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Geologic map of the Packwood quadrangle, southern Cascade Range, Washington

by

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CONTENTS

PLATES

FIGURES

TABLE

Geologic map of the Packwood quadrangle, southern Cascade Range, Washington

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INTRODUCTION

The Packwood 7.5–minute quadrangle is centered 30 km south of Mount Rainier, 40 km north-northwest of Mount Adams, and 20 km west of the crest of the Cascade Range in southern Washington (fig. 1). It is one of a series of adjoining quadrangles that have been studied geologically in the past ten years. Geologic maps and accompanying detailed text have been open-filed for the French Butte, Greenhorn Buttes, Tower Rock, McCoy Peak, Blue Lake, East Canyon Ridge, Hamilton Buttes, and Packwood Lake quadrangles (Swanson, 1989, 1991, 1992, 1993, 1994, 1996a, b), as well as the Randle quadrangle (Moore and others, 1994). By November 1996, mapping has been completed in the Old Snowy Mtn. (Swanson) and Purcell Mtn. (Moore, Swanson, and Banks) quadrangles and nearly completed in the Ohanapecosh Hot Springs (Banks and Swanson), Sawtooth Ridge (Moore and Banks), and Wahpenayo Peak quadrangles (Moore and Banks).

The geologic research in these quadrangles forms part of an effort to understand the development of the Cascade arc in southern Washington from its inception in the late Eocene to the present. A primary goal has been to tie the Tertiary stratigraphy of the area near and west of Mount St. Helens (Evarts and Ashley, 1990a, b, 1991, 1992, 1993a, b, c, d; Evarts and others, 1987; Evarts and Swanson, 1994; Swanson, 1989, 1991, 1992, 1993, 1994, 1996a and b) into the now-classic stratigraphic section in the Mount Rainier–White Pass area defined by Fiske and others (1963; see also Waters, 1961) and modified by Vance and others (1987). This work is establishing an improved regional geologic framework for a geologic research corridor across the west side of the Cascade Range in southern Washington (Swanson and Evarts, 1992; Evarts and Swanson, 1994), from the upper Eocene marine rocks of the Puget Lowland to the Late Jurassic–Early Cretaceous Rimrock Lake inlier (Miller, 1989; Miller and others, 1993) along and just east of the crest in the White Pass–upper Tieton River area and eastward to the margin of the Columbia Plateau (Swanson, 1978) (fig. 1). The ongoing study helps geologic interpretation of a seismic refraction and reflection study (conducted in late summer 1995) and other geophysical surveys in a corridor linking coastal Washington with the Columbia Plateau (Wells and others, 1993). Detailed field mapping and related research is examining whether a pronounced electrical conductivity layer in the middle crust, the *southern Washington Cascades conductor* (SWCC) of Stanley and others (1987, 1992), has a recognizable influence on the volcanic evolution and structure of the area. All of the quadrangles under study lie within the SWCC or astride its eastern margin.

The Packwood quadrangle straddles the Cowlitz River (fig. 2), a large stream whose two main forks, the Muddy and Clear, head on Mount Rainier and in the Goat Rocks Wilderness northwest and southwest of White Pass, respectively. Southeast of the Cowlitz, roads follow Johnson and Smith Creeks and crisscross Hall Ridge. Most of this part of the quadrangle is roadless, however, and accessible only by poorly maintained and abandoned trails or cross-country traverses. Roads afford access to much of the quadrangle northwest of the Cowlitz.

Late Eocene, Oligocene, and early Miocene volcaniclastic and volcanic rocks, mainly of basaltic andesite and andesite composition (table 1), underlie most of the quadrangle. These rocks compose what previous workers in the area have called the Ohanapecosh Formation (Hammond, 1980; Swanson and Clayton, 1983; Winters, 1984; Schasse, 1987). Many dikes and especially sills of basaltic andesite to rhyolitic composition cut the layered rocks. Middle Pleistocene andesite flows from the Goat Rocks volcanic center, downstream continuations of those mapped on Snyder Mountain in the Packwood Lake quadrangle (Swanson, 1996b), just enter the northeastern part of the Packwood quadrangle.

Glacial drift covers large parts of the quadrangle, but bedrock crops out along most creeks, steep slopes, and ridges. The bedrock mapping included traverses along most drainages, large and small; such work, though time consuming, finds many exposures, even in densely forested terrain. Nonetheless the exact positioning of contacts is poorly constrained in many places.

Previous small-scale (1:100,000 and smaller) reconnaissance geologic mapping has included the Packwood quadrangle, mainly by Hammond (1980), Schasse (1987; see also Walsh and others, 1987), and Smith (1993). Our mapping is the first to attempt a detailed portrayal of the geology in the quadrangle.

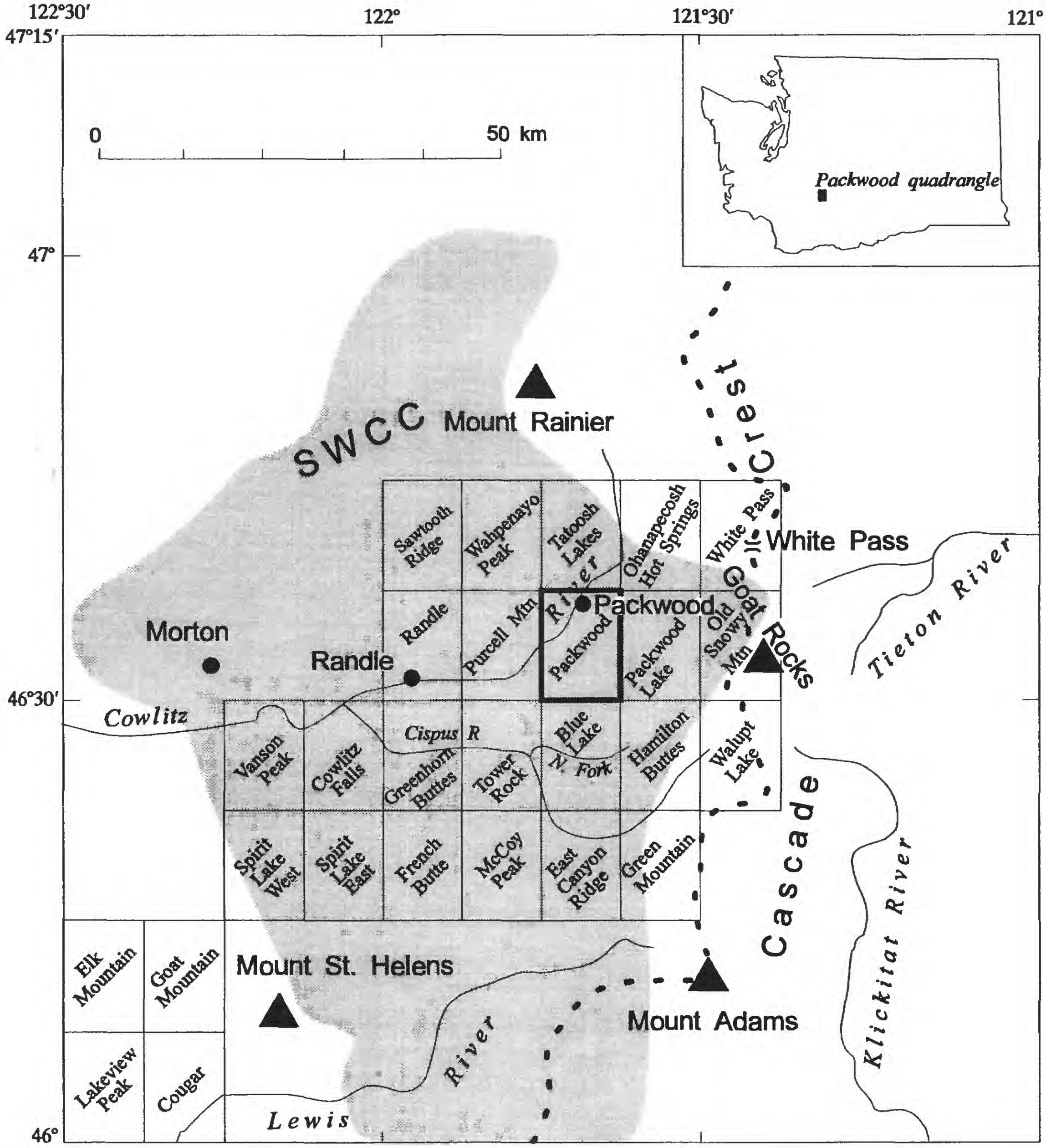

Figure 1. Index map showing location of Packwood quadrangle relative to the three Holocene composite volcanoes in southern Washington, crest of Cascade Range, Pleistocene–Pliocene volcano at Goat Rocks, Southern Washington Cascades Conductor (shaded and labeled SWCC; see text), and other 7-1/2′ quadrangles in which geologic mapping has been completed recently or is on-going. Mapping west of longitude 122° by R.C. Evarts and R.P. Ashley, east of 122° and south of Cowlitz River by D.A. Swanson, and north of Cowlitz River by R.B. Moore, C.R. Thornber, and N.G. Banks.

ACKNOWLEDGMENTS

Paul Hammond provided the two chemical analyses of the ash-flow tuff of Purcell Creek. Barbara White donated considerable logistic help that enabled several steep one-way traverses, and she aided in establishing a remote backpack camp above Goat Dike. Bob Schuster (U.S. Geological Survey, Denver) commented on the age of the landslide that dams Hager Lake. Two U.S. Geological Survey programs supported the research—National Cooperative Geologic Mapping (the principal sponsor) and Deep Continental Studies. In his inimitable way, Dave Sherrod closely reviewed and greatly improved the map and text.

ROCK TERMINOLOGY AND CHEMICAL CLASSIFICATION

For consistency, this section follows closely the format of comparable sections in previous open-file reports, including all relevant figures (despite a relative paucity of data.) This consistency enables ready comparison with data in the other reports.

