SPECIAL PAPER 2

# FIELD GEOLOGY OF S.W. BROKEN TOP QUADRANGLE OREGON

EDWARD M TAYLOR

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STATE OF OREGON

DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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# S.W. BROKEN TOP QUADRANGLE, OREGON

Edward M. Taylor
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FRONTISPIECE. NORTHWEST SIDE OF BROKEN TOP VOLCANO. CENTRAL MASS CONSISTS OF INTERBEDDED AGGLOMERATE AND LAVAS CUT BY SILLS, DIKES, AND A LARGE PLUG. SURROUNDED BY HOLOCENE MORAINES AND RIDGES OF GLACIATED BASALTIC ANDESITE.

## FOREWORD

The southwest quarter of the Broken Top Quadrangle lies in the central High Cascades, immediately southeast of the majestic Three Sisters, in an area of outstanding scenery and recurring volcanism. Portions of the quadrangle lie within the Three Sisters Wilderness Area, but the southwest corner of the study area is accessible by road from Bend. Edward M. Taylor describes the geology and petrochemistry of this quadrangle, including Broken Top Volcano, in considerable detail.

This paper represents the author's research in the High Cascades over a period of several years. The detailed geology of the Oregon Cascades is poorly known, and few portions have been studied in as much detail as the Broken Top area. Some of the volcanism described in this paper occurred as recently as a few thousand years ago, and future volcanic eruptions are possible.

The Broken Top area is currently the topic of continuing debate regarding future land use. Based on geologic factors, considerable interest has been shown in the potential geothermal energy resources adjacent to these young volcanic centers.

This paper provides basic data that will serve the scientific community for decades to come; in addition, it makes available information that will facilitate assessment of mineral and mineral-energy resources and volcanic hazards. Intelligent land use planning must be based upon sound geologic data, and Dr. Taylor's report will be of immediate value for both public decision making and the scientific community.

August 1978

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Oregon Department of Geology and Mineral Industries

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# FIELD GEOLOGY OF S.W. BROKEN TOP QUADRANGLE, OREGON

## INTRODUCTION

The following report is a compilation of geologic field observations and supporting laboratory data accumulated during a study of Broken Top volcano in the central High Cascade Range of Oregon (Figure 1). General geologic relationships are summarized, then followed by detailed geologic maps which are cross-indexed to lithologic descriptions, petrographic determinations, chemical analyses, and other stratigraphic information. The objective is to place a large body of data on record in a form readily accessible to those whose interests range from general geology of the region to specialized study of its many unsolved and challenging geologic problems. Interpretations of broader significance such as the introduction of formal stratigraphic names, an outline of petrographic characteristics and petrologic variations in Cascade rocks, and tectonic development of the central Cascade Range will be deferred until related field data from nearby quadrangles have been placed on record.

### Acknowledgements

C-14 age of Rock Mesa charcoal collected in 1975 by the author was determined by U.S. Geological Survey laboratories in 1977 and generously provided by Donald Mullineaux and Meyer Rubin. Harold Enlows reviewed the text and offered many helpful suggestions. Ruth L. Lightfoot, analytical technician and Therese Belden, typist, must be acknowledged for their extraordinary patience and vital assistance.

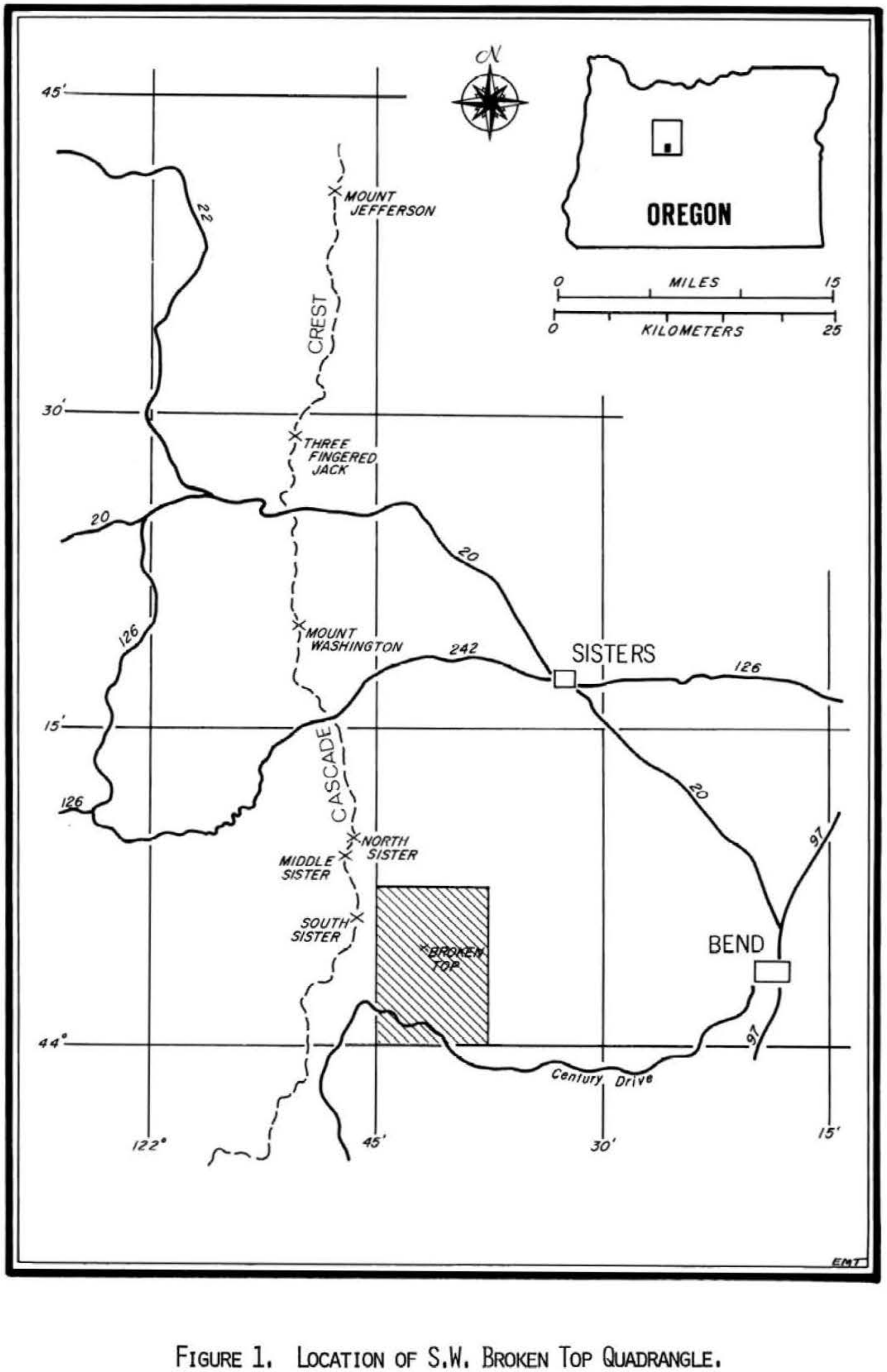


FIGURE 1. LOCATION OF S.W. BROKEN TOP QUADRANGLE.

## GENERAL GEOLOGY OF BROKEN TOP AND VICINITY

The 7.5-minute S.W. Broken Top quadrangle is bounded by 44° and 44°7'30" north latitude and by 121°37'30" and 121°45' west longitude in the vicinity of Broken Top volcano, 30 km west of Bend (Figure 1). The quadrangle is covered by Pleistocene and Holocene calc-alkaline volcanic and volcaniclastic rocks similar to those near the crest of the Cascade Range, approximately 10 km to the west. Basalt, basaltic andesite, andesite, dacite, and rhyodacite rock types are represented in a variety of forms including composite volcanoes, volcanic domes, lava flows, cinder cones, tuff cones, ash-flow tuffs, intrusive plugs, and dikes.

### Pliocene Volcanism and Subsidence

Stratigraphic and structural records of Pliocene volcanic and tectonic activity are obscured in the S.W. Broken Top quadrangle by a thick overburden of younger rocks. However, certain inferences can be drawn from rocks of Pliocene age exposed in areas to the north and east. Within the Deschutes Formation, northeast and east of Broken Top, there is abundant evidence that a great volume of volcaniclastic material was delivered to the eastern slope of the central Cascades (Taylor, 1973) during an interval that began at least 12 million years ago and was abruptly terminated approximately 3 million years ago (Armstrong, Taylor, Hales, and Parker, 1975). This material was produced from a north-south belt of Pliocene Cascade volcanoes. Remnants of the eastern slope of the Pliocene volcanic belt are now preserved in Green Ridge north of Sisters and in other outcrops between Sisters and Bend (Peterson, Groh, Taylor, and Stensland, 1976); none of the Pliocene Source volcanoes is exposed in the modern High Cascade Range.

Extensive crustal subsidence occurred within the central Cascade volcanic belt approximately 2.5-3.5 million years ago. A complex, elongate, north-south basin was probably formed and was bordered on the east by a set of normal faults whose total displacement exceeded 1000 meters. Remnants of a north-south 700-meter fault escarpment are exposed north of Broken Top along upper Metolius River and a southern extension probably exists in the subsurface beneath Broken Top. Normal faults of northwest trend and smaller displacement were also produced at this time; the best preserved example is the Tumalo Fault between Bend and Sisters.

### Construction of a Pleistocene High Cascade Platform

The late Pliocene Cascade depression was flooded (perhaps during subsidence) by basalt and basaltic andesite lavas of the early Pleistocene High Cascades. Eventually, a broad platform of overlapping shield volcanoes filled the depression and spread through low parts of the eastern escarpment; one of these shield volcanoes (Bald Peter) formed against the escarpment 2.1 million years ago. The oldest lavas along the western edge of the platform are 2.0-2.5 million years old (Armstrong and others, 1975).

The central High Cascade platform continued to develop during Pleistocene time. Ancient volcanoes of the Pliocene Cascades were completely buried and basaltic andesite volcanoes such as Three Fingered Jack, Mount Washington, North Sister, Broken Top, and a host of lesser cones and shields were constructed on the top of the platform. Volcanism of this type has persisted until recent times; for example, Bachelor Butte and associated cinder cones south of Broken Top were active 6600-12,000 years ago and Belknap Crater last erupted only 1400 years ago. The remarkable north-south alignment of volcanic vents seen in many parts of the High Cascades is probably a result of magma ascending through buried fault zones in the Pliocene rocks beneath the platform.

Faults have not been recognized within the central High Cascade platform. However, faults of small displacement and northwest trend were active northwest of Bend during

FIGURE 2. TAM MCARTHUR RIM SOUTHWEST OF THREE CREEK LAKE. RHYODACITE LAVA CAPS RIM ON LEFT AND IS OVERLAIN ON RIGHT BY BASALTIC ANDESITE LAVAS FROM BROKEN TOP.

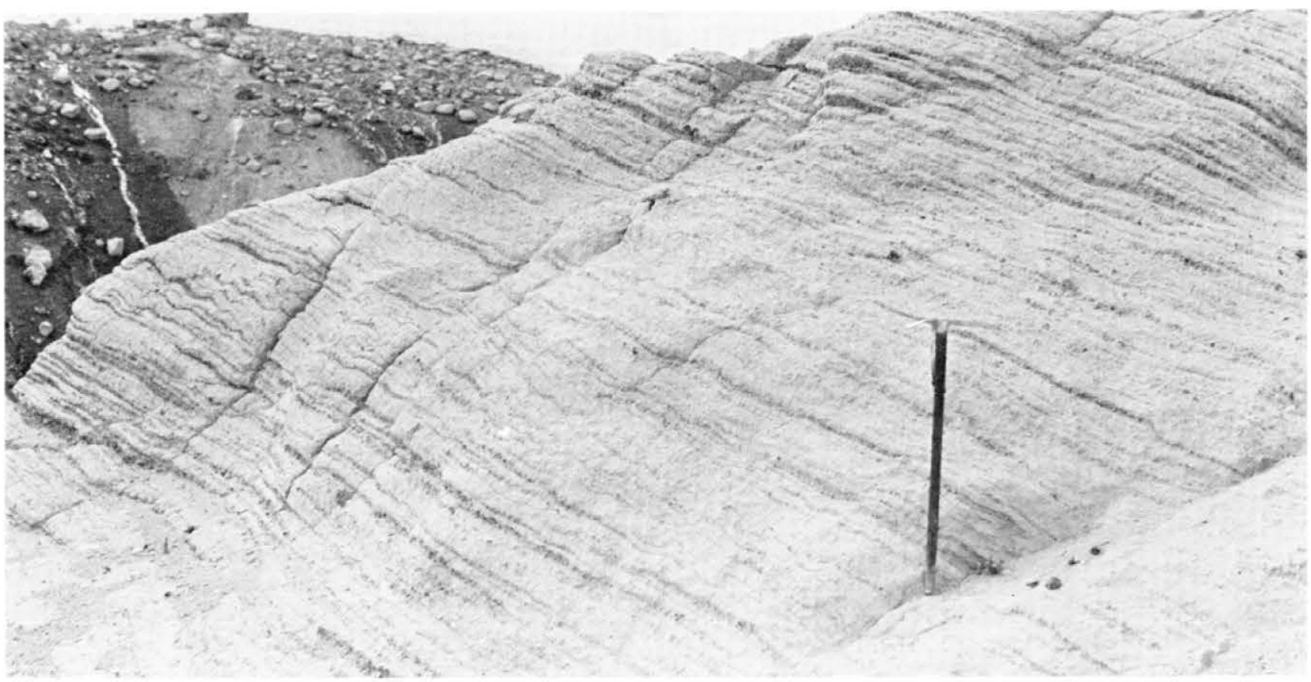

FIGURE 3. LAYERS OF ALTERED RHYODACITE PUMICE IN SILICIC TUFF CONE EXPOSED IN CANYON OF NORTH FORK TUMALO CREEK.

the Pleistocene. Parts of the Tumalo Fault were reactivated and some east-flank Cascade lavas and ash-flow tuffs were displaced. These faults appear to form a northwest extension of the Brothers Fault Zone.

## A Pre-Broken Top Highland of Silicic Volcanoes

In the vicinity of S.W. Broken Top quadrangle, magmas of high-silica andesite, dacite, and rhyodacite composition reached the surface intermittently during early Pleistocene time. A broad highland of volcanic domes, silicic lavas, and ash-flow tuffs was formed on the east margin of the predominantly mafic High Cascade platform. The northeastern margin of this highland can still be seen in the steep mountain front west of Bend. Three Creek Butte, Melvin Butte, and the summits of 9 other partly buried silicic domes, together with silicic lavas in the canyons of Squaw and Tumalo Creeks are the best exposed parts of the early Pleistocene highland. In S.W. Broken Top quadrangle, the much-eroded remnants of dacitic Todd Lake Volcano and the dacite lavas exposed in lower cliffs of Tam McArthur Rim probably represent the highest and youngest parts of the highland.

Silicic volcanism in the Broken Top area appears to have abated for a time during which basalt and basaltic andesite continued to erupt, adding to the High Cascade platform and inundating parts of the silicic highland. It was at this time that the eastern slope of the Cascades between Broken Top and Bend was extensively covered by flows of mafic lava. Remnants of numerous cinder cones which mark source vents are found on the eastern slope and in the mountains. Examples are the Triangle Hill group of cones and the cone near Rim Lake, east and north of Broken Top, respectively.

## Development of Broken Top Volcano

Broken Top is a complex and magnificently exposed composite volcano of basaltic andesite composition. A cone of scoria and ash accumulated near the vent and was repeatedly invaded by dikes and sills which served to strengthen the structure and probably fed numerous streams of a surrounding lava cone. The scoria, dike rocks, and lavas were all of uniform composition, crowded with phenocrysts of plagioclase, olivine, two pyroxenes, and magnetite. Silicic magmas continued to reach the surface through Broken Top vents so that andesite, dacite, and rhyodacite lavas, ash-flow tuffs, and pyroclastic-fall deposits were interbedded with basaltic andesite flows and agglomerates, from the lower flanks to the summit of the volcano.

In mid-development, the summit crater of Broken Top was enlarged to a diameter of 0.8 km, probably by subsidence. The resulting depression was filled by thin flows of basaltic andesite and most of the summit cone was eventually buried beneath a shroud of thin, vesicular lavas. Finally, after the lava conduit attained a width of 0.3-0.5 km, the magma congealed to form a central plug of micronorite. The plug and adjacent rocks were then subjected to an episode of mild hydrothermal alteration. Crowe and Nolf (1977) have recently published a similar interpretation of the development of Broken Top.

## Latest Pleistocene Volcanic Activity

A 10-km alignment of rhyodacite domes extending from Devils Hill on the south to Demaris Lake on the north, was erupted during late Pleistocene time. These domes were partly buried by andesite lavas from South Sister vents. Although many additional silicic vents were active at this time in the vicinity of Three Sisters, only one small rhyodacite dome erupted east of the South Sister. It appeared at the northwest base of Broken Top; its associated air-fall pumice deposits are still preserved on the nonglaciated crest of Broken Top northwest ridge.

A northwest-trending chain of six cinder cone and lava vents erupted between Tumalo Mountain and Broken Top. Each vent produced lava similar to the glomeroporphyritic basaltic andesite of Tumalo Mountain; probably all were developed from the same magma at

FIGURE 4. CROOK GLACIER CIRQUE ON SOUTHEAST SIDE OF BROKEN TOP. APRONS OF TALUS AND HOLOCENE GLACIAL DEPOSITS MANTLE LOWER SLOPES. CIRQUE WALLS ARE CHIEFLY COMPOSED OF THIN BASALTIC ANDESITE LAVA FLOWS AND INTERBEDDED AGGLOMERATE.

FIGURE 5. DACITIC IGNIMBRITE IN SOUTHWEST WALL OF CROOK GLACIER CIRQUE, BROKEN TOP. WHITE BASAL ZONE OF NONWELDED PUMICE IS OVERLAIN BY AN ORANGE POORLY WELDED ZONE WHICH PASSES UPWARD TO BUFF-AND-BLACK LAYERS OF NONWELDED PUMICE.

FIGURE 6. NORTHEAST WALL OF CROOK GLACIER CIRQUE, BROKEN TOP. INCLINED LAYERS OF RED AGGLOMERATE AND SCORIACEOUS LAVA OF EARLY SUMMIT CONE(RIGHT) ARE IN CONTACT WITH HORIZONTAL LAVAS WHICH FILLED A SUBSIDENCE CRATER(CENTER). IRREGULAR SURFACE OF CENTRAL CONDUIT PLUG IS EXPOSED ON THE LEFT.

FIGURE 7. SOUTHWEST WALL OF BEND GLACIER CIRQUE ON NORTH SIDE OF BROKEN TOP. DIKE CUTS DIAGONALLY ACROSS BASALTIC ANDESITE LAVAS AND INTERBEDS OF OXIDIZED AND PALAGONITIZED SCORIA. SOUTH SISTER IN BACKGROUND.

about the same time.

Basaltic magma reached the surface south of South Sister to form a set of palagonitic tuff cones which were soon buried under fresh cinders and lavas of Talupus and Katsuk Buttes. Only the lower parts of these volcanoes were eroded by latest Pleistocene glaciers.

## Pleistocene Glaciation

Late Pleistocene glaciers covered all of the S.W. Broken Top quadrangle except the summit area of Tumalo Mountain and the northwest ridge crest and other prominences near the summit of Broken Top. Evidence of multiple glaciation is obscure. Pleistocene glacial deposits shown on accompanying geologic maps are probably equivalent to Suttle Lake drift of Scott (1977) and were deposited during the last episode of glaciation, ending some 12,000 years ago. Cirque basins were carved into the sides of Broken Top, Tam McArthur Rim, Todd Lake Volcano, and into the east side of Tumalo Mountain. Large tracts of striated bedrock are exposed above 7000 feet elevation; most of the debris from glacial erosion was deposited as moraines and outwash at lower elevations north, east, and south of the quadrangle. There is no evidence that eruptive activity was initiated beneath a thick cover of ice. However, some of the palagonitic tuff cones such as Talapus Butte suggest intimate and localized contact between ascending magma and ground or surface waters during the Pleistocene.

## Holocene Volcanic Activity

After final retreat of Pleistocene glaciers a north-south chain of basaltic cinder cones developed south of Todd Lake and basaltic lavas moved 3 km west to Katsuk Butte. At about the same time, nearly identical magma produced Cayuse Cone and related flows from a vent 2.5 km north of Todd Lake. Still later, but before the appearance of Mazama ash from Crater Lake 6600 years ago, basaltic andesite erupted to form a small shield volcano on the north side of Bachelor Butte. The last eruption of mafic magma in S.W. Broken Top quadrangle also occurred at the north base of Bachelor Butte. A cinder cone over 150 m in height was formed and basaltic andesite lavas spread broadly to Sparks Lake basin, 5 km to the west.

Rhyodacitic ash and lapilli from eruptions of Rock Mesa at the southwest base of South Sister fell over the entire S.W. Broken Top quadrangle 2300 years ago. At a slightly later time similar material was erupted from a chain of vents on the east side of Devils Hill and from another chain of vents extending from the southeast to the northeast base of South Sister. All of these vents are now marked by domes and flows of rhyodacite, some of which moved into the west part of Broken Top quadrangle. It is clear that both mafic and silicic volcanism have continued into Holocene time and that future eruptions in this area are not unlikely.

## Neoglaciation and Modern Erosion

Minor Neoglacial advances are recorded by fresh moraines and outwash fans in cirque basins on the south, east, and north sides of Broken Top summit. Outwash from Neoglacial Carver, Prouty, and Lewis Glaciers on the east flank of Middle and South Sisters is widespread in the northwest part of the Broken Top quadrangle. Some of the Neoglacial moraines are mantled by 2300-year-old rhyodacite pumice; others were formed after the pumice was deposited.

Talus aprons and talus ramparts have formed on over-steep glaciated mountain slopes and alluvium is currently accumulating in the Green Lake and Sparks Lake area. A Neoglacial moraine in the east cirque of Broken Top was breached in 1966, abruptly releasing part of a small lake (Nolf, 1966). Erosional and depositional effects of the resulting flood are still obvious over the 9-km length of affected drainage.

FIGURE 8. RHYODACITE LAVAS OF HOLOCENE NEWBERRY FLOW AND GOOSE CREEK CHAIN OF DOMES. NORTHWEST RIDGE OF BROKEN TOP ON SKYLINE.

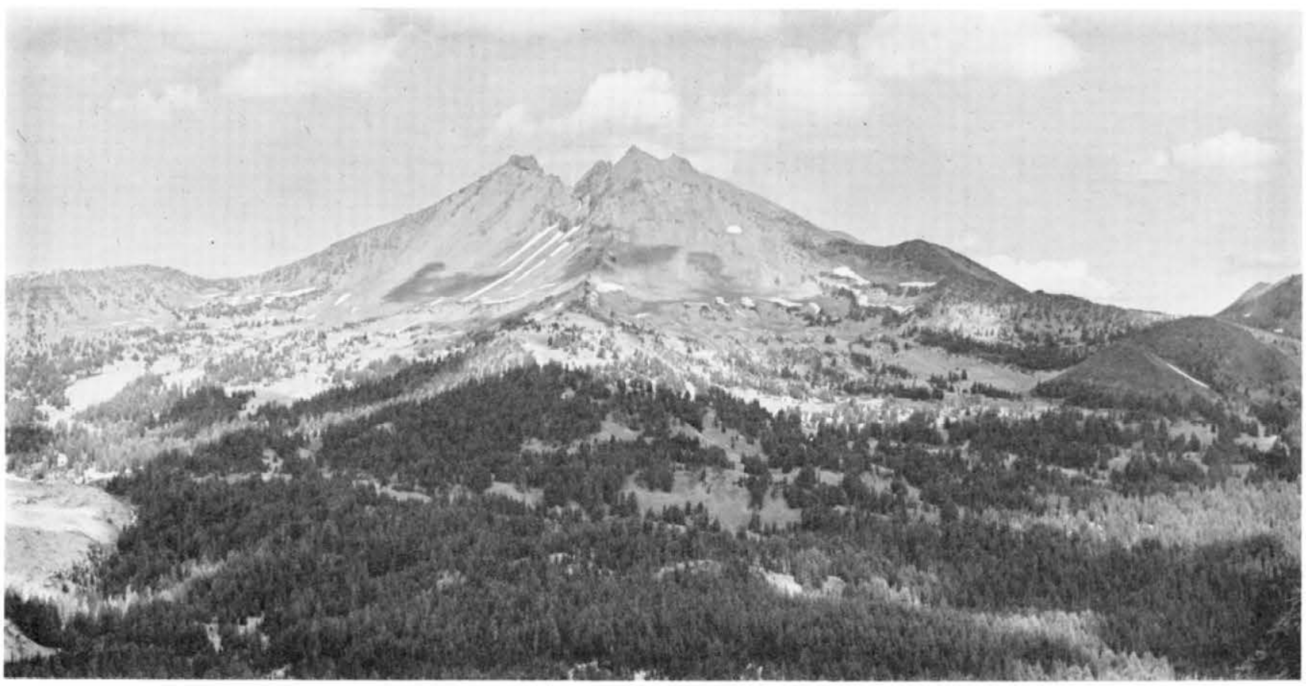

FIGURE 9. SOUTHWEST SIDE OF BROKEN TOP VOLCANO. CAYUSE CONE OF HOLOCENE BASALT(RIGHT) AND TERMINUS OF NEWBERRY RHYODACITE FLOW(LEFT).

