

## FULGURITES FROM MOUNT THIELSEN, OREGON

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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.

## Location of Fulgurites

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 some form a 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 10 mm in diameter protrude above the encrusting material (figure 5). The specific gravity of the fulgurite is



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



Figure 2. Lightning strikes the summit of Mount Thielsen. (This photograph courtesy of F. Leroy Bond, Forest Supervisor, Umpqua National Forest.)

about 2.5 (Diller, 1884), and its hardness is  $6\frac{1}{2}$  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 pre-existing 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, pumice, tachylite, 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 fragments are those of feldspar, pyroxene, and olivine -- the same minerals that make up the bulk of the crystalline portion of the unfused basalt.

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  $\pm 2$  percent silica about a calculated line.

In order to determine whether the index of refraction of the Mount



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

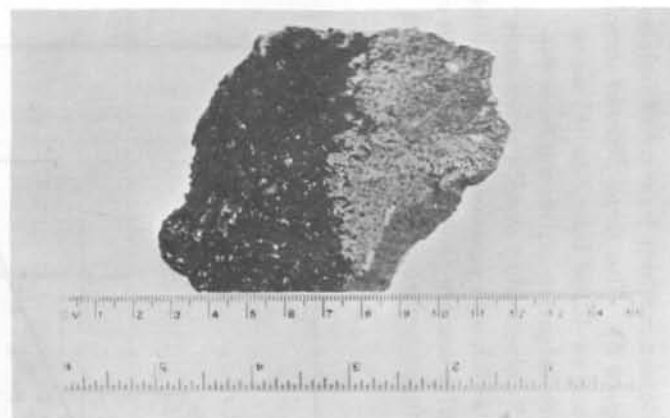


Figure 4. Fulgurite coating basalt from the summit of Mount Thielsen.

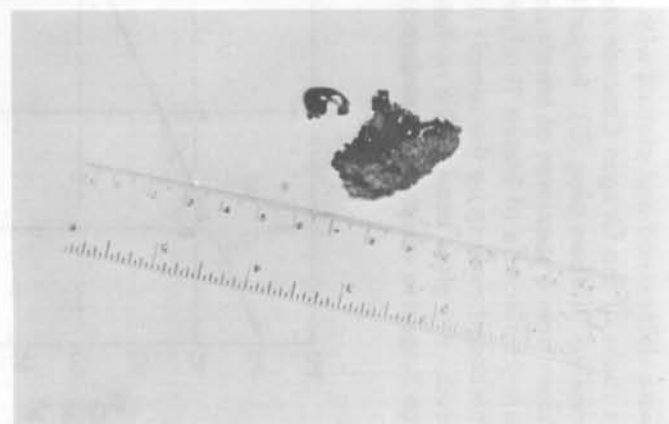
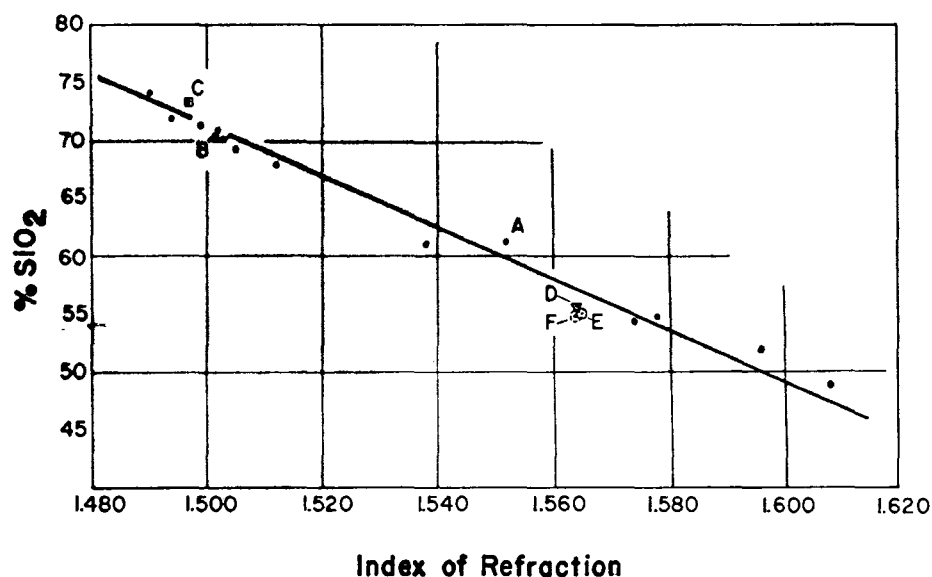


Figure 5. Bubbled fulgurite from Mount Thielsen.

