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

by

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

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INTRODUCTION

The Packwood Lake 7.5-minute quadrangle is centered about 35 km south-southeast of Mount Rainier, 40 km north of Mount Adams, and 10 km west of the crest of the Cascade Range in southern Washington (fig. 1). It is one of a series of adjoining quadrangles that I have studied geologically. 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, and Hamilton Buttes quadrangles (Swanson, 1989, 1991, 1992, 1993, 1994a, 1996). In addition, I mapped that part of the Randle quadrangle south of the Cowlitz River (Moore and others, 1994). I have also finished mapping those parts of the Purcell Mtn., Packwood, and Ohanapecosh Hot Springs quadrangles south of the Cowlitz River (D.A. Swanson, unpublished mapping, 1994, 1995); this mapping will be combined with that by R.B. Moore and N.G. Banks north of the Cowlitz.

The geologic research in these quadrangles forms part of an effort, which began small but over the years has become a major undertaking, to understand the development of the Cascade arc in southern Washington from its inception in the late Eocene. 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, 1994a, 1996) 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 geology of the area. All of the quadrangles that I have studied lie either within the SWCC or astride its eastern margin.

The Packwood Lake quadrangle drains into the Cowlitz River (fig. 2), a large stream whose two main forks head on Mount Rainier and in the Goat Rocks Wilderness west and southwest of White Pass, respectively. Roads follow Johnson Creek, climb to extensive clear cuts on Snyder Mountain, and penetrate short distances into the northwestern part of the quadrangle. Most of the quadrangle, however, is within the Goat Rocks Wilderness and is accessible only by foot. Packwood Lake itself, though not in the Wilderness, can be reached only by trail.

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). Fluvial micaceous arkose and mudstone are interbedded and mixed with the lower part of the volcaniclastic section along Johnson Creek at the southwestern edge of the quadrangle (Winters, 1984; Swanson, 1996). Many dikes and sills of andesite and basaltic andesite cut the layered rocks. Two large intrusions of gabbro and quartz diorite form highs in the northern part of the area. Middle and late Pleistocene basalt, andesite, and dacite flows underlie much of the southeastern part of the quadrangle and form a continuous swath completely across the central part. Most of the lava flows were erupted from vents just east of the quadrangle in the Goat Rocks volcanic center.

Glacial drift covers large areas, but bedrock crops out along creeks, steep slopes, and ridges. The bedrock mapping involved traverses along most drainages, large and small; such work, though time consuming, finds many exposures, even in densely forested terrain.

Previous small-scale (1:100,000 and smaller) reconnaissance geologic mapping has included the Packwood Lake quadrangle, mainly by Hammond (1980), Schasse (1987), and Smith (1993). Winters' (1984) thesis study of the arkose includes a 1:24,000 scale map and cross sections of a small part of the area. The 1:48,000-scale map by Swanson and Clayton (1983) includes that part of the quadrangle within the Goat Rocks Wilderness; the present study builds on this earlier reconnaissance work.

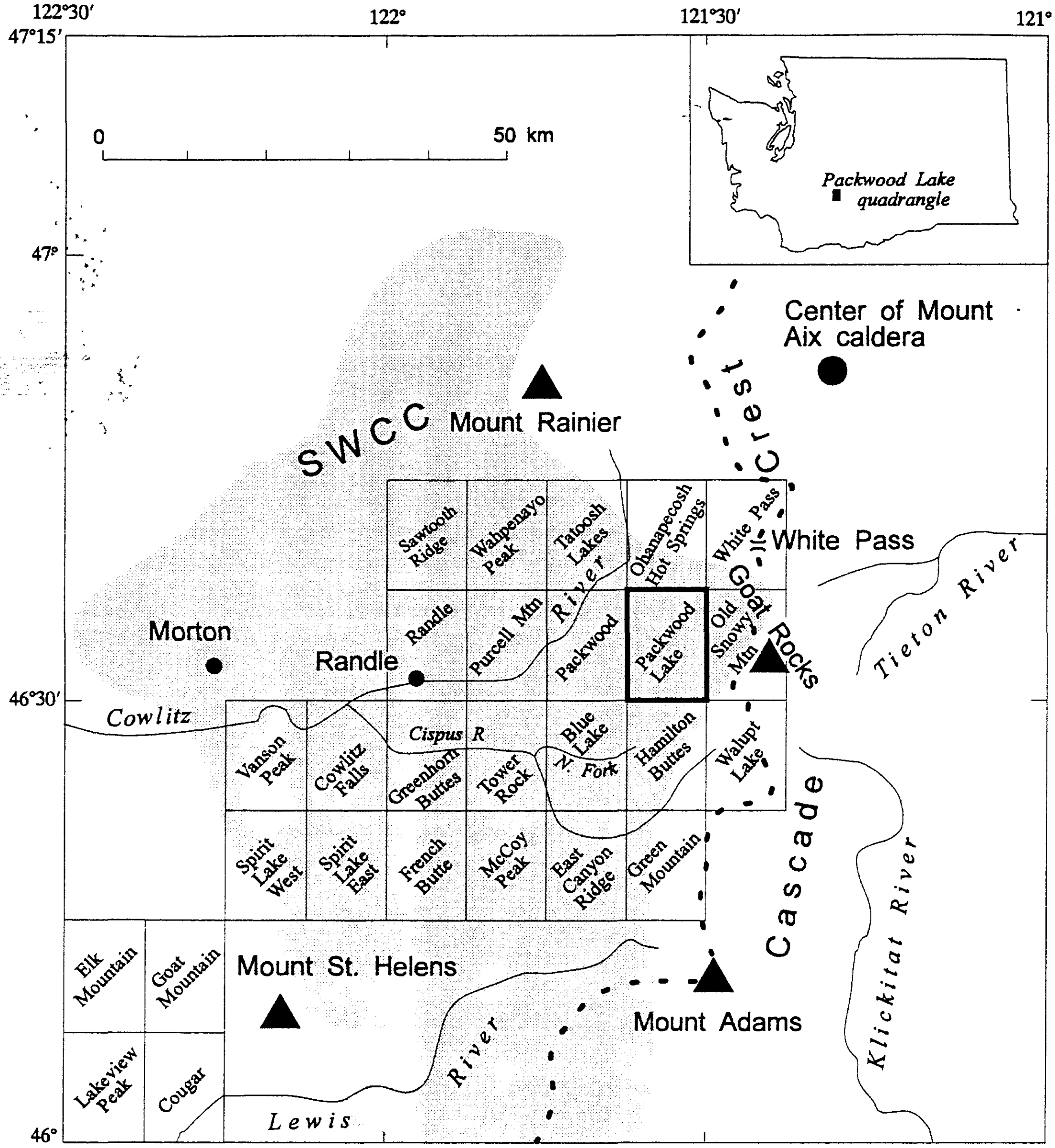

Figure 1. Index map showing location of Packwood Lake quadrangle relative to the three Holocene composite volcanoes in southern Washington, crest of Cascade Range, Pleistocene–Pliocene volcano at Goat Rocks, Southern Washington Cascades Conductor (SWCC; see text), and other 7–1/2′ quadrangles in which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

ACKNOWLEDGMENTS

Warren Winters provided corrected or additional locations for chemical analyses in his thesis (Winters, 1984). Bob Schuster (U.S. Geological Survey) helped interpret the age of the Packwood Lake and Glacier Lake landslides and gave advice on them and other landslides in the area. Geoff Clayton offered many challenging ideas during our work in the Goat Rocks Wilderness in 1981–82. Paul Hammond provided three chemical analyses of the ash-flow tuff of Purcell Creek, as always contributed stimulating ideas, and freely shared his chemical data regarding regional correlations among ash-flow tuffs. Barbara White (my wife) donated logistic help on several long traverses in 1981–82 and backpacked with me to Heart Lake in 1995. Kevin Cannon (U.S. Forest Service) aided logistics in the Goat Rocks Wilderness. Two U.S. Geological Survey programs supported the research—National Cooperative Geologic Mapping (the principal sponsor) and Deep Continental Studies. The preliminary work done in 1981–82 was part of a mineral appraisal of the Goat Rocks Wilderness mandated by the Wilderness Act. Russ Evarts reviewed and 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 paucity of data for the Tertiary rocks.) This consistency enables ready comparison with data in the other reports.

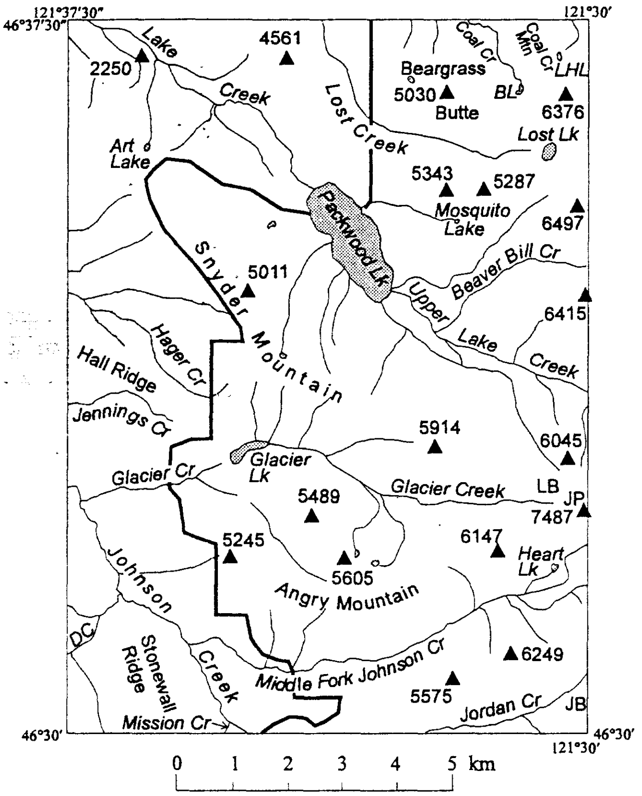

Figure 2. Map of Packwood Lake quadrangle showing locations of geographic features mentioned in text. BL, Beaver Lake; DC, Deception Creek; JB, Jordan Basin; JP, Johnson Peak; LB, Lily Basin; LHL, Lost Hat Lake. Heavy line, western boundary of Goat Rocks Wilderness.