We use the same classification scheme as in previous open-file reports—the IUGS system (Le Bas and others, 1986) modified to include a field for rhyodacite (fig. 3). For the total alkali contents found, the chemically analyzed rocks are grouped under six names: *basalt* (<52 percent SiO_2), *basaltic andesite* (52–57 percent SiO_2), *andesite*

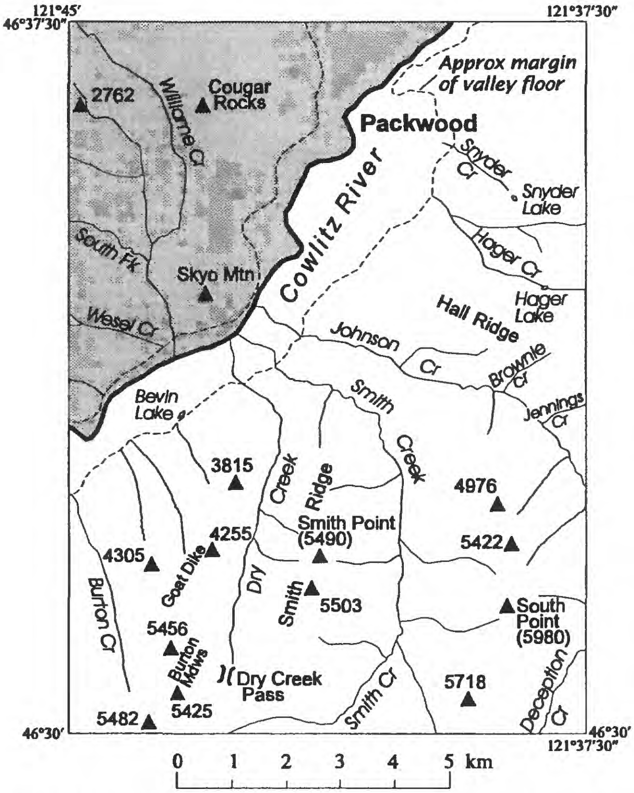

Figure 2. Map of Packwood quadrangle showing locations of geographic features mentioned in text. Shaded area mapped by Moore and Banks, unshaded by Swanson.

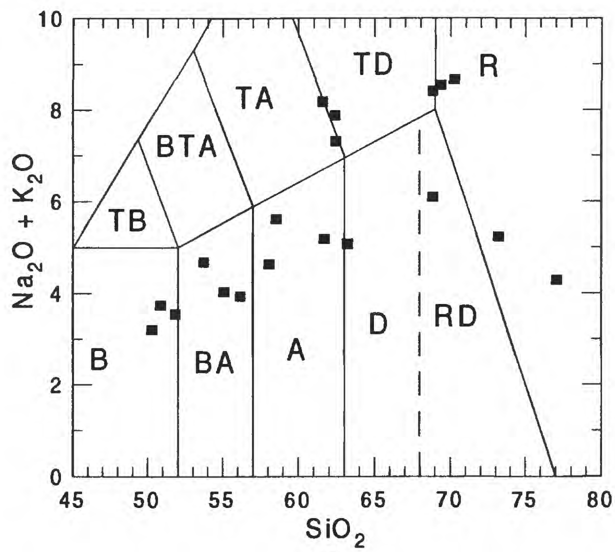

Figure 3. Total alkali-silica classification diagram for chemical analyses of rocks from the Packwood quadrangle, modified from Le Bas and others (1986) to include field for rhyodacite. B, basalt; BA, basaltic andesite; A, andesite; D, dacite; RD, rhyodacite; R, rhyolite; TB, trachybasalt; BTA, basaltic trachyandesite; TA, trachyandesite; TD, trachydacite. Data from table 1. Analyses plotted in this and subsequent figures have been normalized to 100 percent on a volatile-free basis, with all iron as FeO* (right half of table 1).

(57–63 percent SiO_2), *dacite* (63–68 percent SiO_2), *rhyodacite* (generally between 68 and about 72 percent SiO_2; fig. 3), and *rhyolite* (generally greater than about 72 percent SiO_2; fig. 3).

Rocks from all of the mapped quadrangles have rather consistent phenocryst assemblages (fig. 4) (minerals listed in most common order of decreasing abundance): *basalt*, ol ± pl ± cpx ± rare opx; *basaltic andesite*, pl ± cpx ± opx ± ol; *andesite*, pl ± cpx ± opx ± rare ol ± hb; *dacite*, assemblage similar to that for andesite (except for very rare olivine, found only in rocks from the Goat Rocks volcanic center, and rare quartz), but orthopyroxene is less common, and the groundmass commonly displays snowflake texture owing to high-temperature devitrification; *rhyodacite* and *rhyolite*, generally almost aphyric with pl > cpx and no quartz (except for abundant embayed quartz and sparse biotite in the ash-flow tuff of Purcell Creek [map unit Tqt]).

None of the rocks in the Packwood quadrangle bears hornblende phenocrysts, although in adjoining quadrangles hornblende is rather common in Pleistocene andesite and dacite flows from the Goat Rocks volcanic center (Clayton, 1983; Swanson, 1996a, b) and in the Miocene intrusive suite of Kidd Creek south of the quadrangle (Marso and Swanson, 1992; Swanson, 1993).

Samples with thin sections but no chemical analyses can be roughly classified by their phenocryst assemblages and groundmass textures (fig. 4). In all, 47 samples from the Packwood Lake quadrangle were sectioned (fig. 5); of these, 19 samples were chemically analyzed, two in the XRF laboratory of the U.S. Geological Survey in Denver and 17 (two courtesy of P.E. Hammond) in the GeoAnalytical Laboratory of the Geology Department of Washington State University (WSU) (table 1).

The Tertiary suite is barely calcic (Peacock, 1931). Its alkali-lime index is about 61.9 (fig. 6), just on the calcic side of the 61 value separating the calc-alkalic and calcic suites. This value has little significance, however, because of so few data points (19). Nonetheless it is well within the range of indices found in the previously mapped quadrangles and in fact is identical to that of the Packwood Lake quadrangle.

All but one of the chemically analyzed Tertiary rocks are tholeiitic on a plot of FeO*/MgO vs. SiO_2 (fig. 7), according to the classification of Miyashiro (1974). This pattern resembles that in the previously mapped quadrangles.

All of the analyses are subalkaline on a plot of total alkalies vs. SiO_2 (fig. 8; Macdonald and Katsura, 1964; Irvine and Baragar, 1971). One falls on the dividing line in the Irvine and Baragar scheme. The subalkaline character is stronger with increasing SiO_2 content, as is characteristic of Tertiary rocks in the other mapped quadrangles.

Table 1. Chemical analyses from the Packwood quadrangle, arranged in order of increasing SiO_2

Map No.	Map Unit	Field No.	Original analysis SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Total	Recalculated to 100 percent, with iron as FeO SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	$Na_2O + K_2O$	FeO*/MgO	Longitude Deg	Longitude Min	Latitude Deg	Latitude Min
1	Ta	94-024	49.76	1.29	20.92	8.51	0.16	3.70	11.32	2.91	0.27	0.15	98.99	50.27	1.30	21.13	8.60	0.16	3.74	11.44	2.94	0.27	0.15	3.21	2.30	121	38.370	46	31.440
2	Ta	94-015	50.07	1.10	23.00	8.32	0.10	3.71	8.36	3.50	0.20	0.12	98.48	50.84	1.12	23.36	8.45	0.10	3.77	8.49	3.55	0.20	0.12	3.76	2.24	121	41.640	46	33.510
3	Ta	94-016	51.20	1.32	19.98	9.45	0.17	2.34	10.69	3.10	0.41	0.14	98.79	51.83	1.34	20.22	9.57	0.17	2.37	10.82	3.14	0.42	0.14	3.55	4.04	121	42.018	46	33.768
4	Tip	94-049	52.83	1.65	17.85	8.36	0.14	4.13	8.47	3.78	0.82	0.30	98.33	53.73	1.68	18.15	8.50	0.14	4.20	8.61	3.84	0.83	0.30	4.68	2.02	121	39.372	46	37.428
5	Ta	94-047	54.88	1.43	18.45	7.83	0.15	3.42	9.22	3.48	0.55	0.20	99.61	55.09	1.44	18.52	7.86	0.15	3.43	9.26	3.49	0.55	0.20	4.05	2.29	121	41.640	46	30.372
6	Ta	94-029	56.06	1.17	16.76	8.03	0.15	4.85	8.60	2.93	1.01	0.20	99.77	56.19	1.18	16.80	8.05	0.15	4.86	8.62	2.94	1.01	0.20	3.95	1.66	121	44.280	46	31.770
18	Ta	MW94-30[1]	57.60	1.03	17.90	8.22	0.12	3.04	6.52	3.55	1.05	0.16	99.19	58.07	1.04	18.05	8.29	0.12	3.06	6.57	3.58	1.06	0.16	4.64	2.70	121	44.624	46	35.466
7	Ta	94-020[3]	57.78	1.43	14.80	9.91	0.22	1.92	6.92	4.64	0.91	0.19	98.72	58.53	1.45	14.99	10.04	0.22	1.94	7.01	4.70	0.92	0.20	5.62	5.16	121	40.500	46	31.110
8	Tip	94-055	60.91	1.35	16.06	6.25	0.14	1.81	3.82	5.44	2.65	0.46	98.89	61.59	1.37	16.24	6.32	0.14	1.83	3.86	5.50	2.68	0.47	8.18	3.45	121	40.182	46	36.792
19	Tai	MW94-29[1]	59.40	1.29	14.70	8.11	0.14	2.05	5.25	3.61	1.39	0.34	96.28	61.70	1.34	15.27	8.42	0.15	2.13	5.45	3.75	1.44	0.35	5.19	3.96	121	44.436	46	34.475
9	Tai	94-019	61.75	1.31	15.50	6.93	0.14	1.52	3.58	4.76	3.04	0.44	98.98	62.39	1.32	15.66	7.00	0.15	1.54	3.62	4.81	3.07	0.45	7.88	4.56	121	38.412	46	34.320
10	Tai	94-039	61.61	1.30	15.18	6.81	0.13	1.69	4.28	4.23	2.99	0.44	98.67	62.44	1.32	15.39	6.90	0.13	1.71	4.34	4.29	3.03	0.45	7.32	4.03	121	38.958	46	34.962
11	Ta	94-033	61.92	1.02	15.34	7.50	0.19	1.56	5.11	3.97	1.00	0.33	97.94	63.22	1.04	15.66	7.66	0.20	1.59	5.22	4.05	1.02	0.34	5.07	4.81	121	38.208	46	33.000
12	Tri	94-036	66.34	0.57	14.54	3.97	0.12	0.56	4.26	3.47	2.40	0.14	96.37	68.84	0.59	15.09	4.12	0.13	0.58	4.42	3.60	2.49	0.14	6.09	7.09	121	38.292	46	36.162
13	Tri	94-037	68.49	0.60	15.07	3.87	0.11	0.73	2.09	5.88	2.48	0.14	99.46	68.86	0.60	15.15	3.89	0.11	0.73	2.10	5.91	2.49	0.14	8.41	5.30	121	37.992	46	36.342
14	Tri	94-060	69.21	0.56	14.88	3.99	0.11	0.60	1.76	5.88	2.64	0.13	99.76	69.38	0.56	14.92	4.00	0.11	0.60	1.76	5.89	2.65	0.13	8.54	6.65	121	37.830	46	35.622
15	Tri	94-035	69.84	0.50	14.85	3.57	0.10	0.42	1.37	5.63	2.98	0.12	99.38	70.28	0.50	14.94	3.59	0.10	0.42	1.38	5.67	3.00	0.12	8.66	8.50	121	38.808	46	36.618
16	Tqt	94-012[2]	66.57	0.28	13.34	2.59	0.05	0.48	2.79	2.59	2.18	0.08	90.95	73.20	0.30	14.67	2.85	0.06	0.53	3.07	2.85	2.40	0.09	5.24	5.40	121	40.530	46	34.722
17	Tqt	94-044[2]	73.11	0.21	12.29	1.70	0.03	0.21	3.15	2.22	1.86	0.05	94.83	77.09	0.22	12.96	1.79	0.03	0.22	3.32	2.34	1.96	0.05	4.30	8.10	121	39.948	46	34.458

