Petrography and Petrology of Volcanic Rocks in the Mount Jefferson Area High Cascade Range, Oregon

GEOLOGICAL SURVEY BULLETIN 1251-G

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Mount Jefferson from the north. Jefferson Park is in the foreground. Photograph by G. W. Walker.

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By ROBERT C. GREENE

CONTRIBUTIONS TO GENERAL GEOLOGY

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PETROGRAPHY AND PETROLOGY OF VOLCANIC ROCKS IN THE MOUNT JEFFERSON AREA HIGH CASCADE RANGE, OREGON

By Robert C. Greene

ABSTRACT

The Mount Jefferson area lies along the crest of the Cascade Range in Oregon and is about 25 miles long by 10 miles wide. It includes the major volcanic peaks of Mount Jefferson and Three Fingered Jack.

The area is underlain almost entirely by lava flows and local deposits of cinders and breccia; collectively these flows and associated deposits are known as the volcanic rocks of the High Cascades. The rocks, which are undeformed, are of Pliocene to Recent age. They form a high volcanic plateau that is surmounted by the composite cones of Mount Jefferson and Three Fingered Jack and that is locally overlain by Recent cinder cones and intracanyon lava flows.

The volcanic rocks are classified primarily by their silica content, determined from the refractive index of fused beads. In general, the rocks increase in silica content with increasing elevation (decreasing age).

Basalt (49½–52 percent SiO_2) contains phenocrysts of olivine and (or) bytownite in a groundmass of plagioclase, clinopyroxene, opaque minerals, and glass.

Andesite (52–57 percent SiO_2) is the most abundant type of rock. Some andesite is porphyritic, the phenocrysts being of bytownite, olivine, and (or) calcic augite. Aphyric rocks and the groundmass of porphyritic rocks consist of plagioclase, clinopyroxene, opaque grains, and glass. Some andesite contains orthopyroxene.

Silicic andesite (59–65 percent SiO_2) contains phenocrysts of labradorite, and, commonly, calcic augite, orthopyroxene, and oxyhornblende. The aphanitic groundmass consists of plagioclase, alkali feldspar, silica minerals, pyroxene, and glass.

Dacite and rhyodacite (66–74 percent SiO_2) contain phenocrysts of labradorite or andesine and, in some, orthopyroxene, salite, and oxyhornblende in an aphanitic groundmass similar to, but more silicic than, that of the silicic andesite.

The Recent intracanyon flows are andesite with 54–55 percent SiO_2 and phenocrysts of plagioclase, olivine, and clinopyroxene in a groundmass of plagioclase, clinopyroxene, glass, and opaque grains.

Silica variation diagrams for eight chemically analyzed specimens yield smooth curves. The alkali-lime index of 61 is close to that for other areas in the High Cascades. The Mount Jefferson area rocks contain more alumina and less iron oxide than those of either the Western Cascades or the Koolau Volcanic Series from Oahu, Hawaii. The norms show that the four more silicic rocks are per-

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aluminous. Triangular feldspar and quartz-orthoclase-plagioclase diagrams show the paucity of potassium and illustrate the consanguinity of this suite of rocks.

Comparison of Mount Jefferson area rocks with the experimental data on the system SiO_2–FeO–Fe_2O_3–MgO shows that they very likely crystallized at nearly constant oxygen pressure.

The magma forming the volcanic rocks of this area was erupted from a number of vents, probably chiefly from Mount Jefferson and Three Fingered Jack. The Pliocene and Pleistocene lavas represent a differentiated sequence, fed by one or more magma chambers. The Recent intracanyon flows originated from a new, undifferentiated magma.

INTRODUCTION

SCOPE

This report describes the petrography and petrology of a suite of rocks belonging to the volcanic rocks of the High Cascades (Callaghan, 1933), collected from the Mount Jefferson area in Oregon.

LOCATION AND GEOGRAPHY

The Mount Jefferson area is in Linn, Marion, and Jefferson Counties, Oreg., about 40 miles northwest of Bend and about 55 miles east of Salem (figs. 1 and 2). It is part of the Cascade Range, a mountain chain that trends north and south from northern California across Oregon and Washington into British Columbia. The area from which rock samples were collected, about 25 miles long by 8–12 miles wide, lies along the crest of the range. It includes the major volcanic peaks of Mount Jefferson (alt 10,497 ft; frontispiece) and Three Fingered Jack (alt 7,841 ft; fig. 3).

The Cascade Range in the Mount Jefferson area is a north-south-trending ridge whose crest lies at an elevation of 5,500–6,500 feet. The ridge is surmounted by numerous major and minor peaks on its summit and slopes. Spurs lead outward from the crestal ridge and are separated by deep U-shaped valleys which end at steep headwalls against the ridge. Such deep valleys on the west side of the ridge have floors as low as 3,000 feet and thus provide as much as 7,500 feet of relief against Mount Jefferson.

PREVIOUS WORK

The earliest work on the Mount Jefferson area was a report on the geology of Mount Jefferson by Hodge (1925), who described the general sequence of volcanic rocks and discussed the physiography and glacial history.

Thayer (1937) described the petrography and petrology of the rocks from an area extending from Detroit (18 miles west of Mount Jefferson to Olallie Butte (north of the area shown in fig. 2) and Mount Jefferson. Rocks in this area belong to both the volcanic rocks of the Western Cascades and those of the High Cascades and were divided by Thayer

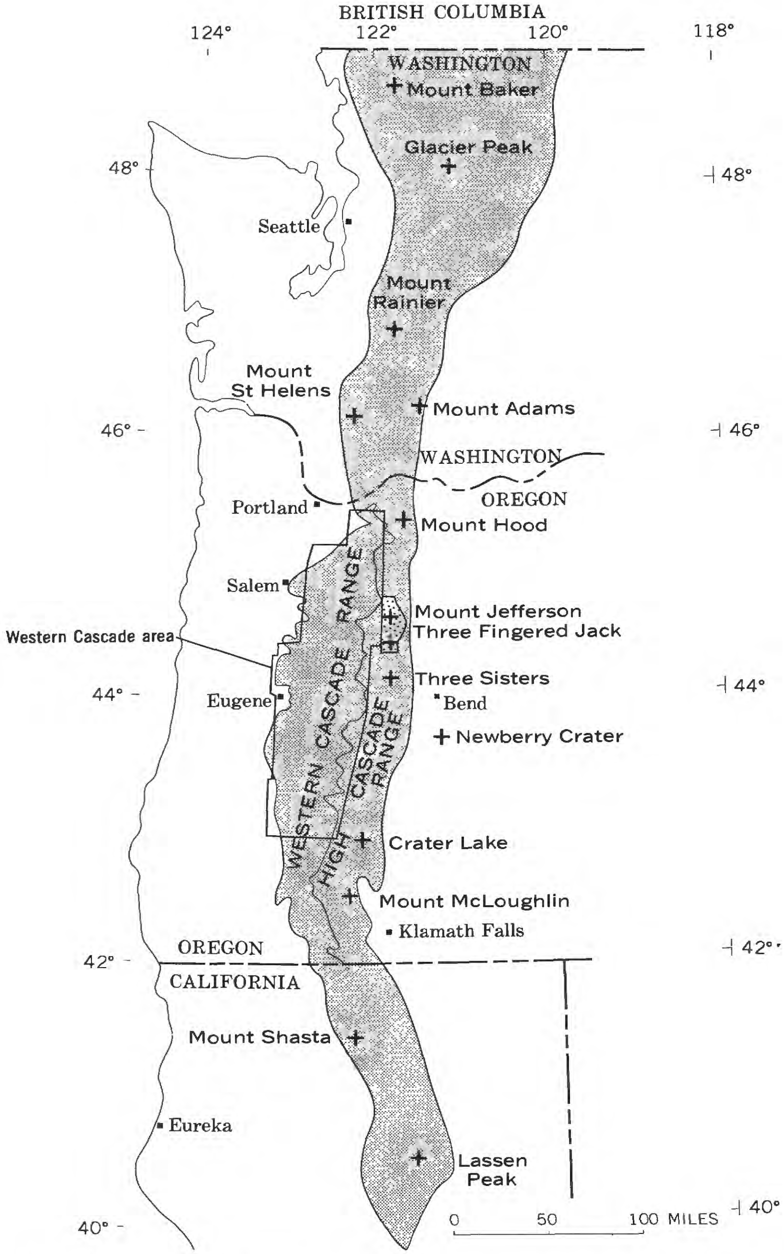

FIGURE 1.—Location of Cascade Range (shaded), principal volcanoes, part of Western Cascades studied by Peck, Griggs, Schlicker, Wells, and Dole (1964), and area of this report (stippled). Boundary between Western Cascade Range and High Cascade Range in Oregon, from Peck, Griggs, Schlicker, Wells, and Dole (1964).

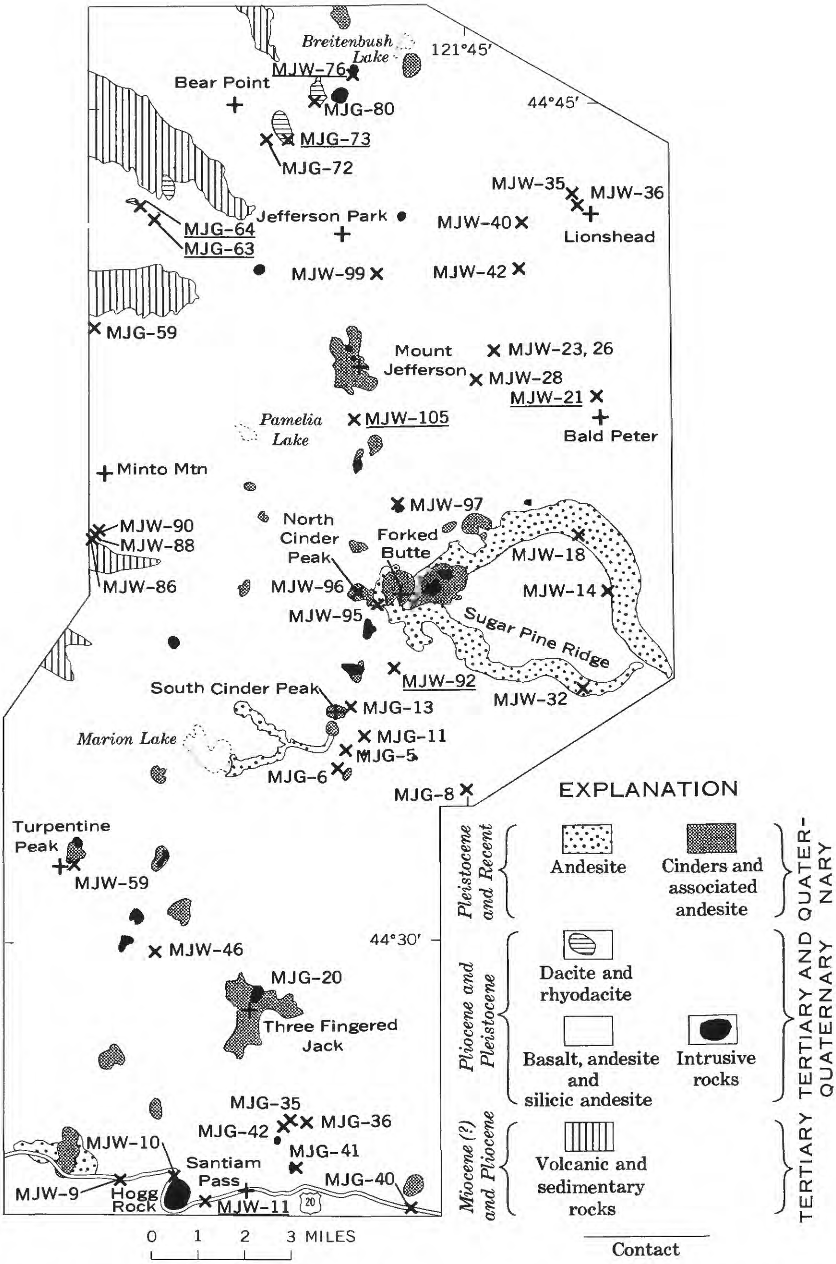

FIGURE 2.—Generalized geologic and sample locality map of the Mount Jefferson area (from Walker and others, 1966, pl. 1, and additional mapping in 1965 by R. C. Greene and G. W. Walker). Numbers of chemically analyzed samples underlined; ×, location of specimen; +, geographic feature.

Figure 3.—Three Fingered Jack from the south. Intrusive plug behind shoulder to right.

into several local map units. Sixteen chemical analyses were presented by Thayer, five of which (Thayer, 1937, p. 1622–1623, nos. 5–7, 11, 15) were of High Cascade lavas from within the area of the present report. Four of these are basalt (andesite in my terminology) that contains 52.96–54.09 percent SiO_2 and are comparable to MJW–92 (52.6 percent SiO_2, table 8), except that the iron is less oxidized. The other analysis reported by Thayer is of a pyroxene andesite (silicic andesite in my terminology) that contains 60.11 percent SiO_2 and is comparable to MJW–105 (61.2 percent SiO_2, table 8). Thayer's conclusion that the volcanic rocks of the High Cascades near Mount Jefferson are poorer in K_2O and total iron and richer in Al_2O_3 than those of the Western Cascades is substantiated by the analyses given in this report.

Thayer later (1939) described additional structural details of the lavas in the area covered by the 1937 report and discussed the physiography and glacial history of Mount Jefferson, Jefferson Park, and adjacent areas.

Williams (1957) briefly described the Three Fingered Jack volcano and has also written several other reports on volcanic rocks of the High Cascades (Williams, 1932a, 1932b, 1933, 1935, 1942, and 1944).

The geology of much of the Western Cascade Range in Oregon has been described by Peck, Griggs, Schlicker, Wells, and Dole (1964). Their report provides descriptions of the stratigraphy and structure of the early Tertiary rocks that emerge from beneath the High Cascades west of the Mount Jefferson area. The eruptive history is traced from the Eocene through the culminating eruptions forming the volcanic rocks of the High Cascades.

ACCESSIBILITY

The Mount Jefferson area is accessible by U.S. Highway 20 from Bend and State Highway 22 from Salem; these highways join near Santiam Pass at the south edge of the area. Logging roads from State Highway 22 provide access to the west edge of the area and logging and U.S. Forest Service roads along the Metolius River (southeast of fig. 2) lead to the east edge. An extensive system of trails penetrates the area.

