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RECENT VOLCANISM BETWEEN THREE FINGERED JACK AND NORTH SISTER OREGON CASCADE RANGE

Part I: History of Volcanic Activity*

By Edward M. Taylor**

Introduction

On the crest of the Oregon Cascade Range, between the Pleistocene volcanoes known as Three Fingered Jack and North Sister, an impressive array of cinder cones stands in the midst of Recent basaltic lava fields whose total area exceeds 85 square miles (fig. 1). Although each major field is closely approached by a highway, several lava flows and many cones, vents, and other volcanic features have not been described in print. In this paper, the history of each eruptive center first will be interpreted from the standpoint of field observations, and then will be reviewed in an integrated outline of recent volcanism. The volcanic history and geologic maps presented here have been abstracted from a general survey of petrology in the High Cascades of Oregon which the writer has followed for several years and which has progressed from Bachelor Butte to Three Fingered Jack.

North and south geographic limits of the present study are placed along straight east-west lines through Three Fingered Jack and North Sister, respectively; east and west boundaries are drawn coincident with the east and west borders of the High Cascades as outlined by Williams (1957). The temporal range of geologic events extends from the end of the last major glacial episode to the present. It is believed that all exposed eruptive units within these boundaries of space and time are included in this report. Several unofficial, but suitable, geographic names are introduced where reasonable discussion demands them. For background information, the reader is referred to the appended Glossary of Selected Terms and to Williams (1944).

Cones and Flows of Questionable Recent Age

The maps presented in this paper differ slightly from earlier reconnaissance geologic maps (Williams, 1944, 1957) in their definition of Recent basaltic cones and flows. Discrepancies arise with respect to: (1) identification of landforms, (2) recognition of cones and flows which have been glaciated, and (3) recognition of possible pre-Recent cones and flows which have not been glaciated. Included in the first group are the following land forms not previously identified: a glaciated dome of rhyolite and obsidian at the southeast base of Condon Butte, a knob of glaciated bedrock near the terminus of the northwest lava flow from Collier Cone, a nearly flat glaciated

* Part II, Petrographic studies and chemical analyses, to be published at later date.
** Department of Geology, Washington State University.

surface between Collier and Four-in-One lavas, two glaciated steptoes which rise through Little Belknap lava near McKenzie Pass, a glaciated hill $1\frac{1}{2}$ miles northwest of Yapoah Cone, and a glaciated steptoe at the west end of the Belknap lava field. Landforms of the second group are located on figure 1 by the symbol "X". The third group includes four lava flows which do not appear on the older maps, Scott Mountain, Two Butte, a feature known as the "Cinder Pit," and two cinder cones on the northeast slope of Black Crater. This group is described as follows:

Lava flows, so old that deep forests now hide them from view, issued from four separate vents close to the western boundary of the High Cascades. Their individual histories are relatively unknown. Included here are the Park Creek flow, the flows on the west slope of Maxwell Butte, and the Anderson Creek flow (fig. 1). No cinder cones have been recognized in association with these lavas.

The Park Creek flow is composed of blocks which have been somewhat rounded by weathering. Crustal features and the outlines of lava tongues can be seen only where ancient fires have limited the forest cover. The flow originated near a small hill at the north lava margin, moved south for two miles, and forced Park Creek to undercut a high cliff of sedimentary rocks.

Equally vague is the eruptive history of flow rocks on the side of Maxwell Butte. Two source vents approximately 2.3 miles west of the Maxwell summit are indicated by the distribution of lava, but neither has been located precisely nor has it been possible to trace contacts between flow units. Here too, old forest fires have exposed slaggy crusts and numerous pressure ridges. Where the North Santiam Highway cuts through the flows, their thin, vesicular character can be seen in cross section. Farther west, about two miles from their source, they are found adjacent to the Park Creek flow; relative age has not been determined.

To trace the Anderson Creek flow one must learn to "feel" it beneath the forest floor; indeed, the very existence of fresh lava would be difficult to prove if logging operations had not disclosed striking examples of lava levees and vesicular flow tops. The advanced age of this flow is inferred from the condition of its forest cover in comparison with the cover found on other flows which lie at similar elevations to the north and south. Lava issued from a subdued spur 2.3 miles west of Scott Mountain summit and poured as a cascade into the valley of Anderson Creek. A north lobe appears to have advanced, then stagnated, three miles from the source. Another lobe was channeled west by an intervening hill, and then was deflected northward, where it lies in contact with the northernmost lobe. This western lobe eventually spread into the valley of Olallie Creek. Its terminal lava front, six miles from the source, can be seen beside the Clear Lake Highway.

Scott Mountain is a glaciated shield volcano, located southwest of the Belknap lava field (fig. 1). Upon the summit of Scott Mountain is a small cinder cone of recent appearance. Layered deposits of ash and scoria are abundant near the top, where only an indistinct remnant of the crater rim has survived erosion. The flanks are composed of coarse red scoria and perfectly shaped spindle bombs. Black lava spread over the west and southwest lip of the crater but did not move beyond the cone.

Two Butte is a double cinder cone located 3.4 miles south of Scott Mountain (fig. 1). The cones are 400 feet high, are aligned north-south, and have lost their craters by erosion. Red scoria and spatter are exposed near their summits, but their flanks are mantled in dense forest. Except to the south, where small flows can be traced to the edge of the Lost Creek glacial trough, surrounding terrain bears the

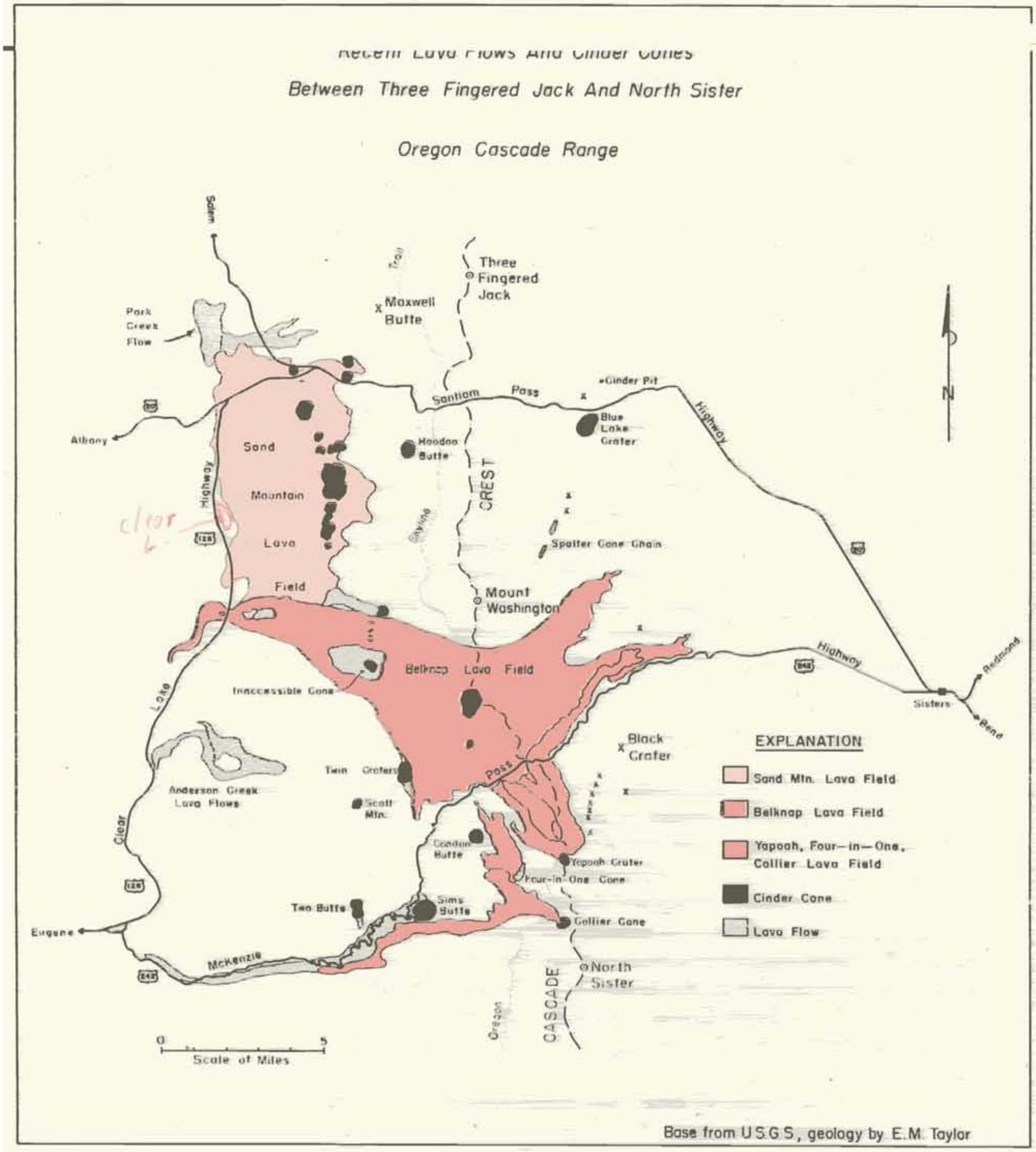


FIGURE I. INDEX MAP

imprint of profound glaciation.

One and one-half miles north of Blue Lake Crater (fig. 1), a diminutive cinder cone has been excavated for road metal. As a result, the conduit - now occupied by a plug of basalt - has been laid bare within a shallow, cinder-covered pit. The designation "Cinder Pit," which appears on the Three Fingered Jack topographic map (U.S. Geological Survey, 1959, 15-minute), will be adopted here. A narrow stream of lava moved only a few hundred feet east from the conduit. The lava rests upon glacial deposits which, as exposed in the pit, have been oxidized by volcanic emanations.

Two other cinder cones with well-preserved summit craters stand 250 and 350 feet above the north and northeast flanks of Black Crater. No glacial deposits nor striae occur upon these cones, but the coarse, weathered scoria on their slopes strongly resembles ejecta from other cones north and south of Black Crater which have been glaciated.

A Recent age for the above cones and flows is open to question, even though they rest upon older glaciated bedrock surfaces or glacial deposits. The last (latest Wisconsin?) major advance of glacial ice between Three Fingered Jack and North Sister is recorded by a variety of features which include lateral and terminal moraines, bedrock striations, vegetation patterns, and glacially transported erratic lithologies. Glaciers, as interpreted from these records, did not cover the Anderson Creek nor west Maxwell lavas during Late Wisconsin time, but may have obliterated their source cones. It is clear that such glaciers reached neither the Park Creek flow nor the Cinder Pit. Similarly, glaciers did not affect Two Butte, but they might have destroyed Two Butte lavas in the adjacent glacial trough. Glacial ice, as outlined by morainal patterns, probably moved between the two cones on Black Crater without disrupting them, and might not have significantly eroded the Scott Mountain cone because of its high-standing position.