X-ray fluorescence analyses done at GeoAnalytical Laboratory of Washington State University except where noted

[1] *Analysis done in U.S. Geological Survey laboratory in Denver, Colo., analysts D.F. Siems and J.S. Mee*

[2] *Analysis provided by Paul Hammond and done at GeoAnalytical Laboratory of Washington State University*

[3] *Sample is from dike cutting unit Ttv*

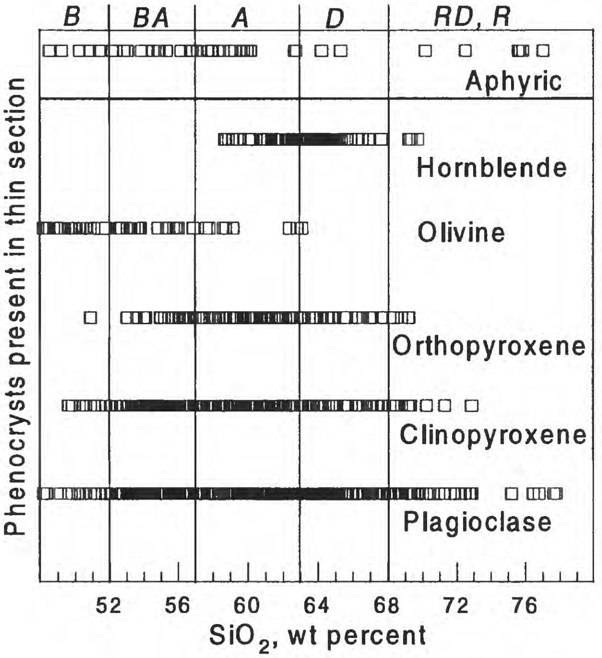

Figure 4. Plot of phenocryst assemblage vs. SiO_2 for 493 porphyritic and 42 nonporphyritic Tertiary rocks, chiefly in the mapped quadrangles but including a few in other quadrangles. □ , phenocryst observed in thin section; Rock types along top edge from figure 3. Revised from Swanson (1996b). Modal amounts of phenocrysts range widely to a maximum of nearly 50 percent; typical values are 5-20 percent.

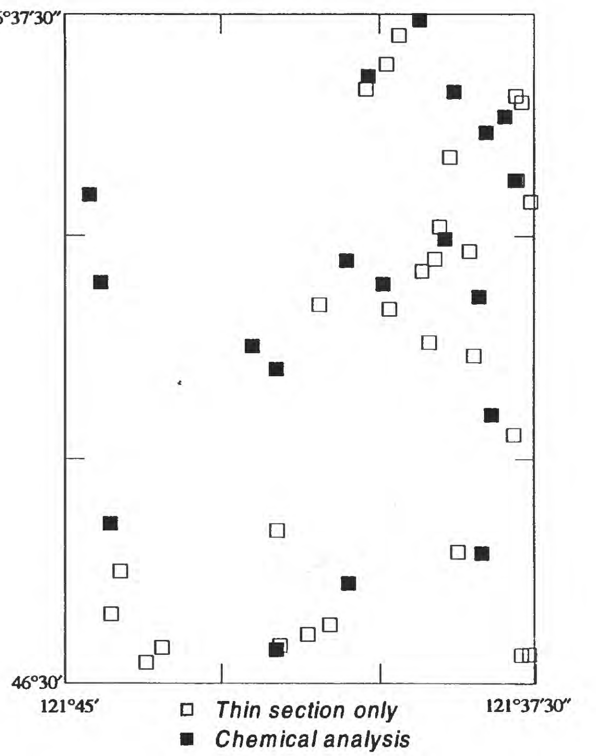

Figure 5. Map showing distribution of 47 sample localities in Packwood quadrangle.

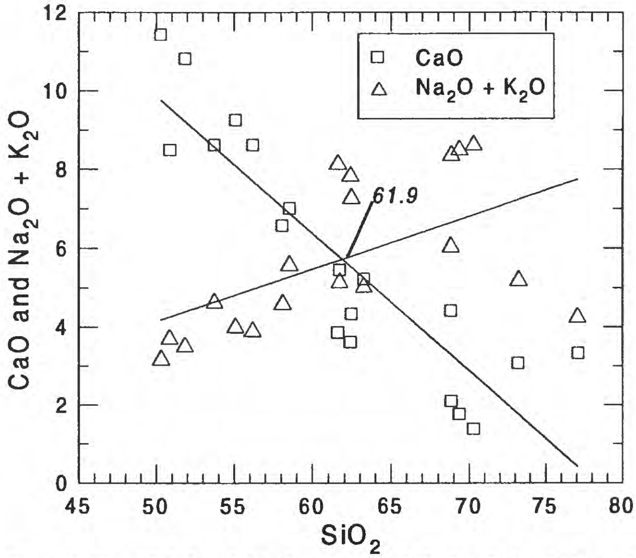

Figure 6. Plots of CaO and ($Na_2O + K_2O$) vs. SiO_2 for all chemically analyzed rocks in Packwood quadrangle. Linear regressions of both plots cross at SiO_2 content of 61.9—slightly calcic in terminology of Peacock (1931).

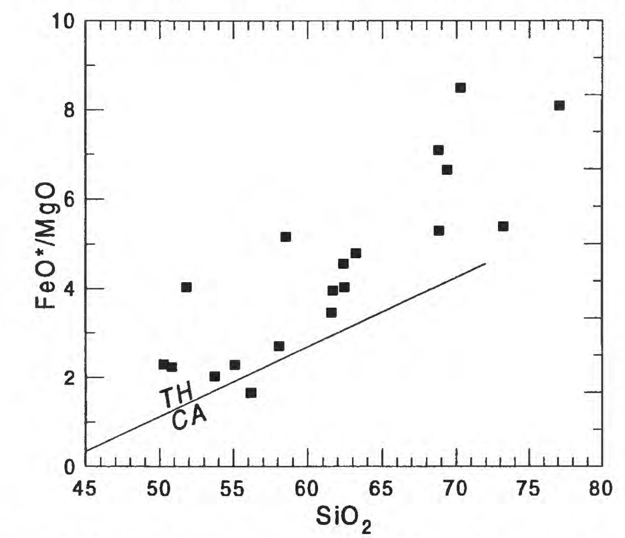

Figure 7. Plot of FeO*/MgO vs. SiO_2 for all chemically analyzed rocks from Packwood quadrangle. Subdivision into tholeiitic (TH) and calc-alkaline (CA) suites after Miyashiro (1974).

A plot of K_2O vs. SiO_2 (fig. 9) shows that most samples with SiO_2 between 52 and 63 percent are medium-K mafic and silicic andesite according to Gill (1981; called basaltic andesite and andesite, respectively, in the IUGS terminology used here). The more mafic rocks, just outside the bounds of Gill's classification, contain relatively low K_2O befitting their high content of calcic plagioclase phenocrysts. Three analyses of silicic andesite are high-K in Gill's classification. The two most silicic samples, both of unit Tqt, are probably depleted in K_2O owing to leaching during alteration.

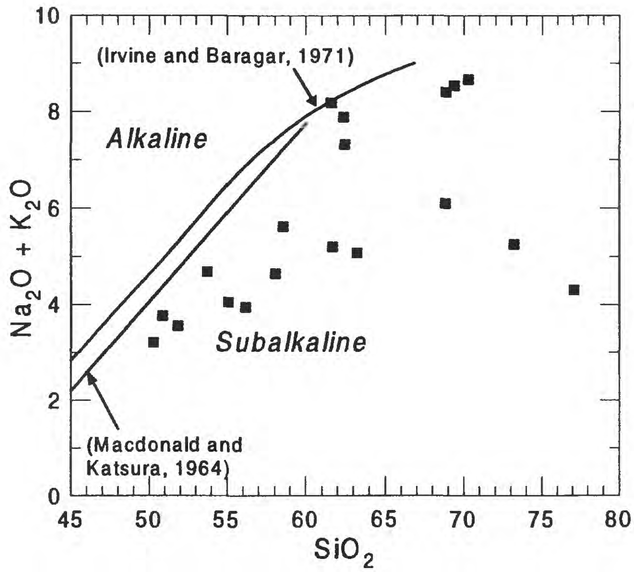

Figure 8. Plot of $(Na_2O + K_2O)$ vs. SiO_2 for all chemically analyzed rocks in Packwood quadrangle. Boundaries shown between subalkaline and alkaline suites after Macdonald and Katsura (1964) and Irvine and Baragar (1971).