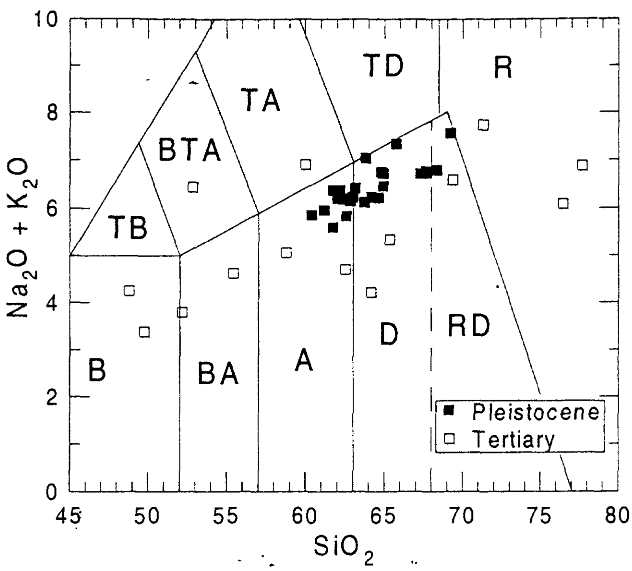

Figure 3. Total alkali-silica classification diagram for chemical analyses of rocks from the Packwood Lake quadrangle, modified from Le Bas and others (1986) to include field for rhyodacite. B, basalt; BA, basaltic andesite; A, andesite; D, dacite; RD, rhyodacite; R, rhyolite; TB, trachybasalt; BTA, 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).

I 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* (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 quartz and sparse biotite in the ash-flow tuff of Purcell Creek [map unit Tqt] in the Packwood Lake quadrangle).

Hornblende phenocrysts are rather common in a number of Pleistocene andesite and dacite flows from the Goat Rocks volcanic center (Clayton, 1983; Swanson, 1996; this report). In Tertiary rocks, hornblende occurs mainly in the intrusive suite of Kidd Creek (not found in the Packwood Lake quadrangle), the composition of which is silicic andesite and dacite (Marso and Swanson, 1992; Swanson, 1993). It also forms small phenocrysts in some samples of the quartz diorite of Beargrass Butte in the Packwood Lake quadrangle.

Samples with thin sections but no chemical analyses can be roughly classified by their phenocryst assemblages and groundmass textures (fig. 4). In all, 83 samples from the Packwood Lake quadrangle were sectioned (fig. 5); of these, 31 samples were chemically analyzed, 24 in the XRF laboratory of the U.S. Geological Survey in Denver and seven (one courtesy of P.E. Hammond) in the GeoAnalytical Laboratory of the Geology Department of Washington State University (WSU) (table 1). In addition, table 1 includes six chemical analyses included in Winters' (1984) thesis and done at WSU.

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 (14). Nonetheless it is within the range of indices found in the previously mapped quadrangles. The Quaternary rocks, on the other hand, are slightly calc-alkalic, with an alkali-lime index of 60.6 (fig. 7). This too is a questionable value, because of the lack of analyses with SiO_2 contents less than 60 percent.

Most of the chemically analyzed Tertiary rocks are tholeiitic on a plot of FeO*/MgO vs. SiO_2 (fig. 8), according to the classification of Miyashiro (1974). This