Volcanic History of the Sand Mountain Lava Field

Within the High Cascades there are many examples of volcanic mountains arranged in nearly perfect linear or arcuate patterns. Few are as easily recognized as the chain of 22 cinder cones and 41 distinct vents referred to here as the Sand Mountain alignment (fig. 2). An elongate zone of weakness probably developed in the rocks beneath the cones along which magmatic gases and liquids were conducted from the depths to the surface. In detail, this zone diverges northward into two distinct branches. Sand Mountain Cones are the largest volcanoes on the alignment and rise above the intersection of the branches. The principal landforms are geographically as follows: Little Nash Crater and the Lost Lake Group on the north, Nash Crater and the Central Group farther south, Sand Mountain Cones, and the South Group (see fig. 2).

Over a long span of time, the numerous and closely spaced eruptive centers of the Sand Mountain alignment discharged about three-quarters of a cubic mile of lava and a large but unknown volume of ash. The result was an intricate accumulation of overlapping cones, flows, and sheets of ejecta, whose volcanic history is set forth in approximate chronological sequence below.

The oldest volcano exposed on the alignment probably is a small, 150-foot cinder cone located between Nash Crater and the junction of North and South Santiam Highways. Erosion has destroyed all trace of a summit crater, and the lower forested slopes are covered with ash from younger cones. Another denuded cinder cone, approximately 400 feet high, lies one mile southwest of Lost Lake, and has retained only a vestige of its crater rim. Any lava which may have issued from these cones is now lost to view beneath younger flows from later vents.

The Central Group is a tight cluster of five cinder cones, three of which overlap to form an east-west volcanic ridge, half a mile long and 200 feet high. The west end of the ridge contains a small symmetrical crater, but the east end has been breached at its northern base by a great outpouring of lava. The central part of the ridge is occupied by two craters, one nested within the other. Lava issued also from the west base of the ridge, undermining a small satellite cone. In the lava field a short distance west and northwest stand two 100-foot cones with well-preserved craters. Two additional cones at the northwest base of North Sand Mountain strongly resemble those of the Central Group. One is 200 feet high and breached on the west; the other is only 50 feet high but contains a small summit crater.

Lava from the Central Group spread widely to the west, northwest, and north. Much of the west lava now is covered by a younger flow from Nash Crater. To the north, however, lavas poured from the Central Group onto the floor of a broad, glaciated valley, moved over the region now occupied by Santiam Junction, and probably reached the ancestral upper McKenzie River. Several long, isolated ridges and gutters are seen in these lavas just south of the junction, where they trend westward and pass beneath a flow from Little Nash Crater. The ridges often are capped by lava crust, and their sides have been vertically striated by the foundering of adjacent blocks. These features are evidence that the Santiam Junction area was at one time a lake of lava which drained out to the west, probably from beneath a congealed crust.

A short alignment of four cinder cones forms a great ridge across the glaciated valley of Lost Lake Creek, two miles east of Santiam Junction. The lava-dammed lake nearby gives to these cones the collective name "Lost Lake Group." The smallest cone lies against the north valley wall, 700 feet above the lake. On the south, it overlaps the rim of a lower, but much larger cone. Consequently, both cones share a common rim which separates an elongate, shallow crater on the north from a symmetrical, deep crater on the south. A low saddle lies between these northern cones and a centrally located third cone on which there remains only an indistinct crater. The rim of the southernmost cone rises 320 feet above the adjacent Santiam Highway, though the bottom of its crater extends to highway level.

Lava issued from the east base of the north cone and spread eastward, as did a much larger flow from the saddle. Irregular slabs of jagged crust can be seen protruding through a thick overburden of ash along the west shore of Lost Lake. Lava from the saddle also moved west as far as Santiam Junction, where it is deeply buried beneath ash from Little Nash crater, and therefore is exposed best in road cuts.

A large volume of lava was discharged from the base of the north Sand Mountain cone, building a broad ridge which extended 2,000 feet to the west. The ridge was capped by a lava gutter whose walls were breached at frequent intervals. A collapsed lava tube descends the western extremity of the ridge. This lava, which moved far to the west, may be seen on the north shore of Clear Lake. The northern contact with Central Group lava is obscured by ash deposits, but the southern limit of exposure is traced easily against a younger flow from a vent southwest of Sand Mountain.

The South Group consists of four principal cinder cones, all of which probably were associated with extensive lavas, now buried beneath younger flows. The northernmost cone is 1,000 feet south of Sand Mountain, rises 300 feet in height, and contains a deep crater. Next south is a smaller cinder cone which was built adjacent to an elongate southwest-trending ridge of spatter and bombs. Lava issued from the west base of this cone. The largest cinder cone of the south group stands south of the spatter ridge and is 400 feet high. A large central crater is attended by a smaller counterpart on the north flank of the cone, and by a great bocca near the southwest base. Lava from the bocca spread south, surrounding a small breached cone, and southwest to form an extensive flow. The McKenzie River pours over this lava at Koosah Falls. The lava is obscured on the south by flows from Belknap Crater; to the east and north the lava is overlain by later flows from Sand Mountain.

Nash Crater is a cinder cone which was built 500 feet above a lateral moraine. The summit contains a north-south trench-like crater 1,000 feet long with a smaller symmetrical crater set into its west rim. A narrow ridge of spatter extends from the south base of Nash Crater, and is surmounted by six vertical conduits which range from 30 to 5 feet in diameter and from 40 to 30 feet in depth. These conduits lead to a lava tube which has collapsed at the south end of the ridge. Lava from this vent moved west, damming Hackleman Creek to form Fish Lake, and for this reason is called the Fish Lake Flow.

At the northwest base of Nash Crater is a broad depression rimmed with spatter. Approximately 100 feet northwest, a 5-foot spatter cone surrounds a vertical conduit which is 25 feet deep. Both vents probably lie above a lava tube and mark the source of the extensive flow now crossed by South Santiam Highway. Sawyer's Cave, adjacent to the highway, is a lava tube far removed from the source of the flow. Lava from the northwest vent of Nash Crater dammed the ancestral McKenzie River (now called Park and Crescent Creeks) to form a swampy area known as Lava Lake. At this point, the flow turned abruptly southward, following the McKenzie drainage to Fish Lake. The Lava Lake Flow rests upon lava from the Central Group and is overlain by a flow from Little Nash Crater.

The most extensive lava flow exposed on the Sand Mountain alignment (referred to here as the Clear Lake Flow) was fed from a vent located half a mile southwest of Sand Mountain Cones, and dammed the lake for which it is named. A circular pit, 50 feet in diameter, displays several flow units in its walls and probably represents a collapse depression over the lava source. A smaller pit, 200 feet to the east, separates the collapse depression from an east-west spatter ridge 600 feet long. The west end of the ridge contains a shallow crater 30 feet in diameter. On the summit of the ridge are two vertical pipes, 3 and 6 feet in diameter, which are at least 40 feet deep. Lava from the collapse depression spread west to the McKenzie River, forming a dam from Sahalie Falls to Clear Lake. The upright trees which may be seen in the depths of the lake are well known. Wood from one of the submerged trees, drowned as the lake rose behind its lava dam, has been given a radiocarbon age of approximately 2,950 years B.P. (Benson, 1965), thus fixing the date of the eruption of the Clear Lake Flow at about 1,000 B.C.

The south flank of Sand Mountain is interrupted by a broad furrow which, at its base, leads to a bocca and a lava gutter. Lava from this vent moved chiefly eastward and then four miles to the south, where it now lies buried beneath younger flows from Belknap Crater. It should be noted that, although eruptions from the southwest