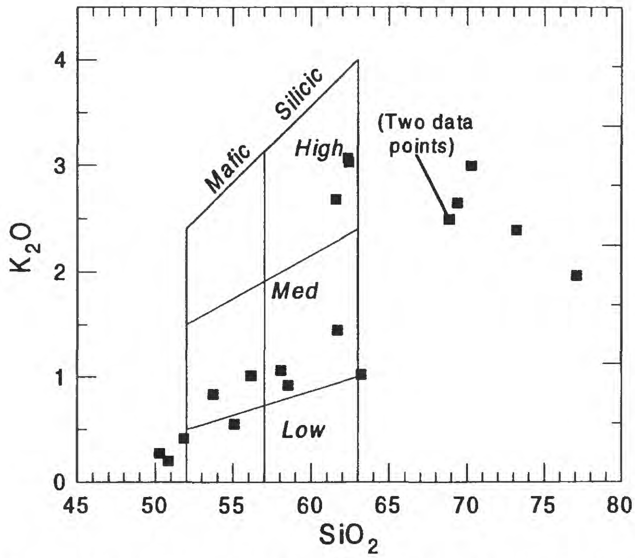

Figure 9. Plot of K_2O vs. SiO_2 for all chemically analyzed rocks from Packwood quadrangle. Fields modified from Gill (1981), so that mafic andesite (basaltic andesite in IUGS terminology used in this paper) extends down to 52percent.

GEOLOGIC OVERVIEW OF QUADRANGLE

Bedded volcaniclastic rocks—mainly volcanic sandstone but including mudstone, diamictite (mostly laharic deposits), fallout tuff, and ash-flow tuff—of late Eocene and Oligocene age underlie most of the quadrangle. They overlie and intertongue with a thick section of andesite and basaltic andesite lava flows on the ridge between Smith and Johnson Creeks. The flows form part of a shield volcano especially well exposed on Angry Mountain in the adjacent Packwood Lake quadrangle. Thin isolated andesite flows are interbedded with volcanic sandstone and tuffaceous rocks elsewhere in the mapped area.

One of the youngest eruptive units in the Tertiary section is the (biotite)-quartz-phyric ash-flow tuff of Purcell Creek (Swanson, 1996b), which crops out in spotty fashion in the northern third of the quadrangle. This tuff is one of the those assigned to the Stevens Ridge Formation by Fiske and others (1963; Stevens Ridge Member of the Fifes Peak Formation of Vance and others, 1987).

The Tertiary section is intruded by numerous sills and larger bodies that range from diorite and microdiorite (and finer-grained equivalents) to rhyodacite and even granodiorite. These intrusions can be subdivided into three map units on spatial, petrographic, and chemical grounds. Many of the most silicic sills, which cluster in the northeast part of the quadrangle, are slightly mineralized. Dikes of andesite and basaltic andesite cluster in the southern third of the quadrangle, where east of Dry Creek they trend east-northeast and west of the creek, northwest.

Dips range up to 50° but generally are 25°–40°. The prevailing dip direction is northeastward, away from the axis of the Castle Butte anticline, which crosses the southwest corner of the quadrangle (plate 1). The age of folding relative to the youngest Tertiary intrusions is unknown. Farther south and southwest, folding postdates all but the youngest intrusions (about 12 Ma), as constrained geometrically and paleomagnetically (Swanson, 1993; Hagstrum and Swanson, 1994).

After erosion following the folding, volcanism from the Goat Rocks volcanic center fed thick andesite flows down paleovalleys, one of which is exposed in cross section in cliffs north of Hager Lake. These flows are far more extensively exposed in the adjoining Packwood Lake quadrangle. The flows north of Hager Lake are magnetically normal and probably younger than 0.78 Ma.

The area was extensively glaciated during the late Pleistocene. Till of Evans Creek Drift covers large parts of the quadrangle, particularly the gentler terrain northwest of the Cowlitz River.

Numerous landslides postdate glaciation. One dammed Hager Creek to form Hager Lake several hundred years ago. This landslide is still active and necessitates frequent road repairs.

TERTIARY ROCKS

Volcaniclastic rocks (map unit Ttv)—Bedded volcaniclastic rocks of various origins underlie most of the quadrangle. They are best exposed in the area between Dry and Burton Creeks, on the south face of Skyo Mountain, and on the steep ridge southwest of South Point. Elsewhere they are commonly obscured by vegetation, drift, or colluvium, except where revealed in road cuts or quarries.

Included in the map unit are: 1) epiclastic rocks (mapped locally as unit Tvs), such as volcanic sandstone, siltstone, and conglomerate, consisting of detritus eroded from penecontemporaneous volcanic rocks or unconsolidated deposits and transported by streams; 2) pyroclastic rocks, such as bedded fallout tuff and lithic-lapilli tuff of ash-flow origin, deposited directly by eruption-related processes, and 3) lithic and (or) pumiceous diamictite whose origins are uncertain but most likely result from debris flows (lahars) fed either directly by eruptions or by other, but fundamentally volcano-related, erosional processes.

The epiclastic suite consists entirely of clasts either eroded from older Cascade volcanic rocks or reworked from deposits of contemporary eruptions. Clasts range in grain size from silt to gravel but are predominantly medium to coarse sand. Pebble conglomerate composed entirely of volcanic clasts is locally prominent and associated with cross-bedded and channeled sandstone. Wide ranges in degree of sorting and rounding characterize the deposits; in many places, well-sorted volcanic sandstone is interbedded with poorly sorted rocks including even diamictite with a matrix-supported framework. Beds range in thickness from less than 1 cm to more than 50 cm, averaging a few centimeters. Channels and lensoid beds are especially common. Plant remains, including tree trunks and limbs a few to tens of centimeters in diameter, occur in many beds; most smaller pieces are flattened along bedding planes.

The pyroclastic suite is dominated by lithic-lapilli tuff and lithic-pumice lapilli tuff, most of which is probably of ash-flow origin. Overall, welding is uncommon, and distinguishing a nonwelded primary pyroclastic flow from a pumiceous or even lithic lahar is difficult. An exception is the readily identifiable quartz-phyric ash-flow tuff of Purcell Creek (unit Tqt), which is welded in places and clearly of ash-flow origin (see section on the Purcell Creek unit). Lithic-lapilli tuff and pumice-lapilli tuff commonly intertongue with other volcaniclastic deposits throughout the quadrangle but are not nearly as abundant as the epiclastic and laharic deposits. Fallout tuff is easily misidentified as epiclastic mudstone, and in fact much of the fine-grained sedimentary rocks in unit Tvs could be reworked or even *in situ* tuff.

Lithic diamictite is a volumetrically important rock type, particularly in the lower two-thirds of the section. It occurs in beds from a few centimeters to a few meters thick; the much thicker diamictite of Burton Meadows (unit Tbmd) is described in a following separate section. The lithic diamictite is typically supported by matrix but locally by clasts. Subrounded boulders tens of centimeters in diameter are fairly common, though the dominant size is in the pebble or cobble range. Many beds contain fragments of wood, including limbs and trunks. Some beds of diamictite contain much pumice, though most are almost entirely lithic. Generally the upper and lower surfaces of a bed are almost planar, but in places one or both may be irregular, probably because of erosion. Most of the diamictite doubtless formed from volcanic debris flows (lahars), but some could be colluvial or landslide deposits.

Most of the bedded rocks in the quadrangle were apparently deposited in lowlands rather than on the flanks of cones. This conclusion, reached by Stine (1987), Winters (1984), and Swanson (1993, 1996a, b) for the bedded rocks in the Blue Lake, Hamilton Buttes, and Packwood Lake quadrangles, is supported by the observation that bedding attitudes are nearly everywhere consistent with regional structure and hence were probably subhorizontal when deposited. Many of the deposits, such as sandstone and conglomerate, were clearly deposited by streams, just as expected in the "alluvial apron" setting envisioned by Stine (1987) or the intermediate to distal fluvial facies described by Smedes and Prostka (1972), Kuenzi and others (1979), Vessell and Davies (1981), and Smith (1987). The thick accumulation, perhaps 4.5–5 km, of alluvial-apron volcaniclastic rocks in this and the mapped quadrangles farther southwest is consistent with the concept of syndepositional subsidence as the volcanic pile accumulated (Swanson, 1993, 1996a; Evarts and Swanson, 1994).

Some of the volcaniclastic rocks apparently had substantial primary dips, however, and probably were deposited on the irregular and locally steep surfaces of the Angry Mountain eruptive center. The relatively steep dips along Johnson Creek may indicate such a setting. Steep and irregular attitudes just north of Smith Point probably reflect a cone at a small explosive vent.

Volcanic sandstone, siltstone, and shale (map unit Tvs)—Well-bedded carbonaceous sandstone, siltstone, and shale dominate the section of epiclastic rocks in and surrounding Packwood, where they are mapped separately as unit Tvs. One of the best exposures is in a borrow pit along the west side of Highway 12 on the north side of town. Zircon from tuff interbedded with siltstone in the borrow pit has a fission-track age of 23.5 ± 0.6 Ma (Schasse, 1987). Unit Tvs is several tens of meters thick and is near or at the top of the Tertiary stratigraphic section in the quadrangle, definitely overlying the 24.8–Ma quartz-phyric ash-flow tuff of Purcell Creek, as map relations show. Its base and lateral boundaries are arbitrarily portrayed, for the unit grades imperceptibly into a mixed assemblage containing diverse volcaniclastic rocks. Complicating the outcrop pattern and apparent thickness of the unit are numerous sills (units Tip and Tri) that crop out far better than the sedimentary rocks.

In informal discussions over the years, geologists working in the Packwood area have often described unit Tvs as "lake beds". However, the abundance of fine-grained sandstone makes a wholly lacustrine environment unlikely. We believe the unit more likely records a broad floodplain dotted with small ephemeral ponds and bordered by gentle valley slopes.

Unit Tvs is the most extensive and thickest section of fine-grained sedimentary rocks found in any of the mapped quadrangles. In those quadrangles, such rocks have typically been included in unit Ttv because they are not readily mappable units and are generally intricately interbedded with coarser volcaniclastic or volcanic rocks. In the Packwood quadrangle, unit Tvs is mapped separately both because of its substantial thickness and lateral continuity and because it is exposed at the surface over a wide area.

