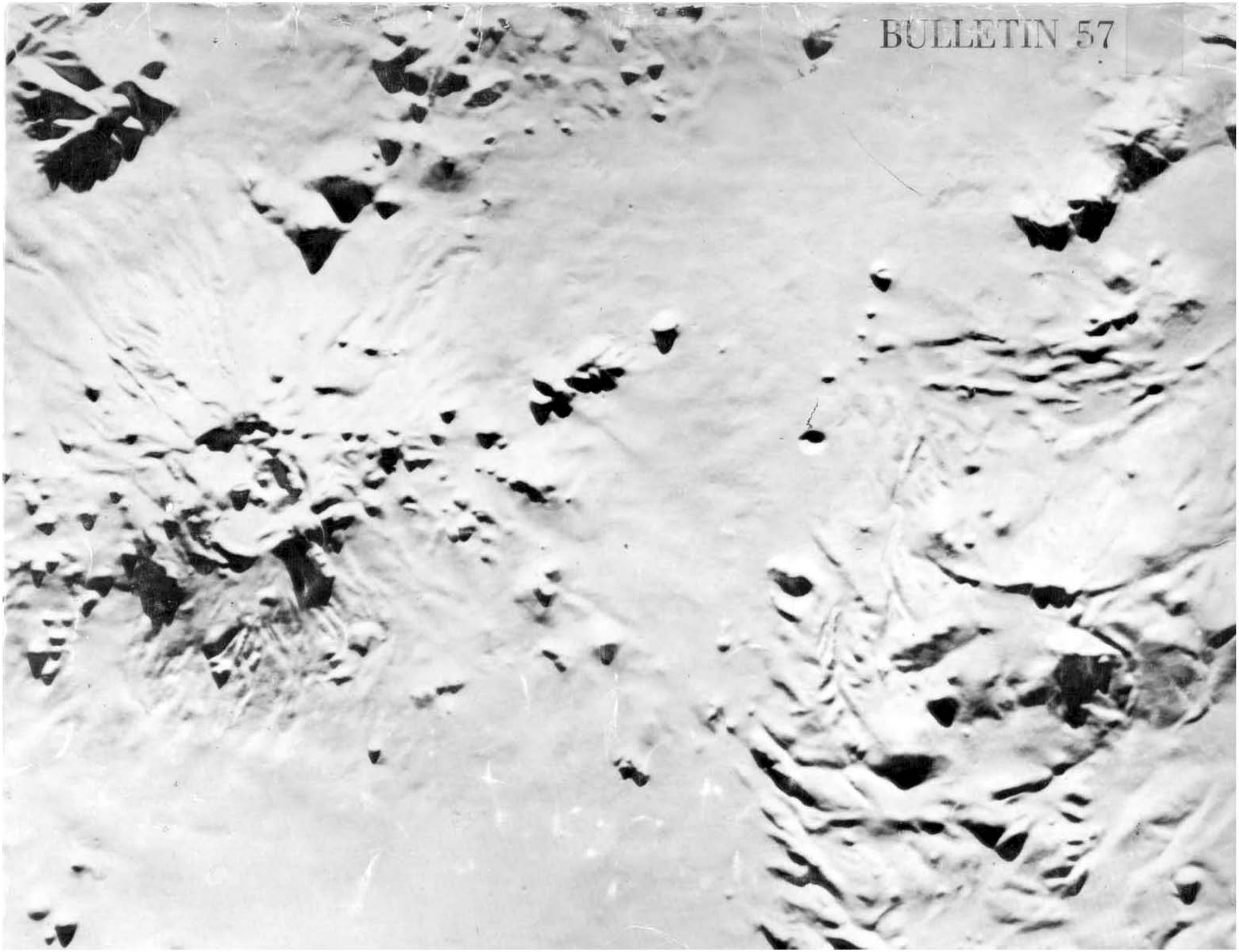
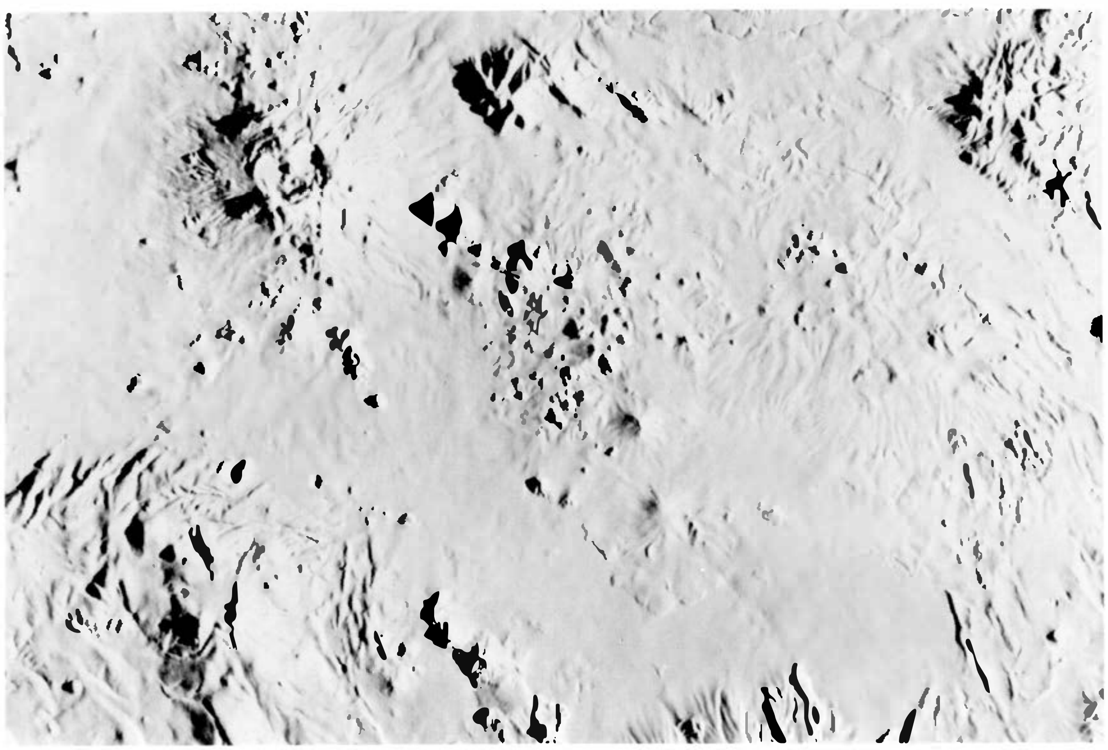

BULLETIN 57



MARE INCOGNITUM

The features in the above photograph and its enlargement on the cover will not be found in the Photographic Lunar Atlas, although the resemblance to the lunar surface is very striking. It was produced by photographing a major portion of the Crescent, Oregon, plastic relief map, NK 10-3, Series V502P after all printing had been removed. Relief on this map is exaggerated by a factor of two.

Newberry Volcano and caldera in the northwest quadrant, complemented by volcanic and lake basin features to the south and east, effect this "moonscape" of central Oregon terrain. It was necessary to invert the enlargement in order to bring Newberry Volcano onto the front cover.

OFFICE OF THE GOVERNOR
STATE CAPITOL
SALEM

MARK O. HATFIELD
GOVERNOR

To Our Guest Scientists and Others:

May this be but the first of many warm welcomes you will receive during your stay in Oregon.

We have a deep and abiding respect for science and scientists as you work with the wonders of the earth and space. We genuinely hope this Lunar Field Conference will contribute further to your sum total of knowledge and we hope also that you may find time for some pleasurable leisure time pursuits as well.

We are deeply appreciative of the efforts of your sponsors who saw the wisdom in your coming here and of your hosts who, we trust, will make your stay most productive and enjoyable.

I look forward to joining you during your visit and we invite you to make the most of your stay in Oregon whether it be for a while....or a lifetime.

Mark O. Hatfield
Governor

CITY of BEND

P. O. BOX 431
PHONE 382-4211

June 19, 1965

Greetings:

The City of Bend joins in welcoming you to the State of Oregon Geological Lunar Field Conference.

We are proud to host such a gathering of world renowned scientists in your fields of vulcanology, geology, and the related disciplines.

It is our sincere hope that your studies will be profitable and rewarding, and that each of you will find much of value in the Conference and in your experiences here. It is our hope also that each of you will carry to your homes the memories of an enjoyable period in our Central Oregon Area.

We trust that the Conference associations here will add in substance to the knowledge of each, and in the fields of interest, that men everywhere may profit.

If we can be of assistance in any way during your stay, please feel free to call on us at any time.

Sincerely,

Paul Reynolds
Mayor

STATE OF OREGON
LUNAR GEOLOGICAL FIELD CONFERENCE GUIDE BOOK

Prepared by
N. V. Peterson and E. A. Groh—Editors
C. J. Newhouse—Cartographer
and the Editorial Staff of the
State of Oregon Department of Geology and Mineral Industries

1965

Sponsored by the University of Oregon Department of Geology and
The New York Academy of Science

August 22 to 29, 1965
Bend, Oregon, U.S.A.

WELCOME

This Lunar Geological Field Conference, organized by our two sponsors, the University of Oregon Department of Geology and the New York Academy of Sciences, highlights geological relationships between the earth and the moon that have both academic and practical implications. Comparison of the earth and the moon will lead to an understanding of the differences which exist between them. This, in turn, may provide clues to the origin and development of all planetary bodies.

Conventional welcomes usually begin with a statement of joy by those who have organized the conference that you were able to attend. Let us break with tradition. Our pleasure in having you as our guests extends beyond your mere presence. We have invited you here to see some remarkably well exposed and accessible lunar-like geology. The association of crater alignments on the flanks of calderas to the parent caldera, the shear-strength of ash flows and falls, the morphology of lava tubes -- are all things which deserve careful analysis before manned landing on the moon. Has there been unintentional neglect of field data in the space programs? We have invited you to see and discuss geological field relationships that, we hope, will increase your store of information and promote better international communication on the ways and means of lunar exploration.

Lloyd Staples
University of Oregon Department of Geology

Jack Green
New York Academy of Sciences

FOREWORD

Oregon has the largest area of Tertiary and Recent volcanics of any state in the conterminous United States. A large variety of intrusives, flows, and ash beds combined with many dissimilar textures and structures, all well displayed, make our State an ideal laboratory for the study of this phase of geology. The central Oregon area around Bend is especially adapted to research on Recent volcanic activity because of the great diversity of lava types and landforms within a comparatively short radius. Access can be had to the whole area with a minimum of difficulty through a fine network of State highways and U.S. forest roads.

Over the years several great volcanologists have written monographs on some of the major and spectacular features of Oregon, but our State still has much to contribute to the science of volcanology. The recent establishment of the Volcanological Center within the Department of Geology at the University of Oregon and the addition of a volcanologist to the geologic staff at Oregon State University are assurance that contributions will continue.

This Guidebook and the Lunar Geological Conference will give a brief introduction to the potential of the area, both as an outdoor laboratory for the study of volcanics and as a site for some of the research prerequisite to the establishment of a manned base station on the moon. In addition, the Guidebook will prove popular to the layman and the tourist, for it outlines trips and describes, by text, maps, and photographs, the geology of a vast and spectacular area relatively untouched by man or erosive forces. It is truly a large dose of "Nature in the raw."

The Department presents this publication with the hope that it will whet the interest of others in sharing with us the study and enjoyment of one of the world's great untapped regions of geologic interest.

Hollis M. Dole
State Geologist

TABLE OF CONTENTS

LIST OF FIGURES

Devils Hill—Broken Top Area and Lava Butte Area Field Trip

Geologic Summary

Westward from Bend, the Cascade Lakes Highway passes over Quaternary lava flows which have poured from vents on the eastern flank of the Cascade Range. Some of the lavas flowed from fissures, but the majority erupted from vents now marked by the numerous cinder cones to the south. These lavas are but a later manifestation of the same process which built the greater part of the High Cascade Range beginning in early Pliocene time. Williams (1933, 1941, 1944, 1957) has shown that great basaltic and basaltic andesite shields, with parasitic cones, make up the bulk of the High Cascades and that these lie on a pre-Pliocene basement of predominantly volcanic rock. Culminating eruptions of pyroclastic material, accompanied by andesite and dacite flows, then formed the peaks or stratovolcanoes, many of which are now deeply eroded.

Mt. Bachelor (Bachelor Butte) is a large, basaltic cone which has continued its volcanic activity to very recent time, as shown by the fresh flows and cinder cones on its northern slope. From the top of the chair lift at 7,700 feet (2,350 m) elevation, the area of study to the north and west is well presented in panorama.

The features of interest lie about the southern flank of the South Sister, an imposing stratovolcano which still has a crater on its summit. The sequence of its formation began with the building of the original lava shield. Then the eruption of andesite and dacite lavas formed a summit cone. This was followed by the growth of a basaltic lava and cinder cone at the apex. The cinder cone was then partially eroded and was subsequently buried by a younger cone of similar composition. The almost complete lack of glacial sculpturing indicates that volcanic activity has continued down to recent time.

Broken Top, situated 4 miles (6.4 km) east of South Sister, grew in a similar manner, although some pyroxene andesite was erupted during the later stages of shield formation. The summit cone consists of scoria, lapilli tuffs, and tuff-breccias with some thin lava flows. Subsidiary vents produced such features as Ball Butte and several now-eroded cinder cones. Volcanic activity ceased at Broken Top prior to the end of the Pleistocene Epoch, and deep glacial carving has revealed the internal structure of the volcano (fig. 1). The only eruption to occur since has been the building of Cayuse Cone and extrusion of a basaltic lava flow from a parasitic vent on the south slope of Broken Top.

Other older features such as Devils Hill and Kaleetan Butte are composed of dacite. Devils Hill is a dome built over its vent, and Kaleetan Butte consists of stumpy flows that had their source on the flank of South Sister. Kokostick Butte, on the other hand, is made up of pyroxene andesite and may also represent a dome and flows overlying a vent. All of these features are probably coeval with the formation of the andesite and dacite cone of South Sister. Talapus and Katsuk Buttes are two unglaciated cinder cones which developed on a ridge composed of older tuffs and tuff-breccias; both vents contributed extensive flows of basalt.

Of greater interest are the most recent volcanic features consisting primarily of dacite extrusions. An exceptional chain of dacite domes and flows follows a north-trending fracture from the Cascade Lakes Highway northward over Devils Hill and on up the flank of South Sister to an elevation of nearly 8,000 feet (2,440 m). At least a dozen domal protrusions occur along the fracture, which extends for a distance of 3.5 miles (5.6 km) (fig. 2).

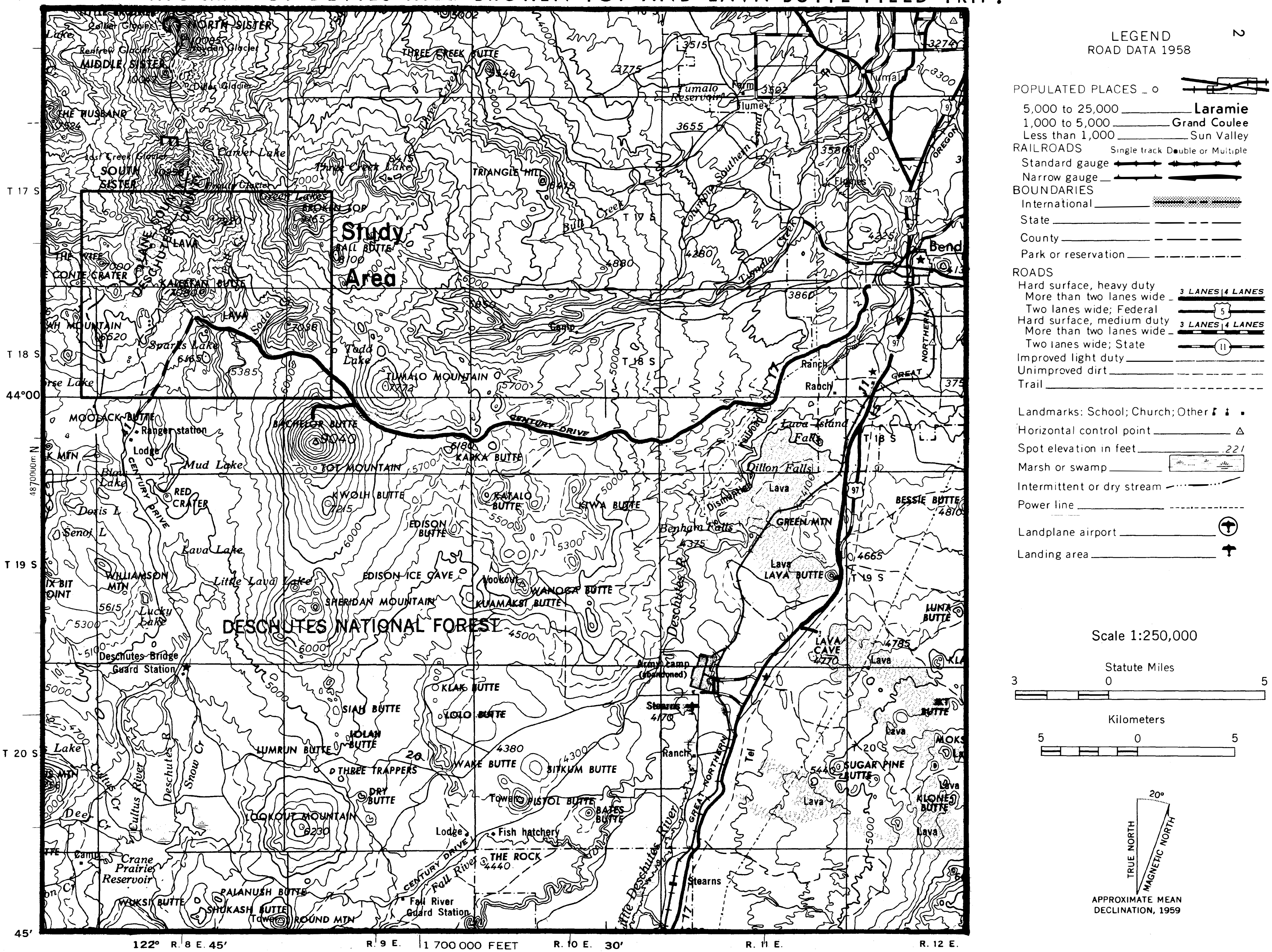
Two miles (3.2 km) west from the chain of domes is the dacite obsidian flow of Rock Mesa. This oval mass, about $1\frac{1}{2}$ square miles in area (3.9 km^2), is some 75 to 100 feet (23 to 31 m) thick along the margins. Great block ridges and spires show the typical sluggish manner of flow from a vent over which a dome or tholoid accumulated in the final stage of extrusion (fig. 3). Much of the surface is composed of obsidian, although a large portion is pumiceous. A small tholoid eight-tenths of a mile (1.3 km) east of Rock Mesa dome may have been a coeval satellitic eruption.

Another feature of most recent volcanism, but one that formed prior to Rock Mesa, is Le Conte Crater (fig. 3) and its lava flows. This fresh basaltic cinder cone overlies a vent from which lava poured south around Kokostick Butte and beyond for another two or three miles (3.2 to 4.8 km). Another flow, which underlies Rock Mesa, is exposed for about a mile (1.6 km) in Mesa Creek valley. Oddly, the cone of Le Conte Crater is covered by pumice and fragments of obsidian, dacite, andesite, and basalt. This superficial debris has not come from any exposed vent in the vicinity and must, therefore, be from one concealed under Rock Mesa (Williams 1944, p. 53-54). These pyroclastics were probably thrown out from the vent of Rock Mesa during the initial explosive eruptions along with older volcanic rock fragments torn from the conduit walls.

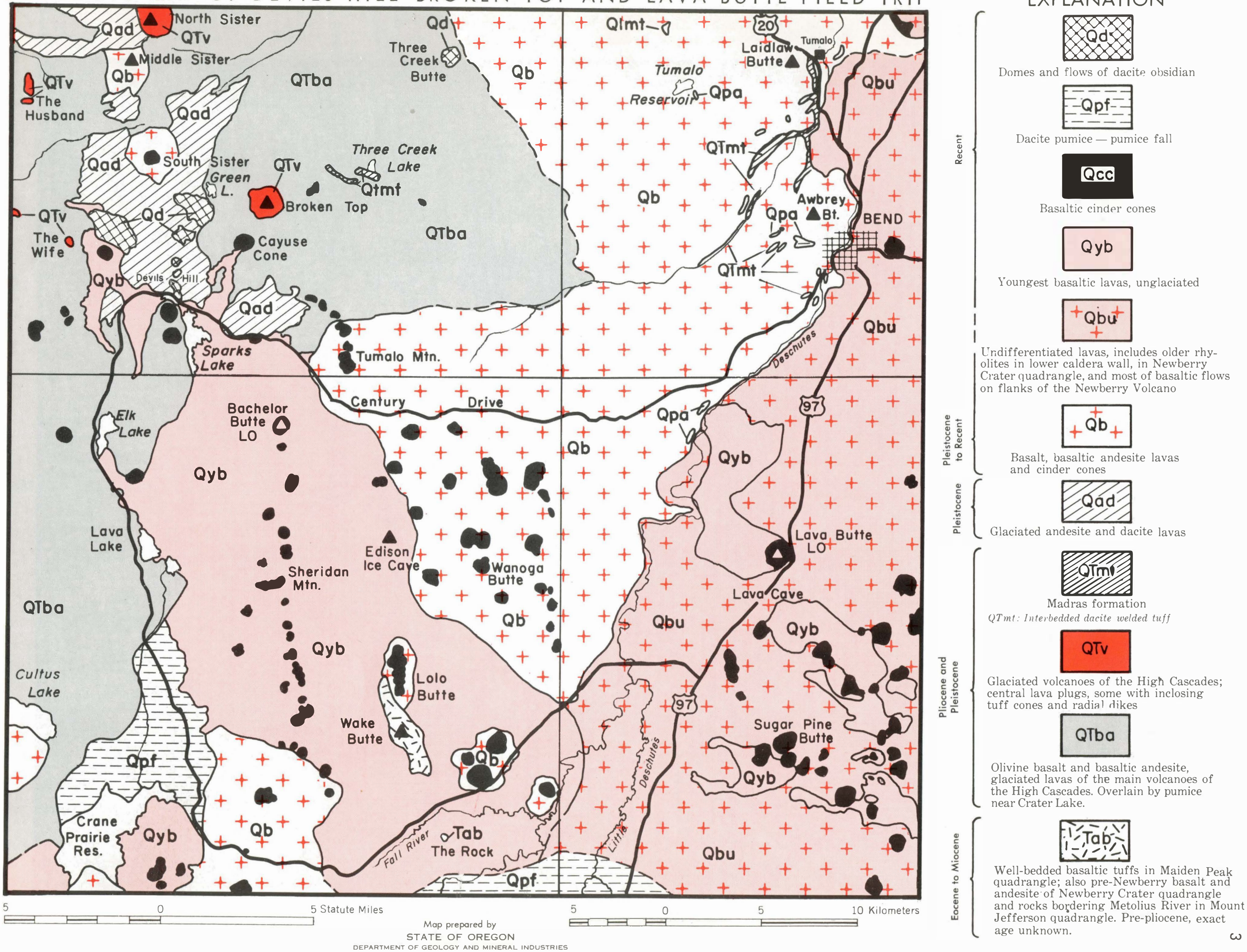
Volcanism of the Lava Butte area is described on page 9 in connection with the recent lavas of the Northwest Rift Zone.

E. A. Groh, Editor

TOPOGRAPHIC MAP OF DEVILS HILL-BROKEN TOP AND LAVA BUTTE FIELD TRIP.



GEOLOGIC MAP OF DEVILS HILL-BROKEN TOP AND LAVA BUTTE FIELD TRIP



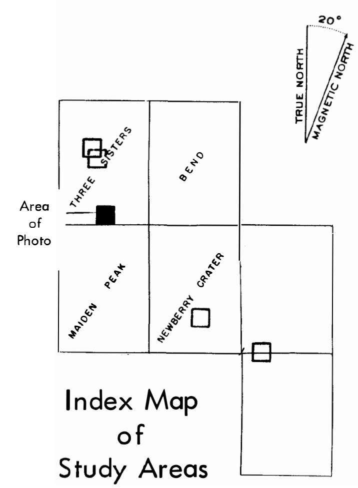
AERIAL PHOTOGRAPH OF THE DEVILS HILL - BROKEN TOP STUDY AREA

The geologic map below refers to the area of the photograph and the map scale may be used to make approximate measurements on the photograph.

The southern flank of South Sister is in the upper part of this high-altitude photograph and Broken Top in the upper right corner.