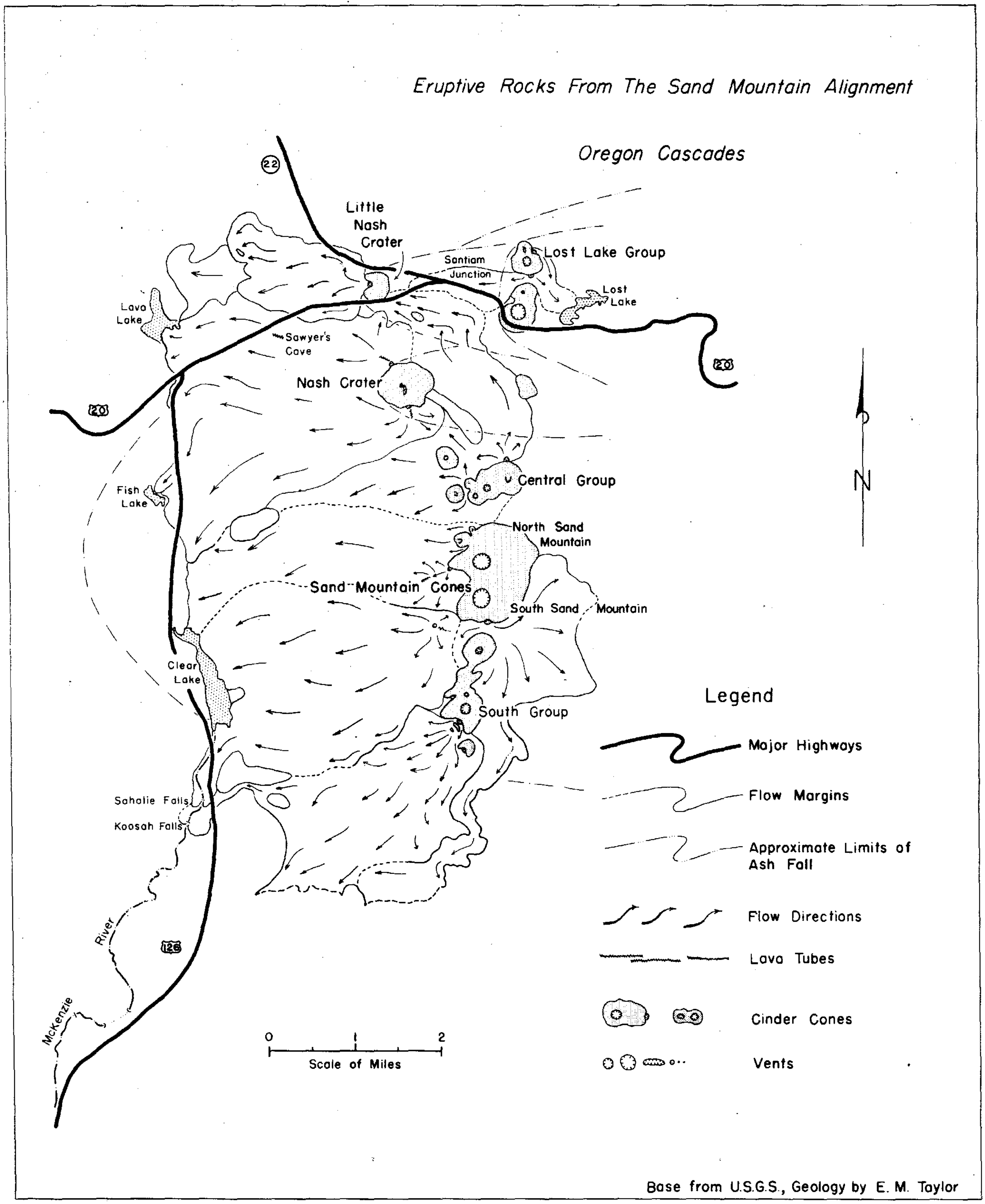

Eruptive Rocks From The Sand Mountain Alignment
Oregon Cascades
22
Little
Nash
Crater
Santiam
Junction
Lost Lake Group
Lost
Lake
Lava
Lake
Sawyer's
Cave
20
Nash Crater
20
Central Group
Fish
Lake
North Sand
Mountain
Sand Mountain Cones
South Sand Mountain
Clear
Lake
South Group
Legend
Major Highways
Flow Margins
Approximate Limits of
Ash Fall
Flow Directions
Lava Tubes
Cinder Cones
Vents
Sahalie Falls
Koosah Falls
River
McKenzie
126
0
2
Scale of Miles
N
Base from U.S.G.S., Geology by E. M. Taylor

FIGURE 2.

and south Sand Mountain vents probably occurred at about the same time, their common lava boundaries are obscured by ash deposits and their relative age is unknown. Consequently, the age of Clear Lake does not necessarily define a maximum age for Belknap lava.

Lavas from the cinder cone called Little Nash Crater probably are the youngest eruptive rocks on the Sand Mountain alignment. The cone has been quarried, exposing a complex internal stratification. A persistent structural discontinuity may be seen in the quarry faces, which suggests that the process of cone building was interrupted briefly by violent explosions which greatly enlarged the crater.

Road cuts north of the cone display weathered till overlain by a three-inch layer of fine black ash, which is attributed to eruptions from Nash Crater. Resting upon the ash layer is a 4- to 5-foot bed of coarse ejecta from Little Nash Crater. The lower part of this bed contains abundant accidental fragments derived from glacial deposits beneath the cone. Late in its history, Little Nash Crater was breached on the west by a flow whose volume is approximately nine million cubic yards.

Some cones of the Sand Mountain alignment, such as Little Nash Crater, were constructed and ceased to emit ash before a significant amount of lava appeared; others, such as Nash Crater and the Sand Mountain Cones, ejected ash throughout the course of lava extravasation. It is a significant fact that as one crosses westward over the lava field from Sand Mountain Cones (which were the greatest producers of ash), the average thickness of ash cover increases because older lava surfaces are encountered and more of the total ash fall is exposed. Most of the ash from Sand Mountain Cones drifted east and northeast, heavily blanketing an area of more than 100 square miles. This material has been so extensively reworked by surface water that it is difficult to reconstruct an original thickness distribution.

The modern appearance of Sand Mountain Cones is one of surprising freshness and perfection in view of the fact that most of the ash was expelled more than 3,500 years ago (see discussion of Blue Lake Crater). Some ejecta fell upon the 3,000-year-old Clear Lake flow, and it is possible that still later eruptions contributed to the form of the cones.

Eruptive Rocks from Inacessible Alignment and Twin Craters

Three and one-half miles southwest of Mount Washington, a short alignment of four cinder cones has been nearly buried by Belknap flows (fig. 1). The southernmost and largest cone, here named Inaccessible Cone, now lies five miles from the nearest road and is surrounded by a wide barrier of jagged lava. The cone contains a symmetrical crater and is encircled by flows which issued from numerous boccas at its base. The Belknap flows partly obscure three smaller cones which lie one mile to the north. An unnamed cone, offset near the north end of the Inaccessible alignment, is 300 feet high and has been breached on the west and southwest by a flow of gray basalt, charged with bombs. The flow has been traced westward beneath the Sand Mountain and Belknap lava fields, and thus is older than both of them. In outward appearance, the lava from this cone closely resembles the glaciated and nearly ubiquitous, pale gray bedrock which is so abundant in older parts of the High Cascades. It is probable that additional vents and a small field of lava associated with the alignment have been lost to view.

Twin Craters is a cinder cone located at the margin of the Belknap field, three miles southwest of the Belknap summit (fig. 1). The cone is 300 feet high and the north and south craters are about 200 feet deep. A small pit, 30 feet in diameter, is set into the east rim of the north crater. The final ejecta from the north vent consisted of fine scoria and ash which accumulated in stratified deposits on the crater rim. The south crater emitted clots of spatter which, as they fell upon the rim, split apart and disgorged tiny streams of lava. Scoria and bombs litter the glaciated landscape to the west. North of the cone, several mounds of red cinders are imperfectly exposed along the margin of Belknap lava; whether they represent separate cones or scoria-covered flow ridges is not known. Boccas exist on all sides of the Twin Craters cone, but most of them are clustered upon the north and south flanks. Lava from these vents must have been very fluid, for some flows are only three feet thick and their upper surface is coated with minute, glassy spines. An extensive lava field may have spread into the broad glaciated valley which then existed to the north; if so, it is deeply buried beneath the Belknap volcano.

Hoodoo Butte

Hoodoo Butte is an isolated cinder cone which rises 500 feet above the eastern edge of a glaciated platform, midway between Sand Mountain Cones and Santiam Pass (fig. 1). The small summit crater is open to the east, but could not have been breached by lava because none has been found in association with this cone. Instead, the incomplete appearance of the crater rim is a result of the very irregular topography on which the cone was built; much of the ejecta simply fell over the east edge of the platform. Although Hoodoo Butte stood in the path of fallout from Sand Mountain Cones, most of this ash has been washed onto the surrounding lowlands. A thick deposit of Sand Mountain ash still survives on the crater floor.

History of the Belknap Volcano

Of the volcanic centers discussed in this paper, none poured forth a greater volume of lava than the shield volcano which is surmounted by Belknap Crater, Little Belknap, and related vents (fig. 3). Williams (1944) has provided a lucid description of the Belknap shield; only its salient features are outlined here. The surface of the mountain is covered largely by lava which poured repeatedly from vents marginal to a composite summit cone. This lava was relatively fluid and eventually inundated an area of more than 37 square miles. It did not move in long, continuous streams. Instead, short channels branched and crossed one another, resulting in thin lobes with complex drainage patterns. Accurate reconstruction of the surface on which the volcano rests is precluded by the great thickness and widespread distribution of lava. Consequently, 1 1/3 cubic miles is regarded as only a rough estimate of the volume of Belknap rocks.

The oldest exposed lavas of the Belknap shield occur on its eastern flanks. They were erupted from vents now poorly defined, which may have been subsequently buried as the summit cone reached final development. These lavas moved principally northeastward, diverging into two lobes on either side of a ridge called Dugout Butte. Both lobes descended to an elevation of 4,150 feet, seven miles from their source.

The summit cone of the Belknap volcano rises 400 feet above its basal shield. Two deep craters at the top of the cone emitted ashes and coarse cinders, which accumulated as high mounds of stratified lapilli-tuff on their east rims. In the walls of