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

Map No.	Map Unit	Field No.	Original Analysis SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^+	H_2O^-	CO_2	Total	Recalculated H_2O- and CO_2-free 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	Tai	DCR102[1]	48.6	0.90	22.7	4.37	5.00	0.17	3.62	10.36	3.23	1.00	0.12				100.01	48.76	0.90	22.79	8.97	0.17	3.64	10.40	3.24	1.00	0.12	4.25	2.47	121	36.648	46	31.242
2	Taih	MFJ011[1]	49.5	0.98	22.2	4.37	5.01	0.17	4.28	10.00	3.11	0.26	0.12				99.98	49.75	0.98	22.26	8.98	0.17	4.30	10.05	3.12	0.26	0.12	3.39	2.09	121	34.932	46	30.750
33	Tgl	95-004[3]	51.5	1.08	18.6		7.62	0.14	5.16	10.67	2.92	0.82	0.21				98.71	52.15	1.09	18.86	7.72	0.14	5.23	10.81	2.96	0.83	0.21	3.79	1.48	121	34.332	46	36.318
3	Tgl	81-047	50.2	1.25	17.4	4.70	3.69	0.17	4.13	7.47	4.48	1.63	0.36	2.87	0.48	0.40	99.23	52.84	1.32	18.31	8.34	0.18	4.35	7.86	4.72	1.72	0.38	6.43	1.92	121	34.017	46	36.483
4	Tai	JC251[1]	55.1	1.58	16.4	5.24	6.01	0.20	3.07	7.41	3.30	1.30	0.37				99.99	55.43	1.59	16.47	10.78	0.20	3.09	7.45	3.32	1.31	0.37	4.62	3.49	121	35.400	46	30.210
5	Tai	MFJ417[1]	58.4	1.28	15.1	5.82	6.67	0.23	1.25	5.62	3.59	1.44	0.54				100.00	58.77	1.29	15.22	11.98	0.23	1.26	5.65	3.61	1.45	0.54	5.06	9.53	121	35.148	46	30.378
34	Tqdb	95-044[3]	59.7	1.40	16.7		6.34	0.16	2.35	5.60	4.66	2.20	0.39				99.50	59.99	1.40	16.80	6.37	0.16	2.36	5.63	4.68	2.21	0.39	6.89	2.70	121	31.308	46	36.864
6	Qgr_2	82-014	59.3	0.97	16.3	1.64	4.46	0.11	3.76	5.89	3.64	2.11	0.21	0.61	0.15	0.00	99.15	60.37	0.99	16.59	6.04	0.11	3.83	6.00	3.71	2.15	0.21	5.85	1.58	121	31.450	46	30.617
7	Qgrh	82-110	60.3	1.13	17.0	2.66	3.35	0.10	2.46	5.74	3.95	1.92	0.27	0.23	0.08	0.00	99.19	61.15	1.15	17.24	5.82	0.10	2.49	5.82	4.01	1.95	0.27	5.95	2.33	121	32.800	46	31.150
8	Qgr_2	82-112[5]	60.7	0.96	16.6	2.17	3.78	0.11	2.87	5.70	3.85	1.66	0.24	0.63	0.21	0.00	99.48	61.67	0.98	16.87	5.82	0.11	2.92	5.79	3.91	1.69	0.24	5.60	2.00	121	31.067	46	32.417
9	Qgr_2	81-021	60.6	1.08	15.9	2.37	3.56	0.09	3.09	5.23	3.77	2.48	0.26	0.27	0.46	0.00	99.16	61.72	1.10	16.19	5.80	0.09	3.15	5.33	3.84	2.53	0.26	6.37	1.84	121	30.033	46	35.767
10	Qgr_3	82-071	61.0	0.95	16.4	2.10	3.67	0.10	2.68	5.39	3.73	2.36	0.21	0.20	0.34	0.00	99.13	62.00	0.97	16.67	5.65	0.10	2.72	5.48	3.79	2.40	0.21	6.19	2.07	121	32.250	46	31.633
11	Qaa	82-009	60.9	1.04	15.7	1.33	4.32	0.10	3.02	5.24	3.66	2.58	0.25	0.95	0.21	0.00	99.30	62.14	1.06	16.02	5.63	0.10	3.08	5.35	3.73	2.63	0.26	6.37	1.83	121	35.200	46	31.867
12	Qgr_3	82-002	60.8	0.92	16.3	1.52	3.96	0.09	2.57	5.27	3.64	2.39	0.20	1.20	0.37	0.00	99.23	62.35	0.94	16.72	5.46	0.09	2.64	5.40	3.73	2.45	0.21	6.18	2.07	121	33.350	46	32.800
13	Tai	MFJ401Z[1]	62.2	1.29	14.9	5.05	5.78	0.20	1.54	4.25	4.34	0.34	0.19				100.01	62.48	1.30	14.93	10.38	0.20	1.55	4.27	4.36	0.34	0.19	4.70	6.70	121	35.202	46	30.498
14	Qgr_3	82-018	61.9	0.91	16.7	2.45	3.15	0.10	2.50	5.51	4.00	1.78	0.23	0.00	0.11	0.00	99.34	62.53	0.92	16.87	5.41	0.10	2.53	5.57	4.04	1.80	0.23	5.84	2.14	121	34.817	46	33.317
15	Qgr_3	81-019	62.0	0.88	16.4	1.62	3.76	0.09	2.75	5.11	3.77	2.30	0.19	0.16	0.27	0.00	99.30	62.81	0.89	16.61	5.29	0.09	2.79	5.18	3.82	2.33	0.19	6.15	1.90	121	33.683	46	36.250
16	Qgr_2	82-073	61.2	0.91	15.8	1.34	4.01	0.09	2.62	5.08	3.68	2.37	0.22	1.28	0.24	0.00	98.84	62.97	0.94	16.26	5.37	0.09	2.70	5.23	3.79	2.44	0.23	6.23	1.99	121	30.650	46	30.833
17	Qgr_2	82-015	61.7	0.85	15.7	1.34	3.98	0.09	2.88	4.90	3.64	2.63	0.20	1.19	0.17	0.00	99.27	63.10	0.87	16.06	5.30	0.09	2.95	5.01	3.72	2.69	0.20	6.41	1.80	121	31.350	46	30.683
18	Qgr_3[4]	82-013	62.8	0.92	15.9	2.10	3.34	0.09	2.43	4.93	3.77	2.26	0.26	0.45	0.15	0.00	99.40	63.70	0.93	16.13	5.30	0.09	2.46	5.00	3.82	2.29	0.26	6.12	2.15	121	31.717	46	30.600
19	Qgr_2	82-075	62.7	0.93	15.8	2.60	2.67	0.09	2.23	4.41	3.91	3.01	0.23	0.36	0.80	0.00	99.74	63.77	0.95	16.07	5.10	0.09	2.27	4.49	3.98	3.06	0.23	7.04	2.25	121	30.333	46	31.867
20	Ta	82-010	60.0	1.14	11.1	7.04	4.28	0.17	2.73	3.62	2.44	1.50	0.26	2.60	0.37	1.48	98.73	64.12	1.22	11.86	11.34	0.18	2.92	3.87	2.61	1.60	0.28	4.21	3.89	121	35.150	46	31.767
21	Qgr_3	82-007	63.4	0.77	16.2	2.21	2.79	0.09	2.41	4.82	3.77	2.38	0.19	0.27	0.09	0.00	99.39	64.16	0.78	16.40	4.84	0.09	2.44	4.88	3.82	2.41	0.19	6.22	1.98	121	34.467	46	33.967
35	Tqdb	95-045[3]	64.5	0.55	17.4		3.23	0.07	1.95	5.66	4.91	0.35	0.14				98.67	65.33	0.55	17.59	3.27	0.07	1.98	5.74	4.98	0.35	0.14	5.33	1.66	121	31.326	46	37.278
22	Qgr_3	81-041[5]	63.5	0.76	16.2	1.59	3.27	0.09	2.35	4.39	3.76	2.34	0.19	0.13	0.10	0.00	98.67	64.61	0.77	16.48	4.78	0.09	2.39	4.47	3.83	2.38	0.19	6.21	2.00	121	36.317	46	36.050
23	Qgr_3	81-042	63.4	0.79	15.7	1.14	3.58	0.08	2.11	4.42	3.84	2.76	0.18	1.24	0.24	0.00	99.48	64.77	0.81	16.04	4.71	0.08	2.16	4.52	3.92	2.82	0.18	6.74	2.18	121	33.550	46	35.983
24	Qgr_3	81-046	64.3	0.79	15.9	1.28	3.51	0.08	2.07	4.43	3.92	2.73	0.19	0.10	0.00	0.00	99.30	64.90	0.80	16.05	4.71	0.08	2.09	4.47	3.96	2.76	0.19	6.71	2.25	121	34.900	46	35.017
25	Qgr_3	82-017	64.2	0.78	16.3	1.88	2.89	0.09	1.90	4.50	3.90	2.48	0.18	0.13	0.34	0.00	99.57	64.91	0.79	16.48	4.63	0.09	1.92	4.55	3.94	2.51	0.18	6.45	2.41	121	34.867	46	33.550
26	Qgr_3	82-008	64.6	0.83	15.6	2.02	2.60	0.07	1.68	3.63	3.86	3.34	0.22	0.47	0.20	0.00	99.12	65.75	0.84	15.88	4.50	0.07	1.71	3.69	3.93	3.40	0.22	7.33	2.63	121	32.417	46	33.617
27	Qdj	JOR102[1]	67.1	0.66	15.9	2.03	2.33	0.07	1.53	3.56	3.87	2.82	0.14				99.99	67.25	0.66	15.90	4.17	0.07	1.53	3.57	3.88	2.83	0.14	6.70	2.72	121	33.000	46	30.048
28	Qgrh	82-072	66.4	0.69	15.6	1.28	2.56	0.08	1.26	3.63	4.23	2.40	0.22	1.11	0.30	0.00	99.76	67.60	0.70	15.88	3.78	0.08	1.28	3.70	4.31	2.44	0.22	6.75	2.95	121	32.183	46	31.550
29	Qdj	82-016	66.9	0.62	15.5	2.94	1.08	0.07	1.69	3.59	3.92	2.73	0.15	0.27	0.07	0.00	99.53	67.65	0.63	15.67	3.77	0.07	1.71	3.63	3.96	2.76	0.15	6.72	2.20	121	30.717	46	30.467
30	Qdj	82-011	67.2	0.60	15.1	2.72	1.27	0.08	1.47	3.40	3.88	2.79	0.14	0.42	0.10	0.00	99.17	68.31	0.61	15.35	3.78	0.08	1.49	3.46	3.94	2.84	0.14	6.78	2.53	121	32.983	46	30.083
31	Qgrh	82-069	68.2	0.56	15.4	1.58	1.74	0.08	0.79	2.78	4.59	2.86	0.16	0.18	0.10	0.00	98.98	69.21	0.57	15.59	3.21	0.08	0.80	2.82	4.66	2.90	0.16	7.56	4.00	121	31.233	46	31.933
36	Trj	94-041[3]	69.0	0.43	16.2	3.39	3.39	0.27	0.81	2.74	5.08	1.46	0.10				99.42	69.35	0.43	16.28	3.41	0.27	0.81	2.76	5.11	1.47	0.10	6.58	4.19	121	36.498	46	33.390
37	Trd	95-042[3]	70.6	0.41	15.4		3.28	0.09	0.77	0.68	4.42	3.23	0.12				98.96	71.29	0.41	15.57	3.31	0.09	0.78	0.69	4.47	3.26	0.12	7.73	4.26	121	32.898	46	35.442
38	Tqt	95-048[3]	75.9	0.22	13.9		1.96	0.04	0.23	0.91	3.28	2.76	0.05				99.26	76.46	0.22	14.02	1.97	0.04	0.23	0.92	3.30	2.78	0.05	6.09	8.52	121	31.482	46	35.760
32	Tqt	95-002[2]	72.2	0.19	11.6		1.52	0.01	0.14	0.85	3.08	3.31	0.04				92.92	77.66	0.20	12.51	1.64	0.01	0.15	0.91	3.31	3.56	0.05	6.88	10.86	121	34.812	46	36.762

X-ray fluorescence analyses, except those otherwise noted, done in U.S. Geological Survey laboratory in Denver, Colo. (analysts, D.F. Siems and J.S. Mee)

FeO, CO_2, and water done in U.S. Geological Survey laboratories in Menlo Park, Calif. (analyst, N.H. Elsheimer) and Denver, Colo

[1] *Analysis from Winters (1983) and done at Washington State University using XRF techniques; sample sites approximately located*

[2] *Analysis courtesy of P.E. Hammond and done at GeoAnalytical Laboratory of Washington State University*

[3] *Analysis done at GeoAnalytical Laboratory of Washington State University*

[4] *Sample is from dike and assigned to stratigraphic unit on basis of normal magnetic polarity. Alternatively, it could be assigned to unit Qgr_1, which also has normal magnetic polarity*

[5] *Sample from talus from nearby outcrop.*

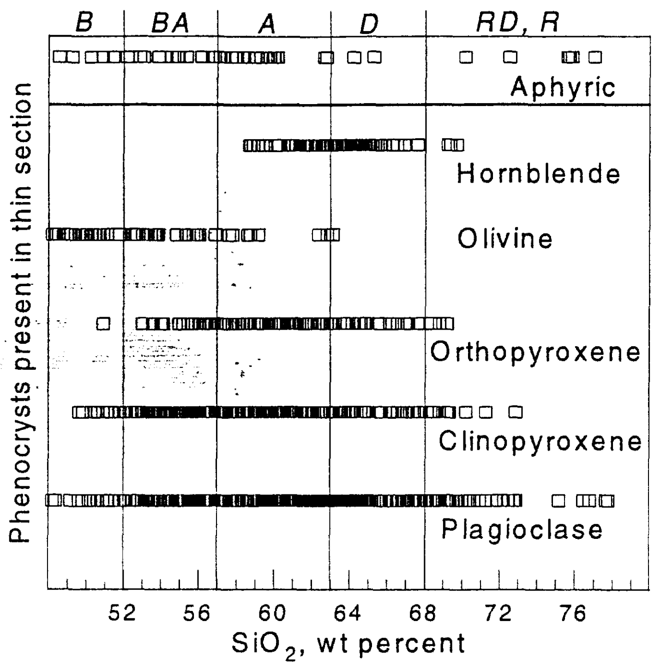

Figure 4. Plot of phenocryst assemblage vs. SiO_2 for 446 porphyritic and 42 non-porphyritic Tertiary rocks, chiefly in the eight mapped quadrangles but including a few in other quadrangles. □ , phenocryst observed in thin section; Rock types along top edge from figure 3. Revised from Swanson (1996). Modal amounts of phenocrysts range widely to a maximum of nearly 50 percent; typical values are ≤20 percent.