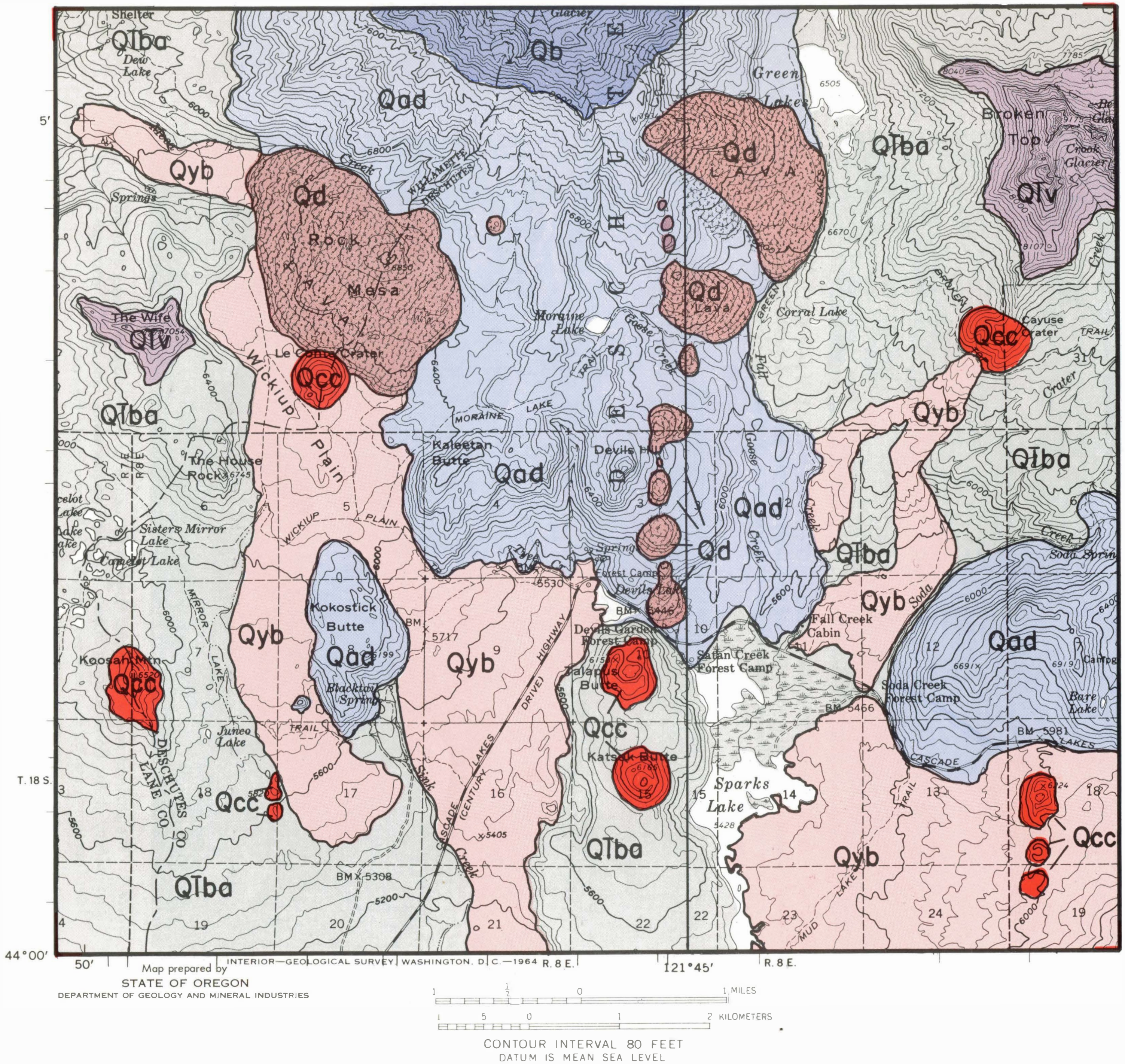
A light snowfall, which occurred prior to the photographing of this area, tends to obscure some of the fine detail at higher elevations. Despite this, features such as LeConte Crater, Rock Mesa, the chain of dacite domes and flows, and Cayuse Crater can be easily noted. Basalt lavas which have flowed into Sparks Lake are from the base of Mt. Bachelor, whose summit is about 2 miles (3.2 km) southeast off the limits of the lower right corner of the photograph.

Roll 22, Exposure 2294, Western U.S. Project 109F.



Index Map of Study Areas

GEOLOGIC MAP OF THE DEVILS HILL - BROKEN TOP STUDY AREA.



EXPLANATION

Recent

- **Qd** — Domes and flows of dacite obsidian
- **Qcc** — Basaltic cinder cones
- **Qyb** — Youngest basaltic lavas, unglaciated

Pleistocene to Recent

- **Qb** — Basalt, basaltic andesite lavas and cinder cones

Pleistocene

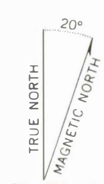
- **Qad** — Glaciated andesite and dacite lavas

Pliocene and Pleistocene

- **QTv** — Glaciated volcanoes of the High Cascades; central lava plugs, some with inclosing tuff cones and radial dikes
- **QTba** — Olivine basalt and basaltic andesite, glaciated lavas of the main volcanoes of the High Cascades. Overlain by pumice near Crater Lake.

ROAD CLASSIFICATION

Medium-duty — Light-duty — Unimproved dirt



APPROXIMATE MEAN DECLINATION, 1959

Figure 1. Broken Top seen from the southeast. Glacial erosion has laid bare the internal structure of this volcano. Beds of pyroclastics and lava flows indicate the many volcanic episodes that formed the original cone. Pumice-covered glacial debris lies in the foreground. (Oregon State Highway Department Photograph 3904)

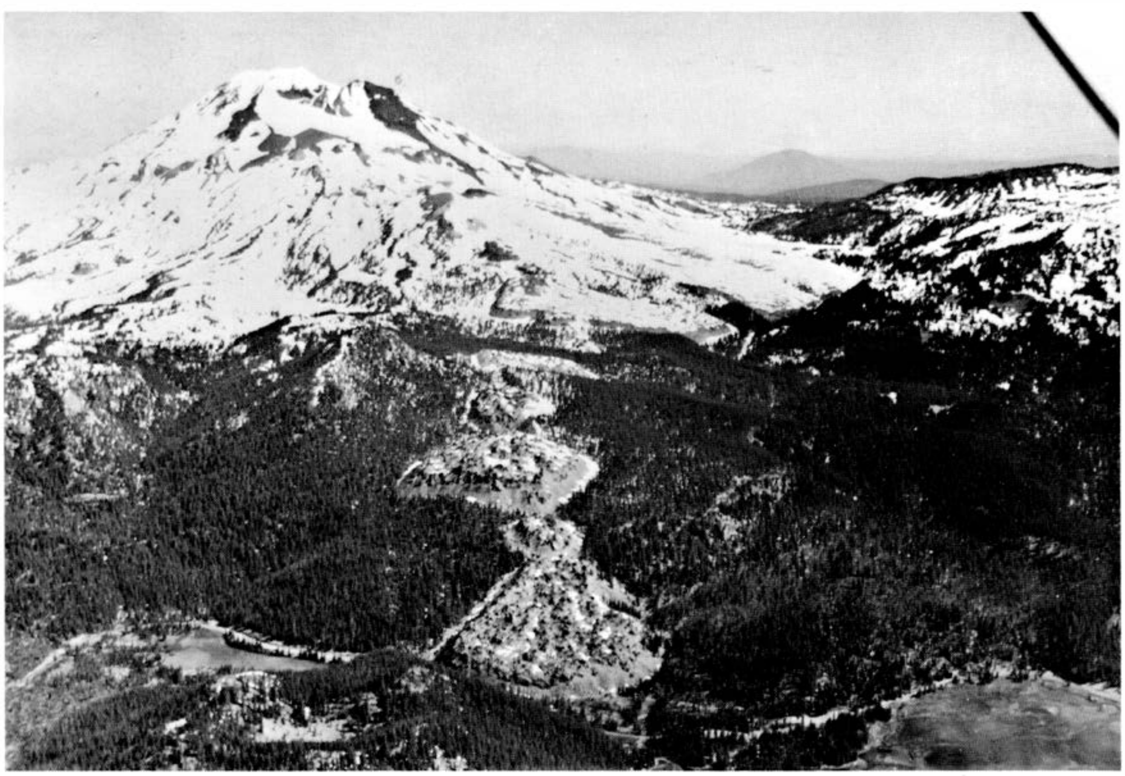
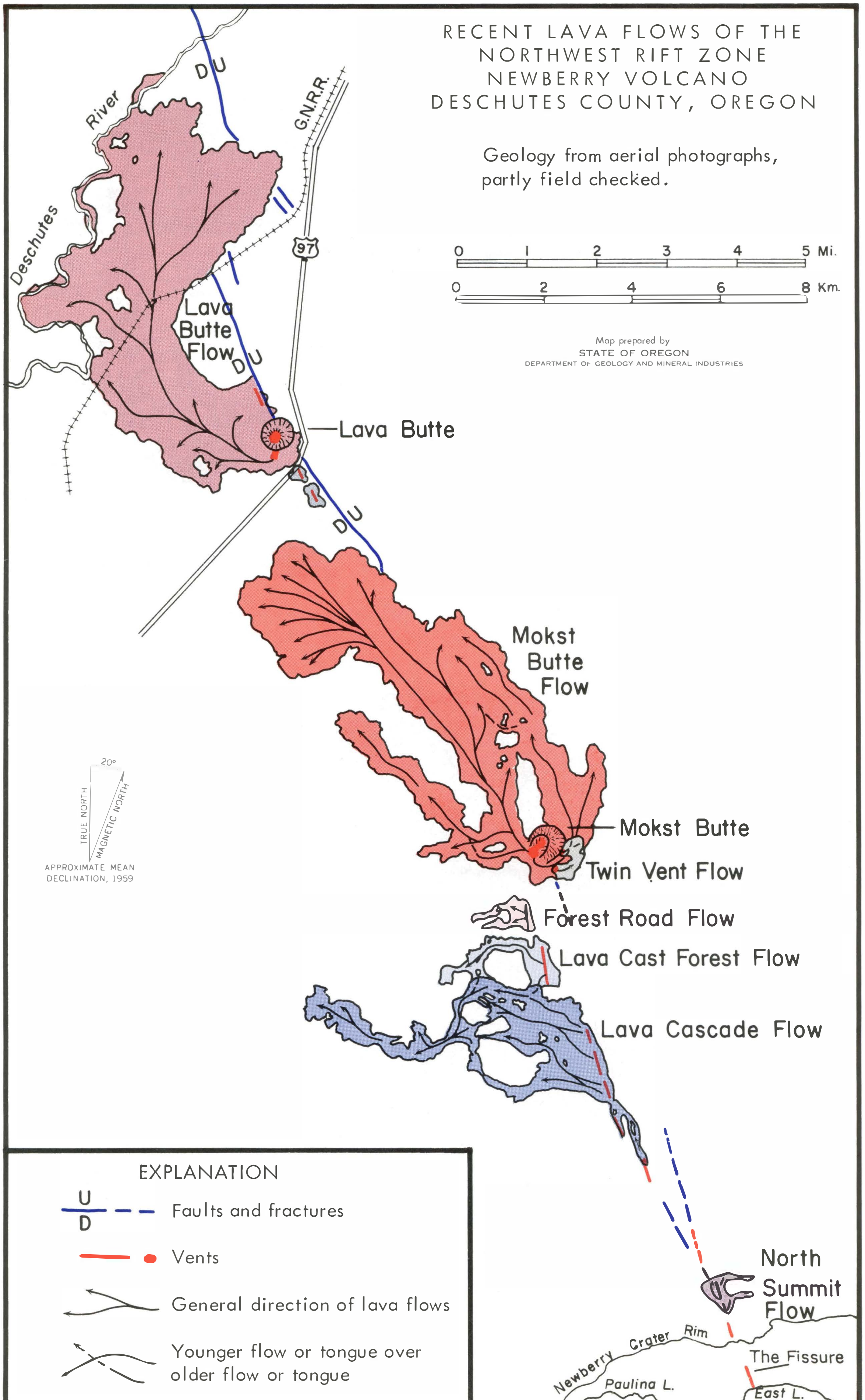


Figure 2. The chain of dacite domes and flows in the center of the photograph passes over Devils Hill and halfway up the flank of South Sister. View is from the south. The northernmost vent erupted a long flow which can be seen as a snow-covered ridge sloping to the east.

Figure 3. Le Conte Crater is in the center of the photograph as seen from the southeast. Rock Mesa, a large dacite obsidian flow is to the right. Unusually heavy winter snows had not melted away when this photograph was taken in June.

Figure 4. The fissure vents of the Lava Cascade Flow, Northwest Rift Zone, on the northern slope of Newberry Volcano. The view is towards the south. Spatter ramparts formed along the vents as lava flowed to the west.


RECENT LAVA FLOWS OF THE
NORTHWEST RIFT ZONE
NEWBERRY VOLCANO
DESCHUTES COUNTY, OREGON
Geology from aerial photographs,
partly field checked.
0 1 2 3 4 5 Mi.
0 2 4 6 8 Km.
Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
Deschutes River
G.N.R.R.
97
Lava Butte Flow
Lava Butte
Mokst Butte Flow
Mokst Butte
Twin Vent Flow
Forest Road Flow
Lava Cast Forest Flow
Lava Cascade Flow
North Summit Flow
Newberry Crater Rim
The Fissure
Paulina L.
East L.
20°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN
DECLINATION, 1959
EXPLANATION
Faults and fractures
Vents
General direction of lava flows
Younger flow or tongue over
older flow or tongue

L A V A   B U T T E   S T U D Y   A R E A

FISSURE ERUPTIONS NEAR BEND, OREGON*

By Robert L. Nichols and Charles E. Stearns

ABSTRACT

A fissure eruption, near Bend, Oregon, of very recent date is marked by at least five basaltic flows, tremendous quantities of spatter, which forms long ridges and cones, and collapse features. The fissure strikes northwest, is about 20 miles (32 km) long, lies entirely on the Newberry Crater quadrangle, and extends from a point north of Lava Butte on The Dalles-California Highway southeast to Devils Horn, which is about 4 miles (6.4 km) south of East Lake.

From Mokst Butte it can be traced fairly continuously to the fissure which Howel Williams (1935) has described on the north wall of East Lake. From this part of the fissure at least four flows were erupted, all of which ran into dense forests. Tree molds and casts are so common on these flows that a part of the area has been set aside for the public by the National Forest Service and is called the Lava Cast Forest. In many places the trees remained standing while the lava flowed around them; in other places the trees were knocked down by the lava and were rafted along so close together as to remind one of a log jam in a river. These casts and molds are found in both aa and pahoehoe flows.

Nothing in the Craters of the Moon (Idaho) appears any fresher or younger than certain parts of this fissure. Apparently not all the spatter and lava extruded is of the same age. The freshest and youngest material lies between Mokst Butte and East Lake.

Note by the Editors:

Since 1938, when the above abstract was published, high-altitude photographs of this region have become available. Study of these photographs has revealed a zone of faults and fissures running about N. 30° W. from East Lake in Newberry Crater down the slope of Newberry Volcano. This feature is referred to in these notes as the "Northwest Rift Zone."

The sketch map on the opposite page shows that at least eight separate basaltic flows have been erupted from the Northwest Rift Zone. Because these flows are not mantled by the pumice ejected during the caldera collapse of Mt. Mazama, now the site of Crater Lake, they all are assumed to be post-Mazama in age. Photographic and field evidence indicate that Lava Cast Forest Flow and Forest Road Flow are probably the same age and the oldest of the post-Mazama group of lavas. Here lava issued from fissure vents, and fire-fountain activity produced spatter ridges or ramparts along the vents. Charcoal found in a horizontal tree mold in the Lava Cast Forest Flow by Peterson and Groh (1964, unpublished) has been dated as 6150 ± 210 y. B. P., a surprisingly old age considering the fresh appearance of the lava.

Mokst Butte Flow and the attendant explosive eruptions which formed the cinder cone were probably the next events to occur along the rift zone. Lava Cascade Flow and North Summit Flow appear to have been coeval and the next youngest in the sequence. They are also the product of fire-fountain activity and extrusion from fissure vents (fig. 4). Their relative age assignment is based on the fact that Lava Cascade Flow buried part of Lava Cast Forest Flow and both appear less weathered.

Pyroclastic eruptions formed the cinder cone of Lava Butte, and the large aa flow extruded from a vent at its southern base (fig. 5). This flow and Twin Vent Flow appear to be about the same age and are believed to represent the latest volcanism along the Northwest Rift Zone.

The two small, unnamed flows just southeast of Lava Butte are mantled by cinders from Lava Butte and therefore are older. Where they stand in the sequence of activity along the rift zone cannot be determined, but an estimate would place them as younger than the Mokst Butte Flow.

Nichols (1940) has made a detailed examination of the lavas northwest of Lava Butte. His study indicates that several earlier basaltic flows or flow units were extruded prior to the largest aa flow.

About $1\frac{1}{2}$ miles (2.4 km) south of Lava Butte, in one of the older pahoehoe flows of Newberry Volcano, is Lava River Cave. This large lava tube (fig. 6) is a mile long (1.6 km), and it can be easily entered where the roof has collapsed. The point of entry is the site of a small state park just east of U.S. Highway 97.

---

* Reprinted by permission from Geological Society of America Bulletin, vol. 49, p. 1894, 1938.

Figure 5. Lava Butte viewed from the south. An observatory is located at the top of this fine example of a very young cinder cone. The cone is about 500 feet (153 m) high and 2,000 feet (610 m) across at the base. A large aa lava flow covering some 10 square miles (26 km^2) streamed south and west from a vent on the side of the cone. As can be seen in the lower half of the photograph, lava flowing along the main channel intermittently overflowed westward into branch channels.

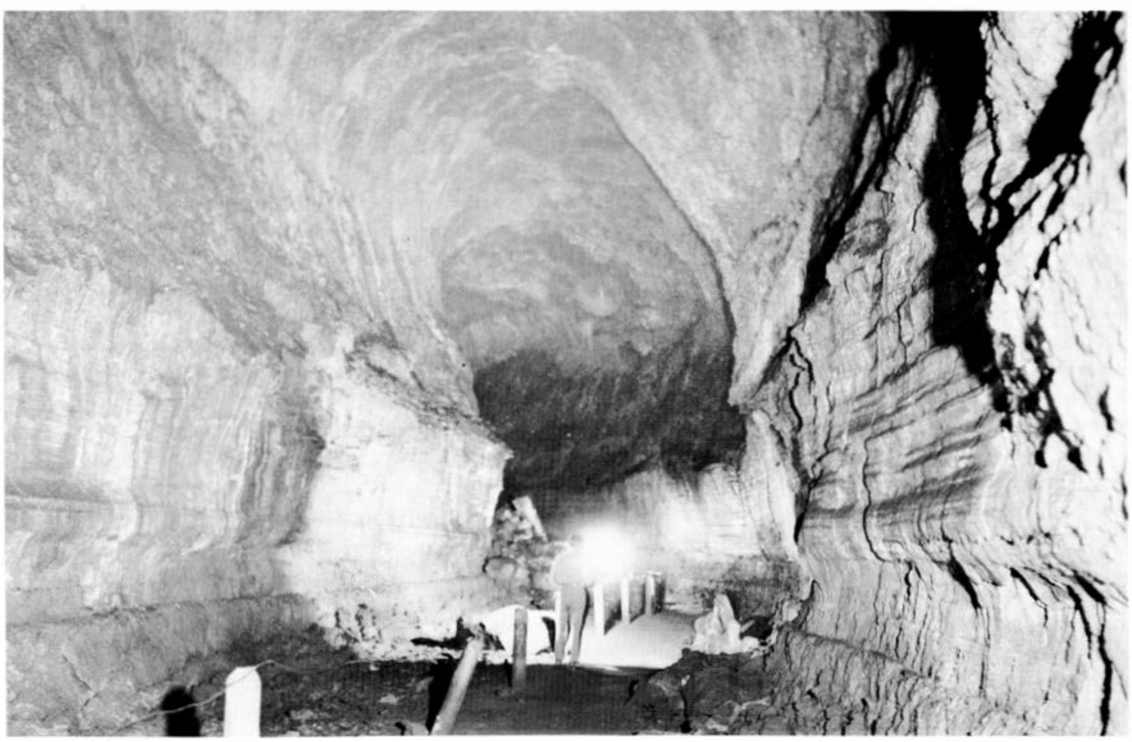


Figure 6. Lava River Cave, a typical lava tube. This large tube represents the main internal channel within a pahoehoe lava flow. It conveyed a river of fluid lava from the vent to the branching secondary tubes at the active margins of the flow. The terraces along the lower walls of the tube mark the temporary pauses in the level of the molten river as it drained out in the closing stage of activity. (Oregon State Highway Department Photograph 4177)

Newberry Volcano Area Field Trip

Geologic Summary

About 25 miles (40 km) south of Bend, Oregon, and some 35 miles (56 km) east of the crest of the High Cascades is the enormous prehistoric Newberry Volcano. The broad shield has a basal diameter of nearly 20 miles (32 km) and Paulina Peak, the highest point on its caldera rim, is 7,985 feet (2,395 m) high, about 4,000 feet (1,200 m) above the basalt-covered plain from which it rises. It must have once been at least 1,000 feet (305 m) higher with a smaller summit crater and certainly must have been majestic.

It now has an oval-to-rectangular summit caldera, 5 miles (8 km) long and 4 miles (6.4 km) wide. The encircling walls on all but the west side rise steeply up to 1,500 feet (458 m) above the hummocky floor. Figure 13 identifies points on the rim and positive features within the caldera.

Inside this caldera are two large lakes, Paulina and East Lakes, separated by pumice cones, basaltic tuff rings, and barren flows of obsidian, the products of post-caldera eruptions from a narrow zone that almost bisects the caldera from north to south. The outer slopes of Newberry Volcano are impressive for their abundant cinder cones and the flows of stark, black lava that accompany them.

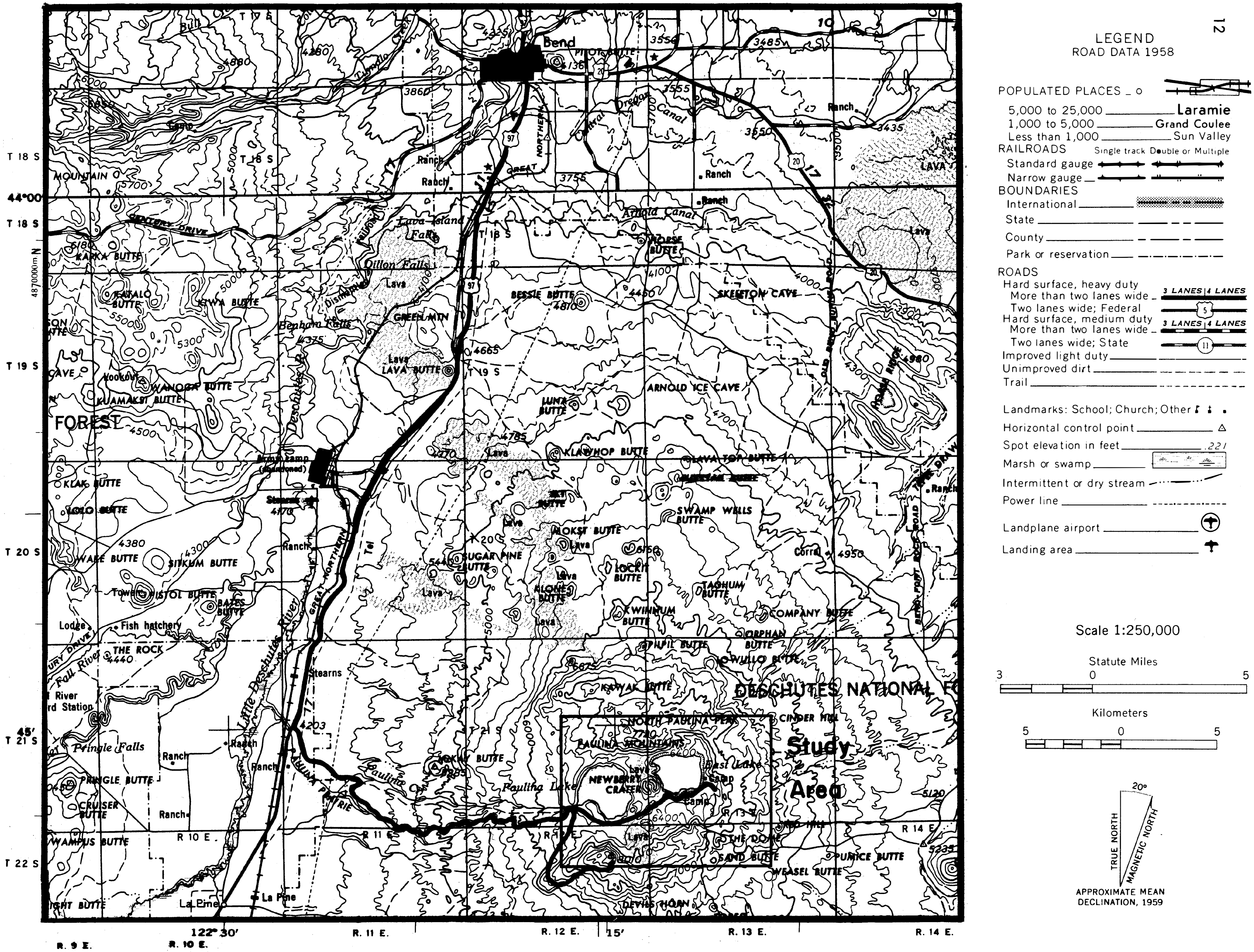
The nature of the bedrock on which the Newberry Volcano is built is conjectural, but some of it is certainly volcanic in origin, since accidental fragments and blocks of augite basalt are found in younger eruptive rocks within the crater. The volcanic activity that built Newberry Volcano probably began during the Pliocene when the shield volcanoes of the Cascades were beginning to rise, but its chief development belongs to the Pleistocene, and its numerous vents continued to erupt until a few centuries ago. Dating of charred logs encased in the top-most layers of pumice within the caldera show that the latest eruptions occurred no more than 2,054 $\pm$ 230 years ago.

The first episode in the history of the volcano was the building of the main shield. Unlike the High Cascade volcanoes to the west, where the lavas were mainly andesite, the early flows of the Newberry Volcano were basalt, followed by thick sheets of rhyolite with later basaltic ash. After the volcano had reached its maximum size, quiet but rapid eruptions of basaltic lavas from fissures low on the flanks drained the central feeding pipes, thus withdrawing support from beneath the summit. The top of the volcano then collapsed along concentric fractures. Repeated avalanching and piecemeal caving of the walls has enlarged the caldera to its present size, with glacial erosion perhaps playing a minor part. The fractures that ring the caldera can be easily seen on the aerial photograph on page 14, and are marked by mounds and ridges of scoria and cinders that formed as lava escaped to the surface through the zones of weakness. How deep the caldera was after its enlargement and how long a time elapsed before eruptions of rhyolite and basalt again began to build up hummocky masses on the crater floor is unknown. Post-caldera explosive eruptions alternated with the quiet outflow of lava to form a great variety of landforms. There are partially eroded rhyolite domes on the southeast side of Paulina Lake. Between the lakes is a cluster of north-trending pumice cones, the largest of which is centrally located and has a blocky dome of obsidian within its own crater (fig. 7). South of the lakes there are the remains of at least three basaltic tuff rings or maars, one of which still retains a broad shallow crater (fig. 8). These resulted from rather violent rhythmic explosions of a basaltic magma. On the north side of Paulina Lake is a cone of basaltic cinders (fig. 9).