Thielsen fulgurite might be indicative of its silica content, these values were determined and 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 fused to produce a glass bead. The re-fused fulgurite sample represents a portion of the fulgurite which was powdered and re-fused before determination of its



- 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.

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

I wish to thank Dr. L. R. Kittleman for providing the apparatus used to fuse the powdered rock samples, and for his helpful suggestions.

#### References

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Gov. Mark O. Hatfield, Dr. Burt Brown Barker, and James H. McClain admire the bronze plaque honoring Herbert Clark Hoover. The plaque was presented by McClain, chairman of the Oregon Section of AIME, and dedicated by the Governor.

#### GOVERNOR HATFIELD DEDICATES HOOVER PLAQUE

A bronze plaque honoring Herbert Clark Hoover was dedicated by Governor Mark O. Hatfield at the late President's boyhood home in Newberg on August 11. The plaque was prepared by the Oregon Section of the American Institute of Mining, Metallurgical, and Petroleum Engineers. Dr. Burt Brown Barker, President of the Herbert Hoover Foundation of Oregon, accepted the plaque from James H. McClain, chairman of the Oregon Section of AIME. McClain lauded Hoover as a foremost mining engineer, a philanthropist, and a humanitarian who brought the finest talents and skills of the engineering profession to bear on wide-spread suffering in many parts of the world. Governor Hatfield, a long-time admirer of Hoover, stressed his essential humanity which, combined with rare engineering and administrative talents, produced an outstanding citizen of the world. Hoover served as President of AIME in 1920. His boyhood home, the Minthorn House, has been carefully restored under the direction of Dr. Barker, and contains numerous mementos of his life.



## ZONING IN AN ASH FLOW OF THE DANFORTH FORMATION HARNEY COUNTY, OREGON

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The Pliocene Danforth Formation, a heterogeneous rock unit in the Harney Basin, Harney County, Oregon, consists of lake-deposited sediments, basalt flows, and silicic pyroclastic members. It is underlain by the Miocene Steens Basalt and silicic volcanic rocks and overlain by the Harney Formation (Pliocene?), itself a heterogeneous unit consisting of basalt flows and tuffaceous sediments. The Danforth Formation was first described by Piper and others (1939) and was named for the Danforth Ranch. The type section is along Cow Creek in T. 22 S., R. 32 $\frac{1}{2}$  E., in the northern part of Harney Basin.

### Ash-flow Units

Several welded ash-flow units occur in the upper part of the formation of the basin. Erosion and faulting have produced prominent escarpments on these units in the higher land that borders the flat plain in the northern and western parts (figure 1). The escarpments and "rimrock" constitute a major feature on the Harney Basin landscape (figure 2).

Three ash flows are well exposed in the walls of Devine Canyon along U.S. Highway 395 a few miles north of this highway's intersection with U.S. Highway 20 (figure 3). The lowermost unit, exposed at the junction of Poison Creek and Devine Canyon about 5 miles north of the highway intersection, is a loosely consolidated tuff consisting of pumice and other rock particles, finer vitric particles, and crystal fragments. It is generally referred to as a crystal tuff because of its high content of crystalline material, a feature that readily distinguishes it from the overlying units. This unit is widespread, and, though only weakly indurated, it forms nearly vertical escarpments along stream valleys and in places where it is faulted.

The escarpments in the ash flows are maintained partly because of vertical jointing and partly because of a layer of very weakly lithified basal ash. This ash erodes more rapidly than does the overlying harder material, leaving a re-entrant at the base, thus removing support from the upper part of the unit. As long as mass movement extracts talus material from the base of the unit, the escarpment persists. Where talus accumulates and covers the basal ash layer, erosion of the ash stops and the escarpment is eliminated. The re-entrant at the base of the upper ash flow is shown in figure 4.

