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THUNDEREGG*: OREGON'S STATE ROCK

The thunder egg, an agate-filled nodule characteristic of certain parts of central and eastern Oregon, became the official state rock on March 29, 1965. On that day Senate Joint Resolution 18 (see page 191 for text of resolution) was passed, whereupon the "thunderegg" joined the other nature symbols of Oregon, namely: the state animal (beaver), the state flower (Oregon grape), the state bird (western meadowlark), the state tree (Douglas fir), and the state fish (Chinook salmon).

Senator Glen M. Stadler, Lane County, who co-sponsored the resolution with Rep. Gerald Detering, Linn County, tells how it all came about in a letter to State Geologist Hollis M. Dole.

"The man who started the ball (excuse me, 'rock') rolling was Harold M. Dunn, of Lane County. About three years ago he was a Federation Director of the American Federation of Mineralogical Societies, and an officer of the Springfield Rock and Gem Club.

"He had read a story in the Federation's publication about a girl in South Dakota who had written the editor, asking for a list of state rocks. The editor's reply was that there was no such list.

"Mr. Dunn told the story to the Springfield Club which instructed him to 'do something about it' for Oregon. He contacted me as a newly elected State Senator. While I had a Senate Bill drawn, he sent letters to some four dozen rock and gem clubs in Oregon, asking their preference for a State Rock. The Thunderegg won the most votes.

"Then, OMSI held an 'election,' asking visitors their preference. It was 'Thunderegg, two to one.' By that time it was getting a bit late in the 1963 session. In fact, the deadline for bills had passed. However, I submitted the measure to the Senate Rules Committee, after getting a number of signatures, and the co-sponsorship of State Representative Gerald Detering of Linn County, whose late brother had been a longtime ardent 'rockhound.' Gerry and I 'politicked' for the bill, but the Senate Rules Committee did not have time to pass it out.

"Then, when the 1965 session convened, Gerry and I again submitted the measure. SJR 18 was passed in the Senate, 23 to 2, and in the House, 48 to 5. Because it was a Joint Resolution, it did not have to be signed by the Governor, and became the 'law of the land,' in effect, by the signatures of President Boivin and Speaker Montgomery on March 29, 1965.

"There were those who thought the measure was 'frivolous' and joshed us about it, but it now appears that the publicity being given the storied and romantic 'Thunderegg' is resulting in quite an economic factor in our increasing tourist industry.

"Thus ends, for the historical record, the answer to the Thunderegg-as-the-State-Rock question of 'Who-Dunn-it'."

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*Note: "Thunderegg" as one word was adopted by the Oregon Legislature for the name of the state rock and, therefore, is the correct spelling when referring to the state rock; however, in describing the geology and mineralogy of thunder eggs, the two-word spelling has priority, because of its use in the literature.

A pen set made from the new state rock in the outline of the State of Oregon was presented on March 29 to Governor Mark O. Hatfield. This was the pen that was used by Senate President Harry Boivin and House Speaker F. F. Montgomery to sign the resolution. On the Governor's desk are a number of other thunder eggs, some sawed open and others uncut. Standing behind Governor Hatfield from left to right are: Rep. Sam Johnson, Sen. Harry Boivin, Rep. William Gallagher (hidden), Sen. R. R. Raymond, Rep. L. B. Day, Rep. G. W. Detering, Sen. Ed Ahrens, Sen. Glen Stadler, Mr. Ed Nichols, Sen. Gordon McKay, Mr. Marion Cady, and Mr. Al Keen. (Photograph by Joseph V. Tompkins)

Senate Joint Resolution 18

Introduced by Senator STADLER, Representative DETERING, Senators AHRENS, VERNON COOK, WARD COOK, CORBETT, ELFSTROM, HUSTON, IRELAND, MONAGHAN, POTTS, RAYMOND, THIEL, WILLNER, YTURRI, Representatives BESSONETTE, DAY, GALLAGHER, SAM JOHNSON, LANG, McKINNIS and read February 19, 1965

Whereas the great and sovereign State of Oregon has a state flag, a state animal (the beaver), a state flower (the Oregon grape), a state bird (the western meadow lark), a state seal, a state tree (Douglas fir) and a state fish (the Chinook salmon); and

Whereas the State of Oregon, being of unbounded international importance as a "rockhound's paradise"; and

Whereas the State of Oregon needs a designated state rock; and

Whereas a number of rock and gem clubs representing all areas of Oregon and the Oregon Museum of Science and Industry have conducted a popular vote to select a state rock; and

Whereas this vote favored the thunderegg two to one; and

Whereas the thunderegg is described as a "remarkable and colorful agate-filled spherical mass of silicified claystone, and rhyolite found throughout the State of Oregon" ranging in size up to four feet in diameter; and

Whereas an old legend of the Warm Springs Indians tells us that these spherical masses were once hurled from the craters of Mt. Hood and Mt. Jefferson when the "spirits of the mountains" were angry and that the "thunder spirits" who lived in the craters hurled the nodules to the accompaniment of much lightning and thunder and therefore the agate-filled nodules became known as "thundereggs"; now, therefore,

Be It Resolved by the Legislative Assembly of the State of Oregon:

That this ancient symbol of geological significance and absorbing native legend, the thunderegg, be acclaimed the Oregon state rock.

What Is A Thunder Egg?

Thunder eggs are spherical masses of rock that range in size from less than an inch to 4 feet in diameter. Most are about the size of a baseball. They have a knobby rind of drab, siliceous rock and a cavity filled with agate. From the outside they appear nondescript, but when sawed open and polished they may reveal the most exquisite and colorful designs ranging from five-pointed stars to miniature gardens. Consequently, they are highly prized by rockhounds, who come from every state in the Union to hunt for them. Thunder eggs make handsome jewelry, book ends, paper weights, pen stands, and many other decorative objects. Each year they contribute thousands of dollars to the state's million-dollar semiprecious gem-stone industry.

How Did Thunder Eggs Form?

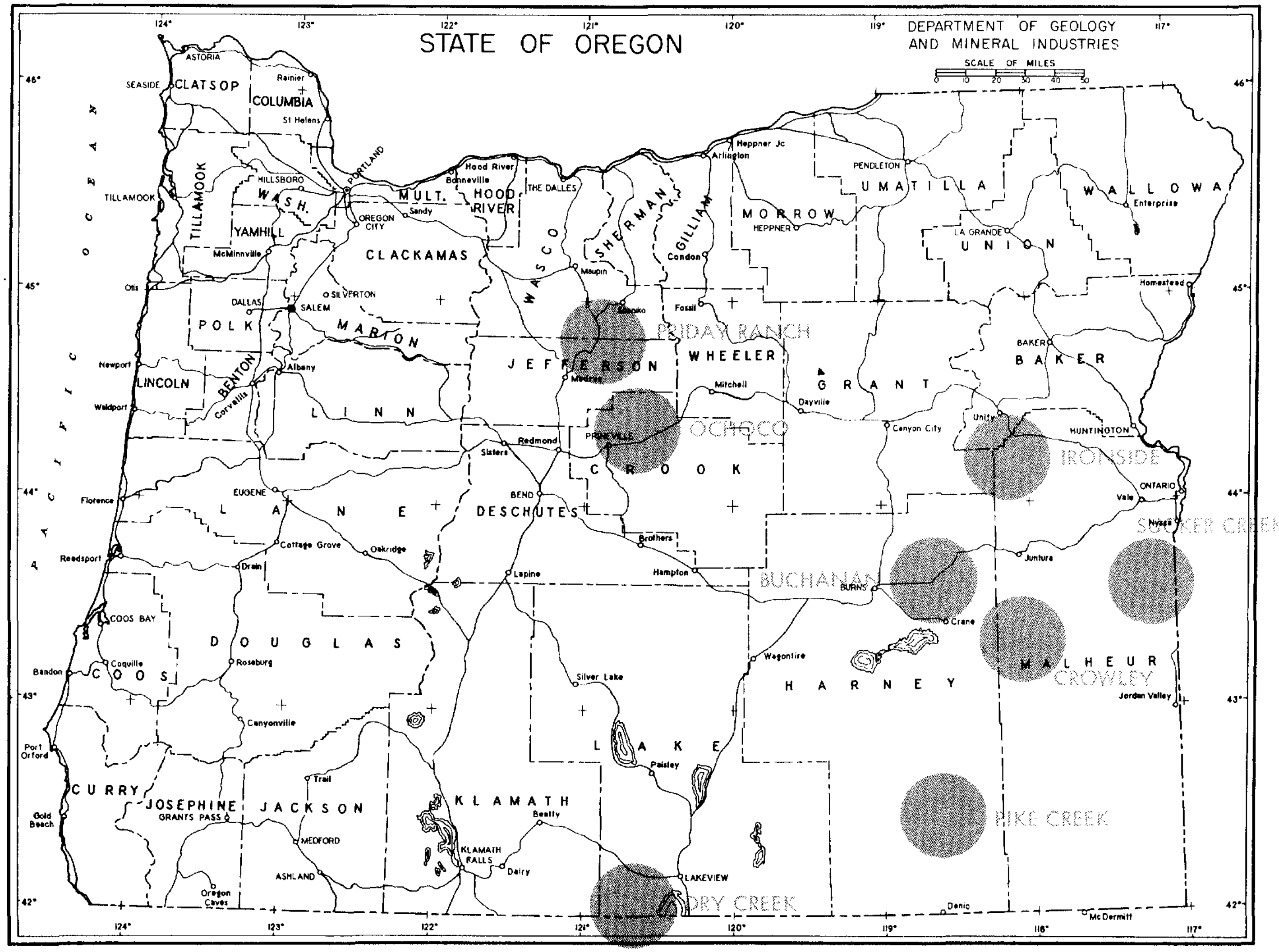
Thunder eggs are always associated with silicic volcanic rocks such as welded tuffs and rhyolite flows. Millions of years ago, fiery avalanches of this type of molten rock poured out of volcanoes and flowed over the land. In central and southeastern Oregon there are wide areas in which rocks of this type are well exposed.