FIELDWORK AND ACKNOWLEDGMENTS

Fieldwork in the Mount Jefferson area was done by the writer and G. W. Walker during the summer of 1965 as part of a mineral resource evaluation of the Mount Jefferson primitive area. Traverses were made on all major trails and up many canyons, ridge crests, and outlying peaks. A summary of the geology and mineral resources has been published (Walker and others, 1966).

ROCK NOMENCLATURE

The rock classification scheme used in this report is in part modal and in part chemical and essentially follows that of Howel Williams (Williams and others, 1954). This scheme is a simple one requiring the use of only a few names and is especially useful for the rocks in the report area, many of which are too fine grained for complete modal analysis. Chemical data necessary for classification were supplied by eight chemical analyses and by estimates of silica content based on the refractive indices of fused beads. The classification used is summarized in table 1.

TABLE 1.—*A partial classification of volcanic rocks*

Rhyodacite	$>$10 percent modal or normative quartz; alkali feldspar ⅓–⅔ total feldspar.
Dacite	$>$10 percent modal or normative quartz; alkali feldspar $>$⅛ and $<$⅓ total feldspar.
Andesite	52–66 percent SiO_2; color index, $<$40; alkali feldspar $<$⅓ total feldspar.
Basalt	Plagioclase more calcic than Ab_{50} An_{50}; $<$10 percent alkali feldspar; color index, $>$40.

Silica content, as determined from the refractive indices of fused beads, is used in this report as the principal independent variable with which to compare the other properties of the rocks. A smooth curve is obtained by plotting the silica contents of the eight analyzed samples versus the refractive index of their fused beads (fig. 4). Only two samples lie off the curve, and these, at short distances.

Huber and Rinehart (1966) discussed the curves of the refractive index of fused beads versus silica content for several volcanic rock suites. They emphasized the necessity of constructing an individual curve for a given suite rather than relying on an average curve derived from samples of varying affinity. The Mount Jefferson curve (fig. 5) is plotted with several curves discussed by Huber and Rinehart. It lies close to the curve for the Western Cascade suite near its ends, but bulges toward the more alkalic suites at intermediate SiO_2 content.

LABORATORY WORK AND PETROGRAPHIC TECHNIQUES

About 200 rock samples were collected from the Mount Jefferson area. Eighty-one thin sections were prepared, of which 44 were selected for modal analysis and detailed study. Fused beads were prepared for all sectioned rocks and several samples of cinders. Chemical analyses of eight rocks selected on the basis of the fused beads to represent a wide range of silica content were prepared by the rapid rock analysis laboratory of the U.S. Geological Survey.

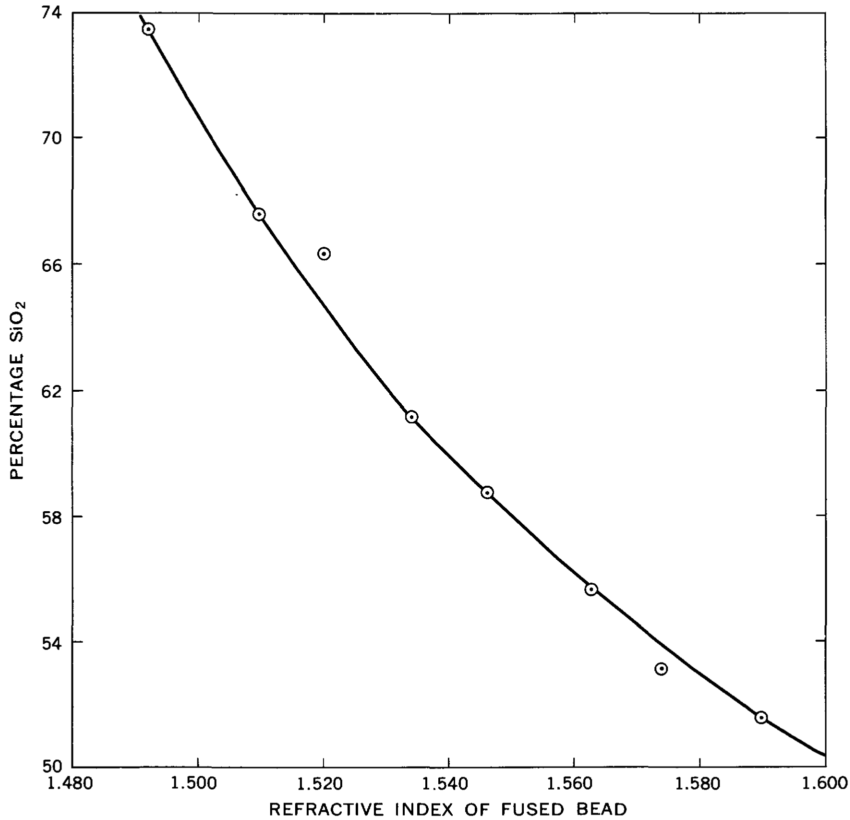

FIGURE 4.—Comparison of silica content and refractive index of fused bead for eight chemically analyzed volcanic rocks from the Mount Jefferson area. Extrapolated to 50 percent SiO_2.

Modal analyses were made by counting a thousand points in a standard thin section. Where groundmass was too fine for a reasonably accurate count of its individual minerals, it was counted as "groundmass," and a visual estimate of the mineral proportions was made.

The color index was calculated by dividing the sum of the modal percentages of ferromagnesian minerals by the sum of all minerals present. Glass and voids were ignored.

To identify groundmass minerals, X-ray diffractometer charts were made from whole-rock powders of the silicic andesite, dacite, and rhyodacite. Some scans from 2θ values of 10°–52° at 2° per minute were supplemented by scans of 20°–40° at 1° per minute.

FUSED BEADS

Fused beads were prepared from powdered whole-rock samples with a carbon arc. Three or four beads were made for each sample. The re-

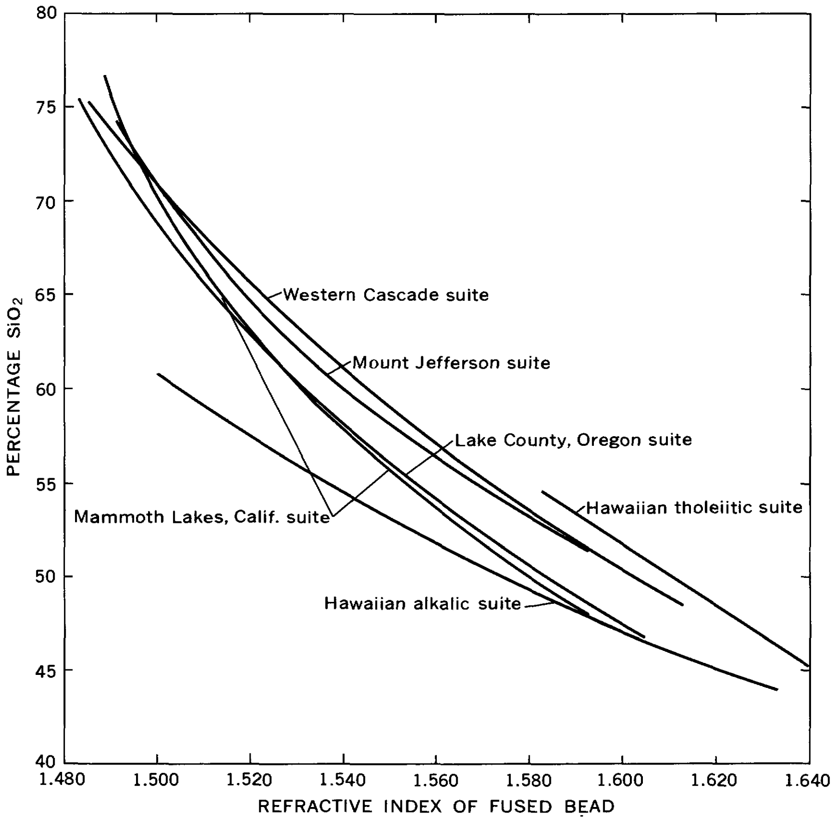

FIGURE 5.—Comparison of silica content and refractive index of fused bead for several different suites of volcanic rocks. All curves except the one for the Mount Jefferson area taken from Huber and Rinehart (1966).

fractive index of fragments of each bead was determined by oil immersion, by using a set of oils with 0.002 divisions. A sodium light was employed, and temperature corrections were applied. Because fused-bead fragments vary in index, commonly within the range of 0.002–0.005, it was necessary to record the percentage of the fragments with indices higher and lower than any given oil and interpolate accordingly between the two closest oils. In this way the median index of the bead was obtained to an accuracy of ± 0.001 or better. Triplicate determinations gave a total deviation of 0.003 or less in 60 percent of the measurements, of 0.006 or less in 85 percent, and of 0.008 or less in 95 percent.

PLAGIOCLASE

Plagioclase composition was determined by oil immersion. The β index was measured in sodium light using a $-50+200$-mesh separate and a set of oils with 0.002 divisions.

The An content was determined from the β refractive index using the curve of J. R. Smith (1958). This curve is derived from plagioclases from plutonic rocks which were heated to invert them to the "high" structural state. It was chosen in preference to curves derived from "low temperature" plutonic plagioclase (Calkins and Hess, in Kennedy, 1947; Smith, in Hess, 1960) or composite curves for plagioclase from a variety of sources (Chayes, 1952). Compositions obtained from Smith's β index curve may be slightly in error, however, for many natural calcic volcanic plagioclases have intermediate structural states owing to partial ordering during cooling.

This method should yield refractive indices that are within ± 0.001 of the true value and that correspond to ± 2 percent of the An content. The chief limitation of this method is that fragments of the larger crystals, especially the core zones of phenocrysts, tend to be selected, and they are more calcic than the average for the rock.

OLIVINE

The composition of olivine was determined by measurement of the optic axial angle on the universal stage, using the conoscopic method. Corrections for refraction were made by using the graph of Emmons (1943, pl. 8). The Fa content was found by comparing the $2V$ values with those on the graph of Poldervaart (1950), whose nomenclature is also used.

Scatter of the $2V$'s was rather large, and the optic-angle measurements are accurate to only $\pm 4°$. Such measurements correspond to about ± 8 percent of the Fa content and thus produce only very approximate compositions.

CLINOPYROXENE

Clinopyroxene was determined by refractive index and optic axial angle measurement. The β index was measured in sodium light by using a $-50+200$-mesh separate and oils with 0.004 divisions. Accuracy is probably about ± 0.002. Optic axial angles were determined with the universal stage and the conoscopic method. Scatter of the $2V$'s was appreciably less than for olivine, and the $2V$'s are accurate to $\pm 2°$–$3°$.

Composition was determined by plotting the optic angles and β refractive indices on the diagram of Hess (1949). The specified accuracy of the $2V$'s gives ± 2 percent Wo, that of the β refractive indices gives ± 1–2 percent Fs. The nomenclature for clinopyroxene is that of Poldervaart and Hess (1951).

ORTHOPYROXENE

Orthopyroxene was determined by measurement of the optic axial angle. The Fs content was taken from the curve of Kuno (1954).

The nomenclature is that of Poldervaart and Hess (1951). Scatter of $2V$ values was large, so the optic angles are probably accurate to only $\pm 4°$, a value which corresponds to ± 3 percent Fs at less than 35 percent Fs.

β refractive indices were determined for two orthopyroxenes as a check on the $2V$ determinations. When these indices were applied to a curve calculated from the α, γ, and $2V$ values of Kuno (1954), they gave the same composition as that given by the $2V$'s.

OXYHORNBLENDE

The optic axial angles of oxyhornblende were determined with the universal stage, using the conoscopic method. Scatter of the $2V$'s was large, as was expected since the grains vary widely in color and birefringence within the same specimen. Refractive indices were determined by immersion with oils of 0.004 and 0.005 divisions.

LITHOLOGY AND STRATIGRAPHY

INTRODUCTION

The oldest rocks exposed in the Mount Jefferson area are volcanic and sedimentary rocks correlative with the volcanic rocks of the Western Cascade Range (Peck and others, 1964, p. 7–8). They are of Miocene(?) and Pliocene age and crop out only in a few deep canyons on the west side of the area. They were briefly described by Walker, Greene, and Pattee (1966) and are not further considered in this report.

The remainder of the Mount Jefferson area is underlain by lava flows with local cinders and breccia collectively known as the volcanic rocks of the High Cascades (Callaghan, 1933; Peck and others, 1964, p. 7). They are of Pliocene to Recent age and are undeformed. Most of these rocks are andesite (52–65 percent SiO_2, fig. 6), but they range from basalt (49½–52 percent SiO_2) to dacite and rhyodacite (66–73½ percent SiO_2).

FIELD DESCRIPTION

To facilitate a field description of the volcanic rocks, the Mount Jefferson area is best divided into (1) a high volcanic plateau; (2) the composite cones of Mount Jefferson and Three Fingered Jack; and (3) cinder cones, intrusive plugs, and intracanyon lava flows.