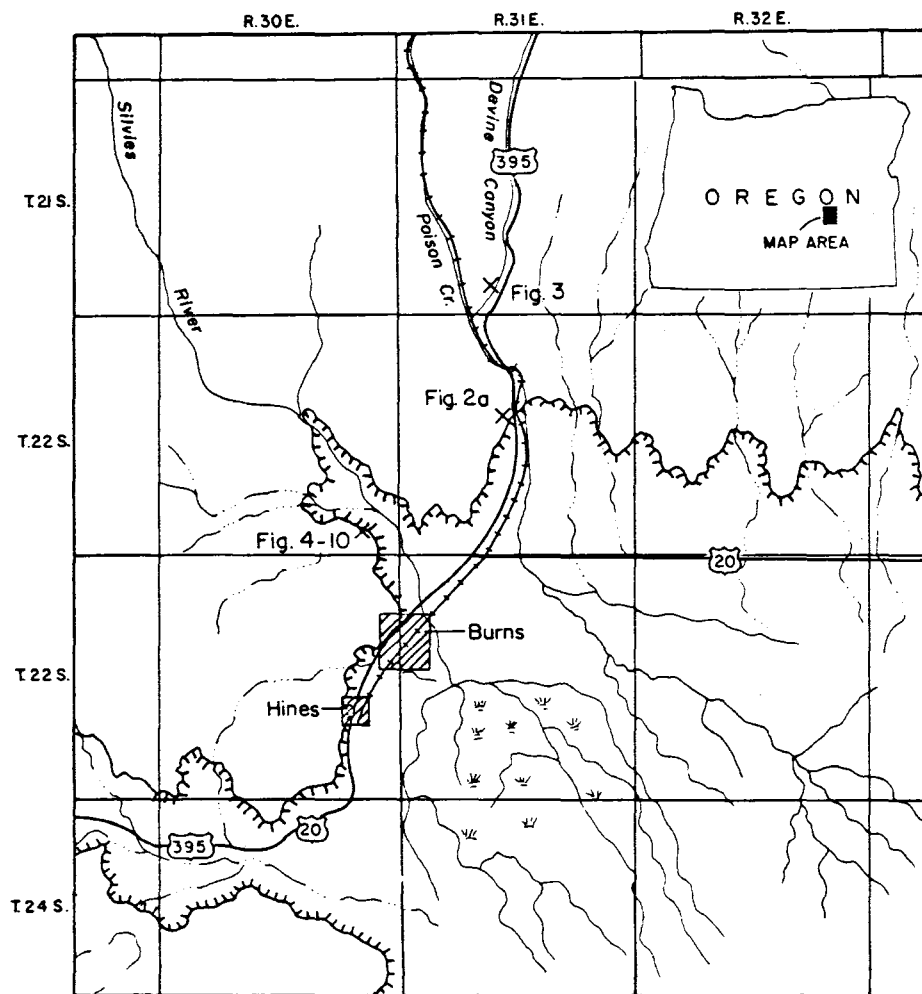


Figure 1. Index map of the Burns area showing the northwest margin of the Harney Basin. Figure numbers on map indicate location of photographs accompanying text.

The middle and upper ash flows consist mostly of fine vitric particles and small pumice fragments; they contain only small amounts of other rock fragments, and crystal fragments of anorthoclase, oligoclase, quartz, and green pyroxene. Both units are welded, but the upper one is particularly noteworthy because of the high degree of welding and the distinct zoning. The upper unit is described in detail below.

#### Upper Ash Flow

The upper unit underlies much of the area in the vicinity of Burns and is the source of the stone used in several of the local stone-block buildings.



Figure 2. Escarpments on ash-flow units in the Danforth Formation. Devine Canyon (above); along road to Frenchglen at mile-post 39 (below).