FIGURE 10. CAYUSE CONE ON SOUTHWEST SLOPE OF BROKEN TOP. TODD LAKE VOLCANO DACITE PLUG IN BACKGROUND WITH BACHELOR BUTTE ON SKYLINE.

FIGURE 11. MORAINE-DAMMED LAKE ON EAST SIDE OF BROKEN TOP. DIMINISHED IN SIZE FOLLOWING EROSIONAL BREACH IN 1966. BALL BUTTE AND TUMALO MOUNTAIN IN BACKGROUND, EXHAUSTED FIELD ASSISTANT IN FOREGROUND.

## GEOLOGIC MAPS OF S.W. BROKEN TOP QUADRANGLE

The 7.5-minute S.W. Broken Top quadrangle has been divided into nine 2.5-minute rectangular areas and consecutively numbered according to the pattern shown in Figure 12. Distribution of mapped volcanic and nonvolcanic deposits within these areas is represented on the following geologic maps, Figures 14 through 22. Unit symbols are explained in the text; other symbols are given in Figure 13.

### Representation of Mapped Units

In this report, symbols representing mapped volcanic rocks convey four categories of information: age, composition, occurrence, and unit number. For example, "HoDaLa3" designates the third-numbered unit of Holocene dacite lava and "PsBsPt4" designates the fourth-numbered Pleistocene basaltic tuff cone.

#### Age

It is unlikely that rocks older than one million years are exposed in the S.W. Broken Top quadrangle; most are younger than a few hundred-thousand years. Therefore, a paleomagnetic indication of rocks older than 700,000 years is of limited utility. Mazama ash (6600 years, Rubin and Alexander, 1960) is of widespread occurrence but few rock units within the quadrangle are younger. Most rock units in the central High Cascades can be assigned without ambiguity to either Holocene (younger than 10,000-12,000 years) or Pleistocene (10,000-12,000 to 2-3 million years) on the basis of their relationship to glaciated surfaces and glacial deposits.

Ho: Holocene deposits. Includes Neoglacial deposits, alluvium, and volcanic and volcaniclastic rocks less than 10,000-12,000 years old.

Ps: Pleistocene deposits. Includes glacial deposits, alluvium, and volcanic and volcaniclastic rocks older than 12,000 years but less than 2 million years.

#### Composition

At this writing, there is no universally accepted and precisely defined nomenclature applied to calc-alkaline rocks. Because many calc-alkaline Cascade rocks cannot be characterized adequately without chemical data, and because silica is a significantly variable, abundant, and easily determined constituent, it is probably the most suitable compositional parameter for classification. There is ample precedent relating an increase in silica content to the names basalt, basaltic andesite, andesite, dacite, and rhyodacite (Williams, 1942; Peck and others, 1964; Greene, 1968). In this study, five weight percent increments of silica content are assigned to basalt (48-53), basaltic andesite (53-58), andesite (58-63), dacite (63-68), and rhyodacite (68-73+)*. These values closely follow the silica subdivisions used for calc-alkaline volcanic rock series by S. R. Taylor (1969), Wise (1969), and Mackenzie and Chapell (1972); they are not in serious conflict with previously published petrographic names of rocks from the central High Cascades (Williams, 1944).

Bs Basalt, 48-53 weight percent $SiO_2$, $H_2O$-free.

BA Basaltic andesite, 53-58.

*Many High Cascade rocks contain more than 73 percent silica but none should be designated "rhyolite" unless it also contains more than 4 percent potash. Rocks that contain less than 48 percent silica might best be called "melabasalt," but they are virtually unknown in the High Cascades.

An Andesite, 58-63.

Da Dacite, 63-68.

Rd Rhyodacite, 68 or more.

Occurrence of Volcanic Deposits

Volcanic and volcaniclastic rocks in the S.W. Broken Top quadrangle occur in the form of intrusive dikes, sills, and plugs or as extrusive lava flows and volcanic domes, ash-flow deposits, ash-fall deposits, near-vent agglomerates, cinder cones, and tuff cones.

La Lavas. Includes volcanic domes, single flows, and composite flows in which pyroclastic material is subordinate.

Pc Coarse pyroclastic deposits. Includes mafic and silicic scoria and agglomerate of cinder cones and parts of composite volcanoes in which pyroclastic material is predominant; also includes pumice ramparts adjacent to volcanic domes.

Pt Tuff cones and tuff cone remnants. Includes altered (palagonitic) and fresh mafic and silicic varieties; also includes palagonitized deposits of bedded ash and lapilli in composite volcanoes.

Pf Fine-grained pyroclastic-fall deposits. Includes surficial blankets of mafic or silicic ash, generally far removed from the source vent.

Pi Ignimbritic deposits. Includes all welded and nonwelded deposits of pyroclastic-flow origin.

Id,s,p Intrusive dikes, sills, and plugs.

Occurrence of Nonvolcanic Deposits

Mapped nonvolcanic deposits are represented by symbols which designate age and occurrence only. Unit numbers are given to these deposits if they possess characteristics that require separate description.

Al Alluvium. Includes well-sorted glacial outwash, flood deposits; silt, sand, and gravel of stream and lake beds.

Gd Glacial drift. Includes till of terminal, latteral, and ground moraines, and some poorly sorted outwash near terminal moraines.

Ta Talus. Includes extensive aprons of talus, talus ramparts, and blockfields.

Sn Glacial ice, "permanent" snowfields.

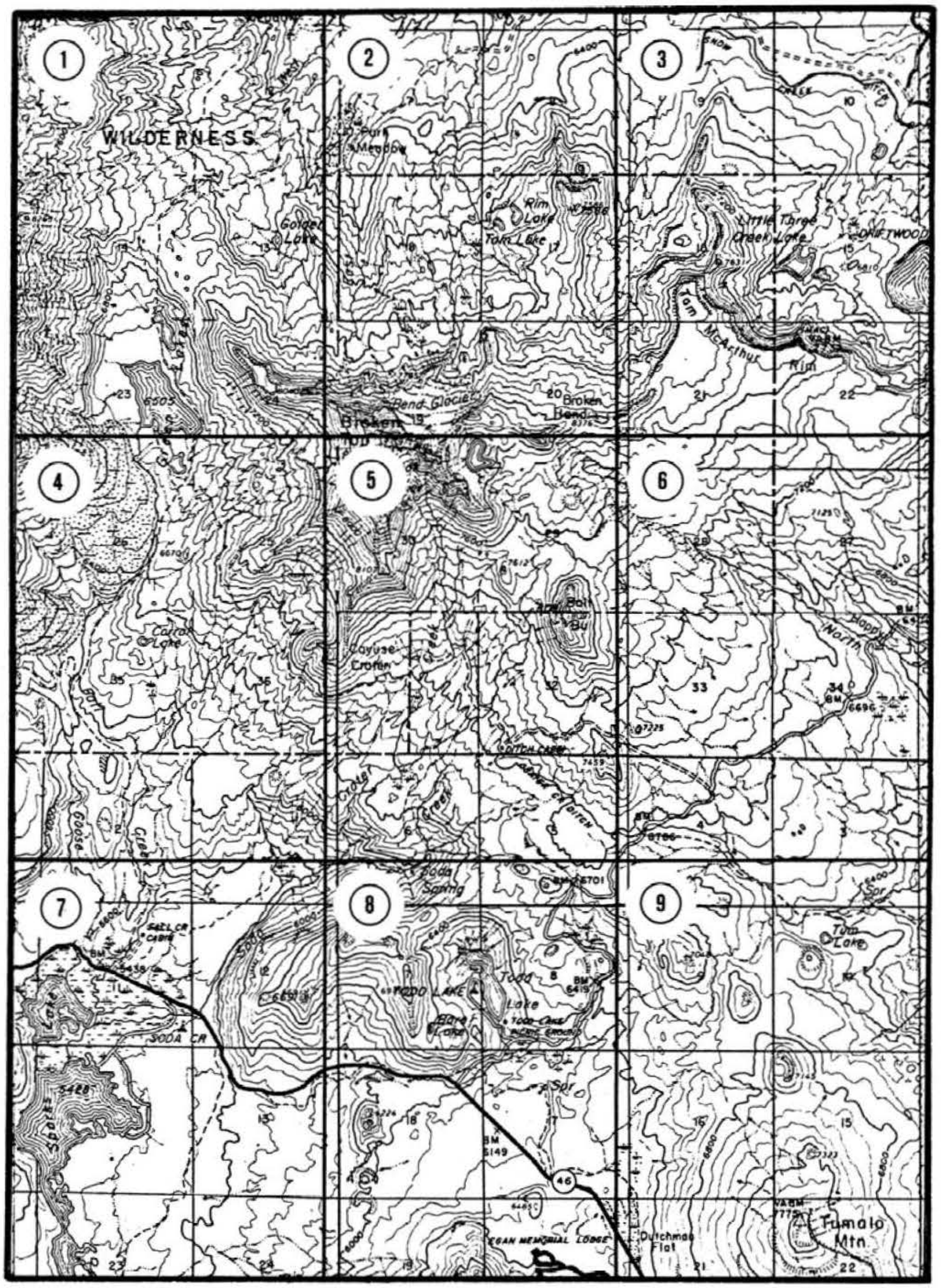


FIGURE 12. INDEX TO 9 GEOLOGIC MAPS OF S.W. BROKEN TOP QUADRANGLE.

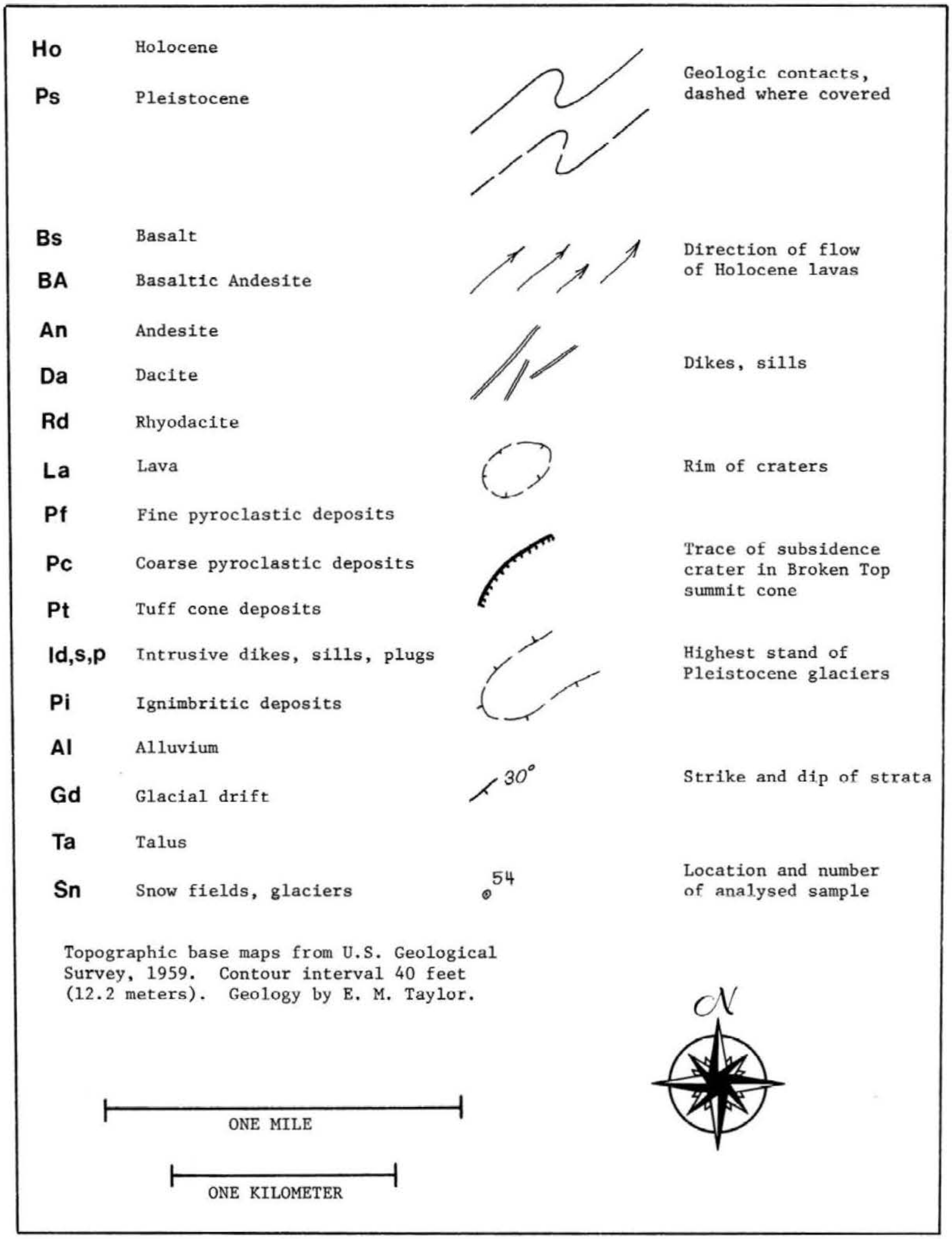


FIGURE 13. LEGEND FOR 9 GEOLOGIC MAPS OF S.W. BROKEN TOP QUADRANGLE.

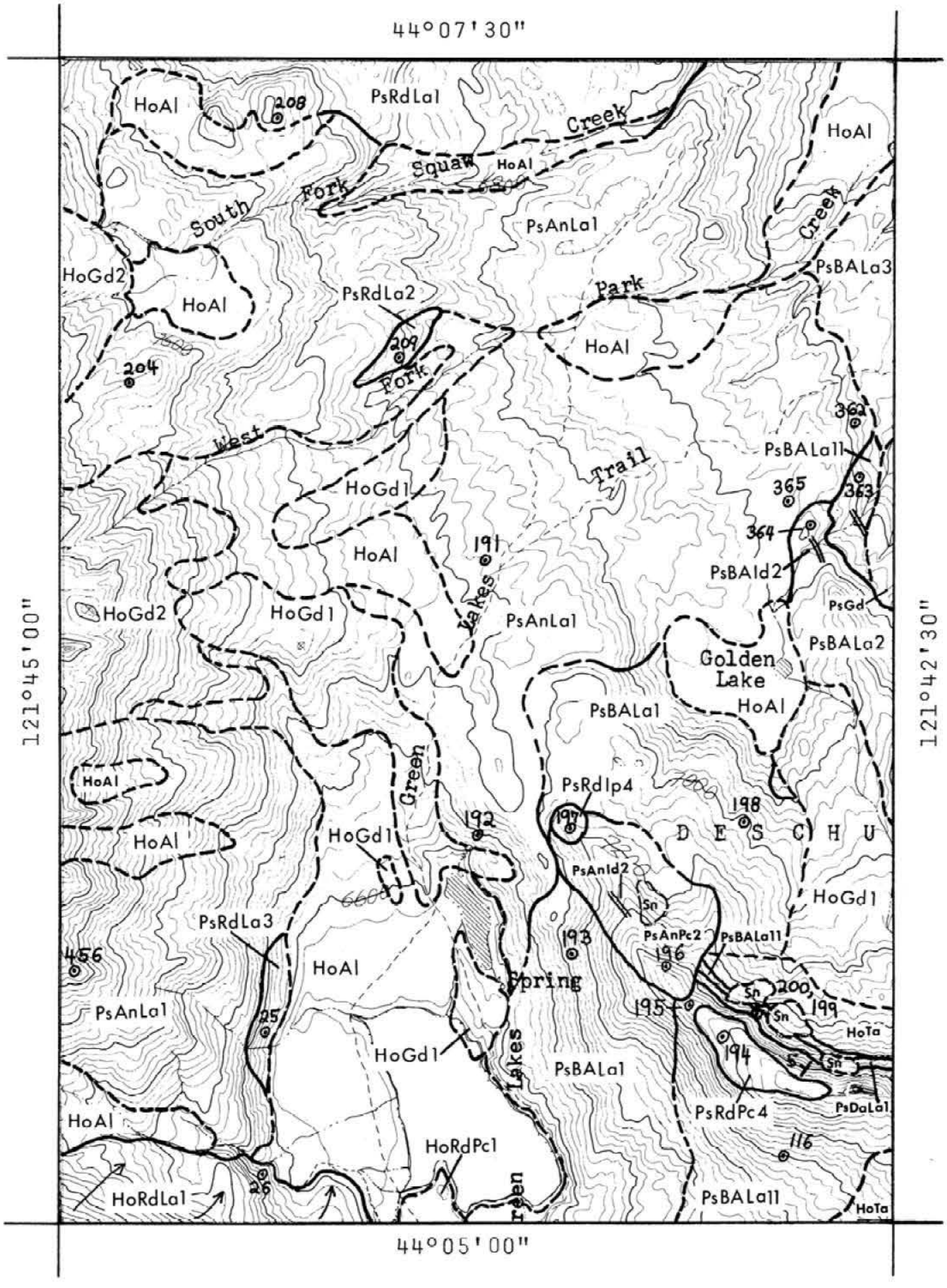


FIGURE 14. GEOLOGIC MAP NO. 1, S.W. BROKEN TOP QUADRANGLE, OREGON.

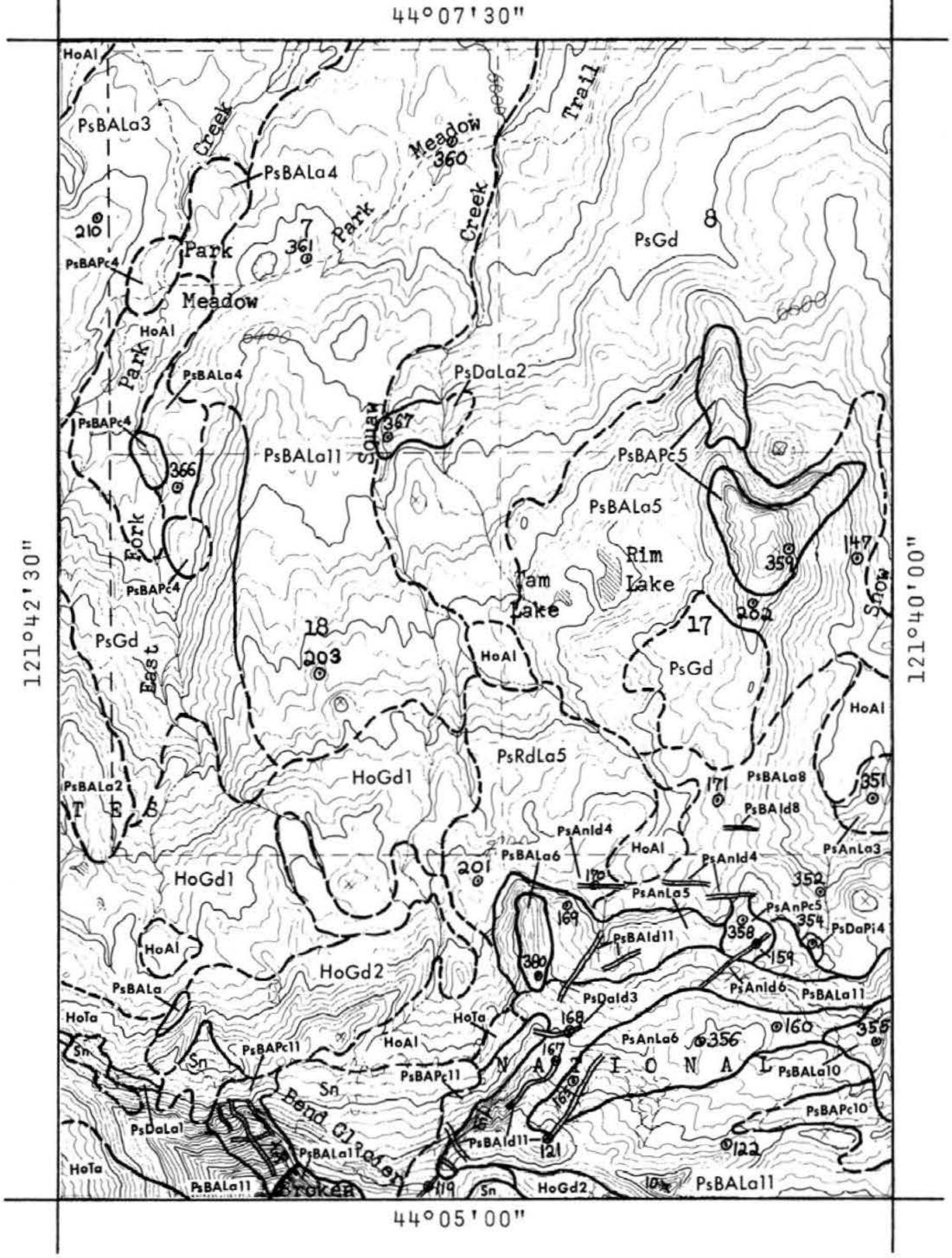


FIGURE 15. GEOLOGIC MAP NO. 2, S.W. BROKEN TOP QUADRANGLE, OREGON.

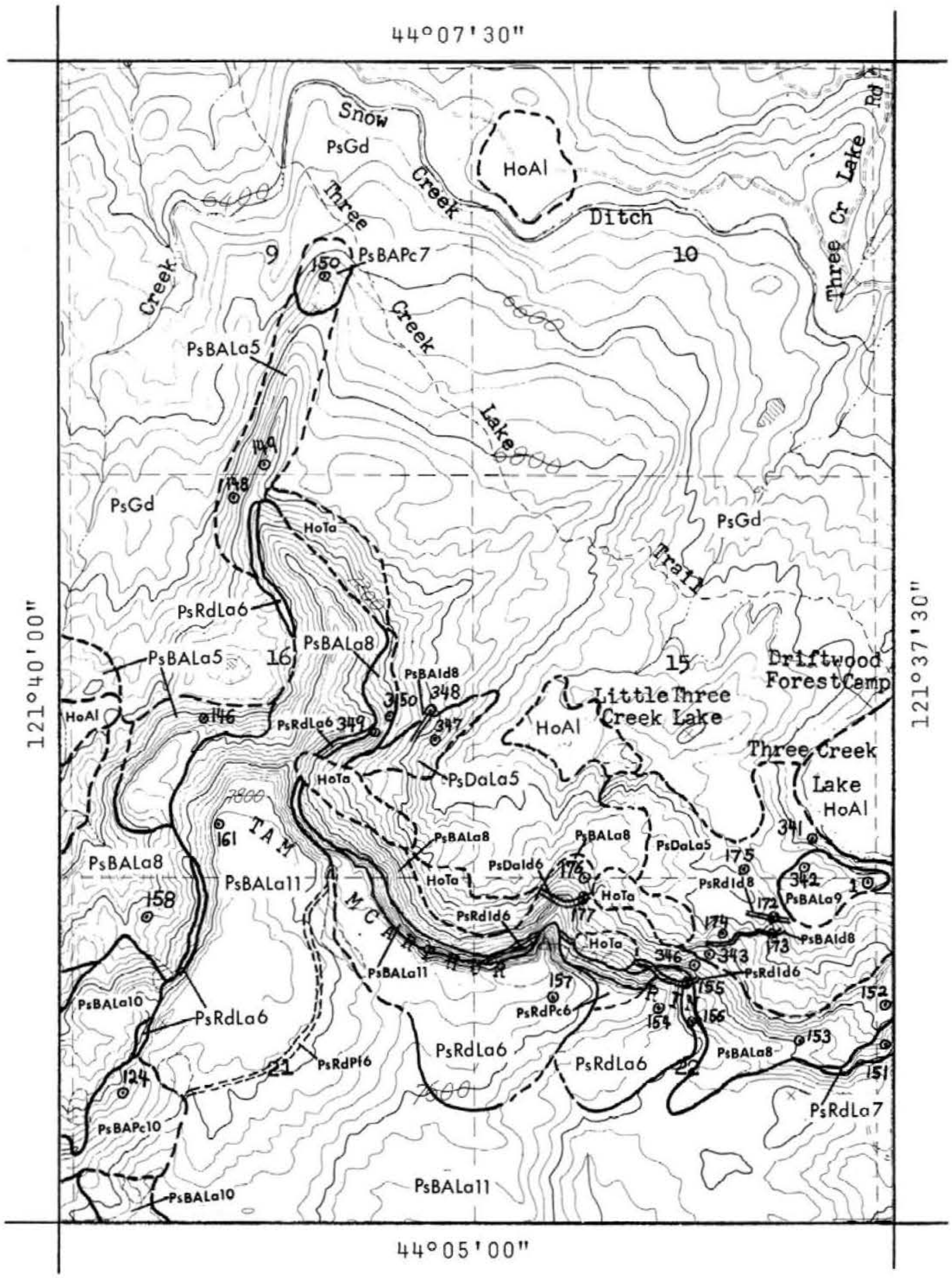


FIGURE 16. GEOLOGIC MAP NO. 3, S.W. BROKEN TOP QUADRANGLE, OREGON.