Although the host rock in which thunder eggs occur is known, the development of these spherical objects in the parent material is not completely understood and various theories have been advanced to explain the complex process. One of the persons who has been particularly interested in these enigmatic structures is Dr. Lloyd W. Staples, Head of the Department of Geology at the University of Oregon. By studying thin, transparent sections of these rocks under a microscope, Dr. Staples has come up with some new ideas on their growth. His paper, which follows this introductory section, sums up all the known information and theories on thunder eggs, presents his own observations, and suggests areas in chemistry, mineralogy, and field geology where further research might clarify many of the least understood processes in the formation of thunder eggs.

Where Can Thunder Eggs Be Found?

In the early days of rockhounding, thunder eggs were gathered from on top of the ground where they had weathered out of the enclosing rock and remained as a surface residue after the less resistant matrix had been eroded. Now most of the surface specimens are gone, and so one must dig in the soil and talus slopes in order to find these agate-filled treasures.

The best-known thunder-egg localities in Oregon occur in the John Day Formation of late Oligocene to early Miocene age. Two of the better localities in the state occur in high-silica rhyolite flows or welded tuffs of this formation, namely the Priday Ranch northeast of Madras and the Ochoco Mountains east of Prineville (see accompanying map). Owners of the Priday Ranch charge a nominal fee for digging on their private lands, but in the Prineville area the city has staked out a number of good agate localities which are open to the public. Detailed information on the exact location of the Ochoco deposits can be obtained by writing to the Prineville Chamber of Commerce. Thunder eggs are also known to occur in John Day tuffs on the Warm Springs Indian Reservation where the name had its origin, but the reservation is closed to mineral collectors.



THUNDER EGG LOCALITIES IN OREGON

Six other localities are found in volcanics of similar or younger age in Lake, Harney, and Malheur Counties of southeastern Oregon (see map). The Buchanan deposits are associated with a rhyolite flow that crops out along the east edge of the Harney Basin near the town of Buchanan; the Crowley deposit, also associated with a rhyolitic lava, is near the old Crowley ranch east of State Highway 78, approximately 25 miles southeast of Burns; the Sucker Creek deposits are found near a thick welded tuff prominently exposed in the walls of Sucker Creek Canyon; the Ironside thunder eggs are found along a rhyolite dike near the east fork of Bridge Creek; the Pike Creek deposit is associated with rhyolite flows of the Pike Creek Formation at the base of Steens Mountain; the Dry Creek area lies along the west side of Goose Lake a few miles north of the California border.

Miocene and Pliocene rhyolitic flows and welded tuffs are exposed in a broad area extending from the Harper Valley near Vale westward through the Malheur River gorge as far as Buchanan, and from the vicinity of Creston near Juntura northward toward Ironside Mountain. Although no one has as yet publicly reported finding any thunder egg deposits within this part of southeastern Oregon, the presence of these silicic volcanics affords the proper geologic environment for their occurrence.

Thunder eggs are not limited to Oregon. Among some of the other reported localities in the West are Berkeley Hills and the Mojave region in California; Virgin Valley, Beatty, Coyote Springs, and Duckwater in Nevada; and Weiser, Twin Falls, and American Falls in Idaho. No thunder eggs have been reported from Washington.

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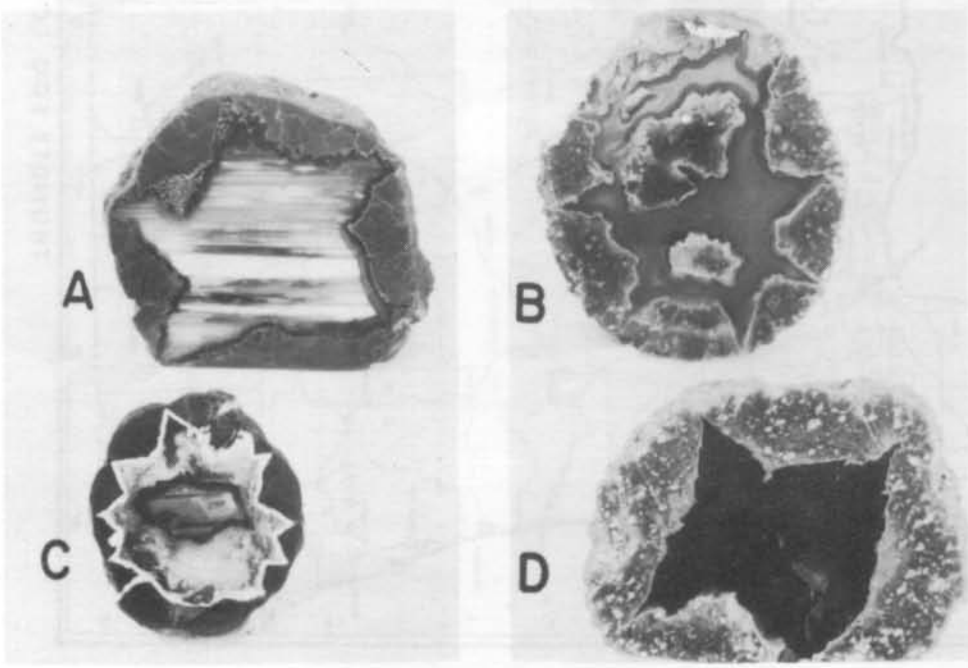

Figure 1. Cut and polished thunder eggs from four localities: (A) Priday Ranch, (B) Sucker Creek, (C) Buchanan, and (D) Ochoco. All are approximately ½ natural size. (Photograph by Leo F. Simon)

ORIGIN AND HISTORY OF THE THUNDER EGG

By

Lloyd W. Staples
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With the passage of Senate Joint Resolution 18 of the Oregon 53rd Legislative Assembly, the thunder egg became the Oregon state rock. Because no other rock material is more prized by the amateur collectors and lapidaries in Oregon, it is appropriate that if any one type of specimen was to be chosen, the thunder egg deserved that recognition. Although thunder eggs or similar specimens are known from many other areas, the Oregon material is unsurpassed for beauty, variety, and abundance, and in the minds of collectors the world over thunder eggs and the State of Oregon are closely related.

Considering the great interest in thunder eggs in Oregon, it is not surprising that many collectors have wondered about the origin of the fascinating structures observed in the specimens (figure 1, p. 194). However, it is surprising that very little careful scientific work has been done, by competent researchers with adequate scientific background, to explain the geologic history of the formation and development of thunder eggs. Because any careful study requires a combination of fieldwork and attentive experimentation in a well-equipped laboratory, the work can be expected to take considerable time. Some of these investigations are under way at the Center for Volcanology at the University of Oregon under the writer's supervision.

This paper is an attempt to bring together the known information on the origin and occurrence of thunder eggs with observations made by the writer in the field and laboratory. Much work remains to be done, and it is hoped that this work will aid in answering some of the unexplained observations presented in this paper.

History of The Name

The origin of the name "thunder egg" is difficult to determine with certainty. J. Lewis Renton probably deserves recognition for first putting it in print (Renton, 1936, p. 12) and giving credit to the Warm Springs Indians for "long ago" originating the name. He states (1936, p. 46), "Since the Indian appears to have prior preference in the matter of a name we will term the material 'Thunder Eggs' until such time when a specific scientific term is given to the specimens."

Renton (1951, p. 171-172) explains the origin of the name by citing an Indian legend, "... the two adjacent snow capped peaks -- Mt. Hood and Mt. Jefferson -- would at times become angry with one another. During these disputes, accompanied with thunder, Mt. Hood and Mt. Jefferson would hurl these spherical masses of rock at each other. Stray shots would land over in the Indian reservation, hence the Indian name of 'thunder eggs.'" Brown (1957, p. 329) adds, "The embattled gods presumably obtained these missiles by robbing the nests of thunderbirds." This idea is also held by Renton (written communication, 1965) who states, "I believe the Indians assumed that the egg shaped nodules were the egg of the thunder bird."