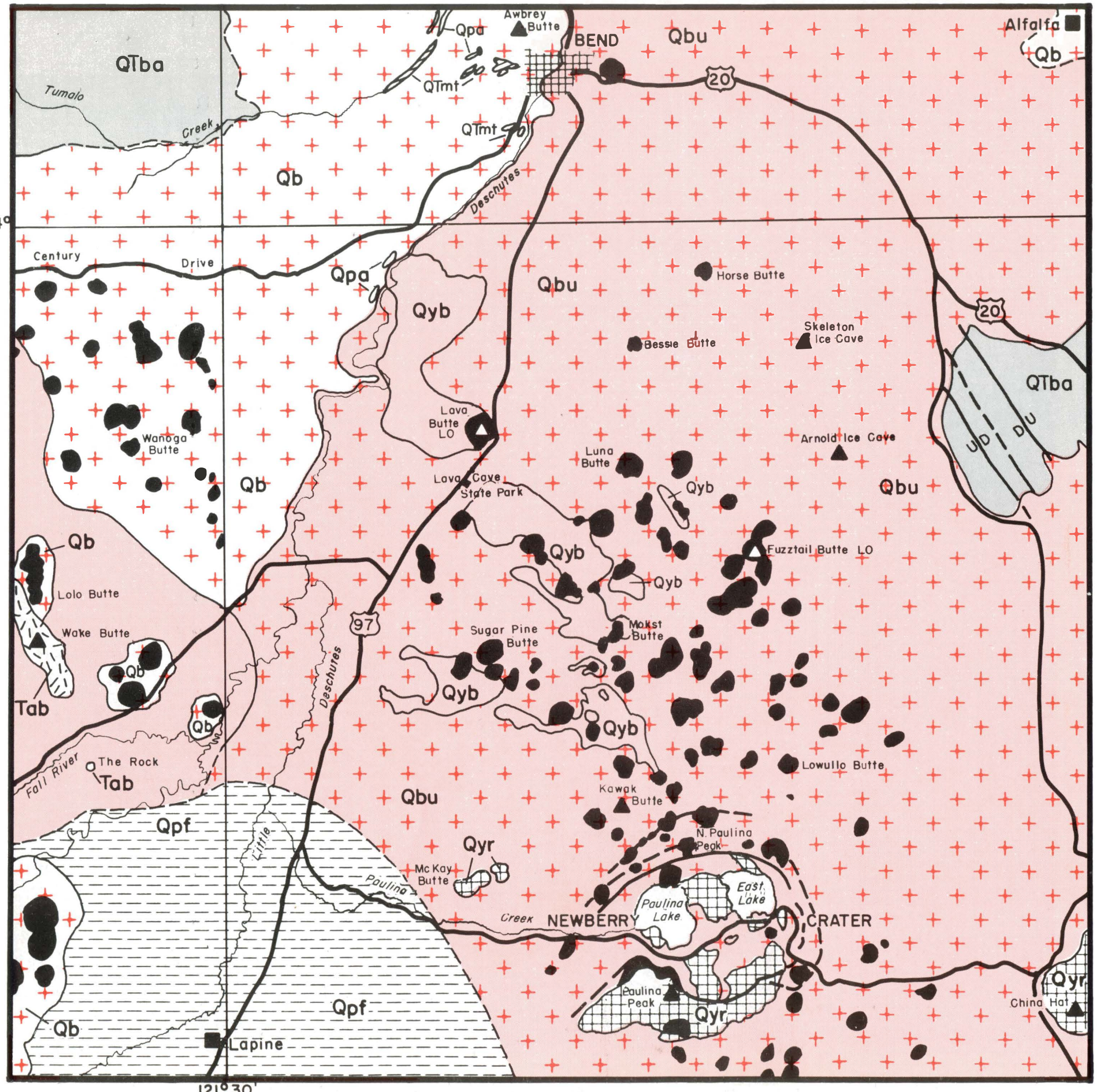
There are four separate, steep-sided flows of glistening, black obsidian. The "Big Obsidian Flow" (fig.10) covers a square mile and has its own plug dome of pumiceous obsidian. Two smaller obsidian flows south of East Lake (fig. 11) straddle a northeast-trending fissure from which they were erupted, and the "between the lakes flow" erupted from a vent on the caldera north wall and flowed both east and west. Finally, there is the interesting "Fissure" (fig. 12), exposed for some 700 feet (210 m) on the caldera wall near the northwest corner of East Lake. This fissure, bordered by red and black basaltic scoria, is a vent where both basalt and rhyolite eruptions occurred at nearly the same time (Williams, 1935).

N. V. Peterson
Editor

TOPOGRAPHIC MAP OF THE NEWBERRY VOLCANIC AREA FIELD TRIP.



GEOLOGIC MAP OF THE NEWBERRY VOLCANIC AREA FIELD TRIP.



Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

EXPLANATION

Recent

Qpa / Qpf

Qpa: Dacite pumice — glowing avalanche deposits
Qpf: Dacite pumice — pumice fall

Qcc

Basaltic cinder cones

Qyr

Pumice cones inside Newberry caldera; obsidian flows and domes of the Newberry Crater quadrangle

Qyb

Youngest basaltic lavas, unglaciated

Pleistocene to Recent

Qbu

Undifferentiated lavas, includes older rhyolites in lower caldera wall, in Newberry Crater quadrangle, and most of basaltic flows on flanks of the Newberry Volcano

Qb

Basalt, basaltic andesite lavas and cinder cones

Pliocene and Pleistocene

QTmt

Madras formation

QTmt: Interbedded dacite welded tuff

QTba

Olivine basalt and basaltic andesite, glaciated lavas of the main volcanoes of the High Cascades. Overlain by pumice near Crater Lake.

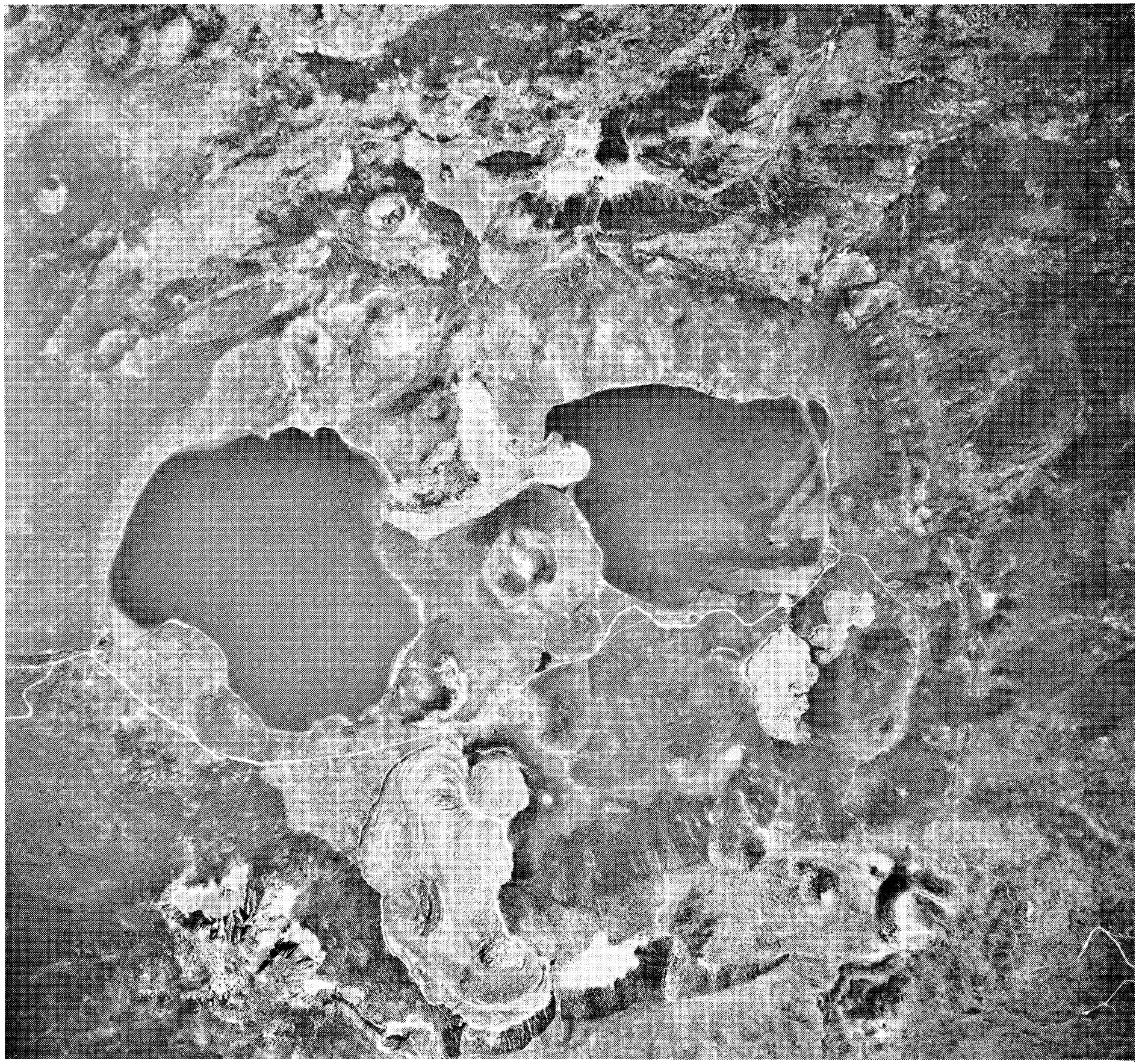
Eocene to Miocene

Tab

Well-bedded basaltic tuffs in Maiden Peak quadrangle; also pre-Newberry basalt and andesite of Newberry Crater quadrangle and rocks bordering Metolius River in Mount Jefferson quadrangle. Pre-pliocene, exact age unknown.

Statute Miles
5 0 5

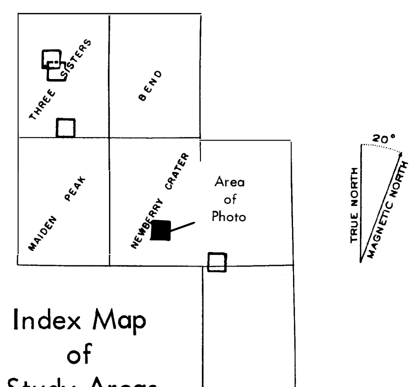
Kilometers
5 0 5 10



AERIAL PHOTOGRAPH OF THE NEWBERRY CRATER STUDY AREA

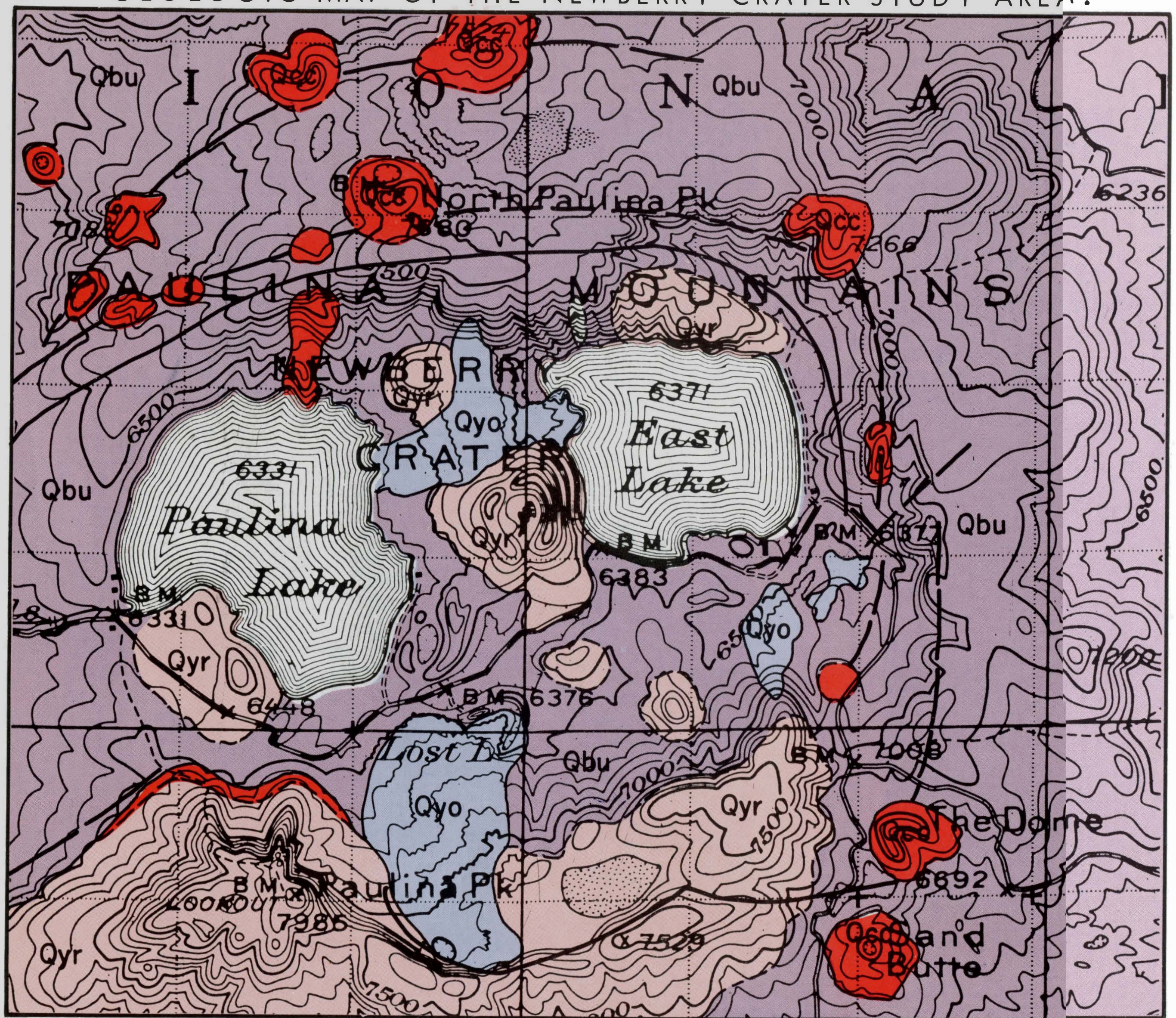
Aerial view of the summit caldera of Newberry Volcano from about 27,000 feet (8200 m). The facing geologic map has approximately the same scale as this photo. The highest and lowest points of the crater are at the lower left. Paulina Peak, the highest, is just to the left of the "Big Obsidian Flow," and Paulina Creek on the northwest side of Paulina Lake is the lowest and drains the lake where erosion has breached the low west rim. The broad eruptive zone that trends northwestward between the lakes is particularly notable as well as the central pumice cone. The concentric faults bounded by mounds of cinders and scoria are most apparent on the east rim. Also just south of East Lake note the later offsetting fault straddled by two exogenous domes of gray-black obsidian.

Roll 28, Exposure 3194, Western U.S. Project 109F.



Index Map of Study Areas

GEOLOGIC MAP OF THE NEWBERRY CRATER STUDY AREA.



Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

1 ½ 0 1 MILE

1 .5 0 1 KILOMETER

Contour interval 100 feet

Datum is mean sea level

EXPLANATION

Recent

Qyo — Youngest obsidian flows and domes

Qcc — Basaltic cinder cones

Qyr — Pumice cones inside Newberry caldera; rhyolite of the Newberry Crater quadrangle

Pleistocene to Recent

Qbu — Undifferentiated lavas, includes older rhyolites in lower caldera wall, in Newberry Crater quadrangle, and most of basaltic flows on flanks of the Newberry Volcano

Formation contacts (Dashed where inferred)

Faults

20°
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1959

ROAD CLASSIFICATION

Medium-duty Light-duty

Unimproved dirt

Figure 7. Pumice Cone. This feature, seen from the north, is the central peak in Newberry Crater. The notched crater has a floor of obsidian which was extruded in the final stage of activity. Bread-crust bombs and large lumps of pumice compose the lower flanks.

Figure 8. A maar located on the southeast shore of Paulina Lake. Thin layers of tan palagonite tuff breccias dip outward from the bowl-shaped crater. Erosion has caused little modification of this explosively erupted landform.

Figure 9. The Red Slide. Eruptions of reddish scoria and cinders formed a cone on the caldera wall north of Paulina Lake. The cone is breached on the side facing the lake.

Figure 10. Big Obsidian Flow looking to the south. Patches of snow tend to accentuate the flow ridges and show the direction of flow. A plug dome exists over the vent. At the lower left, a tongue of the flow extends into the crater of an older pumice cone. Parasitic cinder cones lying on the outer slope of Newberry Volcano are seen in the upper part of the photograph.

Figure 11. The East Lake obsidian flows looking to the west. These flows erupted along a fissure trending in a southwest direction and are composed of block obsidian mixed with pumiceous material. Obsidian spines have been protruded at some of the vents.

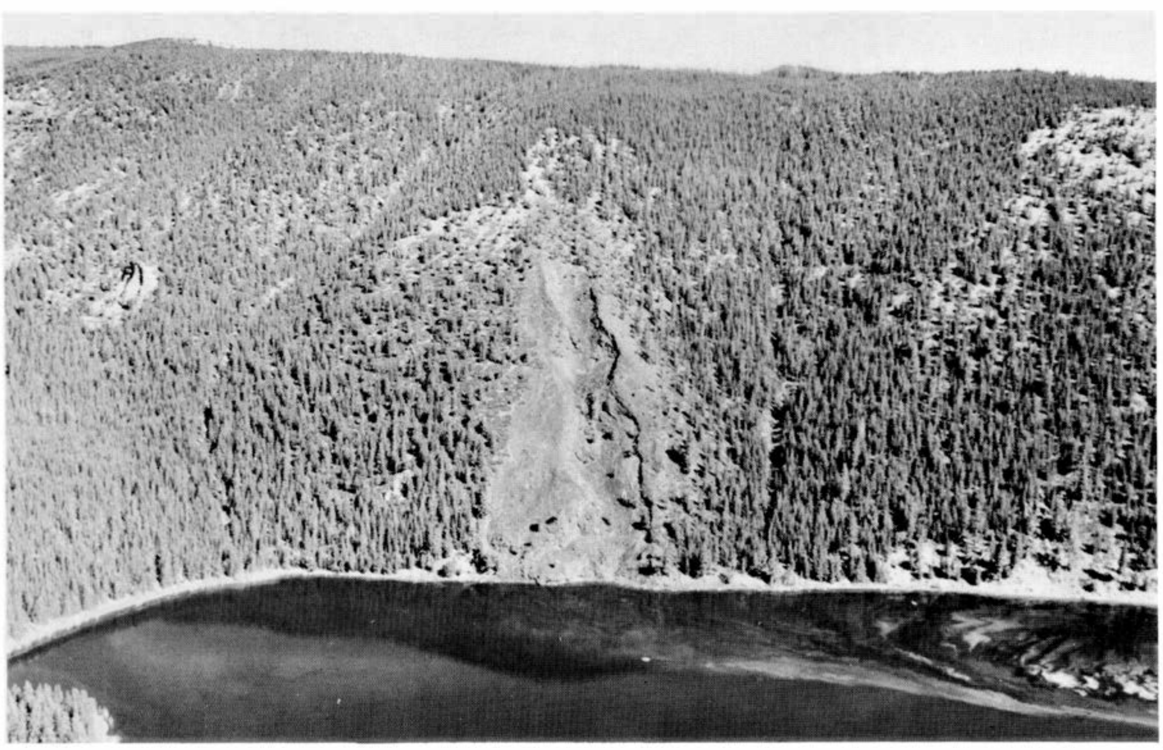
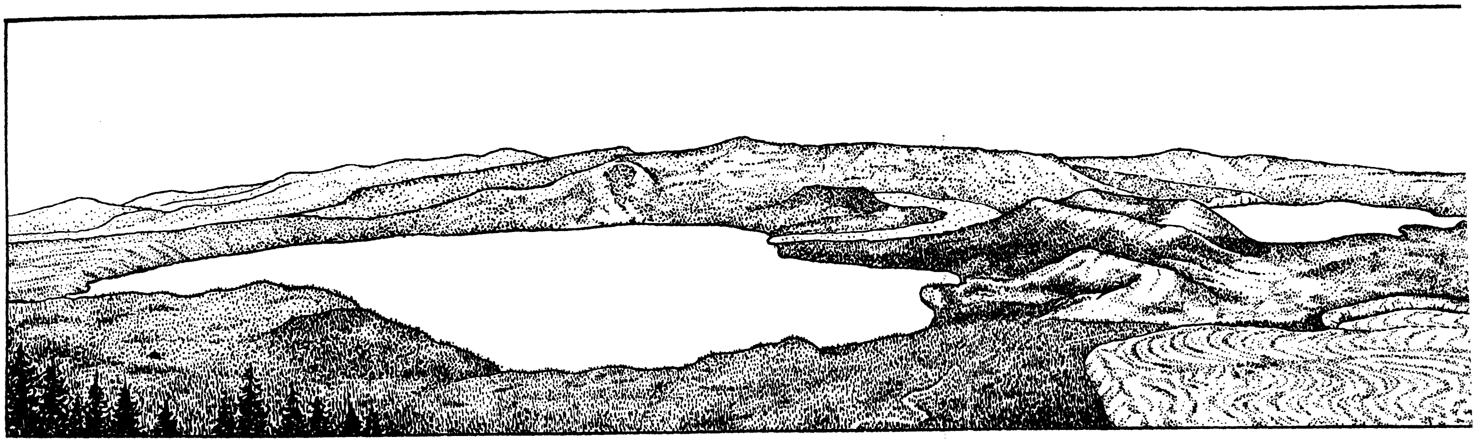
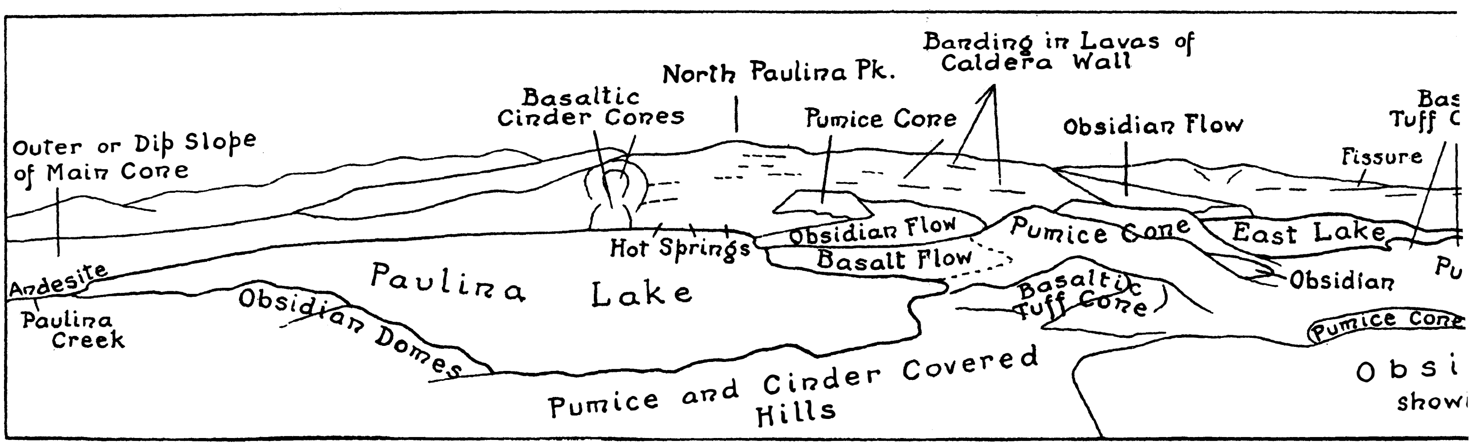


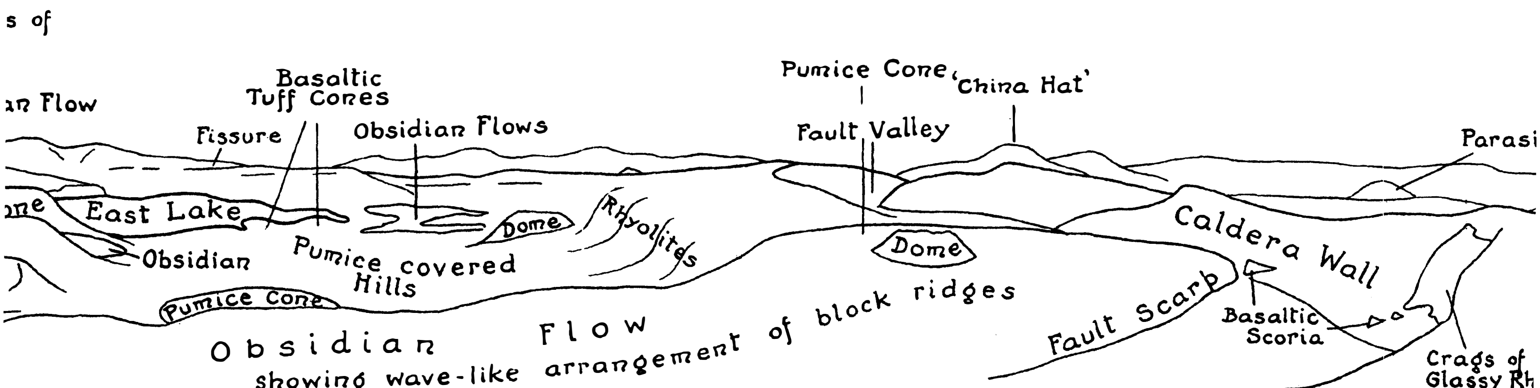
Figure 12. The Fissure, located on the north wall of Newberry Crater. Red and black scoria and cinders, some mixed with obsidian, flank this eruptive fissure that extends from the level of East Lake to a height of about 700 feet (214 m). This fissure is part of the Northwest Rift Zone of Newberry Volcano.