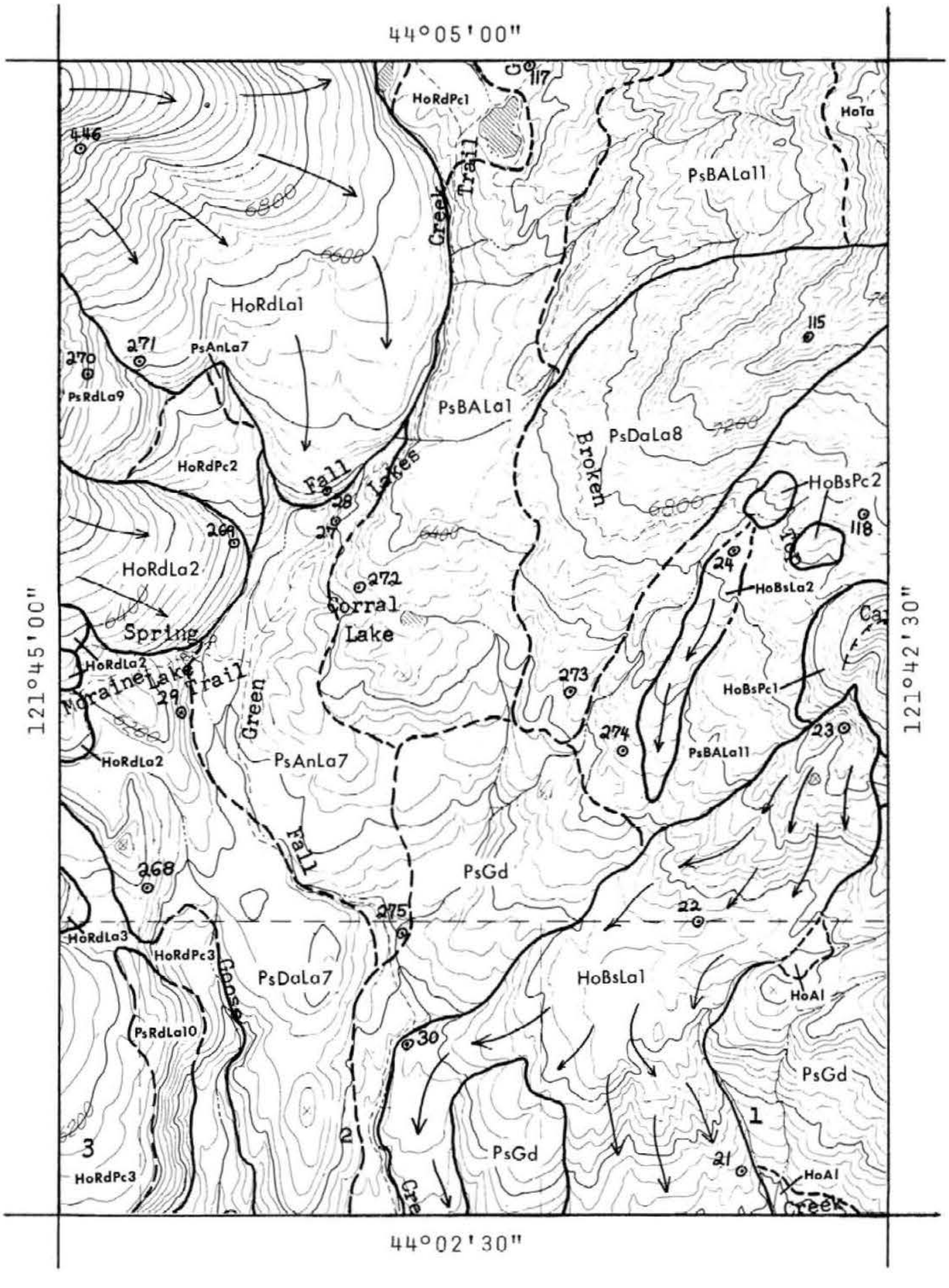


FIGURE 17. GEOLOGIC MAP NO. 4, S.W. BROKEN TOP QUADRANGLE, OREGON.

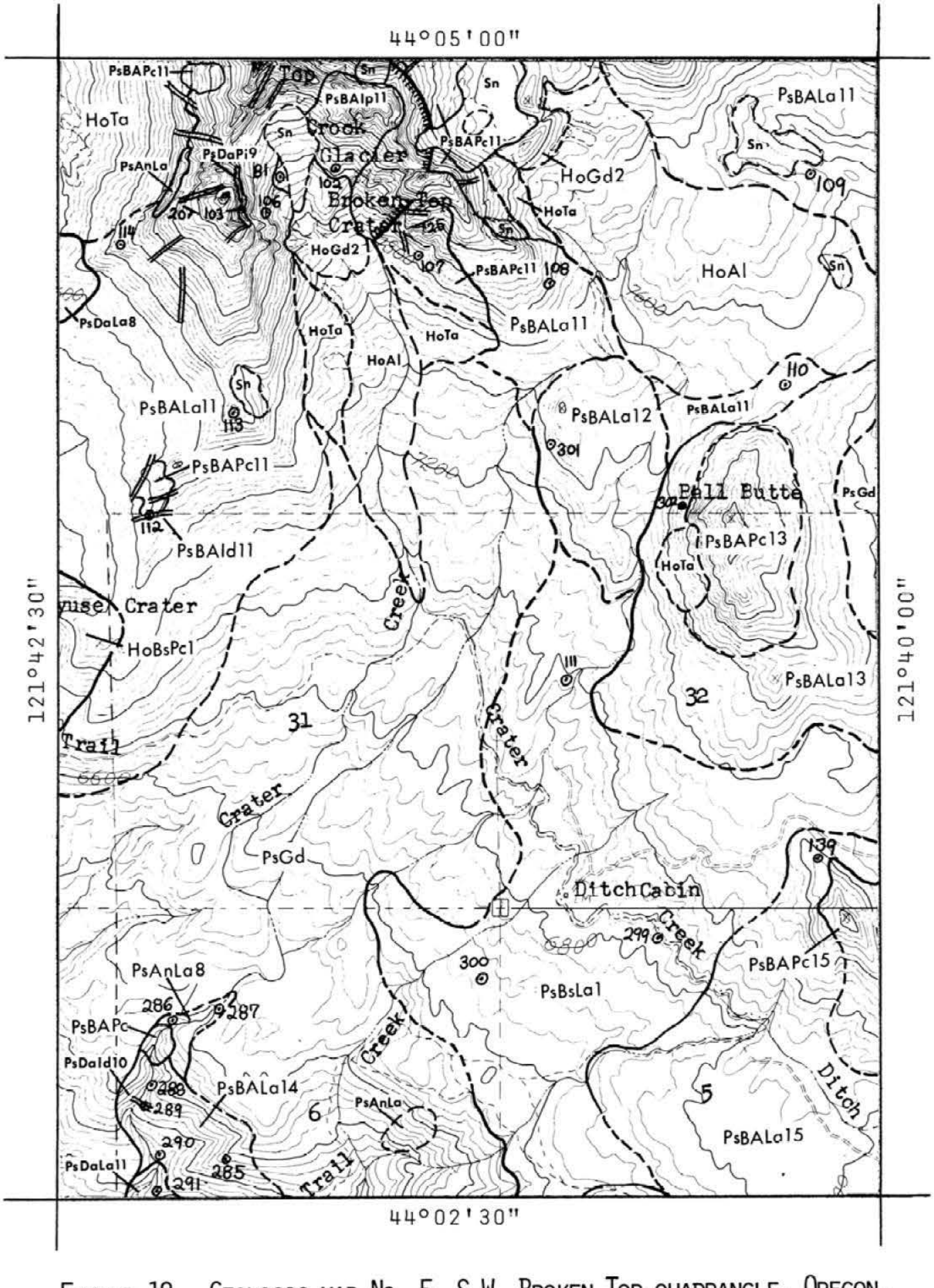


FIGURE 18. GEOLOGIC MAP NO. 5, S.W. BROKEN TOP QUADRANGLE, OREGON.

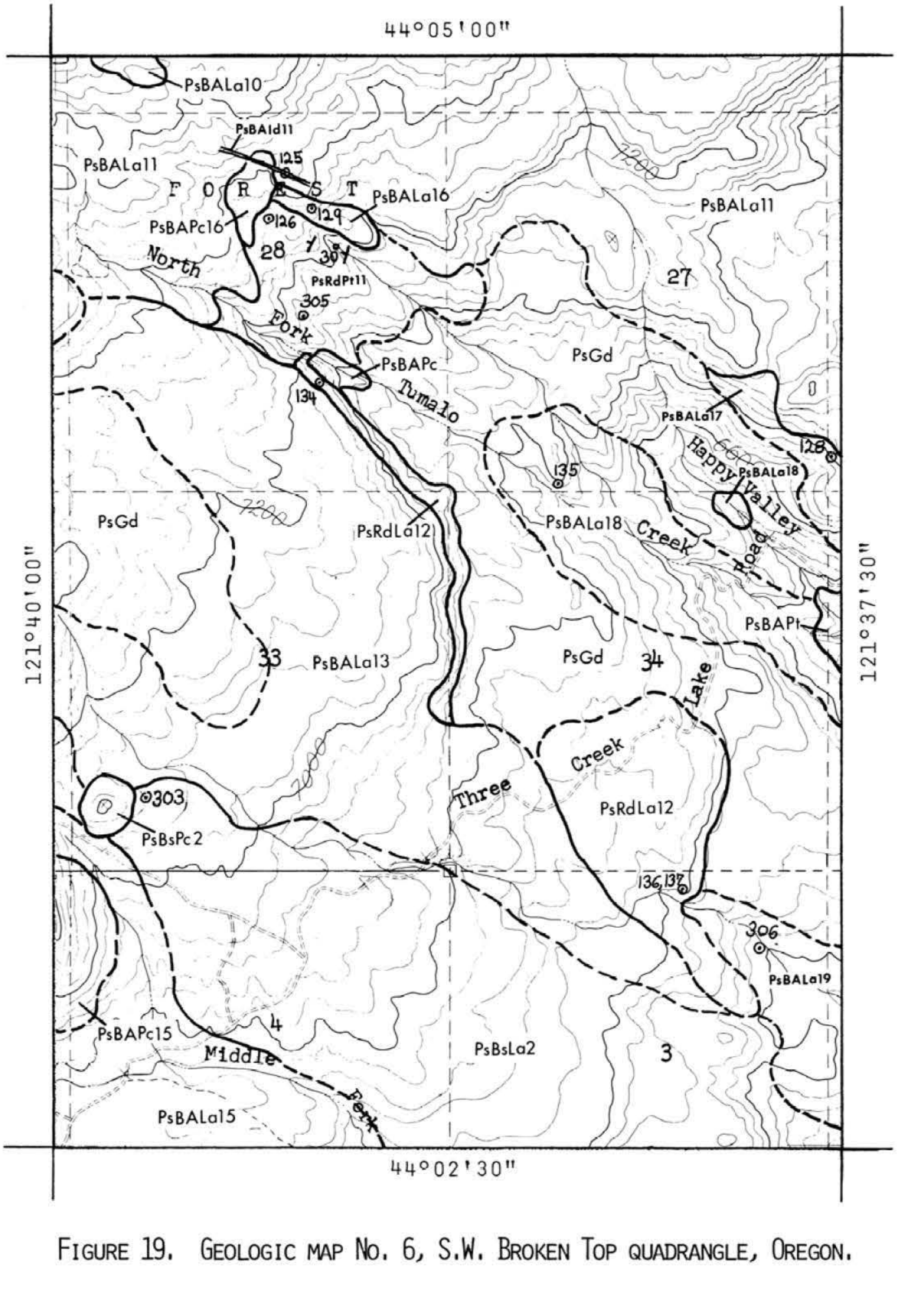


FIGURE 19. GEOLOGIC MAP NO. 6, S.W. BROKEN TOP QUADRANGLE, OREGON.

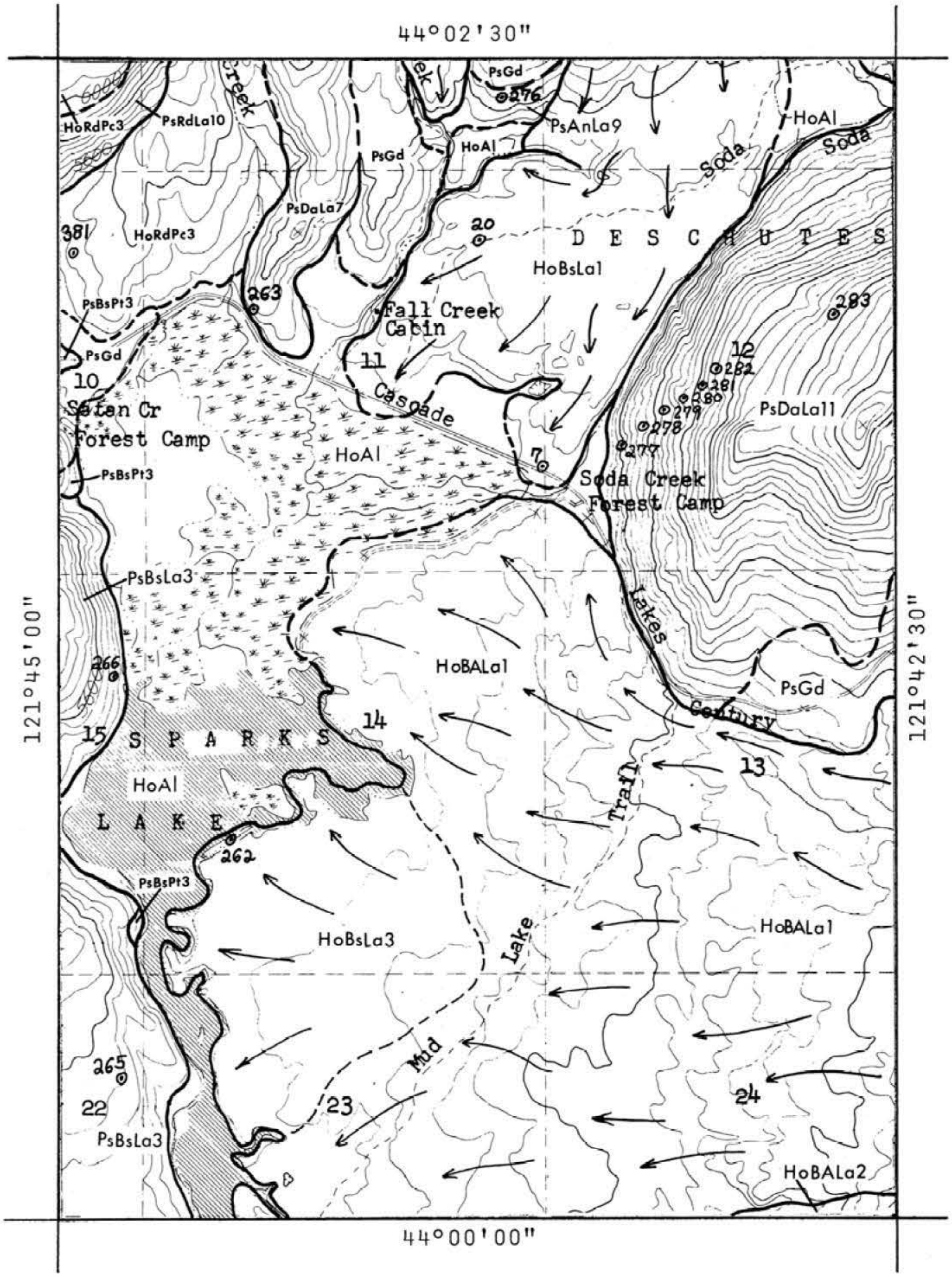


FIGURE 20. GEOLOGIC MAP NO. 7, S.W. BROKEN TOP QUADRANGLE, OREGON.

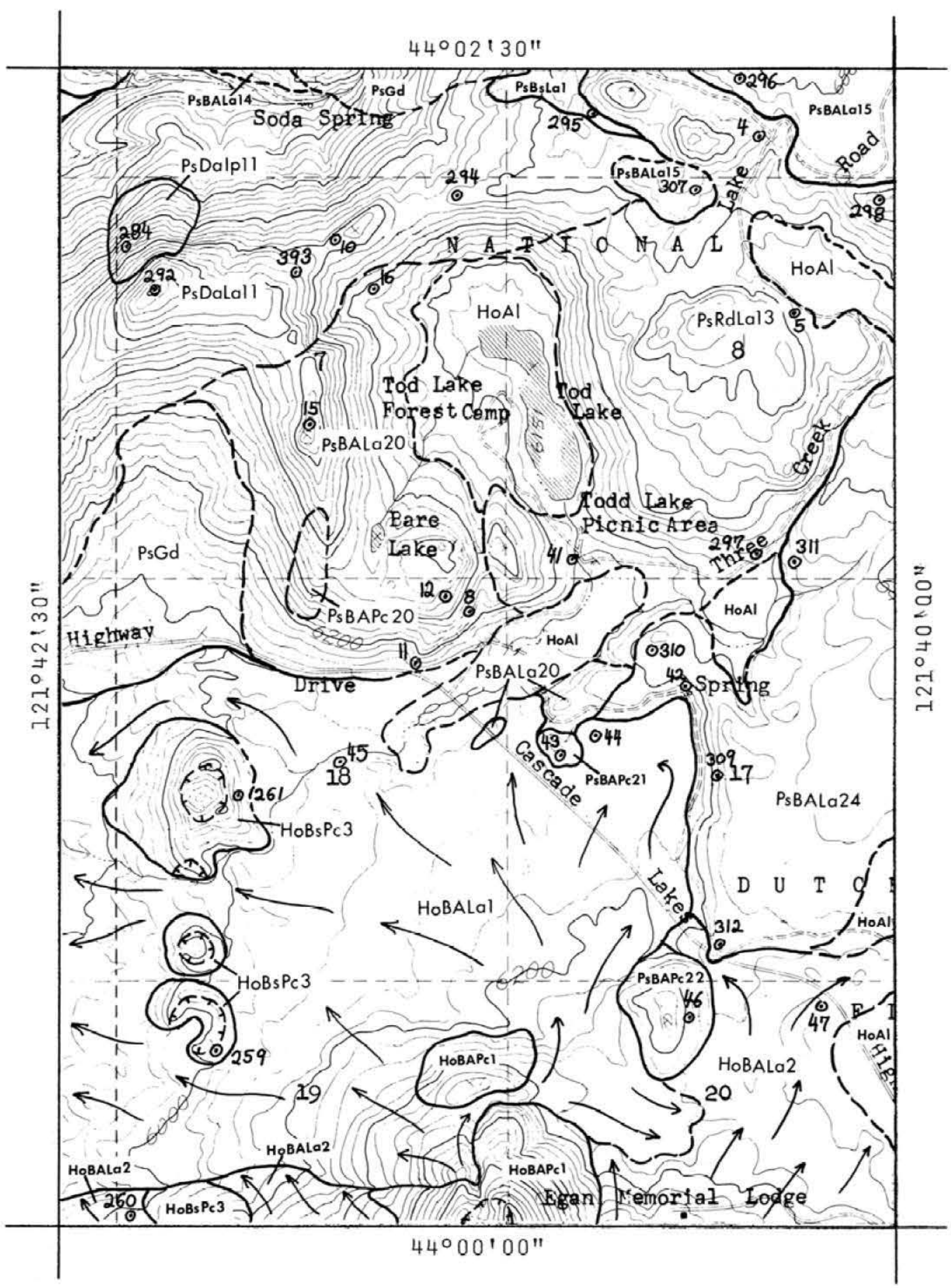


FIGURE 21. GEOLOGIC MAP NO. 8, S.W. BROKEN TOP QUADRANGLE, OREGON.

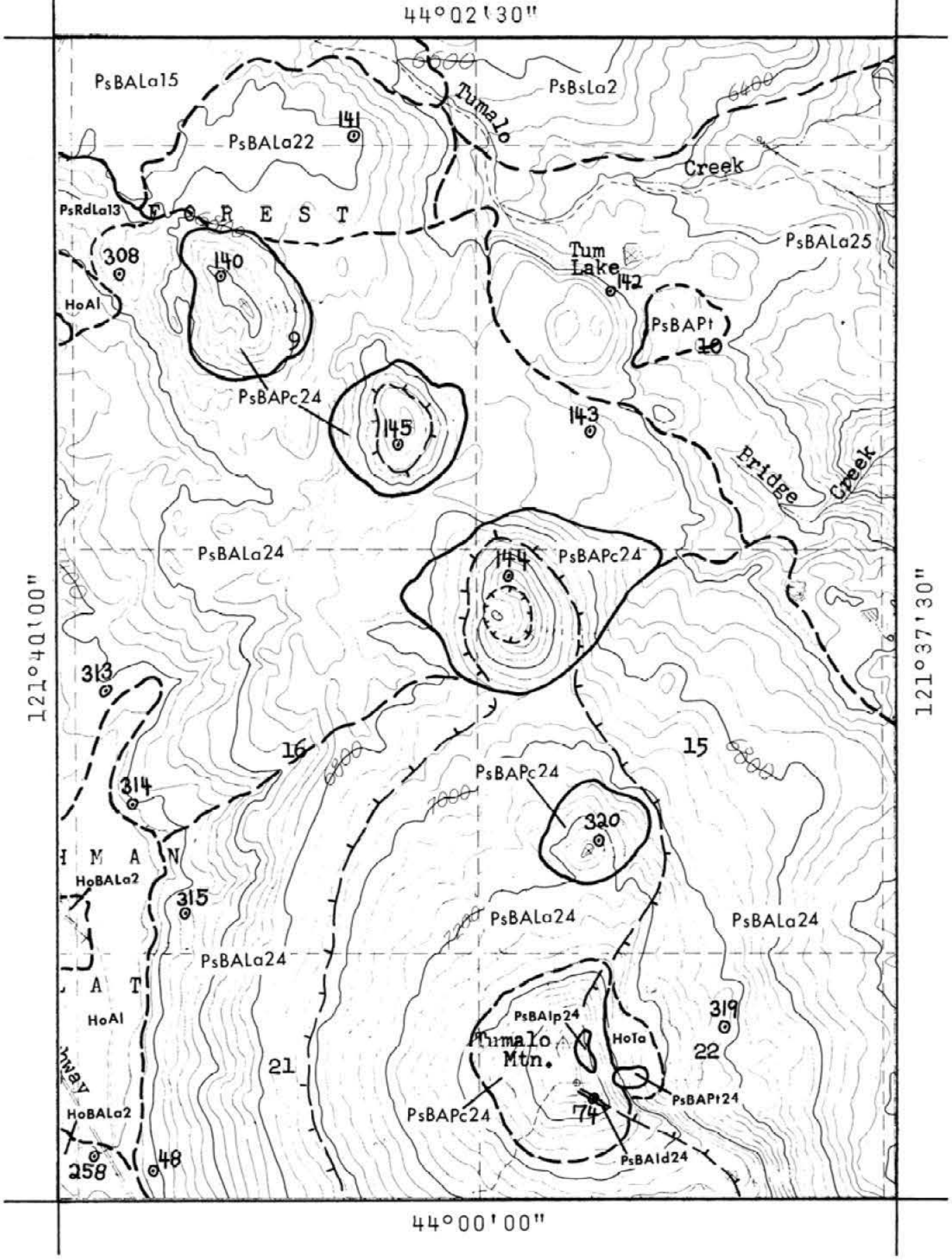


FIGURE 22. GEOLOGIC MAP No. 9, S.W. BROKEN TOP QUADRANGLE, OREGON.