HIGH VOLCANIC PLATEAU

The high volcanic plateau consists primarily of flows of andesite and basalt. Some have initial dips of 5°–10°, but most are flat lying. They range from a few feet to a few tens of feet in thickness. The upper and lower parts of many flows are somewhat vesicular and, rarely, weakly brecciated. Exposed top surfaces commonly show ropy

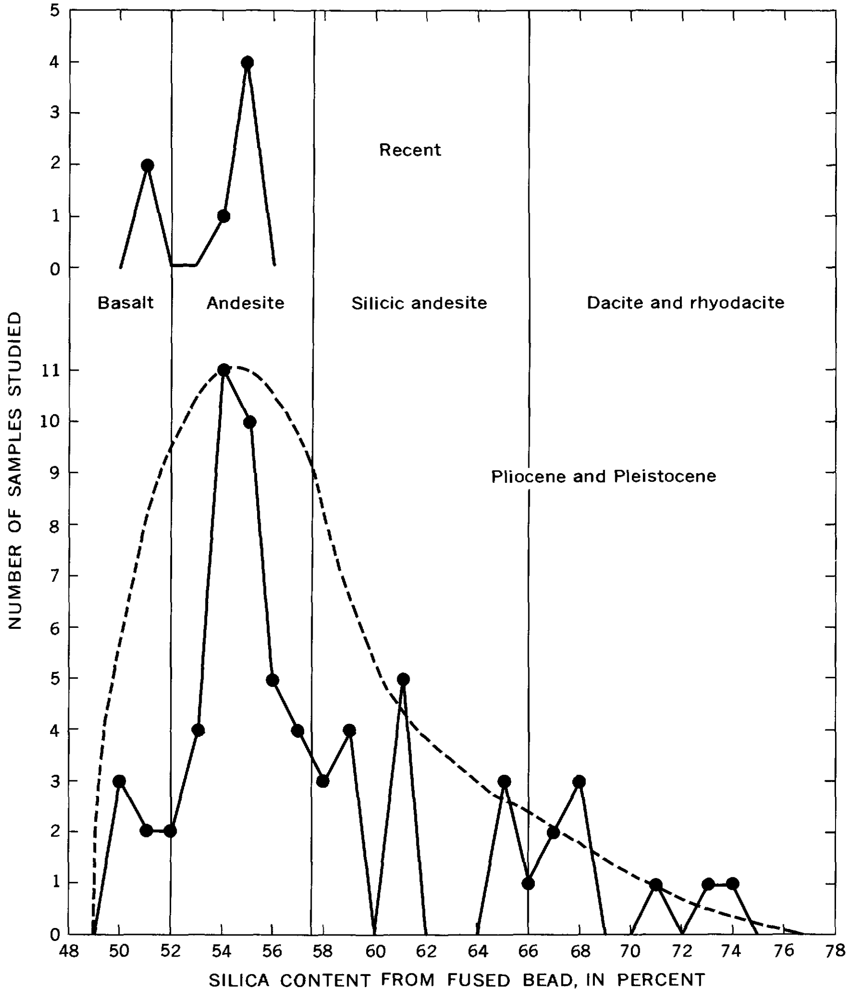

FIGURE 6.—Frequency distribution of silica content in rock samples from the Mount Jefferson area. Dashed line is projected curve (log scale) for a systematic series of samples.

texture. Platy jointing is common in the fine-grained flow rocks but rare in aphanitic rocks. Such jointing may or may not be parallel to the top and bottom of the flow.

The andesite and basalt flow rocks are light to dark gray[1] and brownish gray. (See section on "Petrographic description.") Weathered surfaces are slightly darker and browner. Dacite is pale red and weathers to a grayish red.

[1] Color terminology is that of the National Research Council's Rock-Color Chart (Goddard and others, 1948).

Interbedded cinders are rare in most of the high volcanic plateau and are essentially absent near the base of the High Cascade volcanic rocks. Cinders are more common, however, near the bases of Mount Jefferson and Three Fingered Jack, where the rocks of the high plateau merge with those of the composite cones.

COMPOSITE CONES

Mount Jefferson (frontispiece) is a slightly dissected stratovolcano consisting of flows of andesite (dominantly silicic andesite) with interbedded cinders. Both cinders and flows crop out toward the base of the cone where it has been deeply eroded by glaciers, but aretes high on the flanks and near the summit are almost entirely flows. Initial dips of flows and cinder beds are as great as 25° and are generally away from the summit. The silicic andesite flows are from several feet to a few tens of feet thick and rarely show original surface features. These medium- to light-gray rocks show little surface weathering, owing to the rapid spalling of the surface. The cinder beds exposed toward the base of the cone are similar to those on Three Fingered Jack. A small intrusive plug near the summit may represent the filling of the principal lava conduit.

Three Fingered Jack is a severely dissected stratovolcano (fig. 3). Erosion, primarily glacial, has exposed a precipitous face exhibiting alternating lava flows and beds of cinders. Most of the flows are only a few feet thick, are scoriaceous near their tops and bases, and have rough, commonly ropy, surfaces. The surface color is brownish; where weathered it is duller yellowish brown. The cinders are an unsorted mixture of fine and coarse material ranging from ash through lapilli to blocks and bombs. They are generally agglutinated into a coherent rock which may be crudely bedded. The cinder agglutinate is a colorful rock, ranging from various shades of red and reddish brown to yellowish brown and yellowish orange. Flows and cinders are interlayered remarkably evenly in 5- to 20-foot layers (fig. 3) from the summit to the base of the mountain. The lower part of the cone is about half flows and half cinders, but cinders become dominant toward the top. Initial dips are as much as 35°. Numerous dikes transect the stratified rocks, and an intrusive plug north of the present summit marks the probable site of the conduit.

CINDER CONES, INTRUSIVE PLUGS, AND INTRACANYON LAVA FLOWS

Cinder cones and intrusive plugs are scattered irregularly about the Mount Jefferson area, but intracanyon lava flows occur only in the central part and on the south margin (fig. 2). These rock units are commonly related, though cinder cones or plugs may occur separately.

Most of the cinder cones are prominent rounded hills. They are composed chiefly of cinders, predominantly grayish to dusky red, but in places dark gray and brownish gray. Sorting is poor, and the cinders may be loose or agglutinated. Vesicular flow material is locally interbedded.

Some of the cinder cones contain intrusive plugs of vesicular and flow-banded rocks which apparently represent the final surge of magma into the eruptive vents. Other intrusive plugs show little obvious relationship to vents. They form topographic highs and owe their greater resistance to erosion to the fact that they have less closely spaced jointing than the surrounding flow rocks. They are composed of varied types of rock, which differ from their extrusive equivalents mainly in their somewhat coarser textures.

Intracanyon lava flows are distinguished by their unmodified bare rock surfaces and their perched positions conforming to present topography. Each flow emanates from the flank of a cinder cone and has an aa, or blocky, surface. A crude pattern of pressure ridges may be seen where the flows are gently sloping. The andesite making up the flows is vesicular, and surface weathering stains it dark gray to grayish black.

PETROGRAPHIC DESCRIPTION

For purposes of description, the Pliocene and Pleistocene rocks of the area are divided into groups based on silica content, which was estimated from the refractive index of their fused beads. These groups also have stratigraphic significance, for the younger rocks at a higher elevation are generally more silicic. The recent intracanyon flows—andesite with 54–55 percent silica—are treated last.

BASALT (49½–52 PERCENT SiO_2)

Basalt is found principally at low elevations on the flanks of the crestal ridge. It forms a unit, perhaps mappable, which underlies the main mass of andesite of the High Cascades, and which overlies the volcanic and associated sedimentary rocks of the Western Cascade Range. Five samples of basalt were studied in detail (table 2), four from the basal basalt unit, and one from higher in the section at Santiam Pass. These rocks are dark to medium gray, rarely mottled with olive gray. They are aphanitic to fine grained, commonly diktytaxitic, and aphyric to porphyritic (fig. 7).

The basalt contains phenocrysts of olivine and (or) plagioclase in a groundmass of plagioclase, clinopyroxene, opaque grains, and glass. Olivine is fresh, iddingsitized, (fig. 8) or partly or wholly altered to clays. In sample MJW–34, several unusual patterns of iddingsitization

TABLE 2.—*Modes, in volume percent, and other characteristics of basalt*

Sample	MJW-34	MJW-86	MJW-90	MJW-88	MJW-11
Modes					
Phenocrysts:					
Plagioclase	Trace	3.2			1.0
(An)	(75)	(77)			(77)
Olivine	.9		15.6	10.3	3.6
Total	.9	3.2	15.6	10.3	4.6
Groundmass:					
Plagioclase	51.9	32.6	50.1	43.7	52.3
(An)			(73)	(43)	
Clinopyroxene	30.7	37.6	17.2	16.1	29.4
(Wo:En:Fs)	(44:32:24)		(41:29:30)		(44:32:24)
Magnetite and ilmenite	2.7	10.6	3.5		4.0
Glass	1.2		4.2	27.1	2.2
Void	10.1	4.6	9.4	1.6	7.5
Total	96.6	85.4	84.4	88.5	95.4
Alteration materials:					
Iddingsite	2.5				
Clays after olivine		1.3			
Clays after glass		10.1		1.2	
Total	2.5	11.4	0	1.2	0
Total	100.0	100.0	100.0	100.0	100.0
Other characteristics					
Color index	41	58	42	38	41
Refractive index of fused bead.	1.608	1.604	1.600	1.592	1.590
Silica content from fused bead.	49½	50	50	51	51½
Texture	Diktytaxitic, porphyritic, intergranular.	Porphyritic, intergranular, flow-alined.	Diktytaxitic, intergranular to intersertal.	Intersertal	Porphyritic, diktytaxitic, intergranular to intersertal, flow-alined.
Grain size (mm):					
Phenocrysts	0.5–1.5	0.5–1.5			0.5–1.
Groundmass	0.03–0.5	0.05–0.3	0.1–2.	.05–2.	0.05–0.5

are seen (fig. 9). Some grains have iddingsite centers and clear margins; others have clear centers, an iddingsite zone, and then a clear margin. In these latter grains the iddingsite zone has a fuzzy inner margin and sharp outer margin. Obviously, these olivine phenocrysts were iddingsitized while the lava was still in part molten; then additional olivine was deposited on their surfaces (Sheppard, 1962).

The cores of plagioclase phenocrysts and larger microlites from nonporphyritic rocks are bytownite (fig. 10). Clinopyroxene and opaque grains fill much of the space between groundmass plagioclase microlites; the remainder is occupied by glass, which is tachylitic in some specimens. Clinopyroxene, where indentifiable, is calcic augite or calcic ferro-augite (fig. 11). The alteration materials are clays derived from olivine or glass.

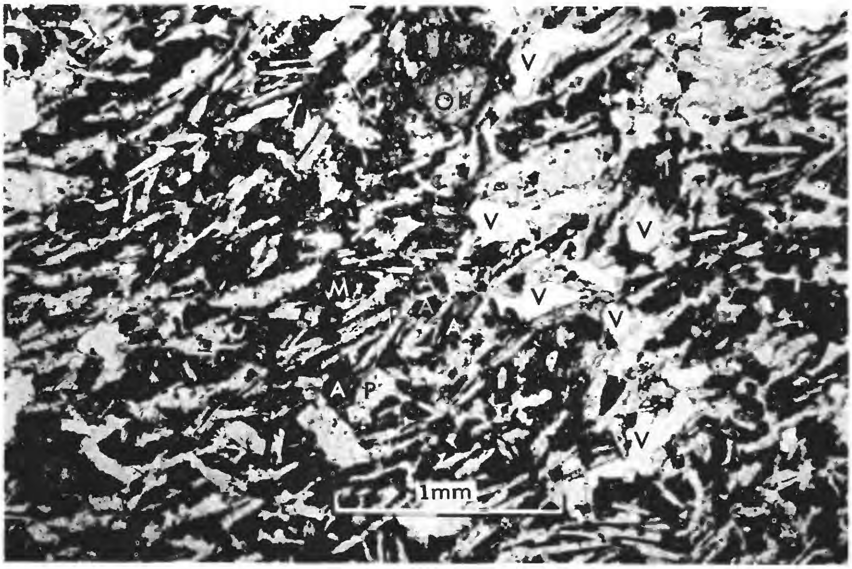

FIGURE 7.—Intergranular texture with diktytaxitic openings and flow-alined plagioclase microlites (P) in basalt. Augite (A) and magnetite (M) are in intergranular position, voids (V) are largely surrounded by plagioclase, and an olivine phenocryst (Ol) is near the upper margin. Plane light, × 30. Sample MJW-11.

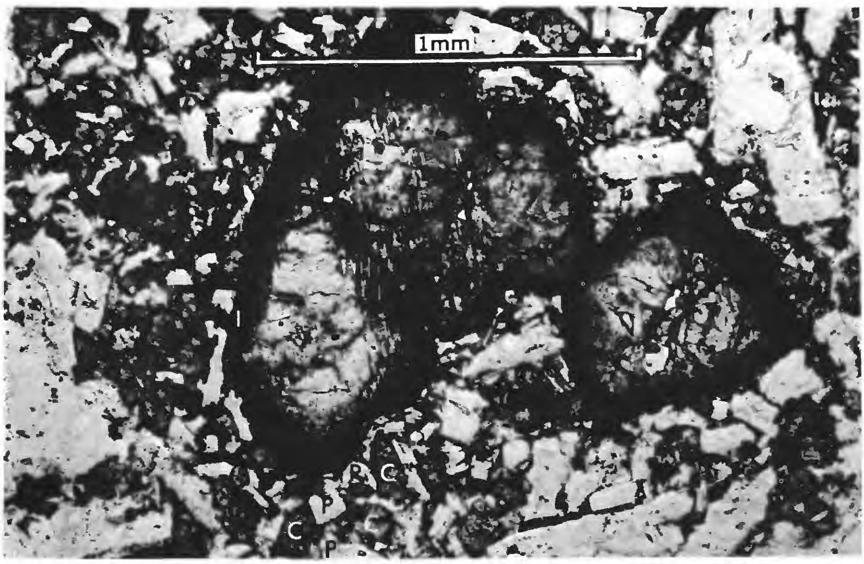

FIGURE 8.—Olivine phenocryst with iddingsitized margin (I) and preferential iddingsitization on 010(?) plane, in andesite. Groundmass is plagioclase (P) and clinopyroxene (C). Plane light, × 50. Sample MJW-59.

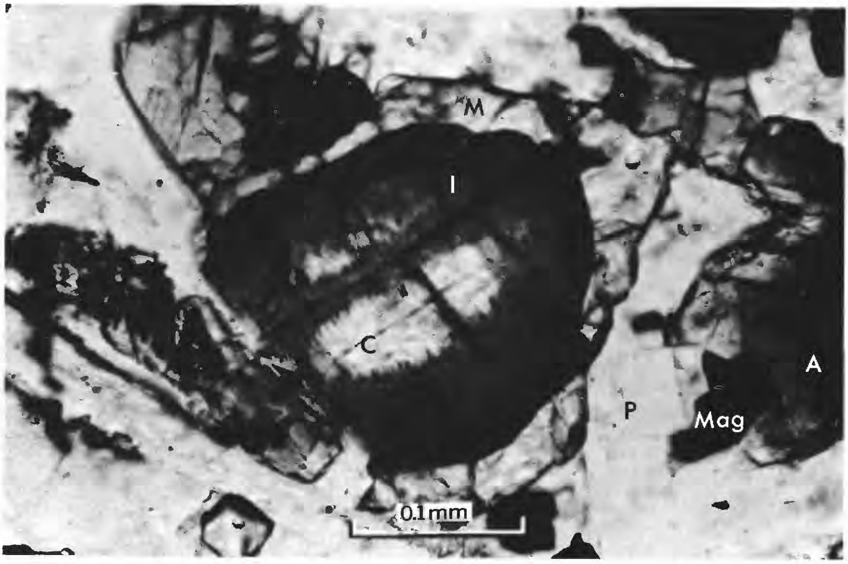

FIGURE 9.—Olivine phenocryst with clear core (C), iddingsitized zone (I), and clear margin (M), in basalt. Groundmass is plagioclase (P), augite (A), and magnetite (Mag). Plane light, × 240. Sample MJW–34.