Dake (1938, p. 214) offers a slightly different version of the legend, which is that the thunder spirits who lived in the craters (of Mt. Hood and Mt. Jefferson) hurled the nodules to the accompaniment of much lightning and thunder, therefore the agate-filled nodules became known as thunder eggs. This account is less likely to be accurate than Renton's because, although it relates the name to thunder, it does not closely relate it to eggs. However, this version was used in connection with Senate Joint Resolution 18 which copied Dake's wording of the legend. An exception is the use of "thunderegg" as a single word, which usage was adopted by the authors of the Resolution, disregarding well-established priority of the name "thunder egg" as two words.

Definition of Thunder Egg

Unfortunately, popular names usually are not precise in definition and "thunder egg" is no exception. It will forever be impossible to determine the limitations on the term that might have been imposed by the Warm Springs Indians, if indeed they had in mind any limitation, which is very unlikely. Popular usage has clearly indicated the name for certain types of nodules, but it is difficult to limit the varieties which may be included. If names were defined by legislative action, then we would have a definition, but unfortunately the "legal" definition is incorrect. Senate Joint Resolution 18 uses the description from Dake (1938, p. 214), "a remarkable and colorful agate-filled spherical mass of silicified claystone and rhyolite found throughout the State of Oregon." It is now known that the thunder egg is a spherulitic nodule and is not related to silicified claystone.

It should be pointed out that, although the thunder egg has been designated as the state rock, it is not, strictly speaking, a rock. A rock is defined by the geologist as an aggregate of mineral matter constituting an essential and appreciable part of the earth's crust. Thunder eggs are <u>structures</u> found in a rock, the rock being the welded tuff or rhyolite enclosing them. However, both "rock" and "mineral" are words which are used loosely, and it is in this sense that the term "rock" is applied to thunder eggs in S.J.R. 18.

Renton (1951, p. 172) states that a thunder egg should be (1) spherical or nearly so, (2) have an exterior shell of varying thickness of rhyolite, (3) contain a core of agate, veins of agate, or an interior cavity partly filled or completely empty. Brown (1957, p. 329) defines thunder eggs as spherulitic geodes, restricted to the weathered outcrops of a prehistoric lava flow which is now a rhyolitic welded tuff in whose glassy matrix they originate. Peck (1964, p. D25) calls them "chalcedony-filled spherulites," and states that "The outer shell of each thunder egg is composed chiefly of shards, fine ash, and collapsed pumice lapilli, all of which are altered to radially oriented sheaves of fibrous cristobalite and alkalic feldspar."

The typical Oregon thunder egg (figures 1, 2, and 3) has the following features: (1) It is generally spherical or ellipsoidal in shape; (2) the surface is usually smooth or wart-like or cauliflower-like with ribs which encircle the specimen and intersect each other; (3) it has a shell of rhyolitic welded tuff or rhyolite which has devitrified to various degrees and in which spherulites or lithophysae have developed; (4) the center or core consists of chalcedony or quartz, which may be banded or contain

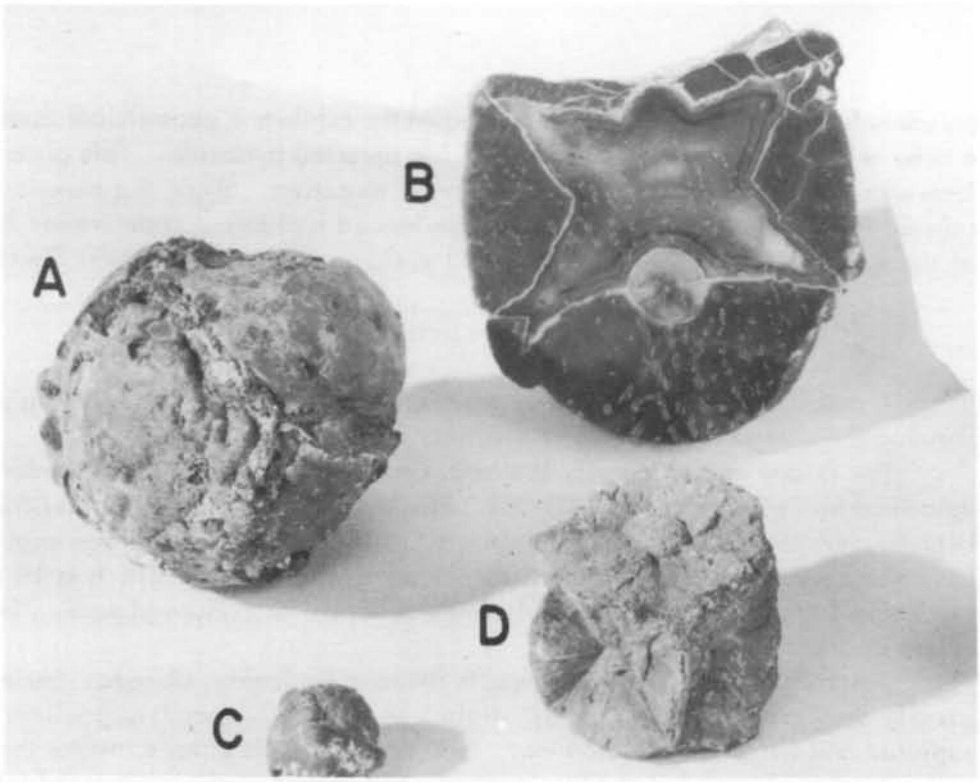

Figure 2. Group of four thunder eggs: (A and C) Exterior of Priday Ranch specimens, (B) sectioned thunder egg showing spherulite at bottom of filled cavity and corresponding hole at top [note Liesegang rings in chalcedony center], (D) chalcedony core of thunder egg weathered out of its shell [note "button" spherulite cast on top]. All are approximately 2/3 natural size. (Photograph by Leo F. Simon)

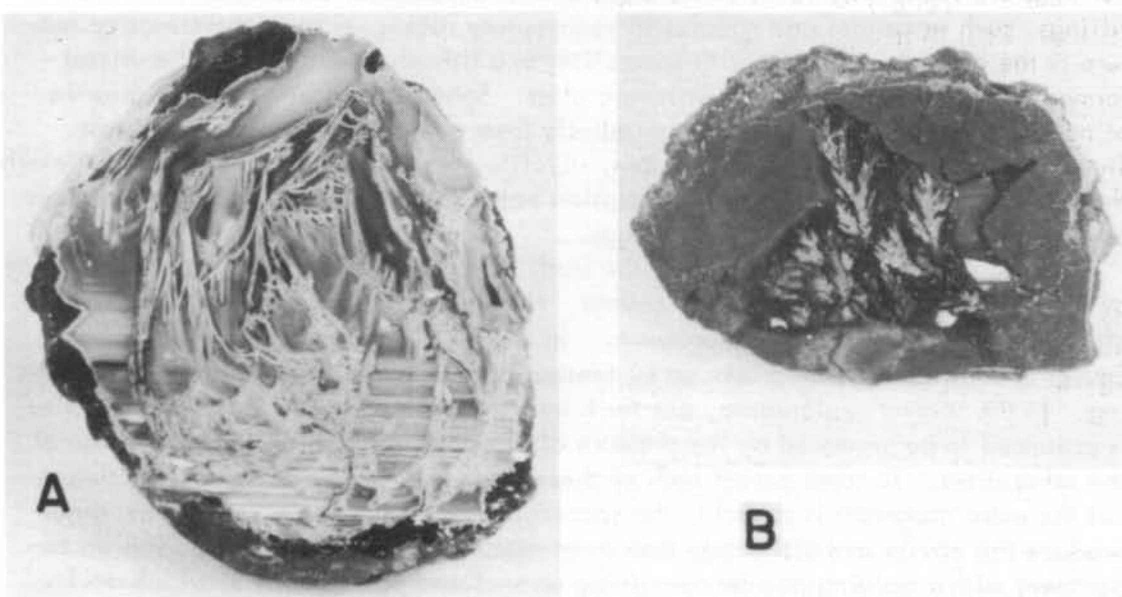

Figure 3. Two Priday Ranch thunder eggs: (A) Green moss agate, (B) red, yellow, and orange plume agate. All are approximately 2/3 natural size. (Photograph by Leo F. Simon)

pseudo-algal structures; (5) the core frequently exhibits a geometrical form, such as a cube or pyritohedron with the faces being inverted pyramids. This gives a star-like form when the specimen is cut in the correct direction. Since the exterior ribs are related to the apexes of the star, an experienced lapidary can determine from a study of the specimen which cutting plane will yield sections with the best figures.

Occurrences

A description of the places in which thunder eggs are found, along with a map showing the Oregon localities, is given on pages 192-194.

The Priday agate deposit, the best-known Oregon source for thunder eggs, is described by Peck (1964, p. D23-25). This deposit lies about six miles from U. S. Highway 97, and about 10 miles northwest of Ashwood. The thunder eggs occur chiefly in the lower few feet of a weakly welded rhyolite ash flow which is 10 to 20 feet thick and composed of black perlitic angular lapilli of collapsed pumice in a matrix of shards and ash.