Readers should realize that rock types found in unit Tvs are scattered throughout the stratigraphic section and are not necessarily characteristic of only the upper part of the section.

Diamictite of Burton Meadows (map unit Tbmd)—An unusually thick cliff-forming diamictite caps the ridge at the head of Burton Creek, underlies Burton Meadows and Dry Pass, and forms misnamed Goat Dike, a high cliff prominently visible from the Cowlitz valley. It can not be recognized with certainty north of Goat Dike, probably because it thins and resembles other diamictites in the section. It disappears down dip in the drainages of Dry and Smith Creeks. The unit extends southward into the Blue Lake quadrangle, where it was named the *diamictite below Castle Butte* (Swanson, 1993), and westward into the Purcell Mountain quadrangle. It also reaches southwestward into the Tower Rock quadrangle but was not mapped separately there, in part because it is thinner than farther north and east (Swanson, 1991).

The diamictite of Burton Meadows is thick, about 200 m at the type locality and just west of Burton Creek, where it is capped by an andesite flow. Elsewhere in the quadrangle and the adjoining Blue Lake quadrangle the unit is 120–150 m thick, except where it apparently thins north of Goat Dike. Andesite caps the diamictite east of Dry Creek Pass, in a small erosional remnant west of Burton Creek, and extensively in the Blue Lake and Purcell Mountain quadrangles. From these relations we interpret the preserved thickness of the unit to be nearly the same as the true thickness before modern erosion.

The diamictite of Burton Meadows is nearly massive throughout its great thickness. Only locally are discontinuous partings apparent. For example, two partings extending several tens to hundreds of meters are visible in the cliff north of Burton Meadows, and several partings of unknown extent cross the cliff face at Goat Dike. Whether these partings record separate flow units or developed during emplacement is unclear.

Clasts in the diamictite are lithic and seemingly all andesite but of several types. By far the most common rock type is moderately pyroxene-plagioclase-porphyritic andesite, but some clasts lack pyroxene phenocrysts and others are nearly nonporphyritic. The clasts are typically a several centimeters to a few tens of centimeters in diameter, subangular to subrounded, and somewhat vesicular (or amygdaloidal). Near the base of the unit andesite clasts are commonly several meters across. The clasts typically float in a matrix of smaller lithic clasts and crystals but locally form a clast-supported framework. No prismatically jointed clasts (*hot blocks*) were found.

Commonly the diamictite rests on a rubbly andesite flow similar lithologically to the most common clast type. In fact, the contact between the andesite and diamictite appears gradational in some places, particularly in the Blue Lake quadrangle (Swanson, 1993). The lower part of the diamictite near the ridge crest west of Burton Creek contains several lenses of this andesite, several meters thick and 20–30 m long, that dip 10°–40° southeast, very different from the nearly flat strata. These andesite lenses may be megaclasts derived from nearby andesite flows, though their shapes are quite unusual for clasts.

Elsewhere, such as 1 km east-southeast of Dry Creek Pass, clasts of lithic-lapilli tuff and other volcaniclastic rocks occur near the base of the unit and were apparently derived from underlying rocks.

Broken pieces of wood are abundant in the diamictite. Limbs, stems, and trunks as long as a few tens of centimeters are especially common near the base of the unit south of Burton Meadows. The wood is silicified, and it is difficult to determine if it was charred first. One piece found in the Blue Lake quadrangle is carbonized and was interpreted as charred by Swanson (1983).

The magnetic orientations of several andesite clasts were determined in the field with a portable fluxgate magnetometer by Craig Tozer, a student at the University of Washington. No preferred direction was found, consistent with emplacement below the blocking temperature of magnetite. However, more samples need to be examined to verify this tentative observation.

Where seen, the base and top of the diamictite of Burton Meadows are more or less planar. Evidence for a hummocky upper surface was anticipated but not found. Hummocks might have been eroded away before younger rocks were deposited, but no evidence suggesting such erosion was recognized.

The diamictite of Burton Meadows covers an area of at least 45 km^2, calculated from its north-south outcrop extent of 8 km and east-west extent of 5.5 km. Assuming an average thickness of 150 m, its minimum volume is about 6.7 km^3. This minimum volume is about six times the volume of the 1980 debris avalanche from Mount St. Helens. The actual area and volume are more by an unknown but probably considerable amount. For example, a thick lithic diamictite with andesite clasts resembling those in the diamictite of Burton Meadows occurs at about the same stratigraphic position on Davis Mountain, north of the Cowlitz River 10 km northwest of Goat Dike. If the two diamictites are the same, the area and volume of the Burton Meadows unit could be several times that calculated.

The diamictite was probably emplaced as a debris avalanche, despite the lack of preserved hummocks. Several observations suggest this interpretation: lithic nature of deposit, total lack of observed pumice, heterolithologic character, apparently cool emplacement, large area and volume, lack of internal contacts except local discontinuous partings, and planar base (therefore not a crater fill). No source for the debris avalanche is apparent. It is older than the lava flows below South Point (erupted from the Angry Mountain eruptive center in the Packwood Lake quadrangle), the only nearby large edifice known. Such a large avalanche might have traveled far from its source, as did that from ancestral Mount Shasta 300–360 ka, which traveled about 43 km and covered at least 450 km^2 with a volume of about 26 km^3 (Crandell and others, 1984).

Quartz-phyric ash-flow tuff of Purcell Creek (map unit Tqt)—The most distinctive stratigraphic unit of the Tertiary section in all of the mapped quadrangles is a biotite-quartz-phyric ash-flow tuff. This tuff crops out extensively in the Packwood Lake (Swanson, 1996b) and Ohanapecosh Hot Springs quadrangles but is confined to only a narrow belt between lower Johnson and Hager Creeks.

The tuff has ages of 24.8 ± 0.3 Ma (U-Pb method) and 26.5 ± 2.1 Ma (zircon fission-track method) (Vance and others, 1987; table 1, locality 22; note that the sample number for locality 22 in Appendix I is incorrect and should be JV 67; this confusion led to an incorrect statement in the road log of Swanson and others [1989, p. 31, mile 70.8] that the tuff is 36.4 Ma [J.A. Vance, oral commun., 1995]).

The ash-flow tuff is light gray or even white to pink, in contrast to the darker color of most of the Tertiary rocks. It contains 10–15 percent phenocrysts of quartz, commonly 3–4 mm in diameter and highly embayed. The quartz phenocrysts give the rock a sparkly appearance in sunlight. Plagioclase (and possibly alkali feldspar) phenocrysts constitute 5–10 percent of the rock and are typically 2–4 mm long. Biotite is a minor phenocryst, but flakes 1–2 mm wide can be seen in about half of the samples examined in thin section or with a hand lens in the field.

Pumice lapilli are generally about 1-2 cm long, but some are 10 cm or more. Some flattened lapilli are much larger. Lithic inclusions are not particularly common except locally; the same is true of wood fragments.

The bulk-rock composition of the tuff is rhyolitic (table 1, nos. 16 and 17; see also Swanson [1996b], table 1, nos. 32 and 38). It probably lost Na_2O and possibly K_2O during hydration, judging from the low content of total alkalies (figs. 3 and 8) and K_2O (fig. 9), a conclusion reached for the analyses in the Packwood Lake quadrangle as well.

The tuff is weakly welded in the quadrangle, though subsequent alteration commonly obscures the eutaxitic texture. The upper part of the tuff is nonwelded. The thickness of the Purcell Creek unit is no more than 10 m in the quadrangle but more than 60 m farther east in the Packwood Lake quadrangle.

The source for the ash-flow tuff is not known, but a good possibility is the Mount Aix caldera about 20 km northeast of White Pass (Schreiber, 1981; Hammond and others, 1994; Hammond, 1996; P.E. Hammond, written and oral commun., 1995). This possibility is discussed at some length by Swanson (1996b).

Lava flows (map unit Ta)—A belt of lava flows stretches discontinuously northwestward across the central part of the quadrangle. This belt extends into the Packwood Lake quadrangle, where many of the flows were erupted from the Angry Mountain eruptive center (Swanson, 1996b).

The section of lava flows is at least 800 m thick below South Point but thins northwestward, away from the source. Most of the flows are thin (a few meters to 20 m), vesicular (now amygdaloidal), and rubbly. A few flows are thicker than 20 m and are comparatively massive except for upper and lower zones of breccia. Nearly all the flows are plagioclase-phyric, some strikingly so; the most highly porphyritic flows, below South Point, contain phenocrysts 2–3 cm long making up more than 50 percent of the rock. Some of the highly plagioclase-phyric flows resemble gabbro or diabase in the field, but thin sections show the strikingly porphyritic texture (sample 3 of table 1 is a good example). Five chemical analyses in table 1 range from basalt (nos. 1–3) to andesite (no. 18) to mafic dacite (no. 11). The high contents of Al_2O_3 and CaO in nos. 1 and 3 reflect accumulation of calcic plagioclase phenocrysts. The Al_2O_3 content of no. 2 is even higher, yet the CaO content is normal.

Interbeds of tuffaceous rocks and lithic diamictite (probably mostly talus and laharic deposits) are common and become more numerous northwestward, as the flows thin and end. Many interbeds in the South Point area are too thin to map.

The section of lava flows may be wholly equivalent to that on Angry Mountain. Alternatively, another center may lie north of South Point, judging from a concentration of thin vesicular flows. Flows from this possible center might be interbedded with those from Angry Mountain. The dike swarm near Smith Point might be related to a South Point center. Relatively few dikes cut the section of flows itself near South Point, perhaps because they did not intrude to such a high level.

Lava flows of intermediate composition (table 1, nos. 5 and 6) older than those of the main belt crop out at and east of Dry Creek Pass and in upper Burton Creek. None is as porphyritic as many of the flows near and northwest of South Point.

Intrusions—Dikes are particularly common south of the Cowlitz River and Johnson Creek, where they define two distinct sets. The larger set contains dikes with an east to east-northeast strike (fig. 10B). Such dikes are most abundant cutting volcaniclastic rocks between Smith and Deception Creeks and on the ridge topped by Smith Point, but dikes of similar orientation cut lava flows near and 3 km north of South Point and tuffaceous rocks 0.5 km south of Bevin Lake and between Dry and Burton Creeks. A thick dike, mapped as an elongate intrusion 300 m south of Smith Point, belongs to this set.