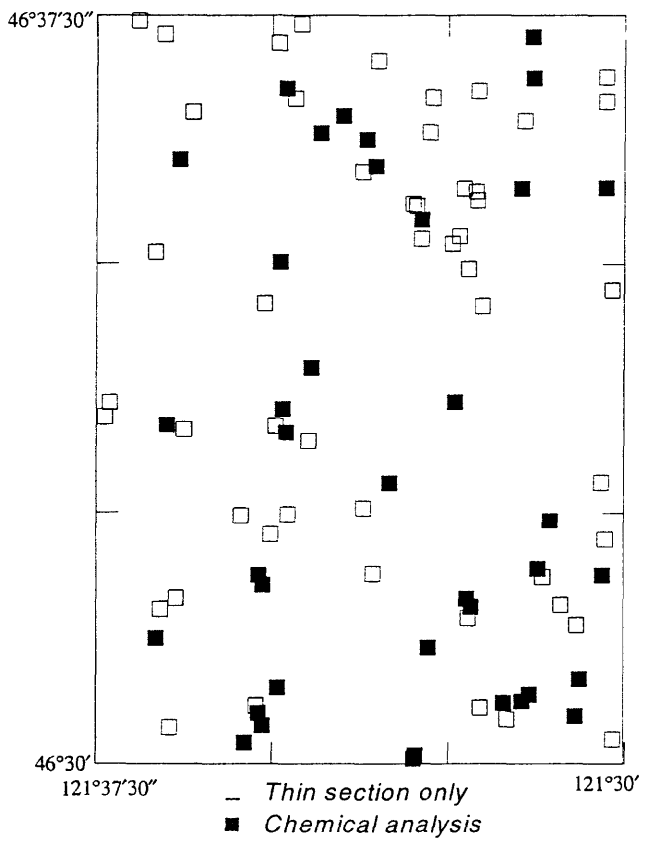

Figure 5. Map showing distribution of 89 sample localities in Packwood Lake quadrangle, including localities for analyzed samples collected by Winters (1984) and listed in table1.

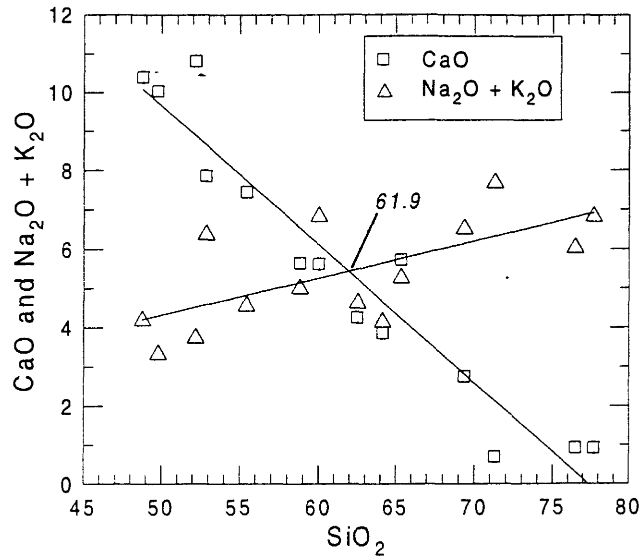

Figure 6. Plots of CaO and (Na_2O + K_2O) against SiO_2 for all analyzed Tertiary rocks in Packwood Lake quadrangle. Linear regressions of both plots cross at SiO_2 content of 61.9—slightly calcic in terminology of Peacock (1931).

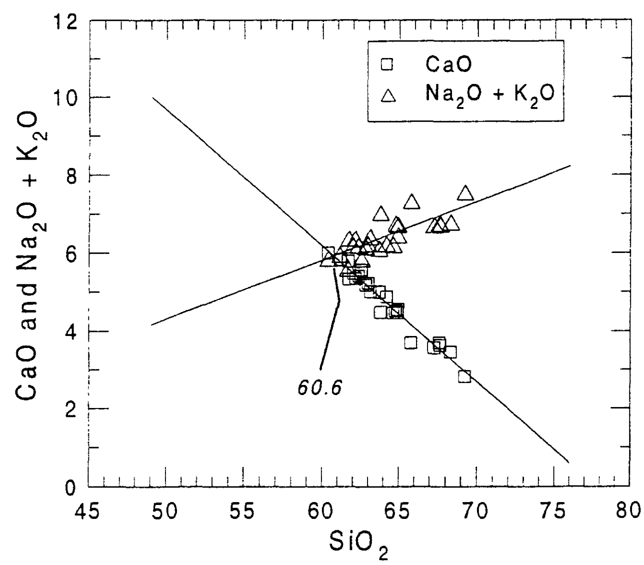

Figure 7. Plots of CaO and (Na_2O + K_2O) against SiO_2 for all analyzed Quaternary rocks in Packwood Lake quadrangle. Linear regressions of both plots cross at SiO_2 content of 60.6—slightly calc-alkalic in terminology of Peacock (1931).

pattern resembles that in the previously mapped quadrangles. All of the Quaternary lava flows are calc-alkaline, as are those farther west and south, where only the least silicic basalt is tholeiitic and all other compositions are calc-alkaline.

All but two of the analyses are subalkaline on a plot of total alkalies vs. SiO_2 (fig. 9; Macdonald and Katsura, 1964; Irvine and Baragar, 1971). One of the Tertiary samples (the gabbro of Lake Creek) is mildly alkalic in both classifications, and another falls on the dividing line in the Irvine and Baragar scheme. The subalkaline character is stronger with increasing SiO_2 content for both the Tertiary and Pleistocene rocks.

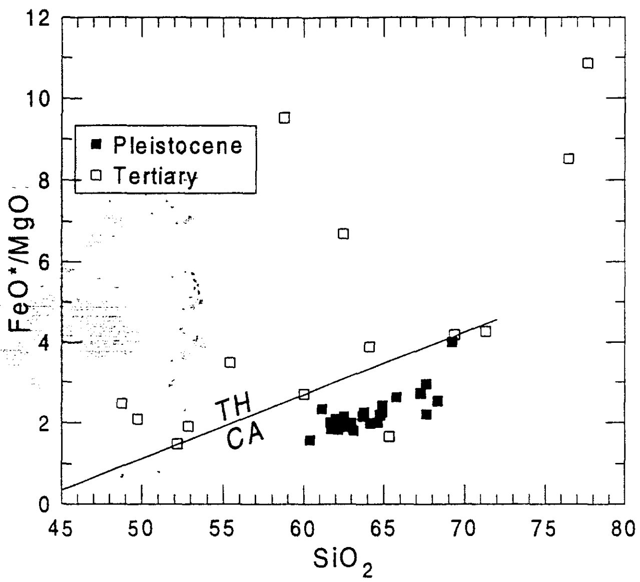

Figure 8. Plot of FeO*/MgO vs. SiO_2 for all chemically analyzed Tertiary and Quaternary rocks from Packwood Lake quadrangle. Subdivision into tholeiitic (TH) and calc-alkaline (CA) suites after Miyashiro (1974). Most Tertiary rocks are tholeitic, but all Pleistocene lava flows are calc-alkaline.

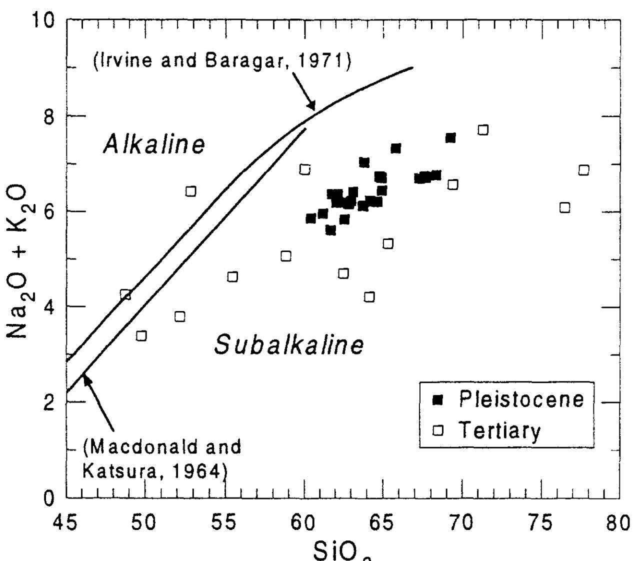

Figure 9. Plot of (Na_2O + K_2O) against SiO_2 for all chemically analyzed Tertiary and Quaternary rocks in Packwood Lake quadrangle. Boundaries shown between subalkaline and alkaline suites after Macdonald and Katsura (1964) and Irvine and Baragar (1971). Nearly all samples are decidedly subalkaline. Tertiary sample (table 1, no. 3) in alkaline field is gabbro of Lake Creek, but other analysis of that unit (table 1, no. 33) is subalkaline.

A plot of K_2O vs. SiO_2 (fig. 10) 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). Many silicic Quaternary rocks have high K_2O contents (as in the Hamilton Buttes quadrangle). One of the Tertiary basalt samples (table 1, no. 2) is poor in K_2O, possibly owing to accumulation of calcic plagioclase in this highly plagioclase-phyric rock. Two other Tertiary rocks of intermediate SiO_2 contents (nos. 13 and 35) have low K_2O. I have no thin section of no. 13 (the analysis comes from Winters [1984]) and so can't evaluate the degree of obvious alteration. The thin section of no. 35 is of a seemingly fresh hornblende-phyric dacite.