An unusual type of thunder egg is found at Buchanan, Oregon. Some specimens clearly demonstrate the spherulitic origin where numerous small spherulites have been ruptured and filled with chalcedony. The occurrence is unique in that the chalcedony sometimes is colored red by cinnabar. The presence of cinnabar, which forms at temperatures below 344°C (Dickson and Tunell, 1955), the inversion point to metacinnabar, gives us some idea of the temperatures exising during the deposition of the cavity-filling material.

Origin of Thunder Eggs

There are still many unanswered questions concerning the details of the origin of thunder eggs, but the general processes involved are fairly well understood. Thunder eggs are found only in volcanic areas and in this respect differ from other cavity fillings, such as geodes and nodules in sedimentary rocks. A second distinctive feature is the close relationship with spherulites and lithophysae (hollow spherulites) formed during crystallization of volcanic glass. Spherulites are spheroidal growths of needlelike crystals which develop radially from one or more centers in a glass. These structures are common in obsidian, rhyolite, and vitric tuffs. One of the details that needs further study is the exact relation between the development of spherulites and the control of growth of thunder eggs.

An outstanding contribution to the study of spherulites and lithophysae was made by Wright (1915) on obsidian from Iceland. He discusses the two theories for the origin of hollow spherulites or lithophysae. In the first, advanced by Iddings, the cavity is considered to be produced by tension developed by the magma during cooling. In the second explanation, put forth by Von Richthofen and Zirkel, the cavity is presumed to be produced by the pressure of the gases set free on crystallization of the spherulites. To some extent both of these processes may be of some importance, but the more important is probably the second theory, which assumes that the gases produce the cavity and ultimately may even rupture it. Buddhue (1941) cites an experiment with a molding powder containing an enclosed pressure blister which resulted in a cavity similar to those found in thunder eggs. He concludes that this is laboratory proof that the star-shaped centers of thunder eggs are produced by expansion.

The tension or shrinkage origin is advanced by Dake (1954). Frondel (1962, p. 215) states, "In a highly viscous material expansion of the gas cavity by rupture may require less energy than spherical expansion, giving angular cavities which may be symmetrically developed." The evidence for expansion rather than shrinkage appears overwhelming to this writer.

Mansfield and Ross (1935, p. 320) state that the gas cavities are developed subsequent to complete welding of the tuff and the gas promotes devitrification and the formation of spherulites which sometimes act as a locus for the gas cavities. Wright (1915, p. 268) believes that the formation of the lithophysae or hollow spherulites take place at relatively high temperatures.

Frondel (1962, p. 215) states, "These chalcedony nodules generally contain or border on a spherulite aggregate of intergrown feldspar and cristobalite, the crystallization of which is believed to have initiated the release of gases dissolved in the rhyolitic glass."

Wright (1915) gives the first good description of the formation of the star-shaped cavities, explaining that they are due to rupture along cube diagonal planes. Ross (1941) expands on these studies and discusses the probable origin of the pentagonal shapes that are frequently encountered in Oregon thunder eggs. He describes the history of the development of thunder eggs as follows (1941, p. 732):

> "The following geologic history is, therefore, revealed by the Oregon 'thunder eggs.' Explosive volcanic activity produced finely divided glassy ash, which fell in a hot plastic condition that permitted its rewelding into a homogeneous material. While still hot, local centers of crystallization were set up, around which spherulitic masses of intergrown cristobalite and feldspar were formed. The formation of these anhydrous minerals released volatiles originally in solution in the glass. The gradual collection of volatiles exerted a pressure which, combined with the cooling shrinkage of the enclosing material, forced the walls of the cavity outward, expansion being by rupture along symmetrically arranged planes. The more perfect of these cavities had the geometrical symmetry of a modified pyritohedron bounded by 12 inward-projecting, 5-sided pyramids, formed by the shear along 30 triangular planes. The resultant cavity was later filled by chalcedony that was probably deposited during the alteration of the enclosing material to a clay."

The writer has studied many thin-sections of thunder eggs, and also transparent slabs projected on a screen. The sequence of formation, the manner of crystallization, and the order of deposition within the thunder egg are readily observed in this way. In most thunder eggs it can be seen that the glass shards, which are usually collapsed and well aligned, have a different orientation than the minerals produced during devitrification of the glass. These minerals, usually feldspar and cristobalite, are often radially arranged and produce the spherulites which cause the thunder egg's knobby or warty appearance. The spherulites under crossed nicols give a dark cross which simulates a positive uniaxial interference figure, the fibers being length slow. The phenocrysts of plagioclase (often oligoclase) in the welded tuff (figure 4) were fractured and somewhat corroded in the original rock. They remain fresh in their centers but are sometimes corroded during the growth of the spherulites.

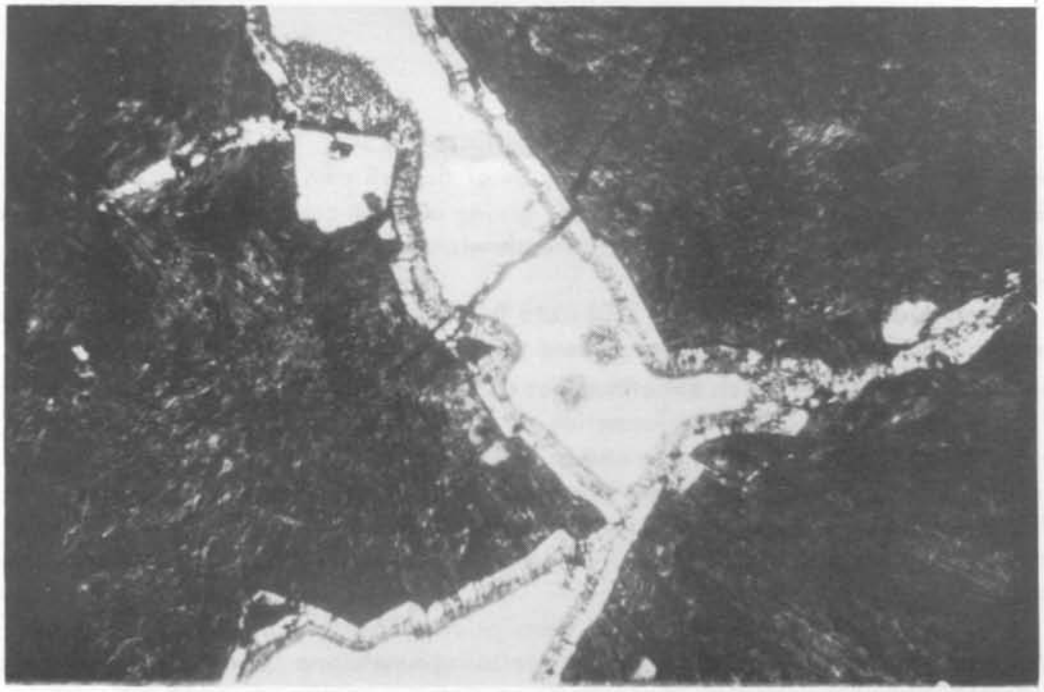

Figure 4. Photomicrograph of thin section of Priday thunder egg. Dark matrix is welded tuff showing glass shards. Central light channel is chalcedony. Zone at contact is composed of spherulites, both light and dark in color. Large crystal is feldspar phenocryst. Veinlet cutting across section is opal. Magnification 23 X, without crossed nicols.

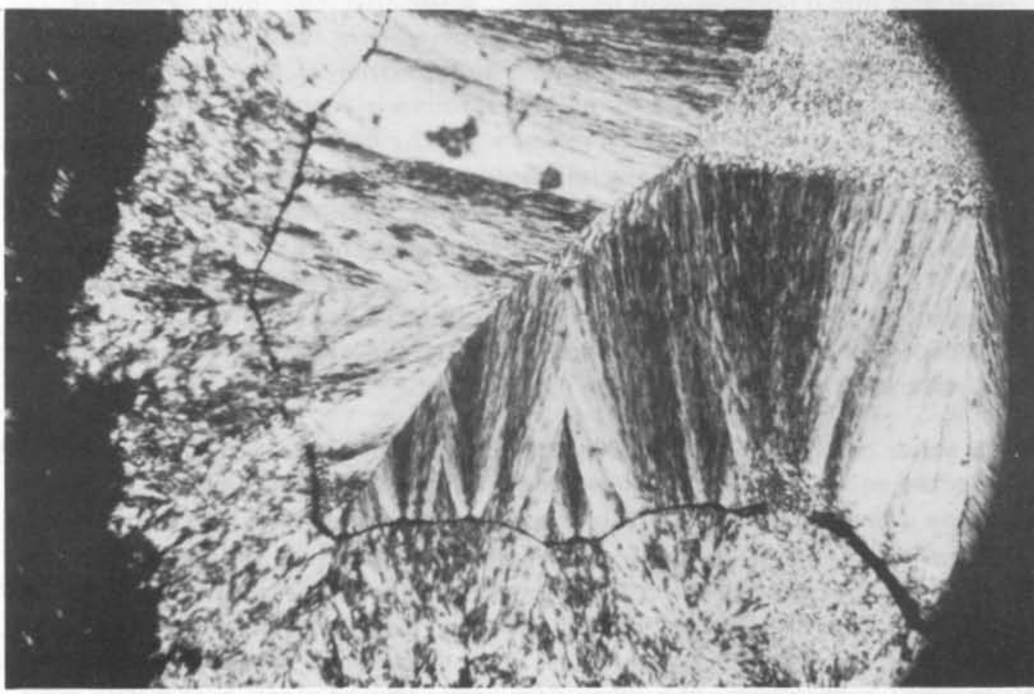

Figure 5. Photomicrograph of thin section of thunder egg from Mutton Mountains, Oregon. Chalcedony in filled cavity showing crystallization in sectors. Salt and pepper structure in upper right sector. Black Liesegang ring parallels contact with rhyolite matrix. Magnification 23 X, crossed nicols.