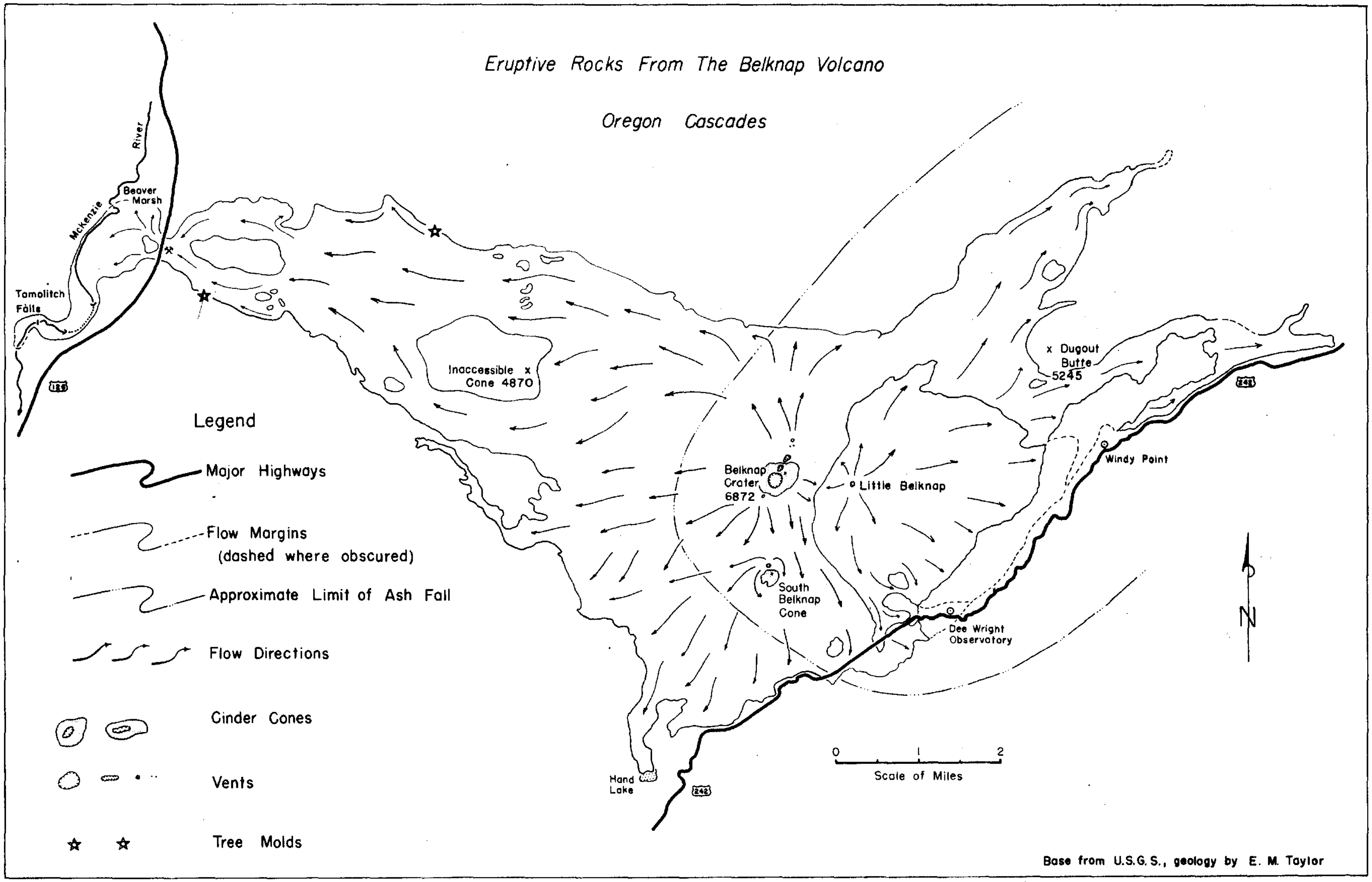

Eruptive Rocks From The Belknap Volcano
Oregon Cascades
Mckenzie
River
Beaver Marsh
Tamolitch Falls
126
Inaccessible Cone 4870
Dugout Butte 5245
Belknap Crater 6872
Little Belknap
South Belknap Cone
Windy Point
Dee Wright Observatory
Hand Lake
242
Legend
Major Highways
Flow Margins (dashed where obscured)
Approximate Limit of Ash Fall
Flow Directions
Cinder Cones
Vents
Tree Molds
0 1 2
Scale of Miles
N
Base from U.S.G.S., geology by E. M. Taylor

FIGURE 3.

the southern crater, which is about 250 feet deep and more than 1,000 feet wide at the rim, thick flow rocks are exposed. Some lava poured over the southwest lip of this crater and is now partly obscured by spatter. Well-formed spindle bombs, up to three feet in length, are common along the west rim of the north crater. A broad pit 200 feet long was blasted through a bocca at the north base of the cone. Two small spatter cones appeared at a late stage about 1,000 feet still farther north.

The distribution of ash and cinders on the rim of Belknap Crater, as described above, was caused by strong and prevailing wind transport to the east. Thin deposits of scoria are found on lava immediately west of the cone, but as the eastern slopes are approached the lavas become mantled in black ashes and fine cinders. A wide area from Dry Creek on the north to Black Crater on the south was heavily blanketed. Deposits have been recognized eight miles to the east.

During a late stage in the development of the Belknap summit cone, vast quantities of lava issued from boccas on the south, west, and north and poured west toward the McKenzie River. Ropy surfaces and lava squeeze-ups between large rafted platforms of broken crust are common here. Lava from the south vent poured across older lava from Twin Craters; three miles from the Belknap summit, the western streams overran lava and cinder cones of the Inaccessible alignment. Farther west, the Belknap lavas poured over flows from the south vent of Sand Mountain and from the south group of the Sand Mountain alignment, before finally plunging in a steep cascade into the McKenzie Canyon.

The McKenzie River was altered profoundly by the lava which spread across its path. A broad, swampy area known as Beaver Marsh formed upstream from the point where the river now flows onto the Belknap rocks. Where it once flowed freely through its open canyon, the river is now gradually absorbed into the buried talus along the canyon margins and into permeable zones between lava units, reappearing at Tamolitch Falls. Downstream from the falls, the flow has been reduced by erosion to a lateral terrace, perched on the west canyon wall 30 feet above the level of the river.

Tree molds were formed along the margins of the west Belknap flows. They are displayed best at the westernmost locality shown in Figure 3. Here, several dozen molds range from 1 to 5 feet in diameter and from 6 to 15 feet in depth. Most of them are vertical and widen downward. Hemicylindrical trenches as much as 35 feet long occur where trees fell onto the pasty lava. In most areas tree molds are rare because lava must be sufficiently fluid to conform to the shape of a tree, yet must not flow or be deformed after the tree has been consumed. In the present instance, the Belknap flow spilled into a protected recession in a steep, north-facing slope which presumably was, at the time of the eruption, as moist and deeply forested as it is today. The level surface of the resulting pond is an indication of the fluidity of the lava at the time of its isolation from the active stream. From the buried soil at the base of one of the molds, the writer excavated a radial system of large roots which had been deeply charred. Radiocarbon analysis of this material indicates that trees were burned by the west Belknap flows about A.D. 360 $\pm$ 160 years (WSU-292). This date is based upon a C-14 half-life of 5,570 years.

One mile south of the Belknap summit is a small volcano referred to here as the South Belknap Cone. This cone was breached on the southwest by lavas which then spread over the south base of the Belknap shield. A later flow, from a vent 300 feet to the northwest, surrounded the cone and inundated the early lavas. The later flow overlapped the west Belknap lava and, at its farthest extension, poured south through a narrow gap into Lake Valley, where it now forms the north shore of Hand Lake.

The latest addition to the Belknap volcano took the form of quiet discharge of lava from a vent called Little Belknap, one mile east of the summit craters. So much lava issued from this one point that a subsidiary shield was formed. It is surmounted by a chaotic heap of cinders and blocks from which collapsed lava tubes diverge radially. One of the western tubes can be followed to its confluence with a vertical conduit which is approximately 20 feet in diameter, and which remains choked with snow, even in late summer. Lava from Little Belknap spread east to within one mile of Windy Point and southeast to McKenzie Pass. It rests upon the ash from Belknap Crater and is overlain by younger flows from Yapoah Cone.

A peculiar, and general, feature of the flow rocks from Little Belknap is seen along the Skyline Trail half a mile northwest of the McKenzie Pass Highway, where the lava stream diverged after passing between two prominent steptoes. As it cooled, the contracting surface warped upward to lift part of the crust, together with its still-plastic substratum, and peel it back upon itself. Thick overturned slabs may be found which are as much as 10 feet wide and 50 feet long, usually parallel to the direction of flow. Except for distortion due to contraction and fragmentation, each slab matches perfectly the adjacent counterpart surface from which it was pulled. Such features will be referred to as lava curls.

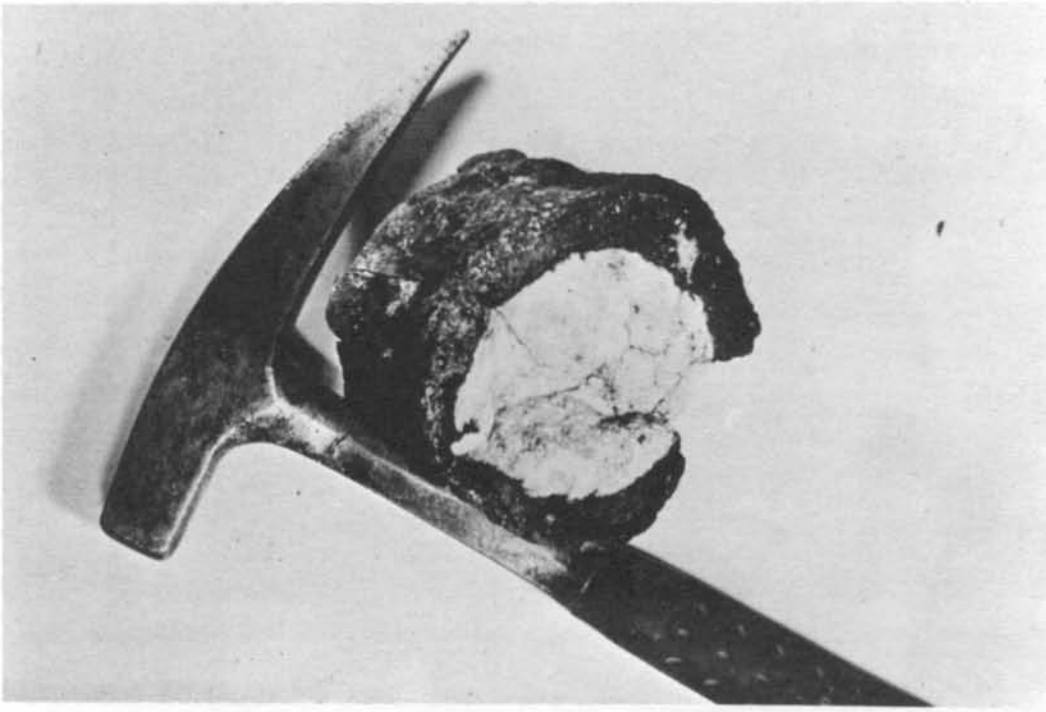
Blue Lake Crater

Blue Lake, as seen from the Santiam Pass Highway, is $3\frac{1}{2}$ miles east of the Cascade crest (fig. 1). It is 0.5 mile long and 0.2 mile wide, and set in a deep pit formed by Recent volcanic explosions of great violence. The Blue Lake eruptions resulted in at least three overlapping craters which are aligned approximately N.25°E., and which fall within a geographic trend common to Belknap Crater and the Spatter Cone Chain to the south, and the "Cinder Pit" to the north. The first (and only?) published suggestion that Blue Lake might occupy a volcanic crater appeared in 1903 (Langille and others).

The southern half of Blue Lake is rimmed by a crescentic ridge which, in places, stands 300 feet above the water and 150 feet above the adjacent topography. The outer slopes are covered with basaltic cinders, bombs (some of which are six feet long), and accidental fragments of older, underlying lavas. Inner slopes of the rim generally lead to cliffs which disappear into azure depths. If one may compare Blue Lake crater to other Cascade craters of similar diameter, the lake is probably in excess of 300 feet deep.