## DESCRIPTIONS OF MAPPED UNITS

Salient features of mapped units are summarized below in consecutively numbered age-composition groups. Each unit is numbered on the geologic maps and appropriate geologic map numbers are included in each description. Consequently, a description of any given mapped unit is easily found and the mapped locations of each type of deposit are readily identified.

Petrographic characteristics were determined through study of thin sections, usually of fresh, nonvesicular glassy samples taken from widely separated parts of each unit. Phenocryst proportions were measured using standard point-counting techniques and are reported as volume percent of solid rock, excluding void spaces. Compositions of plagioclase are reported as mole percent An and were determined by measurement of extinction angles according to the method of combined albite and Carlsbad twins, the a-normal method, and the Michel-Levy method, in that order of preference. Charts published by Tobi (1963), Von Burri (1967), and Shelley (1975) for volcanic plagioclase were used in support of these methods, respectively.

A silica content is given for each described unit as well as the sample numbers of pertinent chemical analyses and calculated averages. All analyses are listed consecutively by sample number in Appendix 1, corresponding to Appendix 2, sample locations and geologic map numbers. Each sample site is also identified by number on the appropriate geologic map. Analytical values are expressed as weight percent oxides of the eight principal cations Si, Al, Fe, Ca, Mg, K, Na, and Ti. All iron is expressed as FeO. Each analysed sample was split from at least 0.5 kg of uniform rock powder and was converted to an anhydrous condition. A lithium borate fusion technique was used to prepare samples for x-ray emission spectrometry for Al, Fe, Ca, K, and Ti. This was followed by a silicomolybdate colorimetric method for Si and atomic absorption spectrophotometry for Mg and Na. All determinative procedures were calibrated to a set of U.S. Geological Survey analysed rock standards. Replicate analyses have established that results are reproducible to within 0.5, 0.5, 0.1, 0.1, 0.1, 0.05, 0.1, and 0.05 of the respectively tabulated values. Analyses were performed by E. M. Taylor with able assistance from Mrs. R. L. Lightfoot.

### Units of Holocene Nonvolcanic Deposits

HoGd1
HoGd2 — Terminal and lateral Neoglacial moraines (HoGd1) in the vicinity of Broken Top and Three Sisters which are overlain by fragments of pumice and obsidian from 2300-year-old Rock Mesa eruption, and Neoglacial moraines (HoGd2) which are not.

### Units of Holocene Basalt

HoBsLa1
HoBsPc1 — Olivine basalt lavas from Cayuse Cone. Silica 49-51. Cone of red and black scoria 200 m high, breached on S.W. side by lavas which moved in two lobes, 4.5 km S. to Sparks Lk. and 1.3 km W. to Fall Cr. Black to gray scoriaceous aa surface with lava levees, gutters, and hummocky terrain. Phenocrysts of Ol (10-12%; up to 2.0 mm) and sparse microphenocrysts of Plag. Groundmass Plag An60-65. Not glaciated; overlain by pumice from Devils Hill Chain of Domes, Rock Mesa (2300 C-14 yrs), and Mazama ash (6600 yrs). Terminus of main lobe is buried in alluvial deposits of Sparks Lk. basin. Analyses 7, 20, 21, 22, 23, 30; average Cayuse lava, 1000. Maps 4, 7.

HoBsLa2
HoBsPc2 — Olivine basalt lava and two small cones 0.2 and 0.5 km N.W. of Cayuse Cone. Silica 51-52. Narrow lava flow, 1.2 km long, issued from S.W. base of N.W. cone. Surface features, composition, mineralogy, and probable age similar to Cayuse lavas and cone. Analysis 24. Map 4.

HoBsLa3 Olivine basalt lava and chain of cinder cones S.W. of Todd Lk. Silica 50-52.
HoBsPc3 Hummocky black and gray lava surfaces composed of aa fragments. Very large, coherent, tipped blocks along flow margins. Phenocrysts of Ol (11-12%; up to 1 mm) with sparse microphenocrysts of Plag. Pilotaxitic groundmass of An 65-70 Plag microlites in subophitic intergrowth with Cpx. Two-km N-S alignment of 4 cinder cones with remnants of 5 vents. Black and red cinders, spatter, and bombs. Partly exposed flows from these cones probably exist in the basaltic andesite lava fields to the W. but are mapped separately only along E. side of Sparks Lk. Cones and lavas not glaciated; overlain by pumice from Rock Mesa and ash from Mazama. Also overlain by basaltic andesite lavas from Bachelor Bu. and from cone at N. base of Bachelor Bu. Analyses 259, 261, 262; average, 1001. Maps 7, 8.

## Units of Holocene Basaltic Andesite

HoBALa1 Basaltic andesite lavas which extend from source cone at N. base of Bachelor
HoBAPc1 Bu., 4.5 km W. to Sparks Lk. Silica 54-55. Hummocky, scoriaceous, black and gray lava surfaces with lava levees, blocky near source. Microphenocrysts of Plag and Ol (both <1%). Groundmass pilotaxitic intergranular, Plag microlites An 40-45. Cone of red and black cinders and spatter was breached on N.W. side. Lavas and cone not glaciated; overlain by Rock Mesa pumice and Mazama ash. Terminus of flow is partly buried in alluvium of Sparks Lk. basin and alluvium has been deposited on the lava field S. of Todd Lk. Lavas and cone rest on lavas from Bachelor Bu. Analyses 44, 45; average, 1002. Maps 7, 8, and Quad. S.

HoBALa2 Olivine- and clinopyroxene-bearing glomerophyric basaltic andesite lavas S.W. and W. of Dutchman Flat, not mapped separately. Silica 54-57. From adventive shield at 7800' elev. on N. side of Bachelor Bu. Flow surface black to gray, blocky to aa with pressure ridges. Phenocrysts and glomerocrysts of Plag (12-15%; partly resorbed with normal oscillatory zones from An 75 core to An 45 rim; up to 2 mm), Ol and Cpx (both approximately 2%; up to 1 mm). In some flows olivine is surrounded by narrow jackets of granular pyroxene. Groundmass Plag An 40-45; hyaloophitic to intergranular. Not glaciated; overlain by Rock Mesa pumice, Mazama ash, and lavas from cone at N. base of Bachelor Bu. Rests upon lavas and cone chain S.W. of Todd Lake. Analyses 47, 258, 260; average, 1003. Maps 7, 8, 9 and Quad. S.

## Units of Holocene Rhyodacite

HoRdLa1 Orthopyroxene-bearing rhyodacite lava and pumice deposits from Newberry vent.
HoRdPc1 Flow 3 km long, 1.5 km wide. Blocky surface with extensive pressure ridge system. Blocks composed of black, flow-banded obsidian and white, partly inflated crust. Spherulitic in part. S.W. 1/4 of flow contains mixed red and black glass. Phenocrysts of Plag (7-9%; An 35-45, normally zoned and extensively resorbed; up to 3 mm), Opx (0.5-1.5%; very small), Mag and fresh Hb (both sparse and very small). Not glaciated; Newberry flow rests upon early pumiceous deposits from Newberry vent and from Rock Mesa (2300 C-14 yrs.). Overlain by pumice from nearby Goose Cr. chain of domes. Analyses 26, 28, 271, 446; average Newberry, Goose Cr., Devils Hill chains of domes, 1004. Maps 1, 3, Quad. W.

HoRdLa2 Orthopyroxene-bearing rhyodacite lava and pumice deposits from Goose Cr.
HoRdPc2 chain of domes. Silica 72-73. Five domes, 10 vents, 2.0 km long, aligned N.10W. Surface of domes and marginal crumble breccia composed of gray, partly inflated blocks. Plag phenocrysts up to 12%; otherwise mineralogy and texture identical to Newberry flow. Pumice ramparts on W. side of domes; elsewhere overlain by domes and lava flow. Goose Cr. pumice rests upon Newberry flow and is underlain by pumice from Rock Mesa. Analyses 269, 445, 447; average Newberry, Goose Cr., Devils Hill chains of domes, 1004. Map 4 and Quad. W.

HoRdLa3 Orthopyroxene-bearing rhyodacite lava and pumice deposits from Devils Hill
HoRdPc3 chain of domes. $SiO_2$ 71-72. Four domes, 5 vents, 2.4 km long. aligned N.3W. Lithology and mineralogy identical to Goose Cr. chain of domes. Pumice depo-

sits thicker and more extensive. Pumice rampart E. of domes is up to 50 m thick, composed of poorly sorted white-to-gray lumps and breadcrust bomb fragments up to 0.5 m in diameter. Collapse of steep-sided pumice ramparts probably contributed small pyroclastic flows to the pumice blanket in lower Goose Cr. valley. Domes, lavas, and deposits rest on pumice from Rock Mesa (2300 C-14 yrs.), but probably was produced at about the same time. Analyses 381, 448; average Newberry, Goose Cr., and Devils Hill chains of domes, 1004. Maps 4, 7, and Quad. W.

## Units of Pleistocene Basalt

PsBsLa1 Olivine- and clinopyroxene-bearing basalt lavas in vicinity of Ditch Cabin, not separately mapped. Silica 52-53. Dark gray glaciated lavas from 7000' elev. S.W. of Ball Bu. to 6600' elev. on E. rim of Soda Cr. canyon. Phenocrysts and glomerocrysts of Plag (15-30%; An 50-60; up to 1 mm; larger crystals contain up to 50 close-set oscillatory normal zones ranging over approximately 10 An), Ol (6-8%; up to 1.5 mm), and Cpx (2-3%; 0.5 mm). Groundmass plag An 45. Flows 1.3 km S. of Ditch Cabin are coarse diktytaxitic microporphyries with phenocrysts of Plag (38%; An 70-80; up to 8 mm), Ol (17%; 2 mm), and Cpx (4%; 1.5 mm). Normal paleomagnetic polarity. Analyses 111, 295, 299, 300; average Ditch Cabin basalts, 1005. Maps 5, 6, 8.

PsBsLa2
PsBsPc2 Olivine-bearing basalt lava from small glaciated cinder cone remnant, 1.0 km S.E. of Ball Bu. Silica 52-52. Dark gray glaciated lava extends 3.3 km S.S.E. from source cone at 7200' elev. to 6200' elev. in Middle Fork Tumalo Cr. canyon. Phenocrysts and glomerocrysts of Plag (10-12%; An 55-65; up to 3 mm). Larger crystals contain normally zoned An 65-55 cores surrounded by repeated sets of An 60-65 oscillatory zones and rim zones to An 45. Ol (8-10%; up to 4 mm) and Cpx (<1%; small). Analysis 303. Maps 6, 9.

PsBsLa3
PsBsPt3 Olivine-bearing basalt lavas from Talapus and Katsuk Buttes. Silica 51-52. Dark gray interior, black to red scoriaceous surfaces. Principal flows were produced from a vent in saddle between Talapus and Katsuk, and from a vent on the S. side of Katsuk. Lavas have been moderately glaciated, especially at lower elevations. Phenocrysts and small glomerocrysts of Plag (17-19%; An 60-65 in cores, normal zoned to An 45 rims; up to 2 mm; larger crystals possess extensively resorbed cores) and Ol (5-7%; up to 1 mm). Groundmass Plag An 40-45. Talapus Bu. cinder cone was constructed on a large palagonitic tuff cone whose glaciated flanks are now occupied by Devils Lk. Bedded hyaloclastites are best exposed in roadcuts near Devils Lk., on the N. side of Talapus, and along the E. margin of the Talapus-Katsuk lava field. Overlain by lavas from Bachelor Bu. Analyses 264, 265, 266, 525, 526; average Talapus-Katsuk basalts, 1006. Map 7 and Quads. W, SW, S.

## Units of Pleistocene Basaltic Andesite

PsBALa1 Basaltic andesite lavas between Golden, Green, and Corral Lakes, not mapped separately. Dark to light gray, blocky, glaciated. Lavas between Golden and Green Lks: Silica 53-54. Very fine grained with sparse microphenocrysts of An 50-55 Plag. Groundmass Plag An 40-45. Between Corral and Green Lks: Silica 53-57. Phenocrysts of Plag (5-12%; An 65-70 in cores with normal zones to An 50-55 rims; up to 4 mm), Ol and Cpx (both <1%; up to 0.5 mm). Overlain by Broken Top basaltic andesites and dacites. Analyses 117, 193, 198, 272. Averages 1007, 1008. Maps 1, 4.

PsBALa2
PsBAId2 Olivine- and clinopyroxene-bearing basaltic andesite lavas and dike on ridge east of Golden Lake. Silica 55-56. Platy, gray to pink. Phenocrysts of Plag (18-20%; An 70-75 in cores with delicate oscillatory normal zoning to rims of An 55; up to 4 mm), Ol (4-5%; rounded with rims of granular Mag, up to 0.5 mm), Cpx (1-2%; up to 3 mm). Groundmass Plag An 45-50. Glaciated. Analysis 364. Maps 1, 2.

PsBALa3 Orthopyroxene-bearing basaltic andesite lavas N.W. of Park Meadow. Silica 56-57. Glaciated remnants of pressure ridges. Gray to brown, scoriaceous to platy. Phenocrysts of Plag (27-29%; An 35-55, oscillatory normal zones; up to 2 mm), Opx and microphenocrysts of Mag (both 1-2%). Sparse phenocrysts of large resorbed Plag with patchy zoning; glomerocrysts of Plag, Opx, and Cpx up to 6 mm. Groundmass Plag An 35. Overlain by andesite lavas from S. Sister. Analysis 210. Maps 1, 2, and Quad. N.

PsBALa4 PsBAPc4 Olivine-bearing basaltic andesite lavas and remnants of glaciated cones in Park Meadow area. Silica 54-55. Red to black scoriaceous lava and red cinders. Phenocrysts of Plag (24-26%; An 70-80, normal zones; up to 3 mm) and Ol (2-3%; 0.5 mm). Groundmass Plag An 60. Analysis 366. Map 2.

PsBALa5 PsBAPc5 Glaciated basaltic andesite lavas and remnant of glaciated cinder cone E. of Rim Lake. Silica 54-56; unusually high Fe, Ti. Lavas gray in blocky-to-platy interior, brown on scoriaceous surface. Cinders red. Microphenocrysts of Plag (reverse zoned from An 50 to An 60 in cores, surrounded by thin rim of An 50, up to 1.5 mm in length) with Ol and Cpx (up to 1 mm), all $\lesssim$1%. Very fine-grained groundmass with Plag An 50. Glaciers carved deep circular pit in N. flank of cone. Glacial debris and striations to summit. Analyses 146, 147, 148, 149, 202, 359; average, 1009. Maps 2, 3.

PsBALa6 Clinopyroxene-bearing microporphyritic basaltic andesite capping ridge at 7600' elev., 1.3 km S. of Tam Lk. Silica 57-58. Black vitrophyric to brown holocrystalline, blocky. Microphenocrysts of Plag (16-18%; reverse-zoned cores An 55-65 surrounded by a thin rim zoned normally to An 55; up to 1 mm), Cpx (1-2%; 0.5 mm), and Mag (<1%). Some of the Plag crystals are extensively resorbed. Glaciated and overlain by basaltic andesite lavas from Broken Top. Analysis 380. Map 2.

PsBAPc7 Glaciated remnant of basaltic andesite cinder cone 2.6 km N.W. of Three Cr. Lk. Silica 56-57. Red and black scoria. Phenocrysts of Plag (<1%; up to 2 mm) and Cpx (<1%; 0.4 mm). Analysis 150. Map 3.

PsBALa8 PsBAId8 Basaltic andesite lavas in cliffs of Tam McArthur Rim and Snow Creek cirque, not mapped separately. Overlain by lavas of Broken Top. Lavas on upper shelf S. of Three Cr. Lk: $SiO_2$ 55-56. Thick blocky flows, gray interior with reddish-brown crust. Phenocrysts of Plag (16-17%; An 70-75 in core, rim zones of An 40; up to 4 mm), Ol (<1%; rounded and embayed; 0.5 mm), and Cpx (<1%; 0.4 mm). Normal paleomagnetic polarity. Analyses 152, 153; average, 1010. Map 3 and Quad. E. Lavas in Tam Mac Rim and Snow Cr. cirque: Silica 54-58. Thick blocky flows, light gray and flow banded. Sparse phenocrysts of Plag (generally <1%; An 60-65; in two habits within same rock - short and broad with reverse zoning in resorbed cores, and narrow prisms 1-2 mm long without zoning or evident resorption), Cpx, Opx, and Mag (all <1%; small). Groundmass commonly pilotaxitic intergranular with An 40 Plag. Normal paleomagnetic polarity. Analyses 158, 171, 176, 346, 349, 350, 352; average including dikes, 1011. Maps 2, 3. Dikes: Silica 54-56. Gray to black, generally 2-3 m thick and irregular in trend. Phenocrysts as in basaltic andesite lavas of Tam Mac Rim and Snow Cr. cirque. Analyses 173, 348. Maps 2, 3.

PsBALa9 Basaltic andesite lavas on lower shelf S. of Three Cr. Lk., not mapped separately. Interbedded with dacite lavas of PsDaLa5. Lavas on E. side of shelf: Silica 53-54. Brown to oxidized red, platy. Phenocrysts of Plag (15%; An 70-75, zoning oscillatory but indistinct in most crystals, rim zone An 45; up to 5 mm), Ol (1%; rounded, enclosed in rim of granular Mag; 0.5 mm), Cpx (<1%; small). Normal paleomagnetic polarity. Analysis 1. Lavas on W. side of shelf: Silica 55-56. Gray to brown, platy. Phenocrysts of Plag (1-2%; An 40, zoning indistinct; up to 1.0 mm), Ol and Cpx (both <1%; up to 1.5 mm). Normal paleomagnetic polarity. Analysis 342. Map 3.

PsBALa10 PsBAPc10 Glaciated basaltic andesite lavas and cinder cone on crest of Broken Top E. ridge, 1.2 km S.W. of Tam McArthur Rim. Silica 53-54, high Al. Lavas blocky, gray to red. Phenocrysts of Plag (20-22%; cores of diffuse oscillatory zoning from An 80 to An 85 with rims zoned normal to An 50; some crystals extensively resorbed; up to 4 mm) and Ol (1%; 0.5 mm). Unusual abundance of well-formed volcanic bombs mixed with red cinders of cone. Lavas and cone are overlain and underlain by basaltic andesite lavas from Broken Top. Analyses 124, 355; average 1012. Maps 2, 3, 6.

PsBALa11 PsBAPc11 PsBAIp11 PsBAId11 Orthopyroxene- and olivine-bearing basaltic andesite microporphyries of Broken Top volcano, not separately represented. Silica 54-56. Gray, black, and red vesicular flows, usually 5-10 m thick, from dike, sill, and plug sources in the summit cone and from dikes on the lower slopes. The basaltic andesite lavas of Broken Top contain 25 to 60% phenocrysts, glomerocrysts, and microphenocrysts of Plag, Ol, Opx, Cpx, and Mag, usually in that order of abundance, suspended in a hyaloophitic to intergranular groundmass. Two generations of phenocrysts are commonly represented, often in the same rock. The prominent, and presumably earlier, generation consists of olivine crystals (up to 2 mm; often rounded, embayed, and partly converted to red alteration products) and plagioclase crystals (up to 4 mm; cores as calcic as An 85 but more often An 60-70, surrounded by a broad band of An 50-60 oscillatory zones which grade to a thin rim normally zoned to An 45). Irregular blebs of glass tend to be concentrated in the oscillatory band, but are sometimes distributed uniformly. The second generation consists of stout prisms of fresh orthopyroxene (up to 0.5 mm) and plagioclase (short tablets up to 1 mm long, with oscillatory zoning from An 60 to 45 in some rocks and continuous normal zoning in others). The plagioclase is usually honeycombed with irregular inclusions of glass. The chief variation in mineralogy and texture of Broken Top lavas lies in the relative proportions of these two generations of phenocrysts. Crystals of the first generation predominate in early Broken Top lavas; intermediate stages leading to a complete replacement of the first generation by the second are best represented in later lavas from higher levels in the volcano.

Broken Top dikes and sills vary from 1 to 5 m in thickness and correspond to the lavas in phenocryst composition, texture, and variability. The central plug of Broken Top, however, is approximately 0.3 by 0.6 km in diameter and varies from a fine-grained platy margin to a blocky interior of altered hypidiomorphic-granular micronorite. It is composed of Plag (78-80%; An 55 cores normally zoned to An 30 rims; av. 1-3 mm), Opx (12-14%; 0.5-1 mm), Cpx (5-6%; 0.5-1 mm), Mag (2-3%; up to 0.5 mm), and Ol (<1%; up to 1 mm; often altered to serpentine).

Broken Top basaltic andesite lavas were deposited on a glaciated platform of many separate basaltic andesite volcanoes, are interbedded with small andesitic, dacitic, and rhyodacitic lava flows and ash-flow tuffs, and are overlain by basaltic andesite lavas of the Tumalo Mtn. chain of volcanoes and by rhyodacite pumice and andesite cinders from Pleistocene vents on the N.W. ridge. Broken Top volcano has been extensively glaciated on all but the highest ridge crests. Paleomagnetic polarity was determined in nine separate lava flows representing high, intermediate, and low stratigraphic positions in Broken Top; all were normal. Analyses: (lavas) 106, 107, 108, 109, 110, 113, 114, 116, 118, 122, 156, 161, 195, 199, 203, 274, 360, 361, 363, average 1013; (dikes) 112, 119, 121, 125, 167, average 1014; (plug) 81, 101, 102, average 1015. Maps 1, 2, 3, 4, 5, 6.

PsBALa12 Olivine- and clinopyroxene-bearing basaltic andesite lava west of Ball Butte. Silica 55. Light gray, blocky. Phenocrysts of Plag (10-11%; delicate oscillatory zoning throughout cores of An 75-80, narrow rims zoned An 75-45; up to 1.5 mm), Cpx and Ol (both 2% and up to 0.5 mm). Probably the NW member of a glaciated chain of cones which extends from Tumalo Mtn to Broken Top. Analysis 301. Map 5.

PsBALa13 PsBAPc13 Clinopyroxene- and olivine-bearing basaltic andesite lava and pyroclastic deposits of Ball Butte. Silica 56-57. Lavas red to brownish gray, fine grained, blocky. Abundant microphenocrysts with sparse phenocrysts and glomerocrysts of Plag (12-13%; An 55-60, delicate oscillatory zoning of very limited compositional range; up to 3.0 mm), Cpx and Ol (both 1-2% and up to 1.0 mm). Olivine is embayed and surrounded by granules of Cpx and Mag. Some of the glomerocrysts are associated with an altered amphibole, minute shreds of biotite, and anhedral alkali feldspar. Groundmass intergranular with Plag An 45. Red cinder cone is approximately 200 m high, nearly buried beneath lavas from summit vents, and has been extensively glaciated. Ball Bu. lavas are overlain by basaltic andesite lavas from glaciated center 0.8 km NW (PsBALa 12). Analysis 302. Maps 5, 6.