ANDESITE (52–57½ PERCENT SiO_2)

Andesite (52–57½ percent SiO_2) is by far the most abundant type of rock in the Mount Jefferson area (fig. 6) and is found at all elevations from directly above the lower basalt unit to the ridge crest between the two main volcanic cones. It is most commonly medium dark gray but ranges from dark to medium light gray and brownish gray. Some is gray mottled with brownish gray; in general, the more brownish the rock, the higher the content of glass. The andesite is aphanitic to fine grained and commonly is porphyritic.

The andesite is composed primarily of plagioclase, olivine, clinopyroxene, opaque material, and glass (table 3). Some is porphyritic, the principal phenocrysts being equidimensional grains of bytownite (fig. 10). Compositions of plagioclase from andesite and other rocks plotted in figure 11 are the core portions of larger phenocrysts. In general, the core portions are oscillatory zoned, and so the composition reported represents the average of the alternating zones. (See Harloff, 1927; Bowen, 1956, p. 274–275; Hills, 1936; Carr, 1954; Vance, 1962; and Vance, 1965, for discussion of oscillatory zoning). Outside the oscillatory zoned core, a progressively zoned margin completes the phenocryst. The width of the margin is generally one-fifth or less the radius of the phenocryst; a sharp contact locally showing resorption separates the margin from the core.

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Bytownite phenocrysts are accompanied by phenocrysts of olivine (fig. 12), and, in a few rocks, of clinopyroxene. Where the composition of the clinopyroxene can be determined, it is calcic augite (fig. 11). Orthopyroxene phenocrysts (Fs_{30}) are present in one example. The porphyritic rocks contain a groundmass of plagioclase laths more sodic than the phenocrysts, minute grains of clinopyroxene, opaque minerals, and interstitial glass (fig. 12).

Nonporphyritic andesite samples exhibit considerable variety in composition and texture. In general they are similar to the porphyritic rocks except that the plagioclase grades continuously in size from microphenocrysts to smaller microlites, and equidimensional grains are absent. Larger plagioclase grains are calcic labradorite to

TABLE 3.—*Modes, in volume percent,*

Sample	MJW-46	MJW-9	MJG-14
Modes			
Phenocrysts:			
Plagioclase	7.3	----	16.3
(An)	(79)	----	(79)
Olivine	3.2	2.9	4.2
Clinopyroxene	.1	----	----
(Wo:En:Fs)	----	----	----
Orthopyroxene	----	----	----
(Fs)	----	----	----
Total	10.6	2.9	20.5
Groundmass:			
Plagioclase	38.4	50.9	28.0
(An)	----	(82)	----
Clinopyroxene	22.5	15.6	22.1
(Wo:En:Fs)	----	----	----
Orthopyroxene	----	----	----
(Fs)	----	----	----
Magnetite and ilmenite	----	----	----
Glass	28.5	[3] 23.1	27.3
Void	----	7.5	[4] 2.1
Total	89.4	97.1	79.5
Alteration materials:			
Iddingsite	----	----	Trace
Clays after olivine	----	----	----
Clays after glass	----	----	----
Total	----	----	----
Total	100.0	100.0	100.0
Other characteristics			
Color index	36	27	37
Refractive index of fused bead	1.584	1.581	1.576
Silica content from fused bead	52½	53	53½
Texture	Glomeroporphyritic, intergranular to intersertal.	Intersertal to subophitic.	Porphyritic, intersertal to to intergranular.
Grain size (mm):			
Phenocrysts	0.1 -0.8	----	0.1 -1.
Groundmass	<0.01-0.1	0.05-0.8	0.02-1.

See footnotes at end of table.

calcic bytownite. As in the porphyritic rocks, the spaces between plagioclase laths are principally filled with clinopyroxene, opaque minerals, and glass. In some samples, orthopyroxene (ferrous bronzite or magnesian hypersthene) is also present. One unusual rock (MJG–42) contains bronzite and olivine but no clinopyroxene.

All the andesite samples contain glass in the groundmass; several have as much as 30 percent. The color, and probably the composition of this glass, varies widely. In some samples the glass is a black tachylite that is nearly opaque (fig. 13); in others, it is a transparent brown.

Texture is intergranular-intersertal or intersertal-intergranular (fig. 13), depending upon whether pyroxenes or glass predominate in

and other characteristics of andesite

MJG–42	MJW–92	MJG–5	MJG–11	MJG–35	MJG–6
		Modes—Continued			
------	7.2	------	31.3	20.1	------
------	(81)	------	(73)	(82)	------
11.6	2.5	0.5	4.0	6.6	3.0
------	------	------	3.0	3.6	------
------	------	------	(45:32:23)	(44:32:24)	------
------	------	------	------	------	------
------	------	------	------	------	------
11.6	9.7	0.5	38.3	30.3	3.0
63.0	46.9	67.6	25.9	42.2	46.5
(69)	------	(75)	------	------	(81)
------	28.3	[1] 19.3	11.0	20.4	10.3
------	------	------	------	------	------
19.0	------	4.0	------	------	------
(34)	------	(35)	------	------	------
4.4	[2] 11.9	3.8	.9	3.1	------
.8	3.2	4.0	22.2	4.0	31.1
------	------	------	1.7	------	9.1
87.2	90.3	98.7	61.7	69.7	97.0
------	------	------	------	------	------
------	------	.4	------	------	------
1.2	------	.4	------	------	------
1.2	------	.8	------	------	------
100.0	100.0	100.0	100.0	100.0	100.0
		Other characteristics—Continued			
36	44	29	25	35	22
1.574	1.574	1.573	1.573	1.572	1.571
54	54	54	54	54	54
Intergranular	Porphyritic, intergranular.	Intergranular to intersertal.	Diktytaxitic, porphyritic, intersertal to intergranular.	Porphyritic, intergranular.	Intersertal, trachytic.
------	0.1 -1.	------	0.2 -1.	0.1 -1.	------
0.05–0.8	0.05–0.1	0.05–1.2	0.02–1.	<0.01–.05	0.07–0.7

TABLE 3.—*Modes, in volume percent,*

Sample	MJG-59	MJG-40	MJG-8
Modes			
Phenocrysts:			
Plagioclase			
(An)			
Olivine	Trace	2.3	0.4
Clinopyroxene			
(Wo:En:Fs)			
Orthopyroxene			
(Fs)			
Total		2.3	0.4
Groundmass:			
Plagioclase	55.6	52.7	58.9
(An)	(77)	(67)	(86)
Clinopyroxene	31.7	25.2	23.6
(Wo:En:Fs)			
Orthopyroxene			Trace
(Fs)			
Magnetite and ilmenite	5.1	4.8	2.8
Glass	3.7	10.8	9.1
Void		4.2	5.2
Total	96.1	97.7	99.6
Alteration materials:			
Iddingsite		Trace	
Clays after olivine	3.9		
Clays after glass			
Total	3.9		
Total	100.0	100.0	100.0
Other characteristics			
Color index	42	38	31
Refractive index of fused bead	1.571	1.568	1.566
Silica content from fused bead	54	55	55
Texture	Intergranular	Intergranular to intersertal, flow-alined.	Integranular to intersertal, trachytic.
Grain size (mm):			
Phenocrysts			
Groundmass	0.05–1.	0.02–1.	0.05–1.

[1] Contains 17.3 percent augite and 2.0 percent pigeonite.
[2] In part after olivine.
[3] This figure includes 8.3 percent partially devitrified tachylitic glass.

the spaces between plagioclase laths. In one sample, larger clinopyroxene grains partly enclose plagioclase subophitically. Alinement of plagioclase is weak to absent in most of the rocks, but it is strong and forms trachytic texture in some.

In general, the andesite is little altered. Olivine is partially iddingsitized in several samples (fig. 8); in others it is partially altered to clays, even though the remaining minerals are unaffected.

Color indices of these rocks range from 20 to 44 (fig. 14); this rather wide variation can be largely attributed to the abundance of glass. The generally low color index for the composition of rocks with high glass content suggests that the glass is relatively mafic.

and other characteristics of andesite—Continued

MJW-59	MJG-13	MJW-21	MJW-42	MJG-36	MJW-28
			Modes—Continued		
----------	24.8	----------	8.2	----------	42.3
----------	(71)	----------	(90)	----------	(75)
2.1	4.5	0.5	.4	Trace	.2
----------	4.6	----------	.9	----------	.6
----------	(39:36:25)	----------	----------	----------	----------
----------	----------	----------	Trace	----------	10.9
----------	----------	----------	(24)	----------	(35)
2.1	33.9	0.5	9.5	----------	54.0
64.0	23.2	53.4	65.1	68.4	29.5
(67)	----------	(67)	----------	----------	----------
22.2	22.9	8.6	19.4	1.7	11.3
----------	----------	----------	----------	(40:37:23)	----------
----------	----------	14.1	1.1	13.6	----------
----------	----------	(27)	----------	(29)	----------
3.8	4.1	3.4	2.3	1.5	2.5
7.0	11.8	16.6	[5]2.6	9.7	[5]2.7
----------	4.1	3.4	----------	5.1	----------
97.0	66.1	99.5	90.5	100.0	46.0
0.9	----------	----------	----------	----------	----------
----------	----------	----------	----------	----------	----------
----------	----------	----------	----------	----------	----------
0.9	----------	----------	----------	----------	----------
100.0	100.0	100.0	100.0	100.0	100.0
			Other characteristics—Continued		
31	43	33	25	20	----------
1.566	1.565	1.563	1.557	1.554	1.552
55	55	56	56½	57	57½
Intergranular, trachytic.	Porphyritic, intergranular to intersertal.	Intergranular to intersertal, trachytic.	Porphyritic, trachytic.	Intergranular to intersertal.	Porphyritic, intergranular.
----------	0.1–1.	----------	0.3–1.2	----------	0.1–2.
0.02–1.	0.02–0.07	0.1–0.5	0.02–0.3	0.05–1.	0.02–0.1

[4] This figure includes 0.3 percent opal lining vesicles.
[5] May be in part K-feldspar.

SILICIC ANDESITE (59–65 PERCENT SiO_2)

Silicic andesite (59–65 percent SiO_2) is found principally on Mount Jefferson, but can also be found interbedded with different andesite at other localities of high elevation within the report area.

The silicic andesite contains abundant phenocrysts of plagioclase and sparse phenocrysts of dark minerals in an aphanitic groundmass (table 4). The groundmass is dark to medium gray and rarely mottled with pale brown or light gray. Most of the rocks are somewhat vesicular. The core of the plagioclase phenocrysts is generally intermediate labradorite. The mafic phenocrysts include calcic augite or salite similar to that found in the less silicic andesite (fig. 11). The somewhat more abundant orthopyroxene is ferrous bronzite or magnesian

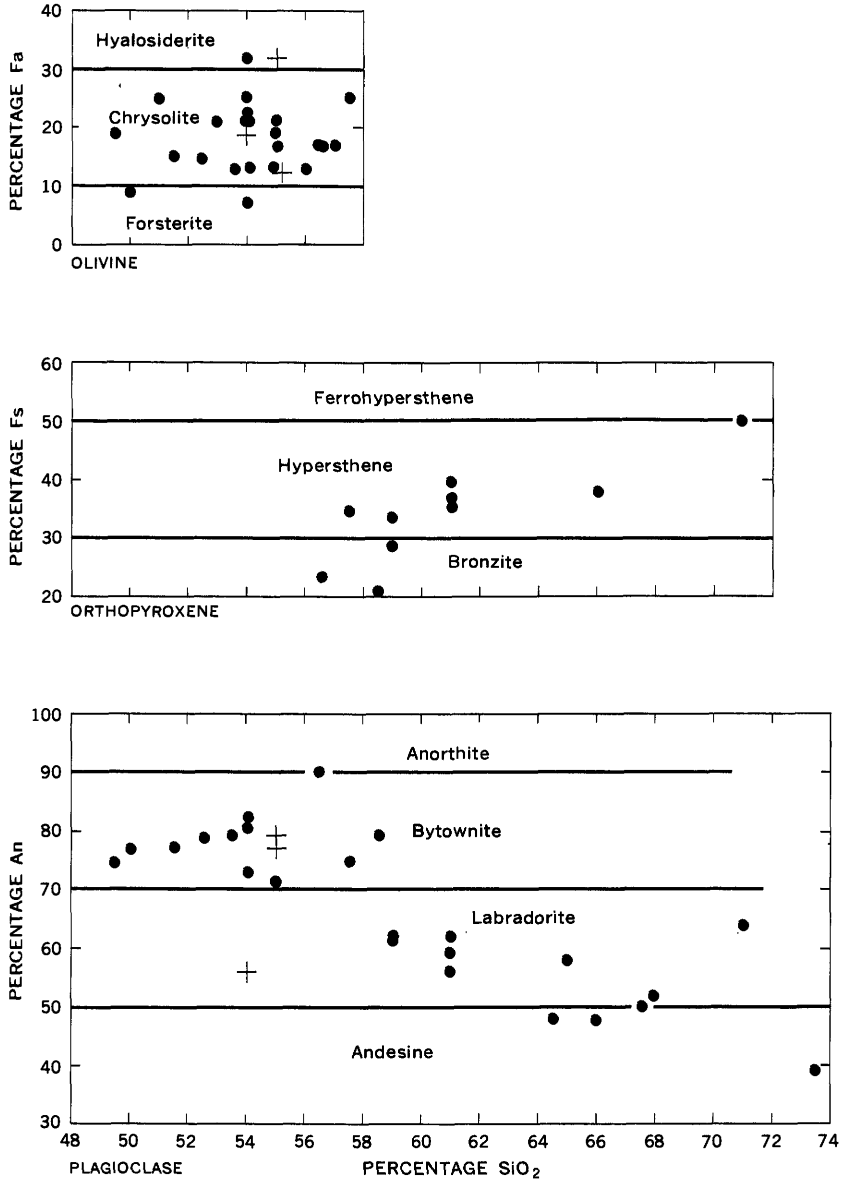

FIGURE 10.—Comparison of composition of plagioclase, orthopyroxene, and olivine phenocrysts with silica content of the enclosing rock for various samples from the Mount Jefferson area. +, Recent; ●, Pliocene and Pleistocene.