Figure 13. PANORAMIC SKETCH OF NEWBERRY CA

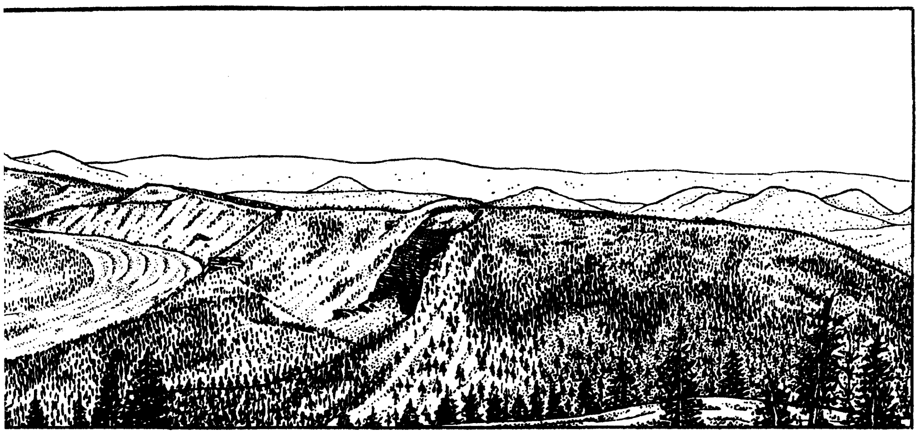


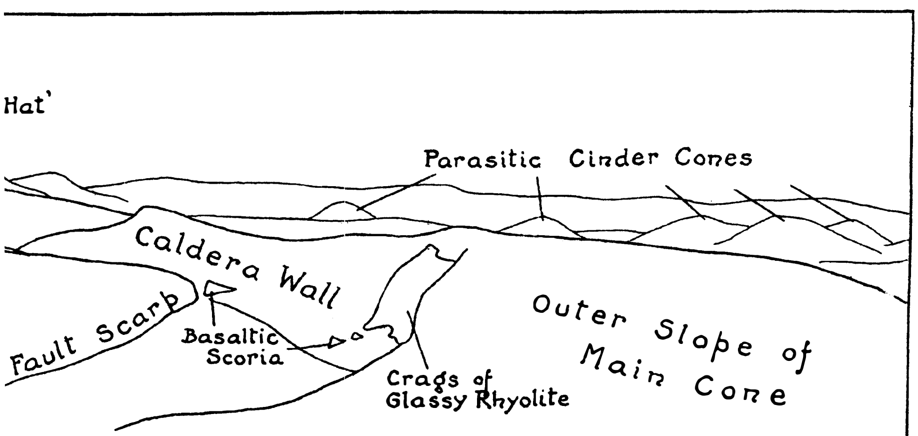


SKETCH OF NEWBERRY CALDERA, FROM PAULINA PEAK ON SOUTH RIM (WILLIAMS, 1935)



35)




Hat'
Parasitic Cinder Cones
Caldera Wall
Fault Scarp
Basaltic Scoria
Crags of Glassy Rhyolite
Outer Slope of Main Cone

Hole-in-the-Ground—Fort Rock—Devils Garden Area Field Trip

Geologic Summary

Hole-in-the-Ground, Fort Rock, and the Devils Garden are volcanic landforms near the center of the High Lava Plains of central Oregon, roughly 50 miles (80 km) southeast of Bend.

The High Lava Plains form a hummocky, undulating upland region underlain by a thick section of Cenozoic volcanic rocks. Most of the surface shows little or no erosion. The few established drainages empty into broad, shallow basins that have no outlets. It is an area of relatively low relief that merges southward into the Basin and Range topography where prominent fault scarps, tilted mountain blocks, and intervening graben valleys are so characteristic. The predominant northwest trend of the faults of the Basin and Range continues into the High Lava Plains, and along these weakened zones are the vents and rifts that erupted the enormous amounts of fluid basalt that mantled the surface.

The oldest rocks exposed are Pliocene andesites, dacites, and glassy rhyolites that piled up around their vents to form steep-sided, dome-shaped masses. Eroded remnants of these still project above the surrounding basaltic lavas in Pine Mountain, Cougar Mountain, and Hogback Butte. Accompanying explosive eruptions showered pumice and ash into lakes that intermittently filled the basins. Also, as diatoms thrived and died in the silica-rich waters, layers of ashy diatomite were deposited in the lakes.

Basaltic eruptions predominated at the close of the Pliocene, continued into the Pleistocene, and finally waned in Recent time. Low basaltic domes and numerous cinder cones, their summit craters now breached or filled, mark the widespread vents where basaltic lavas rose and flowed out. Where a vent was situated within or near one of the shallow lakes, magma nearing the surface and encountering large amounts of water burst into steam and violent, closely spaced explosions of comminuted rock that shot high into the air. This material dropped back to form maars with broad, shallow craters and low rims of laminated palagonite tuffs and tuff breccia. Some of the more prominent maars or remnants of them are Hole-in-the-Ground (figs. 14 and 15), Fort Rock (fig. 16), Flat Top (fig. 17), and Table Mountain.

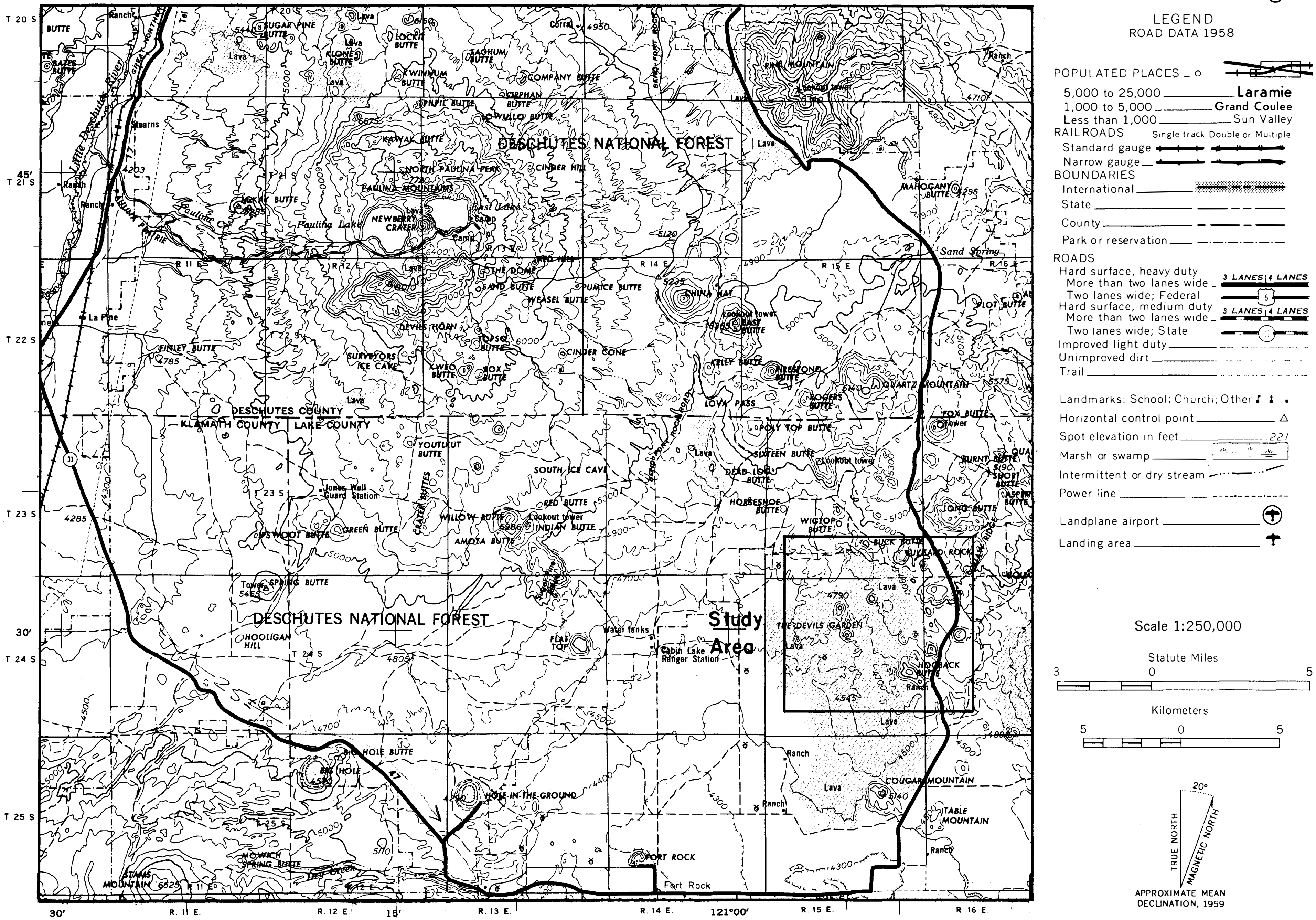
Perhaps the most interesting and spectacular volcanic features are those that emerged in pre-historic Recent time, as fluid black lava erupted from numerous vents in the area. The largest is the Devils Garden lava field, where about 45 square miles (117 km^2) has been covered by thin flows of pahoehoe lava. For the student of lava-flow features the Devils Garden is rich in excellent examples.

The lava originated from fissure vents in the north and northeast part of the Devils Garden and spread to the south and southwest. Several rounded hills and slightly higher areas of older rocks are now "kipukas" completely surrounded by the fresh black lava. The eruptions were of the quiet type, with only moderate fire fountaining at the two vents from which all the lava flowed. Figure 18 shows the main vent bordered by low spatter ramparts. From here there was flowage northwest through a narrow, open lava gutter and also to the south, where the lava was distributed through a large, sinuous, well-developed lava tube, Derrick Cave. This part of the fissure is marked by a row of small spatter cones that extend to the southeast (fig. 19). About a mile south the eruptive fissure is marked by another row of spatter cones, two of which, "The Blowouts" (fig. 20), are exceptionally large. The pahoehoe surfaces are pockmarked by depressions of various sizes and shapes caused by collapse as fluid lava drained from beneath a hardening crust (figs. 21 and 22). Most of the upper surfaces of the jumbled slabs and sheets of lava display the typical ropy, wrinkled crusts. Where resistance to the further spreading of the lava was too great, the crust swelled upward into low rounded, cracked-open domes or tumuli.

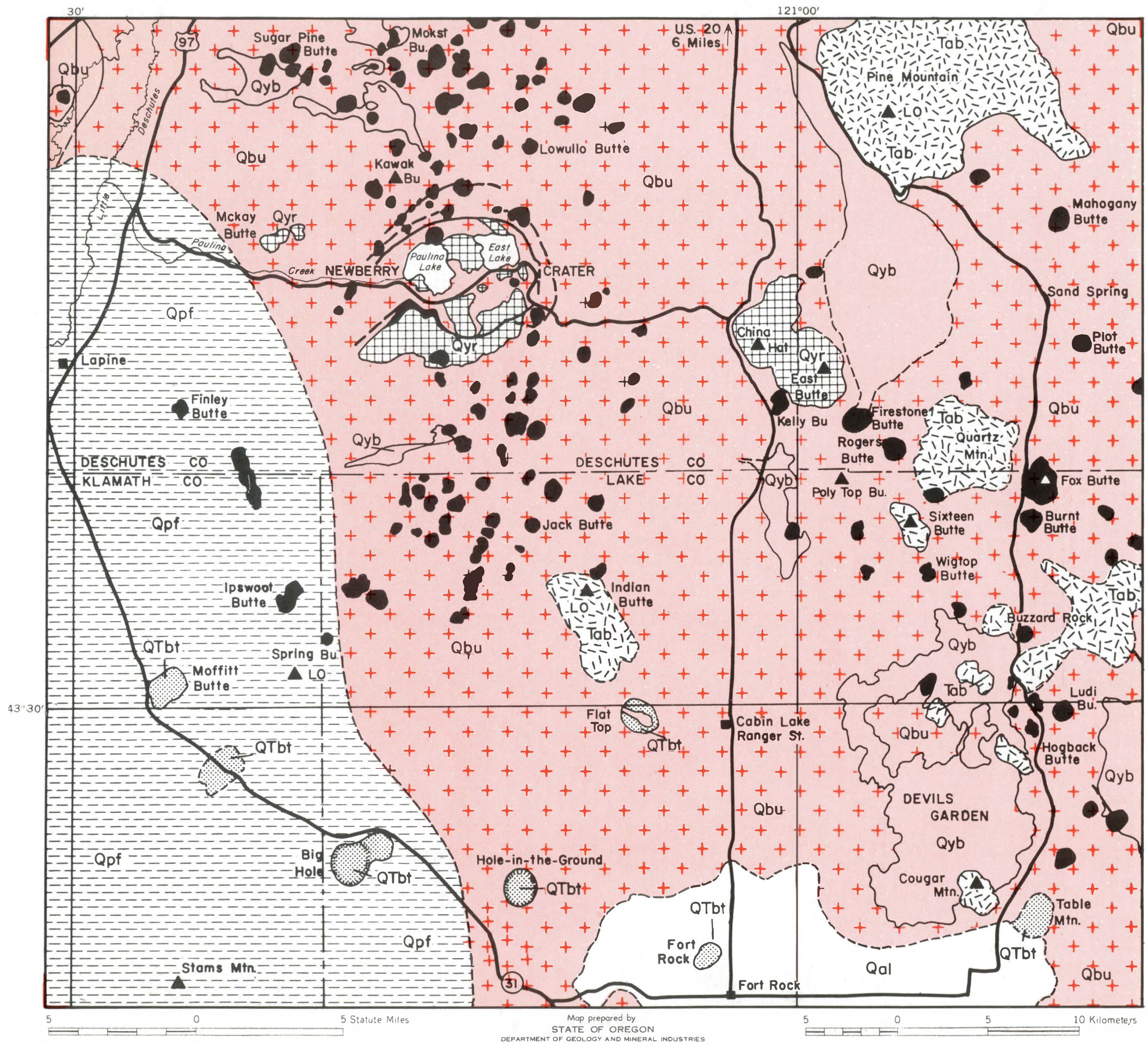
The age of the Devils Garden flows can only be conjectured. Apparent freshness of the spatter cones and lava surfaces is deceitful. Telltale ashy soil and pumice fragments indicate a date prior to Mount Mazama's cataclysmic eruptions some 6,600 years ago. North of the Devils Garden much of the slightly older lava surface has been blanketed by pumice showered from explosive eruptions of Mazama and Newberry volcanoes. Shallow depressions and level areas like Sand Flat (fig. 23) have accumulated thicker deposits of pumice lapilli, and a vegetative cover has not yet been established.

N. V. Peterson
Editor

TOPOGRAPHIC MAP OF THE HOLE-IN-THE-GROUND, FORT ROCK, DEVILS GARDEN FIELD TRIP.



GEOLOGIC MAP OF THE HOLE-IN-THE-GROUND, FORT ROCK, DEVILS GARDEN FIELD TRIP.



EXPLANATION

Recent

Qal — Alluvium

Qpf — Dacite pumice - pumice fall

Qcc — Basaltic Cinder Cones

Qyr — Pumice cones inside Newberry caldera; obsidian flows and domes of the Newberry Crater quadrangle.

Qyb — Youngest basaltic lavas, unglaciated

Pleistocene to Recent

Qbu — Undifferentiated lavas, includes older rhyolites in lower caldera wall, in Newberry Crater quadrangle, and most of basaltic flows on flanks of Newberry Volcano.

Pliocene to Recent

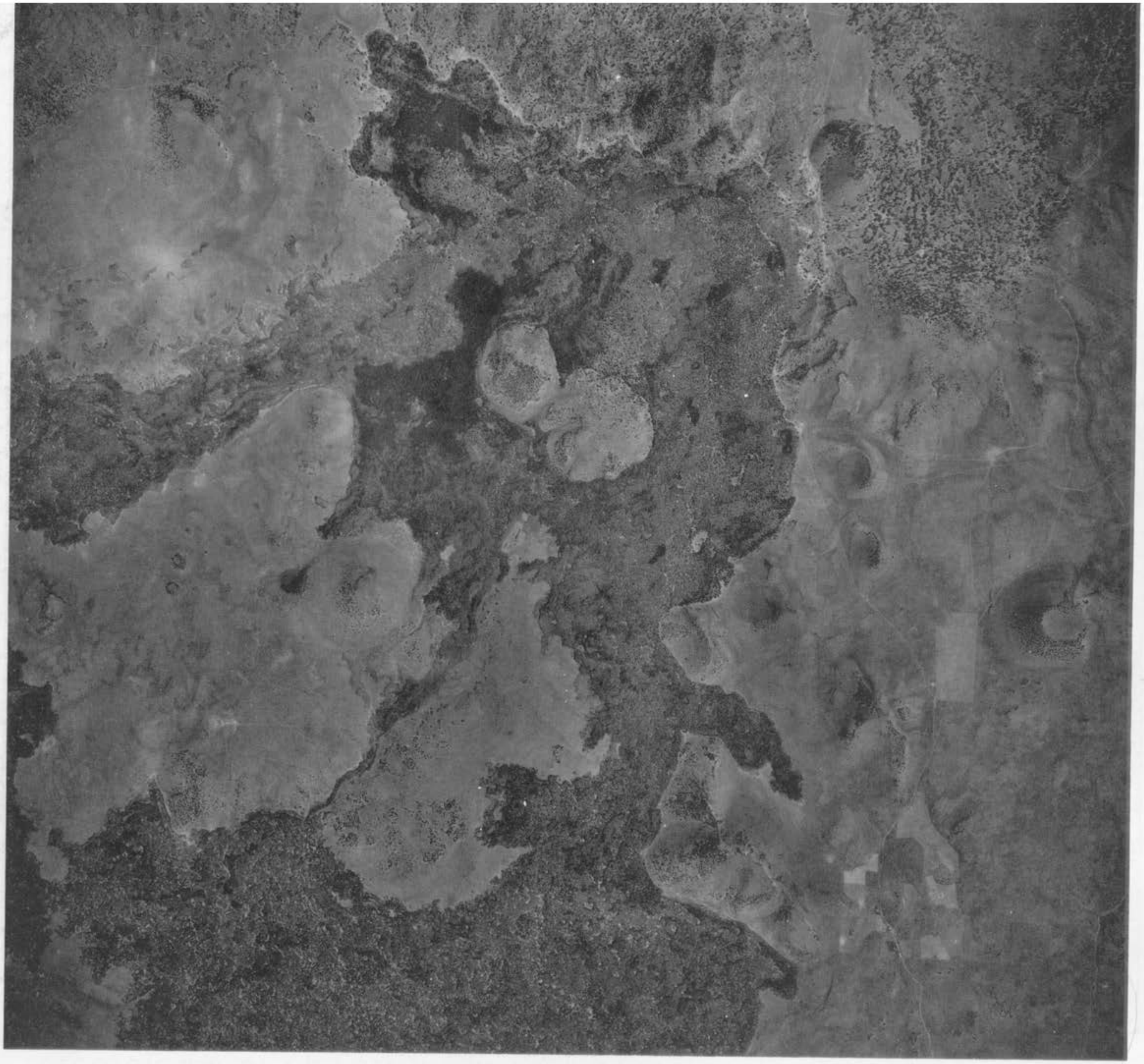
QTbt — Basaltic (palagonite) tuffs tuff rings and maars

Mio-Pliocene

Tab — Pre-Newberry basalt and andesite of Newberry Crater quadrangle, includes rhyolite domes and flows of uncertain age of High Lava Plains - pre-Pliocene, exact age unknown.

Formation contacts dashed where inferred

Faults

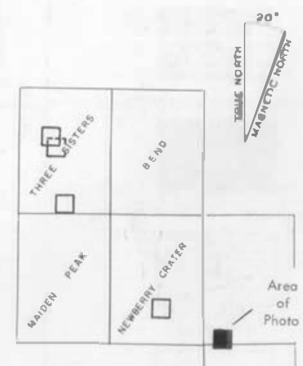


AERIAL PHOTOGRAPH OF THE DEVILS GARDEN LAVA FIELD STUDY AREA

Aerial view of the northern part of the Devils Garden lava field from around 27,000 feet (8200 m). The scale of the photograph and the facing geologic map are approximately the same.

The two main vents can be seen at the extreme east edge of the fresh block lava. The northernmost Devils Garden vent is bounded by low ridges of spatter and cinders; the vent to the south is marked by two closely spaced spatter cones, locally called "The Blowouts." To the east of the Devils Garden, partially eroded cinder cones project above the surrounding basalt. The largest, Ludi Butte, is the source of a flow of block lava that can be discerned beneath the soil and vegetative cover. Hogback Butte, an eroded ridge of Pliocene (?) andesite, lower right, has been surrounded on three sides by the Devils Garden flows.

Roll 28, Exposure 3224, Western U.S. Project 109F.



Index Map of Study Areas

GEOLOGIC MAP OF THE DEVILS GARDEN LAVA FIELD STUDY AREA.

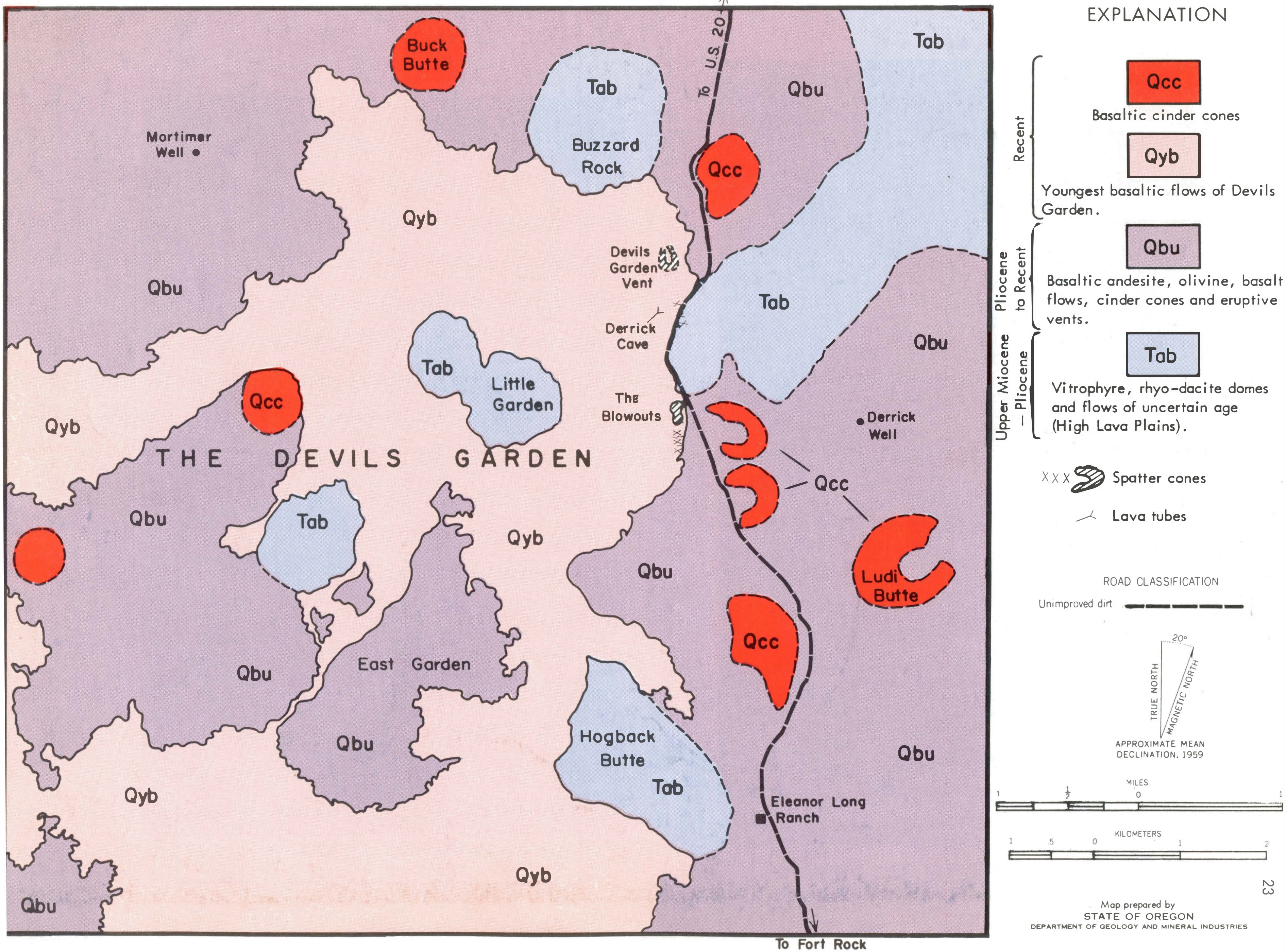


Figure 14. Hole-in-the-Ground, a late Pleistocene maar, viewed from the south. This crater is nearly a mile (1.6 km) in diameter and the highest point on the east rim is 500 feet (153 m) above the crater floor. Basalt flows exposed in the far wall underlie the explosion tuff breccias as shown in the geologic cross-section below (fig. 15).

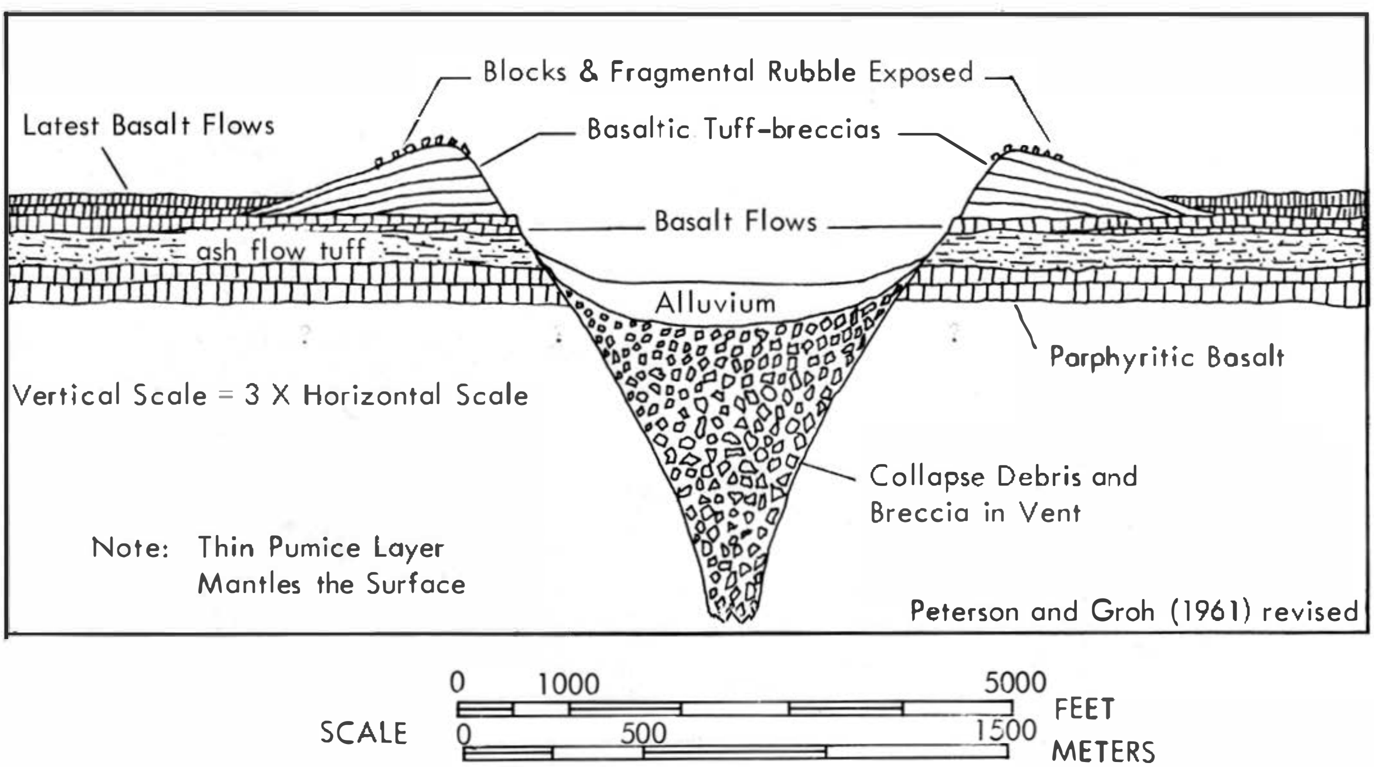


Figure 15. Generalized Geologic Cross Section of the Hole-in-the-Ground.

