the loose sand is shifted by the wind they are sometimes left protruding above the surface of the dunes.

Other than sand dunes, the most common sites for the occurrence of Fulgurites are high, sharp mountain peaks devoid of tall vegetation. Fulgurites on rock in such areas were recognized by European naturalists as long ago as the late 18th century. They have been reported from Mount Shasta in California, and on Union Peak and Mount Thielsen in Oregon. Fulgurites doubtless occur on many of the high, barren peaks in the western United States, but probably have gone largely unnoticed.

MOUNT THIELSEN FULGURITE

In the summer of 1884 a party of the U.S. Geological Survey in the charge of J. S. Diller made a geological reconnaissance of the Cascade Range (Diller, 1884). One of the party climbed Mount Thielsen, situated about 15 miles north of Crater Lake (figure 1). Among the samples collected from the summit of Mount Thielsen were several of fulgurite. Mount Thielsen is a likely site for lightning strokes (figure 2). It has been referred to as the Matterhorn of the Cascades, and is, in fact, a nearly classic glacial horn. Its sides are precipitous and give way to well-formed cirques on all sides of the summit. The uppermost 100 feet of the peak are very steep and without vegetation.

The author ascended Mount Thielsen on a totally cloudless day in the summer of 1963 and collected several samples of fulgurite from the peak. The fulgurite is confined to the uppermost 5 or 10 feet of the summit. The material occurs as spattered patches of brownish black to olive-black glass scattered randomly over the basalt making up the summit pinnacle. These patches are generally between 2 cm and 10 cm in diameter, but

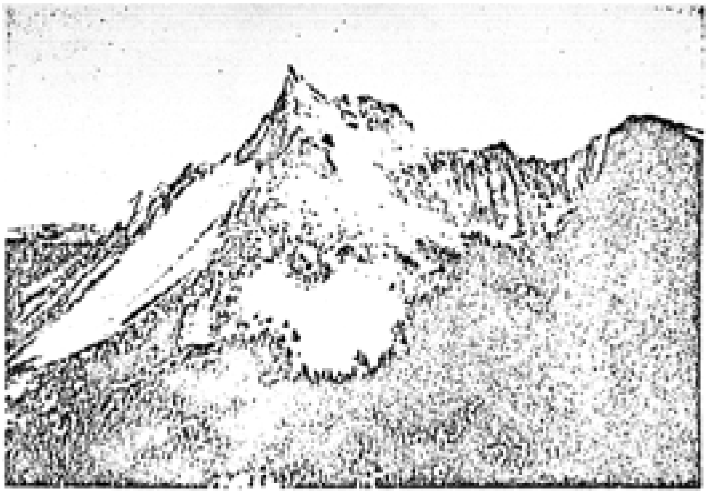
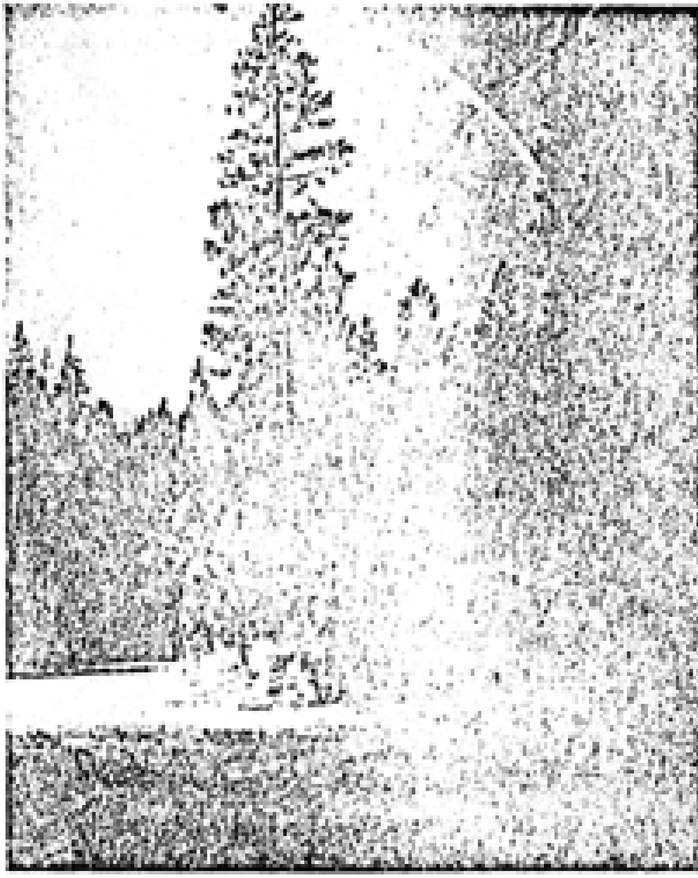