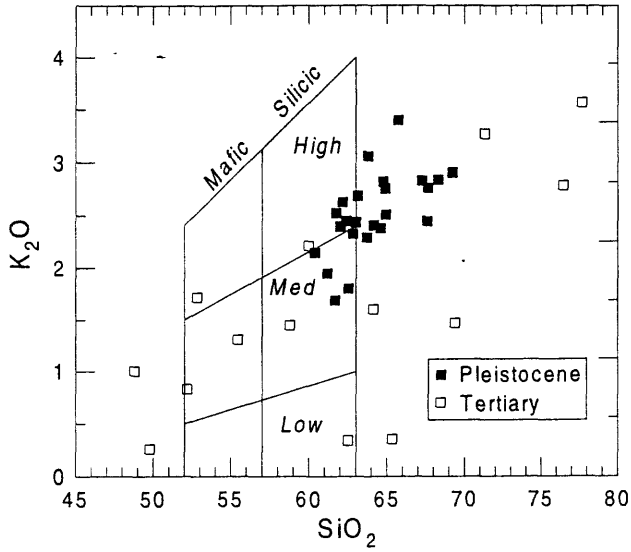

Figure 10. Plot of K_2O against SiO_2 for all chemically analyzed Tertiary and Quaternary rocks from Packwood Lake quadrangle. Fields modified from Gill (1981), so that mafic andesite (basaltic andesite in IUGS terminology used in this paper) extends down to 52 percent. Note relatively high K_2O contents for many fresh Pleistocene rocks.

GEOLOGIC OVERVIEW OF QUADRANGLE

Bedded volcaniclastic rocks—mainly volcanic sandstone but including mudstone, diamictite (mostly laharic deposits), air-fall tuff, and ash-flow tuff—of late Eocene and Oligocene age underlie most of the quadrangle. They overlie and are interbedded with a section of fluvial micaceous arkose 1–1.5 km thick that was derived from a medium-grade metamorphic terrane in northeastern Washington. The arkose crops out only along Johnson Creek in the southwestern part of the quadrangle; it is prominent in the adjacent Hamilton Buttes quadrangle.

Lava flows of andesite and basaltic andesite form a thick pile on Angry Mountain in the south-central part of the quadrangle and spread from there in all directions. The flows probably record a near-vent, shield-like environment, which is also suggested by a thick accumulation of poorly bedded to unbedded breccia south of Glacier Lake. Dikes cut the pile and crudely radiate from the presumed eruptive center south of Glacier Lake. The lava flows are interbedded laterally with volcaniclastic rocks.

One of the youngest eruptive units in the Tertiary section is the (biotite)-quartz-phyric ash-flow tuff of Purcell Creek, which crops out in spotty fashion in the northern third of the quadrangle. This tuff chemically resembles the tuff of Bumping River erupted from the Mount Aix caldera (Hammond and others, 1994; Hammond, 1996 and oral commun., 1996), 30 km northeast of the quadrangle, and is of about the same age (~26.5 Ma by zircon fission-track dating and ~25 Ma by U/Pb dating [Vance and others, 1987]). It also is one of the tuffs assigned to the Stevens Ridge Formation by Fiske and others (1963; Stevens Ridge Member of the Fifes Peak Formation of Vance and others, 1987) and forms a marker that can be easily traced to the type locality of the Stevens Ridge in Mount Rainier National Park.

The Tertiary section is intruded by numerous sills and larger bodies that range from gabbro to quartz diorite and finer-grained equivalents. The intrusions can be subdivided into several map units on petrographic and chemical grounds. Dikes are most numerous near the Angry Mountain eruptive center but also occur between Packwood and Mosquito Lakes and on Coal Creek Mountain. The ages of the intrusions, except for the radial dike swarm on Angry Mountain, cannot be constrained well, but several of the intrusions cut the quartz-phyric ash-flow tuff of Purcell Creek and so are probably younger than any of the stratified Tertiary rocks and most likely Miocene.

Folding warped the area into two right-stepping *en echelon* fold sets, the Johnson Creek-Lake Creek anticlinal pair and the Jordan Creek-Lost Creek synclinal pair. The age of folding relative to the youngest Tertiary intrusions is unknown. In the previously mapped quadrangles, folding postdates all but the youngest intrusions (about 12 Ma), as constrained geometrically and paleomagnetically (Swanson, 1993; Hagstrum and Swanson, 1994).

After post-folding erosion, volcanism resumed in the middle Pleistocene with the eruption of several units of lava flows ranging in composition from silicic andesite to rhyodacite. Most and perhaps all of these flows came from Goat Rocks volcano, the largest edifice of the Goat Rocks volcanic center. All of the flows are confined to paleovalleys radiating from the volcanic center; erosion was ongoing between eruptions, possibly abetted by middle Pleistocene glacial erosion, and younger flows occupy deep canyons eroded into older flows from the same center. The youngest flows are probably 0.02–0.14 Ma on the basis of relations to glacial deposits. Most of the lava flows predate 0.14 Ma, however, and a large part of the section is magnetically reversed and hence older than 0.78 Ma. The reversed lava flows themselves overlie normally polarized flows and breccia of uncertain age but clearly related to the Goat Rocks center.

The area was extensively glaciated during the late Pleistocene. Till of Evans Creek Drift covers large parts of the quadrangle.

Several extensive landslides postdate glaciation. One dammed Glacier Creek to form Glacier Lake, perhaps about 650 radiocarbon years ago. The largest dammed Lake Creek and created Packwood Lake, probably 1100–1200 radiocarbon years ago (ages courtesy of R.L. Schuster, written commun., 1993).

TERTIARY ROCKS

Arkose of Chambers Creek (map unit Tsc)—Well-bedded, generally micaceous arkose and lesser pebble conglomerate, siltstone, and mudstone are the oldest rocks in the quadrangle. They crop out along Johnson Creek near the southwestern edge of the quadrangle. The unit is widespread in the adjoining Hamilton Buttes quadrangle, where it was studied by Winters (1984) and Swanson (1996). Volcaniclastic detritus is commonly interbedded with, and mixed into, the arkose throughout a section 1–1.5 km thick. A tuff about midway through the section has a zircon fission-track age of 35.9 ± 0.7 Ma (Winters, 1984).

The arkose of Chambers Creek was probably derived from medium-grade metamorphic rocks in northern and northeastern Washington and northern Idaho. West- and southwest-flowing streams carried detritus into the area, where it mixed with freshly erupted volcaniclastic material signaling the onset of activity in the Cascade arc. The thickness of the interbedding implies ongoing subsidence in order to trap the fluvial deposits (Swanson, 1994b). Growth of the arc eventually overwhelmed the river system, presumably forcing it southward into some proto-Columbia River configuration. Nonetheless, subsidence must have continued as the arc became fully active, because at least 5 km of volcanic rocks accumulated above the arkose before folding (Evarts and Swanson, 1994; Swanson, 1993, 1996).

Volcaniclastic rocks (map unit Ttv)—Bedded volcaniclastic rocks of various origins underlie most of the quadrangle. They are particularly well exposed in the high east-facing cliff of Stonewall Ridge and along the east side of Coal Creek Mountain. Elsewhere they are commonly obscured by vegetation, drift, or colluvium.

Included in this map unit are: 1) epiclastic rocks, 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 airfall 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 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). 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. Air-fall tuff is easily misidentified as epiclastic mudstone, and in fact much of the mudstone could be reworked or even *in situ* tuff.

Lithic diamictite is an important rock type, particularly in the upper half of the section. It occurs in beds from a few centimeters to a few meters thick and 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 me (Swanson, 1993, 1996) for the bedded rocks in the Blue Lake and Hamilton Buttes 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 west is consistent with the concept of syndepositional subsidence as the volcanic pile accumulated (Swanson, 1993, 1996; 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. Bedding attitudes in thin, unmapped interbeds between lava flows on Angry Mountain show abrupt discordances seemingly unrelated to regional structure. Attitudes west of Glacier Lake, north of Jennings Creek, and south of Mosquito Lake likewise are only marginally consistent with one another. Deposits in all these areas are dominantly diamictite or pyroclastic rocks, not well-bedded fluvial sandstone. Presumably through-going drainages were farther away from the Angry Mountain center.

Lava flows (map unit Ta)—Angry Mountain dominates the landscape of the south-central part of the quadrangle, held high by of a thick pile of lava flows that defines a former volcano. The center of the volcano cannot be determined with certainty. A crudely radial dike swarm focuses on an area underlain by thick, vaguely bedded to nonbedded breccia south of Glacier Lake that may be a crater-fill deposit. This is the most likely vent area yet found, but conceivably the center could be somewhat farther north, buried by younger cover.

The section of andesite flows is more than 300 m thick at the west end of Angry Mountain and more than 700 m thick in craggy cliffs overlooking Middle Fork Johnson Creek. Most 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 flows are plagioclase-phyric, some strikingly so, with phenocrysts 2–3 cm long making up more than 50 percent of the rock. Interbeds of tuff and diamictite (probably mostly talus and laharic deposits) are common but too thin to map.