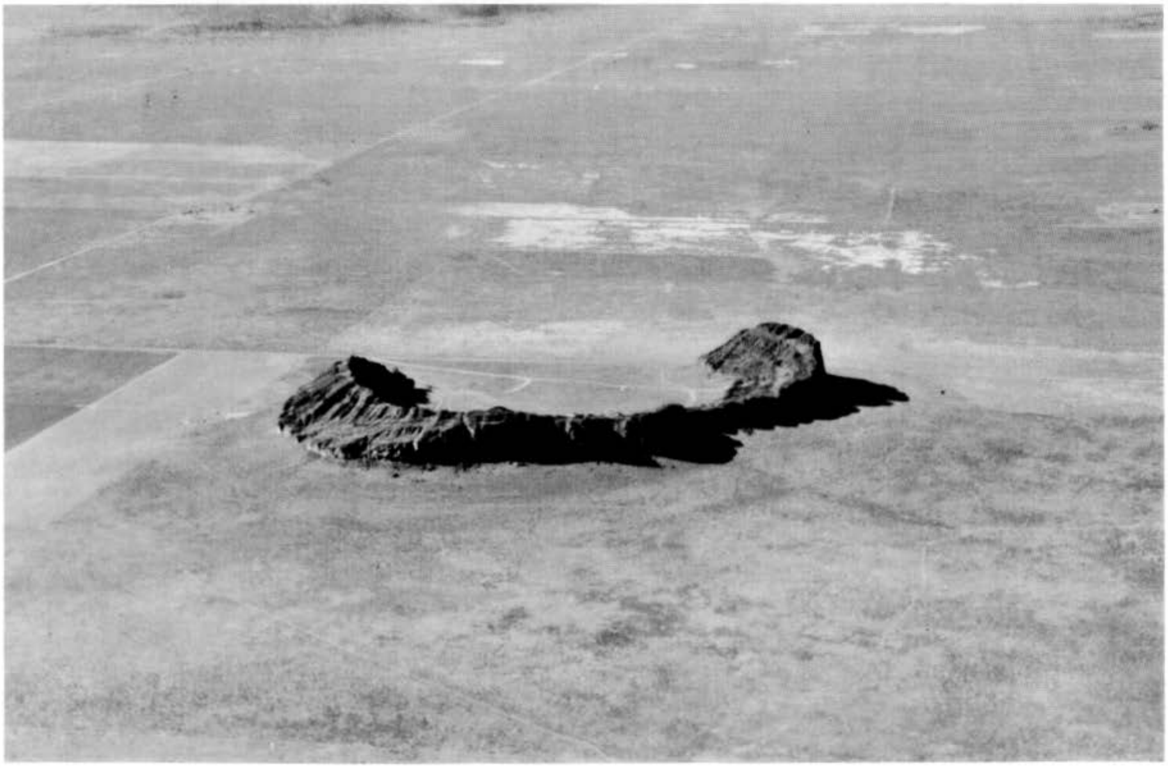


Figure 16. Fort Rock, looking south. Erosional remnants of the rims of a large tuff ring that once projected as an island above ancient Fort Rock Lake. The steep wave-cut cliffs of Fort Rock display the initial dips of thin layers of palagonite tuff that accumulated when exploded debris settled around a broad crater.

Figure 17. Flat Top, a rounded lava-capped mesa. This is the remains of a large tuff ring, composed of inward-dipping, thin layers of yellow-brown palagonite tuffs and breccias. After the tuff ring was built, lava welled up inside to form a molten lake, which overflowed the northwest rim.

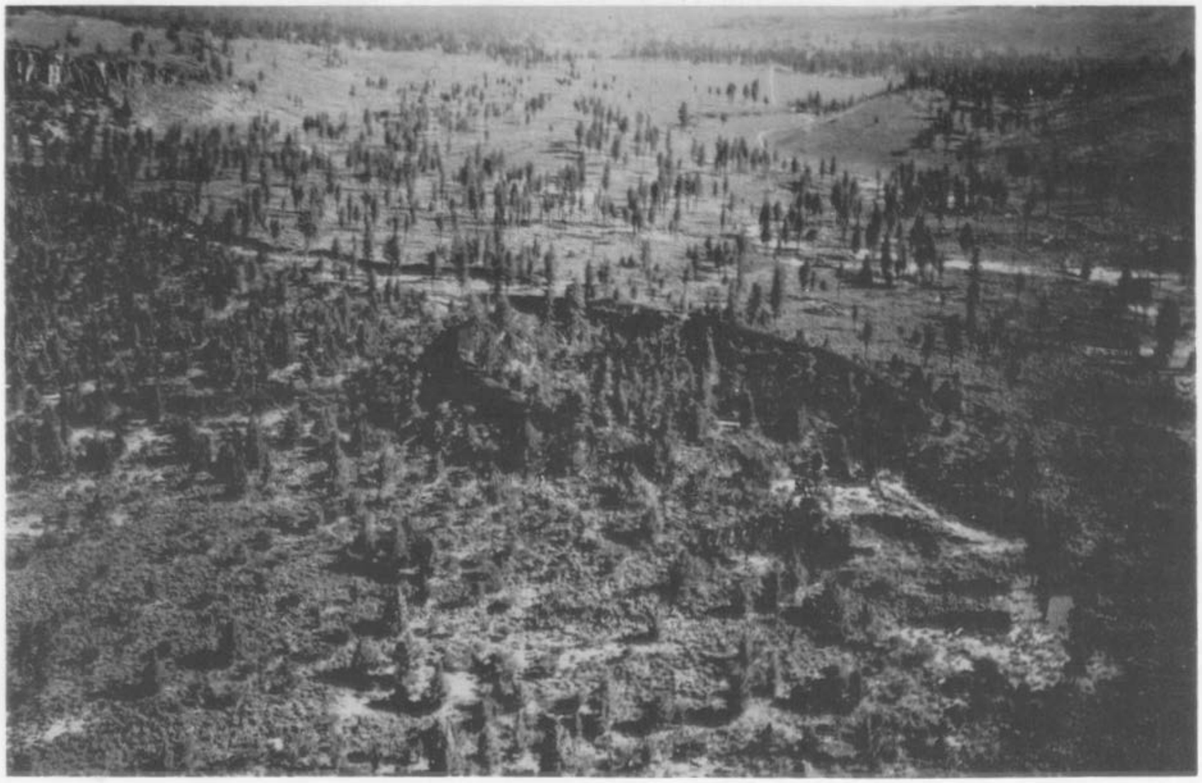


Figure 18. Main vent of Devils Garden, looking north, from 1,000 feet (305 m) above. The channel or gutter through which the lava flowed to the northwest can be seen in the upper left. A stream of lava also flowed to the south through a well-developed lava tube.

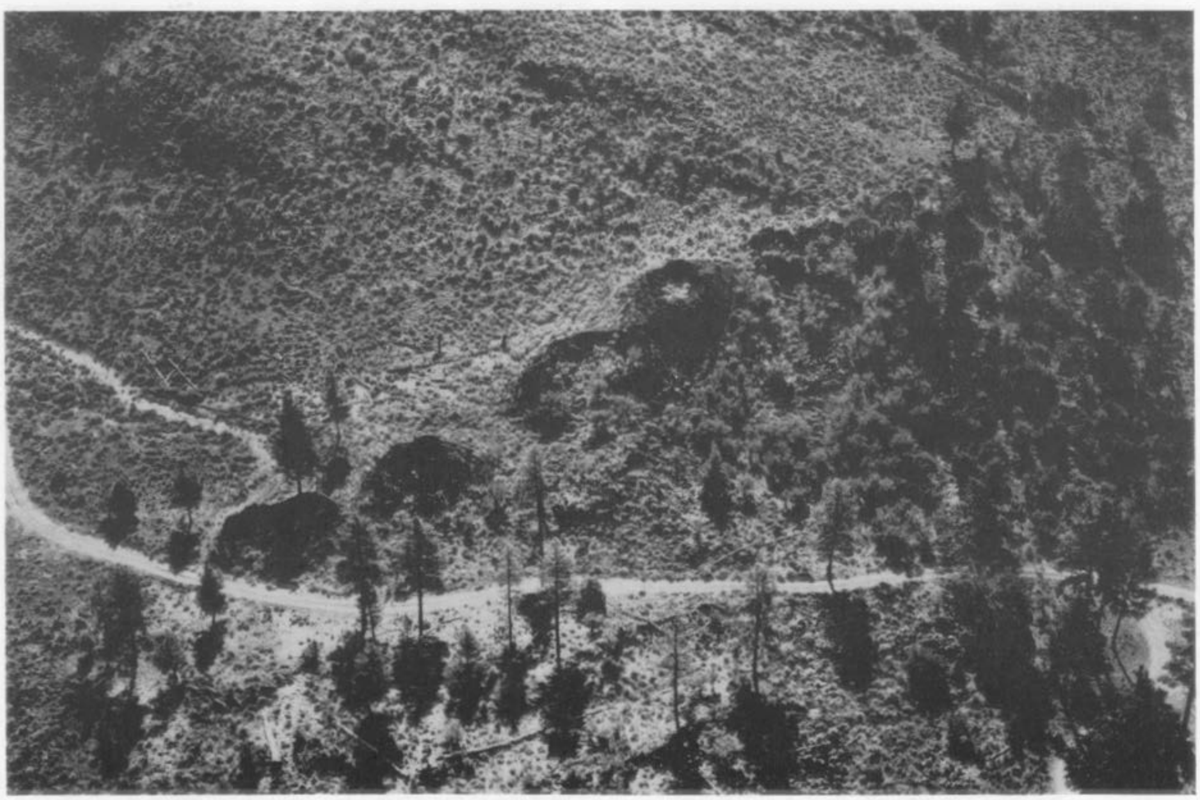


Figure 19. Row of spatter cones at the eastern edge of the Devils Garden. Here eruptive activity weakened and died out to the southeast at upper right. These hollow cones of reddish agglutinate range in size from a few feet in diameter to as much as 30 feet (10 m) in diameter.

Figure 20. Bird's-eye view of "The Blowouts" from the south. Note the row of smaller spotter cones extending to the south. The north blowout is about 400 feet (122 m) in diameter and 150 (46 m) feet high, and the south one is only slightly smaller. Banks of the gutter where lava flowed can be seen just to the west of "The Blowouts."

Figure 21. Pahoehoe lava surface of the Devils Garden lava field viewed from an altitude of about 1,000 feet (305 m). Numerous collapse depressions are evident. A light coating of ash and wind-blown soil is present within irregularities on the lava surface.

Figure 22. View of the pahoehoe lava surface of the Devils Garden lava field from 1,000 feet (305m) altitude. Collapse depressions of many sizes and shapes show the sinuous nature of the subcrustal distributary channels. Note the abundance of small, almost circular, depressions.

Figure 23. Sand Flat, a barren area about 20 miles (32 km) east of Newberry Volcano, where popcorn-size pumice lapilli have accumulated to a considerable thickness. The source has not been determined, but it may have been Newberry Volcano, whose broad shield can be seen in the background.

Belknap Crater—Yapoah Crater—Collier Cone Area Field Trip

Geologic Summary

Along U.S. Highway 20 northwest of Bend the underlying rock is predominantly Quaternary basalt that erupted from various vents at the foot of the Cascade Range. Pumiceous tuffs and ash-flow tuffs exposed in the vicinity of the Deschutes River may be late Pliocene in age. From the junction at Sisters, the route follows the McKenzie Highway westward on a gradual climb to the crest of the Cascade Range. At this point is Dee Wright Observatory from which a panorama of lava fields and peaks can be seen. With the aid of maps and photographs the features of the study area are presented.

North Sister is the oldest volcano of the Three Sisters and, according to Williams (1944), it began with the growth of a large shield composed of olivine basalt and basaltic andesite which rests on a pre-Pliocene volcanic basement. This stage of development was followed by the eruption of pyroclastic rocks and some flows which built the summit cone. The volcano Little Brother, a parasitic cone on the western slope of North Sister, is a small replica of its host. Mt. Washington to the north formed in a manner similar to North Sister. All have been deeply eroded by glaciation, exposing dikes and central plugs which were the eruptive feeders.

Middle Sister is younger than North Sister and has been less modified by glacial action. The composition of its summit cone is more like that of South Sister, described in a previous section of this publication. Obsidian Cliffs, a large flow of glassy dacite, lies on the western flank of Middle Sister.

Black Crater was formed mainly from flows of basic lavas, which were glacially modified, but volcanic activity continued into post-glacial time and built a pile of cinders and agglomerate over the vent. More recently, two cinder cones have erupted, one on the northeast flank and the other, Millican Crater, at the southern base.

Within the study area there are a number of cinder cones, such as Sims Butte and Twin Craters, that are of recent origin; but attention is drawn to the latest volcanic features. These are the immense, barren lava fields of Belknap Crater and Little Belknap (aerial photograph on page 32) and the cones and lavas of Yapoah Crater, Four-in-One Cone, and Collier Cone (aerial photograph on page 34).

Between the opposing slopes of North Sister and Mount Washington, out-pouring of basalt formed a shield volcano now the site of Belknap Crater. Parasitic cinder cones erupted about its flanks, but later flows buried most of these cones, leaving only a few kipukas (islands) surrounded by lava. Two kipukas can be seen northwest of Dee Wright Observatory. Pyroclastic eruptions occurred also at the summit of the shield, building a large, double-cratered cinder cone, and lavas were extruded from the base (fig. 24). Most of the lavas were erupted as pahoehoe flows, but, because of the steep gradient, the hardened crust was continually broken up during flowage. Large slabs were overturned, upended, sheared, and piled. This disarray was compounded by collapse of the crust as fluid lava drained from beneath it.

Little Belknap, a parasitic eruption, lies on the eastern flank of Belknap Crater. Copious amounts of basaltic lava were extruded from a single vent as pahoehoe flows, which were broken to form a chaotic surface like that described above. The vent is now plugged by a dome of blocky lava reddened by fumarolic action (fig. 25). An unusual feature at the summit is a small feeder conduit, roofed over by spatter, which connects directly with a lava tube and probably is the last extrusion on Little Belknap.

On the north flank of the North Sister are typical cinder cones, Yapoah Crater and Collier Cone, of very recent age. Basaltic lava flowed to the west from the base of Collier Cone and consequently breached the cone (fig. 26). This aa flow shows an excellent example of lava levees which confined a river of molten lava. A second flow or branch proceeded part way along the north side of the earlier flow. A large area strewn by cinders lies to the east of Collier Cone and is named the "Ahalapam Cinder Field." Most of these pyroclastics were produced by the explosive activity at Collier Cone, although Williams (1944, p. 55) believes that hidden fissure vents contributed some of the ejecta.

Yapoah Crater (fig. 27) is notable for the thick, coarse aa flow which ran north to Little Belknap and then turned east to travel more than 4 miles (6.4 km). Dee Wright Observatory is situated just to the west of the main channel of this flow. A later, branched aa flow ran northward from Yapoah but its course was west of the earlier flow.

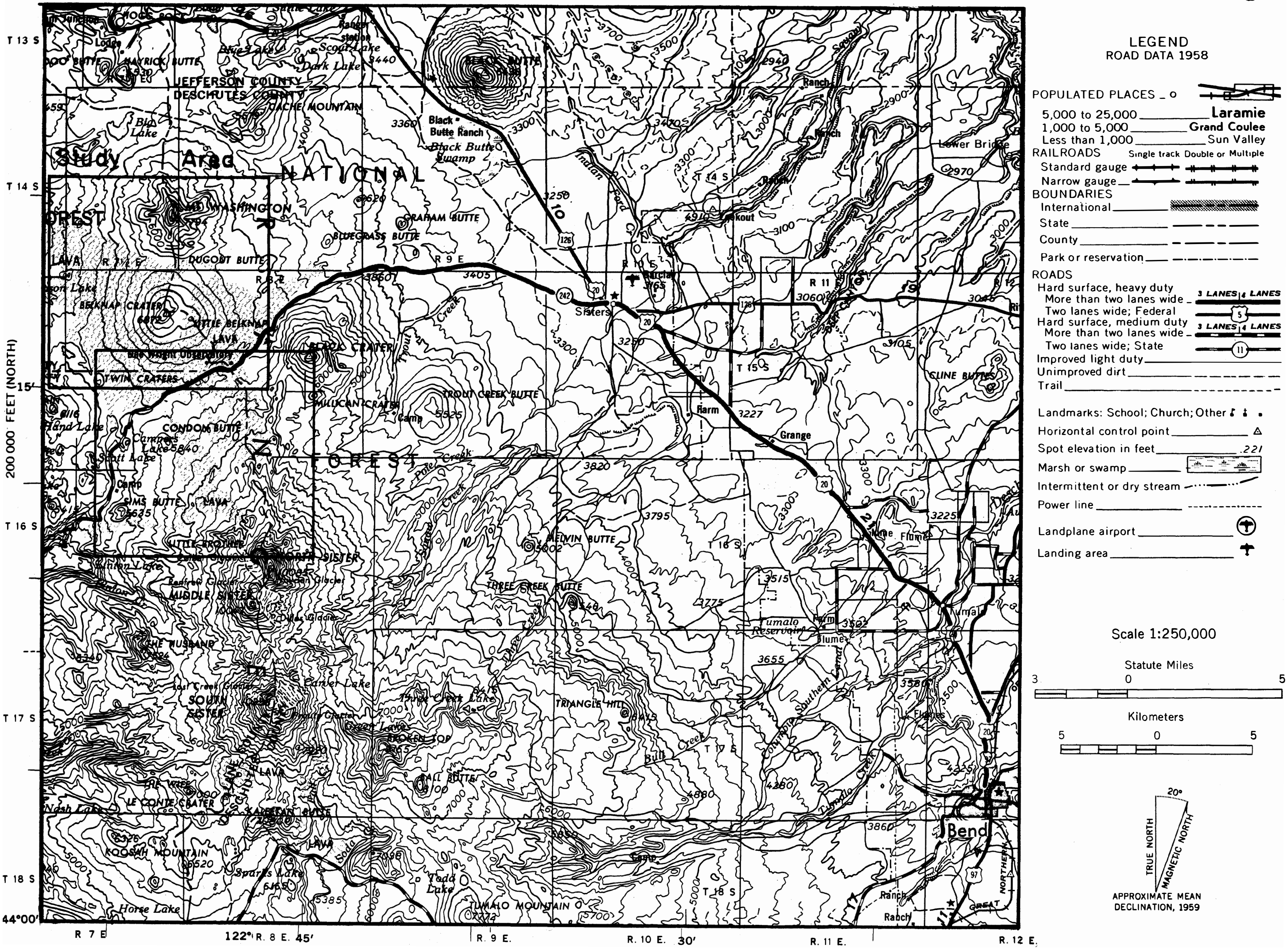
Four-in-One Cone is unique in that four closely spaced eruptive centers along a fissure [illegible] cinders to form a feature consisting of four cinder cones coalesced into one elongated, scalloped ridge. Lava flowing simultaneously from the quadruple vents breached their western sides.

Benson (1964) indirectly dates a flow from Sand Mountain, which lies northwest of the study area, at about 3,000 y.B.P. From contact relationships he has determined that the Belknap and Little Belknap flows are younger and, in turn, the Yapoah, Four-in-One, and Collier lavas are the youngest in this region. Figure 28 shows the Yapoah flow and Little Belknap flows in contact.

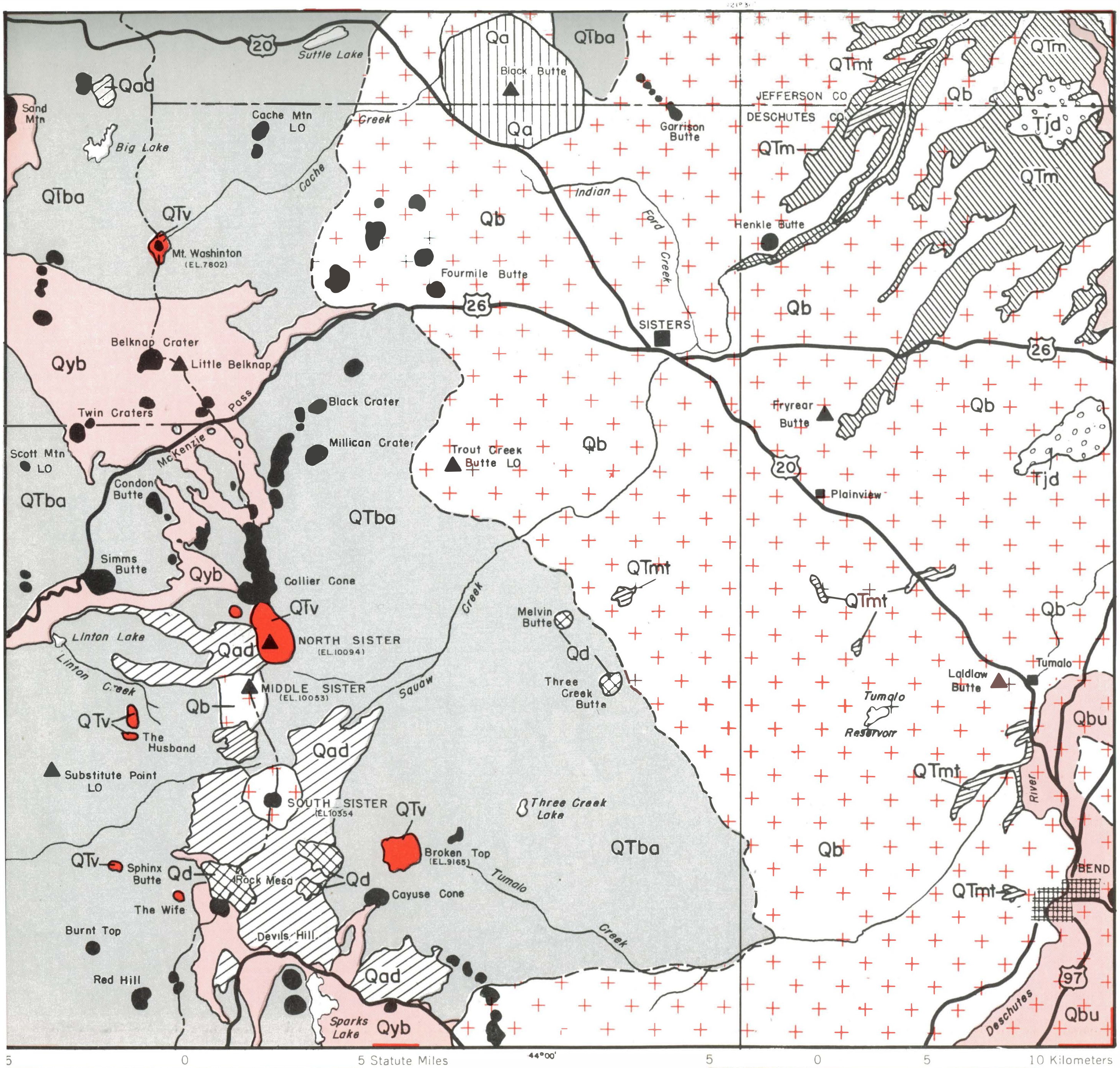
Along the return route between Tumalo and Bend, exposures of ash-flow tuff are numerous. Similar material crops out in several abandoned pumice quarries near Bend (fig. 29).

E. A. Groh, Editor

TOPOGRAPHIC MAP OF THE BELKNAP CRATER, YAPOAH CRATER, COLLIER CONE FIELD TRIP.



GEOLOGIC MAP OF THE BELKNAP CRATER, YAPOAH CRATER, COLLIER CONE FIELD TRIP.