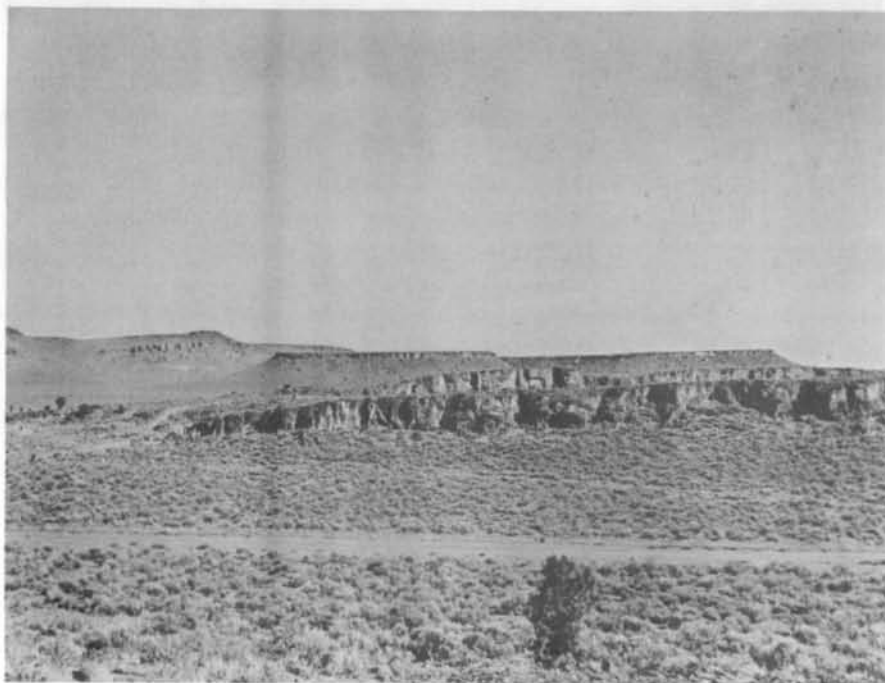




Figure 3. Three ash flows along Devine Canyon.



Figure 4. Base of upper ash flow in Silvies River locality, center of section 36.

It is well exposed in a number of places along Silvies River northwest of the town. There are two excellent outcrops in the bluffs on the southwest side of the river in sec. 36, T. 22 S., R. 30 E. Here the flow is about 50 feet thick and is exposed in its entirety except for an upper layer of nonwelded ash that probably was present originally but has been stripped. The rock in the outcrop near the road in the SE $\frac{1}{4}$  sec. 36, about half a mile north and west of the Indian Village, is described in the paper by Piper and others (1939, p. 43). The other and more extensive outcrop is a few hundred yards north of the road near Hayes Ranch and about in the center of section 36.

In the Silvies River locality the upper ash flow overlies sorted and stratified pumiceous ash and lapilli. A few feet of this material is exposed at the base of the escarpments in section 36, and it is separated from the overlying ash flow by a distinct disconformity.

At its base the ash flow is a gray, unstratified, and unsorted pumiceous tuff consisting mostly of ash but containing numerous pumice particles 2 inches or more in length. Scattered fragments of basaltic rock are also present here and elsewhere in the flow. This part of the flow is not welded but is weakly cemented, largely by fibrous aggregates of quartz and possibly other minerals that occur in isolated clusters through the rock. Because of its low resistance to erosion, the ash flow is marked where exposed by the re-entrant at its base (figure 4).

No distinct surface separates the nonwelded ash from the welded part. Rather, the amount of welding increases progressively upward in the unit through a thickness of about 5 feet (figure 4). This transitional zone of partial welding is characterized by an increase in density as pore space is reduced, flattening of glass shards (figure 5) and pumice fragments, a change in color from light, brownish gray through shades of brown to black, and a change from an earthy to a pitchy luster. The pumice fragments maintain their identity in this zone, but have been deformed into thin lenses oriented essentially horizontally. Some retain their gray color, but in the densely welded part most have become black.

The hard, densely welded rock in the upper part of this zone grades almost abruptly into rock with a pronounced perlitic structure that gives the rock a granular appearance. Because of the perlitic structure, this rock disintegrates easily, and its erosion has created a bench on top of the dense, compact underlying rock and a bulbous overhang in the more resistant material above it (figure 6).

Spherulites and lithophysae appear a short distance above the base of the perlitic zone and mark the beginning of a zone of gaseous activity. The perlitic structure continues upward into the spherulitic zone.

The spherulitic zone (figure 7) is about 30 feet thick, and the spherulitic and lithophysal structures make up about half the rock. Pumice particles, so prominent in the lower part of the flow, are inconspicuous in this zone. Lenticular masses of fragmented obsidian-like glass (figure 8), some more than a foot long, occur in the lower part of the spherulitic zone and