The andesite flows extend away from Angry Mountain in all directions, though subsequent folding eventually carries them out of the present level of exposure. A thick section of flows crops out north of Deception Creek, west of Johnson Creek, and between Glacier Creek and Hall Ridge in both the Packwood Lake and adjacent Packwood quadrangles. These flows resemble those on Angry Mountain and doubtless are equivalents. Likewise, andesite flows on both sides of upper Jordan Creek canyon, as well as those in a >800–m–thick section north of Johnson Peak and along Upper Lake Creek, were probably erupted from the Angry Mountain center. Similar andesite flows crop out even west of Point 6497 north of Beaver Bill Creek, though here they are interleaved with volcanic sandstone and other volcaniclastic rocks perhaps deposited in a valley adjacent to the Angry Mountain center.

The concentration of dikes in a 2–km swath at the west end of Angry Mountain is partly an artifact of the presentation. The dikes are portrayed schematically, because there are many problematic rocks here, including screens of hornfelsed volcaniclastic rocks and larger intrusions, that are difficult to distinguish from the dikes themselves. Also, the dikes define this array because of fortuitous cuts along an old logging road; away from this road, exposures on the west side of Angry Mountain are very poor. These factors lead to a highly skewed rose diagram for the strikes of dikes (fig. 12B). Schematically shown or not, there are many dikes in this area, possibly reflecting a wide rift zone on the volcanic edifice or offshoots of a larger nearby intrusion. Similar dikes were not recognized west of Johnson Creek. This area too is poorly exposed, but there may be a dextral fault along Johnson Creek that displaces the dikes northward beyond current limits of exposure (see section on *Structure*).

The lava flows west of Johnson Creek are part of a >800–m–thick section exposed in the adjacent Packwood quadrangle. This section may be equivalent to that on Angry Mountain, exposed on the west limb of the Johnson Creek anticline. Alternatively, there could be another center in the Packwood quadrangle, north of a prominent peak called South Point. Flows from this possible center might be interbedded with those from Angry Mountain. Some dikes cut the flows on and north of South Point.

Breccia of Glacier Lake (map unit Tbg)—A thick, mostly nonbedded section of breccia, interpreted as a crater fill (most likely) or near-vent deposit associated with the Angry Mountain center, underlies the ridge southeast of Glacier Lake. As mapped, its outcrop area is rather limited (about 1.8 km long and 0.8 km wide), but the deposit is very thick, more than 240 m.

The breccia is best exposed–and spectacularly so–in a southwest-facing cliff just south of the west end of the lake. Here bedding is absent except for thin tuff beds near the top of the section. Crude partings in the breccia, defined by joints and long dimensions of some clasts, simulate bedding in places; whether this is true bedding is unclear. The partings define a vague north to northeast dip of about 30°, though probably half of this amount is related to later folding. Most of the andesite clasts are angular and a few tens of centimeters in diameter, although some reach 6 m or even more across. The clasts generally are supported by matrix, but clustered clasts in local pockets support each other.

The margins of the deposit are unsatisfactorily defined. In part this reflects exposure problems, especially on the northeast side of the ridge. I doubt if the margins of the breccia are as simple as portrayed on the map and suspect that lava flows are interbedded with the breccia at least locally.

Nonetheless, the breccia cannot extend far beyond the limits as mapped, where flow on flow relations are generally observed. Given that, the deposit is notable by its great thickness-to-area ratio, which suggests either the filling of a crater or the piling of explosive ejecta near a vent. Its location near the focus of the radial dike swarm supports this interpretation of a near-vent accumulation. The dominantly matrix-supported and unbedded nature of the breccia suggests emplacement by mass transport, such as landsliding from crater walls (not simply talus, which is typically framework-supported). Even a thick near-vent deposit that accumulated from explosions should show better bedding and sorting.

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 discontinuously in the northern third of the Packwood Lake quadrangle, as well as in the neighboring Packwood and Ohanapecosh Hot Springs quadrangles. It helps define paleogeography, amount of offset by intrusions, and fold amplitudes, and its potential regional correlation triggers speculation about a potential source caldera.

The tuff takes its name from prominent cuts along Highway 12 just west of Purcell Creek, in the Ohanapecosh Hot Springs quadrangle 4.5 km north of the map area. Here the tuff has been dated as 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]). I have mapped the tuff nearly continuously from the Highway 12 cuts into the Packwood Lake quadrangle.

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. Flattened lapilli can be 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. 32 and 38, as well as two unpublished chemical analyses from sites within the Packwood quadrangle). It probably lost Na_2O and possibly K_2O during hydration, judging from the low content of total alkalis (figs. 3 and 9).

The tuff is welded in many places, though subsequent alteration commonly obscures the eutaxitic texture. The upper part of the tuff is nonwelded. The tuff consists of only one cooling unit, as judged from the upward change in texture from welded to nonwelded with no reversal. One outcrop showing rheomorphic folding was found in the Ohanapecosh Hot Springs quadrangle 2.5 km north of the mapped area.

The maximum thickness of the Purcell Creek is more than 60 m. Nowhere did I find an exposure of the basal or upper contact, although both could be located within several meters in a few places.

The ash flow covered a wide area in the three quadrangles. Probably, therefore, the surface across which it moved had relatively low relief. The precise configuration of this surface cannot be determined, however, because of remarkable post-emplacement disturbance caused by intrusion of the gabbro of Lake Creek and the quartz diorite of Beargrass Butte (discussed in the section *Intrusions*).

Regional correlation and possible source area—The quartz-phyric ash-flow tuff of Purcell Creek has long been considered as part of the Stevens Ridge Formation, first defined by Fiske and others (1963) in Mount Rainier National Park. From the road cut near Purcell Creek, the tuff can be mapped northward along Backbone Ridge into the Park and the section of Stevens Ridge described by Fiske and others (for example, see map in Hammond and others [1994, fig. 1]). Vance and others (1987) agree with this interpretation but assign the tuff to the Stevens Ridge member of the Fifes Peak Formation—a nomenclatorial change but not one of fundamental significance. I agree with the interpretation that the Purcell Creek is part of the Stevens Ridge Formation (or member, depending on the terminology used); in fact, it is the oldest tuff of the Stevens Ridge in this area.

Their volume and lateral extent of the ash flows suggest a caldera source. Recently, Sue Schreiber and especially Paul Hammond and co-workers have recognized and mapped 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 discovery is fundamental for understanding of the late Oligocene eruptive history of this part of the Cascades. Collapse of the 10 by 18 km-wide Mount Aix caldera accompanied eruption of at least three quartz-phyric rhyolitic ash flows, most notably the Bumping River tuff (the Bumping River tuff north lobe of Hammond and others, 1994). Zircon fission-track ages for the Bumping River tuff are similar to that for the tuff of Purcell Creek (Bumping River: five ages ranging from 26.3 to 27.7 Ma [Schreiber, 1981; Vance and others, 1987; P.E. Hammond, written commun., 1995]; Purcell Creek: one age of 26.5 [Vance and others, 1987]). Furthermore, the Purcell Creek and Bumping River resemble one another petrographically (my observations) and chemically (P.E. Hammond, written commun., 1996).

Though far from proven, the possible correlation of the Purcell Creek with the Bumping River, first tentatively suggested by Vance and others (1987), is a stimulating working hypothesis. At the least, this hypothesis provides a reasonable source area for the tuff of Purcell Creek and, by extension, for some or all of the quartz-phyric ash-flow tuff in the Stevens Ridge Formation. If the Purcell Creek and Bumping River are the same unit, the ash flow traveled about 30 km from the Mount Aix caldera to the Packwood Lake quadrangle—well within expected distances for large ash flows moving across relatively flat terrain. If this correlation holds, the name *Bumping River tuff* will take precedence over *tuff of Purcell Creek.* For now, however, I think it prudent to retain the name *Purcell Creek* until (and if) the hypothesized correlation can be demonstrated.

Intrusions—A number of intrusions cut eruptive rocks in the quadrangle. Some, particularly dikes, probably are related to volcanoes that erupted the lava flows and pyroclastic rocks, because the dikes are concentrated in thick piles of lava flows that represent eruptive centers. Examples are the dikes cutting andesite flows at Angry Mountain and east of Packwood Lake. Dikes (and similar sills) near Lost Hat Lake (map unit Tdlh), however, are more silicic than the pyroxene andesite flows they cut and contain phenocrysts of hornblende. It is unclear whether they belong to a later center that has been eroded away, or to a different stage in activity of the volcano that produced the andesite flows.

Other intrusions, however, are probably younger than any of the preserved Tertiary eruptive rocks. The gabbro of Lake Creek (map unit Tgl) and the quartz diorite of Beargrass Butte (map unit Tqdb) each intrude rocks as young as the quartz-phyric ash-flow tuff of Purcell Creek, very near the top of the Tertiary stratigraphic section. The glomeroporphyritic sill complex of Packwood (map unit Tip) intrudes volcaniclastic sandstone and siltstone in the town of Packwood, 3 km west of the quadrangle, that have a zircon fission-track age of 23.5 ± 0.6 Ma (Schasse, 1987, table 2); these volcaniclastic rocks are probably a little younger than the Purcell Creek on stratigraphic grounds as well. Sills of dacite, rhyodacite, and related quartz diorite and granodiorite (unit Tri) intrude similar sandstone and siltstone south of Packwood. All of these intrusive units probably postdate the youngest erupted rocks in the quadrangle.

The relative ages of other intrusions are poorly constrained. The sills of Hugo Lake (map unit Taih) occur far down in the stratigraphic section, and the silicic dikes and sills of Lost Hat Lake (map unit Tdlh) cut rocks half to two-thirds of the way up the stratigraphic section. Obviously these bodies could be older or younger than the top of the section.