The centers of the thunder eggs contain chalcedony which is sometimes banded, forming agate (figure 1A). More rarely moss-like, plume, fern-like, or tubular inclusions are present giving rise to the name "moss agate" (figure 3, A and B). Brown (1957) describes the origin of these features showing that the filaments, derived from salts along the walls of the cavity, grew into the silica gel which filled the cavity. He states (p. 335), "These pseudoalgae shot up rapidly in pulses by chemical precipitation (probably as iron hydroxide and silicate), osmosis, and diffusion." It is evident that the inclusions are not organic as some people have concluded.

The chalcedony filling of the centers (figure 5) consists of fibers which for the most part are length fast, indicating that the c axis of the mineral is at right angles to the elongation. At the outer edges of the cavity adjacent to the host rock, the fibers radiate toward the cavity center and are normal to the boundary reflecting the shape of the cavity walls. On the other hand, toward the center of the cavity, the silica gel which filled it was crystallized in sectors with well-defined straight edges, possibly determined by the planes in the cubic or pyritohedral core. In addition to the fibrous or radiating structure of the chalcedony, it frequently shows the salt-and-pepper or aggregate structure. Superimposed on the fibrous chalcedony structure are Liesegang rings which are parallel to the cavity wall and perpendicular to the elongation of the fibers. Liesegang rings, named after their discoverer, are rings or curved bands formed by the rhythmic precipitation of salts in a gel. The structure produced may be easily confused with layers formed by deposition, but whereas depositional structures are primary, Liesegang rings are secondary due to diffusion. A simple method for making Liesegang rings is described by Cassirer (1936, p. 11, 12). Where there is incomplete filling, euhedral quartz often lines the cavity.

Excellent examples of weathered-out cores of chalcedony are found on Dry Creek, southeast of Lakeview in Lake County (figure 2D). These are casts of the cavity and each face has radial markings with a button at the center. The button is hemispheric on one face with a corresponding hollow on the opposite face. Because opposite sides of the cavity often would fit together if joined (figure 4B), it may be assumed that the sides were spread apart by fluid pressure, forming the cavity. This explains the positive and negative buttons seen on the weathered-out chalcedony cores and is further proof that the cavity formed after the development of the spherulites which produced the hemispherical buttons.

The zone of greatest difficulty to interpret is at the contact between the chalcedony core and the tuffaceous outer shell (figure 4). A complete understanding of the history of this zone of contact would clarify many of the least understood processes in the formation of thunder eggs. (The term "contact zone" used here refers only to location at the contact of the outer shell and matrix, and has no genetic significance as in ore deposits.) The rim of the cavity is often coated with colloform opal and this in turn may have a shell of spherulitic material on it. This spherulitic shell determines the form of the chalcedony bands which are composed of fibers lying normal to the shell, with Liesegang rings superimposed and paralleling the shell. In the contact area the spherulites can be recognized by their length slow habit as well as the radiating structure (figure 6).

In hand specimens there often appears a zone of chalcedony parallel to the cavity wall into which abut the paralleled bands of the agate. This zone seems, on cursory examination, to have been the first to form, as a cavity wall coating, and later to have been covered with banded agate as the cavity filled up. However,

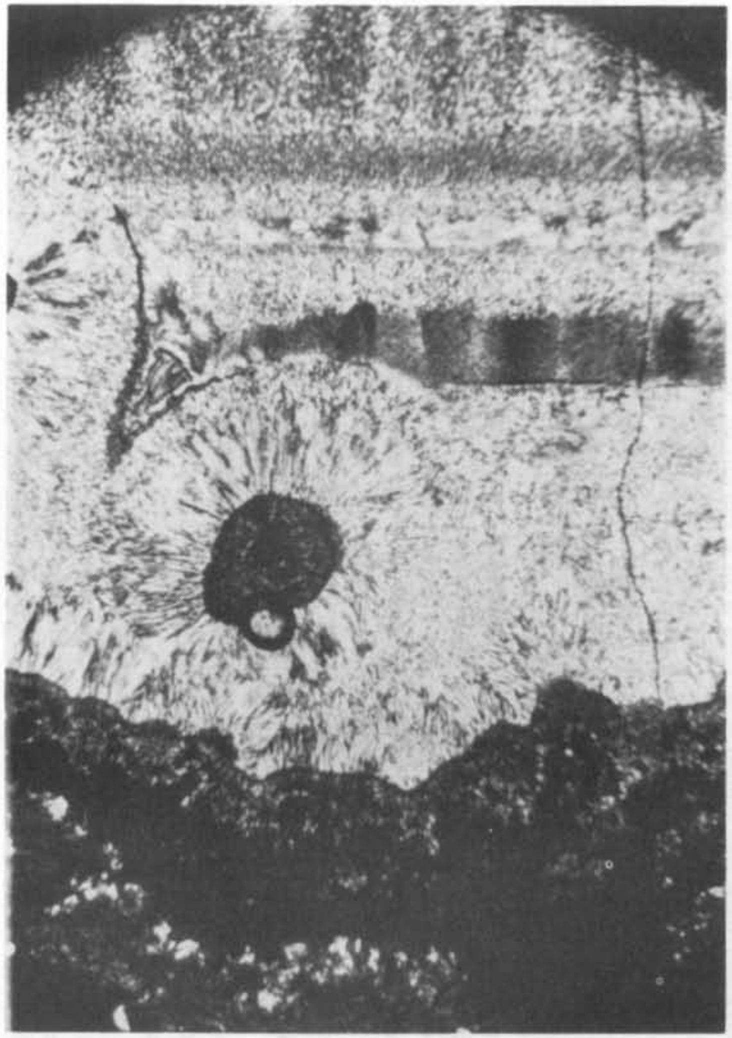

Figure 6. Photomicrograph of spherules surrounded by radiating chalcedony which has corroded earlier bands of agate. Contact zone of dark spherulites. Mag. 23 X, crossed nicols.

Figure 7. Moss agate showing Liesegang rings paralleling tubes and corroding earlier-formed horizontal bands of agate. Magnification 5 X.

careful observation of this zone, supported by thin-section studies (figure 6), shows the reverse sequence to be true. It appears that the cavity was filled with gel, layer on layer, which, due to slightly different compositions, produced banding. In some cases a tilting of the cavity during deposition resulted in an unconformity between the first set of bands and a later set. For reasons which are not now understood, the wall of the cavity often directs a Liesegang effect into the agate, eradicating the original structure. This is also seen where pseudoalgae or "moss" protrudes into the agate. The pseudoalgae are outlined by rings which cut across the agate bands, eradicating them (figure 7). The pseudoalgae or filaments, according to Brown, (p. 336), "...originated after and not before the cavity was filled with the gel."

The chemistry of the formation of the feldspar and cristobalite spherulites from rhyolitic glasses is not well enough understood to predict the amount and kind of material that would be liberated. Possibly some of the contact effects and growth of quartz crystals along the contact may be due to devitrification, but it seems unlikely that the large amount of silica which fills the central cavity could originate in this fashion. This silica which deposits as silica gel in the central cavity, and later crystallizes to chalcedony, and the quartz which lines or fills the remaining voids, undoubtedly entered the cavity through minute cracks or through the porous walls. The amount of secondary silica in veinlets, amygdules, and cavities in the rocks where thunder eggs are found is very great and there is little doubt that silica was transported and introduced from ground-water solutions.

Summary

The sequence of events in the formation of a thunder egg varies from specimen to specimen and some exhibit much greater complexity than others. The best examples are those which, when cut, exhibit four- (figure 1D) or five-pointed stars (figure 1A) and in which there is distinct banding. Possibly of greater beauty, but more difficult to explain are those which contain pseudoalgal structures (moss agate, plume agate [figure 3]), and those which have multiple-filled or very irregular cavities (figure 1C).