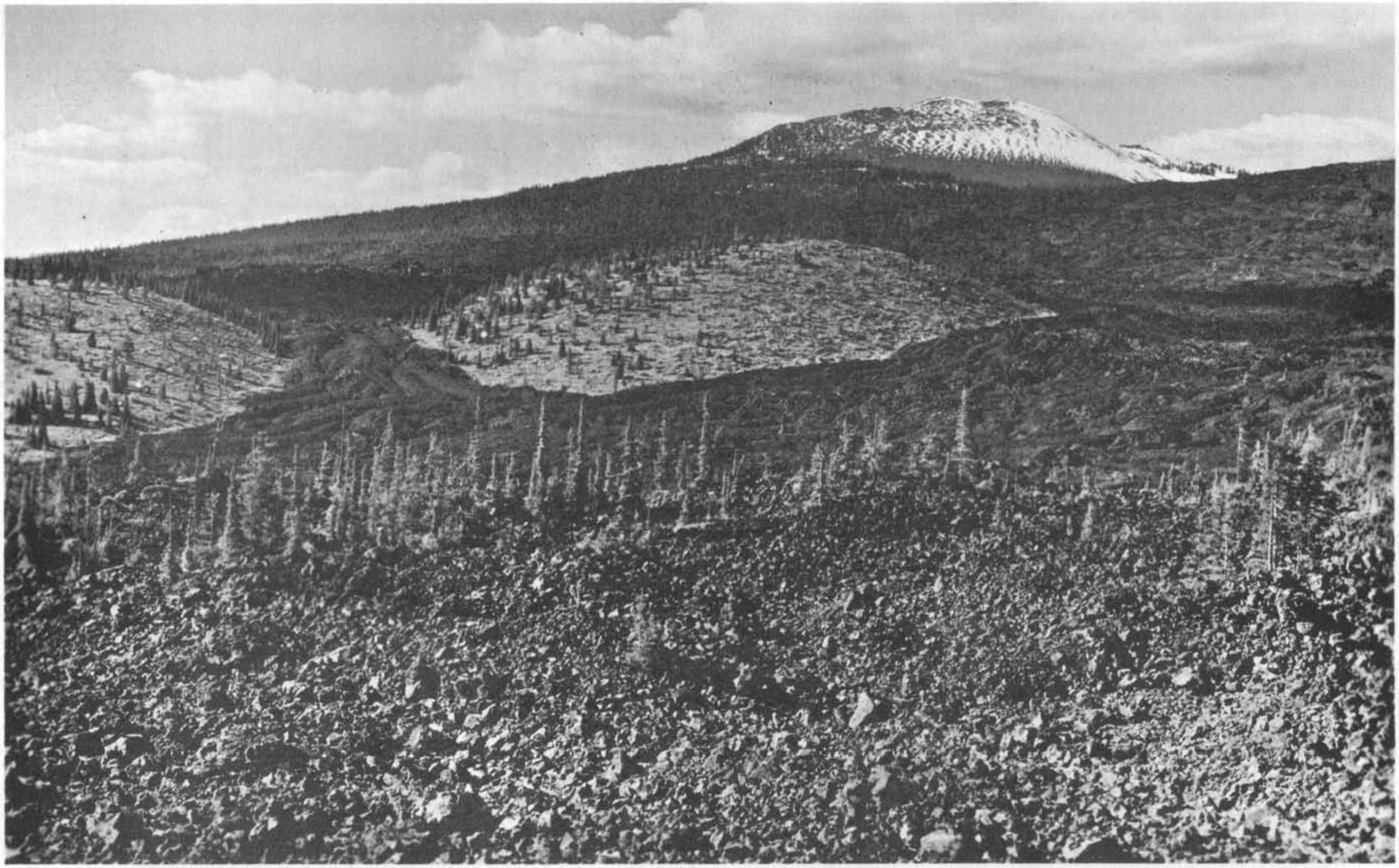
Some of the lakeshore cliffs may have been formed by the collapse of over-steepened crater walls, but no prominent dislocations of a concentric type have been found. The north crater wall, now largely submerged, was blasted through pre-existing bedrock, fragments of which are found scattered over the nearby landscape. Consequently, it appears that Blue Lake crater was the result of upward explosions rather than interior subsidence. Above lake level, the southern crater walls are composed of crudely stratified cinders and bombs with intermixed bedrock blocks. No Recent lava flows have been recognized in the Blue Lake area.

Bombs and blocks were ejected in all directions from the crater, but most of the fine scoria and ashes drifted east and southeast. A typical section taken through these deposits contains, at its base, weathered till overlain by 2 to 3 feet of fine black ash attributed to eruptions of the Sand Mountain alignment. Capping the black ash is a



Pumice-cored volanic bomb with basaltic rind from Four-in-One Cone.

Lava gutter west of Collier Cone provides pathway for Skyline Trail.



Belknap Crater seen from Dee Wright Observatory: Belknap Crater (snow-covered skyline) is impressive in stature, but is only a pile of cinders on the summit of a vast shield of recent lava. Forests in background grow upon old Belknap lavas; trees in foreground stand upon young lava from Yapoah Cone. Lava of intermediate age and position surrounds "islands" and issued from a subsidiary vent called Little Belknap. (Oregon State Highway Department Photograph No. 423)

Lava from Little Belknap: Desolate fields of blocky lava (foreground) from Yapoah Cone, and hummocky lava (background) from Little Belknap, lie between Dee Wright Observatory and the volcanic plug of Mount Washington. The jagged features of these lava surfaces were formed less than 1,500 years ago. (Oregon State Highway Department Photograph No. 427)

Lava flows from Collier Cone: Collier Cone (upper left) and lava streams which spread from its crater down the west slope of the Cascade Range (foreground), are probably the most recent manifestation of millions of years of Oregon vulcanism. Left of the cone is the Ahalapam Cinder Field; lava gutters lead west and northwest to lava lobes which are marked by levees and pressure ridges. Large volcanoes behind the cone are North Sister (left) and Middle Sister (right). Collier Glacier (center) has receded from the cone to its present position in only 40 years. In the background are Broken Top (left) and South Sister (right). Four-in-One Cone and lavas are visible at lower left. (Delano Aerial Oblique No. 631234) thick accumulation of scoria which may be traced directly to Blue Lake. Charred wood from the limb of a conifer has been excavated from the sharp interface between the scoria and ash. The radiocarbon age of this material is 3,440 $\pm$ 250 years B.P. (WSU-291), assuming a C-14 half-life of 5,570 years. The eruption of Blue Lake Crater commenced therefore, at about 1,500 B.C. This date, when compared with the age of Clear Lake (about 1,000 B.C.), suggests that most of the ash from the Sand Mountain alignment was deposited in the Blue Lake area 500 years before the final eruptions of Sand Mountain lava.

The Spatter Cone Chain

A chain of spatter cones, one mile long, trends N.23°E. across the valley of Cache Creek between Blue Lake Crater and Mount Washington (fig. 1). Volcanic features are restricted to north and south segments, but several trench-like depressions aligned parallel to the midsection of the chain outline a strong subsurface continuity. The northernmost vent is a circular crater, 10 feet deep, which appears to have emitted only gas. About 200 feet south is the first of four spatter cones, with craters 30 to 40 feet deep, which surmount a narrow ridge of spatter and scoria. Still farther south, a series of discontinuous grabens, averaging 10 feet in width and 3 feet in depth, leads to a southern line of vents. Deposits of ejecta occur intermittently along the grabens. Fractured bedrock is exposed where the trend of this chain intersects Cache Creek, but no displacements have been recognized. There are seven southern vents, as follows: Three small craters to the north are separated by a short graben from three large craters located on a spatter ridge to the south; the central crater on this ridge contains a small crater in its north rim. A shallow graben extends about 150 feet south from the ridge. Volcanic rocks of the Spatter Cone Chain overlie ash deposits that are correlative with the deposits of fine ash near Blue Lake Crater.

Sims and Condon Buttes

The western third of McKenzie Pass Highway follows a Recent lava flow, $9\frac{1}{2}$ miles from source to terminus. The source cone is Sims Butte, located $6\frac{1}{2}$ miles south of the Belknap volcano (fig. 1). The cone is 650 feet high and is broadly indented on the west side by a shallow crater, located 400 feet below the summit. Ejecta are coarse and are confined largely about the vent within a circular area of one-mile radius. The limited extent and symmetrical distribution of ejecta suggest that the asymmetry of the cone is a result of lava breaching rather than prevailing wind direction.

Short flows emerged from the north base of the cone, but most of the lava issued from a west bocca, 200 feet below the shallow crater. Collapsed lava tubes may be traced downstream from this bocca for several hundred yards. At one point, where the flows are steeply inclined, a 70-foot lava tube descends beneath the crust. Two "skylights" penetrate the thin roof, and collapse depressions define an inaccessible western continuation of the tube.

The extensive lava flows from Sims Butte spread onto a topographic shelf west of the cone, then poured into the Lost Creek glacial trough. They covered the floor of the trough and moved westward to within a quarter of a mile of Limberlost Forest Camp. White Branch, Obsidian, Linton, and Proxy Creeks all disappear beneath this blanket of lava before reappearing in a series of large springs at the head of Lost

Creek. It has not been possible to trace single flow units from Sims Butte for long distances because of the overlying Collier lavas and the heavy forest cover, and because the Sims lava advanced as thin, overlapping sheets of limited extent. Lava tongues, only one foot thick, cover several acres along some parts of the flow margins. The best cross-sectional exposures of Sims lava are seen along the switchbacks of the McKenzie Pass Highway, where five or more separate flows can be counted in one 15-foot embankment. A typical flow is 3 to 5 feet thick with a thin, dense crust resting upon a base of unconsolidated rubble.

Condon Butte is three miles northeast of Sims Butte and is considered here to be genetically related to it. The cones are about the same size, equally forested, and their ejected material is, for all practical purposes, identical. Condon Butte, however, did not emit a great volume of lava and as a consequence the cone is symmetrical. In the summit are two nested craters from which short, stubby flows moved down the southwest flanks.

Volcanic History of Yapoah Cone and Related Vents

Between McKenzie Pass Highway and the North Sister, the Skyline Trail (fig. 1) leads across an alignment of six cinder cones and gas vents which is 1.4 miles long and trends S. 4°W. At the midpoint of the alignment stands Yapoah Cone, and from its base several lava streams extend northward, covering 6 square miles (fig. 4). Lava from Yapoah Cone rests upon Little Belknap lava and is overlain by ashes and fine scoria from Four-in-One Cone.

Prior to Recent time, an unusual type of flow rock was erupted from a set of fissures along the Cascade crest between Black Crater and North Sister (fig. 1). Bombs and lava were discharged simultaneously and spread down the western slopes in what might be described as an agglutinate flow. A typical unit is 30 feet thick with a 10-foot crust of red bombs and spatter which passes gradationally into an underlying dense lava choked with bombs. Yapoah Cone and related vents, together with Collier Cone and the Ahalapam Cinder Field (fig. 5), rests upon the glaciated agglutinate flow rocks. Some of these Recent and older-than-Recent eruptive features are not easily distinguished along the crest; consequently, an interpretation of the volcanic history of this area may be subject to a wide variety of opinion.