hypersthene (fig. 15). The Fs content is higher in rocks of higher SiO_2 content (fig. 10). Oxyhornblende, also present in some of the samples, is rimmed with opaque material (fig. 16). Part of the oxyhornblende

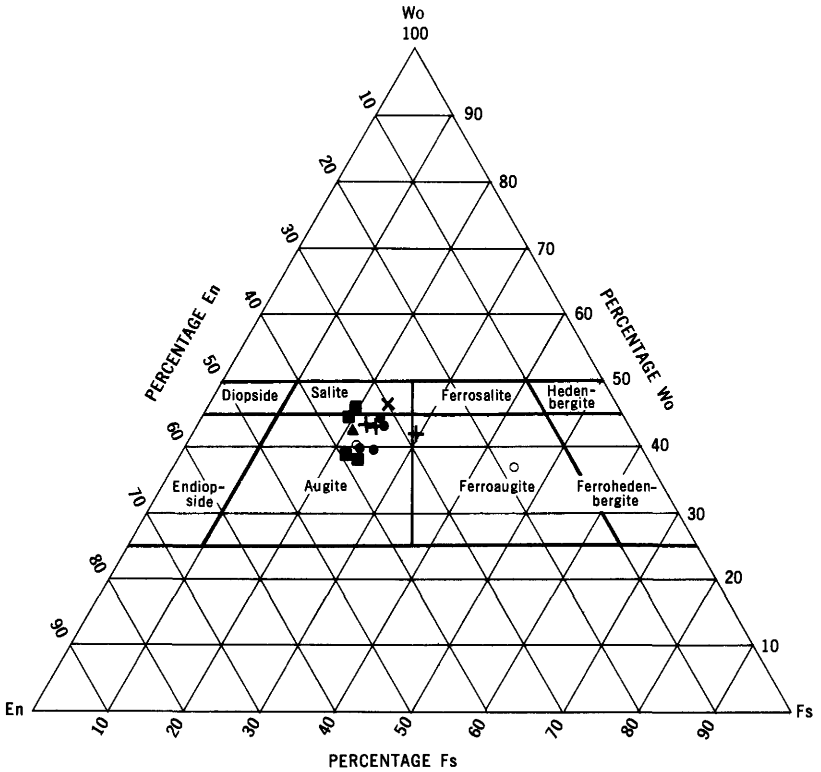

FIGURE 11.—Composition of clinopyroxene from rocks in the Mount Jefferson area: +, from basalt; ●, from andesite; ■, from silicic andesite; x, from dacite; ○, from intrusive andesite; ▲, from Recent andesite. Nomenclature from Poldervaart and Hess (1951).

in each rock studied is strongly colored, pleochroic, and highly birefringent, and part is nearly colorless and weakly birefringent. Optical data for the strongly colored oxyhornblende from MJW–76 is as follows: $n_{\alpha}=1.674$, $n_{\beta}=1.718$, $n_{\gamma}=1.746$, $2V=75(-)$.

The groundmass in the silicic andesite samples is much too fine grained to determine a point count. Estimates of the composition commonly give about 50 percent plagioclase with varying amounts of pyroxene, glass, alkali feldspar, cristobalite and indeterminate murky "dust" along grain boundaries. Sample MJW–40 contains quartz in addition to cristobalite.

Plagioclase phenocrysts are commonly flow alined in these rocks; in the two most silicic samples, alined plagioclase microlites form a distinct trachytic texture (fig. 16). Color indices are generally low (fig. 14), reflecting, as in the andesite, the presence of a rather mafic glass.

TABLE 4.—*Modes, in volume percent, and other characteristics of silicic andesite*

Sample	MJG-63	MJW-35	MJW-99	MJW-23	MJW-105	MJW-26	MJW-76	MJW-40
Modes								
Phenocrysts:								
Plagioclase	22.6	32.8	30.7	28.3	44.6	30.3	12.5	5.5
(An)	(62)	(62)	(58)	—	(62)	(56)	(48)	(58)
Clinopyroxene	2.7	.1	[1] .4	.9	.5	.9	Trace	.3
(Wo:En:Fs)	(40:38:22)	---	---	(40:38:22)	---	(46:35:19)	---	(46:35:19)
Orthopyroxene	5.6	5.0	3.5	5.4	15.1	4.7	.2	1.7
(Fs)	(29)	(34)	(40)	(35)	(37)	(40)	---	---
Oxyhornblende opaque alteration	---	---	---	---	.2	---	4.4	2.5
Magnetite and ilmenite	.7	2.0	.6	1.2	1.6	.6	1.2	---
Total	31.6	39.9	35.2	35.8	62.0	36.5	18.3	10.0
Groundmass:								
Mode expressed as total groundmass	68.4	60.1	54.1	64.2	34.0	59.3	75.1	90.0
Void	---	---	10.7	---	4.0	4.2	6.6	---
Visually estimated composition:								
Alkali feldspar and silica minerals	(45)	---	---	(32)	---	---	(38)	(23)
Plagioclase	(17)	(39)	(27)	(32)	---	(30)	(38)	(45)
Pyroxene	(7)	(Trace(?))	(5)	---	---	---	---	---
Glass	---	(21)	(22)	(Trace)	(34)	(30)	---	(23)
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Other characteristics								
Color index	16	9	14	7	28	9	6	5
Refractive index of fused bead	1.546	1.544	1.536	1.534	1.534	1.533	1.520	1.518
Silica content from fused bead	59	59	61	61	61	61	64½	65
Texture	Porphyritic, flow-alined.	Porphyritic, flow-alined.	Porphyritic	Porphyritic, pilotaxitic, flow-alined.	Porphyritic, intersertal.	Porphyritic, intersertal.	Porphyritic, trachytic.	Porphyritic, trachytic.
Grain size (mm):								
Phenocryst	0.1–2.0	0.1–0.8	0.1–1.5	0.05–2.0	0.1–1.5	0.1–2.0	0.05–1.5	0.1–2

[1] Contains also trace(?) of olivine.

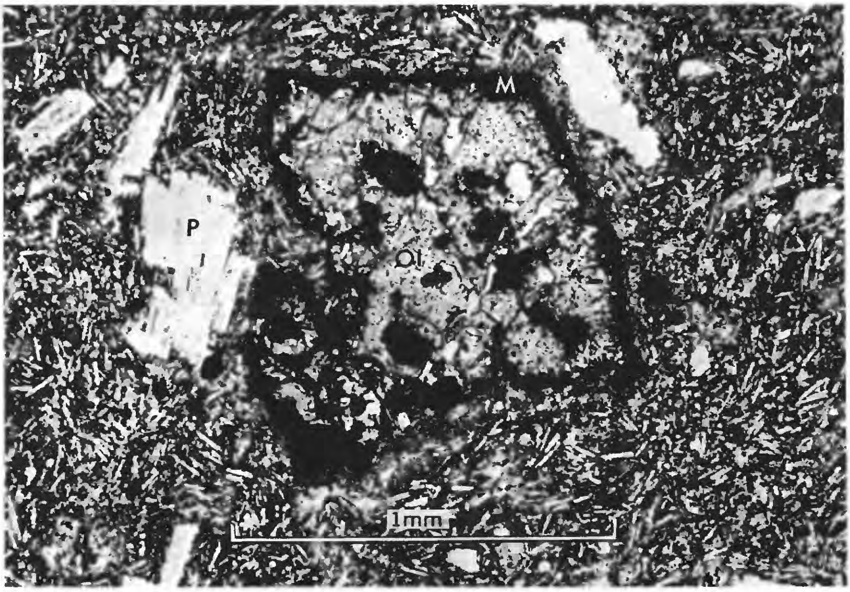

FIGURE 12.—Olivine phenocryst (Ol) embayed and partially altered to magnetite (M) in andesite; plagioclase phenocrysts (P). Groundmass is composed of plagioclase microlites with intergranular clinopyroxene and minor glass. Plane light, × 50. Sample MJW–92.

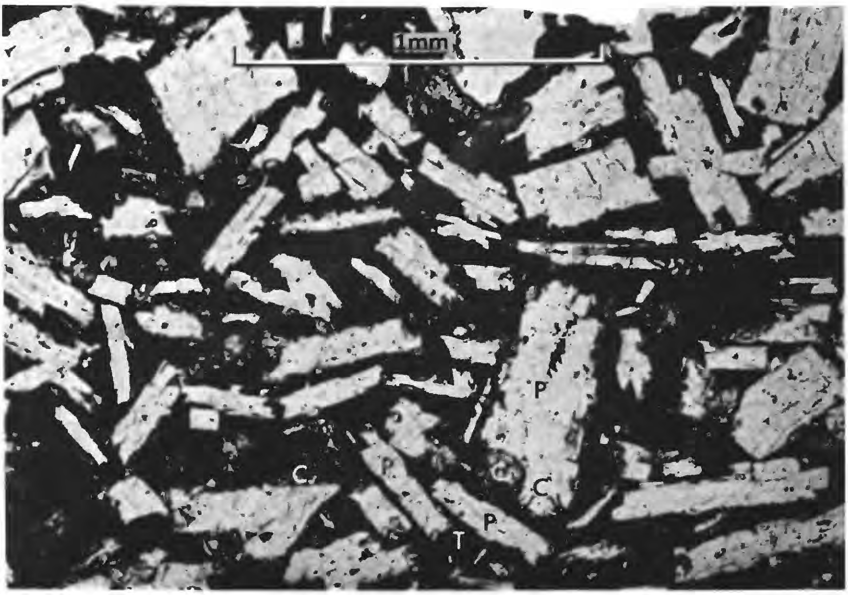

FIGURE 13.—Intersertal texture in andesite. Euhedral plagioclase laths (P), clinopyroxene grains (C) clinging to larger plagioclase grains, and tachylitic glass (T). Plane light, × 50. Sample MJG–6.

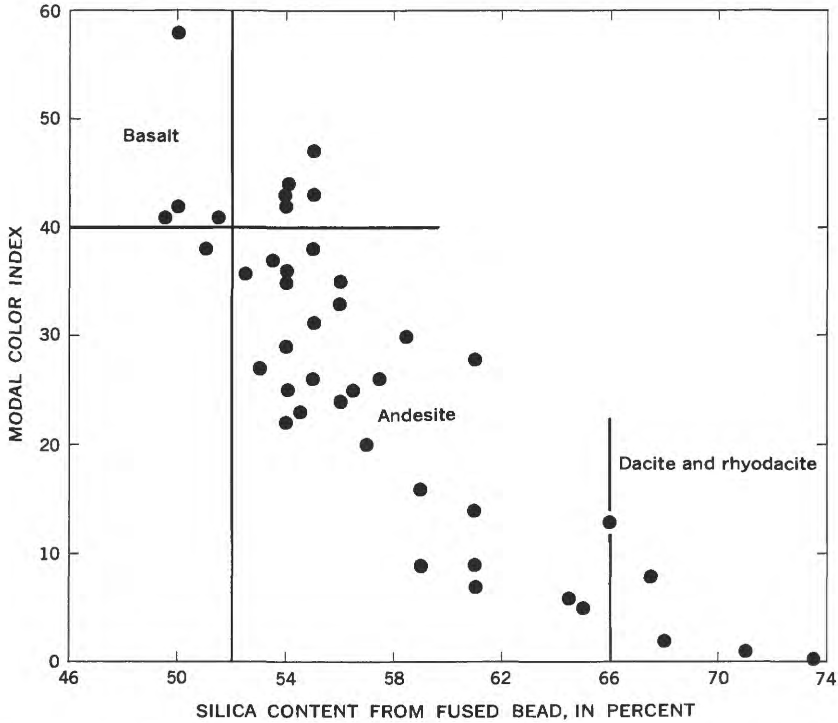

FIGURE 14.—Comparison of modal color index and silica content of rocks from the Mount Jefferson area.

DACITE AND RHYODACITE (66–74 PERCENT SiO_2)

Dacite and rhyodacite (66–74 percent SiO_2) are present in several isolated patches on ridgetops in the northern part of the Mount Jefferson area (fig. 2, table 5). They form a mappable unit of minor extent. The rocks are rather variable in appearance; the most typical (MJG–73 and MJG–80) are light grayish red to pale red and are flow banded so that narrow alternate bands are lighter in color and visibly porous. The rhyodacite, MJG–64–2, is light olive gray and less porous. There is a small amount of obsidian associated with it at this locality. Sample MJW–36 (not separately mapped) is a grayish-black rock with glassy luster and dense texture. All these rocks have an aphanitic groundmass with sparse, progressively zoned phenocrysts of plagioclase. The composition of the core portions ranges from sodic labradorite to intermediate andesine.

Oxyhornblende phenocrysts are present in MJG–73 and MJG–80, and small amounts of magnesian hypersthene and salite, in MJW–36. The groundmass consists of alkali feldspar, plagioclase, cristobalite,

FIGURE 15.—Hypersthene phenocryst (H) in silicic andesite. Plagioclase (P) and magnetite (M) grains in brown glass (G) with minute crystallites. Plane light, × 120. Sample MJW–105.

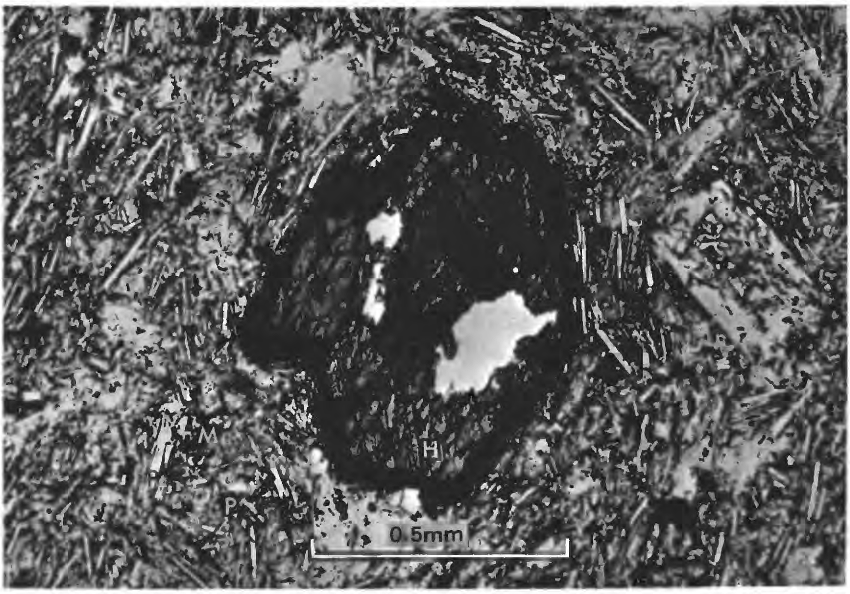

FIGURE 16.—Oxyhornblende phenocryst (H) with opaque margin in silicic andesite. Groundmass is plagioclase (P) and magnetite (M) grains with interstitial cristobalite and alkali feldspar; trachytic texture. Plane light, × 75. Sample MJW–76.