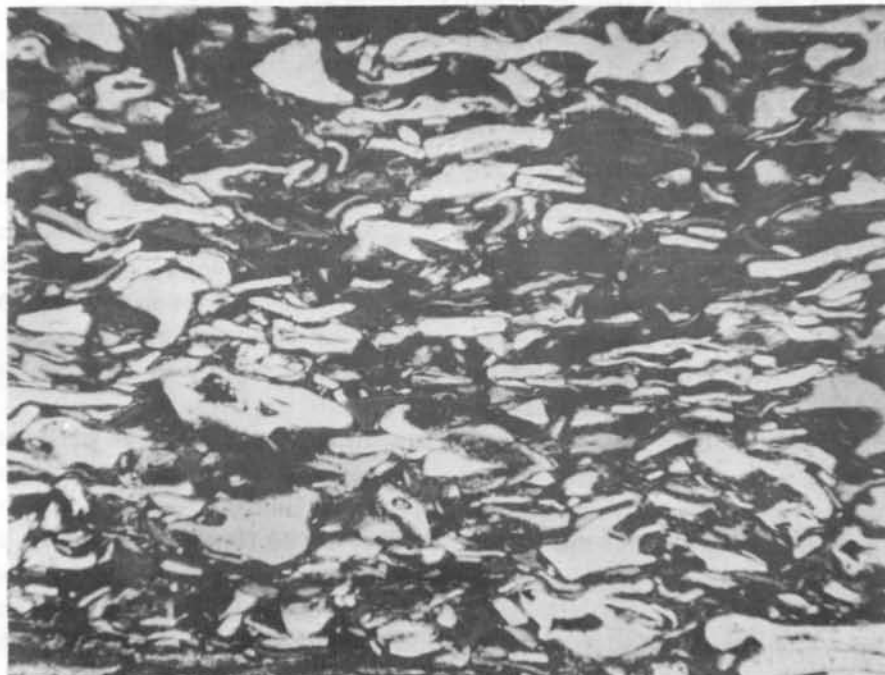


Figure 5. Flattened glass shards. Ordinary light. Mag. approx. X40.

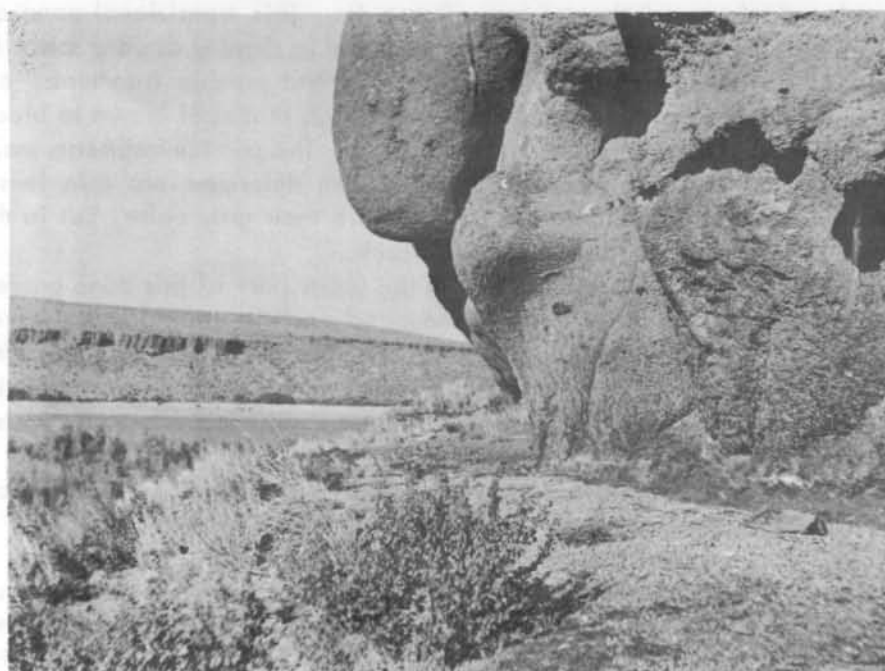


Figure 6. Bench on densely welded ash. Perlite rock at base of overhanging spherulitic rock.



Figure 7. Spherulites and lithophysae.