A lesser set is defined by north-northwest-striking dikes (fig. 10B). This set is most obvious at Goat Dike, but dikes of similar orientation crop out on Skyo Mountain, south of Bevin Lake, near Burton Meadows, south of Smith Point, and as far east as the southeast corner of the quadrangle.

No dike intersection was observed, so the general age relation between the two sets is unclear. Dikes of both sets cut the diamictite of Burton Meadows and all younger rocks up to the large belt of lava flows. Only dikes with east-northeast strikes cut that belt. On this vague basis the

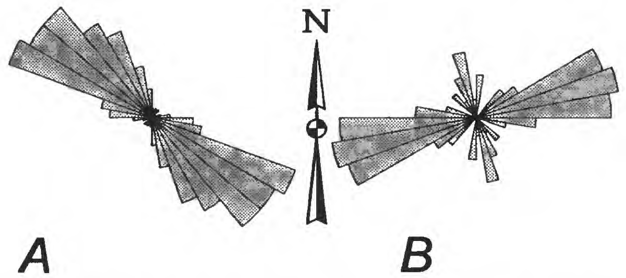

Figure 10. Equiarea rose diagrams in 10° increments showing strikes of bedded rocks and dikes in Packwood quadrangle. *A*, 196 strikes of bedding (mean direction, 306.5°; standard deviation, 2.4 percent); *B*, 139 dikes (mean direction, 73.5°; standard deviation, 2..9 percent). Note the bimodal distibution of dikes (see text).

east-northeast set may be younger than the north-northwest-trending set. However, the northwest-striking dikes might simply be confined far enough west so that none ever reached the belt of andesite flows. The east-northeast dikes may well be related to eruptive activity near South Point and as such may not be much younger than the host lava flows.

Other intrusions almost certainly postdate the youngest erupted rocks in the quadrangle. The glomeroporphyritic sill complex of Packwood (map unit Tip) intrudes volcaniclastic sandstone and siltstone (unit Tvs) in Packwood that have a zircon fission-track age of 23.5 ± 0.6 Ma (Schasse, 1987, table 2). The sills of unit Tip are typically moderately to highly plagioclase glomeroporphyritic and several meters thick. Screens of sandstone and siltstone separate the sills but are poorly exposed and generally too thin to map. Two chemical analyses of the glomeroporphyritic sills range from basaltic andesite (table 1, no. 4) to silicic andesite (table 1, no. 8). Texturally the sills are typically microdiorite.

Another sill complex (unit Tri), more silicic and less porphyritic than the sills of Packwood but easily confused with them, intrudes unit Tvs east of Packwood. These sills are rhyodacitic chemically (table 1, nos. 12–15) and microdiorite to microgranodiorite texturally. Many contain pyrite and are iron stained. The staining commonly obscures textures and makes it difficult to decide if the rock was originally glomeroporphyritic and hence part of unit Tip. In the field this unit was commonly misidentified as glomeroporphyritic, and it is only thin sections and chemical analyses that enable proper assignment. On the map some confusion probably remains. In fact, there may be complete gradation from the glomeroporphyritic sills of Packwood into the more silicic unit Tri.

The rhyodacite sills of unit Tri are several meters to several tens of meters thick. Screens of unit Tvs separate the sills but are rarely thick enough to map. The sills are particularly well exposed in road cuts at and north of the site of analysis 15, along a track road at the site of analysis 13, and in a cliff above the site of analysis 14. Commonly, though, exposures are poor and the unit can be mapped only by float.

Two other intrusive units (Tai) could either predate or postdate the youngest eruptive rocks in the quadrangle. Several sills on Hall Ridge, silicic andesite in composition (table 1, nos. 9–10), intrude volcaniclastic rocks high in the section, just below the level of unit Tvs. The thickest of these sills, which caps Hall Ridge, feeds an active landslide that forms the dam holding back Hager Lake.

The other intrusion of uncertain relative age is a thick body along the west edge of the quadrangle between Wesel and South Fork Williame Creeks (*Williame* is spelled *Willame* on many Forest Service maps and signs, and it is not clear which spelling is correct). It has an andesite composition and microdiorite texture (table 1, no. 19). The intrusion is crosscutting rather than sill-like, the only such discordant body except for dikes in the quadrangle.

STRUCTURE

The structure of the quadrangle is dominated by the Castle Butte anticline, part of a right-stepping *en echelon* anticline pair including the Bishop Ridge anticline in the Blue Lake quadrangle (fig. 11). The trough of another fold, the Stonewall Ridge syncline, just enters the southeast corner of the quadrangle; this syncline combines with the Pimlico Creek syncline to form another right-stepping pair most prominent in the Hamilton Buttes quadrangle (Swanson, 1996a; fig. 11). The Stonewall Ridge syncline is barely perceptible in the quadrangle, whereas the Castle Butte anticline is well defined and continues far northward across the Cowlitz River. These two folds are part of the regional deformation field, characterized by northwest strikes and right-stepping folds. The remarkable uniformity of bedding strikes (fig. 10A) illustrates how strongly the regional structures control attitudes in the quadrangle.

Local shear zones and minor fault offsets are common in the quadrangle. The most notable fault strikes northwest across lower Johnson Creek and has subhorizontal slickensides stepped to indicate dextral movement. Northeast-striking shears and minor faults were noted near the southeast corner of the quadrangle (sinistral), on the south side of Hall Ridge west of Brownie Creek (sinistral), and at the southern boundary of the quadrangle southeast of Dry Creek Pass (normal). Prominent lineaments on air photos were mapped west of Skyo Mountain and 500 m south of Point 2762 west of Williame Creek. None of these zones can be demonstrated to be a major fault, however.

The general pattern of faults and shears in the quadrangle is part of a regional system typical of the southern Washington Cascades, in which north and northwest shears and faults are dextral and less prominent northeast and east shears and faults are sinistral. The pattern is part of a broad regional shear couple well displayed by dextral faults cutting the Columbia River Basalt Group farther southeast, approximately along strike with the mapped area (Walsh and others, 1987).

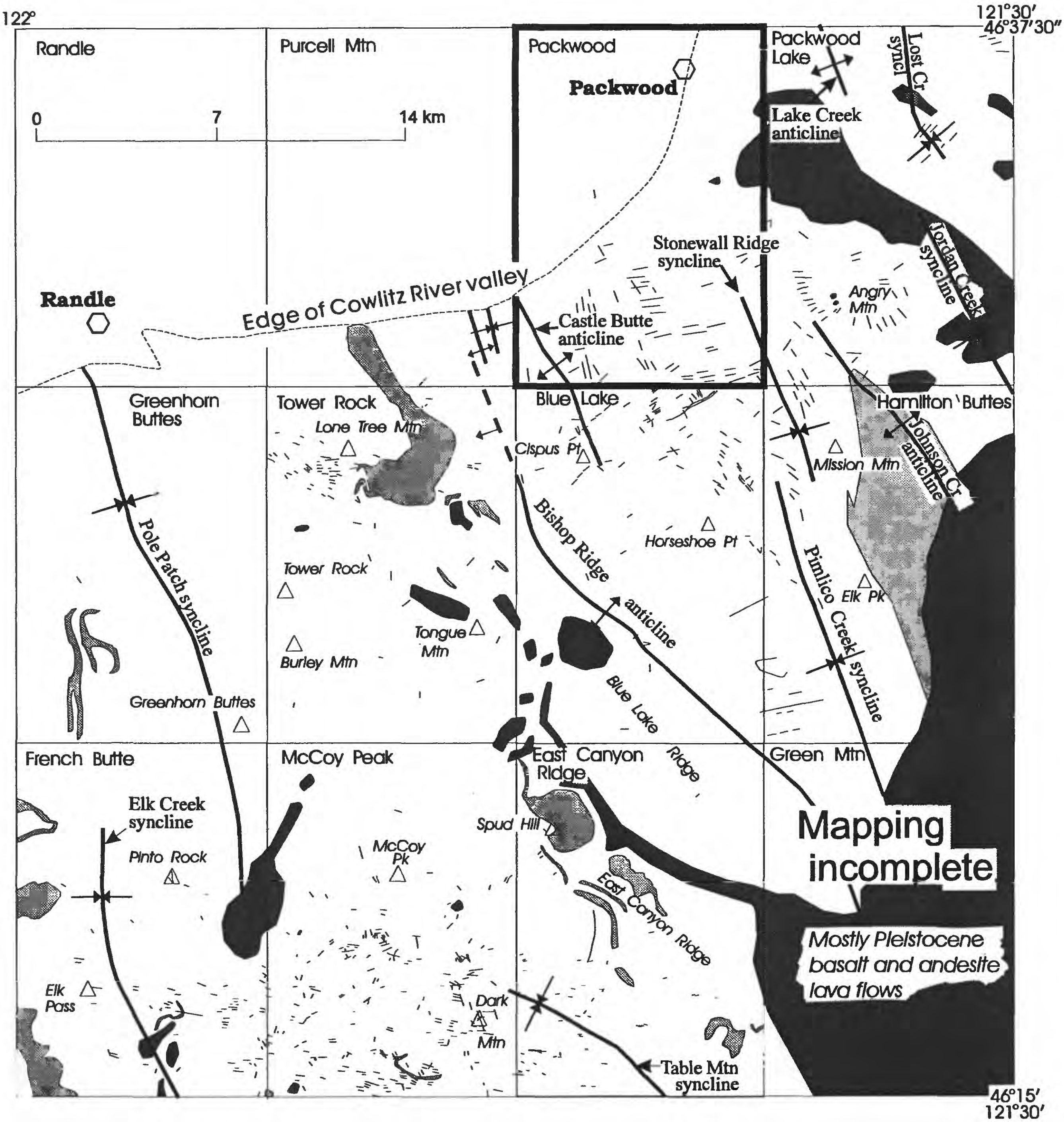

Figure 11. Generalized distribution of Tertiary pyroxene andesite and basaltic andesite dikes (short lines), arkose of Chambers Creek (light shade; Swanson, 1996a), two main belts of Tertiary dacite and rhyolite extrusions and intrusions (intermediate shade), and Pleistocene basalt to dacite in mapped quadrangles south of Cowlitz River. Packwood quadrangle heavily outlined. Dikes shown schematically and incompletely. Axial traces of major folds also shown. Note right-stepping pattern of five major fold pairs: Pole Patch-Elk Creek syncline, Bishop Ridge-Castle Butte anticline, Pimlico Creek-Stonewall Ridge syncline, Johnson Creek-Lake Creek anticline, and Jordan Creek-Lost Creek syncline.