EXPLANATION

Recent

Qd — Domes and flows of dacite obsidian

Qa — Pyroxene andesite

Qcc — Basaltic cinder cones

Qyb — Youngest basaltic lavas, unglaciated

Qbu — Undifferentiated lavas, includes older rhyolites in lower caldera wall, in Newberry Crater quadrangle, and most of basaltic flows on flanks of the Newberry Volcano

Pleistocene to Recent

Qb — Basalt, basaltic andesite lavas and cinder cones

Pleistocene

Qad — Glaciated andesite and dacite lavas

Pliocene and Pleistocene

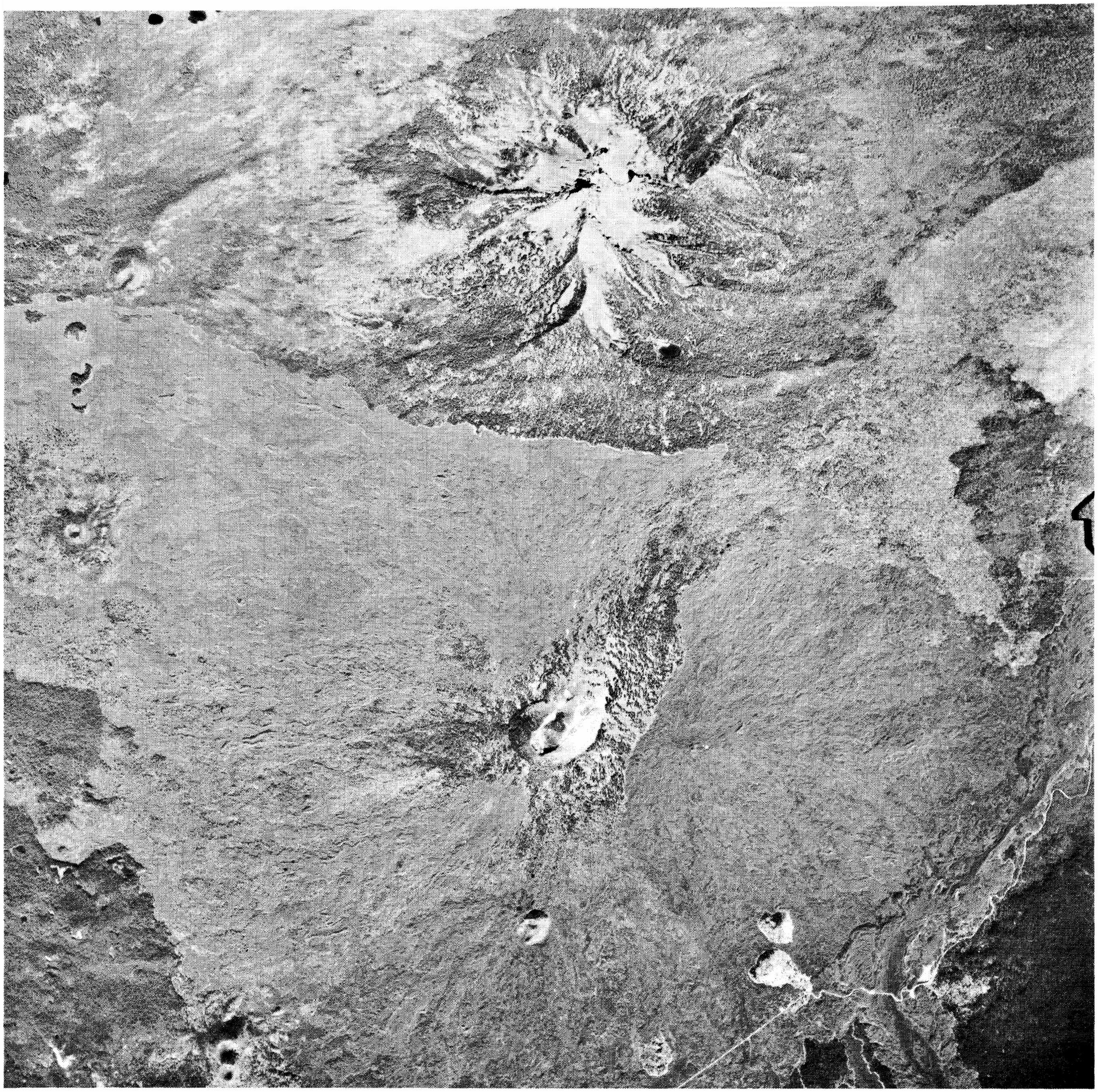
QTm / QTmt — Madras formation
QTm: Chiefly fluviatile volcanic sediments; subordinate tuffs and basaltic flows
QTmt: Interbedded dacite welded tuff

QTv — Glaciated volcanoes of the High Cascades; central lava plugs, some with inclosing tuff cones and radial dikes

QTba — Olivine basalt and basaltic andesite, glaciated lavas of the main volcanoes of the High Cascades. Overlain by pumice near Crater Lake.

Upper Oligocene and lower Miocene

Tjd — John Day formation
Rhyolitic domes, flows, welded tuffs, bedded tuffs, and tuffaceous sediments; minor flows of dacite and andesite.



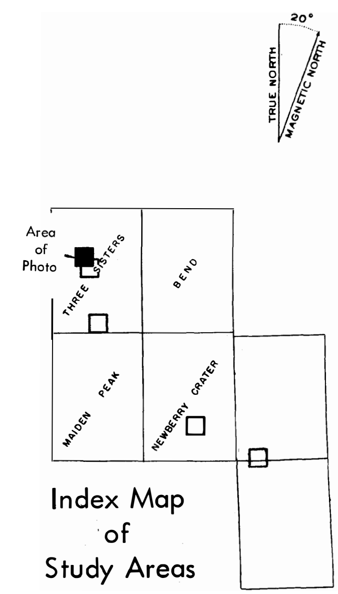
AERIAL PHOTOGRAPH OF THE BELKNAP CRATER - LITTLE BELKNAP STUDY AREA

Below is the geologic map which explains the area covered by this high-altitude photograph. The map scale also approximates distances in the photograph.

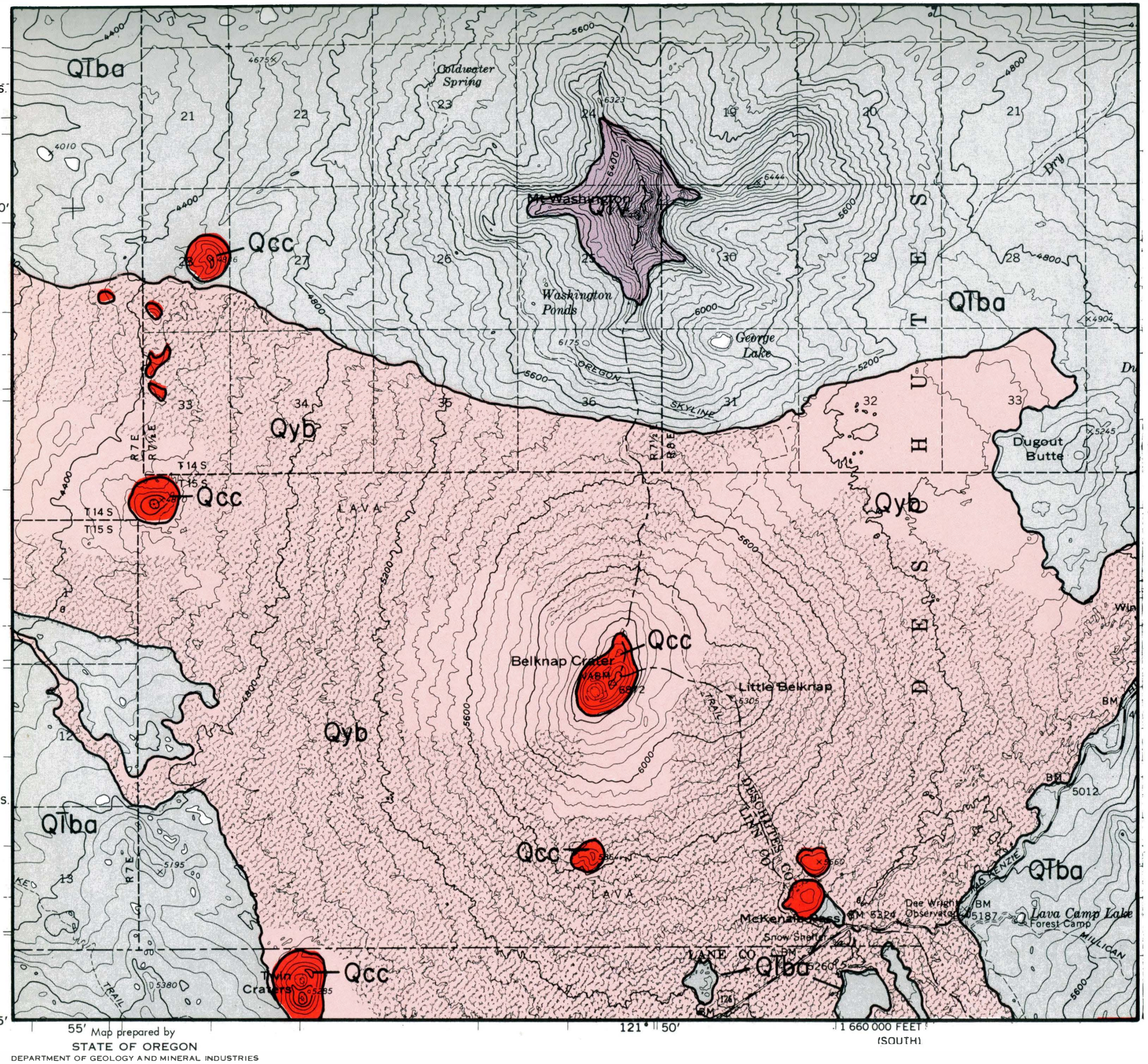
The snow-covered peak in the upper center is Mt. Washington. The vast area of barren lavas is a basalt shield topped by a snow-covered cinder cone, Belknap Crater. Slightly darker and younger lavas on the eastern flank are from the parasitic vent, Little Belknap.

Near the lower right corner is the McKenzie Highway. Dee Wright Observatory, a constructed viewing point, is on the High Cascades divide at an elevation of about 5,400 feet (1,650 m).

Roll 63, Exposure 7884, Western U.S. Project 109F.



GEOLOGIC MAP OF THE BELKNAP CRATER AND LITTLE BELKNAP STUDY AREA



EXPLANATION

Recent

Qcc — Basaltic cinder cones

Qyb — Youngest basaltic lavas, unglaciated

Pliocene and Pleistocene

QTv — Glaciated volcanoes of the High Cascades; central lava plugs, some with inclosing tuff cones and radial dikes

QTba — Olivine basalt and basaltic andesite, glaciated lavas of the main volcanoes of the High Cascades. Overlain by pumice near Crater Lake.

ROAD CLASSIFICATION

Heavy-duty — Light-duty

Medium-duty — Unimproved dirt

U.S. Route

1 ½ 0 1 MILE

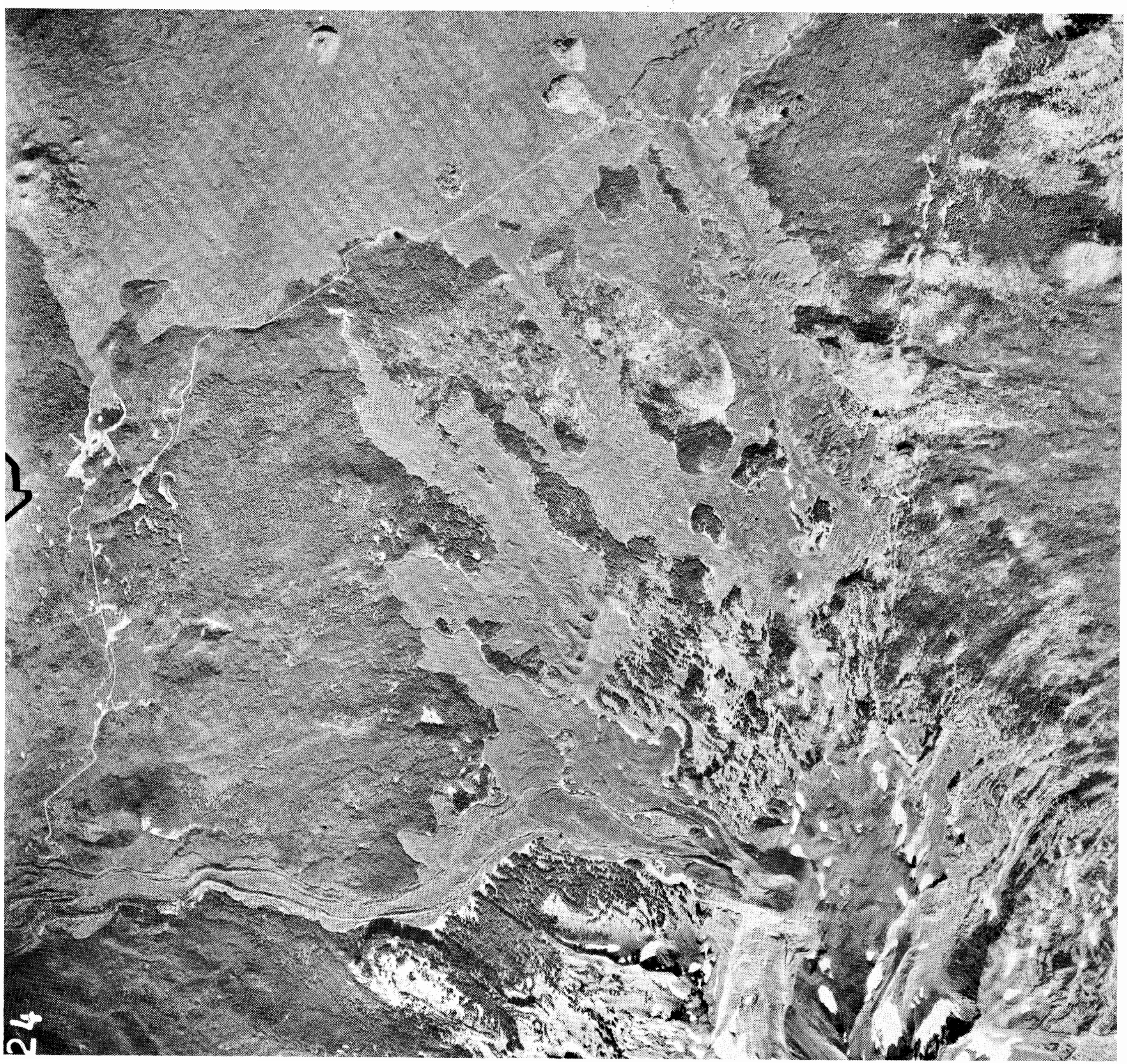
3000 0 3000 6000 FEET

1 .5 0 1 2 KILOMETERS

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

TRUE NORTH — MAGNETIC NORTH 20°

APPROXIMATE MEAN DECLINATION, 1959

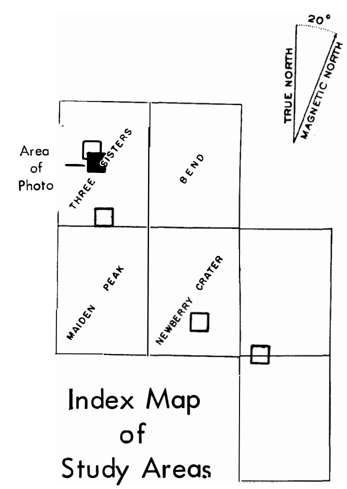


AERIAL PHOTOGRAPH OF THE YAPOAH CRATER - COLLIER CONE STUDY AREA

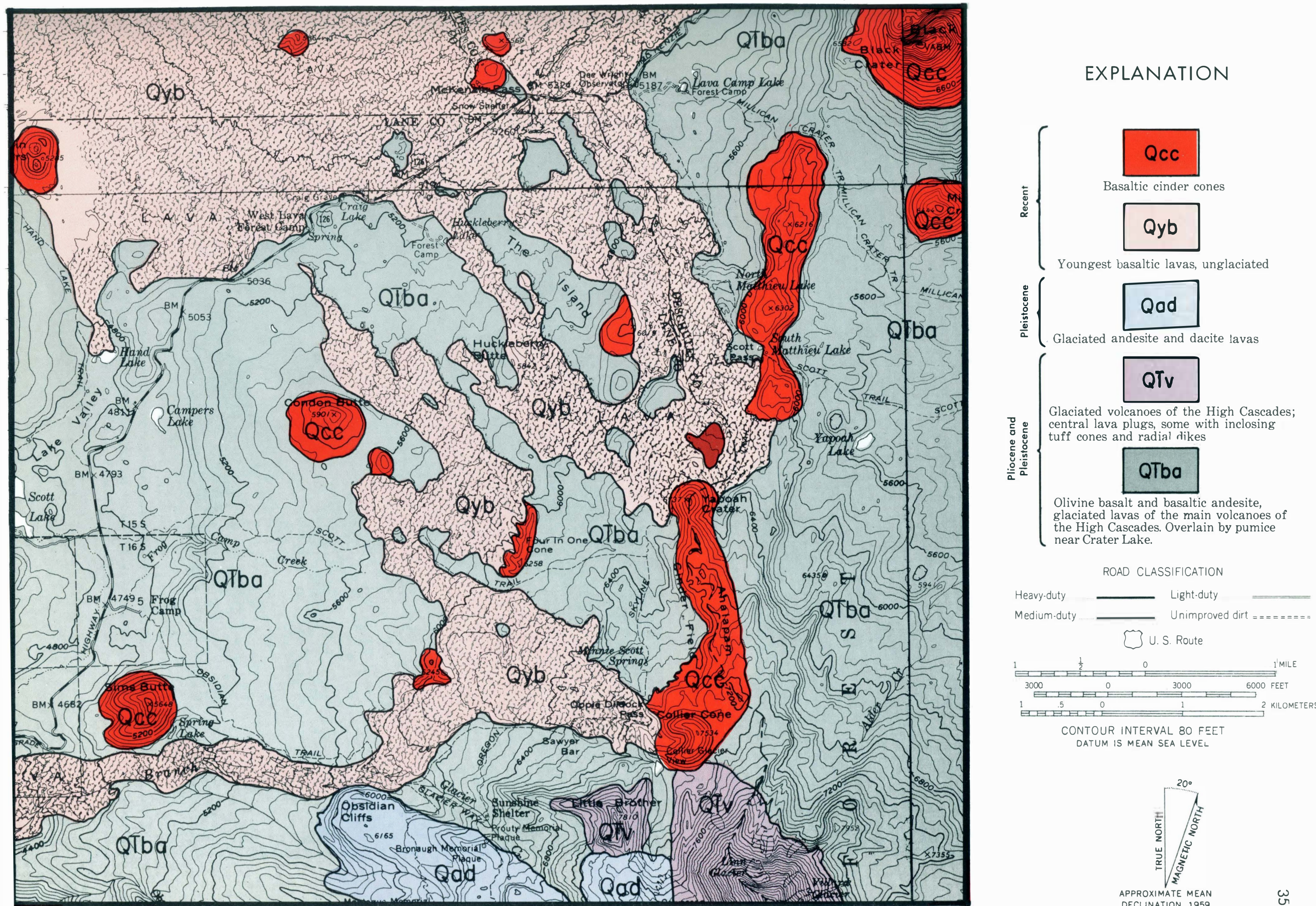
Below is a geologic map which covers the area of the photograph. The scale of the map may be used to approximate distances on the photograph.

The northern flank of North Sister is at the lower right of this high-altitude photograph. In detail can be seen the basaltic lavas which have streamed to the westward from Collier Cone. Excellent examples of lava levees show on the flow which poured to the west off the limits of the photograph into the White Branch of the McKenzie River. The blocky flow from Yapoah Crater flowed more than three miles (4.8 km) northward, meeting the barrier of Little Belknap, then turned northeast to flow on for 5 miles (8 km) more. Dee Wright Observatory is located on this flow just to the left of the bend in the lava channel.

Roll 67, Exposure 8424, Western U.S. Project 109F.



GEOLOGIC MAP OF THE YAPOAH CRATER–COLLIER CONE STUDY AREA.



Map prepared by
STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

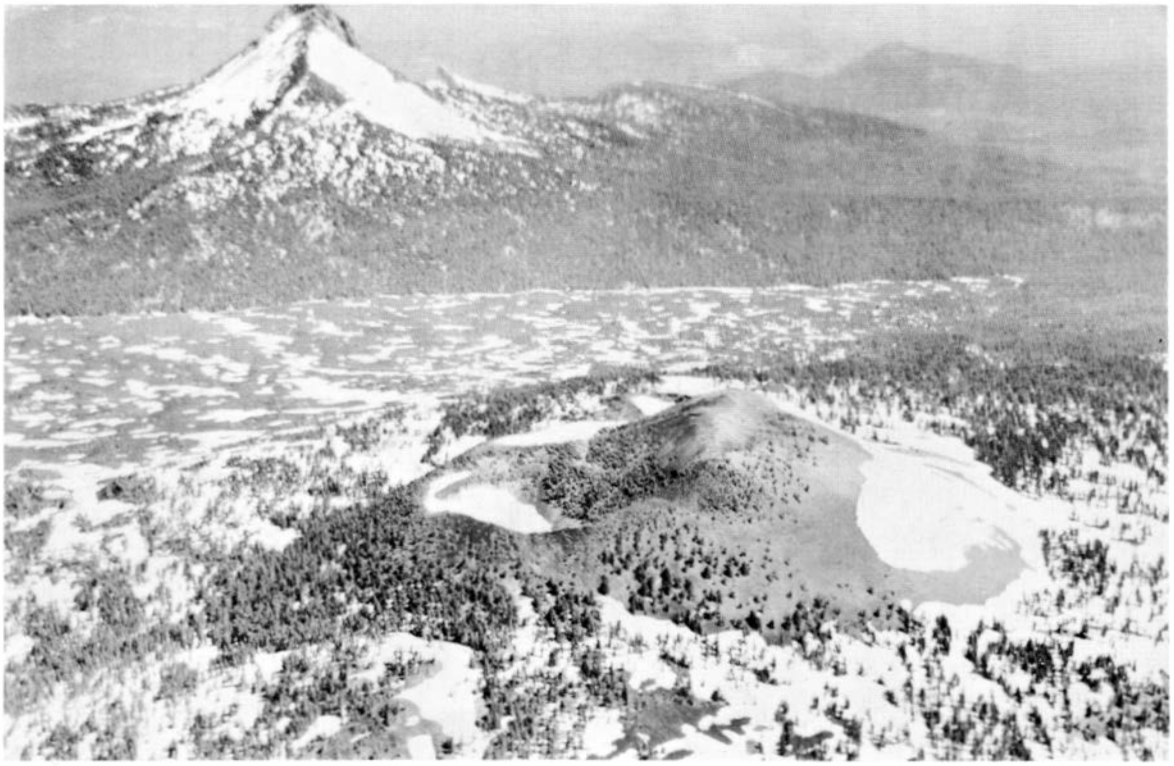


Figure 24. The summit of Belknap Crater looking to the north. The large cinder cane caps a brood basaltic lava shield. Mount Washington, a glaciated stratovolcano, is in the background.

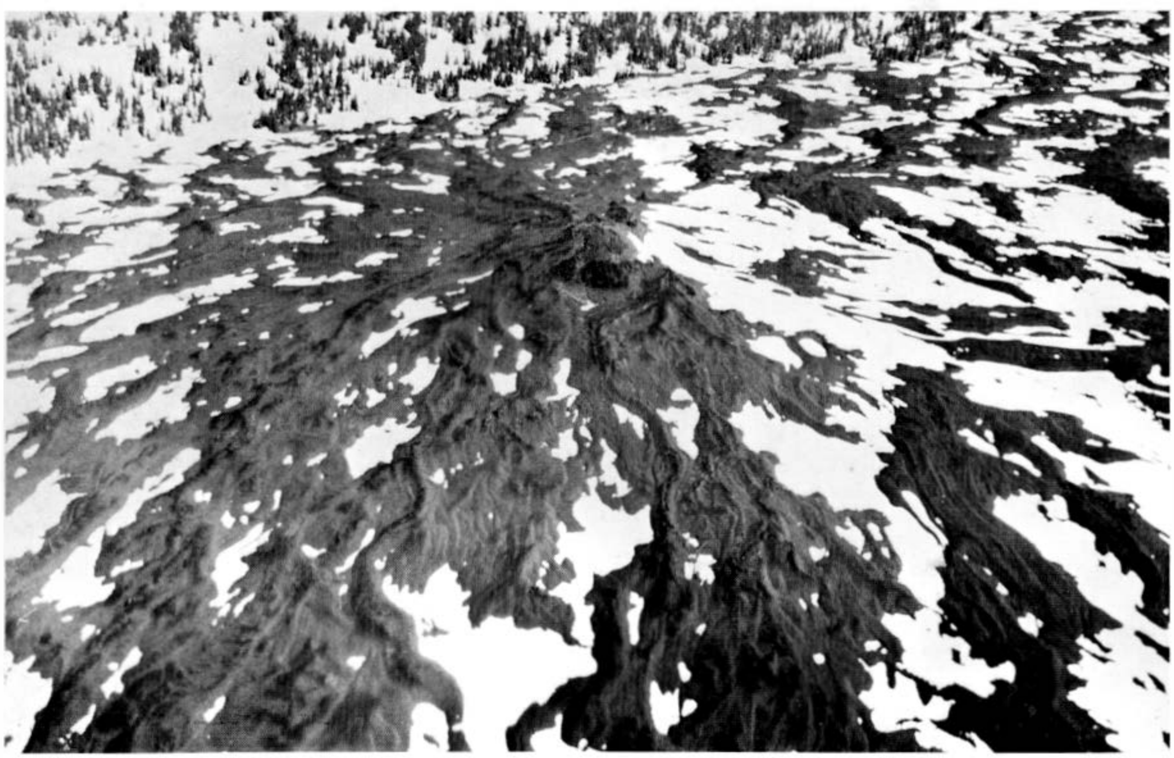


Figure 25. The summit of Little Belknap, a parasitic lava eruption on the eastern flank of Belknap Crater. Lava has flowed radially away from the vent located in the center of the photograph. Detail has been considerably obscured by the presence of unmelted snows produced during an abnormal winter.