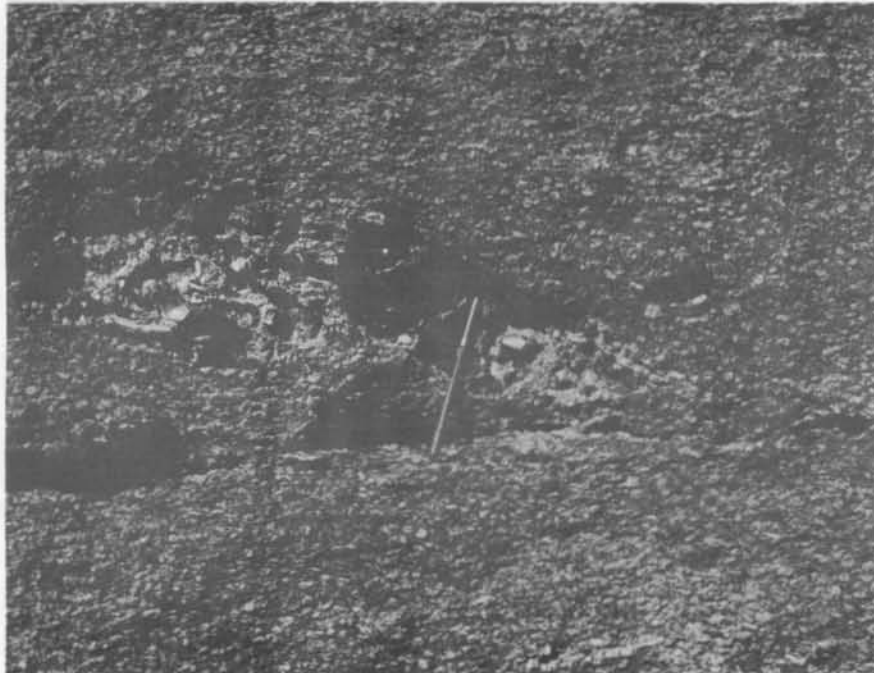


Figure 8. Fragmented glass lens in spherulitic zone.

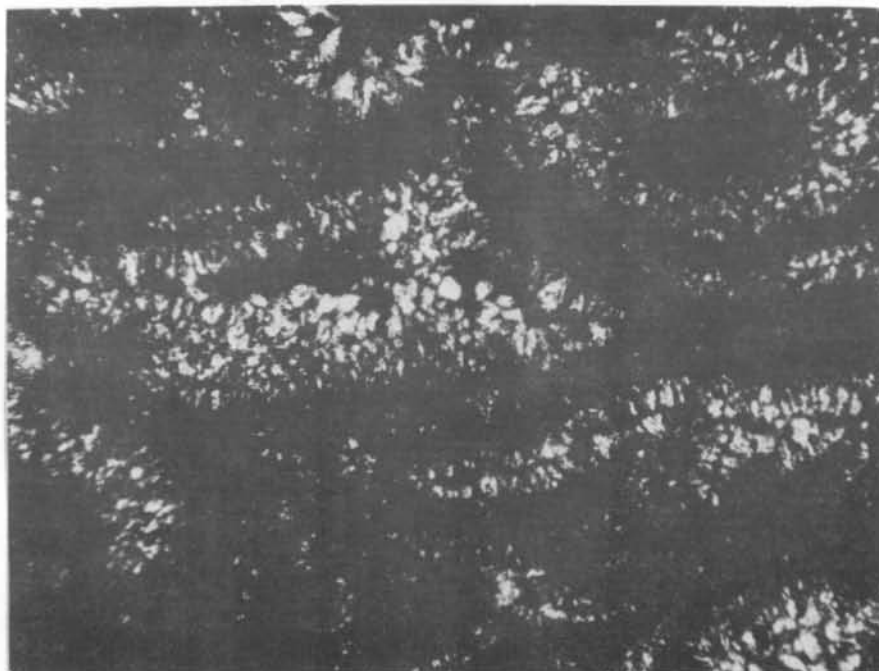


Figure 9. Axiolitic structure in devitrified tuff. Crossed polars. Magnification approximately X110.



Figure 10. Platy structure in porcelaneous rock.



may represent small local spots where the tuff was completely melted and resolidified, or they may be obsidian inclusions. The shard structure that characterizes the ash flow from bottom to top is absent in this glass. The glass separates into small fragments which have somewhat rounded edges and resemble the so-called "Apache tears." Particles of basaltic rock are essentially unchanged in the spherulitic zone.

In the upper part of the spherulitic zone the glass is devitrified, the glassy luster is lost, and the rock becomes "stony" and porcelainous in appearance. The shard structure has been preserved in the devitrified rock, and the crystalline material formed through devitrification is arranged in axiolitic structure around the borders of the shards (figure 9). The minerals that were formed by devitrification of the glass are cristobalite, tridymite, albite, and anorthoclase. The same minerals line the cavities in the lithophysae of the spherulitic zone.

The spherulitic rock grades into a dense, pinkish-gray rock that makes up the top 10 feet of the flow in the Silvies River locality and elsewhere in the Burns vicinity. It is exposed in a number of road cuts west of Burns along U.S. Highway 20. The transition from the spherulitic rock to the porcelainous rock is marked by many large, flattened gas vesicles. The number of vesicles diminishes upward in the zone of porcelainous rock, and they are sparse in the upper few feet.