The development of thunder eggs has been discussed above. To summarize this briefly, they are rock structures formed in welded tuffs and rhyolites, of spherical or ellipsoidal shape, containing cores of chalcedony and sometimes quartz. The specimens consist of three concentric shells: an outer shell, usually brown in color with a ribbed, warty surface; a contact zone which borders the former cavity; and a core representing the cavity filling and consisting chiefly of chalcedony but sometimes containing quartz, opal, and pseudoalgal structures. The contact zone between the core and outer shell is sometimes only apparent microscopically. The most characteristic feature of thunder eggs is the devitrification of the rhyolitic glass by incipient crystallization forming spherulites. Although it has not been definitely proved, the devitrification probably releases gases which initiate spherulite growth and act as the force to open the central cavity, often between or around spherulites, but sometimes within them. The spherulitic growth produces the hardened outer shell, which becomes a residual structure in the surrounding rock as it alters to clay. Most specimens consist not of a single spherulite but rather of many of them intergrown, some of which may contain no cavities. The central filled cavity of many thunder eggs contains a hemispherical protuberance (button) on one side with a hole of a

similar size on the opposite side (figure 2B), indicating that the cavity was formed around some spherulites and that the two sides were formerly joined. The cavities with regular shapes, yielding a four-sided or five-sided figure in section, have been explained by Wright (1915) and Ross (1941) as due to expansion and rupture along planes representing the faces of negative or inward-projecting four-sided and five-sided pyramids. Natural casts (figure 2D) of the cavities well illustrate these forms.

A careful study of thunder eggs raises nearly as many questions as it answers. Details concerning the types and pressures of fluids involved in forming and filling the cavities; the length of time required for devitrification, crystallization, and filling; the physical chemistry of development of spherulites; and the paragenesis of the minerals involved, including the temperatures of formation, all need to be given attention. In addition, further field work should be pursued in the hope that it would aid in solving some of the problems related to sources of the material which must be derived from outside of the thunder egg. Other field studies should consider the orientation and location of the thunder eggs in the flows or beds, the relations of spherulites and lithophysae, and the types of alteration involved.

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LUNAR GEOLOGICAL FIELD CONFERENCE

From all quarters, the first International Lunar Geological Conference, which was held in Oregon in the summer of 1965, has been judged a complete success.

During the week-long meeting at Bend, August 22 to 29, geologists, geophysicists, and astronomers from Australia, Belgium, Canada, Czechoslovakia, England, Iceland, Norway, South Africa, and West Germany joined with their counterparts from United States Universities, government agencies, and space industries to exchange information about the lunar surface.

Two State of Oregon Departments (Planning and Development, and Geology and Mineral Industries) staged the conference under the sponsorship of the University of Oregon and the New York Academy of Science. Dr. Lloyd Staples and Dr. Jack Green were the co-chairmen for the respective sponsors. The Lunar Base Research Committee and Chamber of Commerce committees of Bend proved to be extremely hospitable hosts. The State Highway Department contributed to the conference by demonstrating a vane sheer test at a pumice quarry near Bend.

Unlike typical conferences where most of the time is allotted to the lecture room for technical papers and discussions, this was designed with five days of field trips to show the visiting scientists the great variety of initial surfaces and volcanic landforms of central Oregon, and also to permit on-the-spot discussions of views concerning volcanic processes and the origin of the moon's surface.

Three Trailways buses were required for transportation of the 70 to 80 participants on the five separate field trips, which covered the central Oregon landscape from Bachelor Butte and the Three Sisters areas to Newberry Volcano, to Fort Rock and the Devils Garden, on to magnificent Crater Lake, and back to the McKenzie Pass lava field. The bus caravan never failed to negotiate the back roads that kept blocky obsidian flows, pumice flats, spatter cones, lava tubes, spiny lava fields, and large calderas within view the better part of every day. See pictures, pages 209-216.

The official guidebook for the five days of field trips was the Department's Bulletin 57 prepared especially for the conference. Its cover portrayed a photographically denuded central Oregon landscape as a fictitious lunar mare termed "Incognitum." Official photographer for the conference was Earl Roarig, 1735 E. 11th Street, Bend, Oregon, who shot a voluminous number of pictures with three cameras and took orders for prints.

During the conference week the Bend community used every available moment to entertain its distinguished guests. The opening event was a banquet at which Governor Mark O. Hatfield welcomed the conference members and noted that the key to Oregon's future lies in science and research. As proof of this, Dr. Arthur S. Flemming, President of the University of Oregon, announced the establishment of the Center of Volcanology at Eugene, to be headed by Dr. A. R. McBirney.

The Rim Rock Riders of Bend provided a buckaroo breakfast, and the Fort Rock Grange, with Reub Long in charge, put on an old-fashioned western barbecue lunch in the shadows of Fort Rock. And to top the week of hospitality, on Wednesday evening each visiting scientist was the personal guest in the home of a Bend family.

Many of the highlights of the conference were provided by the visiting scientists:

At East Lake within the Newberry Caldera, Dr. Haroun Tazieff, dynamic volcanologist from Paris and Brussels, demonstrated a portable gas analyzer used during actual eruptions to check the composition of emanating gases at erupting volcanic vents. The fumarolic gases bubbling to the surface at East Lake were found to be almost entirely carbon dioxide.

Deep within the enormous lava tube called "Lava River Cave," Dr. Gordon Macdonald, dean of Hawaiian volcanologists, vividly described the processes involved in its creation.

From the rim of sparkling blue Crater Lake, Dr. Howel Williams of the University of California described, as only he can, the building of mighty Mount Mazama, its eruption, and its collapse. The story was told from spectacular viewpoints where, in his own words, "The scene is one of overwhelming beauty."

Evening discussion groups at Pilot Butte Inn were led by Dr. Aaron Waters, Head of the Department of Geology at the University of California, Santa Barbara. One day of the week was devoted to presentation of technical papers with Dr. Jack Green as moderator. The papers are to be published by the Department.

On the last trip of the conference, into the vast McKenzie lava field, the conference delegates paused briefly to conduct their only official business meeting. Still unsolved was the answer to the main question of the lunar surface controversy: Are the craters volcanic or meteorite impact? Dr. Nicholas Short of the University of Houston presented resolutions for the members' approval that basically recommended the selection of a volcanic crater and an impact crater for intensive studies prior to manned landings on the moon. "Hole-in-the-Ground" near Fort Rock was mentioned as a possible volcanic crater and Oregon's new Center for Volcanology at the University of Oregon was urged to seek funds for a systematic study of the structure. Meteor Crater, Arizona, was chosen as the crater to be studied for impact phenomena. The resolutions were left with an "ad hoc" committee for final editing and circulation to conference delegates for signing.

As stated before, the conference has been judged by nearly everyone as an unqualified success, and if the only purpose had been to enhance Oregon's scientific image, it did. If it was to show space-oriented industries that Oregon has adequate research facilities and the terrain on which to experiment, it did. If it was to further publicize Oregon's volcanic scenery, it did. If it was to encourage the new Center for Volcanology at the University of Oregon, it did.

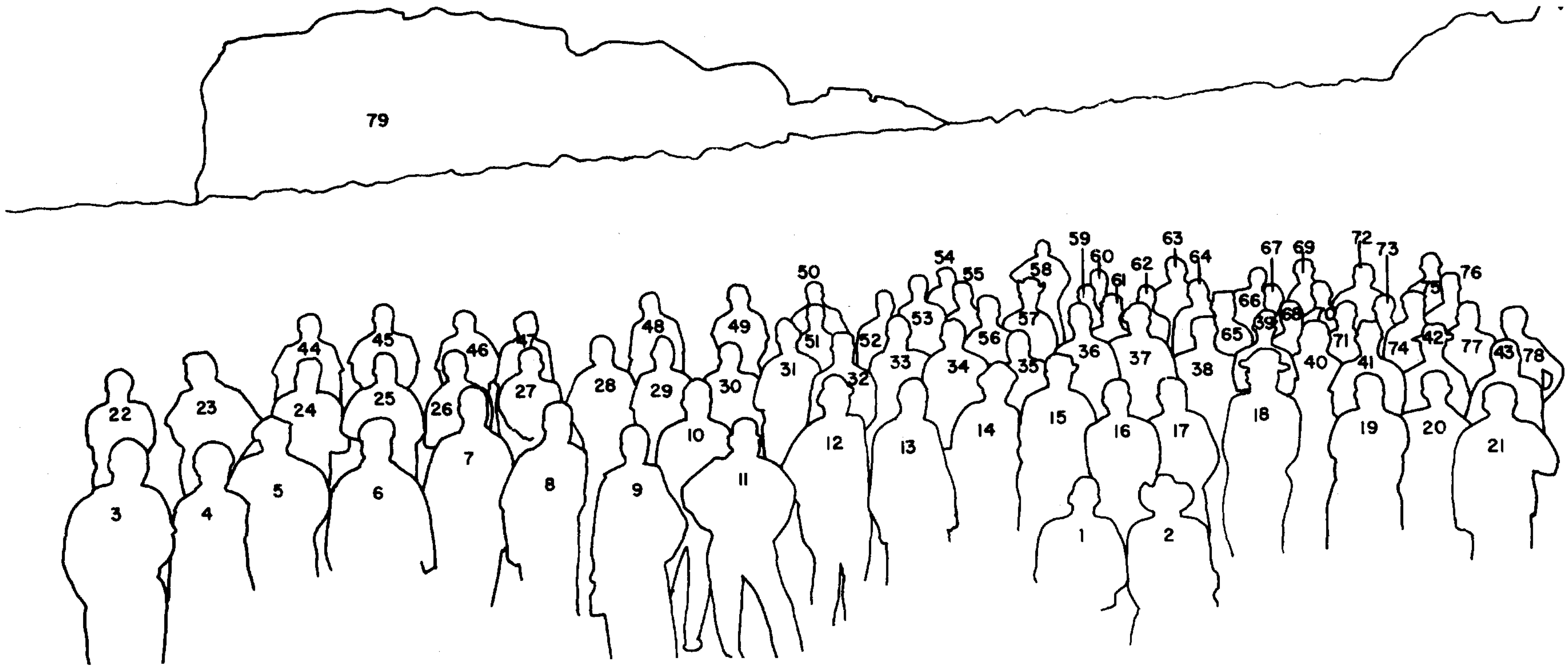
When asked for comments on the achievements of a meeting such as this, one of the participants replied as follows: "Besides getting to know the people of what is surely one of the finest States in the Union, and getting to understand its volcanic terrain, we had an exchange of views. It is the discussions which go on during such conferences between scientists of widely differing experience and from distant parts of the world that are the most important aspect."