Plug-like emplacement of larger intrusive bodies—The two largest intrusions in the quadrangle, the gabbro of Lake Creek and the quartz diorite of Beargrass Butte, intruded plug-like into their country rock, as did another large diorite-microdiorite intrusion just north of the quadrangle at Coal Creek Bluff. The relations between host rock and intrusion can be worked out at each locality, because the host rock contains the distinctive quartz-phyric ash-flow tuff of Purcell Creek, an excellent marker bed that defines the geometry of deformation associated with intrusion.

The quartz-phyric ash-flow tuff of Purcell Creek crops out on the west flank of the gabbro of Lake Creek and dips eastward into the intrusion. The Purcell Creek and a thin section of underlying tuffaceous rocks also occur as a cap on the north part of the intrusion, about 400 m higher than on the west flank. The tuffaceous rocks are baked against the chilled top of the intrusion, not deposited on it. On the east flank, the contact between the gabbro and the still east-dipping ash-flow tuff, observable in places where the tuff is a hornfels clinging to the vertical side or gently dipping top of the intrusion, climbs more than 360 m from

Lost Creek to the crest of the ridge, where it is eroded away. Thus the intrusion lifts the Purcell Creek at least 400 m, and probably somewhat more if the east dip is accounted for, from its pre-intrusion position.

A similar though less well-defined relation is shown at Beargrass Butte. The ash-flow tuff is nearly 200 m lower along Lost Creek than on the northwest and southeast flanks of the intrusion. (On the southeast flank the unit consists mostly of reworked quartz-rich sandstone rather than ash-flow tuff, but the sand must have been derived from the tuff, the only quartz-phyric unit in the section.) The situation on the northwest flank of the butte is complicated, and I portray it as a fault that drops the Purcell Creek down along the margin of the intrusion. This may well be an oversimplification. Whatever the actual relation, I suspect that the complications are related to the mechanics of intrusion.

Still another intrusion significantly deformed the ash-flow tuff of Purcell Creek. A diorite-microdiorite body forming Coal Creek Bluff, 2 km northwest of Beargrass Butte in the Ohanapecosh Hot Springs quadrangle, warps the Purcell Creek about 400 m upward along a nearly continuously exposed contact (Swanson and Clayton, 1983, unit Tsr; D.A. Swanson, unpublished data, 1996).

These relations clearly indicate that each intrusive body, at the present level of exposure, moved upward more or less like a plug, lifting overburden by warping or faulting rather than stoping or simply shoving the wallrock aside. This type of intrusion probably implies a relatively shallow depth, in order to minimize the weight that was lifted.

Several other intrusive bodies in the mapped quadrangles have roofs with chilled contacts against hornfelsed country rock; most notable is the rhyolite intrusion of Spud Hill, 30 km south of Packwood (Swanson, 1994). However, lack of a distinctive marker bed at Spud Hill and the other intrusions precludes estimating amounts of displacement, if any. The relations just described in the Packwood Lake quadrangle and at Coal Creek Bluff suggest that plug-like intrusion may explain these stratigraphically ambiguous situations and in fact may be common within the mapped quadrangles.

STRUCTURE

The structure of the quadrangle is dominated by two sets of *en echelon* north- to northwest-trending folds, the Johnson Creek-Lake Creek anticlinal pair and the Jordan Creek-Lost Creek synclinal pair. Each *en echelon* pair is right-stepping, a pattern that holds from the French Butte quadrangle to the Packwood Lake quadrangle (fig. 11). The trough of another fold, the Stonewall Ridge syncline, crosses the southwest corner of the quadrangle; this syncline is paired with the Pimlico Creek syncline to form another right-stepping set prominent in the Hamilton Buttes quadrangle (Swanson, 1996).

The fold patterns are affected and to some extent obscured by primary dips in the proximal andesite flows on Angry Mountain and surroundings. The cover of Pleistocene lava flows and younger surficial deposits further inhibits precise mapping of the fold axes.

The rose diagram of strikes of bedding (fig. 12A) shows a peculiar eastward swing from the dominant fold directions. This swing reflects in part the effect of the primary dips in the near-vent lava piles. Also, many attitudes were measured in the well-bedded part of the section on the shared limb of the Stonewall Ridge and Johnson Creek folds, both of which plunge fairly steeply north-northwest. The strikes on this limb are thus skewed easterly from the bearing of the axes. The rose diagram of strikes is less definitive than that in the other quadrangles for these two reasons. Moreover, bedded rocks are not as common as in the other mapped quadrangles, so fewer strikes were measured.

An important issue is the age of folding. Southwest of the quadrangle, evidence indicates that folding predates about 12 Ma, the age of the undeformed intrusive suite of Kidd Creek (Swanson, 1992; Hagstrum and Swanson, 1994). Rocks of the Kidd Creek suite are distinctively hornblende porphyritic and easily recognized. They have not been found in the quadrangle and so cannot be used to estimate the age of folding.

No unambiguous age relations between intrusion and folding can be determined in the quadrangle. Bedding attitudes in host rocks for the intrusions better reflect the folds than any local intrusion-caused deformation. For example, bedding conforms to the west flank of the Lost Creek syncline on both sides, and on top, of the gabbro of Lake Creek. This relation does not indicate relative age, however. The gabbro could have intruded folded rocks in plug-like fashion without associated deformation, or folding could have been superimposed on the intrusion and its undeformed host rock. Detailed paleomagnetic work will be required to determine the age of the intrusions relative to the folding.

Local shear zones and minor fault offsets are common in the quadrangle, particularly along the Johnson Creek anticline. None of these zones can be demonstrated to be a major fault, however. The large contrast in density of diking across Johnson Creek suggests a fault more or less along the crest line of the Johnson Creek anticline, but this possibility cannot be tested because of the lack of marker beds and the generally poor exposures. A similar uncertainty plagues interpretation of the anticline in the Hamilton Buttes quadrangle, where lithologic contrast on the two flanks suggests faulting but could also reflect a facies change (Swanson, 1996).

Two faults were found with relatively clear indications of subhorizontal strike-slip movement, one 1.5 km south-southeast of Packwood Lake and the other 500 m north of Jordan Creek. Each fault is a northwest-striking, striated, vertical plane that contains small steps indicative of right-lateral movement. This relation appears to be typical of the southern Washington Cascades, in which north and northwest shears and faults are dextral and less prominent

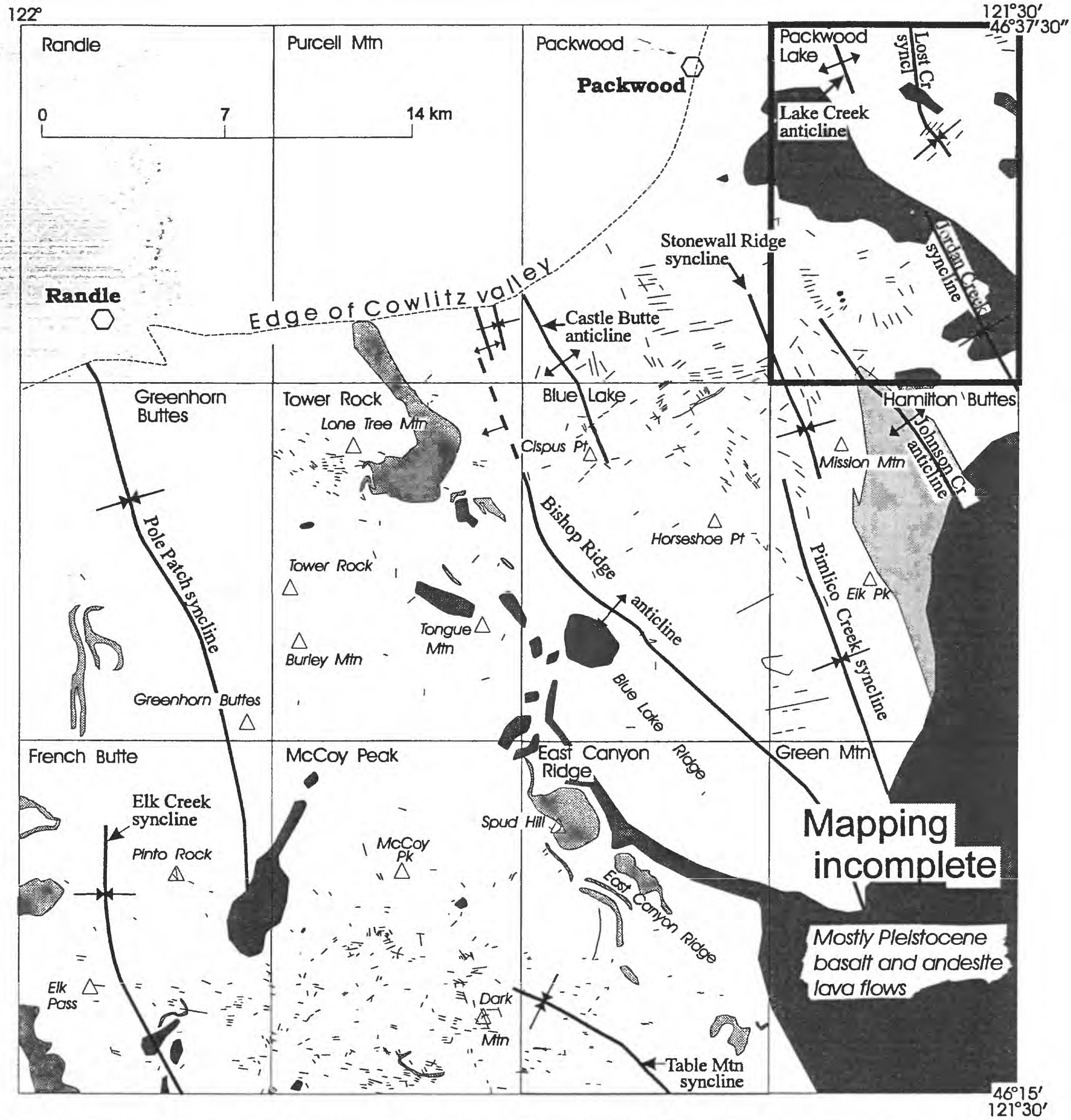

Figure 11. Generalized distribution of Tertiary pyroxene andesite and basaltic andesite dikes (short lines), arkose of Chambers Creek (light shade), two main belts of Tertiary dacite and rhyolite extrusions and intrusions (intermediate shade), and Pleistocene basalt to dacite in mapped quadrangles south of Cowlitz River. Packwood Lake quadrangle heavily outlined. Dikes in Packwood quadrangle shown schematically and incompletely. Dikes in northeast corner of Packwood Lake quadrangle contain sparse hornblende. 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.