PsBALa14 Basaltic andesite lavas exposed in ravine north of Soda Creek, W. Sec. 6, not mapped separately. Silica 54-58. Thick units of red flow breccia and gray lava containing phenocrysts of Plag (2-3%; An 70 without zoning, An 45-60 with normal zoning; both types up to 1 mm), Ol and Cpx (both <1%; small). Underlain by thinner flows of porphyritic basaltic andesite and palagonitic breccia interbeds. Entire sequence rests upon lavas from Todd Lake volcano. Analyses 285, 288, 290. Maps 5, 8.

PsBALa15 PsBAPc15 Clinopyroxene- and olivine-bearing basaltic andesite lavas from glaciated cinder cone remnant, 1.5 km S.E. of Ball Butte. Silica 55-56. Light gray glaciated lavas extend from source cone at 6700' elev., 1.5 km S. to approximately 6700' elev. Phenocrysts and glomerocrysts of Plag (8-12%; cores of An 70-55 with normal and reverse sets of oscillatory zones surrounded by narrow rims zoned normal to An 50; up to 2 mm), Ol (1-3%; up to 0.5 mm), Cpx (1-2%; up to 0.5 mm). Mag in glomerocrysts with Plag and Cpx. Groundmass intergranular, pilotaxitic in part, Plag An 45. Analyses 139, 296, 307; average 1016. Maps 5, 6, 8, 9.

PsBALa16 PsBAPc16 Basaltic andesite lava flow, 0.5 km long, from small glaciated cinder cone north of upper North Fork Tumalo Creek. Silica 55. Lavas gray to black, vesicular; cinders black and red. Sparse phenocrysts of Plag (An 35-40, resorbed; up to 1.0 mm; accompanied by crystals of An 55-60, not resorbed; up to 2 mm), Cpx and Ol (both <1%; up to 0.5 mm) in a fine pilotaxitic intergranular groundmass. Analysis 129. Map 6.

PsBALa17 Basaltic andesite lavas of Happy Valley, not mapped separately. Silica 56-57. Fine grained, platy, black to gray where fresh, tan to yellow where altered. Phenocrysts of Plag (An 55) and Cpx (both <1% and <1 mm). Exposed best in glaciated cliffs and on floor of Happy Valley E. of Map 6. Analysis 128.

PsBALa18 Basaltic andesite lavas of upper North Fork Tumalo Creek, not mapped separately. Silica 53-54. Glaciated flows, gray to black, blocky. Phenocrysts of Plag (4-6%; An 65 cores normal zoned to An 35 rims; up to 4 mm), Cpx (<1%; up to 0.5 mm), and sparse Mag. Small outcrop in center of Happy Valley contains partly fused pumiceous xenoliths. Analysis 135. Map 6 and Quad. E.

PsBALa19 Olivine-bearing basaltic andesite microporphyry in canyon between north and middle forks of Tumalo Creek. Silica 54-55. Black to gray scoriaceous flows, generally less than 10 m thick. Phenocrysts of Plag (40-45%; An 50-55, indistinct zoning; clouded with minute inclusions of mafic silicates and blebs of dark glass; up to 3 mm), Ol (5%; up to 1 mm), and Opx (<1%; up to 0.5 mm). Groundmass hyaloophitic with An 35 Plag. Interbeds of palagonitic breccia are common. Overlain by rhyodacitic lava of upper N. Fork Tumalo Cr. Analysis 306. Map 6 and Quad. E.

PsBALa20 PsBAPc20 Glaciated basaltic andesite lavas (not mapped separately) and remnant of glaciated basaltic andesite cone in vicinity of Bare Lake. Silica 57. Holocrystalline lavas are gray and platy to blocky, but black and less platy with increasing glass content. Red, scoriaceous flow crust near vents. Phenocrysts of Plag (<2%; An 60-70; up to 1 mm), Cpx (<1%; 0.4 mm), and traces of Mag. Some flows are nonporphyritic and some contain as much as 1% xenoliths of fine and coarse two-pyroxene dacite lavas and plug rocks. Beds of red scoriaceous agglomerate are exposed in cliffs 0.3 km W. of Bare Lk. Rests on rhyodacite lavas S. of Todd Lk. and is overlain by dacite lavas of Todd Lk. volcano. Normal paleomagnetic polarity. Analyses 8, 11, 12, 15, 16; average, 1024. Map 8.

PsBAPc21 PsBAPc22 Glaciated remnants of basaltic andesite cinder cones 1.0 km S. of Todd Lake and 0.7 km W. of Dutchman Flat. Silica 56-57. Red spatter and scoriaceous oxidized lava. Cone near Todd Lk. contains less than 1% microphenocrysts of Plag and two pyroxenes. Cone near Dutchman Flat contains only sparse microphenocrysts of Plag. Analyses 43, 46. Map 8.

PsBALa22 Clinopyroxene-bearing basaltic andesite lavas 1 km W.N.W. of Tum Lake. Silica 55-56. Gray to black, blocky. Phenocrysts of Plag (30%; An 75 cores, normal zoned to An 45 rims; up to 3 mm), Cpx (2-3%; euhedral; up to 2 mm), Ol (<1%; rounded; up to 1 mm), Mag (<1%; up to 0.5 mm). Sparse glomerocrysts reach 4 mm in diameter. Groundmass intergranular with An 40 Plag. Glaciated, overlain by lavas from cone N.W. of Tumalo Mtn. Analysis 141. Map 9.

PsBALa24 PsBAPc24 PsBAPt24 PsBAIp24 PsBAId24 Glomeroporphyritic olivine- and clinopyroxene-bearing basaltic andesite lavas, intrusive rocks, and tuff cones associated with Tumalo Mountain and three cones N.W. of Tumalo Mountain. Silica 55-56. Surfaces of nonglaciated lavas above 7000' elev. on W. flank of Tumalo Mtn. are black and scoriaceous. Elsewhere, the glaciated interior of lava flows is gray and blocky. Phenocrysts and microphenocrysts of Plag (23-26%; An 60-75, commonly zoned in two or more sets of oscillatory normal zones surrounded by a reverse zone which passes into a thin rim zoned normally to An 45; up to 2 mm), Cpx (5%; up to 1 mm), Ol (1%; 0.5 mm), and rare Opx. Glomerocrysts of Plag, Cpx, and Ol commonly reach 6 mm in diameter and make up 3-7% of the rock. Tumalo summit cone is composed of red and black cinders, bombs, and spatter with glomerocrysts of Plag, Cpx, and Ol. Fragments of white fine-grained rhyodacite up to 3 cm are included within the cinders. Glaciated eastern face of summit cone contains a small central plug with associated radial dikes and remnants of an early-formed palagonitic tuff cone. Of the cones N.W. of Tumalo Mtn., the southernmost was glaciated up to approximately 6900' elev. but still retains a breached summit crater. The middle cone was glaciated over all but the summit area; no crater survived. The northernmost cone was extensively glaciated and stands as an irregular resistant butte of thin lava flows and interbedded scoria. Normal paleomagnetic polarity. Analyses 42, 48, 74, 140, 143, 144, 145, 308, 309, 310, 311, 312, 313, 314, 315, 319, 320; average Tumalo Mtn., 1017. Maps 8, 9, and Quads E., S.E., S.

PsBALa25 Glaciated basaltic andesite lavas exposed in vicinity of Tum Lake. Silica 56. Gray, fine grained, blocky. Phenocrysts and microphenocrysts of Plag (0.5-1.0%; An 70 cores, An 45 rims; up to 1 mm; anhedral with irregular margins gradational to groundmass), Opx, Cpx, Mag (all <0.1% and less than 0.1 mm). Groundmass intergranular with An 45 Plag. Overlies remnant of palagonitic tuff cone. Analysis 142. Map 9.

## Units of Pleistocene Andesite

PsAnLa1 Glaciated two-pyroxene andesite lavas from South Sister volcano, not mapped separately. Silica 59-63. Units exposed in Broken Top quadrangle possess gray to black, platy, flow-banded interiors with blocky vitrophyric margins. Phenocrysts of Plag (5-20%, most units contain 11-13%; cores An 50 normally zoned to An 35 in some units, reverse zoned from An 50 to 60 and surrounded by a narrow rim zoned to An 35 in other units; up to 3 mm). Pyroxenes total 2-4%. Cpx exceeds Opx by a factor of 1 to 4. Cpx is surrounded by narrow rims of granular pyroxene. Mag from 0.8 to 1.5%, up to 1 mm. Sparse crystals of apatite with dark pleochroic inclusions are as long as 0.5 mm in some units. In Broken Top quadrangle, these andesites overlie rhyodacites E. of Chambers Lk and basaltic andesites near Golden and Green Lks. Analyses 191, 192, 204, 250, 362, 365, 456, 458; average 1018. Map 1 and Quads. W., N.W., N.

PsAnPc2 PsAnId2 Glaciated remnant of andesite cinder cone and included dikes at 7000' to 7700' elev. on N.W. ridge of Broken Top. Silica 61. Red to black cinders, coarse spatter, and thin flowrock cut by several short dikes less than 1 m wide. At high levels in cone deposits, cinders are interbedded with lumps of white rhyodacite pumice of ridge-crest unit PsRdPc4. Cinder cone overlies N.W. margin of basaltic andesite lava from Broken Top. Analysis 196. Map 1.

PsAnLa3 Glaciated andesite lava on shelf at 7000' elev., head of Snow Creek cirque. Silica 62-63. Black vitrophyre at margins, gray platy interior. Phenocrysts and glomerocrysts of Plag (6-7%; An 45, some much-resorbed cores of An 55 contain patchy zoning; up to 1 mm), Cpx, Opx, and Mag (all <1%; 0.5 mm). Sparse olivine crystals occur separate from glomerocrysts and are rounded and embayed. Analysis 351. Maps 2, 3.

PsAnId4 Three east-west andesite dikes 1.3 km S. of Rim Lake. Silica 60-61. Gray to white, blocky, 3-4 m wide. Microphenocrysts and small glomerocrysts of Plag (2-3%; An 50-55; up to 1 mm), Cpx and Mag (both <1%; up to 0.5 mm). Mineralogy, texture, and composition are distinct from andesite dike and lavas of units PsAnLa5 and PsAnLa6, only 0.2 to 0.5 km S. Analysis 170. Map 2.

PsAnLa5 PsAnPc5 Glaciated clinopyroxene-bearing andesite lavas at 7400' elev., 1.4 km S. of Rim Lake and probable andesitic source cone at 7480' elev., on S.W. edge of Snow Creek cirque. Silica 60-61. Lava mottled and streaked in black, gray, and red. Red andesitic scoria incorporated into base of flows; small xenoliths of basaltic andesite common throughout. Phenocrysts of Plag (4-5%; An 47; up to 1 mm), Cpx (1-2%; up to 0.5 mm), Opx and Mag (both <1%; <0.5 mm). Sparse crystals of apatite and small xenocrysts of resorbed olivine. Groundmass of light-colored, coarser, pilotaxitic streaks in dark-colored, finer, intergranular matrix. Cpx within light-colored streaks is surrounded by granular rims. Cone is composed of black cinders and brown pumice. Analyses 169 (lava), 358 (cone). Map 2.

PsAnLa6 PsAnId6 Glaciated clinopyroxene-bearing andesite lavas, not mapped separately and S.W.-N.E. dike, 7600 to 8000' elev. on S.W. side of Snow Creek cirque. Silica 61-63. Phenocrysts of Plag (7-8%; oscillatory normal zones over range of An 40-45; up to 2.5 mm), Cpx (1%; 0.5 mm), Opx and Mag (both <1%; <0.5 mm). Approximately 10% of Plag phenocrysts are extensively resorbed, but are of same composition and zonation pattern. At lower E. end of outcrop is a flow unit which is slightly more mafic and contains only 1-2% Plag phenocrysts with minor pyroxenes and Mag. Mineralogical and chemical compositions of the dike are similar to the lowermost flow and it is probably a feeder. Interbedded with basaltic andesite lavas from Broken Top. Analyses 165, 356 (upper flows), 160 (lower flow), 159 (dike); average lower flow and dike, 1019; average upper flows, 1020. Map 2.

PsAnLa7 Glaciated andesite lavas west of Corral Lake not mapped separately. Silica 62-63. Gray to pink, close-set platy joints. Microphenocrysts, phenocrysts, and glomerocrysts of Plag (5-7%; An 45-50 with poorly developed normal zoning; up to 1 mm), Cpx, Opx, and Mag (all <1%; very small). Cpx is surrounded by jackets of granular pyroxene. Groundmass hyalopilitic to intergranular. Analyses 27, 275; average 1021. Map 4.

PsAnLa8 Glaciated clinopyroxene-bearing andesite lavas at head of ravine, 6400' elev., W. Sec. 6, N. of Soda Creek, not mapped separately. Silica 62-63. Flows gray to black, platy, up to 20 m thick. Phenocrysts and glomerocrysts of Plag (5-6%; An 45-50; up to 2 mm), Cpx (1-2%; 0.5 mm), Opx and Mag (both <1%; <0.5 mm). Analyses 286, 287; average 1023. Map 5.

PsAnLa9 Glaciated andesite lava at 5600' elev. on lower Fall Creek. Silica 59-60. Gray to tan, platy. Phenocrysts of Plag (11-12%; cores oscillatory zoned An 85-90 surrounded by broad rim zone An 40-45; up to 4 mm), Cpx (<1%; granular Cpx rims; up to 0.5 mm), Ol (<1%; altered; 0.5 mm), and Mag (<1%; up to 0.2 mm). Groundmass Plag An 40. Analysis 276. Map 7.

## Units of Pleistocene Dacite

PsDaLa1 Clinopyroxene-bearing dacite lava interbedded with basaltic andesite flows at 7600' elev. in cliffs 1.5 km S. of Golden Lake. Silica 64-65. Platy, dark gray to brown. Microphenocrysts of Plag (3%; An 45-50 with indistinct zoning), Cpx (1-2%; 0.5 mm), and Mag (<1%; up to 0.2 mm). Overlain by lavas from Broken Top; rests on lavas similar to Broken Top lavas but of uncertain affinity. Analysis 200. Maps 1, 2.

PsDaLa2 Glaciated dacite lava E. of Squaw Creek, 1.0 km E. of Park Meadow. Silica 64. Platy, light gray to pink. Phenocrysts of Plag (6-7%; An 35 in two broad normal zones of less than 5 An range; up to 3 mm), Cpx (0.4-0.5%; up to 0.5 mm; mostly converted to granular pyroxene), Opx (0.5-0.6%; up to 1 mm; no granular rims), and Mag (0.7-0.8%; up to 0.5 mm). Opx and Cpx commonly form parallel crystal aggregates. Sparse but unusually large apatite crystals (up to 0.25 mm). Analysis 367. Map 2.

PsDaLa3 East-west dacite dike at 7800' elev., 1.8 km S. of Rim Lake. Silica 66-67. Gray interior, black glassy margins, 0.5-1 m wide. Phenocrysts of Plag (5-7%; An 35-40, normal zoning over small compositional range; up to 1 mm), Opx, Cpx, Mag (all <1%; <0.5 mm). Part of a multiple dike set dominated by basaltic andesite

(PsBAId11). Analysis 168. Map 2.

PsDaPi4 Dacite welded tuff of Snow Creek cirque. Silica 66-67. Small outcrop exposed on W. side of Snow Cr. at 7360' elev. Yellow to light brown, glassy, poorly welded eutaxitic matrix containing fragments of pink rhyodacite and gray andesite, partly collapsed black pumice lumps, and 1-2% of small Plag phenocrysts (An 45-50, normal oscillatory zones). Other phenocrysts include Cpx and Mag, both less than 1%. Much of the unit has been removed by erosion; maximum exposed thickness is only 8 m. Overlain by andesite lavas of PsAnLa5. Analysis 354. Map 2.

PsDaLa5 Glaciated dacite lavas S.W. of Three Creek Lake and W. of Little Three Creek Lake, not mapped separately. Silica 64-68. Gray to brown, platy. Phenocrysts of Plag (9-11%; An 25-30, patchy zoning in cores surrounded by oscillatory normal zones; up to 4 mm); Opx, Cpx, and Mag all <1%; 0.5 mm). Lavas from approximately 6800 to 7000' elev., 0.7 km S.W. of 3 Cr. Lk. are low-silica dacites in which phenocrysts of Plag (An 40-50), 2 pyroxenes, and Mag are all <1%. Unit includes some of the oldest lavas exposed in the Tam Mac Rim area. Normal paleomagnetic polarity. Analyses of high-silica dacites, 175, 341, 347; average 1025. Analyses of low-silica dacites, 162, 174, 343; average 1026. Map 3 and Quad. E.

PsDaId6 East-west dacite dike at base of main protrusion of Tam McArthur Rim, 1.0 km W.S.W. of Three Creek Lake. Silica 63-64. Gray interior, black glassy flow-banded margins, dike 2-3 m wide. Phenocrysts of Plag (An 50) and Cpx are sparse and very small. Chemically and mineralogically similar to higher-elevation, low-silica dacite lavas of PsDaLa5, 0.5 km S.W. Analysis 177. Map 3.

PsDaLa7 Glaciated clinopyroxene-bearing dacite lava between Goose Creek and Fall Creek. Silica 64-65. Black, glassy, columnar-jointed margins and gray to pink, holocrystalline, platy-jointed interior. Phenocrysts and glomerocrysts of Plag (7-9%; An 40-45, normal zonation in resorbed cores surrounded by reverse oscillatory zones and a thin normal rim; up to 3 mm), Cpx (0.5-1.5%; <0.5 mm; surrounded by jackets of granular pyroxene, Opx and Mag microphenocrysts both <1%. Sparse prisms of apatite up to 0.3 mm long. Overlies andesite W. of Corral Lk. and is overlain by Goose Cr. chain of Holocene domes. Normal paleomagnetic polarity. Probably from a vent near S. Sister. Analyses 29, 263, 268; average 1027. Maps 4, 7, and Quad. W.

PsDaLa8 Glaciated clinopyroxene-bearing dacite from buried vent above 7800' elev. on S.W. side of Broken Top. Silica 63-64. Flow exposed on crest of Broken Top S.W. ridge down to 6200' elev. Gray, platy, and holocrystalline interior with black, blocky, and glassy margins. Microphenocrysts, phenocrysts, and glomerocrysts of Plag (5-6%; An 40-50; up to 1.5 mm), Cpx (1-2%; surrounded by jackets of granular Cpx; 0.5 mm), Mag (<1%; 0.5 mm). Apatite prisms up to 0.5 mm long are commonly enclosed within phenocrysts and occur free in the goundmass. Groundmass hyalopilitic to intergranular with Plag An 35. Analyses 115, 273; average 1022. Maps 4, 5.

PsDaPi9 Dacite welded tuff of Broken Top summit cone. Silica 64-65. Interbedded with basaltic andesite lavas at 8600' elev. in the W. wall of Crook Glacier cirque. Outcrop approximately 8-9 m thick and 0.2 km long. White, clay-rich, poorly welded lapilli tuff in the basal three meters is composed of dacite pumice, devitrified glass shards, and particles of black and red basaltic andesite scoria. It is overlain by a zone of orange, very poorly welded, hydrated dacite pumice which contains increasing amounts of large black and glassy dacite bombs toward the top. The orange zone grades upward to 1-2 meter gray-to-black band of pumiceous lapilli and ash which contains abundant black glassy bombs. In places, a thin orange layer can be seen at the top of the deposit. Approximately 5% of plagioclase phenocrysts with minor orthopyroxene and magnetite occur in the pumice and in the glassy bombs. This unit was deposited from a small ash flow which was produced at a near-summit vent and probably moved only a short distance down the S.W. flank of Broken Top. Analysis 103. Map 5.

PsDaId10 East-west dacite dike at 6060' elev., in ravine, W. Sec 6, N. of Soda Creek. Silica 64. Gray interior, black glassy margins, 1 m wide. Phenocrysts of Plag (1-2%; An 40 normally zoned to thin rims of An 35; up to 1 mm) with Cpx, Opx, and

Mag (all <1%; up to 0.5 mm). Cuts basaltic andesite lavas and breccias of PsBALa14. Analysis 289. Map 5.

PsDaLa11
PsDaIp11 Orthopyroxene- and clinopyroxene-bearing dacite lavas, interbedded ejecta, and central plug of Todd Lake volcano. Silica 63-66. Brown to gray platy lavas with yellow to orange scoriaceous interbeds and flow tops. Pyroclastic breccias and palagonitic ejecta near source vent. Microphenocrysts, phenocrysts, and glomerocrysts of Plag (18-23%; An 40-55). Large crystals up to 4 mm are resorbed and reverse zoned from An 40 core through oscillatory zone sets to An 55. Thin rim zones are normal oscillatory to An 45. Smaller crystals up to 1 mm are zoned normal An 50-45 and are not resorbed. Also phenocrysts of Mag (2-3%; up to 0.6 mm), Cpx (1-2%; 0.5 mm), and Opx (0.5-1.5%; 0.5 mm). Stout prisms of apatite are enclosed within all phenocrystic phases. Lower level flows (especially in Soda Cr. valley) contain oxidized hornblende; higher level flows (especially near summit of Todd Lk. volcano) contain olivine within glomerocrysts. Lavas and ejecta surround a central conduit plug, 0.4 km in diameter, exposed in S. wall of Soda Cr. canyon, 1.5 km N.W. of Todd Lk. Characterized by platy margins and a blocky interior which is gray where fresh and yellow where deuteric alteration is advanced. Except for coarser groundmass, mineralogy and texture of the plug are similar to associated lavas. Todd Lk. volcano overlies basaltic andesites near Bare Lk. and rhyodacites S. and E. of Todd Lk. Overlain by basaltic andesites of PsBALa14, 15. Paleomagnetic polarity of 7 flows on W. side of volcano all normal. Analyses 10, 277, 278, 279, 280, 281, 282, 283, 291, 292, 293, 294; average 1028. Maps 5, 7, 8.

## Units of Pleistocene Rhyodacite

PsRdLa1 Glaciated rhyodacite dome and flows E. of Chambers Lk. and between two branches of South Fork Squaw Creek. Silica 73. Marginal rocks are black, brown, and red, flow banded, glassy, and spherulitic in part with phenocrysts at center of spherules. Interior of flow is gray to pink, very fine grained, contains well developed platy jointing, and grades into a gray-to-white, coarser-grained, porous core. Plag phenocrysts make up less than 0.1% and seldom exceed 1 mm. They are rounded, resorbed, and embayed. Secondary silica is common in cavities. Probable source vent underlies thickest and highest part of mass just E. of Chambers Lake. Overlain by andesite lava from S. Sister. Analyses 206, 207, 208; average 1027. Map 1 and Quads. W., N.W., N.

PsRdLa2 Glaciated rhyodacite lava on N.W. bank of West Fork Park Creek, 2.5 km W. of Park Meadow. Silica 72-73. Gray to pink, vitrophyric to holocrystalline with contorted spherulitic flow bands. Phenocrysts of Plag (10-11%; An 35-40 in broad, diffuse sets of normal oscillatory zones; up to 2 mm), Opx and Mag (both <1%; 0.5 mm). Sparse crystals of fresh Hb up to 0.1 mm in length and minute crystals of zircon also occur. Probably the exposed flank of a volcanic dome, elsewhere overlain by andesite lavas from S. Sister. Analysis 209. Map 1.

PsRdLa3 Glaciated rhyodacite lava W. of Green Lake. Silica 71-72. Pink-to-gray, platy, holocrystalline interior with black, glassy, blocky margins. Occasional lithophysae and spherulites, flow banded throughout. Phenocrysts of Plag (9-10%; cores of diffuse oscillatory zones reverse from An 25 to 35, surrounded by a broad rim zoned normal An 35 to 25). Some Plag crystals are deeply embayed while others of the same composition are sharply euhedral; whole crystals up to 3 mm, many crystals broken. Opx and Mag (both <1%, 0.5 mm). Rare Hb and zircon. Probably the exhumed east margin of a glaciated volcanic dome which was buried during growth of S. Sister volcano. Analysis 25. Map 1.