TABLE 5.—*Modes, in volume percent, and other characteristics of dacite and rhyodacite*

Sample	MJW-36	MJG-73	MJG-80	MJG-64-2
Modes				
Phenocrysts:				
Plagioclase	4.3	5.7	13.3	1.2
(An)	(48)	(50)	(52)	(39)
Clinopyroxene	.8			
(Wo:En:Fs)	(46:30:24)			
Orthopyroxene	Trace			Trace
(Fs)	(38)			
Oxyhornblende + opaque alteration		2.0	2.0	
Magnetite and ilmenite	.3			.4
Total	5.4	7.7	15.3	1.6
Groundmass:				
Mode expressed as total groundmass	94.6	83.3	76.0	98.4
Void		9.0	8.7	
Visually estimated composition:				
Alkali feldspar and silica minerals		(42)	(37)	(72)
Plagioclase	(28)	(17)	(42)	(24)
Glass	(62)	(21)		
Opaque or nearly so	(5)	(4)	(4)	(2)
Total	100.0	100.0	100.0	100.0
Other characteristics				
Color index	13	8	2	½
Refractive index of fused bead	1.516	1.510	1.508	1.492
Silica content from fused bead	66	67.5	68	73.5
Texture	Porphyritic, intersertal, trachytic.	Porphyritic, trachytic.	Porphyritic, granular.	Porphyritic, granular.
Grain size (mm):				
Phenocryst	.05-0.5	0.1-2.	0.1-1.	0.1-0.5

and glass with scattered opaque minerals. The textures of these rocks are porphyritic with a granular to trachytic groundmass.

RECENT ANDESITE

The Recent andesite studied comes from several intracanyon flows in the east-central part of the Mount Jefferson area. It is medium dark gray, porphyritic, and vesicular and is very fresh in appearance.

Abundant phenocrysts of plagioclase, sparse phenocrysts of olivine and clinopyroxene, and in some samples, rare phenocrysts of orthopyroxene (table 6) are set in a fine-grained groundmass of plagioclase, clinopyroxene, glass, and opaque minerals. In sample MJW-32 the opaque minerals are finely divided throughout the abundant black tachylitic glass; consequently, the rock has a low color index for its SiO_2 content. Plagioclase microlites are flow alined in each of the Recent andesite samples.

TABLE 6.—*Modes, in volume percent, and other characteristics of Recent andesite*

Sample	MJW-18	MJW-95	MJW-32
Modes			
Phenocrysts:			
Plagioclase	4.5	9.3	6.3
(An)	(56)	(79)	(77)
Olivine	1.5	.8	.7
Clinopyroxene	.1	1.6	2.2
(Wo:En:Fs)			(41:38:21)
Orthopyroxene		.8	.6
Total	6.1	12.5	9.8
Groundmass:			
Plagioclase	48.3	31.5	27.7
Clinopyroxene	32.8	29.8	9.2
Magnetite and ilmenite	5.8	3.7	
Glass	4.7	9.8	33.2
Opal			.8
Void	2.3	12.7	19.3
Total	93.9	87.5	90.2
Total	100.0	100.0	100.0
Other characteristics			
Color index	43	47	26
Refractive index of fused bead	1.574	1.569	1.566
Silica content from fused bead	54	55	55
Texture	Porphyritic granular flow-alined.	Porphyritic intersertal flow-alined.	Porphyritic intersertal flow-alined.
Grain size (mm):			
Phenocrysts	[1] 1.0–2.0; 0.1–1.	0.2–1.	0.1–2.
Groundmass	0.02–0.10	<0.01–0.2	0.01–0.5

[1] Includes two generations of plagioclase phenocrysts.

INTRUSIVE ROCKS

Most of the intrusive rocks occur as plugs, or round to oval bodies that probably fill old vents. They are 500–2,500 feet in maximum dimension and are scattered throughout the Mount Jefferson area. All these rocks are andesite except MJG–72, which is a dacite dike with a composition similar to the dacite flow of MJW–36 (p. 26). The intrusive andesite samples form a heterogeneous group and are described separately (table 7).

The coarsest grained rock studied from the Mount Jefferson area is an intrusive andesite (MJW–97) that contains sodic labradorite, an iron-rich ferro-augite (fig. 11, point farthest to right), and hypersthene. Its low color index indicates that the inferred SiO_2 content of 54½ percent is low for this rock; apparently a high iron content caused the fused bead to give an abnormally high refractive index and, hence, the low inferred SiO_2 percentage.

A sample from the plug at North Cinder Peak (MJW–96) is texturally similar to MJW–97 but is less rich in iron. It contains calcic labradorite, calcic augite, and intermediate bronzite.

Table 7.—*Modes, in volume percent, and other characteristics of intrusive rock*

Sample	MJW-97	MJG-20	MJW-96	MJG-41	MJW-10	MJG-72
Modes						
Phenocrysts:						
Plagioclase	-	-	-	-	12.8	3.0
(An)	-	-	-	-	(79)	(64)
Olivine	0.6	0.1	-	0.5	-	-
Orthopyroxene	-	-	-	-	1.9	.5
(Fs)	-	-	-	-	(21)	(approx 50)
Total	0.6	0.1	-	0.5	14.7	3.5
Groundmass:						
Plagioclase	76.9	64.7	72.5	59.4	37.8	-
(An)	(54)	(86)	(67)	(75)	-	-
Clinopyroxene	7.8	24.7	12.5	2.8	-	-
(Wo:En:Fs)	(37:18:45)	-	(40:37:23)	-	-	-
Orthopyroxene	13.3	Trace	7.1	16.8	16.9	-
(Fs)	(43)	-	(25)	-	-	-
Magnetite and ilmenite	1.4	7.3	3.6	2.4	2.5	0.6
Glass	(1)	.4	3.4	11.4	28.1	-
Void	-	-	-	6.7	-	-
Total	99.4	97.1	99.1	99.5	85.3	.6
Mode expressed as total groundmass	-	[2] 2.8	0.9	-	-	95.9
Visually estimated composition:						
Plagioclase	-	-	-	-	-	(32)
Alkali feldspar and silica minerals	-	-	(0.9)	-	-	(63)
Total	100.0	100.0	100.0	100.0	100.0	100.0

Other characteristics

Color index	23	35	24	35	30	1
Refractive index of fused bead	1.570	1.561	1.559	1.557	1.547	1.500
Silica content from fused bead	54½	56	56	56½	58½	71
Texture	Granular	Intergranular	Granular	Diktytaxitic, intergranular to intersertal, trachytic.	Microporphyritic, intersertal, trachytic.	Porphyritic, granular.
Grain size (mm):						
Phenocrysts	---	---	---	---	0.2–0.5	0.1–1.0
Groundmass	0.1–1.5	<0.01–0.5	0.1–0.8	0.02–0.7	0.02–0.2	<0.01–0.05

[1] Contains trace of clays.
[2] Contains 2.8 percent altered inclusions now consisting principally of clinopyroxene and opaque minerals.

A sample from the central plug of Three Fingered Jack (MJG–20) is an aphyric rock with plagioclase microlites surrounded by minute "beady looking" clinopyroxene grains of indeterminate composition. The larger plagioclase microlites are calcic bytownite. The rock contains clinopyroxene-rich patches, which are probably altered inclusions.

Samples from two intrusives near Santiam Pass (MJG–41 and MJW–10) have a pronounced intersertal-trachytic texture (fig. 17). They contain sodic to intermediate bytownite and their principal mafic mineral is orthopyroxene.

PETROLOGY

ANALYSES

Eight rock samples from the Mount Jefferson area have been chemically analyzed by the Rapid Rock Analysis Laboratory of the U.S. Geological Survey. The analyses, their norms, and the modes of the analyzed rocks are presented in Table 8.

The percentages of the major elements composing these eight samples are plotted against percent silica in variation diagrams in figures 18 and 19. The curves are drawn by inspection. Each element

FIGURE 17.—Intersertal-trachytic texture in intrusive andesite. Euhedral plagioclase microphenocrysts (P) and elongate microlites (M) separated by brown glass (G). Orthopyroxene (Or) grains partly in intergranular position. Plane light, × 120. Sample MJW–10.

TABLE 8.—*Chemical analyses, norms, and modes of Mount Jefferson area rocks*

[Analysts: P. L. D. Elmore, S. D. Botts, G. Chloe, Dennis Taylor, Hezekiah Smith, J. L. Glenn, Lowell Artis]

Rocks	Basalt	Andesite		Silicic andesite			Dacite	Rhyodacite
Sample	MJW-11	MJW-92	MJW-21	MJG-63	MJW-105	MJW-76	MJG-73	MJG-64-2
Chemical analysis (weight percent)								
SiO_2	51.6	52.6	55.7	58.8	61.2	66.4	67.6	73.6
Al_2O_3	17.9	17.1	17.8	17.0	18.1	16.7	16.1	14.2
Fe_2O_3	1.5	5.7	1.4	2.6	1.5	3.3	3.3	1.6
FeO	7.1	2.6	5.8	3.6	3.7	.80	.10	.22
MgO	7.0	6.9	4.6	3.9	2.6	1.4	.9	.1
CaO	8.6	8.4	7.6	6.2	5.2	4.1	3.2	.85
Na_2O	3.2	3.2	3.5	3.6	4.5	4.3	4.5	4.0
K_2O	.60	.82	1.0	1.3	1.1	1.5	1.9	3.7
H_2O-	.11	.04	.15	.61	.11	.10	.31	.17
H_2O+	.45	.40	.53	.59	.78	.30	1.0	1.0
TiO_2	1.4	1.2	.98	.87	.76	.59	.48	.20
P_2O_5	.42	.40	.35	.21	.18	.17	.14	.05
MnO	.16	.14	.13	.11	.10	.08	.07	.00
CO_2	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Sum	100	100	100	99	100	100	100	100
Norms (weight percent)								
CIPW:								
Q	0.1	5.7	6.9	13.6	14.3	25.3	26.5	34.5
C	----	----	----	----	.5	1.0	1.16	2.2
or	3.5	4.9	5.9	7.7	6.5	8.9	11.3	21.9
ab	27.1	27.2	29.8	30.6	38.1	36.5	38.2	34.0
an	32.7	30.0	30.0	26.5	24.7	19.3	15.0	3.9
wo	3.0	3.9	2.3	1.3	----	----	----	----
en	17.4	17.3	11.5	9.8	6.5	3.5	2.3	.3
fs	9.8	----	8.2	3.3	4.5	----	----	----
mt	2.2	5.4	2.0	3.8	2.2	1.1	----	.1
hm	----	2.0	----	----	----	2.5	3.3	1.5
il	2.7	2.3	1.9	1.7	1.5	1.1	.4	.4
ru	----	----	----	----	----	----	.3	----
ap	1.0	1.0	.8	.5	.4	.4	.3	.1
Total	99.5	99.7	99.3	98.8	99.2	99.6	98.76	98.9
Salic	63.4	67.8	72.6	78.6	84.1	90.9	92.1	96.4
Femic	36.0	31.8	26.7	20.3	15.0	8.7	6.5	2.4
Niggli:								
K	11	14	16	19	14	19	22	38

TABLE 8.—*Chemical analyses, norms, and modes of Mount Jefferson area rocks*—Continued

Rocks	Basalt	Andesite		Silicic andesite			Dacite	Rhyodacite
Sample	MJW-11	MJW-92	MJW-21	MJG-63	MJW-105	MJW-76	MJG-73	MJG-64-2
Modes (volume percent)								
Phenocrysts:								
Plagioclase	1.0	7.2		22.6	44.6	12.5	5.7	1.2
(An)	(77)	(81)		(62)	(62)	(48)	(50)	(39)
Olivine	3.6	2.5	0.5					
Clinopyrozene				2.7	.5	Trace		
(Wo:En:Fs)				(40:38:22)				
Orthopyroxene				5.6	15.1	.2		Trace
(Fs)				(29)	(37)			
Oxyhornblende					.2	4.4	2.0	
Total	4.6	9.7	0.5	30.9	60.4	17.1	7.7	1.2
Groundmass:								
Plagioclase	52.3	46.9	53.4					
(An)			(67)					
Cinopyroxene	29.4	28.3	8.6					
(Wo:En:Fs)	(44:32:24)							
Orthopyroxene			14.1					
(Fs)			(27)					
Magnetite and ilmenite	4.0	11.9	3.4	0.7	1.6	1.2		0.4
Glass	2.2	3.2	16.6		34.0			
Void	7.5		3.4		4.0	6.6	9.0	
Total	95.4	90.3	99.5	0.7	39.6	7.8	9.0	0.4
Mode expressed as total groundmass				68.4		75.1	83.3	98.4
Visually estimated composition:								
Alkali feldspar and silica minerals				(45)		(38)	(42)	(72)
Plagioclase				(17)		(38)	(17)	(24)
Pyroxene				(7)				
Opaque or nearly so							(4)	(2)
Glass							(21)	
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

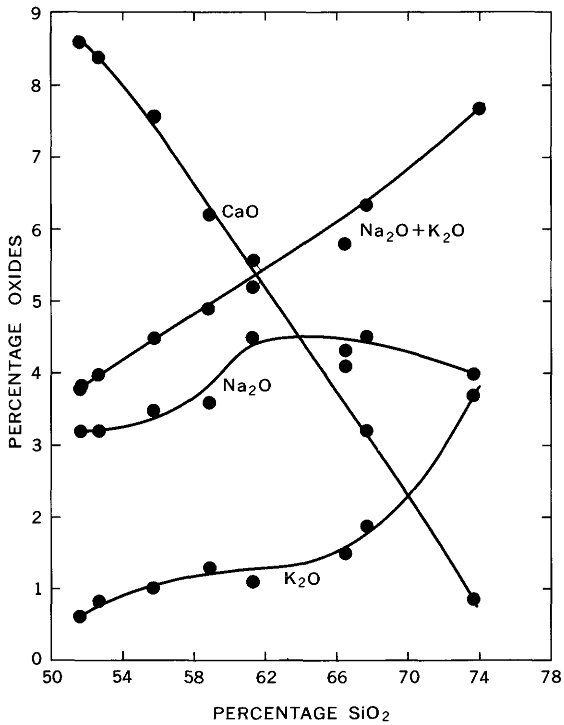

FIGURE 18.—Silica variation diagram showing percentage of SiO_2 plotted against percentages of K_2O, Na_2O, CaO, and K_2O+Na_2O for Mount Jefferson area rocks.

varies in a fairly smooth fashion in this suite of rocks. Iron is highly oxidized in some of the rocks and less so in others, but total iron decreases smoothly as silica increases.