The scroll reproduced on the opposite page was sketched by Dr. B. B. Brock of the Union of South Africa during the field trip to Crater Lake; it was signed later by members of the conference. On the last day of the conference, at a noon luncheon in Bend, Dr. Fred M. Bullard, Texas volcanologist, made the formal presentation of the scroll to Oregon's State Geologist, Hollis M. Dole, who accepted it for the Lunar Conference Committee. →

August 28, 65

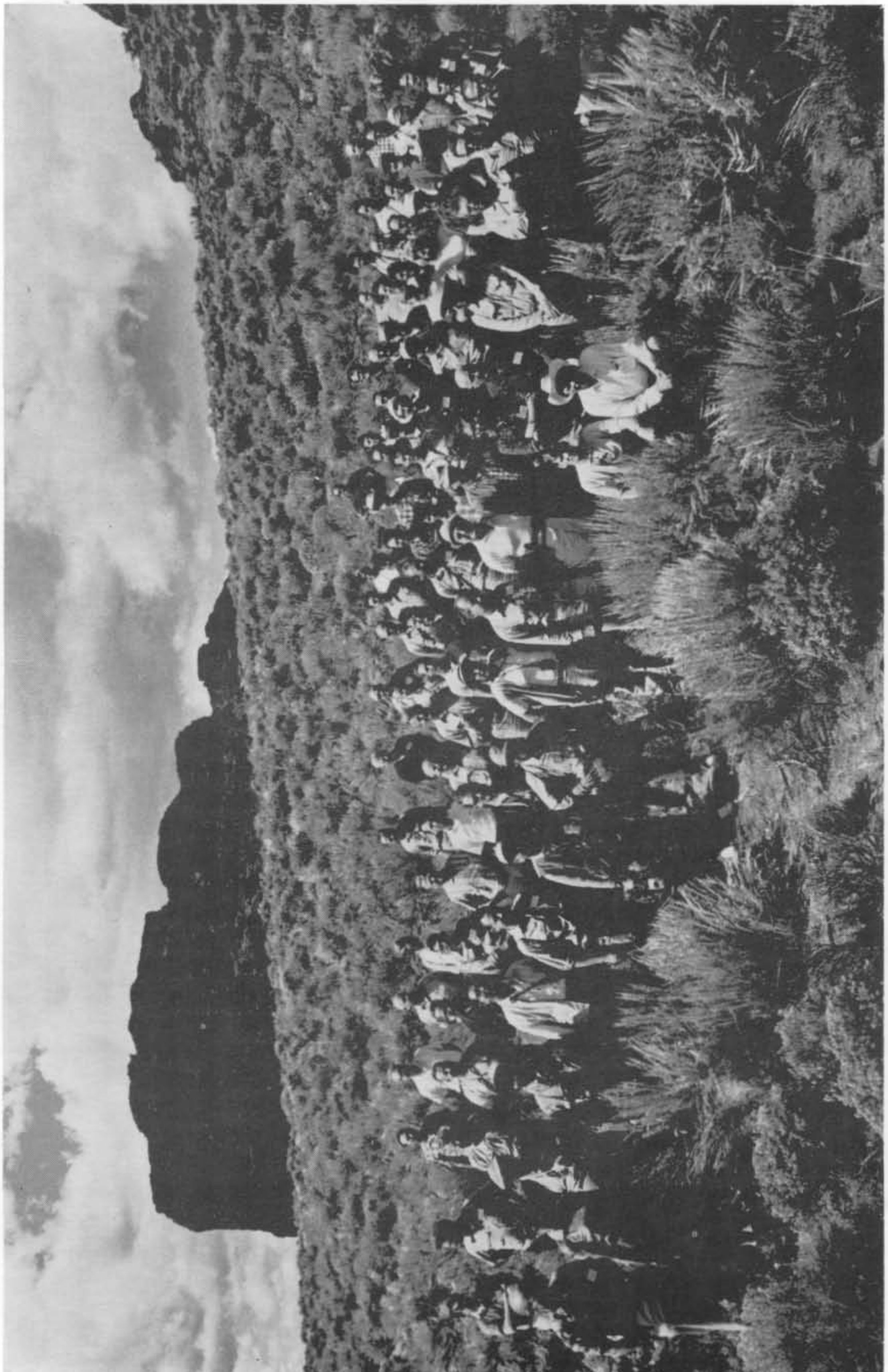
Having enjoyed a week's sojourn and study in the magnificent volcanic landscapes of Oregon, we, the undersigned wish to express our sincere gratitude to the organizers and sponsors of the Conference.
We also wish to thank the citizens of the beautiful City of Bend for their most gracious and generous hospitality.

Members of the International Lunar Geological Field Conference

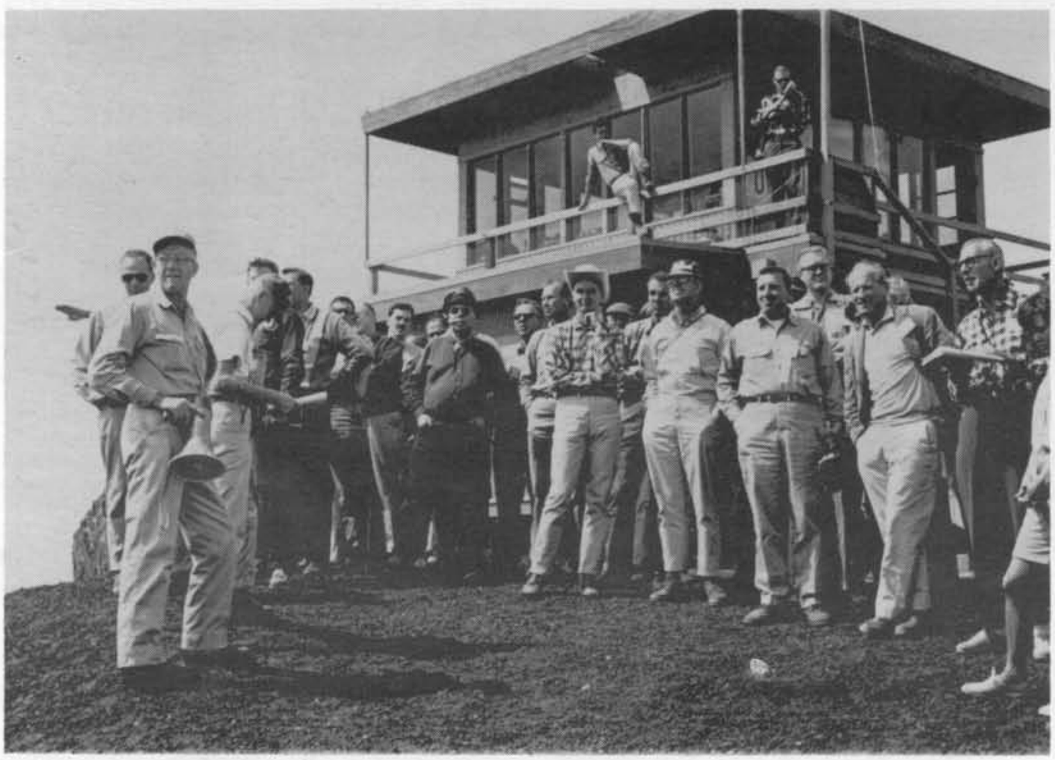


Lunar Geological Field Conference participants at the base of Fort Rock are identified by the numbered outlines above. Sixteen are from foreign countries, as indicated; all others are from the United States.