Hodge (1925) named the Ahalapam Cinder Field and described it as "two rows of volcanoes having the appearance of morainal topography." Williams (1944) suggested that "ejecta from Collier and Yapoah cones had accumulated on morainic mounds," but noted the presence of "many large bombs, several more than four feet across and a few even eight feet across, scattered among the fine scoria." The bombs were cited as evidence of eruption from local vents and most of the crest in this area was mapped as a field of Recent eruptive activity (Williams, 1957). In the opinion of the writer, however, the Ahalapam Cinder Field is a mantle of scoria and ash ejected from the Collier vent and deposited upon glacially dissected agglutinate flows. Recent eruptions between McKenzie Pass and North Sister have occurred only adjacent to Scott Pass and along the Four-in-One and Yapoah-Collier alignments, as described below.

Yapoah Cone rises 500 feet above its surroundings except on the south side, where it abuts against a glaciated ridge of agglutinate flows. The summit crater is about 300 feet long in a north-south direction, 100 feet wide, and mantled with red cinders. Stratified deposits of yellow lapilli-tuff occur on the east rim, but outer

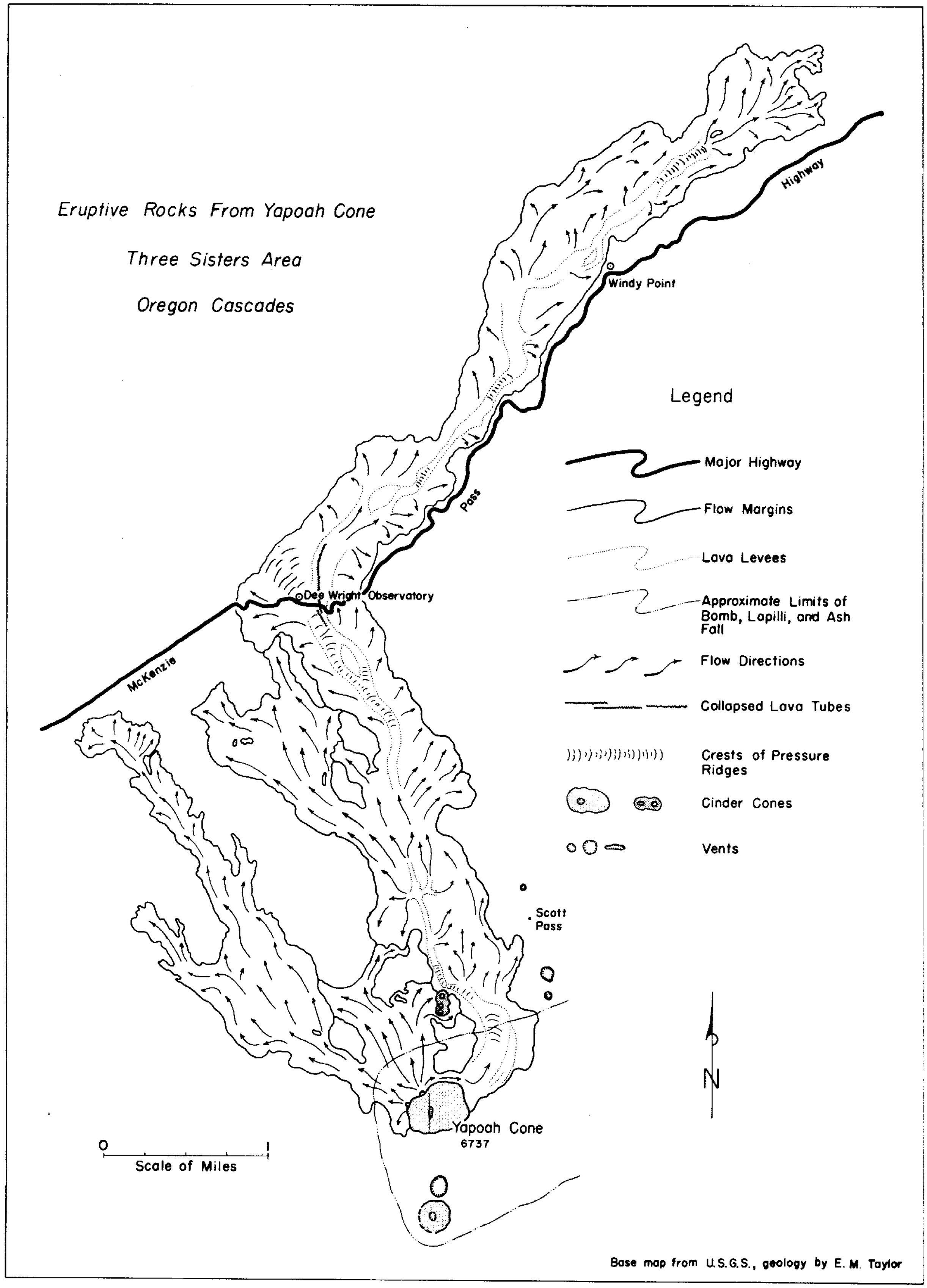

Eruptive Rocks From Yapoah Cone
Three Sisters Area
Oregon Cascades
Highway
Windy Point
Pass
Dee Wright Observatory
McKenzie
Scott Pass
Yapoah Cone
6737
0
1
Scale of Miles
N
Legend
Major Highway
Flow Margins
Lava Levees
Approximate Limits of Bomb, Lapilli, and Ash Fall
Flow Directions
Collapsed Lava Tubes
Crests of Pressure Ridges
Cinder Cones
Vents
Base map from U.S.G.S., geology by E. M. Taylor

FIGURE 4.

slopes of the cone are covered with black cinders. The remarkable symmetry of Yapoah Cone may be due to persistence of explosive activity until a late stage; all lavas adjacent to the cone are partly obscured by ashes and scoria. Pyroclastic deposits resulting from Yapoah eruptions, however, are neither as thick nor as widely distributed as similar material from nearby Collier and Four-in-One Cones.

Half a mile north of Yapoah Cone, a linear cluster of three small spatter cones was nearly engulfed by Yapoah lava. Rocks from these vents are identical to ejecta of the Yapoah type, and probably came into existence during the same eruptive episode.

Other Recent volcanic activity near Yapoah Cone may antedate the Yapoah eruptions. A gas vent was blasted through the agglutinate flows 0.3 mile south of Yapoah Cone, leaving a circular depression 300 feet in diameter (fig. 4). Immediately south of the gas vent a small, asymmetrical cinder cone was built on the margin of a precipitous ridge. The west flank of this cone rises 350 feet above nearby lowlands, while its eastern rim stands only 30 feet above the ridge top. Near Scott Pass, one mile to the northeast, a deep, round pit, 400 feet in diameter, interrupts a glacially striated surface cut on red agglutinate flow rocks. Other poorly defined gas vents exist to the north and south of Scott Pass and are located along the system of agglutinate flow fissures mentioned previously. These vents may be assigned on a provisional basis to a Recent, but pre-Yapoah, eruptive episode. The activity was confined largely to the incipient Yapoah alignment, but also reached the surface through conduits along the older agglutinate flow fissures.

Lava units from Yapoah Cone are composed of porous crustal blocks which become increasingly coherent downward, grading into a thin, dense base. A cross-section of this structure is exposed in highway cuts east of Dee Wright Observatory on McKenzie Pass.

Yapoah lava was discharged first from a bocca on the north, then from a bocca on the northwest side of the cone. The first lobe, here referred to as the Observatory Lobe, was channeled northward until it reached that part of the Cascade crest now traversed by McKenzie Pass Highway. At this point it encountered the Little Belknap shield volcano and was deflected down the east slope of the range, eventually reaching a total length of 8 1/3 miles.

For a distance of $1\frac{1}{2}$ miles downstream from Yapoah Cone the final lavas of the Observatory Lobe moved in a narrow channel perched on the lobe crest, and confined by lava levees. At intervals the levees were breached, releasing dendritic cascades which poured laterally down their flanks. At its terminal end, the channel split into three principal branches. The central and eastern branches fed the main lobe; the west branch produced a subsidiary lobe only two miles long. The remaining length of the Observatory Lobe is surmounted by a system of lava gutters which are, in some places, narrowly confined between lava levees. Upstream from such constrictions, transverse pressure ridges were formed; downstream, the lava frequently drained from beneath a congealed crust. In this way lava tubes were produced and long narrow trenches occur where their ceilings have collapsed. An excellent example of a collapsed tube is to be seen just east of the Dee Wright Observatory on both sides of McKenzie Pass Highway.

A later lobe issued from a bocca approximately 100 feet above the northwest base of Yapoah Cone. Initially, the lava spread northward, plunged down a steep slope, and chilled to a standstill at the head of a large steptoe called "The Island." Succeeding lava flows by-passed this lobe on the west and formed an extensive ribbon which ceased to move only after it had reached the base of the Belknap volcano three miles distant. The northwest bocca now is represented by a gutter leading to an open tube, which descends 20 feet into the flanks of the cone before it pinches out above a fill of jagged lava.

Volcanic History of Four-in-One Cone and Related Vents

A series of 19 visible vents forms a short volcanic alignment about $1\frac{1}{2}$ miles southwest of Yapoah Cone. The northern end of this alignment is marked by an elongate ridge of four coalescing cinder cones, appropriately named Four-in-One (fig.5). At its southern end the alignment was inundated by lavas from Collier Cone. Between Four-in-One Cone and the margin of Collier lava, three small vents can be seen. One is slightly offset to the east and covered with scoria; two others are half-obscured by the Collier lobe, and emitted pasty clots of black spatter and accidental fragments of underlying rocks. In the Collier midstream, the summits of four cinder cones are exposed, each with a well-defined crater. The northern cone of this group was breached on its southwest flank by a lava flow which now is covered by the Collier lobe. Only the source area of the lava and its terminal extremity, one mile to the northwest, are exposed.

The eruptive history of Four-in-One Cone is not known in detail, but several major events can be outlined. Activity developed first along a half-mile fissure, and probably was soon concentrated at four conduits separated by a uniform interval of about 700 feet. Concurrent eruption of bombs and coarse cinders resulted in the construction of four overlapping cones which attained a height of 200 feet. Lava escaped from the southern base of the south cone, covering several acres with a thin veneer of black vitreous rock, crowded with tiny vesicles. During the height of the eruption the cone was enveloped in black spatter, while scoria and ashes, composed chiefly of turbid brown glass, drifted east to the Cascade crest. Near the vents, the resulting deposits are more than 50 feet thick. Southward, they pass beneath Collier lavas; to the north they rest upon flow rocks from Yapoah Cone.