ALKALI-LIME INDEX

The alkali-lime index (Peacock, 1931), or the percent SiO_2 at which K_2O+Na_2O equals CaO, is about 61 (fig. 18), a number which is on the boundary between Peacock's calc-alkalic and calcic suites. The Mount Jefferson area rocks are thus slightly more calcic than the Western Cascade suite (Peck and others, 1964), which has an alkali-lime index of 60. The indices of other suites of High Cascade rocks are 62 for Crater Lake, 63.7 for Mount Shasta, 63.9 for the Lassen region, and 63.2 for Mount St. Helens (Williams, 1942, p. 153). Thus the

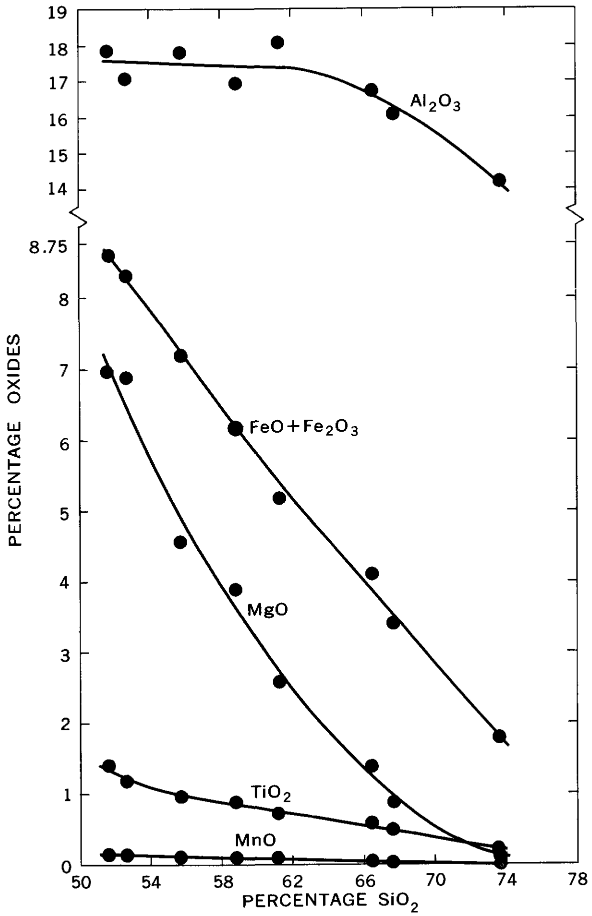

FIGURE 19.—Silica variation diagram showing percentage of SiO_2 plotted against percentages of Al_2O_3, $FeO+Fe_2O_3$, MgO, TiO_2, and MnO for Mount Jefferson area rocks.

volcanic rocks of the High Cascades form a unified group in the lower part of the calcic suite.

COMPARISON WITH OTHER SUITES

The silica variation curves for the Mount Jefferson area are compared with points for 17 rocks from Crater Lake (Williams, 1942, p. 148, analyses 4-8; p. 150–151, analyses 14–25) in figure 20. The two suites, both from the High Cascades, show similar trends, the

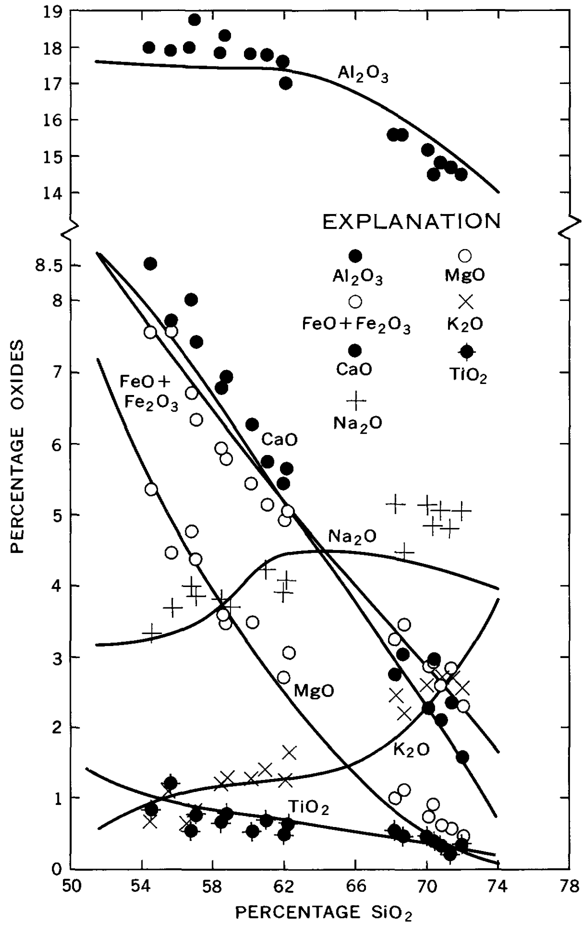

FIGURE 20.—Silica variation diagram for Crater Lake rocks compared with Mount Jefferson area rocks. Points represent analyzed Crater Lake rocks (Williams, 1942). Curves are from Mount Jefferson area trends in figures 18 and 19.

most notable difference being the higher content of Na_2O in Crater Lake rocks at 68–72 percent SiO_2.

The variation curves for the Mount Jefferson area rocks are compared in figures 21 and 22 with points for 22 rocks from the Western Cascades (Peck and others, 1964, p. 44–45, analyses 1–22). The trends for some elements show a close relationship; others show clear differences, despite the greater scatter in the more heterogeneous Western Cascade group.

The Mount Jefferson rocks contain more Al_2O_3, and, at less than 58 percent SiO_2, less $FeO+Fe_2O_3$ than the Western Cascade suite. This confirms the results reported by Peck, Griggs, Schlicker, Wells, and Dole (1964, p. 46). Other elements show smaller differences: K_2O is less abundant in Mount Jefferson rocks, though points overlap; Na_2O and CaO are comparable; MgO is less abundant in Western Cascade rocks in the range of 51–60 percent SiO_2. The Western

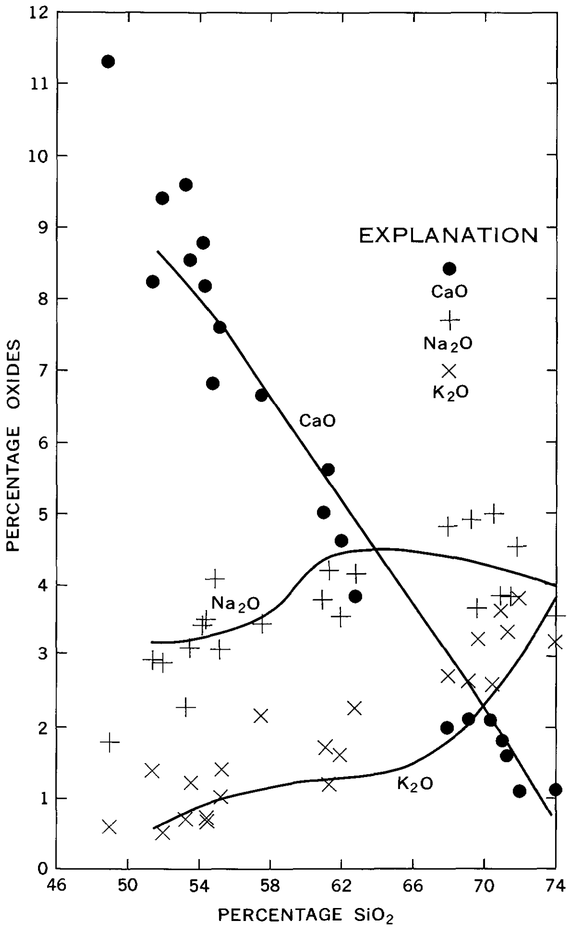

FIGURE 21.—Silica variation diagram of K_2O, Na_2O, and CaO for Western Cascade rocks compared with Mount Jefferson area rocks. Points represent analyzed Western Cascade rocks (Peck and others, 1964). Curves are from Mount Jefferson area trends in figure 18.

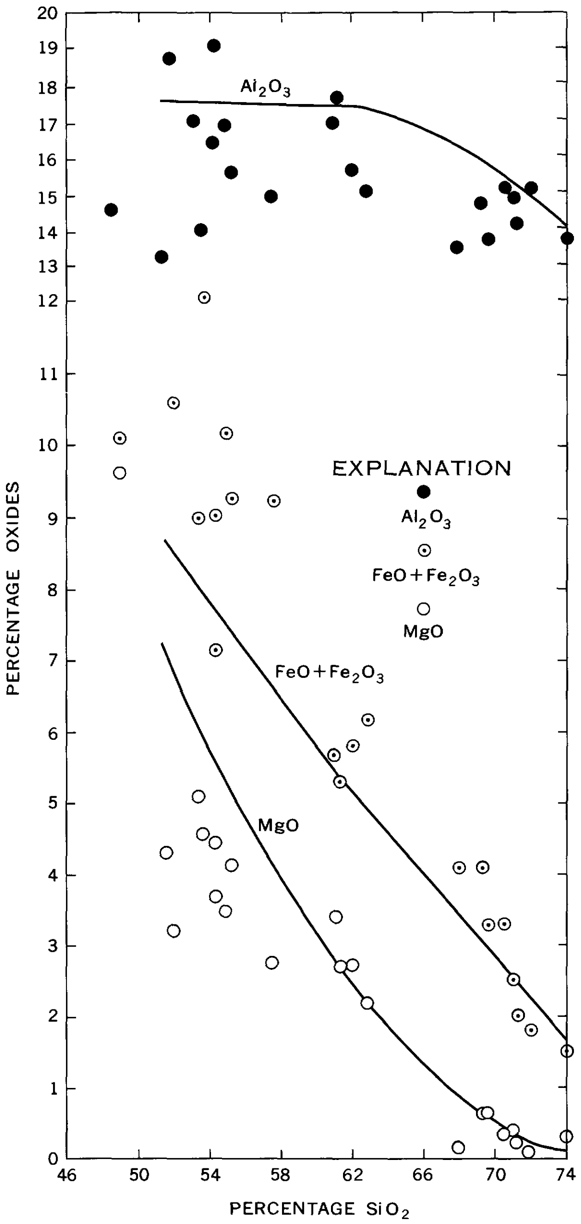

FIGURE 22.—Silica variation diagram of Al_2O_3, $FeO+Fe_2O_3$, and MgO for Western Cascade rocks compared with Mount Jefferson area rocks. Points represent analyzed Western Cascade rocks (Peck and others, 1964). Curves are from Mount Jefferson area trends in figure 19.

Cascade rocks, therefore, differ significantly from the High Cascade rocks in chemistry as well as age.

A further comparison with a more distant tholeiitic suite is given in figure 23. The points in this diagram represent two lavas and a differentiated intrusive from the Koolau Volcanic Series on the Island of Oahu, Hawaii (Wentworth and Winchell, 1947). The Koolau is richer in TiO_2 and much richer in $FeO+Fe_2O_3$ than the Mount Jefferson rocks, but poorer in Al_2O_3 and Na_2O. Percentages of K_2O, CaO, and MgO are similar. Despite the lower Na_2O, the alkali-lime index for the Koolau is only 62, owing to the marked decrease in CaO in the most silicic differentiate.

NORMATIVE MINERALS

Standard CIPW norms and ratios (table 8) for plotting were determined by using a Boroughs B–5500 computer. All the chemically analyzed rocks contain normative quartz. There is some similarity between normative and modal plagioclase but very little between normative and modal pyroxene. The highly oxidized state of the iron in several of the rocks creates large amounts of normative magnetite at the expense of ferrosilite, and in one sample the Fe_2O_3:FeO ratio is so high that rutile appears in the norm. Normative corundum appears in the four most silicic rocks. This extra alumina must be present in the glass or substituted in the pyroxenes.

The presence of normative wollastonite in the four least silicic rocks shows them to be meta-aluminous (mol. percent of $Al_2O_3>K_2O+Na_2O$ but $<K_2O+Na_2O+CaO$) and the presence of normative corundum in the four more silicic rocks shows them to be per-aluminous (mol. percent of $Al_2O_3>K_2O+Na_2O+CaO$).

Niggli K values (molecular ratio K_2O to K_2O+Na_2O) exceed 20 only above 67 percent SiO_2. The paucity of K in these rocks is illustrated by the triangular plots (figs. 24 and 25) showing the proportions of the normative feldspar components and the proportions of normative plagioclase, orthoclase, and quartz. The latter diagram also suggests that differentiation of the magma or magmas in the Mount Jefferson area approached compositions near the isobaric minima in the silica-alkali feldspar-water system (Tuttle and Bowen, 1958).