LAVA FLOWS FROM GOAT ROCKS VOLCANIC CENTER

A cliff north and west of Hager Lake defines the distal end of a paleocanyon filled with lava flows of silicic andesite and mafic dacite erupted from the Goat Rocks volcanic center. The flows moved down valleys and canyons reaching northwest from vents southeast of the quadrangle in what is now the deeply eviscerated core of the Goat Rocks volcanic center (Swanson and Clayton, 1983). The flows are extensive in the Packwood Lake quadrangle and have been described in some detail by Swanson (1996b).

Several thick flows fill a steep-sided paleocanyon eroded about 340 m into a sill of unit Tri 1.2 km east-southeast of Snyder Lake. The canyon continues eastward into the Packwood Lake quadrangle. The northwest side of the canyon is well exposed in cross section, visible from the floor of the Cowlitz River valley. Hager Creek above Hager Lake may flow along the southern edge of the paleocanyon in both quadrangles, but glacial drift covers all bedrock.

Chemical analyses of these flows from localities in the Packwood Lake quadrangle show silicic andesite and mafic dacite compositions, typically with 62–64.5 percent SiO_2 (Swanson, 1996b, table 1). The flows are uniformly two-pyroxene-plagioclase porphyritic and contain small gabbro or diorite clots, a distinctive feature of andesite and mafic dacite flows from the Goat Rocks center. Some flows carry minor amounts of hornblende.

The flows in the quadrangle are all normally magnetized and belong to the youngest of three magnetostratigraphic units of pyroxene andesite and mafic dacite erupted from the Goat Rocks center (Swanson, 1996a). They are younger than about 780 ka but older than about 140 ka, the probable age of Hayden Creek Drift, which overlies the flows farther upstream.

QUATERNARY SEDIMENTARY DEPOSITS

Glacial deposits—Drift, chiefly till but including glaciofluvial deposits in valleys, is extensive in the quadrangle. The thickness of weathering rinds was examined in many places and is consistently less than 1 mm. Following Colman and Pierce (1981), this observation indicates that the drift is of Evans Creek age, about 20 ka.

A thick gravelly deposit along Deception Creek in the southeast corner of the quadrangle may be a moraine of Evans Creek age. Probable Evans Creek Drift reaches farther downstream than the moraine(?), as well as upstream in the Blue Lake quadrangle.

Deposits of gravel above the modern flood plain of the Cowlitz River probably represent outwash of Evans Creek age. Crandell and Miller (1974) show such valley-filling outwash on their small-scale map of the Cowlitz River valley.

Landslide deposits (map unit Qls)—Landslides are common in the quadrangle. Notable active slides include the one extending from Cougar Rocks to the Cowlitz River valley, the landslide from the top of Hall Ridge that dams Hager Creek to form Hager Lake, and an active mass along the west side of Deception Creek valley. Four smaller landslides dot the dip slope west of Smith Creek, underlain by well-bedded, clay-rich tuffaceous rocks that slip easily.

Standing snags in Hager Lake suggest that the forest was drowned not long ago, and one of the snags has a modern radiocarbon age, as obtained by R.L. Schuster (U.S. Geological Survey, written commun., 1994). The landslide that dams Hager Lake is very active, necessitating frequent repair of roads near the main intersection just west of the lake.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qal **Alluvium (Holocene and Pleistocene)**—Unconsolidated, moderately to well-sorted deposits of silt, sand, and gravel along major modern streams and in small basins. Includes deposits of debris flows in Cowlitz River valley. Holocene and very late Pleistocene. One debris-flow deposit at mouth of Smith Creek has radiocarbon age of 550 ± 60 years before present (WW-918 96PW3-F1C). Locally includes colluvium, alluvial fan deposits, and drift

Qc **Colluvium (Holocene and Pleistocene)**—Unsorted, unconsolidated deposits of slope wash and open-work talus, mostly along sides of major streams and below cliffs. Mostly Holocene and very late Pleistocene. Locally includes alluvium, landslide deposits, fan deposits, and probably considerable drift

Qf **Alluvial fan deposits (Holocene and Pleistocene)**—Poorly bedded and poorly sorted alluvial deposits, in part deposits of debris flows, at mouths of tributaries of Smith and Dry Creeks and along southeast side of Cowlitz River valley. Mostly Holocene but could include some deposits as old as latest Pleistocene. Locally includes alluvium, colluvium, and drift

Qls **Landslide deposits (Holocene and Pleistocene)**—Diamictons produced by mass movement down slope. Includes both active and inactive slides. Most record failure on steep dip slopes. Some slides result from movement of relatively dense Tertiary or Quaternary lava flows or intrusive rocks down and across volcaniclastic rocks. Others developed wholly in tuffaceous volcanic sandstone and related deposits, or as earthflows of colluvium. Hager Lake is impounded by one active landslide, and several other active slides occur in quadrangle. Mostly Holocene and latest Pleistocene. Locally includes colluvium, talus, and drift

GLACIAL DEPOSITS

Qed **Evans Creek Drift (Pleistocene)**—Till, outwash, and morainal deposits, principally along major streams and mantling relatively flat upland surfaces. Slightly weathered to unweathered; most andesite clasts in B soil horizon lack significant weathering rinds. Age is late Pleistocene, approximately 17–25 ka (Barnosky, 1984; Crandell, 1987). Queried where age could be older (Hayden Creek Drift) or where deposits could be colluvium or alluvium. Locally subdivided into:

Qeo **Outwash**—Deposits of gravel on valley sides above flood plain of present Cowlitz River

Qem **Moraine**—Thick pile of poorly sorted sand and gravel across valley of Deception Creek

YOUNG LAVA FLOWS

Qgr_3 **Intracanyon lava flows from Goat Rocks volcanic center (Pleistocene)**—Vitrophyric pyroxene andesite and mafic dacite flows filling 340–m–deep paleocanyon incised into unit Tri north of Hager Lake. Erupted from Goat Rocks volcanic center. Unit predates Hayden Creek Drift (probably about 0.14 Ma) in Packwood Lake quadrangle, where flows overlie reversely magnetized dated flows of Matuyama age and so are younger than about 0.78 Ma. Older flows from Goat Rocks volcanic center (Qgr_2 and Qgr_1) exposed east of quadrangle (Swanson, 1996b) not shown on this map

INTRUSIVE ROCKS

Tip **Glomeroporphyritic sill complex of Packwood (Miocene)**—Moderately to highly plagioclase-glomeroporphyritic andesite and microdiorite forming columnar sills intruding unit Tvs (23.5 Ma) in and near town of Packwood. Unit consists of multiple sills, but they cannot be mapped separately because exposures of host volcaniclastic rock are poor. Many such exposures near Packwood not shown on map owing to scale. Columnar jointing normal to contacts is commonly prominent and good indicator of attitude of host rock. In places iron-oxide stain mostly obscures glomeroporphyritic texture, and rock resembles slightly porphyritic rhyolite. May grade into unit Tri; many outcrops could be assigned to either unit. Probably mostly if not wholly Miocene. Chemically basaltic andesite to silicic andesite (table 1, nos. 4 and 8)

Tri **Sill complex of dacite, rhyodacite, and related fine-grained quartz diorite and granodiorite (Miocene)**—Columnar, tan- to buff-weathering, sparsely to moderately plagioclase-porphyritic silicic sills that cut unit Tvs (23.5 Ma). Easily confused with sills of unit Tip where weathered or altered. Unit consists of multiple sills, but they cannot be mapped separately because exposures of host volcaniclastic rock are poor. Locally pyritic and stained with iron oxide. Chemical analyses of samples range from mafic dacite to silicic rhyodacite (table 1, nos. 12–15). May grade into unit Tip; many outcrops could be assigned to either unit. Probably mostly if not wholly Miocene

Tai **Andesite intrusions (Miocene and Oligocene)**—Dikes, sills, and one small hypabyssal intrusion of aphyric and one- or two-pyroxene-plagioclase-phyric basaltic andesite and andesite. Typically fine- to medium-grained and texturally resembles lava flows (unit Ta). Sills have columnar jointing normal to contacts, quenched margins, and thicknesses ranging from a few meters to more than 20 m. Dikes characterized by subhorizontal columnar jointing, fine-grained margins, steep contacts with host rocks, and widths of 1–5 m. Probably in part feeders for flows of unit Ta, but many dikes could be younger and have fed flows now eroded away. Compositions range from basalt to mafic dacite (table 1, nos. 1–3, 5–7, 11, and 18). Dikes form two distinct sets, the larger containing dikes with east-northeast strikes and the smaller, dikes with north-northwest strikes (fig. 10B)

LAVA FLOWS AND VOLCANICLASTIC ROCKS

Ttv **Volcaniclastic rocks (Miocene? and Oligocene)**—Bedded conglomerate, sandstone, siltstone, and lithic diamictite containing volcanic-derived clasts, as well as lithic- and lesser pumice-lapilli tuff and fine-grained tuff. Typically brown to buff, with the tuffaceous rocks generally green and locally white or mauve. Different rock types are interbedded at all scales, and attempts to map them separately proved unworkable, except in Packwood area (unit Tvs) and in southwestern part of quadrangle (unit Tbmd). Hammond (1980) and Schasse (1987) assigned unit to Ohanapecosh Formation.

Bedded epiclastic rocks range in grain size from silt to gravel (dominantly sand), in sorting and rounding from poor to good, and in bed thickness from less than 1 cm to more than 50 cm (generally a few centimeters). Sedimentary structures, such as crossbedding, channels, and both normal and inverse size grading common. Clasts are entirely of volcanic derivation, chiefly basaltic andesite and andesite but including more silicic rock types. Fossil wood, mainly stems and twigs but including trunks nearly a meter in diameter, is plentiful locally. Detritus probably derived by reworking of freshly erupted debris or by erosion of slightly older volcanic rocks and deposited in fluvial environment.