PsRdIp4
PsRdPc4 Glaciated rhyodacite volcanic dome and pumice deposits on Broken Top N.W. ridge. Silica 68-69. Dome, at 7150' elev., has been reduced by glaciation to level of feeding conduit, 0.05 km in diameter. Conduit filled with dacite, black and glassy along margins with xenoliths of intermediate and mafic rocks, passing into a gray hypocrystalline interior with minute spherulites. Phenocrysts of Plag (6%; An 35; up to 1 mm), Cpx, Opx, and Mag (all <1%; 0.5 mm). Source of rhyodacite pumice on broad crest of Broken Top ridge from 7720 to 7960' elev., 1 km S.E. Deposits are crudely bedded, up to 3 m in total thickness, and contain pumice bomb fragments up to 0.5 m in

diameter. Protected from glaciation by high-standing position. Overlies Broken Top basaltic andesite lava and is mixed with andesitic cinders of cone unit PsAnPc2. Analyses 194, 197; average 1030. Map 1.

PsRdLa5 Glaciated rhyodacite lava S. of Tam Lake and E. of Upper Squaw Creek. Silica 70-71. Platy, light gray to tan. Phenocrysts of Plag (3%; An 30-35; up to 1 mm), Opx and Mag (both <1%; 0.5 mm). Overlain by andesite lava of PsAnLa5, 1.2 km S. of Tam Lk. Analysis 201. Map 2.

PsRdLa6 PsRdPc6 PsRdPf6 PsRdId6 Glaciated rhyodacite lavas with associated coarse and fine pumice deposits and feeder dikes on summit of Tam McArthur Rim, S.W. of Three Creek Lake. Silica 68-69. Glassy lavas are red, black, and flow banded; holocrystalline lavas are white. Phenocrysts of Plag (<1%; An 40-45; rounded and resorbed with patchy zoning in cores; up to 1 mm), Opx and Mag (both <1%; 0.4 mm). Abundant cristobalite in vesicles. E-W feeder dikes are exposed in cliffs of Tam Mac. Rim. They are 2-7 m wide, white and vesicular in the center with black glassy margins, and can be traced directly into flowrocks. Lavas occur in two separate flows. Eastern flow is smaller and is overlain by a much larger western flow which also crops out on the E. side of Snow Cr. valley, 1.5-2.0 km to the W. and N.W. Both lavas rest on deposits of near-vent pumice (PsRdPc6), up to 10 m thick, containing yellow, brown, and black breadcrust bombs. Pumiceous spatter is welded in part. Rhyodacite lavas and pumice are underlain and overlain by basaltic andesite lavas from Broken Top. A thin layer of pumiceous rhyodacite ash (PsRdPf6) is interbedded with Broken Top lavas near the center of Sec. 21. Normal paleomagnetic polarity. Analyses 154, 155, 157; average 1031. Map 3.

PsRdLa7 Glaciated rhyodacite lava of Tam McArthur Rim S. of Three Creek Lake. Silica 68-69. Lavas black and glassy to holocrystalline pink, platy, and lithophysal. Remnant of associated pumice cone stands at N.E. edge of flow, 0.8 km E. of E. boundary of Map 3. Phenocryst mineralogy and texture as well as bulk rock composition is nearly identical to rhyodacite 1 km to the W (PsRdLa6). However, Broken Top lavas that underlie RsRdLa6 overlie this unit. Analysis 151. Map 3 and Quad. E.

PsRdId8 East-west rhyodacite dike, 0.15 km long, at 6760' elev., 0.4 km S.W. of Three Creek Lake. Silica 68-69. White, vesicular, blocky; 2-4 m wide. Nearly identical in mineralogy, texture, and bulk-rock composition to dike feeders of Tam Mac Rim rhyodacite (PsRdId6), 0.4 km to the S.W., but direct connection to flowrocks has been removed by glacial erosion. Normal paleomagnetic polarity. Analysis 172. Map 3.

PsRdLa9 Glaciated rhyodacite lava between Holocene rhyodacite flows of Newberry and Goose Creek Chain of Domes. Silica 72. White to gray, lithoidal to glassy, flow banded. Platy interior. Phenocrysts of Plag (3%; An 35; rounded by marginal resorption; up to 1 mm), Opx and Mag (both <1%; 0.3 mm). Abundant crystallites in glass. One of many outcrops of rhyodacite on S. slopes of S. Sister. Analysis 270. Map 4 and Quad. W.

PsRdLa10 Glaciated orthopyroxene-bearing rhyodacite lava of Devils Hill. Silica 73-74. Gray to white, glassy to holocrystalline, flow banded, spherulitic. Pumiceous crust preserved near summit. Phenocrysts of Plag (7-9%; An 35; up to 1 mm), Opx (1-2%; up to 0.4 mm), and Mag (0.5%; up to 0.2 mm). Remnant of large volcanic dome. Normal paleomagnetic polarity. Analyses 449, 529; average, 1032. Maps 4, 7, and Quad. W.

PsRdPt11 Glaciated remnant of an orthopyroxene-bearing rhyodacite tuff cone on upper North Fork Tumalo Creek. Silica 68-69. Beds in tuff cone are 0.01 to 1.0 m thick, composed of white-to-yellow devitrified pumice with obsidian and rock fragments. Dip of beds in well-exposed N. part of cone is approximately 30°W. Near the top of the tuff cone sequence and best exposed on the S.W. flank, are several layers of silicic spatter 0.2 to 3 m thick which contain collapsed pumice bombs, clots of dense rhyodacite, obsidian, and accidental fragments of other volcanic rocks in a welded matrix. Phenocrysts of Plag (10-15%; An 35-40; small angular fragments) and Opx (<1%; small) occur in a largely devitrified, flow-banded glassy matrix. Within an area of approximately 0.25 $km^2$ S.W. of the tuff cone, bedded tuffs, welded spatter, and coarse pyroclastic breccia have all been hydrothermally altered to clay and opaline silica. The deposits are overlain by lavas from Broken Top, Ball Butte, and a small cinder cone along the tuff cone N.W. margin. Analyses 126, 305; average, 1033. Map 6.

PsRdLal2 Glaciated aphyric rhyodacite lavas of upper North Fork Tumalo Creek. Silica 69. Black, dull-luster obsidian crusts with gray, lithoidal, platy interior. Spherulitic in part. Rare microphenocrysts of Plag in a trachytic groundmass of An 20-25 microlites. Source dike exposed in S. wall of N. Fork Tumalo Cr. at 7100' elev. Overlain by lavas from Ball Butte. Normal paleomagnetic polarity. Analyses 134, 136, 137; average 1034. Map 6.

PsRdLal3 Glaciated orthopyroxene-bearing rhyodacite lavas E. of Todd Lake, not mapped separately. Silica 68-69. Gray to pink where platy and holocrystalline, black where glassy and columnar jointed. Phenocrysts of Plag (2-7%; reverse zoned cores An 35-45, surrounded by a broad, diffuse rim zoned normal An 45-35; up to 3 mm with rounded and embayed margins), Mag (1-2%; up to 0.4 mm), Opx (1%; 0.6 mm), and Cpx (<1%; in resorbed laths up to 0.6 mm long). Several distinct flow units from overlapping volcanic domes. Overlain by basaltic andesite lavas of Bare Lk. volcano, dacite lavas of Todd Lk. volcano, and basaltic andesite lavas from cones N.W. of Tumalo Mtn. Normal paleomagnetic polarity. Analyses 4, 5, 41, 297, 298; average 1035. Maps 8, 9.

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APPENDIX 1

Chemical Analyses of Rocks from S.W. Broken Top Quadrangle

| | 1 | 2 | 4 | 5 | 7 | 8 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 53.6 | 54.5 | 68.6 | 67.7 | 51.1 | 56.9 | 63.5 | 57.2 |
| Al2O3 | 19.8 | 17.1 | 15.5 | 15.2 | 17.1 | 16.8 | 16.1 | 16.3 |
| FeO | 8.0 | 8.8 | 3.7 | 4.3 | 8.8 | 8.9 | 6.2 | 9.1 |
| CaO | 8.0 | 9.4 | 2.2 | 2.1 | 9.1 | 7.3 | 4.6 | 7.1 |
| MgO | 4.0 | 4.3 | 0.7 | 0.6 | 8.3 | 3.9 | 2.1 | 3.5 |
| K2O | 0.80 | 0.60 | 2.40 | 2.20 | 0.60 | 0.90 | 2.15 | 1.00 |
| Na2O | 4.5 | 4.2 | 5.6 | 6.2 | 3.4 | 4.2 | 4.4 | 4.2 |
| TiO2 | 1.15 | 1.10 | 0.65 | 0.65 | 1.05 | 1.20 | 1.05 | 1.50 |
| Total | 99.85 | 100.00 | 99.35 | 99.15 | 99.45 | 100.00 | 100.10 | 99.90 |

| | 12 | 15 | 16 | 17 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 57.1 | 57.0 | 56.7 | 55.7 | 49.2 | 51.8 | 51.2 | 49.1 |
| Al2O3 | 16.4 | 16.7 | 15.8 | 18.6 | 17.4 | 17.6 | 17.8 | 16.7 |
| FeO | 8.2 | 8.4 | 8.4 | 6.8 | 9.5 | 8.5 | 8.3 | 9.0 |
| CaO | 8.3 | 7.4 | 5.8 | 8.5 | 8.7 | 9.7 | 8.4 | 8.9 |
| MgO | 4.1 | 3.5 | 2.7 | 5.1 | 8.8 | 7.3 | 8.8 | 8.7 |
| K2O | 0.90 | 1.25 | 1.40 | 0.80 | 0.60 | 0.65 | 0.85 | 0.55 |
| Na2O | 3.9 | 4.2 | 4.8 | 3.2 | 3.9 | 3.1 | 3.1 | 4.3 |
| TiO2 | 1.10 | 1.25 | 1.50 | 0.95 | 1.00 | 1.00 | 1.20 | 1.00 |
| Total | 100.00 | 99.70 | 99.10 | 99.65 | 99.10 | 99.65 | 99.65 | 98.25 |

| | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 41 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 51.5 | 71.5 | 72.0 | 62.9 | 72.3 | 64.4 | 51.2 | 69.3 |
| Al2O3 | 16.6 | 15.5 | 15.0 | 16.3 | 14.9 | 16.3 | 17.1 | 16.3 |
| FeO | 9.1 | 2.4 | 2.4 | 7.0 | 2.6 | 5.6 | 9.4 | 3.5 |
| CaO | 8.7 | 2.1 | 2.1 | 4.5 | 2.1 | 3.8 | 8.0 | 1.9 |
| MgO | 9.7 | 0.4 | 0.5 | 1.2 | 0.4 | 1.5 | 8.8 | 0.5 |
| K2O | 0.60 | 2.90 | 3.10 | 1.55 | 3.10 | 2.25 | 0.65 | 2.45 |
| Na2O | 2.8 | 4.6 | 4.4 | 4.7 | 4.4 | 5.5 | 2.8 | 5.1 |
| TiO2 | 1.00 | 0.30 | 0.30 | 1.50 | 0.35 | 1.00 | 1.20 | 0.40 |
| Total | 100.00 | 99.70 | 99.80 | 99.65 | 100.15 | 100.35 | 99.15 | 99.45 |

| | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 74 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.5 | 56.8 | 54.3 | 54.3 | 56.8 | 54.2 | 55.5 | 55.4 |
| Al2O3 | 17.6 | 16.7 | 16.9 | 17.8 | 17.0 | 17.9 | 17.7 | 17.0 |
| FeO | 7.8 | 8.5 | 9.6 | 9.1 | 9.1 | 8.3 | 8.0 | 7.9 |
| CaO | 8.3 | 7.4 | 8.3 | 8.0 | 6.6 | 8.0 | 9.4 | 10.1 |
| MgO | 5.3 | 4.1 | 4.8 | 4.6 | 3.5 | 6.3 | 3.4 | 3.5 |
| K2O | 0.85 | 1.00 | 0.70 | 0.80 | 1.00 | 1.00 | 1.10 | 1.10 |
| Na2O | 3.6 | 3.9 | 3.7 | 4.0 | 4.4 | 3.8 | 4.0 | 4.7 |
| TiO2 | 1.00 | 1.30 | 1.45 | 1.30 | 1.45 | 1.10 | 1.05 | 1.05 |
| Total | 99.95 | 99.70 | 99.75 | 99.90 | 99.85 | 100.60 | 100.15 | 100.75 |

APPENDIX 1 (continued)

| | 81 | 101 | 102 | 103 | 106 | 107 | 108 | 109 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.5 | 54.3 | 54.5 | 64.7 | 54.8 | 54.4 | 54.0 | 54.6 |
| Al2O3 | 18.3 | 18.9 | 18.2 | 15.8 | 18.2 | 18.7 | 18.2 | 17.9 |
| FeO | 7.3 | 7.5 | 7.9 | 5.3 | 7.5 | 7.7 | 7.8 | 7.6 |
| CaO | 8.1 | 7.7 | 7.5 | 3.4 | 8.4 | 8.2 | 7.9 | 8.0 |
| MgO | 5.5 | 5.2 | 4.8 | 2.4 | 4.8 | 4.6 | 6.1 | 5.2 |
| K2O | 0.75 | 0.80 | 0.95 | 2.10 | 0.70 | 0.60 | 0.65 | 0.70 |
| Na2O | 3.9 | 3.9 | 3.9 | 4.5 | 3.7 | 3.9 | 3.7 | 3.7 |
| TiO2 | 0.80 | 0.90 | 1.05 | 0.95 | 0.95 | 0.90 | 0.95 | 0.90 |
| Total | 100.15 | 99.20 | 98.80 | 99.15 | 99.05 | 99.00 | 99.30 | 98.60 |

| | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.2 | 52.0 | 54.4 | 55.6 | 54.0 | 62.9 | 55.5 | 53.8 |
| Al2O3 | 18.2 | 16.6 | 19.7 | 19.1 | 18.7 | 15.2 | 19.1 | 17.8 |
| FeO | 7.0 | 8.9 | 7.2 | 7.6 | 7.6 | 6.7 | 7.7 | 9.7 |
| CaO | 7.7 | 7.8 | 8.0 | 7.3 | 7.8 | 3.6 | 7.0 | 7.3 |
| MgO | 5.0 | 6.3 | 4.7 | 4.3 | 6.1 | 1.6 | 4.3 | 4.8 |
| K2O | 0.90 | 1.15 | 0.65 | 0.95 | 0.65 | 2.05 | 1.00 | 0.60 |
| Na2O | 3.8 | 3.7 | 4.0 | 4.2 | 3.8 | 5.7 | 4.3 | 4.4 |
| TiO2 | 0.95 | 1.40 | 0.85 | 1.00 | 0.80 | 1.25 | 1.05 | 1.35 |
| Total | 98.75 | 97.85 | 99.50 | 100.05 | 99.45 | 99.00 | 99.95 | 99.75 |

| | 118 | 119 | 121 | 122 | 124 | 125 | 126 | 128 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.4 | 53.2 | 54.1 | 54.4 | 53.7 | 53.8 | 69.3 | 56.2 |
| Al2O3 | 18.0 | 19.3 | 19.8 | 18.7 | 20.0 | 19.5 | 15.3 | 17.1 |
| FeO | 7.2 | 7.8 | 7.2 | 7.4 | 7.7 | 7.6 | 4.3 | 10.1 |
| CaO | 8.0 | 8.0 | 7.9 | 7.9 | 7.8 | 7.8 | 1.9 | 5.9 |
| MgO | 5.2 | 5.0 | 5.1 | 5.8 | 4.1 | 5.1 | 0.4 | 3.2 |
| K2O | 0.75 | 0.75 | 0.65 | 0.85 | 0.85 | 0.70 | 2.10 | 1.20 |
| Na2O | 4.3 | 4.2 | 3.8 | 4.0 | 4.3 | 4.9 | 5.5 | 4.9 |
| TiO2 | 0.85 | 1.05 | 0.75 | 0.95 | 1.00 | 0.90 | 0.75 | 1.85 |
| Total | 99.70 | 99.30 | 99.30 | 100.00 | 99.45 | 100.30 | 99.55 | 100.45 |

| | 129 | 134 | 135 | 136 | 137 | 138 | 139 | 140 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.0 | 69.0 | 53.7 | 68.9 | 69.1 | 55.0 | 54.8 | 54.8 |
| Al2O3 | 17.7 | 14.6 | 18.2 | 15.1 | 14.7 | 18.2 | 19.2 | 17.9 |
| FeO | 10.6 | 3.9 | 10.0 | 4.1 | 3.8 | 9.2 | 7.8 | 8.0 |
| CaO | 6.4 | 1.8 | 7.2 | 1.8 | 1.8 | 6.7 | 7.5 | 7.8 |
| MgO | 3.2 | 0.3 | 3.7 | 0.3 | 0.3 | 3.4 | 4.8 | 5.4 |
| K2O | 0.95 | 2.65 | 0.85 | 2.60 | 2.60 | 1.15 | 0.95 | 0.80 |
| Na2O | 4.6 | 6.2 | 4.6 | 6.1 | 6.1 | 4.5 | 4.1 | 3.8 |
| TiO2 | 1.80 | 0.50 | 1.65 | 0.50 | 0.50 | 1.60 | 0.95 | 0.95 |
| Total | 100.25 | 98.95 | 99.90 | 99.40 | 98.90 | 99.95 | 100.10 | 99.45 |

| | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 55.3 | 56.0 | 55.3 | 55.0 | 53.9 | 55.6 | 53.5 | 54.7 |
| $Al_2O_3$ | 20.5 | 16.1 | 17.8 | 19.2 | 19.7 | 15.1 | 15.1 | 15.6 |
| FeO | 6.4 | 10.0 | 7.6 | 7.7 | 8.0 | 10.3 | 12.1 | 11.0 |
| CaO | 8.3 | 6.6 | 7.7 | 7.7 | 7.7 | 7.3 | 7.1 | 7.1 |
| MgO | 3.6 | 3.6 | 5.6 | 5.0 | 5.6 | 3.5 | 3.8 | 3.7 |
| $K_2O$ | 0.85 | 1.05 | 0.70 | 0.85 | 0.75 | 1.25 | 0.90 | 0.85 |
| $Na_2O$ | 4.2 | 4.8 | 3.7 | 3.9 | 3.9 | 4.6 | 4.6 | 4.6 |
| $TiO_2$ | 0.90 | 1.70 | 0.95 | 0.95 | 0.95 | 1.80 | 2.00 | 1.95 |
| Total | 100.05 | 99.85 | 99.35 | 100.30 | 100.50 | 99.45 | 99.10 | 99.50 |

| | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 55.5 | 56.5 | 68.2 | 55.3 | 55.0 | 68.7 | 67.9 | 54.3 |
| $Al_2O_3$ | 15.5 | 16.6 | 15.3 | 18.1 | 18.1 | 15.5 | 16.2 | 18.0 |
| FeO | 11.4 | 8.8 | 4.7 | 8.4 | 8.4 | 4.1 | 3.9 | 7.7 |
| CaO | 7.0 | 6.6 | 1.7 | 7.9 | 7.3 | 1.7 | 1.6 | 8.0 |
| MgO | 3.2 | 3.8 | 0.7 | 3.8 | 4.0 | 0.4 | 0.5 | 6.1 |
| $K_2O$ | 0.85 | 1.00 | 2.55 | 0.80 | 0.95 | 2.60 | 2.65 | 0.75 |
| $Na_2O$ | 4.6 | 4.6 | 6.2 | 4.1 | 4.4 | 6.0 | 5.9 | 3.8 |
| $TiO_2$ | 1.95 | 1.20 | 0.50 | 1.10 | 1.10 | 0.55 | 0.55 | 0.90 |
| Total | 100.00 | 99.10 | 99.85 | 99.50 | 99.25 | 99.55 | 99.20 | 99.55 |

| | 157 | 158 | 159 | 160 | 161 | 162 | 165 | 167 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 68.6 | 56.0 | 61.7 | 60.7 | 54.2 | 65.3 | 62.4 | 55.7 |
| $Al_2O_3$ | 16.1 | 15.8 | 15.4 | 15.1 | 18.0 | 16.0 | 17.2 | 19.7 |
| FeO | 4.0 | 10.1 | 7.3 | 8.7 | 7.8 | 5.5 | 6.5 | 8.0 |
| CaO | 1.4 | 5.8 | 4.0 | 4.2 | 7.6 | 2.9 | 3.4 | 6.5 |
| MgO | 0.7 | 3.9 | 1.7 | 1.9 | 5.5 | 1.1 | 0.9 | 3.2 |
| $K_2O$ | 2.65 | 1.15 | 2.00 | 1.95 | 0.80 | 2.15 | 1.90 | 1.10 |
| $Na_2O$ | 6.00 | 4.8 | 5.3 | 5.2 | 3.7 | 5.7 | 5.7 | 4.3 |
| $TiO_2$ | 0.60 | 1.50 | 1.45 | 1.45 | 0.80 | 0.95 | 1.05 | 1.05 |
| Total | 100.05 | 99.05 | 98.85 | 99.20 | 98.40 | 99.60 | 99.05 | 99.55 |

| | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 |
|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 66.3 | 60.8 | 60.5 | 58.5 | 68.2 | 55.6 | 64.1 | 66.9 |
| $Al_2O_3$ | 15.9 | 17.5 | 15.7 | 16.1 | 15.9 | 16.6 | 16.0 | 15.7 |
| FeO | 5.5 | 7.0 | 7.8 | 8.0 | 3.9 | 9.8 | 6.1 | 5.0 |
| CaO | 2.8 | 3.6 | 5.4 | 5.5 | 1.8 | 6.7 | 3.1 | 2.3 |
| MgO | 0.9 | 1.5 | 2.1 | 2.8 | 0.7 | 3.5 | 0.7 | 0.7 |
| $K_2O$ | 2.15 | 1.70 | 1.35 | 1.35 | 2.65 | 0.95 | 1.80 | 2.15 |
| $Na_2O$ | 5.6 | 5.8 | 4.9 | 4.9 | 6.0 | 4.6 | 6.0 | 6.1 |
| $TiO_2$ | 0.95 | 1.25 | 1.40 | 1.45 | 0.50 | 1.25 | 0.85 | 0.65 |
| Total | 100.10 | 99.15 | 99.15 | 98.60 | 99.65 | 99.00 | 98.65 | 99.50 |