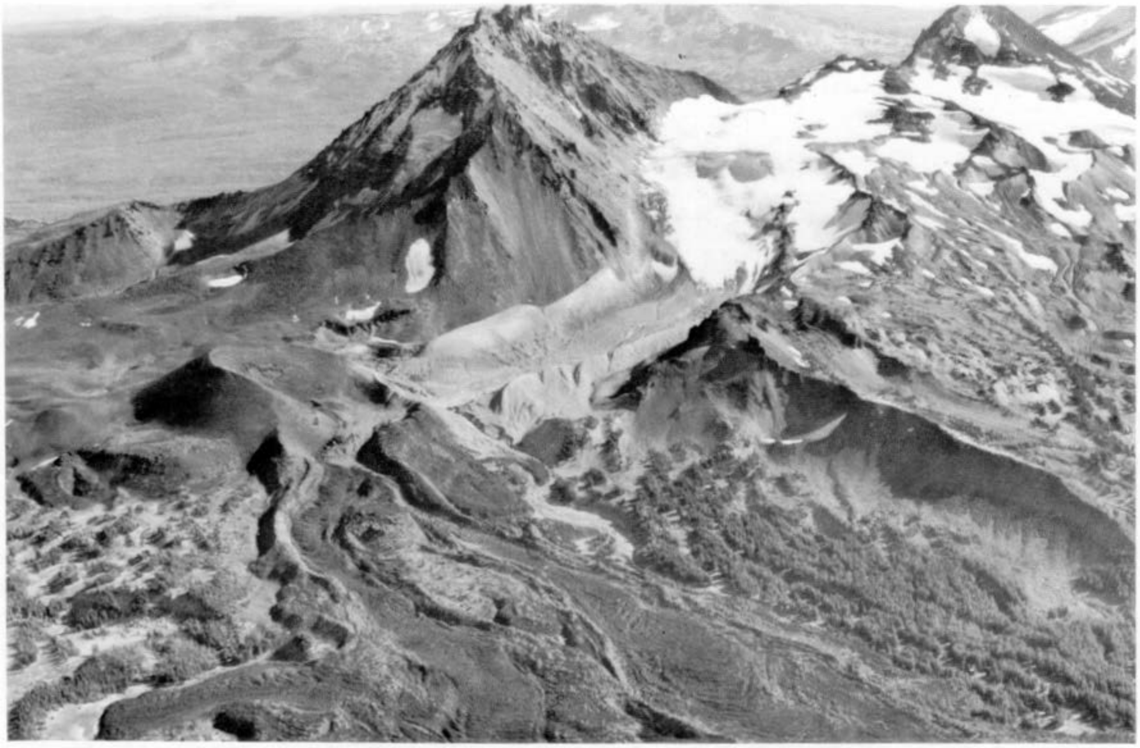


Figure 26. Great quantities of lava flowed from this breached cinder cone, named Collier Cone, located on the northern flank of North Sister. Lateral moraines deposited during the retreat of Collier Glacier are to the right of the cone. (Delano Photographics No. 631234)

Figure 27. Yapoah Crater, a very recent cinder cone, situated on the northern flank of North Sister. Two craters are present on its summit. Large amounts of lava flowed northward from vents at the base of the cone. View is from the north. (U.S. Forest Service photograph)

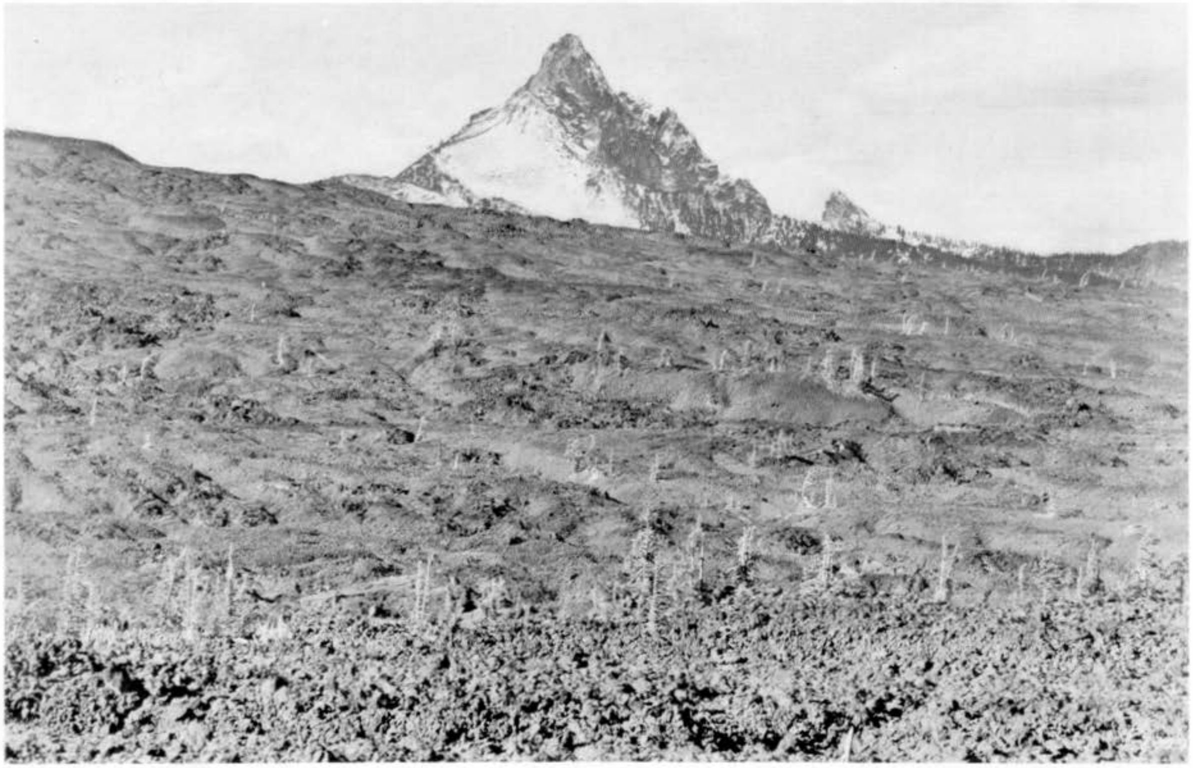


Figure 28. Looking northward over the Yapoah lava flow, in the foreground, and the vast lava flows of Little Belknap in the middle distance. Mt. Washington in the background. (Oregon State Highway Department photograph 427)

Figure 29. An abandoned pumice quarry near Bend, Oregon. The face of the quarry exposes a bed of pumice lapilli overlain by a thin layer of ash, which is in turn covered by an ash-flaw tuff(ignimbrite).

Crater Lake Area Field Trip

THE GEOLOGY OF CRATER LAKE NATIONAL PARK, OREGON*

With a Reconnaissance of the Cascade Range Southward to Mount Shasta

By Howel Williams**

ABSTRACT

In Late Cretaceous times, the site of the Oregon Cascades was largely if not entirely occupied by a shallow sea. During the Eocene period, widespread uplift drove the coast westward beyond the line of the Cascade Range, never to return. Volcanism began in eastern Washington during the early Eocene and gradually spread southward over Oregon. By late Eocene times, volcanoes were active throughout the present Cascade belt and on the plateau of central Oregon. The climate of Oregon was then warm temperate or subtropical, and a low plain spread far inland. During Oligocene and Miocene times, volcanism continued on a grand scale. Farther east, the volcanic deposits of the John Day formation had been laid down over an extensive area and had been buried during the Middle Miocene by enormous outpourings of Columbia River plateau basalt, erupted from swarms of fissures. Meanwhile the climate had become cooler and a temperate, redwood flora had replaced the warmer floras of the Eocene. Still, however, no high mountain range divided eastern from western Oregon.

At the end of the Miocene period, renewed earth movements took place. At the same time, the volcanics of the Western Cascades were intruded by an approximately north-south line of dioritic stock. Simultaneously, north-south fractures opened along and near what is now the crest of the Cascade Range. An important effect of these disturbances was the elevation of a mountain barrier which shut off eastern Oregon from the supply of moisture-laden winds. For the first time, the floras on opposite sides of the Cascades began to show the marked differences which they exhibit today.

During the Pliocene period, the disturbed rocks of the Western Cascades suffered rapid erosion, and along the summit of the range they were buried by the products of High Cascade volcanoes. These volcanoes were less explosive than those which had formed the Western Cascade series, and their products were less diverse. Whereas the older lavas range from rhyolite to basalt, those of the High Cascade cones are almost entirely composed of olivine-bearing basaltic andesite and basalt. Many of these younger flows poured for long distances down canyons cut across the Western Cascades.

By the close of the Pliocene period, the crest of the Cascade Range had become a high plateau surmounted by overlapping shield-shaped cones of basic lava. In the succeeding Pleistocene period, a narrower, north-south belt of giant andesitic volcanoes commenced to form on the basaltic plateau. These continued to erupt and grow until Recent times. Today they form the crowning peaks of the Cascade Range. The bulk of this report deals with the rise of one of these andesitic cones, Mount Mazama, and the manner in which its summit was destroyed.

Mount Mazama rose from a basement the elevation of which lay between 5000 and 6000 feet (1525 and 1830 m). By the time the volcano reached full stature, the summit rose to a height of approximately 12,000 feet (3660 m). The main cone was built chiefly by quiet effusions of hypersthene andesite. Explosive activity was relatively unimportant. Eruptions took place from a number of conduits, the positions of which changed from time to time. Accordingly, Mount Mazama was never a simple, symmetrical cone; it was, rather, a complex of overlapping cones.

Toward the close of the period of andesitic eruptions, flows of dacite escaped from fissures far down the south and east flanks of the volcano, and explosions of dacite pumice alternated with flows of andesite from the summit vents.

---

* Reprinted by permission from Carnegie Institution of Washington Publication 540, 1942.

** Professor of Geology, University of California at Berkeley.

Perhaps from the beginning, Mount Mazama supported many glaciers. Even the oldest visible lavas are underlain by glacial moraines. In many places, the caldera cliffs reveal layers of bouldery till and fluvioglacial sand interbedded with volcanic rocks. The constructional forces building the volcano struggled incessantly with the erosive force of ice. Clearly, the glaciers advanced and retreated many times. Their greatest advance came after the dacitic eruptions mentioned above. At that time, many tongues of ice were more than 10 miles (16.1 km) long, and one extended 17 miles (29.4 km) from the summit. In some of the canyons, the thickness of the glaciers exceeded 1000 feet (305 m). Save for a few projecting arêtes, the whole of Mount Mazama was mantled by an uninterrupted sheet of ice.

After the period of maximum glaciation, when the ice had retreated from the divides and was confined to the canyon bottoms on the upper slopes of the volcano, a semicircular arc of vents opened on the north flank, approximately 5000 feet (1525 m) below the summit. From this Northern Arc of Vents, which determines the position of the north wall of Crater Lake, viscous flows of andesite and dacite were erupted. About the same time, a cluster of acid andesite and dacite domes rose near the east base of Mount Mazama, and many basaltic cinder cones were active on the lower slopes. Explosions of dacite pumice, partly in the form of glowing avalanches (nuées ardentes), also took place from the summit region.

A long period of quiescence ensued. The glaciers retreated until only three small tongues extended beyond what is now the rim of Crater Lake. Even the longest stretched less than a mile and a half (2.4 km) beyond the caldera rim. The slopes of the volcano were almost barren of vegetation.

The climactic eruptions then began. At first they were mild, but soon they increased in violence. During the initial stages, fine dacite pumice was blown high above the summit vents, to be drifted eastward by the wind. As the explosions became more violent and the pumice lumps increased in size, the wind veered toward the northeast. No less than 5000 square miles (13000 km^2) were buried beneath the ejecta to a depth of more than 6 inches (15 cm). The finer dust spread over a vastly larger area. So much pressure was thus released that the gases in the feeding magma escaped from solution with unusual rapidity. The pumice was no longer projected high above the vents, but escaped in prodigious amount, boiling over the crater rims and rushing down the sides of the volcano at a tremendous rate, flowing after the manner of glowing avalances. Most of this pumice was confined to the canyons, down which it raced for distances up to 35 miles (56.4 km). Where no canyons existed, the pumice flows spread as incandescent sheets. Those that swept down the east and northeast sides of the volcano deployed onto the flats bordering the Klamath Marsh. Such was their power that they traveled 25 miles (40 km) from their source, though half their journey lay across a plateau. Twenty miles (32 km) from the vents, the flows include bombs of pumice 14 feet (4 m) across. Just before the glowing avalances ceased, the ejecta changed from dacite pumice to crystal-rich basic scoria. When the eruptions had come to an end, the glacial canyons were transformed into broad plains dotted with countless fumaroles. Each canyon had become a "Valley of Ten Thousand Smokes." The abundance of charred logs within the deposits offers vivid testimony to the destruction of the forests.

When the culminating eruptions were over, the summit of Mount Mazama had disappeared. In its place, there was a caldera between 5 and 6 miles (8 and 9.7 km) wide and 4000 feet (1220 m) deep. How was this formed? Certainly not by the explosive decapitation of the volcano. Of the 17 cubic miles (70 km^3) of solid rock that vanished, only about a tenth can be found among the ejecta. The remainder of the ejecta came from the magma chamber. The volume of the pumice fall which preceded the pumice flows amounts to approximately 3.5 cubic miles (15 km^3). Only 4 percent of this consists of old rock fragments; 10 to 15 percent consists of crystals, and the rest is made up of pumiceous glass. The volume of the pumice flows is approximately 8 cubic miles (33 km^3). Of this amount, only 15 to 20 percent consists of old lava fragments. The remainder represents new magma in the form of crystals and glass. Weak, dying explosions deposited approximately a quarter of a cubic mile of fine ejecta, chiefly crystals and minute chips of rock. Accordingly, 11.75 cubic miles (49 km^3) of ejecta were laid down during these short-lived eruptions. In part, it was the rapid evacuation of this material that withdrew support from beneath the summit of the volcano and thus led to a profound engulfment. The collapse was probably as cataclysmic as that which produced the caldera of Krakatau in 1883.

Some process other than the expulsion of magma from the feeding chamber must also have operated. Whereas 17 cubic miles (70 km^3) of the volcano disappeared, at most 11.75 cubic miles (49 km^3) of ejecta were laid down. Moreover, by far the bulk of these ejecta consists of vesicular glass. The equivalent volume of liquid magma was less than half as much. Accordingly, it must be concluded that during or immediately before the great eruptions, large volumes of magma were injected into fissures at depth. It was by a combination of deep-seated intrusion and explosive eruption that the magma chamber was drained to make room for the collapse of the peak of Mount Mazama. Doubtless the caldera floor also subsided by cooling and solidification of the magma left below.

The collapse of Mount Mazama was eccentric with respect to the former summit, for this lay well to the south of what is now the center of Crater Lake. This eccentric collapse was controlled by the pre-existing semicircular line of weakness along which the Northern Arc of Vents was formed.

The formation of Crater Lake took place approximately 5000 years ago. The discovery of artifacts beneath the pumice deposits shows that man already inhabited this part of Oregon and was a distant witness of the catastrophe.

After a period of quiet of unknown duration, activity commenced anew. Close to the western edge of the caldera rose the cone of Wizard Island, the final act of which was to erupt a rugged sheet of blocky lava, perhaps no more than a thousand years ago. As intra-caldera eruptions went on, rain and snow formed a lake on the floor, and this continued to gain in volume until it reached a depth of almost 2000 feet (610 m).

Note by the Editors:

Since the time Williams published this work on the geology of Crater Lake National Park, radiocarbon dating of charcoal incorporated in the pumice flows revealed an age of about 6600 years for the eruption. This age has been further confirmed by radiocarbon dating of archeological sites at which Mazama ash was identified (Libby 1952; Rubin and Alexander 1960).

Recent studies on the distribution of Mazama ash show that it extends at least 600 miles (970 km) northerly from its source and more than 500 miles (800 km) to the east. This corresponds to a minimum area for the ash fall of about 350,000 square miles (900,000 km^2) (Powers and Wilcox 1964; Fryxell 1965).

A detailed bathymetric survey of Crater Lake was made in 1959 by the U.S. Coast and Geodetic Survey. Byrne (1962) prepared a bathymetric chart from the survey data and described some of the underwater features. His chart and text are reprinted herein.

Figures 30 to 34 are photographs of some of the prominent features of Crater Lake.

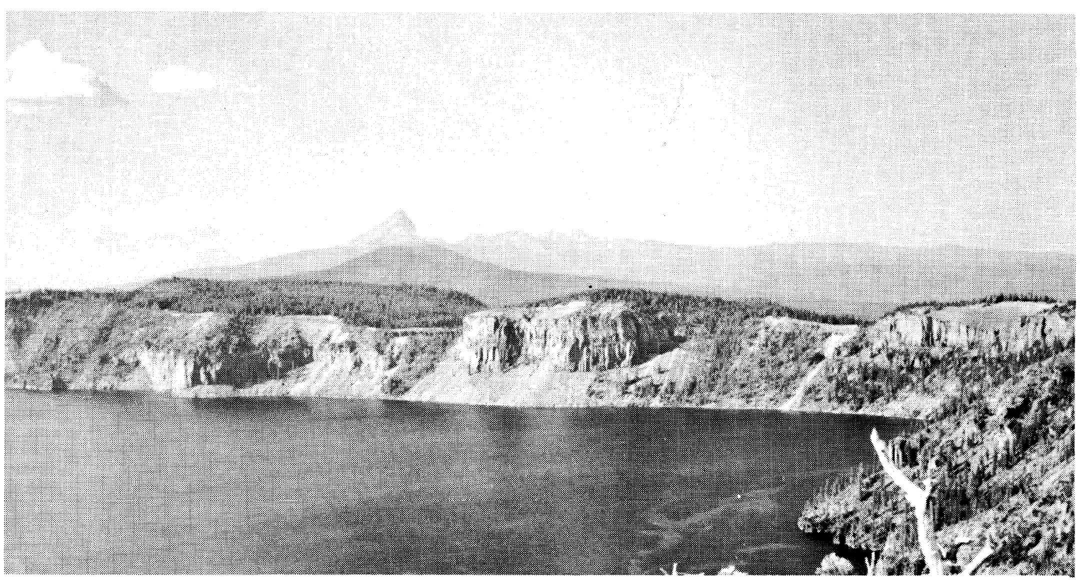
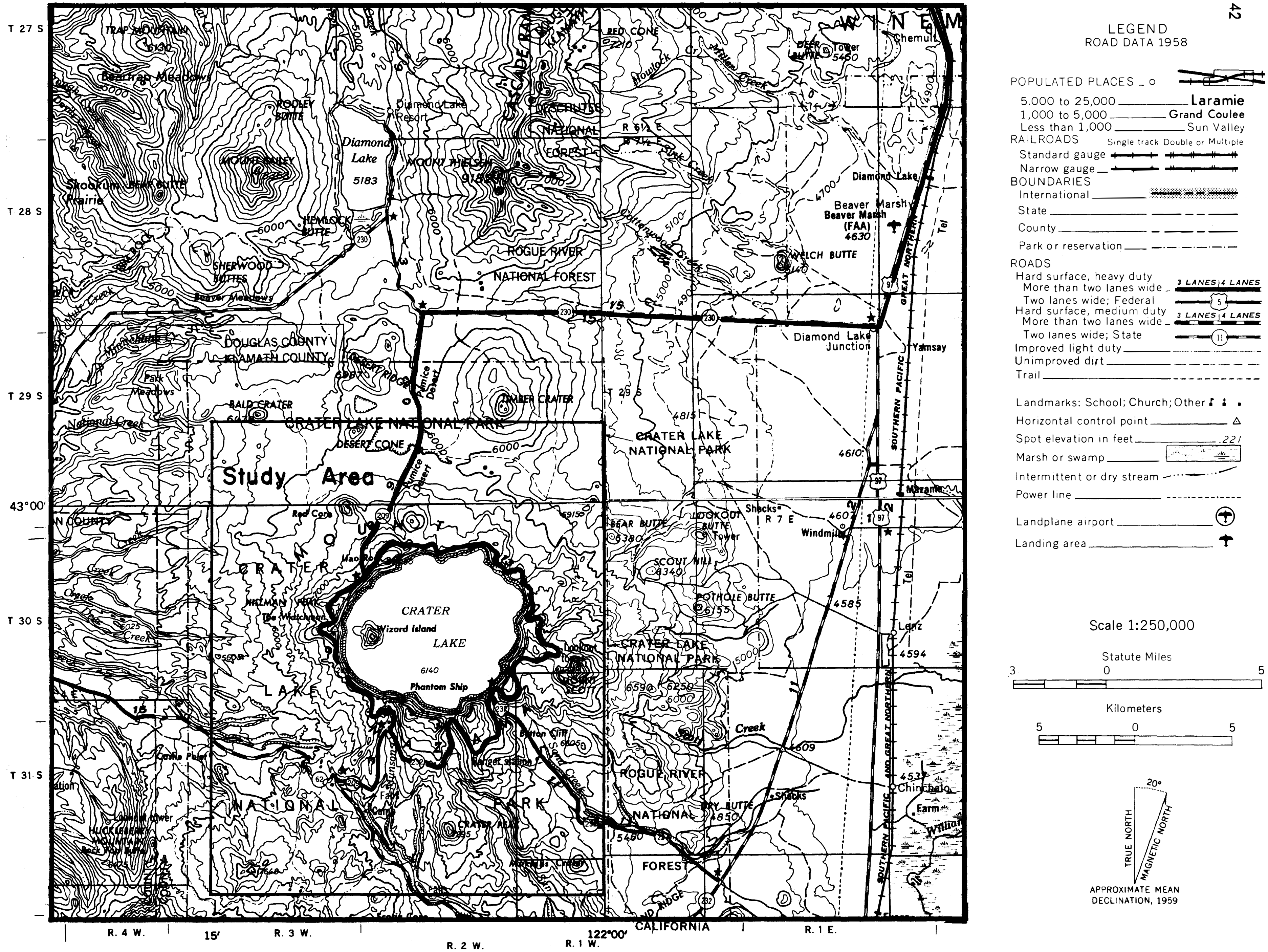
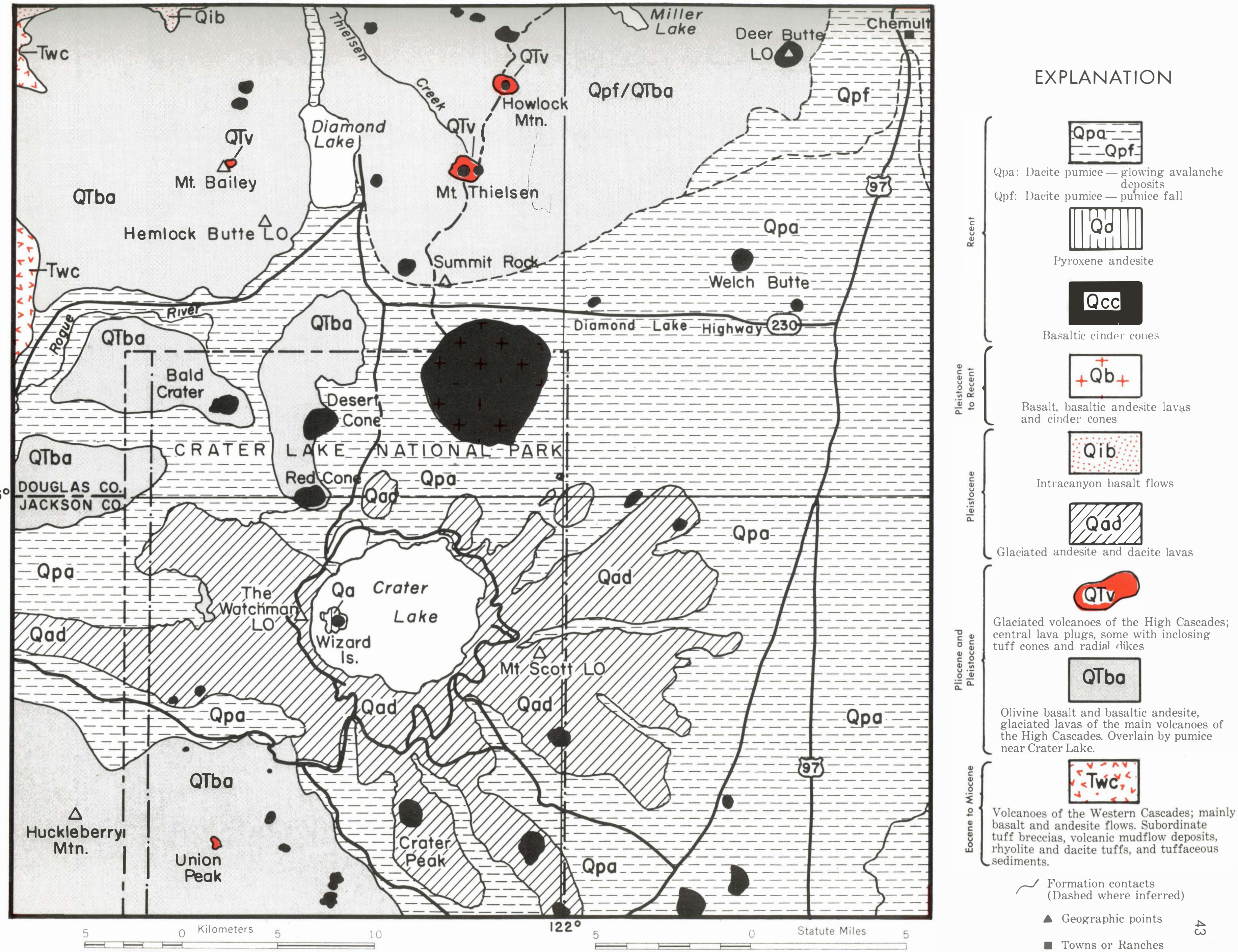


Figure 30. The northeastern wall of Crater Lake. The Palisades at left, Roundtop in middle, and Wineglass at right. Timber Crater lies in middle distance and Mt. Thielsen in background. The Palisades and Roundtop are thick andesite flows. Ignimbrite overlies pumice in Wineglass. (Oregon State Highway Dept. Photograph 6290)

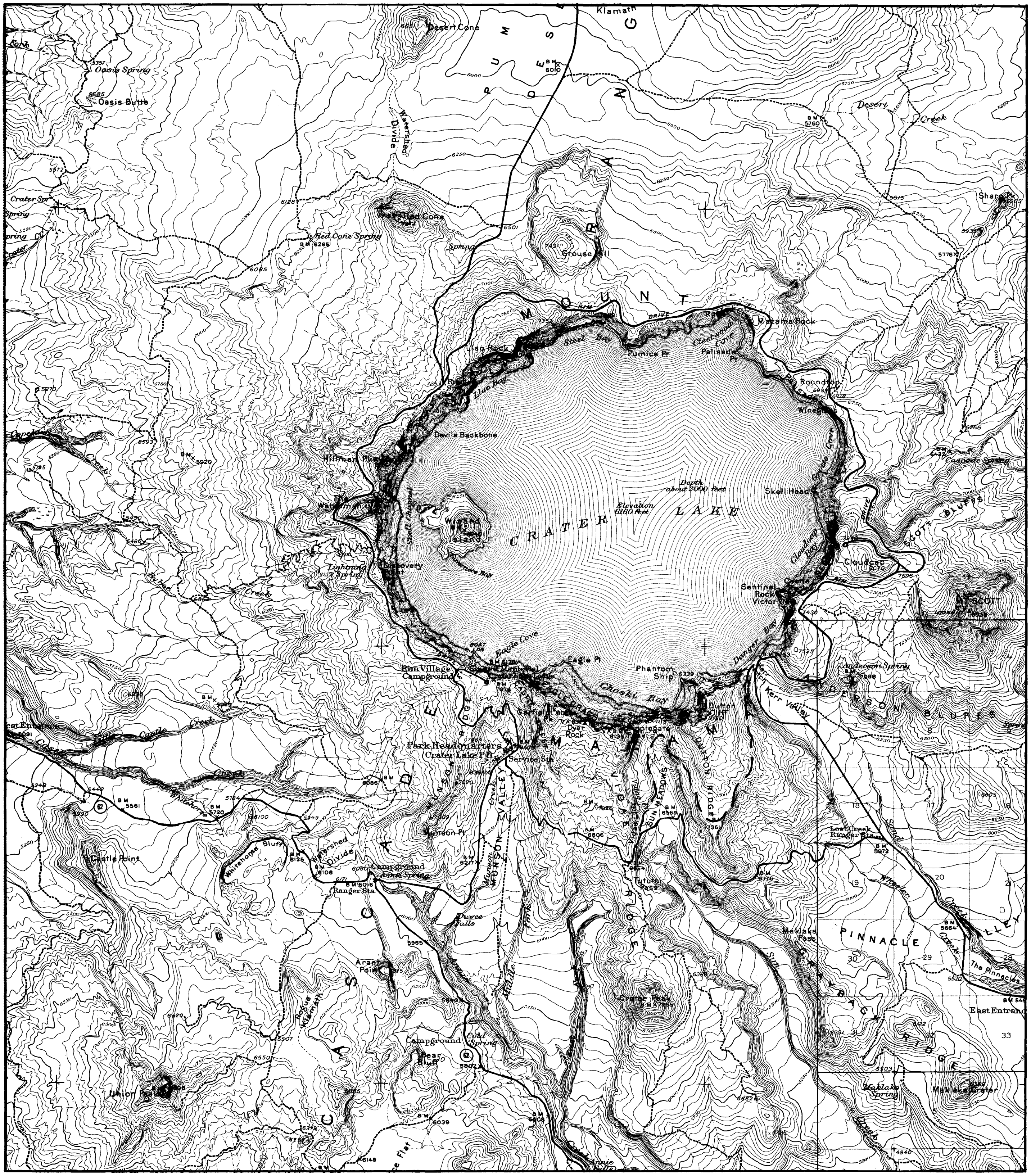
TOPOGRAPHIC MAP OF THE CRATER LAKE AREA FIELD TRIP.