Following the more violent stages of activity, four deep gashes were excavated in the west slope of the cone by streams of lava which eventually covered 1.4 square miles and reached a point 2 3/4 miles to the northwest. Counting from the north vent, the flow from the second was obscured by a subsequent flow from the third, which seems to have issued at about the same time as flows from the first and fourth vents. Because the lavas moved northwest and the ash was blown eastward, they do not in general overlap. The breaching of the cone, however, clearly involved both its reddish core and its black covering of spatter.

Surfaces on Four-in-One lava resemble those found on the Yapoah lobes, except for the prevalence of red scoria (quarried from the cone) and the lack of long, continuous channels bordered by lava levees. The Four-in-One flows tend to branch repeatedly over short distances. This suggests that as the lava moved forward, it congealed quickly and succeeding lava was obliged to take a new course. Marginal lava curls were developed near the source vents.

Finally, it should be noted that fragments of white rhyolitic pumice were expelled with the basaltic ejecta. The pumice is most abundant as fine ash, but large samples occur on the cone, chiefly about the north vent. Occasionally pumice is found encased within the black rind of a spindle-shaped basaltic bomb.

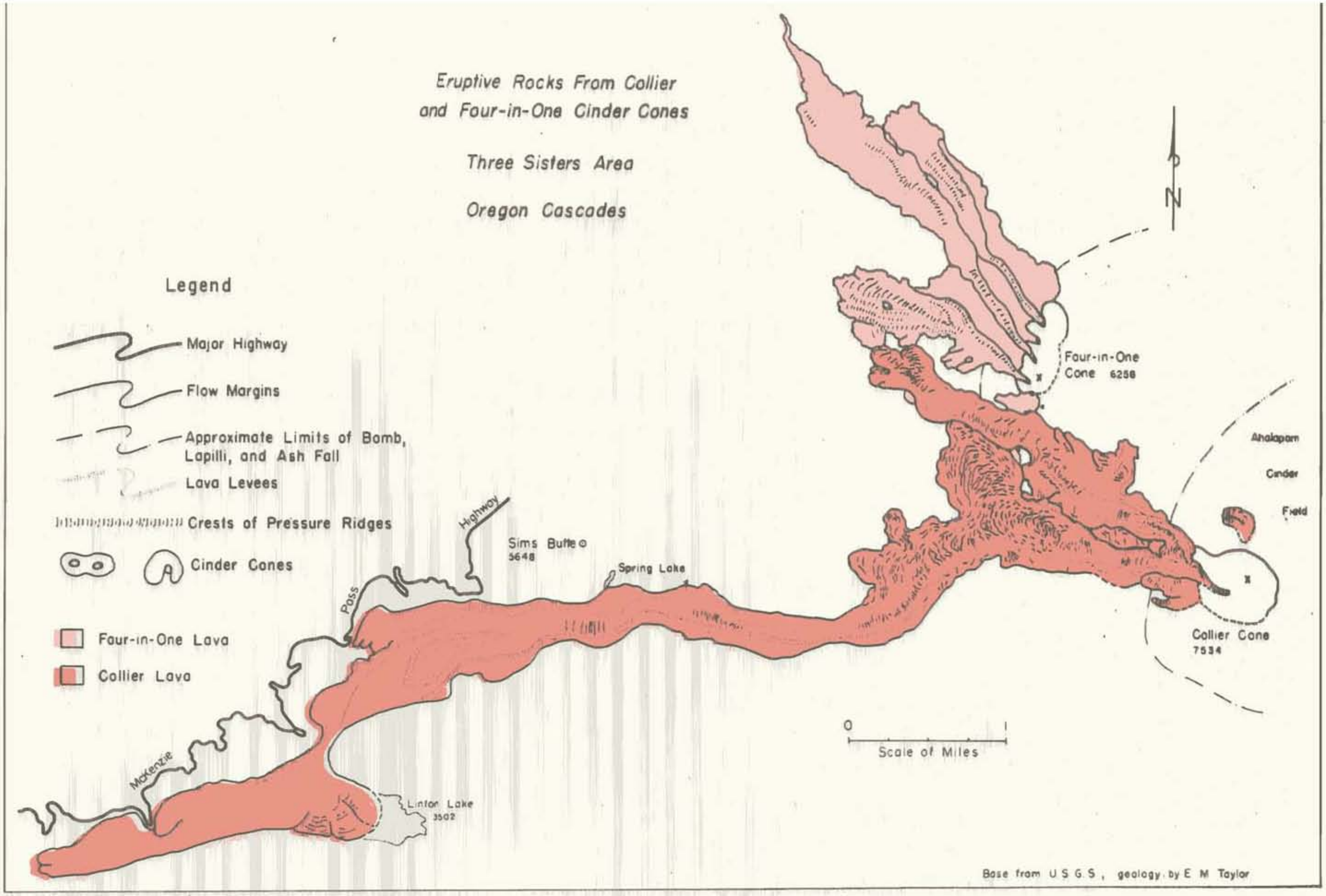

Eruptive Rocks From Collier
and Four-in-One Cinder Cones
Three Sisters Area
Oregon Cascades
Legend
Major Highway
Flow Margins
Approximate Limits of Bomb, Lapilli, and Ash Fall
Lava Levees
Crests of Pressure Ridges
Cinder Cones
Four-in-One Lava
Collier Lava
N
Four-in-One Cone 6258
Ahalapam
Cinder
Field
Collier Cone
7534
Highway
Sims Butte
5648
Spring Lake
Pass
McKenzie
Linton Lake
3502
0
1
Scale of Miles
Base from U S G S , geology by E M Taylor

FIGURE 5.

Volcanic History of Collier Cone

Collier Cone lies at the north-by-northwest base of the North Sister and probably is, of the features described, the most recently active volcano. Stratified cinders and bombs are exposed in the crater walls. Black, fragmented bombs as much as one foot in diameter are abundant on the cone and may be found as distant as half a mile west and a quarter of a mile east of the vent. Fine-grained ejecta were driven eastward by the wind to form a square mile of alpine desolation, known as the Ahalapam Cinder Field. Vitrophyric pumice, often mixed intimately with basaltic glass, is common in deposits of Collier ash and scoria.

Collier flow rocks afford an unusually clear record of eruptive history. An estimated 0.04 cubic mile of lava issued from the cone, producing a west lobe 8½ miles long and a northwest lobe 3 miles long (fig. 5). The lavas advanced in several distinct surges, each different in composition from its predecessor. Outward appearances of these flows, however, are remarkably uniform.

The initial lobe moved westward down the valley of White Branch Creek, blocking the drainage of a large spring to form Spring Lake at the base of Sims Butte. It then plunged into the Lost Creek glacial trough, damming Linton Creek to form Linton Lake. Relief of this west lobe, from source to terminus, is 4,160 feet.

The midsection of the lava stream, especially where it is steeply inclined, is occupied by long, multiple lava gutters. Several surges of lava must have poured down gutters formed previously, because two pairs of lava levees are nearly constant features of the early lobes and three pairs are fairly common.

A final surge of lava filled and overtopped the crater of Collier Cone, mantling its western slopes in a shroud of thin lava tongues. The northwest part of the cone was breached at this time and a large sector was rafted a quarter of a mile by the rising flood. As the breach widened the lava drained away, leaving a smooth coating on portions of the crater walls. The new lavas poured westward, narrowly confined between high levees. This last addition to the west lobe has been traced as far as Linton Lake but its furthest extent has not been recognized.

Several short, broad, subsidiary lobes were formed as lava spilled out of the gutters along the upper third of the west lobe - probably because the narrow channel could not accommodate the large volume of lava discharged into it. Perhaps for this reason, lava burst through an opening north of the breached area to form the northwest lobe. As activity shifted to the northwest, the supply of fresh lava to the west lobe diminished, and the blocky crust was folded into transverse, arcuate pressure ridges which now occur upstream from constrictions in its course. Final motion of the west lobe consisted of draining from the steeply inclined flow near the source vent. The deep gutter thus formed is now the most accessible route to the crater floor, and is occupied by the Skyline Trail. Before the northwest lobe chilled to its present form, a minor extension moved approximately 200 feet into the upper reaches of this gutter.

A few small lava tongues emerged at the north base of Collier Cone from a vent now buried beneath scoria and ashes. The position of these flow rocks in the eruptive history of the cone is uncertain.

At intervals throughout its length, the west lobe has been dissected by White Branch Creek. In the walls of these stream channels, the lobe is seen to be a mass of tumbled blocks and scoria. Close to the source, however, the blocky crust is underlain by dense glassy lava cut by deep transverse fractures.

During the past century, Collier Cone blocked the "Little Ice Age" advance of Collier Glacier. An early photograph (Campbell, 1924) shows Collier ice high on the flanks of the cone. When the ice attained a thickness of 200 feet at its terminus, meltwater was discharged into the crater, much of the floor was covered with outwash, and stream gravels were deposited for more than one mile down the west gutter. As the stream deposits near the cone are discontinuous and without interconnecting channels, the meltwater must have traversed snowfields and probably was active for only a brief time.

Continuity in the Volcanic Record

In the preceding descriptions, reference was made to more than 125 separate vents which have emitted various combinations of lava, ejecta, and gas. A number of genetic interpretations of the resulting landforms and deposits were offered. The shape of cinder cones, for example, depends upon such diverse factors as vent configuration, underlying topography, erosion, lava-breaching, explosive violence, and prevailing wind direction. The thickness of flow rocks and their surface features, aerial distribution, and sequence of superposition are determined by available topographic channels, viscosity and volume of lava, eruptive chronology, and the nature of the volcanic "plumbing" in the subsurface. The interdependence which exists between some of these factors is critical to petrologic interpretations.

Persistent linear vent patterns suggest that systems of faults or fractures must underlie the volcanoes. The most obvious alignments are those of the Sand Mountain groups, Inaccessible Cone, Four-in-One cones, and the Yapoah-Collier vents. While caution must be exercised in tracing vent alignments over long distances, the trend displayed by the Belknap craters, the Spatter Cone Chain, and Blue Lake Crater probably represents a similar continuous connection at depth. Close study of the eruptive centers, however, reveals several interesting irregularities. Some alignments (Four-in-One, for example) are linear over short segments but arcuate over their full length. Nearly all vent patterns except Belknap - Spatter Cone - Blue Lake and Four-in-One, trend individually north-south even where the composite alignment is differently oriented (Nash Crater, for example).