Figure 1: Mount Thielsen in the Oregon Cascades, looking northeast.

some form twisted path a few centimeters wide and up to 30 cm long (figure 3). Some of the patches are smooth, others have a bubbled or spongy appearance. The smooth, glassy fulgurite encrusting the basalt is generally 1 or 2 mm thick (figure 4), but occasionally bubbles 10mm in diameter protrude above the encrusting material (figure 5). The specific gravity of the fulgurite is about 2.5 (Diller, 1884), and its hardness is 6 1/2 on the Mohs scale.

Diller reports the presence of lightning tubes on Mount Thielsen ranging from 10.5 to 20 mm in diameter, but no such glass-lined cavities were found by this author. Diller indicates that the lightning tubes he examined seem to have been formed by lining preexisting cavities and that the rock material adjacent to the lightning tubes offered no evidence of having been compressed.

The unique nature of fulgurite can be seen more clearly under the microscope. The fulgurite coating the basalt is seen to be a homogeneous glass, entirely free of even the smallest crystallites, though occasional unfused crystals indigenous to the original basalt are enclosed. This total absence of crystallinity in fulgurite serves to distinguish it from obsidian, pum-



This photograph courtesy of F. Leroy Bond, Forest Supervisor, Umpqua National Forest

Figure 2: Lightning strikes the summit of Mount Thielsen.

ice, tachylyte, and other natural glasses. However, the Fulgurite is not totally structureless. The upper surface of the fulgurite consists of homogeneous glass containing minute bubbles. Between this layer and the unaltered basalt is a thinner zone of partial fusion, which contains mineral grains of various sizes in all stages of digestion. The most abundant crystal arrangements are those of feldspar, pyroxene, and olivine -- the same minerals that make up the bulk of the crystalline portion of the unfused basalt.


Figure 3: The twisted structure is a fulgurite approximately 2cm wide and 30cm long

Diller correctly attributes the total lack of crystals in the bulk of the fulgurite to its very rapid cooling and cites the existence of lightning tubes in loose sand to support this view. Many such lightning tubes solidify so quickly that the surrounding loose sand does not have time to collapse the tube.

Diller found that heating the fulgurite in the Bunsen burner flame for only two minutes produced minute crystals. Intense heating for a period of several hours produced a dark, stony material similar to basalt in appearance.

INDEX OF REFRACTION

Another, less obvious, property of the fulgurite can be related to the basalt source rock. That property is its index of refraction. Several investigators have demonstrated the relationship between the indices of refraction of glasses and their silica content. The technique was first used to correlate refractive indices with natural volcanic glasses (George, 1924), More recently, powdered rock samples have been fused and the artificial glasses thus produced used for silica content-refractive index correlations (Callaghan and Sun, 1956; Wargo, 1960). Most investigators agree that good correlation exists between these parameters for rocks taken from the same petrographic province or suite. Kittleman (1963) has recently suggested that the relationship between the index of refraction and silica content is approximately linear. His points vary only + 2 percent silica about a calculated line.