GEOLOGIC MAP OF THE CRATER LAKE AREA FIELD TRIP.



TOPOGRAPHIC MAP OF THE CRATER LAKE STUDY AREA



1 ½ 0 1 2 3 4 Miles

1000 500 0 1000 2000 3000 4000 5000 6000 7000 Yards

1000 0 3000 6000 9000 12000 15000 18000 Feet

1 .5 0 1 2 3 4 5 Kilometers

Contour interval 50 feet

Datum is mean sea level

ROAD CLASSIFICATION
1945

Dependable hard-surface heavy-duty road

Secondary hard-surface all weather road

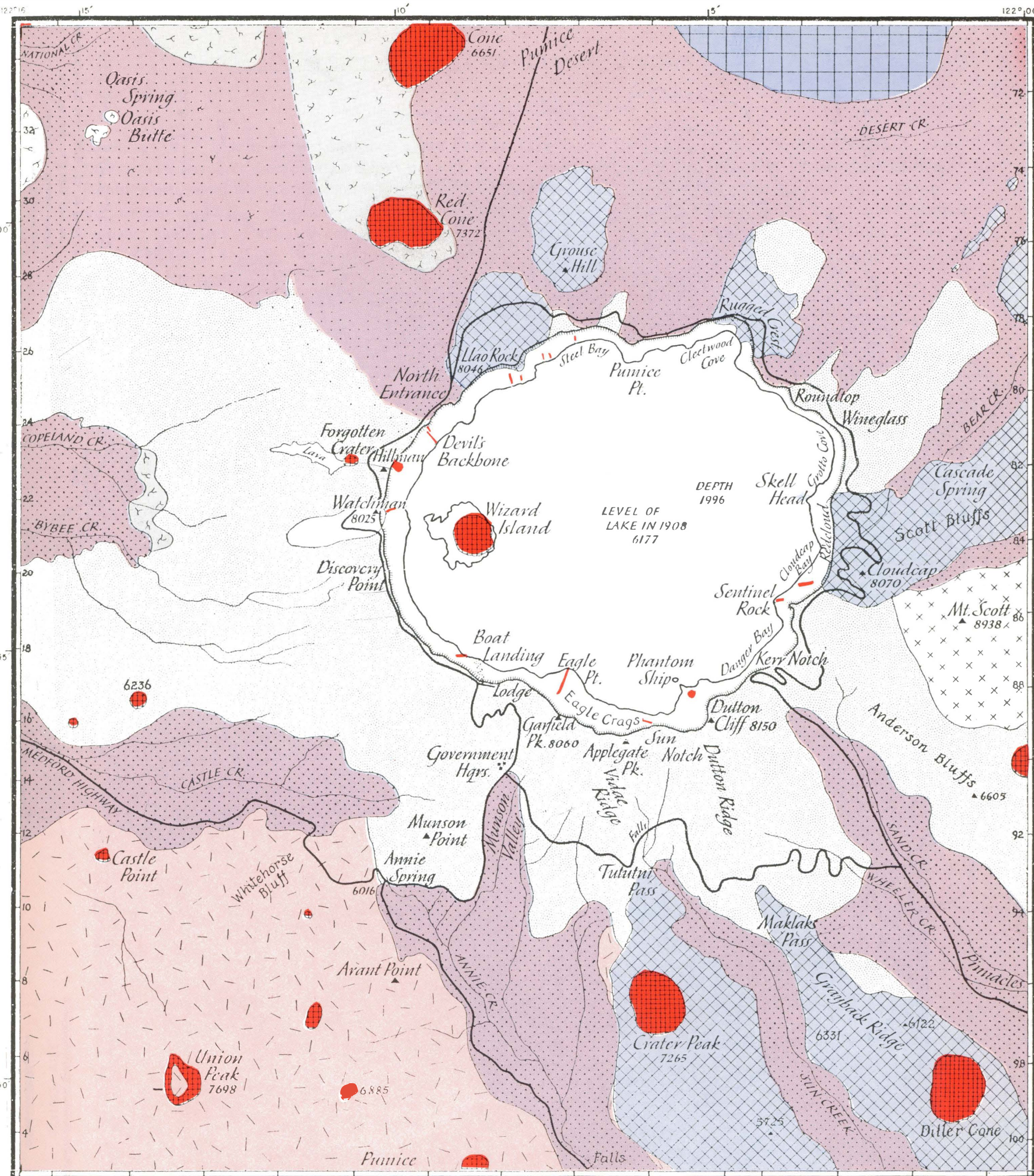
Dry weather roads
Loose surface graded
Unsurfaced, graded
Dirt road

U. S. Route 15

State Route 26

More than two lanes indicated along road with tick at point of change 3 LANE | 4 LANE

GEOLOGIC MAP OF THE CRATER LAKE STUDY AREA.



Pre-Mazama Lavas (olivine basaltic andesites)

Union Peak Lavas (olivine basalt & basaltic andesites)

Mt. Mazama Andesites

Mt. Mazama Dacites

Mt. Scott Lavas (pyroxene andesites)

Dikes and Vents on Caldera Walls (dacite and andesite)

Parasitic Cinder Cones (basalt and basaltic andesites)

Glowing Avalanche Deposits (dacite pumice and basic scoria)

Timber Crater Lavas (olivine basalt & basaltic andesites)

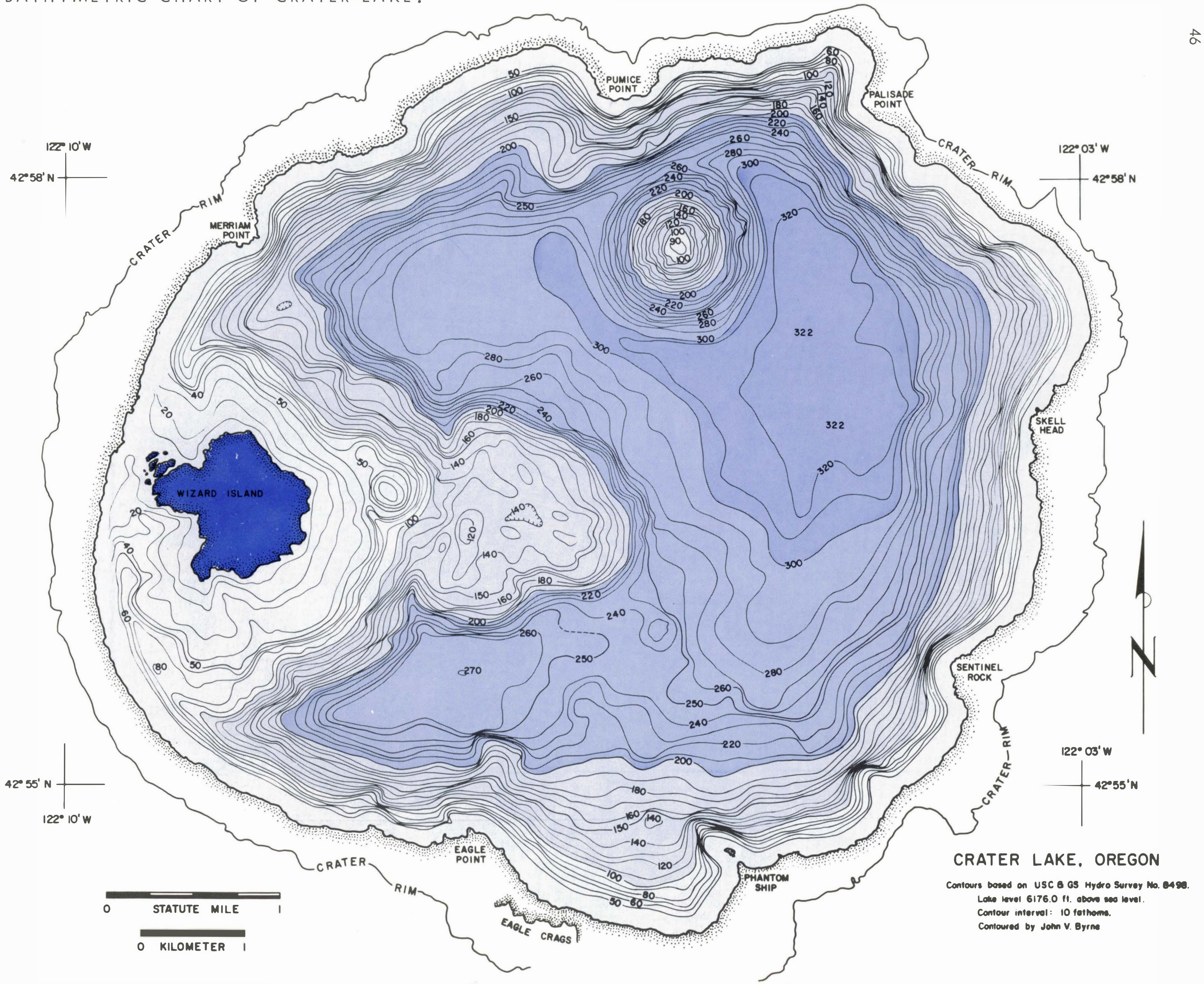
Numbers along margins refer to boundary markers. Elevations in feet. (Drawn by A. W. Severy.)

Williams, 1942

0 1 2 3 4 5 Miles

0 1 2 3 4 5 Kilometers

BATHYMETRIC CHART OF CRATER LAKE.



BATHYMETRY OF CRATER LAKE, OREGON*

By John V. Byrne**

Crater Lake, Oregon, is unquestionably the deepest lake in the United States (1,932 feet [580 m]), and in North America is exceeded in depth only by Great Slave Lake in northern Canada (2,014 feet [605 m]). Depth measurements were first mode in Crater Lake in 1886, again in 1938-40, and most recently during the summer of 1959. The recent study, carried out in great detail by the United States Coast and Geodetic Survey, mode use of echo-sounding methods and was mode under the supervision of R. E. Williams. This survey (U.S.C.& G.S. Hydro Survey No. 8498) provided the basis for the accompanying bathymetric chart, which is controlled by soundings at more than 4,000 individual locations.

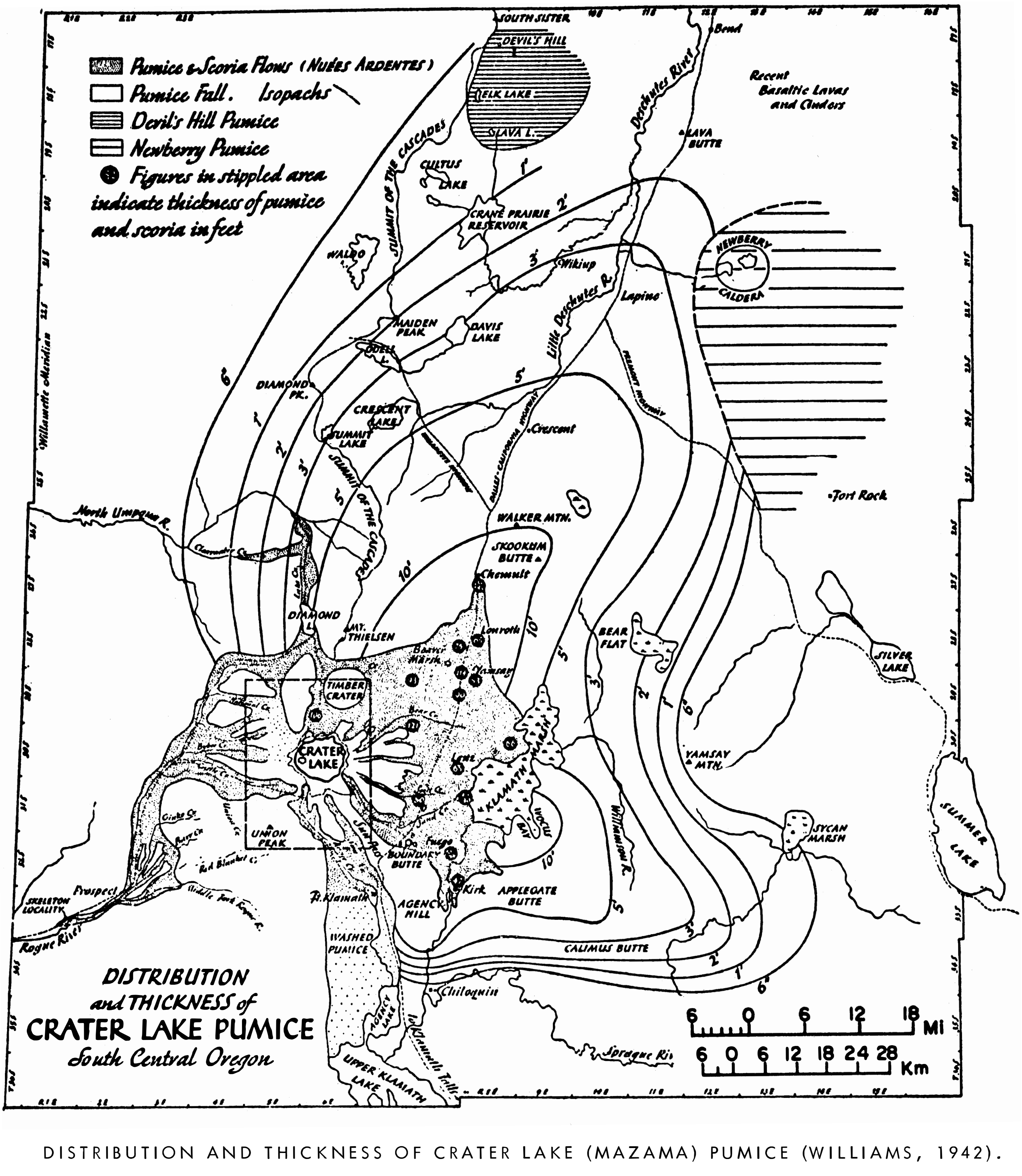
The use of o 10-fothom (60-foot [18.3-m]) contour interval makes several features of geologic interest apparent. As the runoff and amount of sediment supplied to the lake ore limited, little modification of the original surface con have token place by erosion or deposition, and the bathymetric chart, therefore, essentially represents the configuration of the original volcanic surface. Attention is directed to the lobe extending eastward from Wizard Island, undoubtedly o lava flow; to the conical mound at the inner edge of the lava flow, probably o volcanic cone which has been buried to some extent by the lava flow; and to the almost perfect cone rising to 81 fathoms (148 m) in the north-central port of the lake. This cone has been named Merriam Cone by Howel Williams (1961) in a short article which includes o less-detailed chart of the lake based on the some survey. Southeast of Merriam Cone, the lake is deepest, 322 fathoms (1,932 feet [580 m]), and has a flat bottom which Williams considers to be a lava plain smoothed somewhat by later oshfalls.

Rock samples dredged from the flank of Merriam Cone consist of hypersthene-augite andesite, whereas those dredged from the mound at the inner edge of the Wizard Island lava flow ore vitrophyric hypersthene-hornblende dacite (Williams, 1961).

* Reprinted from the ORE BIN, v. 24, no. 10, 1962.

** Deportment of Oceanography, Oregon State University, Corvallis, Oregon.

Figure 31. The Watchman, at left, and Hillman Peak, in the center, on the western rim of Crater Lake. The Watchman is on andesite flow with o domol protrusion over the vent. Hillman Peak is almost 2,000 feet (610 m) above lake level and is the highest point on the rim. It is o remnant of o parasitic cone composed of andesite flows and pyroclastics that developed on the side of Mt. Mazama. (Oregon State Highwoy Deportment Photograph K-5449)



DISTRIBUTION AND THICKNESS OF CRATER LAKE (MAZAMA) PUMICE (WILLIAMS, 1942).

Figure 32. Crater Lake viewed from the west. The ruins of Mt. Mazama after the catastrophic eruptions and caldera collapse, which occurred about 6,600 years ago. The Watchman, overlooking Wizard Island, is in the middle foreground on the caldera rim where the road loops around its flanks. Next to the left is the ridge of Hillman Peak. At the far left is Lloo Rock. Farther on around the rim are Pumice Point, Cleetwood Cove, The Palisades, and Roundtop. On the distant wall rises the Redcloud dacite flow with Mt. Scott beyond. Next is the glaciated Kerr Valley and to its right, Dutton Cliff. On the far right can be seen the U-shaped glaciated Sun and Munson Valleys with Applegate and Garfield Peaks between them. (Delano Photographics photo 581064)

Figure 33. Wizard Island, looking east. This cinder cone rises about 760 feet (230 m) above the lake and has a crater 300 feet (92 m) across and 90 feet (27 m) deep. Two flows of pyroxene andesite lava have extruded from the base of the cone. The right, and older, flow is a block lava; the left, and younger, flow is more representative of aa lava. (Oregon State Highway Department Photograph 7085)

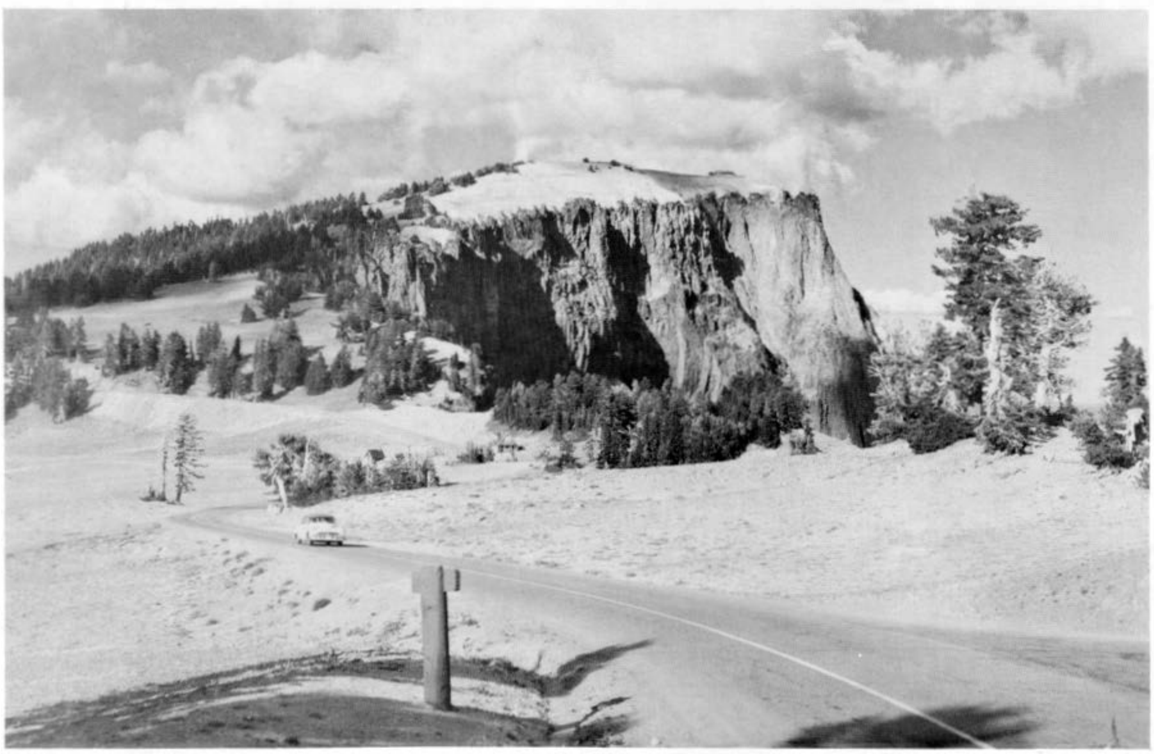


Figure 34. Llao Rock, viewed from the southwest on the Crater Rim Drive road. The height of the cliff is about 400 feet (122 m). Llao Rock, a lava flow, is composed of vesicular vitric dacite which erupted into a glacial valley and was subsequently beheaded by caldera collapse in the formation of Crater Lake. (Oregon State Highway Department Photograph 5312)

References

Benson, G. T., 1965, The age of Clear Lake, Oregon: Oregon Dept. Geology and Mineral Industries, The ORE BIN, v. 27, no. 2, p. 37-40.

Bullard, F. M., 1962, Volcanoes, in history, in theory, in eruption: Austin, Texas, Univ. of Texas Press.

Byrne, J. V., 1962, Bathymetry of Crater Lake, Oregon: The ORE BIN, v. 24, no. 10, p. 161-164.

Cotton, C. A., 1952, Volcanoes as landscape forms: New York, John Wiley & Sons, Inc., first ed. rev.

Fryxell, Roald, 1965, Mazama and Glacier Peak volcanic ash layers; relative ages: Science, v. 147, no. 3663, p. 1288-1290.

Hampton, E. R., 1964, Geologic factors that control the occurrence and availability of ground water in the Fort Rock basin, Lake County, Oregon: U.S. Geol. Survey Prof. Paper 383-B.

Libby, W. F., 1952, Radiocarbon dating: Chicago, Ill., University of Chicago Press.

Nichols, R. L., 1938, Fissure eruptions near Bend, Oregon (abst.): Geol. Soc. America Bull., v. 49, no. 12, pt. 2, p. 1894.

____________, 1940, The flow mechanism of basalts, vol. 1: Cambridge, Mass., Harvard Univ. doctoral dissertation (unpub.).

____________, 1940, A lava-fan near Bend, Oregon (abst.): Am. Geophys. Union Trans. of 1941, p. 357-358.

____________, 1941, The velocity of the Big Obsidian Flow, Bend, Oregon (abst.): Am. Geophys. Union Trans. of 1941, p. 504-505.

____________, 1941, Tree rings in lava (abst.): Geol. Soc. America Bull., v. 52, no. 12, pt. 2, p. 1926.

Peterson, N. V., and Groh, E. A., 1961, Hole-in-the-Ground: The ORE BIN, v. 23, no. 10, p. 95-100.

________________________, 1963, Recent volcanic landforms in central Oregon: The ORE BIN, v. 25, no. 3, p. 33-45.

________________________, 1963, Maars of south-central Oregon: The ORE BIN, v. 25, no. 5, p.73-88.

________________________, 1964, Diamond Craters, Oregon: The ORE BIN, v. 26, no. 2, p. 17-34.

________________________, 1964, Crack-in-the-Ground, Lake County, Oregon: The ORE BIN, v. 26, no. 9, p. 158-166.

Powers, H. A., and Wilcox, R. E., 1964, Volcanic ash from Mt. Mazama (Crater Lake) and from Glacier Peak: Science, v. 144, no. 3624, p. 1334-1336.

Rittman, A., 1962, Volcanoes and their activity: New York, Interscience Publishers, John Wiley & Sons, Inc.

Rubin, Meyer, and Alexander, Corrinne, 1960, U.S. Geol. Survey radiocarbon dates: Am. Jour. Sci. Radiocarbon Supplement, v. 2, p. 129-185.

Taylor, E. M., 1965, Recent lava flows of the Three Sisters area, Oregon: The ORE BIN, v. 27, no. 7, p. 121-142.

Wentworth, C. K., and MacDonald, G. A., 1953, Structures and forms of basaltic rocks in Hawaii: U. S. Geol. Survey Bull. 994.

Williams, Howel, 1932, The history and character of volcanic domes: Univ. Calif., Pub., Dept. Geol. Sci. Bull., v. 21, p. 51-146.

_____________, 1933, Mount Thielsen, a dissected Cascade volcano: Univ. Calif. Pub., Dept., Geol. Sci. Bull., v. 23, p. 195-214.

_____________, 1935, Newberry volcano of central Oregon: Geol. Soc. America Bull., v. 46, p. 253-304.

_____________, 1941, Calderas and their origin: Univ. Calif. Pub., Dept. Geol. Sci. Bull.,v. 25, p.239-346.

_____________, 1942, The geology of Crater Lake National Park, Oregon: Carnegie Inst. Washington Pub.540.

_____________, 1944, Volcanoes of the Three Sisters region: Univ. Calif. Pub., Dept. Geol. Sci. Bull., v. 27, p. 37-84.

_____________, 1953, The ancient volcanoes of Oregon: Oregon State System of Higher Education, Condon Lectures, 2nd ed.

_____________, 1957, Geologic map of the Bend quad., Oregon, and a reconnaissance geol. map of the central portion of the High Cascade Mts.: Oregon Dept. Geology and Mineral Industries.

_____________, 1961, The floor of Crater Lake, Oregon: Am. Jour. Sci., v. 259, p. 81-83.