APPENDIX 1 (continued)

| | 176 | 177 | 191 | 192 | 193 | 194 | 195 | 196 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 54.4 | 63.5 | 59.1 | 58.5 | 53.4 | 68.1 | 54.7 | 61.0 |
| Al2O3 | 15.9 | 16.0 | 17.0 | 16.9 | 18.3 | 15.7 | 18.2 | 17.4 |
| FeO | 10.5 | 6.8 | 8.0 | 8.0 | 8.8 | 4.1 | 8.0 | 6.6 |
| CaO | 7.2 | 3.3 | 5.9 | 6.1 | 8.3 | 2.0 | 7.9 | 3.9 |
| MgO | 4.2 | 1.5 | 3.0 | 3.2 | 5.6 | 0.8 | 5.8 | 2.0 |
| K2O | 0.95 | 2.15 | 1.50 | 1.45 | 0.70 | 2.65 | 0.85 | 1.60 |
| Na2O | 4.5 | 5.7 | 4.9 | 4.6 | 4.0 | 5.8 | 3.9 | 6.0 |
| TiO2 | 1.70 | 0.90 | 1.35 | 1.35 | 1.15 | 0.75 | 1.10 | 1.35 |
| Total | 99.35 | 99.85 | 100.75 | 100.10 | 100.25 | 99.90 | 100.45 | 99.85 |

| | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 68.5 | 54.3 | 54.2 | 64.8 | 70.2 | 55.6 | 53.7 | 60.0 |
| Al2O3 | 15.7 | 16.5 | 18.2 | 15.9 | 15.1 | 16.5 | 19.0 | 16.8 |
| FeO | 3.6 | 10.7 | 8.5 | 4.9 | 3.3 | 10.0 | 7.4 | 7.8 |
| CaO | 2.0 | 6.9 | 7.8 | 3.7 | 1.3 | 6.8 | 8.1 | 5.2 |
| MgO | 0.8 | 3.6 | 4.6 | 1.5 | 0.3 | 3.7 | 5.4 | 2.5 |
| K2O | 2.40 | 0.90 | 0.90 | 1.80 | 2.60 | 0.95 | 0.80 | 1.60 |
| Na2O | 5.7 | 4.8 | 4.3 | 5.6 | 6.2 | 5.0 | 4.0 | 5.1 |
| TiO2 | 0.70 | 2.20 | 1.35 | 1.40 | 0.45 | 1.80 | 1.05 | 1.50 |
| Total | 99.40 | 99.90 | 99.85 | 99.60 | 99.45 | 100.35 | 99.45 | 100.50 |

| | 206 | 207 | 208 | 209 | 210 | 250 | 258 | 259 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 73.4 | 73.0 | 73.0 | 72.5 | 56.8 | 63.9 | 57.5 | 52.4 |
| Al2O3 | 14.3 | 14.2 | 14.9 | 14.6 | 17.6 | 16.2 | 17.3 | 16.3 |
| FeO | 2.8 | 2.1 | 2.8 | 2.2 | 8.0 | 5.2 | 7.0 | 8.7 |
| CaO | 1.5 | 1.5 | 1.5 | 1.5 | 6.8 | 3.9 | 7.2 | 8.7 |
| MgO | 0.3 | 0.3 | 0.3 | 0.3 | 4.0 | 1.5 | 4.1 | 7.9 |
| K2O | 2.90 | 2.95 | 2.90 | 2.95 | 1.20 | 2.05 | 1.15 | 0.50 |
| Na2O | 4.9 | 4.8 | 4.8 | 5.1 | 4.6 | 5.2 | 4.0 | 3.4 |
| TiO2 | 0.25 | 0.25 | 0.30 | 0.35 | 1.25 | 1.00 | 1.05 | 1.25 |
| Total | 100.35 | 99.10 | 100.50 | 99.50 | 100.25 | 98.95 | 99.40 | 99.15 |

| | 260 | 261 | 262 | 263 | 264 | 265 | 266 | 268 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 57.0 | 52.5 | 49.7 | 64.9 | 52.4 | 50.8 | 51.9 | 64.3 |
| Al2O3 | 17.5 | 15.8 | 16.5 | 15.8 | 18.4 | 17.2 | 17.3 | 16.1 |
| FeO | 7.2 | 8.8 | 10.2 | 5.2 | 9.0 | 9.0 | 9.0 | 5.1 |
| CaO | 7.2 | 8.7 | 8.8 | 3.9 | 7.7 | 8.6 | 8.7 | 3.9 |
| MgO | 4.3 | 8.8 | 9.2 | 1.7 | 5.3 | 8.0 | 7.6 | 1.7 |
| K2O | 1.20 | 0.65 | 0.35 | 2.10 | 0.50 | 0.70 | 0.30 | 1.90 |
| Na2O | 3.9 | 3.4 | 3.1 | 5.4 | 3.8 | 3.3 | 3.7 | 5.3 |
| TiO2 | 1.05 | 1.30 | 1.55 | 1.05 | 1.30 | 1.50 | 1.40 | 1.05 |
| Total | 99.35 | 99.95 | 99.40 | 100.05 | 98.40 | 99.10 | 99.90 | 99.35 |

APPENDIX 1 (continued)

| | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 72.3 | 72.0 | 72.0 | 56.3 | 63.5 | 54.8 | 62.0 | 59.5 |
| Al2O3 | 14.8 | 15.6 | 15.0 | 16.2 | 15.7 | 18.4 | 16.8 | 16.8 |
| FeO | 2.2 | 2.0 | 2.2 | 8.3 | 6.3 | 6.8 | 6.2 | 6.9 |
| CaO | 1.9 | 1.5 | 2.0 | 7.3 | 3.7 | 8.3 | 3.7 | 6.4 |
| MgO | 0.7 | 0.3 | 0.8 | 3.7 | 1.5 | 5.7 | 1.6 | 3.1 |
| K2O | 2.95 | 2.90 | 2.95 | 0.95 | 1.75 | 0.60 | 1.75 | 1.15 |
| Na2O | 4.8 | 4.7 | 4.5 | 4.5 | 5.4 | 4.0 | 5.3 | 4.7 |
| TiO2 | 0.30 | 0.25 | 0.30 | 1.55 | 1.35 | 0.95 | 1.35 | 1.30 |
| Total | 99.95 | 99.25 | 99.75 | 98.80 | 99.20 | 99.55 | 98.70 | 99.85 |

| | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 65.3 | 64.8 | 63.9 | 63.9 | 63.0 | 63.5 | 62.9 | 63.0 |
| Al2O3 | 15.8 | 15.8 | 16.6 | 16.0 | 16.1 | 16.0 | 15.8 | 15.8 |
| FeO | 5.3 | 5.4 | 5.4 | 5.6 | 6.1 | 5.8 | 6.3 | 6.0 |
| CaO | 3.4 | 3.5 | 3.7 | 3.7 | 3.7 | 4.2 | 4.2 | 4.2 |
| MgO | 1.5 | 1.5 | 1.5 | 1.5 | 2.0 | 2.1 | 1.7 | 1.8 |
| K2O | 2.25 | 2.20 | 2.20 | 2.20 | 2.10 | 2.10 | 2.00 | 2.00 |
| Na2O | 5.3 | 5.1 | 5.1 | 4.9 | 5.0 | 5.2 | 5.1 | 5.2 |
| TiO2 | 1.05 | 1.05 | 1.05 | 1.05 | 1.15 | 1.10 | 1.20 | 1.20 |
| Total | 99.90 | 99.35 | 99.45 | 98.85 | 99.15 | 100.00 | 99.20 | 99.20 |

| | 285 | 286 | 287 | 288 | 289 | 290 | 291 | 292 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 57.5 | 61.9 | 62.5 | 56.1 | 63.9 | 55.4 | 65.4 | 65.0 |
| Al2O3 | 18.1 | 16.1 | 15.8 | 16.7 | 15.5 | 18.7 | 17.9 | 15.6 |
| FeO | 6.9 | 6.6 | 6.7 | 8.6 | 6.4 | 7.0 | 4.2 | 4.8 |
| CaO | 6.9 | 4.4 | 4.4 | 7.3 | 4.2 | 8.4 | 2.8 | 3.9 |
| MgO | 3.2 | 1.7 | 2.0 | 3.8 | 2.0 | 3.9 | 0.8 | 1.8 |
| K2O | 1.15 | 1.65 | 1.65 | 0.95 | 1.75 | 0.80 | 2.35 | 1.90 |
| Na2O | 4.8 | 5.4 | 5.4 | 4.2 | 5.6 | 4.4 | 5.2 | 4.7 |
| TiO2 | 1.25 | 1.30 | 1.35 | 1.45 | 1.15 | 1.10 | 0.80 | 1.10 |
| Total | 99.80 | 99.05 | 99.80 | 99.10 | 100.05 | 99.70 | 99.45 | 98.80 |

| | 293 | 294 | 295 | 296 | 297 | 298 | 299 | 300 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 63.0 | 66.0 | 52.3 | 54.6 | 68.5 | 67.9 | 52.2 | 52.0 |
| Al2O3 | 17.7 | 16.0 | 18.8 | 19.2 | 16.7 | 17.5 | 18.4 | 19.2 |
| FeO | 5.1 | 4.8 | 8.3 | 7.5 | 3.1 | 3.6 | 8.1 | 8.3 |
| CaO | 3.4 | 3.4 | 8.5 | 7.3 | 1.5 | 1.8 | 8.4 | 8.2 |
| MgO | 1.4 | 1.6 | 5.9 | 4.4 | 0.8 | 0.5 | 5.7 | 5.7 |
| K2O | 2.20 | 2.35 | 0.65 | 0.95 | 2.50 | 2.35 | 1.20 | 1.10 |
| Na2O | 5.3 | 4.6 | 3.4 | 4.1 | 6.0 | 6.0 | 3.1 | 3.9 |
| TiO2 | 1.05 | 0.95 | 1.30 | 1.05 | 0.45 | 0.65 | 1.50 | 1.50 |
| Total | 99.15 | 99.70 | 99.15 | 99.10 | 99.55 | 100.30 | 98.60 | 99.90 |

| | 301 | 302 | 303 | 305 | 306 | 307 | 308 | 309 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.0 | 56.0 | 52.6 | 67.0 | 54.6 | 56.0 | 56.5 | 55.1 |
| Al2O3 | 19.2 | 17.0 | 16.0 | 16.5 | 17.8 | 17.5 | 18.0 | 17.9 |
| FeO | 7.2 | 6.3 | 8.6 | 4.1 | 7.2 | 7.4 | 7.7 | 6.9 |
| CaO | 7.3 | 7.6 | 8.0 | 2.4 | 7.9 | 7.8 | 7.2 | 8.1 |
| MgO | 4.3 | 5.0 | 7.4 | 0.7 | 6.0 | 4.5 | 4.3 | 5.8 |
| K2O | 1.00 | 1.05 | 1.15 | 2.15 | 0.80 | 0.95 | 0.80 | 0.80 |
| Na2O | 4.3 | 4.6 | 3.9 | 6.5 | 3.8 | 4.1 | 4.2 | 3.7 |
| TiO2 | 1.05 | 0.90 | 1.40 | 0.65 | 1.00 | 1.30 | 1.10 | 0.95 |
| Total | 99.35 | 99.45 | 99.05 | 100.00 | 99.10 | 99.55 | 99.80 | 99.25 |

| | 310 | 311 | 312 | 313 | 314 | 315 | 319 | 320 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.6 | 56.3 | 55.5 | 54.7 | 55.4 | 55.0 | 53.8 | 55.5 |
| Al2O3 | 17.9 | 17.3 | 18.0 | 18.6 | 18.5 | 18.0 | 18.7 | 17.7 |
| FeO | 7.3 | 7.4 | 7.3 | 7.4 | 7.4 | 7.5 | 8.2 | 7.5 |
| CaO | 8.0 | 8.0 | 8.1 | 7.9 | 8.0 | 8.6 | 8.6 | 7.8 |
| MgO | 5.7 | 5.7 | 5.5 | 5.7 | 4.5 | 4.5 | 4.7 | 5.6 |
| K2O | 0.80 | 0.80 | 0.85 | 0.85 | 1.20 | 1.15 | 1.10 | 0.80 |
| Na2O | 3.6 | 3.7 | 3.6 | 3.7 | 3.5 | 3.5 | 3.3 | 3.6 |
| TiO2 | 0.95 | 0.95 | 0.95 | 1.00 | 1.25 | 1.05 | 1.10 | 1.05 |
| Total | 99.85 | 100.15 | 99.80 | 99.85 | 99.75 | 99.30 | 99.50 | 99.55 |

| | 341 | 342 | 343 | 346 | 347 | 348 | 349 | 350 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 67.9 | 55.6 | 64.0 | 54.9 | 67.6 | 53.8 | 54.5 | 55.2 |
| Al2O3 | 16.5 | 18.3 | 16.1 | 17.9 | 15.6 | 16.9 | 16.6 | 17.9 |
| FeO | 3.6 | 8.3 | 5.9 | 9.6 | 3.7 | 9.3 | 9.5 | 9.0 |
| CaO | 2.1 | 6.5 | 3.1 | 6.8 | 2.1 | 8.0 | 7.8 | 6.7 |
| MgO | 0.5 | 4.0 | 1.0 | 3.7 | 0.7 | 4.9 | 4.3 | 3.4 |
| K2O | 2.35 | 1.10 | 1.85 | 0.95 | 2.25 | 0.65 | 0.80 | 1.00 |
| Na2O | 6.3 | 4.8 | 6.2 | 4.6 | 6.2 | 4.5 | 4.4 | 4.5 |
| TiO2 | 0.65 | 1.35 | 0.90 | 1.65 | 0.65 | 1.60 | 1.65 | 1.50 |
| Total | 99.90 | 99.95 | 99.05 | 100.10 | 98.80 | 99.65 | 99.55 | 99.20 |

| | 351 | 352 | 354 | 355 | 356 | 358 | 359 | 360 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 62.9 | 57.5 | 66.7 | 54.0 | 62.5 | 60.0 | 55.4 | 55.3 |
| Al2O3 | 17.2 | 17.9 | 17.6 | 20.5 | 17.2 | 15.6 | 17.1 | 18.0 |
| FeO | 6.1 | 8.0 | 3.9 | 6.7 | 5.8 | 7.8 | 8.5 | 8.0 |
| CaO | 3.7 | 5.6 | 2.4 | 8.3 | 3.5 | 5.4 | 7.5 | 8.3 |
| MgO | 1.5 | 2.6 | 0.8 | 4.2 | 1.3 | 2.5 | 4.1 | 5.0 |
| K2O | 1.80 | 1.40 | 2.10 | 0.90 | 2.10 | 1.50 | 0.90 | 0.50 |
| Na2O | 5.4 | 4.7 | 5.9 | 4.0 | 5.6 | 5.0 | 4.5 | 4.5 |
| TiO2 | 1.15 | 1.50 | 0.80 | 1.00 | 1.10 | 1.45 | 1.25 | 1.05 |
| Total | 99.75 | 99.20 | 100.20 | 99.60 | 99.10 | 99.25 | 99.25 | 100.65 |

APPENDIX 1 (continued)

| | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 380 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 55.0 | 62.0 | 56.0 | 55.5 | 61.3 | 54.4 | 63.8 | 57.6 |
| Al2O3 | 17.8 | 16.3 | 17.6 | 17.3 | 17.6 | 18.6 | 16.8 | 16.7 |
| FeO | 7.5 | 6.0 | 7.2 | 7.3 | 6.1 | 7.4 | 4.9 | 9.4 |
| CaO | 8.3 | 4.7 | 7.9 | 8.4 | 5.1 | 8.6 | 3.8 | 6.4 |
| MgO | 5.1 | 2.5 | 4.7 | 5.7 | 2.4 | 5.0 | 1.3 | 3.3 |
| K2O | 0.55 | 1.80 | 0.80 | 0.80 | 1.80 | 0.70 | 1.85 | 1.00 |
| Na2O | 4.2 | 4.8 | 4.2 | 3.8 | 4.8 | 4.2 | 6.1 | 4.6 |
| TiO2 | 1.05 | 1.00 | 0.90 | 0.95 | 1.05 | 1.00 | 0.95 | 1.45 |
| Total | 99.50 | 99.10 | 99.30 | 99.75 | 100.15 | 99.90 | 99.50 | 100.45 |

| | 381 | 445 | 446 | 447 | 448 | 449 | 456 | 458 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 71.7 | 72.9 | 72.3 | 72.3 | 71.6 | 73.2 | 63.0 | 62.7 |
| Al2O3 | 14.9 | 14.2 | 14.9 | 15.0 | 15.0 | 14.2 | 16.0 | 16.5 |
| FeO | 2.9 | 2.5 | 2.4 | 2.6 | 3.0 | 2.3 | 6.3 | 6.4 |
| CaO | 2.1 | 2.0 | 2.0 | 1.9 | 1.9 | 1.4 | 5.1 | 5.2 |
| MgO | 0.8 | 0.5 | 0.4 | 0.5 | 0.8 | 0.3 | 2.0 | 1.8 |
| K2O | 2.90 | 3.10 | 3.05 | 3.10 | 3.00 | 3.10 | 1.70 | 1.90 |
| Na2O | 4.6 | 4.3 | 4.2 | 4.2 | 4.3 | 4.3 | 4.5 | 4.2 |
| TiO2 | 0.30 | 0.30 | 0.35 | 0.35 | 0.30 | 0.30 | 1.10 | 1.10 |
| Total | 100.20 | 99.80 | 99.60 | 99.95 | 99.90 | 99.10 | 99.70 | 99.80 |

| | 525 | 526 | 529 | 1000 | 1001 | 1002 | 1003 | 1004 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 52.1 | 52.5 | 74.3 | 50.7 | 51.5 | 54.3 | 56.2 | 72.2 |
| Al2O3 | 17.7 | 17.6 | 14.6 | 17.2 | 16.2 | 17.4 | 17.6 | 14.9 |
| FeO | 10.1 | 9.7 | 2.5 | 8.9 | 9.2 | 9.4 | 7.5 | 2.5 |
| CaO | 7.7 | 7.7 | 1.4 | 8.8 | 8.7 | 8.2 | 7.5 | 2.0 |
| MgO | 5.1 | 4.8 | 0.1 | 8.6 | 8.6 | 4.7 | 4.9 | 0.6 |
| K2O | 0.50 | 0.65 | 2.65 | 0.65 | 0.50 | 0.75 | 1.10 | 3.05 |
| Na2O | 3.6 | 3.8 | 4.0 | 3.3 | 3.3 | 3.9 | 3.9 | 4.4 |
| TiO2 | 1.50 | 1.30 | 0.25 | 1.05 | 1.35 | 1.40 | 1.05 | 0.30 |
| Total | 98.30 | 98.05 | 99.80 | 99.20 | 99.35 | 100.05 | 99.75 | 99.95 |

| | 1005 | 1006 | 1007 | 1008 | 1009 | 1010 | 1011 | 1012 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 52.1 | 52.0 | 53.9 | 55.0 | 54.9 | 55.2 | 55.6 | 53.9 |
| Al2O3 | 18.3 | 17.6 | 17.4 | 17.0 | 16.0 | 18.1 | 16.8 | 20.3 |
| FeO | 8.4 | 9.4 | 9.8 | 9.0 | 10.6 | 8.4 | 9.3 | 7.2 |
| CaO | 8.2 | 8.1 | 7.6 | 7.3 | 7.1 | 7.6 | 6.7 | 8.1 |
| MgO | 5.9 | 6.2 | 4.6 | 4.3 | 3.7 | 3.9 | 3.7 | 4.2 |
| K2O | 1.00 | 0.55 | 0.80 | 0.80 | 0.90 | 0.90 | 1.00 | 0.90 |
| Na2O | 3.5 | 3.6 | 4.4 | 4.5 | 4.7 | 4.3 | 4.6 | 4.2 |
| TiO2 | 1.45 | 1.40 | 1.65 | 1.45 | 1.80 | 1.10 | 1.55 | 1.00 |
| Total | 98.85 | 98.85 | 100.15 | 99.35 | 99.70 | 99.50 | 99.25 | 99.80 |

APPENDIX 1 (continued)

| | 1013 | 1014 | 1015 | 1016 | 1017 | 1018 | 1019 | 1020 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 54.7 | 54.2 | 54.8 | 55.1 | 55.2 | 61.3 | 61.2 | 62.5 |
| Al2O3 | 18.4 | 19.6 | 18.5 | 18.6 | 18.1 | 16.7 | 15.3 | 17.2 |
| FeO | 7.6 | 7.6 | 7.6 | 7.6 | 7.6 | 6.7 | 8.0 | 6.2 |
| CaO | 7.9 | 7.6 | 7.7 | 7.6 | 8.2 | 5.2 | 4.1 | 3.5 |
| MgO | 5.2 | 4.6 | 5.2 | 4.6 | 5.0 | 2.4 | 1.8 | 1.1 |
| K2O | 0.75 | 0.75 | 0.85 | 0.95 | 0.90 | 1.75 | 2.00 | 2.00 |
| Na2O | 4.4 | 4.2 | 3.9 | 4.1 | 3.8 | 4.8 | 5.3 | 5.7 |
| TiO2 | 0.95 | 0.90 | 0.90 | 1.10 | 1.00 | 1.20 | 1.45 | 1.10 |
| Total | 99.90 | 99.45 | 99.45 | 99.65 | 99.80 | 100.05 | 99.15 | 99.30 |

| | 1021 | 1022 | 1023 | 1024 | 1025 | 1026 | 1027 | 1028 |
|---|---|---|---|---|---|---|---|---|
| SiO2 | 62.5 | 63.2 | 62.2 | 57.0 | 67.5 | 64.5 | 64.5 | 64.1 |
| Al2O3 | 16.6 | 15.5 | 16.0 | 16.4 | 15.9 | 16.0 | 16.1 | 16.2 |
| FeO | 6.6 | 6.5 | 6.7 | 8.6 | 4.1 | 5.8 | 5.3 | 5.5 |
| CaO | 4.1 | 3.7 | 4.4 | 7.2 | 2.2 | 3.0 | 3.9 | 3.7 |
| MgO | 1.4 | 1.6 | 1.9 | 3.5 | 0.6 | 0.9 | 1.6 | 1.6 |
| K2O | 1.65 | 1.90 | 1.65 | 1.10 | 2.25 | 1.95 | 2.10 | 2.15 |
| Na2O | 5.5 | 5.6 | 5.4 | 4.3 | 6.2 | 6.0 | 5.4 | 5.0 |
| TiO2 | 1.45 | 1.30 | 1.35 | 1.30 | 0.65 | 0.90 | 1.05 | 1.05 |
| Total | 98.40 | 99.30 | 99.60 | 99.40 | 99.40 | 99.05 | 99.95 | 99.30 |

| | 1029 | 1030 | 1031 | 1032 | 1033 | 1034 | 1035 |
|---|---|---|---|---|---|---|---|
| SiO2 | 73.1 | 68.3 | 68.4 | 73.8 | 68.2 | 69.0 | 68.4 |
| Al2O3 | 14.5 | 15.7 | 15.9 | 14.4 | 15.9 | 14.8 | 16.2 |
| FeO | 2.6 | 3.9 | 4.0 | 2.4 | 4.2 | 3.9 | 3.6 |
| CaO | 1.5 | 2.0 | 1.6 | 1.4 | 2.2 | 1.8 | 1.9 |
| MgO | 0.3 | 0.8 | 0.5 | 0.2 | 0.6 | 0.3 | 0.6 |
| K2O | 2.90 | 2.55 | 2.65 | 2.90 | 2.15 | 2.60 | 2.40 |
| Na2O | 4.8 | 5.8 | 6.0 | 4.2 | 6.0 | 6.1 | 5.8 |
| TiO2 | 0.25 | 0.75 | 0.55 | 0.30 | 0.70 | 0.50 | 0.55 |
| Total | 99.95 | 99.80 | 99.60 | 99.60 | 99.65 | 99.00 | 99.45 |

APPENDIX 2

Locations of Analysed Rocks, S.W. Broken Top Quadrangle

1. Platy lava at 6620' elev., corner sec 14,15,22,23, 0.1 km S. of 3-Ck. Lk. Map 2.
2. Platy lava in cliffs of E. Tam Mac Rim at 6800' elev, 0.1 km E. of E. edge of Map 3.
4. Columnar-jointed glassy margin of glaciated lava in cut of 3-Cr. Lk. Rd., 0.1 km N. of boundary sec 8,5. Map 8.
5. Platy lava at 6560' elev, S. of 3-Cr. Lk. Rd., N. center sec 8. Map 8.
7. Terminous of Cayuse flow, roadcut at Soda Cr. and Century Dr. Map 7.
8. Top of platy lava in cliffs at 6320' elev, 0.6 km E. of Bare Lk. Map 8.
10. Lava from ridge crest at 6650' elev, 0.6 km N.W. of Todd Lk. Map 8.
11. Base of platy lava in cliffs at 6200' elev, 0.5 km S.E. of Bare Lk. Map 8.
12. Lava at top of S.E.-facing cliffs at 6490' elev, 0.4 km S.E. of Bare Lk. Map 8.
15. Lava from ridge crest at 6920' elev, 0.9 km W. of Todd Lk. Map 8.
16. Platy lava at 6380' elev, S.E. side of ridge N.W. of Todd Lk. Map 8.
17. Thin vesicular lava from summit of hill, E. Tam Mac Rim, W. center sec 23, 0.2 km W. of Map 3.
20. Cayuse flow at 5480' elev, Soda Cr. Tr. in N.E. corner sec 11. Map 7.
21. E. margin Cayuse flow at 5760' elev, 0.6 km N. of Soda Cr. Map 4.
22. Center of Cayuse flow, 1.0 km downstream from Cayuse Cone. Map 4.
23. Lava from head of Cayuse flow in gutter at S. base of Cayuse Cone. Map 4.
24. Lava from head of flow at 6700' elev S.W. base of small source cone 0.5 km N.W. of Cayuse Cone. Map 4.
25. Margin of black vitrophyre, 6680' elev, 0.5 km W. of Green Lk. Map 1.
26. Glassy lava from E. margin of Newberry flow, 0.6 km W. of Green Lk. Map 1.
27. Platy lava at 6200' elev, S.E. side of Fall Cr. opposite S. tip of Newberry flow. Map 4.
28. Spherulitic lava from S. tip of Newberry flow. Map 4.
29. Glassy lava from 6120' elev, 0.35 km S.W. of junction, Moraine Lk. and Green Lk. Trails. Map 4.
30. W. margin of W. lobe of Cayuse flow at 5760' elev. Map 4.
41. Lava at waterfall, 0.2 km downstream from outlet of Todd Lk. Map 8.
42. Glaciated lava from cut at spring near Old Century Drive Rd., 0.8 km S.E. of Todd Lk. Map 8.
43. Cinders from E. side of glaciated cinder cone, 1.0 km S. of Todd Lk. Map 8.
44. Lava from W. margin of N.E. lobe from cinder cone on N. slope of Bachelor Bu. Map 8.
45. Lava, 1.0 km S. of Bare Lk., center sec 18. Map 8.
46. Cinders from E. side glaciated cone, N. sec 20, 1.0 km N. of Bachelor Bu. Map 8.
47. Lava in Century Drive roadcut, W. end of Dutchman Flat. Map 8.
48. Glaciated lava at W. base of Tumalo Mtn., S.E. end of Dutchman Flat. Map 9.
74. SE-trending dike at 7680' elev, S.E. ridge of Tumalo Mtn. Map 9.
81. Fresh, coarse block from Broken Top summit plug, W. base of Crook Glacier cirque. Map 5.
101. Platy margin of Broken Top summit plug, W. base of Crook Glacier cirque. Map 5.
102. Platy margin of Broken Top summit plug, N.E. base of Crook Glacier cirque. Map 5.
103. White pumice lumps from base of welded tuff at 8600' elev, in W. wall of Crook Glacier cirque, Broken Top. Map 5.
106. Lava from lowest exposed flow in W. wall of Crook Glacier cirque, Broken Top. Map 5.
107. Oxidized lava from lowest exposed flow in E. wall of Crook Glacier cirque, Broken Top. Map 5.
108. Lava from 7800' elev on crest of Broken Top S.E. ridge. Map 5.
109. Glaciated lava at 7650' elev, 1.0 km N. of Ball Butte. Map 5.
110. Glaciated lava from 0.2 km N. of Ball Butte. Map 5.
111. Lava from Creek bed at 7000' elev, 0.5 km S.W. of Ball Butte. Map 5.
112. Lowest of 3 dikes beneath cinder cone remnant at 7600' elev, crest of Broken Top S. ridge. Map 5.
113. Lava from prominence at 8050' elev, Broken Top S. ridge. Map 5.