Clasts in lithic diamictite range in size from sand to boulders. Wide range in degree of rounding, with angular boulders commonly mixed with rounded gravel and cobbles. Thickness of single beds typically several meters but ranges from 1 m to more than 15 m. Fossil wood abundant in some beds. Diamictite commonly interbedded with fluvial sandstone but also abundant in tuffaceous part of section. Probably mostly of debris-flow (lahar) origin.

Pumice- and lithic-pumice-lapilli tuff is probably of pyroclastic-flow origin. Welding is uncommon. Single lapilli-tuff beds range in thickness from several meters to more than 10 m. Typically plagioclase-phyric, with minor clinopyroxene; no hornblende and rare quartz. Lithic clasts are sparse to abundant and generally andesite or dacite in composition. Fragments of charred wood are abundant in many lapilli tuffs.

Unit is almost entirely of Oligocene age in quadrangle. Fallout tuff interbedded with siltstone and shale of unit Tvs yielded zircon fission-track age of 23.5±0.6 Ma (Schasse, 1987), most likely early Miocene but, taking into account analytical error, astraddle the Miocene-Oligocene boundary of Cande and Kent (1992; 1995) and Odin and others (1991).

Unit locally includes andesite flows and sills too thin to map separately

Tvs **Volcanic sandstone, siltstone, and shale (Miocene and Oligocene?)**—Well-bedded, typically fine-grained carbonaceous sandstone, siltstone, and shale forming top of stratigraphic section in Packwood area. Includes thin interbeds of fallout tuff, one of which yielded the zircon fission-track age of 23.5±0.6 Ma (Schasse, 1987). Hosts numerous sills of units Tip and Tri

Tqt **Quartz-phyric ash-flow tuff of Purcell Creek (Oligocene)**—Light-gray to pink, highly quartz-phyric lithic-pumice lapilli tuff, welded in places. Commonly platy. Most thin sections show minor amount of biotite. Quartz phenocrysts commonly 3–4 mm in diameter and highly embayed. Plagioclase phenocrysts common and typically 2–4 mm long. Some pumice lapilli larger than 10 cm diameter in nonflattened state. Thickness no more than 10 m in quadrangle though much greater farther east and northeast. Rhyolitic composition (table 1, nos. 16–17, as well as two other analyses in neighboring Packwood Lake quadrangle). Outstanding marker unit, recognizable despite intervening folds in the Ohanapecosh Hot Springs quadrangle farther northeast. Two ages available for unit, both from prominent cut along Highway 12 just west of Purcell Creek in Ohanapecosh Hot Springs quadrangle 4.5 km north of map area: 24.8±0.3 Ma (U-Pb) and 26.5±2.1 Ma (zircon fission-track), obtained from same sample (Vance and others, 1987, table 1, locality 22; note that sample number for locality 22 in their Appendix I is incorrect and should be JV 67 [J.A. Vance, oral commun., 1995]). This unit is considered as basal Stevens Ridge Formation in nomenclature of Fiske and others (1963) and Hammond (1980), and basal Stevens Ridge Member of Fifes Peak Formation in nomenclature of Vance and others (1987)

Tbmd **Diamictite of Burton Meadows (Oligocene)**—Thick (150–200 m in most places), cliff-forming lithic diamictite underlying Burton Meadows, headwaters of Burton Creek, and Goat Dike. Named *diamictite below Castle Butte* in Blue Lake quadrangle (Swanson, 1993). Very coarse in most places, with angular clasts of andesite several meters in diameter common. Generally massive but local discontinuous partings. Woody debris common. Dominant clast type is moderately plagioclase-phyric andesite, but other types of andesite occur, as well as rip-ups from underlying volcaniclastic rocks. No evidence of hot emplacement. Seemingly planar base and top. Could be mapped separately from rest of unit Ttv only because of exceptional thickness and hence exposure in high cliffs. Minimum volume of 6.7 km^3, calculated from outcrop extent in Packwood, Purcell Mountain, and Blue Lake quadrangles. Probably originated as debris avalanche from volcano, but source unknown

Ta **Andesite, basaltic andesite, and basalt lava flows (Oligocene)**—Fine- to medium-grained, highly plagioclase-phyric (>20 percent, in some flows >50 percent) to slightly phyric (<5 percent) or even aphyric, darkly hued lava flows and associated basal and flow-top breccia of basaltic andesite, andesite, and less common basalt. Mostly found in belt trending northwest across middle of quadrangle and extending southeast to Angry Mountain eruptive center in Packwood Lake quadrangle. Flows typically 5–20 m thick, commonly platy and (or) columnar, with vesicular or amygdaloidal zones in many places. Phenocrysts are dominantly plagioclase, with less abundant clinopyroxene and hypersthene; most common phenocryst assemblage is plagioclase-clinopyroxene, followed by plagioclase-clinopyroxene-hypersthene and finally plagioclase-hypersthene-clinopyroxene (minerals listed in decreasing order of abundance). Groundmass texture chiefly fine-grained intersertal or intergranular, with flow-aligned microlites common; very fine-grained pilotaxitic texture characterizes more silicic rocks. Glass generally altered to clay minerals. Chemical analyses from quadrangle range from basalt (table 1, nos. 1–3) through basaltic andesite (no. 5) and andesite (nos. 6 and 18) to mafic dacite (table 1, no. 11). Most flows are probably basaltic andesite and andesite, as shown by more numerous chemical data in previously mapped quadrangles. Dikes and other intrusions of unit Tai probably fed some of the flows. Interbedded with volcaniclastic rocks (units Ttv and Tbmd) and includes volcaniclastic beds too thin to map separately. Flows in major belt may have been erupted from Angry Mountain eruptive center or from possible vent area along ridge north of South Point

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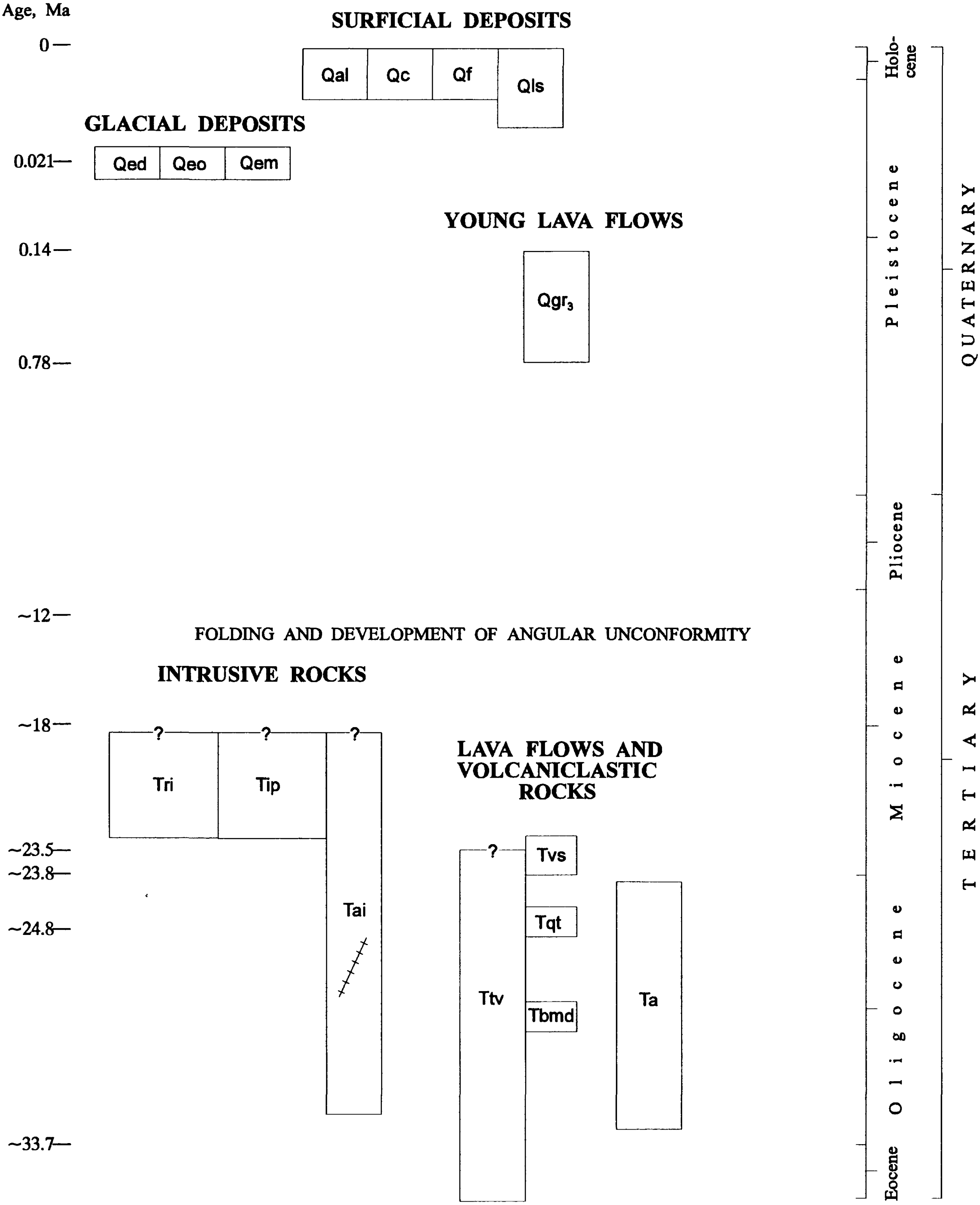
CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

Contact, dashed where approximately located, queried where uncertain, dotted where concealed

Strike and dip of bedding and flow contacts

30 Inclined

Horizontal or dip less than 5 degrees and strike poorly defined

Folds, dashed where approximately located, dotted where concealed

Trace of axis of anticline, showing direction of plunge

Trace of axis of snycline, showing direction of plunge

Faults, dashed where approximately located, queried where of uncertain extent

High-angle fault; bar and ball on downthrown side if known

Fault or shear zone; arrows indicate relative sense of lateral displacement

Air-photo lineament southwest, west, and northwest of Skyo Mountain

Dike of andesite or basaltic andesite of unit Tai

Site of chemically analyzed sample, with map number. Number refers to table 1, column 1

1 Basalt

4 Basaltic andesite

10 Andesite

19 Dacite

32 Rhyolite

Fission-track dating locality of Schasse (1987). See text for rock description and age