With few exceptions, each cinder cone is associated with a swarm of subparallel, north-south vegetation lineaments which are seen best on stereographic pairs of aerial photographs. These lineaments are composed of trees which stand 10 to 30 feet above the surrounding forest. Several lineaments are visible from mountain tops, but only one, on the west flank of Bachelor Butte, has been traced directly on the ground. They are not observed, of course, above timberline or in deforested areas. As seen on a photo scale of 1:50,000, some of the lineaments are only 30 to 50 feet wide, are as much as five miles long, and are nearly straight when plotted on a planimetric base.

The origin of such lineaments is not well known. None transect the most recent of the forested flows, but older lava fields display them in profusion. They occur with greatest frequency upon High Cascade glaciated bedrock which is overlain by thin deposits of ash or ground moraine. While the lineaments are not restricted to areas of Recent volcanic outbreak, they are concentrated near cones and usually a vent pattern coincides perfectly with a lineament. The following interpretation is offered on a provisional basis: Linear patterns of accelerated forest growth reflect irregularities in the supply of ground water which are, in turn, influenced by a bedrock joint set. Because the forest cover generally is scanty on glaciated bedrock surfaces, it is difficult to correlate lineaments on the map with joints in the rocks. If such a joint set exists, it is parallel to the length of the High Cascades and, for the most part, predates Recent volcanism. Volcanic conduits, rising above a broad, magmatic alignment were influenced by the joints. Consequently, the vent patterns generally trend north-south even if the alignment of which they are a part does not. Lineaments of the lava fields are commonly arcuate and concave toward the source cones, and may represent fracture systems above a subsiding magma column.

If the above interpretation is correct, it is likely that vents of a single eruptive center, coincident with a vegetation lineament, were active at about the same time. To what extent can this principle be applied to a whole alignment of eruptive craters? The answer is contained in the statement of lava chronology given in Table I below.

The central column in Table I is an eruptive sequence based upon radiocarbon age determinations, glacial records, and direct superposition of lava flows and ash deposits. Whether or not the approximate correlations in the third column are accepted, it will be seen that strict, detailed interpretation of an alignment as

TABLE I. Lava Chronology

Dates	Eruptive Sequence		Approximate Correlations
Older than 400 years	Collier		
	Four-in-One		
	Yapoah		
	Little Belknap		
	South Belknap flows		
360 A.D. $\pm$ 160 (WSU-292)	West Belknap flows		
1000 B.C. $\pm$ 220	Clear Lake flow	..?..	S. vent Sand Mtn.; Twin Craters; Sims; Condon; Little Nash
1500 B.C. $\pm$ 250 (WSU-291)	Blue Lake Crater	..?..	Latest flow, South Group; Fish Lake, Lava Lake flows; Spatter Cone Chain.
	Central Group and earliest flows from Nash, Sand, South Group; most of the ash from Sand Mtn. Alignment	..?..	Lost Lake Group
	Cone and flow of N. Inaccessible; two old cones of N. Sand Mtn. Alignment; Hoodoo	..?..	S. cones and flows of Inaccessible Alignment
Older than 10,000 years?	Flows and cones of quest. Recent age.		

consisting of coeval rocks is hazardous. The over-all eruptive sequence, however, is clearly related to geographic position; the eruptive history progressed from northwest to southeast. Exceptions to this rule are few and represent a comparatively modest volume of lava.

Several physical characteristics of lava flows in the area of study can be correlated with this eruptive sequence. For example, early lavas were relatively fluid and for this reason formed voluminous shields and extensive lava fields of thin flows with complex, discontinuous drainage patterns. Later lavas were more viscous, and were erupted in lesser volume; they formed thick flow units with high-standing margins and developed pressure ridge and lava gutter systems which are continuous for miles. In Part II of this paper, to be published at a later date, the results of petrographic studies and more than 200 partial chemical analyses will be placed within this framework of volcanic stratigraphy, and it will be shown that textural, mineralogical, and chemical characteristics of the lavas change in a regular way through the eruptive sequence.

Many details of the Recent volcanic history of this interesting region remain unknown. In particular, correlations must be extended over a larger area and additional radiometric dates must be obtained. The evidence at hand suggests that an elongate zone of volcanic activity cuts obliquely across north-south lineaments of the High Cascades in the vicinity of the Three Sisters. It may be continuous with a similar volcanic trend between the Three Sisters and Newberry Caldera to the southeast. For more than 10,000 years intermittent eruptions of basalt have occurred over the northwest extension of this zone, and during the last 4,000 years volcanic activity has shifted from northwest to southeast. The duration, recency, and continuity of such a record all suggest that future eruptions are possible in spite of the brief period of quiescence during historic time.

Acknowledgment

Radiocarbon dates were financed through a Northwest Scientific Association Grant-in-Aid. The writer is indebted to Dr. R. M. Chatters of the Washington State University Radiocarbon Laboratory for his help and advice, and to Roald Fryxell for many fruitful discussions concerning Recent geochronology of Oregon and Washington.

Glossary of Selected Terms

Accidental fragments. Rock particles erupted from a volcanic vent which are foreign to the magma associated with the vent.

Agglomerate. An accumulation of volcanic ejecta, usually near a vent, in which most of the particles are larger than scoria.

Agglutinate. A deposit of mixed bombs and spatter, more or less consolidated.

Ashes. Unconsolidated particles of volcanic ejecta, smaller than scoria.

Blocks. Angular fragments of volcanic ejecta, larger than scoria. Also applied to crustal fragments of lava flows.

Bocca. An Italian term meaning vent. English usage generally refers to a lava vent at the base of a cinder cone.

Bombs. Volcanic ejecta of any size which have assumed a rounded, aerodynamic shape during flight and have retained a recognizable vestige of this shape after impact.

Composite volcano. A volcanic mountain, generally large, in which lava is as abundant as ejecta. Opposed to cinder cone, generally small, in which ejecta predominate.

Lapilli. A class of volcanic ejecta which includes scoria and accidental fragments of scoria size.

Lapilli-tuff. A deposit of consolidated lapilli and ash.

Lava fields, flows, lobes, and tongues. A lava field is a wide and complex expanse of lava flows from separate, but related, vents. A flow is made up of lava from a single vent or from a small source area of closely related vents. Lobes are separate and distinct lava streams belonging to a single flow. A lava tongue is, as the name implies, a small, tongue-like offshoot from a flow.

Lava gutters and lava levees. If the supply of lava to an established channel rapidly diminishes, and if the flow gradient and fluidity is sufficiently great, the medial portion may drain away leaving a long deep gutter. Lava gutters are often bordered by high-standing margins called lava levees.

Pressure ridge. Broad ridges of lava, transverse to the direction of flow. Generally arcuate in plan, concave upstream, and thought to result from differential movement between a stagnant crust and a mobile interior.

Recent. A feature is considered to be of Recent geologic age if it came into existence since the last major glacial episode (here estimated to be 10,000 - 12,000 years ago).

Scoria. Particles of volcanic ejecta having coarse vesicular habit, irregular form, generally basaltic composition, and variable BB-shot (4mm) to walnut (32mm) dimensions.

Shield volcano. A large, broad volcanic mountain with gentle slopes of constructional rather than destructional origin.

Spatter. Irregular clots of ejecta, larger than scoria, but not highly vesicular; similar to bombs in origin but not in shape.

Squeeze-ups. Protrusions of lava extruded through rifts in a solid crust.

Steptoe. An elevated point of land surrounded by lava flows.

Vesicles. Rounded gas-bubble cavities in lava rocks.

Vitrophyric. The texture displayed by predominantly glassy lava which contains abundant megascopic crystals.

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_____________, 1957, A geologic map of the Bend quadrangle and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Dept. Geology and Mineral Industries map.

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NOTABLES TO ATTEND INTERNATIONAL LUNAR CONFERENCE

Nearly 100 scientists from 12 foreign countries and the United States will participate in the International Lunar Geological Field Conference in Bend, Oregon, August 22-28. The scientists are authorities in astronomy, geology, astrophysics, and related fields. Included in the roster of those attending are such names as Dr. Shotaro Miyamoto, Kyoto University, Japan; Dr. Harouin Tazieff, University of Brussels, Belgium; Dr. Aleksandr Mikhailov, Main Astronomical Observatory, Soviet Union; Dr. Nikolay Kozyrev, Physico-Mathematical Sciences, Leningrad; and Dr. Gerard Kuiper, Lunar and Planetary Observatory, University of Arizona.

The Conference is being co-sponsored by the New York Academy of Sciences and the University of Oregon, and is intended to advance investigation into the nature of the lunar surface. At least 10 papers will be presented and discussed by the participants, and five days will be spent on field trips in the area around Bend.

Dr. Jack Green, New York Academy of Sciences, and Dr. Lloyd Staples, Department of Geology, University of Oregon, are co-chairmen of the conference. Other members of the general committee are Lawrence A. Dinneen, Oregon Division of Planning and Development, Hollis M. Dole, State Geologist; and Marion Cady, Lunar Base Research Facilities, Inc., Bend.

KGW-TV, Portland, plans a program on the Conference August 22 at 11:30 a.m.

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CENTER FOR VOLCANOLOGY

Dr. A. S. Flemming, President of the University of Oregon, has announced the establishment of a Center for Volcanology in the Department of Geology. Named as Director of the Center is Dr. A. R. McBirney, who will come to the University of Oregon from the University of California, San Diego, at LaJolla. He has done extensive work in volcanic regions in Central America, and is the author of many papers on volcanic activity.

The decision to establish a Center for Volcanology at the University of Oregon was based on the fact that the State of Oregon contains areas of volcanism, ancient and recent, unsurpassed in variety and scientific interest. More than half of the State is underlain or covered by volcanic rock, much of it extruded during Tertiary and Quaternary times. The Recent cones, flows, and pyroclastic deposits have changed very little since they were formed and are excellent laboratories for field studies.

The early planning of the Center was done by a committee consisting of Dr. A.C.Waters, University of California, Santa Barbara; Dr. Howel Williams, University of California, Berkeley; Dr. Gordon Macdonald, University of Hawaii; Mr. P. D. Snavely, U.S. Geological Survey, and Dr. L. W. Staples, University of Oregon. Dr. Staples, who is Head of the University of Oregon Department of Geology, announced that one of the first activities of the Center for Volcanology will be the co-sponsoring with the New York Academy of Sciences of an International Lunar Geological Field Conference in Bend August 22 to 28. About 17 lunar geologists from abroad and 32 from the United States have indicated their intention of attending the conference. Many scientists will read papers and all will participate in five days of field trips to volcanic features similar in appearance to lunar topography shown by the pictures taken by Rangers 7, 8, and 9.

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