The porcelainous rock is largely devitrified glass in which shard structure has been preserved. Numerous larger fragments, some several inches

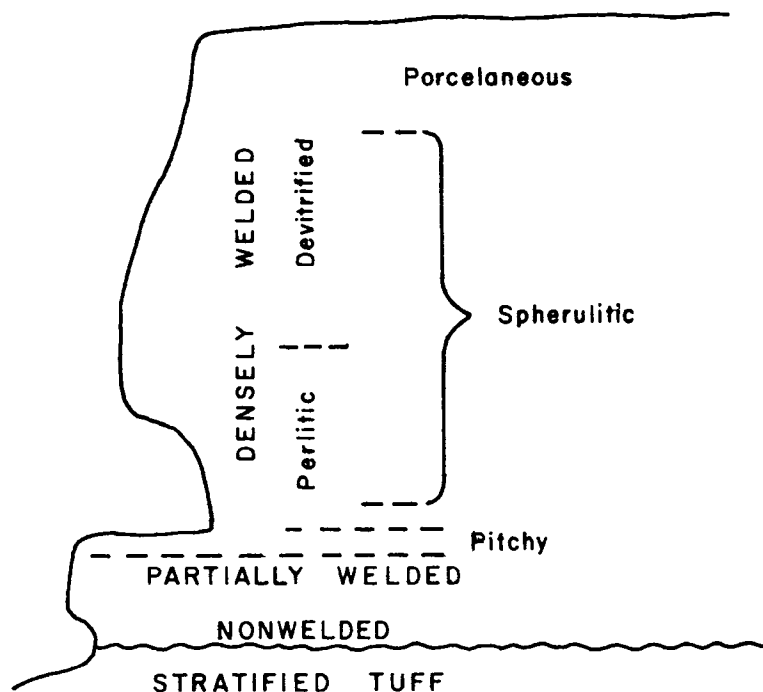


Figure 11. Diagram of zones in upper ash flow.

across, give the rock the appearance of a breccia in places, and it is commonly referred to as a tuff-breccia. These large flattened particles, composed of devitrified glass, are believed to be mostly original pumice fragments that became flattened by compression and oriented horizontally. Locally the rock of the porcelaneous zone is very platy (figure 10).

Nonwelded ash that usually occurs at the top of welded ash flows was not observed. From the amount of compaction in the uppermost part of the densely welded rock, it would seem that originally there was a layer of considerable thickness. Erosion has probably removed most of it, and where it is still present it is covered by soil.

Welding within the upper ash flow of the Danforth Formation ranges from no welding to dense welding, and the major part of the unit in the Silvies River locality and elsewhere is densely welded. Within the densely welded part different zones, as defined by Smith (1960), can be identified. The zone boundaries can be drawn in different places, however, depending upon which features of the rock are used as basis for zoning.

Figure 11 shows positions of significant characteristics in the rock as they exist in the Silvies River locality, section 36. A zone identified by one rock property overlaps zones identified by other properties. For example, the spherulitic zone overlaps a zone of devitrification in its upper part and a perlitic glass zone in its lower part. An initial division of zones is made on the basis of degree of welding. Further division is made within the densely welded zone on the basis of structural and mineralogic criteria.

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Smith, R. L., 1960, Zones and zonal variations in welded ash flows: U.S. Geol. Survey Prof. Paper 354-F, p. 149-159.

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#### PERMIT ISSUED FOR CENTRAL OREGON DRILLING

The Department issued permit No. 57 to Central Oils, Inc., of Seattle, Wash., on August 31, 1966, to re-enter a hole it abandoned in December of 1960. The abandoned test hole, "Morrow 1," is located in the SW $\frac{1}{4}$  sec. 18, T. 12 S., R. 15 E., Jefferson County. Depth reached in the initial drilling was reported to be 3300 feet. The well site lies approximately 10 miles southeast of Madras, and a short distance east of U.S. Highway 26. The firm will attempt to test pre-Tertiary marine rocks underlying younger volcanics. Pre-Tertiary metasediments have been mapped on the surface approximately 5 miles northeast of the drilling site (Peck, U.S. Geol. Survey Bull. 1161-D, 1964).

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## UDALL NAMES OCEAN RESOURCES TEAM

Secretary of the Interior Stewart L. Udall has named a top-level team to develop and coordinate the Department's many programs for utilizing the resources of the sea, including minerals.