PHASE RELATIONSHIPS AND CRYSTALLIZATION HISTORY

Plots of the Mount Jefferson area rocks on an iron enrichment versus silica diagram define a curve similar to experimentally derived curves for crystallization in the system SiO_2–MgO–FeO–Fe_2O_3 (Osborn, 1959; figs. 26, 27 of this paper). The Mount Jefferson area curve also resembles Osborn's curve for volcanic rocks from the

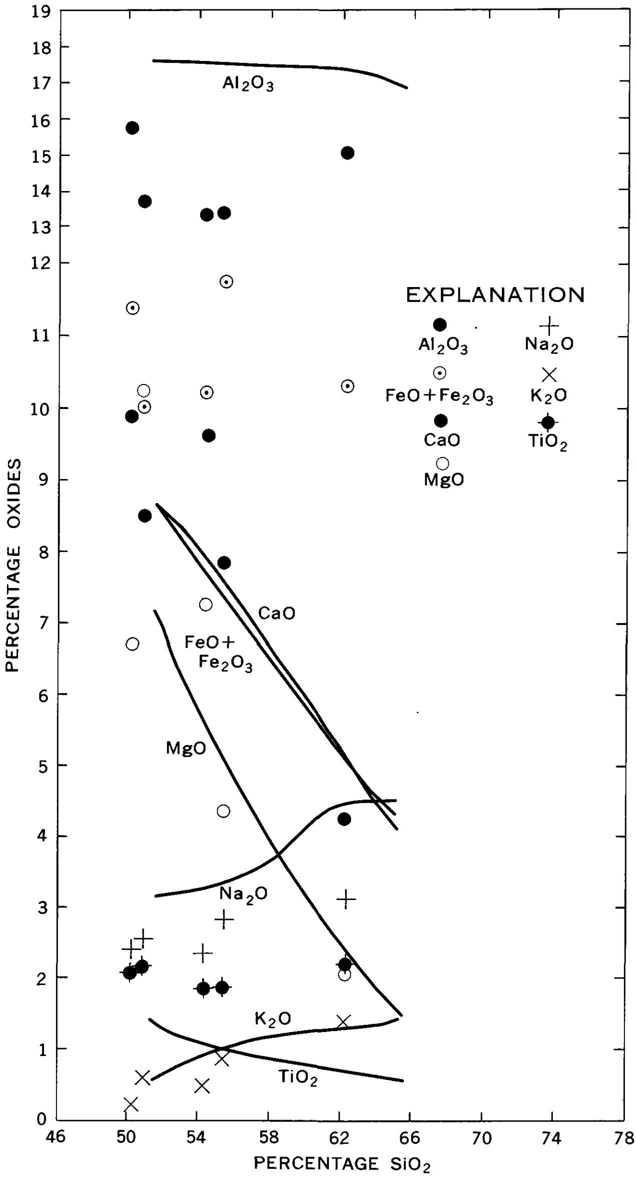

FIGURE 23.—Silica variation diagram for rocks of the Koolau Volcanic Series, Oahu, Hawaii, compared with Mount Jefferson area rocks. Points represent analyzed rocks of the Koolau Volcanic Series. Curves are from Mount Jefferson area trends in figures 18 and 19.

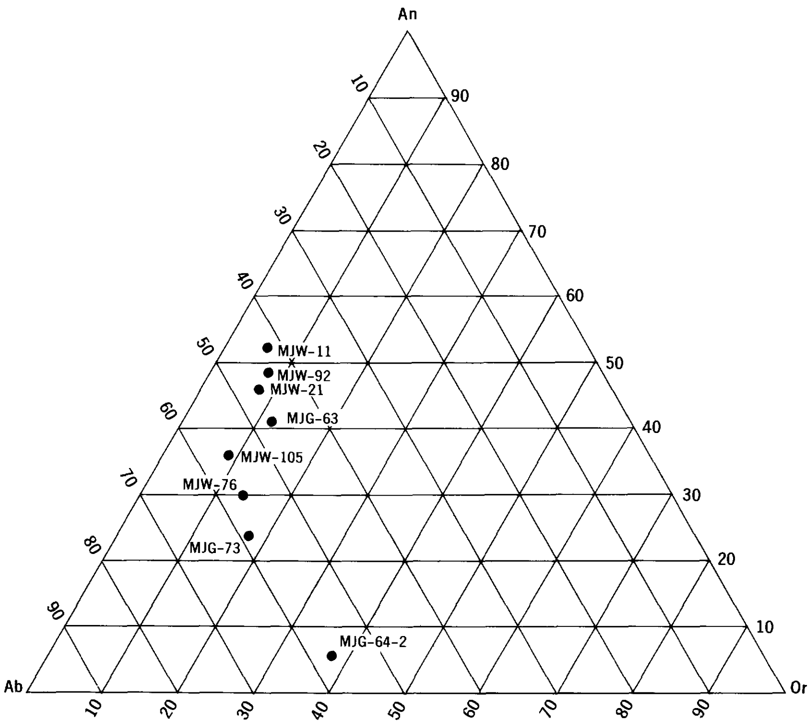

FIGURE 24.—Composition of normative feldspar in eight chemically analyzed rocks from the Mount Jefferson area. Weight ratios plotted.

Cascade Range, and, more poorly, the curve of Nockold's averages. The Mount Jefferson area curve is probably better than the latter two for comparison with the experimental curves because it represents probable successive differentiates collected in a small area.

Insofar as Osborn's experimental data for a simple system are applicable, the Mount Jefferson area rocks can be interpreted to have crystallized under constant or increasing oxygen pressure. The steep slope of the Mount Jefferson curve suggests, however, that the pressure may actually have decreased slightly during crystallization. Recent work (Presnall, 1966) on the system SiO_2–CaO–MgO–FeO–Fe_2O_3 has confirmed Osborn's conclusions about the influence of oxygen pressure on crystallization and has shown them to be applicable to the more complicated system including CaO, which more closely resembles basalt magma.

Osborn (1959) proposed that the oxygen necessary to maintain constant or rising oxygen pressure in a crystallizing magma is supplied primarily by the dissociation of water, and hence, that the magmas crystallizing under these conditions are relatively water rich. Therefore,

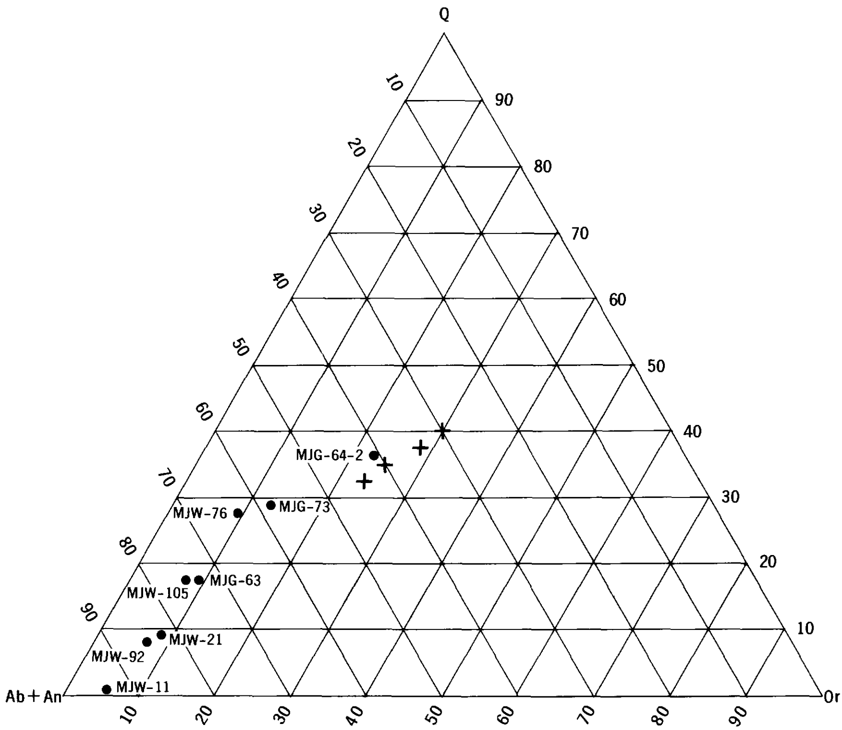

FIGURE 25.—Ratios of normative quartz, plagioclase, and orthoclase in eight chemically analyzed rocks from the Mount Jefferson area. Weight ratios plotted. Crosses represent isobaric minima in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O between 500 and 4,000 kg per cm^2 pressure (from Tuttle and Bowen, 1958, p. 75).

the curves also suggest that the parent magma for the Mount Jefferson area rocks contained a relatively abundant supply of water.

ORIGIN AND DERIVATION OF THE VOLCANIC ROCKS

The volcanic rocks of the High Cascades were erupted from a north-south line of vents lying east of those that produced the volcanic rocks of the Western Cascades (Peck and others, 1964, p. 52). The line of active vents appears to have migrated eastward since the early Oligocene, and its activity culminated in the building of the High Cascades during the Pliocene and Pleistocene.

In the Mount Jefferson area, eruption was from a number of vents. The principal ones were Mount Jefferson and Three Fingered Jack, but venting of lavas also occurred at other places.

Mapped areas of cinders and associated flow rocks (fig. 2) certainly represent vents, and the intrusive plugs very likely mark vent locations. Some of the older vents, particularly those that erupted the

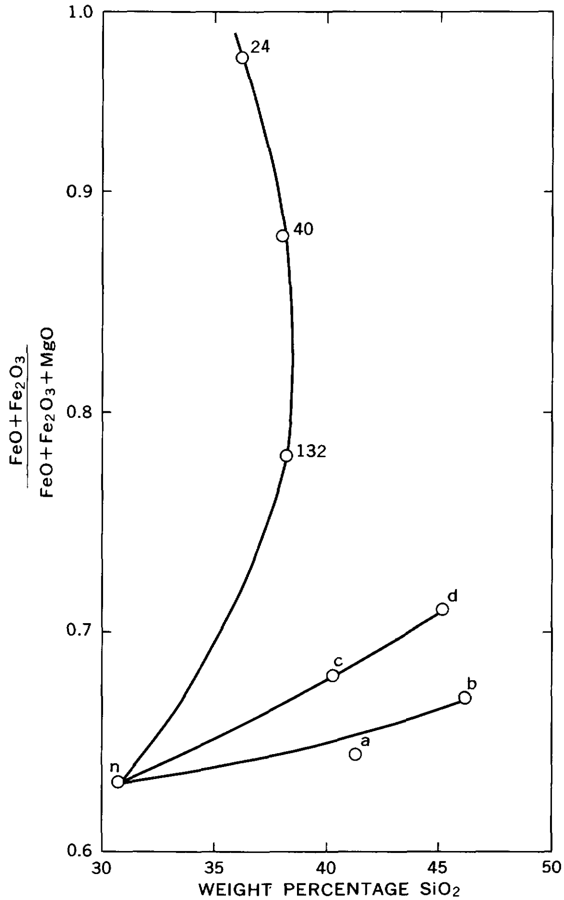

FIGURE 26.—Comparison of iron enrichment and silica content of experimental liquids undergoing fractional crystallization under different conditions: curve n–24, constant total composition; curve n–d, constant O_2 pressure; curve n–b increasing O_2 pressure (from Osborn, 1959).

lowermost basalt of the High Cascade volcanic rocks, are probably buried. The Recent intracanyon flows came from small vents not coincident with Mount Jefferson or Three Fingered Jack, but on the same north-south line.

The field positions of the volcanic rocks are compatible with a general pattern of eruption of successively more silicic lavas from both the main and subsidiary vents. The most silicic rocks are found on ridge crests north of Mount Jefferson. These may be remnants of

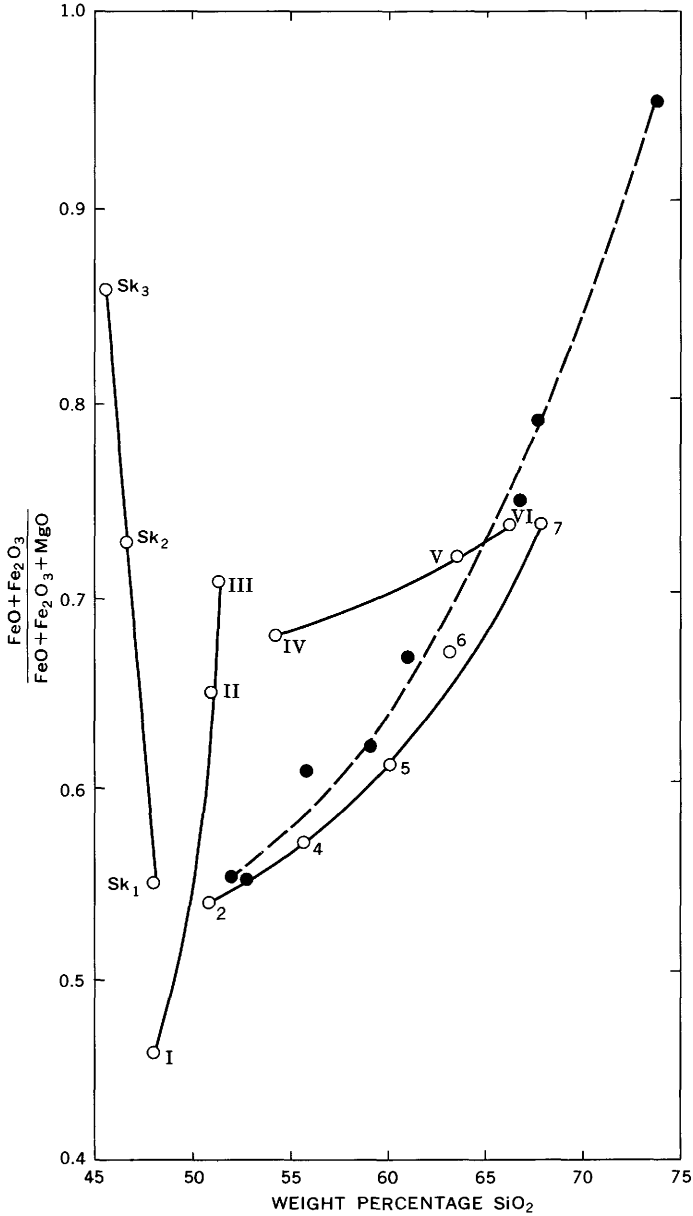

FIGURE 27.—Comparison of iron enrichment and silica content of various magma series: Sk_1–Sk_3, Skaergaard intrusion (Wager and Deer, 1939); I–III, averages for tholeiitic rocks (Nockolds, 1954); IV–VI, averages for andesite, dacite, and rhyodacite (Nockolds, 1954); 2–7, assorted rocks from the Cascade Range (Turner and Verhoogen, 1951); ●, analyzed samples from the Mount Jefferson area (in part from Osborn, 1959).

formerly more extensive flows that originated from Mount Jefferson, or they may have come from local vents.

The graph of frequency of types of rock (fig. 6) is not based on systematic sampling, but it suggests (dashed line) an overall distribution that is unimodal and strongly skewed toward the mafic compositions. Thus there are large volumes of lava with 53–56 percent silica and successively smaller volumes with higher percentages of silica. Small volumes of lava with less than 53 percent silica may be basic differentiates.

Probably systematic sampling designed to give a quantitative estimate of volume versus silica content would give a frequency distribution curve of similar shape. Such a curve plus the regular trends displayed by the petrologic diagrams (fig. 18, 19, 24, 25) suggest that these rocks are either successive differentiates from a common parent magma with about 53–54 percent SiO_2 or from several magmas of similar original composition which have undergone similar differentiation.

The Recent intracanyon flows have compositions similar to the most common composition of the older flows (fig. 6). Therefore, they must represent a reappearance of undifferentiated parental magma in new vents along the same line of crustal weakness occupied by the major vents of the High Cascades.

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