114. Lava at 8100' elev, crest of Broken Top S.W. ridge. Map 5.
115. Glassy crest of glaciated lava at 7520' elev, Broken Top S.W. ridge. Map 4.
116. Thin flow at 7400' elev, S. side Broken Top N.W. ridge. Map 1.
117. Glaciated lava from knoll, 0.1 km S. of Green Lk. Map 4.
118. Lava at 6960' elev, 0.3 km N. of Cayuse Cone. Map 4.
119. Dike at 8200' elev, between N. and E. arms of Bend Glacier, Broken Top. Map 2.
121. S.W. end of dike at 8280' elev in saddle of Broken Top N.E. ridge. Map 2.
122. Lava at 7080' elev, crest of Broken Top E. ridge. Map 2.
124. Cinders from cone at 7700' elev, W. sec 21, 1.3 km S.W. of Tam Mac Rim. Map 3.
125. N.W.-S.E. dike at 7440' elev, upper N. Fork Tumalo Cr. Map 6.
126. Pumice bomb from W. side of silicic tuff cone at 7320' elev, upper N. Fork Tumalo Cr. Map 6.
128. Platy lava from base of cliffs at 6840' elev, S.E. corner sec 27, N. side Happy Valley. Map 6.
129. Lava from cinder cone at 7350' elev, N. central sec 28, upper N. Fork Tumalo Cr. Map 6.
134. Obsidian from base of flow exposed in cliffs at 7160' elev, S.W. bank of N. Fork Tumalo Cr. Map 6.
135. Lava at 6800' elev, N. bank of N. Fork Tumalo Cr. Map 6.
136. Spherulitic glass from top of flow at 6600' elev, center of N. boundary sec 3. Map 6.
137. Base of flow at 6600' elev, center of N. boundary sec 3. Map 6.
138. Platy lava at 6200' elev in bed of N. Fork Tumalo Cr., 0.3 km E. of Map 6.
139. Lava at 7240' elev on N.W. side of glaciated cone, 1.0 km S. of Ball Butte. Map 5.
140. Lava at 7000' elev, N. end of glaciated cone, 3.3 km N.W. of Tumalo Mtn. Map 9.
141. Glaciated lava, 0.5 km W. of corner sec 3,4,9,10, 1.2 km N.W. of Tum Lk. Map 9.
142. Lava from cliffs 0.1 km S.S.W. of Tum Lk. Map 9.
143. Glaciated lava in S.W. sec 10, 0.8 km S.S.W. of Tum Lk. Map 9.
144. Cinders from N. rim of cone 2.0 km N. of Tumalo Mtn. Map 9.
145. Cinders from summit of cone in S.E. corner sec 9, 2.6 km N.N.W. of Tumalo Mtn. Map 9.
146. Platy lava from base of cliffs at 7200' elev, 0.2 km S. of lake, center sec 16. Map 3.
147. Lava at 6950' elev, W. side of Snow Cr. Valley, N.E. sec 17. Map 2.
148. Platy lava at 6900' elev, N. center sec 16. Map 3.
149. Oxidized lava at 7040' elev, saddle of ridge, N. boundary of sec 16. Map 3.
150. Cinders from glaciated cone at 6720' elev, center sec 9, 2.8 km N.W. of 3-Cr. Lk. Map 3.
151. Lithophysal lava at 7120' elev, E. Tam Mac Rim, 0.8 km S. of 3-Cr. Lk. Map 3.
152. Lava from glaciated shelf at 7000' elev, E. Tam Mac Rim, 0.6 km S. of 3-Cr. Lk. Map 3.
153. Lava from glaciated shelf at 7200' elev, E. Tam Mac Rim, 0.7 km S. of 3-Cr. Lk. Map 3.
154. Glassy top of flow at 7400' elev, N. center sec 22, Tam Mac Rim. Map 3.
155. Glassy margin of E. end of dike at 7240' elev, in face of Tam Mac Rim, N. center sec 22. Map 3.
156. Lava from flow below cap of Tam Mac Rim in center of sec 22. Map 3.
157. White lava at 7660' elev, 0.2 km S. of summit of Tam Mac Rim prominence in N.W. sec 22. Map 3.
158. Glaciated lava at 7450' elev, E. side Snow Cr. cirque, N.W. sec 21. Map 3.
159. N.E. end of dike at 7520' elev, S.W. Snow Cr. cirque. Map 2.
160. Platy lava at 7740' elev, head of Snow Cr. cirque. Map 2.
161. Lava from W. summit of Tam Mac Rim, S. center sec 16. Map 3.
162. Platy lava at 6760' elev, on S.E. slope of hill, 0.6 km E. of 3-Cr. Lk., 0.8 km E. of Map 3.
165. Glassy margin of platy flow at 7950' elev, S.W. head of Snow Cr. cirque. Map 2.
167. Center of platy dike at 7900' elev, S.W. head of Snow Cr. cirque. Map 2.
168. Dike at 7780' elev, S.W. head of Snow Cr. cirque. Map 2.
169. Red and gray streaked lava at 7460' elev, W. Snow Cr. cirque. Map 2.
170. Center of E.-W. dike at 7280' elev, W. Snow Cr. cirque. Map 2.

171. Blocky lava at 7280' elev, S. central sec 17, W. of Snow Cr. Map 2.
172. Center of E.-W. dike at 6760' elev, 0.3 km S.W. of 3-Cr. Lk. Map 3.
173. E. end of irregular dike at 6800' elev, below Tam Mac Rim, 0.4 km S.W. of 3-Cr. Lk. Map 3.
174. Platy lava at 6900' elev, 0.5 km S.W. of 3-Cr. Lk. Map 3.
175. Platy lava from ridge crest at 6800' elev, 0.5 km S.W. of 3-Cr. Lk. Map 3.
176. Lowest exposed lava at N. base of main protrusion of Tam Mac Rim, 0.9 km W. of 3-Cr. Lk. Map 3.
177. Glassy margin of E.-W. dike at 7100' elev at base of main protrusion of Tam Mac Rim, 1.0 km W. of 3-Cr. Lake. Map 3.
191. Glaciated lava at 6960' elev, 1.3 km N.W. of Golden Lk. at junction of Park Meadow and Green Lk. Trails. Map 1.
192. Lava from cliffs at 6760' elev, 0.2 km N.E. of Green Lk. Map 1.
193. Lava from cliffs at 7050' elev, 0.5 km N.E. of Green Lk. Map 1.
194. Fresh pumice from deposit at 7750' elev, crest of Broken Top N.W. ridge. Map 1.
195. Lava at 7750' elev on crest of Broken Top N.W. ridge. Map 1.
196. Spatter from glaciated cone at 7640' elev on Broken Top N.W. ridge. Map 1.
197. Glassy margin of glaciated volcanic dome at 7150' elev, crest of Broken Top N.W. ridge. Map 1.
198. Lava from shelf at 7020' elev, 0.6 km S.S.W. of Golden Lake. Map 1.
199. Lava from base of cliffs at 7480' elev, N. side of Broken Top N.W. ridge. Map 1.
200. Lava from middle of N.E.-facing cliffs at 7600' elev, 1.4 km S. of Golden Lk. Map 1.
201. Platy lava at 7320' elev, 1.2 km S.S.W. of Tam Lk. Map 2.
202. Lava at 7480' elev on crest of S. ridge of glaciated cone, W. side of Snow Cr. valley. Map 2.
203. Scoriaceous lava from center of sec 18, 1.5 km E. of Golden Lk. Map 2.
204. Glaciated lava at 7760' elev, ridge crest 0.7 km E. of Carver Lk. Map 1.
206. Platy lava from E. edge of E. Chambers Lk., 0.6 km W. of Map 1.
207. Spherulitic crust of glaciated volcanic dome, 0.2 km E. of E. Chambers Lk., 0.4 km W. of Map 1.
208. Holocrystalline lava at 7400' elev, glaciated volcanic dome 1.5 km E. of E. Chambers Lk. Map 1.
209. Glaciated lava at 7000' elev, N.W. side of W. Fork Park Cr., 1.6 km E. of Carver Lk. Map 1.
210. Platy lava at 6260' elev, center W. boundary sec 7, 0.5 km N. of Park Meadow. Map 2.
250. Platy lava at 5650' elev, center sec 31, 2.5 km N. of Map 2.
258. Lava from S. margin of Dutchman Flat, W. center sec 21. Map 9.
259. Bomb fragment from S. rim of third cone from N. end of chain of cones, S.W. of Todd Lk. Map 8.
260. Scoriaceous lava from center of boundary sec 18, 19. Map 8.
261. Bomb fragment from E. side quarry in N. cone of chain of cones S.W. of Todd Lk. Map 8.
262. Lava from base of marginal block along E. shore of Sparks Lk., central S.W. 1/4 sec 14. Map 7.
263. Platy lava from roadcut of Century Drive, 0.4 km W. of Fall Cr. Map 7.
264. Fresh core of palagonitized bomb from roadcut in tuff cone at N.E. base of Talapus Bu., 0.4 km W. of Map 7.
265. Lava at 5560' elev on glaciated shelf, N.E. 1/4 sec 22, S.W. of Sparks Lk. Map 7.
266. Lava at 5480' elev, N.W. edge of Sparks Lk. Map 7.
268. Lava at 6160' elev, 0.2 km N. of N.W. corner sec 2. Map 4.
269. Obsidian block from N.E. margin of Holocene lava, 0.5 km N. of Moraine and Green Lk. Trail junction. Map 4.
270. Lava from cliffs at 6800' elev between Newberrry Flow and Goose Cr. Chain of domes. Map 4.
271. Red and black banded obsidian at 6620' elev, S. margin of Newberry Flow. Map 4.
272. Glaciated lava from 6280' elev, 0.2 km N.W. of Corral Lk. Map 4.
273. Blocky lava at 6250' elev, 0.7 km S.E. of Corral Lk. Map 4.
274. Lava at 6300' elev, 1.0 km S.E. of Corral Lk. Map 4.

275. Platy lava from cliff at confluence of Fall Cr. and Corral Lk. Cr. Map 4.
276. Lava from cliffs at 5680' elev, 0.4 km E. of Fall Cr. Map 7.
277. Lava at 5600' elev, W. slope Todd Lk. volcano. Map 7.
278. Lava at 5760' elev, W. slope Todd Lk. volcano. Map 7.
279. Lava at 5840' elev, W. slope Todd Lk. volcano. Map 7.
280. Lava at 5960' elev, W. slope Todd Lk. volcano. Map 7.
281. Lava at 6040' elev, W. slope Todd Lk. volcano. Map 7.
282. Lava at 6120' elev, W. slope Todd Lk. volcano. Map 7.
283. Lava at 6360' elev, W. slope Todd Lk. volcano. Map 7.
284. Platy margin at 6500' elev along W. side of plug of Todd Lk. volcano, N.W. corner sec 7. Map 8.
285. Platy lava at 6180' elev on ridge crest W. central sec 6, N. side of Soda Cr. Canyon. Map 5.
286. Blocky lava from base of waterfall at 6320' elev in ravine, W. sec 6, N. of Soda Cr. Canyon. Map 5.
287. Lava at 6400' elev, head of ravine, W. sec. 6, N. of Soda Cr. canyon. Map 5.
288. Gray lava from base of thick flow breccia unit at 6100' elev, in ravine, W. sec 6, N. of Soda Cr. Canyon. Map 5.
289. Glassy margin of silicic dike at 6050' elev in ravine, W. sec 6, N. of Soda Cr. Canyon. Map 5.
290. Porphyritic platy lava at 6000' elev below palagonitic beds in ravine, W. sec 6, N. of Soda Cr. Canyon. Map 5.
291. Top of thick lava flow at 5800' elev, base of ravine, W. sec 6, N. of Soda Cr. Canyon. Map 5.
292. Lava from summit of Todd Lk. volcano, N.W. sec 7. Map 8.
293. Lava at 6700' elev, crest of Todd Lk. volcano N.E. ridge. Map 8.
294. Lava from saddle in ridge crest, 0.5 km N. of Todd Lk. Map. 8.
295. Coarse porphyry at 6720' elev on S.W. side of knoll, S.W. corner sec 5, 0.9 km N.E. of Todd Lk. Map 8.
296. Glaciated lava from S.-facing shelf at 6760' elev, S. central sec 5, 1.4 km N.E. of Todd Lk. Map 8.
297. Platy lava at 6280' elev in cut of 3-Cr. Lk. Rd., 0.9 km E. of Todd Lk. Map 8.
298. Platy lava at 6840' elev on glaciated knoll S. of 3-Cr. Lk. Rd., N.E. corner sec 8. Map 8.
299. Lava at 6840' elev in cut of Crater Cr. Ditch, 0.4 km E.S.E. of Ditch Cabin. Map 5.
300. Lava at 6660' elev, N.E. corner sec 6, 0.5 km S.W. of Ditch Cabin. Map 5.
301. Lava at 7400' elev, lower S.E. ridge of Broken Top. Map 5.
302. Lava at 7480' elev, base of cliffs W. face of Ball Bu. Map 5.
303. Lava at E. base of small glaciated cinder cone in S.W. corner sec 33, 1.0 km S.E. of Ball Bu. Map 6.
305. Fragment of welded spatter at 7160' elev, S. side of silicic tuff cone, upper N. Fork Tumalo Cr. Map 6.
306. Scoriaceous lava in creek bed at 6400' elev, N.E. sec 3, 1.5 km S. of Happy Valley. Map 6.
307. Glaciated lava at 6720' elev, S. base of knoll in S. central sec 5, 0.9 km N.E. of Todd Lk. Map 8.
308. Lava at 6700' elev, 0.4 km W. of glaciated cinder cone, center sec 9. Map 9.
309. Lava from cliffs at 6240' elev, E. bank of Old Century Drive road, center sec 17. Map 8.
310. Lava from summit of glaciated knoll, 0.6 km S.E. of Todd Lk. Map 8.
311. Lava from top of cliffs at 6280' elev, E. side of creek, 0.9 km E. of Todd Lk. Map 8.
312. Glaciated lava from N. side Century Drive roadcut, S. center sec 17, 0.7 km W. of Dutchman Flat. Map 8.
313. Lava at 6380' elev, W. center sec 16, N. side Dutchman Flat. Map 9.
314. Lava at 6360' elev, N.E. side Dutchman Flat. Map 9.
315. Lava at 6450' elev, W.N.W. base of Tumalo Mtn. Map 9.
319. Lava from cliffs at 7080' elev, N. central sec 22, E. flank Tumalo Mtn. Map 9.
320. Spatter from small cinder cone, 0.8 km N. of Tumalo Mtn summit. Map 9.

341. Platy lava at S.W. shore of 3-Cr. Lk. Map 3.
342. Platy lava at 6680' elev on knoll, 0.2 km S.W. of 3-Cr. Lk. Map 3.
343. Platy lava at 7040' elev, 0.6 km S.W. of 3-Cr. Lk. Map 3.
346. Blocky lava at 7160' elev below prominence of Tam Mac Rim in N. central sec 22. Map 3.
347. Platy lava at 6960' elev on shelf, 0.3 km W. of Little 3-Cr. Lk. Map 3.
348. N.E.-S.W. dike at 7060' elev, 0.4 km W. of Little 3-Cr. Lk. Map 3.
349. Blocky lava from top flow of 6 flows below vitrophyre in cliffs 0.6 km W. of Little 3-Cr. Lk. Map 3.
350. Blocky lava from basal flow of 6 flows below vitrophyre in cliffs 0.6 km W. of Little 3-Cr. Lk. Map 3.
351. Glassy base of glaciated lava at 7050' elev, 0.1 km W. of Snow Cr. Map 2.
352. Glaciated lava in bed of Snow Cr. at 7220' elev. Map 2.
354. Pumice bomb from base of welded tuff at 7360' elev, head of Snow Cr. Cirque. Map 2.
355. N.W. margin of glaciated flow from cinder cone, 7660' elev in head of Snow Cr. Cirque. Map 2.
356. Platy lava at 7840' elev, S.W. head of Snow Cr. Cirque. Map 2.
358. Pumice from cone at 7460' elev, crest of ridge W. of Snow Cr. Cirque. Map 2.
359. Lava from E. summit of glaciated cone capping ridge W. of Snow Cr. valley, N.E. sec 17. Map 2
360. Vesicular lava at 6060' elev, Park Meadow Trail, N.E. sec 7. Map 2.
361. Blocky lava at 6260' elev, Park Meadow Trail, center sec 7. Map 2.
362. Platy lava at 6560' elev in cliffs, W. side Park Meadow. Map 1.
363. Lava from cliffs at 6560' elev, 0.8 km N.N.E. of Golden Lk. Map 1.
364. Platy lava at 6600' elev on glaciated knoll, 0.6 km N. of Golden Lk. Map 1.
365. Platy lava at 6560' elev, 0.7 km N. of Golden Lk. Map 1.
366. Scoriaceous lava at 6320' elev between glaciated cinder cones, 0.6 km S. of Park Meadow. Map 2.
367. Platy lava at 6520' elev in bed of Squaw Cr., 1.0 km E. of Park Meadow. Map 2.
380. Lava cap on N.-S. ridge at 7720' elev, 1.3 km S. of Tam Lk. Map 2.
381. Large pumice lump from rampart at S.E. edge of S. dome in Devils Hill chain of domes. Map 7.
445. Pumiceous block from summit of N. dome in Goose Cr. chain of domes, 0.3 km W. of Map 4.
446. Glassy block from Newberry flow at 7260' elev, 0.5 km E. of source vent. Map 4.
447. Glassy block from S.W. margin of large central dome of Goose Cr. chain of domes, 0.2 km W. of Map 4.
448. Glassy block from N. margin of N. dome of Devils Hill chain of domes, 0.3 km W. of Map 4.
449. Spherulitic lava from W. wall of fissure, N.E. base of Devils Hill, 0.3 km W. of Map 4.
456. Lava from prominence at 7900' elev, S.E. side of S. Sister, 1.7 km W. of Green Lk. Map 1.
458. Lava from cleaver at 8600' elev at base of Prouty Glacier, N.E. side of S. Sister, 0.5 km W. of Map 1.
525. Spatter from S. rim of Talupus Bu., 0.6 km W. of Map 7.
526. Lava from glaciated cliffs at 5680' elev, N.W. side of Talupus, Bu., 0.6 km W. of Map 7.
529. Lava from summit of Devils Hill, 0.7 km W. of Map 4.
1000. Average Cayuse lavas. Analyses 7,20,21,22,23,24,30.
1001. Average of analyses 259,261,262 from Holocene lava and cone chain S.W. of Todd Lk.
1002. Average lava from cone at N. base of Bachelor Bu. Analyses 44,45.
1003. Average Bachelor Bu. Analyses 47,258,260.
1004. Average Newberry, Goose Cr., Devils Hill chains of domes. Analyses 26,28,269,271, 381,445,446,447,448.
1005. Average Ditch Cabin basalt. Analyses 111,295,299,300.
1006. Average Talupus and Katsuk Bu. lavas. Analyses 264,265,266,525,526.
1007. Average Golden Lk.-Green Lk. basaltic andesite. Analyses 193,198.
1008. Average Corral Lk.-Green Lk. basaltic andesite. Analyses 117,272.

APPENDIX 2 (continued)

1009. Average Rim Lk. basaltic andesite lavas. Analyses 147,148,149,202,359.
1010. Average basaltic andesite, upper shelves of 3-Cr. Lk. Analyses 152,153.
1011. Average basaltic andesite lavas and dikes of Tam Mac Rim and Snow Cr. Cirque. Analyses 158,171,173,176,346,348,349,450,352.
1012. Average basaltic andesite from cone on Broken Top E. ridge. Analyses 124,355.
1013. Average of 19 lavas from Broken Top volcano.
1014. Average Broken Top dikes. Analyses 112,119,121,125,167.
1015. Average Broken Top plug rocks. Analyses 81,101,102.
1016. Average lavas from cone S. of Ball Butte. Analyses 139,296,307.
1017. Average of 17 lavas, dikes, cinders from Tumalo Mtn. and associated cones.
1018. Average andesites, E. side S. Sister. Analyses 191,192,204,250,362,365,456,458.
1019. Average lower andesite flow and source dike, 7600' elev, W. Snow Cr. Cirque. Analyses 159,160.
1020. Average upper andesite flows, 7800' elev, W. Snow Cr. Cirque. Analyses 165,356.
1021. Average andesite W. of Corral Lk. Analyses 27,275.
1022. Average dacite from S.W. ridge of Broken Top. Analyses 115,273.
1023. Average andesite at head of ravine, W. sec 6, N. of Soda Cr. Analyses 286,287.
1024. Average basaltic andesites from Bare Lk. volcano. Analyses 8,11,12,15,16.
1025. Average high-silica dacite near 3-Cr. Lk. and Little 3-Cr. Lk. Analyses 175,341, 347.
1026. Average low-silica dacite near 3-Cr. Lk. and Little 3-Cr. Lk. Analyses 162,174, 343.
1027. Average dacite between Goose Cr. and Fall Cr. Analyses 29,263,268.
1028. Average 12 analysed lavas and 1 plug rock. Todd Lk. volcano.
1029. Average rhyodacite E. of Chambers Lks. Analyses 206,207,208.
1030. Average rhyodacite on N.W. Broken Top ridge. Analyses 194,197.
1031. Average Tam Mac Rim rhyodacite. Analyses 154,155,157.
1032. Average Devils Hill rhyodacite. Analyses 449,529.
1033. Average silicic tuff cone of upper N. Fork Tumalo Cr. Analyses 126,305.
1034. Average rhyodacite lava of upper N. Fork Tumalo Cr. Analyses 134,136,137.
1035. Average rhyodacite lava E. of Todd Lk. Analyses 4,5,41,297,298.