Dr. Stanley A. Cain, Asst. Secy. for Fish and Wildlife and Parks, was named to head the team, which includes Dr. Thomas F. Bates, science advisor to the Secretary; Asst. Secy. J. Cordell Moore (mineral resources); Asst. Secy. Frank C. DiLuzio (water pollution control); Asst. Secy. Harry R. Anderson (public lands); and Asst. Secy. Kenneth Holum (water and power development). Dr. Walter R. Hibbard, Jr., director, Bureau of Mines, was selected as program manager.

Udall pointed out that among Interior's key responsibilities under the Marine Resources Development Program are mining of minerals on and beneath the ocean's floor, mapping and structural studies of the continental shelf, and geology as related to earthquakes and mineral values.

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## SENATE PASSES RESEARCH CONTRACTS BILL

On August 29 the U.S. Senate passed by voice vote and sent to the House S. 3460, a measure to authorize the Secretary of the Interior to enter into contracts for scientific and technological research.

Such authority presently exists for certain specific programs of the Department, such as for saline water, helium, and coal and water research. However, the Bureau of Mines and the Geological Survey do not have similar authority. This legislation would place all of Interior's programs on an equal basis with respect to use of nongovernmental research facilities, organizations and programs. The measure does not authorize any new programs or any additional appropriations.

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## TOPOGRAPHIC MAP PRICES TO CHANGE

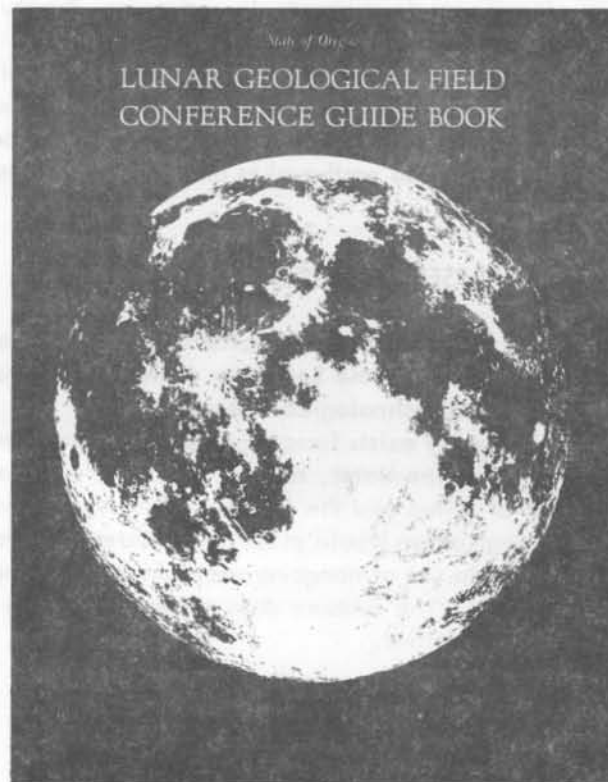
The U. S. Geological Survey has just announced new prices on all of its maps, effective October 1, 1966. The new list price of topographic quadrangle maps at scales 1:24,000; 1:31,680; 1:62,500; 1:63,360; and 1:125,000 is 50 cents each. The list price of topographic maps at a scale of 1:250,000 is 75 cents each.

National Park and other special topographic maps are individually priced. The Survey can provide a price list of these maps upon request. All maps for areas lying west of the Mississippi River should be ordered from the Survey's Map Distribution Office, Denver Federal Center, Denver, Colo.

Discounts on orders amounting to \$20 or more at the list price are 20 percent; on orders of \$100 or more 40 percent is allowed.

### "MOON COUNTRY" BULLETIN REPRINTED

Despite its rather impressive title, "Lunar Geological Field Conference Guidebook," the Department's "Moon Country" bulletin has proven to be one of its most popular. Originally prepared for the use of the 85 space scientists attending the conference in central Oregon a year ago, the book, filled with photographs, maps, and line drawings, attracted wide interest. The first printing was rapidly exhausted and a second edition, with improved illustrations and additional photographs, has been published.



Interest in the bulletin stems from the fact that central Oregon contains a wealth of spectacular volcanic features which, in the opinion of many space scientists, closely resemble those to be found on the moon. The area has been studied by several teams of astronauts and lunar geologists. Five of the six "Lunar Standard" rocks used in lunar research are found in the area. Five field trips are described and illustrated in the bulletin, making it possible for individuals to conduct their own self-guided tours through a lunar-like countryside. The bulletins are also used as texts by the University of Oregon's summer workshop in volcanology. Copies of the bulletin sell for \$3.50 postpaid.