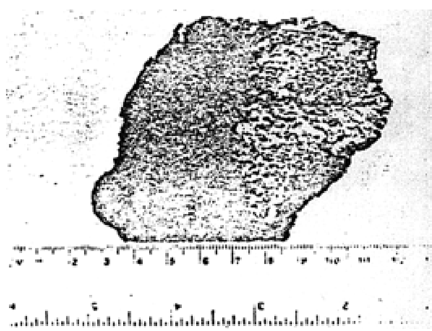


Figure 4: Fulgurite coating basalt from the summit of Mount Thielsen

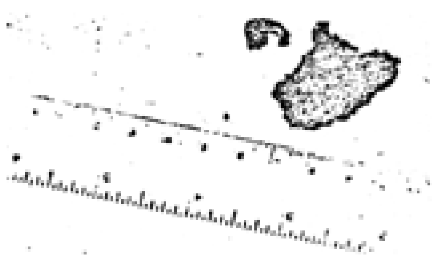
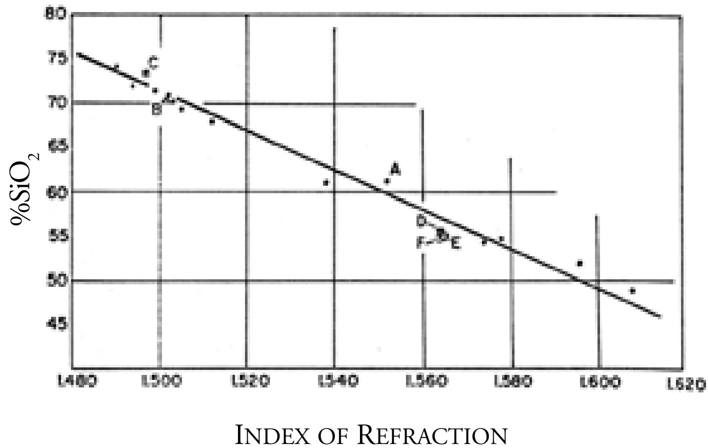


Figure 5: Bubbled fulgurite from Mount Thielsen

In order to determine whether the index of refraction of the Mount Thielsen fulgurite might be indicative of its silica content, these values were determined and



A = Thirteen volcanic rocks of Oregon's Western Cascades, chemical analyses and refractive index determinations after Peck, 1960.
B = Llao Rock obsidian, Crater Lake, chemical analysis after Diller and Patton, 1902, refractive index determination by Purdom.
C = Newberry obsidian, chemical analysis after Williams, 1935, refractive index determination by Purdom
D = Thielsen plug chemical analysis after Williams, 1933, refractive index determination by Purdom.
E = Thielsen fulgurite chemical analysis after Diller, 1884, refractive index determination by Purdom.
F = Re-fused Thielsen fulgurite, refractive index determination by Purdom.

Figure 6: Comparison of silica content and refractive index of fused samples of volcanic rocks of the Oregon Cascades and of fulgurite from Mount Thielsen, Oregon

plotted with similar determinations from other volcanic rocks of the Oregon Cascade region (figure 6). The three plotted samples labeled Thielsen plug (D), fulgurite (E), and re-fused fulgurite (F) were taken from a specimen of basalt coated with fulgurite collected from the summit pinnacle of Mount Thielsen. The Thielsen plug sample represents the basalt making up the summit pinnacle which was powdered and re-fused before determination of its refractive index. Samples were ground and fused using the method and apparatus described by Kittleman (1963). The fusion process consists of placing the powdered specimens in a carbon arc for several seconds.

The close fit of the fulgurite to the graph shown in figure 6 suggests that natural fulgurite has a refractive index correlative with its silica content and with the silica content of the basalt from which it was fused by lightning. The near coincidence of the points representing the natural fulgurite, the re-fused fulgurite, and the fused basalt indicates that the unusual mode of formation of the natural fulgurite did not induce chemical changes that altered its refractive index with respect to that produced by carbon arc fusion.

Acknowledgments

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