(1) Dinneen, (2) Long, (3) Tazieff (Belgium), (4) Mrs. Tazieff (Belgium), (5) Gant, (6) Matumoto (Japan), (7) Bullard, (8) Elston, (9) Kaneko (Japan), (10) Wood, (11) Saito (Japan), (12) Walker, (13) Ingerson, (14) Brown, (15) Raymond, (16) Taylor, (17) Wilkinson, (18) Allen, (19) Tiffany, (20) Saari, (21) Halajian, (22) Gass (England), (23) Dietz, (24) McCall (Australia), (25) Wilson (Canada), (26) Strom, (27) Robinson, (28) Bodvarsson (Iceland), (29) Vaughan, (30) Oftedahl (Norway), (31) Macdonald, (32) Cook, (33) Kocher, (34) McBirney, (35) Howard, (36) Hale, (37) Ronca (Italy), (38) Groh, (39) Fogelson, (40) Cameron, (41) Mason, (42) Hoch, (43) Schloss, (44) Weathers, (45) Van Lopik, (46) Waters, (47) Von Englehardt (West Germany), (48) Benson, (49) Pinson, (50) Arnett, (51) French, (52) Short, (53) Dence, (54) Bryson, (55) Baragar (Canada), (56) Kopecky (Czechoslovakia), (57) Currie (Canada), (58) Denny, (59) Manton, (60) Rogers, (61) Corcoran, (62) Richardson, (63) Kennedy, (64) Cronin, (65) Bledsoe, (66) Hill, (67) Green, (68) Zaitzeff, (69) Bowen, (70) Hafner, (71) Staples, (72) Ryan, (73) Azmon, (74) Brock (Union of South Africa), (75) Lounsbury, (76) Tooley, (77) Williams, and (78) Greiner. No. 79 indicates Fort Rock. (Photograph by Earl C. Roarig)



A stop along the Cascade Lakes Highway by Devils Hill. The party is inspecting and sampling one of the dacite flows of very recent origin.



Viewing the surrounding country from the top of Lava Butte. This fresh cinder cone, its crater, and rugged black lava field was of great interest to the field party.

Phil Brogan, well known for his popular writing on the geology of central Oregon, stands beside the Forest Service sign that names the trail to the Lava Butte gutter in his honor.

Three leading volcanologists having a field lunch at Paulina Falls Forest Camp. From left to right: Dr. Matumoto, University of Kumamoto, Japan; Dr. Williams, University of California; and Dr. Gass, University of Leeds, England.

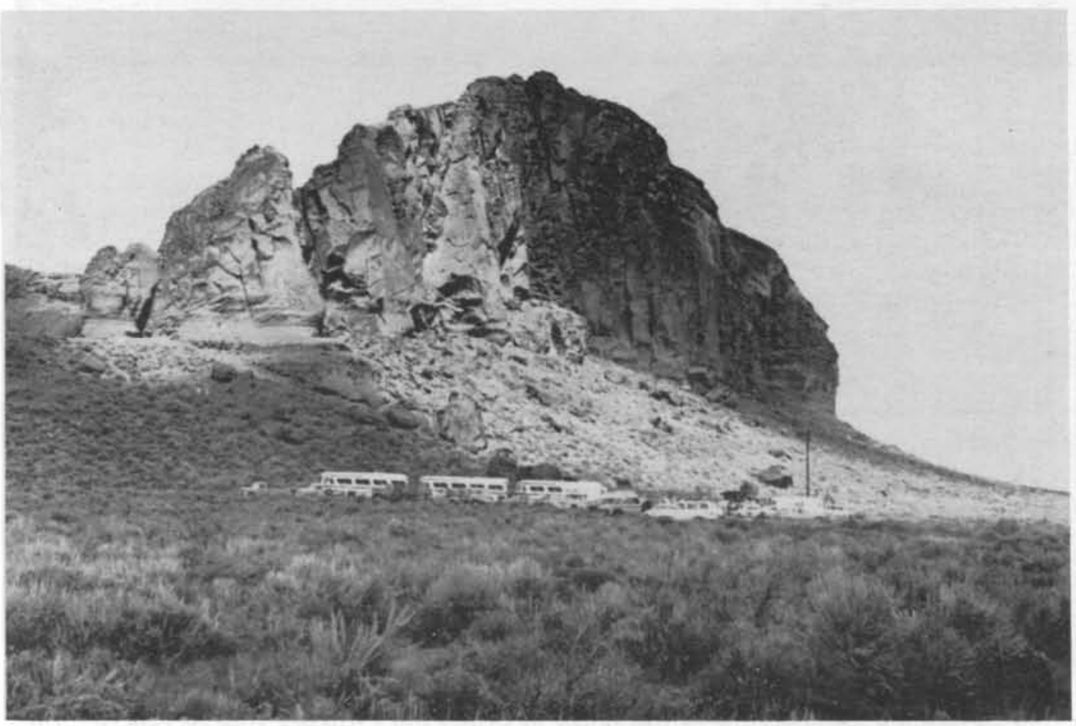
The conversation between Dr. McBirney and Dr. Waters (center of photograph) on the Paulina Lake maar in Newberry Crater was one of the many interesting discussions that took place during the field conference.

Conference group listening intently as Dr. Tazieff, University of Brussels, Belgium, describes the operation of a portable volcanic gas analyzer at the East Lake Hot Spring in Newberry Crater.

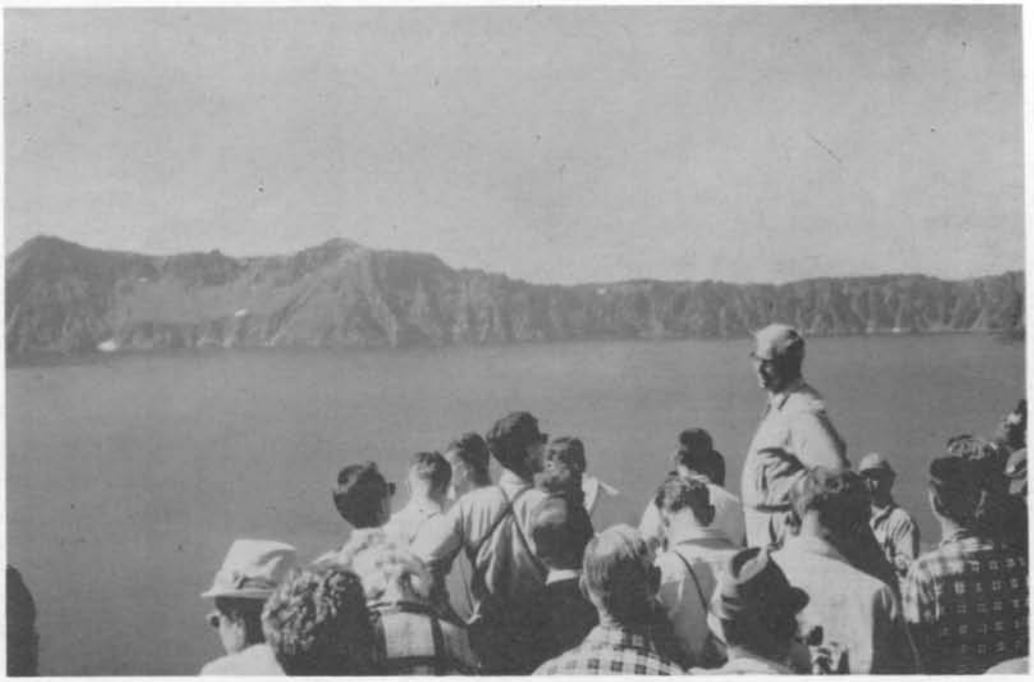
Field trip guide Norman Peterson, Oregon Department of Geology and Mineral Industries, describing Hole-in-the-Ground to the conference group. This feature, so much like a lunar crater, fascinated everyone.

Conference members leave the buses to climb the clinkery side of one of "The Blowouts," a large spatter cone in the Devils Garden area. The Lunar Conference sign on the bus gives a humorous twist to the Trailways slogan, "Easiest travel on earth."

At Fort Rock State Park the group enjoys a genuine western-style barbecue lunch prepared to gourmet taste by the members of the Fort Rock Grange.



Towering above the state park where the barbecue was held is Fort Rock, an eroded tuff ring.



Dr. Williams, authority on the geology of Crater Lake, is giving the conference group the benefit of his knowledge and experience. This spectacular caldera was the climax of the field conference.

Two pipe-smoking earth scientists in friendly discussion at Crater Lake. Dr. Brock, Union of South Africa, on the left and Dr. Macdonald, University of Hawaii, on the right.

Dr. Staples, Department of Geology, University of Oregon and co-chairman of the conference, at left, and Dr. Matumoto, with other members in the background, give their attention to the lecture by Dr. Williams at the view-point overlooking Wizard Island.

Some of the conference scientists observing the jagged lava surfaces at McKenzie Pass from the top of Dee Wright Observatory. North Sister and Middle Sister peaks are in the background.