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).

LAVA FLOWS AND DEBRIS FLOWS FROM GOAT ROCKS VOLCANIC CENTER

About one-fourth of the Packwood Lake quadrangle is covered by intracanyon lava flows of silicic andesite and mafic dacite erupted from Goat Rocks volcano and its en-

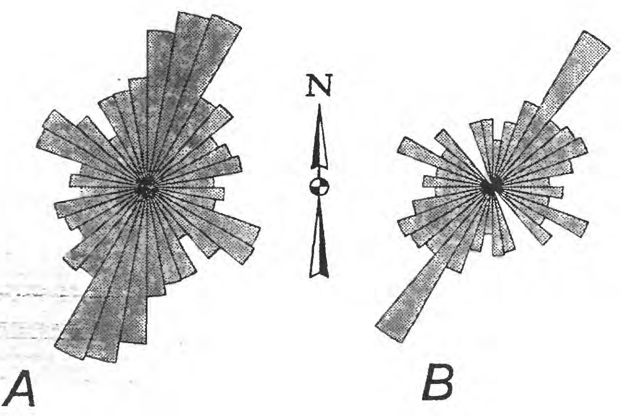

Figure 12. Equiarea rose diagrams in 10° increments showing strikes of bedded rocks and dikes in Packwood Lake quadrangle. *A*, 125 strikes of bedding (mean direction, 4°; s.d., 45°); *B*, 65 dikes (mean direction, 72°; s.d., 48°).

virons, collectively called here the Goat Rocks volcanic center. These flows form Snyder Mountain, cap ridges between Middle Fork Johnson, Jordan, and Glacier Creeks, and occupy former valleys northeast of Packwood Lake and along and just east of the east edge of the quadrangle north of Upper Lake Creek. The flows moved down valleys and canyons radiating outward from vents east of the quadrangle, mostly located in the basin of Upper Lake Creek in what is now the deeply eviscerated core of Goat Rocks volcano (Swanson and Clayton, 1983).

Nearly all flows contain phenocrysts of two pyroxenes and plagioclase. Some flows carry minor amounts of hornblende, and a few of the youngest flows have several percent hornblende phenocrysts. The flows, even the thickest (several tens of meters to locally more than 100 m), contain much groundmass glass and so are generally vitrophyric. The rocks stand out from the Tertiary andesite by being far fresher and containing cognate(?) clots of diorite or gabbro, or of mineral clusters consistent with these two rock types. Only locally, as in the oldest flows (map unit Qgr_1) along Middle Fork Johnson Creek), do the rocks contain opal, smectite, and in places quartz that reflect low-temperature hydrothermal alteration; such rocks can be difficult to distinguish from Tertiary andesite, but the presence of clots, as well as general field relations, enables their identification.

Interbedded with lava flows are diamictites generally consisting wholly of clasts derived from the flows themselves. Rarely, especially low in the section, clasts of Tertiary rocks are mixed with those of young andesite. The diamictites are probably deposits of debris flows (lahars) that moved down valleys during or between eruptions. Some diamictites, particularly at high elevations, could be till left by glaciers on the flanks of Goat Rocks volcano. A few faceted clasts found in diamictites on ridges near Heart Lake could be till stones, but no buried pavements were recognized. Moreover, the facets on the clasts could be prismatic cooling-joint surfaces rather than glacial abrasion features.

Contact relations—The lava flows and interbedded diamictites overlie the tilted Tertiary rocks with marked erosional unconformity. One of the best places to see the contact is on the well-exposed north side of Jordan Basin, where flows fill a 200–m–deep channel eroded into Tertiary andesite. A 300–m–deep paleocanyon is exposed on the north side of the divide between Jordan and Middle Fork Johnson Creeks; it is best seen from Angry Mountain. The steep side of a 200–m–deep gorge is easily walked out in the forest just north of Glacier Lake. A 340–m–deep, almost vertically walled, gorge in a rhyodacitic to granodioritic sill (map unit Tri) is filled with andesite flows along the west edge of map area and in the adjoining Packwood quadrangle, 4.5 km due west of the north end of Packwood Lake. This gorge, mostly exposed in cross section along a conspicuous cliff, is readily apparent in good lighting from many places along the northwest side of the Cowlitz valley.

The section of lava flows not only rests erosionally on the Tertiary rocks but has many striking erosional unconformities within itself. These intraformational unconformities are generally not apparent during casual observation but can be defined by detailed mapping and especially by determination of the magnetic polarity of the flows in the field using a portable fluxgate magnetometer. Good examples of erosional unconformities between the magnetostratigraphic units are present: 1) on the east end of Angry Mountain, where flows of the upper normal unit (map unit Qgr_3 fill a canyon eroded 300 m into the reversed unit (map unit Qgr_2); 2) on the north side of Glacier Creek just west of Lily Basin, where flows of the upper normal unit occupy a valley cut 450 m into the reversed flows; 3) on the north side of Snyder Mountain north of Johnson Peak, where flows of the upper normal unit fill a valley eroded nearly 600 m through the reversed part of the section into the lower normally polarized flows (map unit Qgr_1); and 4) about 1.5 km northwest of Mosquito Lake, where a channel about 200 m deep was cut into the reversed flows and filled by the younger normal flows. Clearly these and other erosional unconformities in the section signify periods of canyon cutting between eruptions and indicate one or more vigorous periods of erosion contemporaneous with development of the Goat Rocks center. Whether contemporary glaciation aided the rapid erosion is an interesting speculation.

Perhaps the most striking erosional unconformity within the section is the least obvious. Mapping of the magnetostratigraphic units shows that the upper normal unit is found chiefly in distal locales but is generally absent in proximal areas, where the reversed flows dominate. The upper normal unit had to have been present in proximal sites at one time but has been eroded away. This erosion raises an issue that cannot be entirely resolved. Did the upper normal flows overlie the presently exposed reversed flows before being stripped away, or did they occupy canyons incised into the reversed flows that have been enlarged to form what are now the modern valleys? The latter interpretation seems most reasonable and general given the abundant evidence for intraformational erosion, but in places stripping of conformable flows may have occurred.

Post-eruption erosion and age of flows—Erosion has inverted topography since even the youngest flows were erupted. With some exceptions noted below, flows now cap ridges that were valleys at the time of eruption. This erosion has been severe and has created relief greater that that before or during the eruptions. Valleys and canyons are incised hundreds of meters beneath the highest preserved flow. The depth of the valley is greatest along Upper Lake Creek, more than 800 m in places.

Most (but not all) of this erosion postdates the upper normal unit. This almost surely means that the vast majority of flows is older than the Hayden Creek Drift, variously thought by different workers to be about 300 ka, 140 ka, or 60 ka (Dethier, 1988; Colman and Pierce, 1981; Crandell, 1987). No drift of Hayden Creek age has been recognized on the flows, however. Instead, till of Evans Creek Drift, identified by the lack of significant weathering rinds on faceted fresh andesite stones in the till, is present in many places. Most likely Evans Creek glaciers eroded away till of Hayden Creek age.

Additionally, a pre-Hayden Creek age is *indicated* for most of the section, and *suggested* for the youngest, by the magnetic stratigraphy of the lava flows. The last time that Earth's magnetic field was reversed was about 780 ka. Thus the reversed and underlying normal sections are older than 780 ka, i.e. of Matuyama Chron age or older. A K-Ar age for the Tieton Andesite (Becraft, 1950; Swanson and others, 1989; Sparks and others, 1993), a distal flow in the reversed part of the section, is about 1 Ma, squarely in the late Matuyama (oral communication from S.M. Farooqui in 1977, as reported by Swanson [1978]).

Apparent continuity in eruptive activity and chemical composition (table 1, numerous analyses) suggests that the upper normally polarized flows are not vastly younger than 780 ka. This is in keeping with the generalization drawn by Hildreth and Lanphere (1994) that large stratocone systems such as Goat Rocks grow in spurts but generally remain active in the broad sense for 500,000 years but probably not much more. So too is the interpretation that the lower, normally polarized section belongs to either the Jaramillo (0.99–1.07 Ma) or the Cobb Mountain (1.21–1.24 Ma) Subchrons of the Matuyama, rather than to an older normal event (Olduvai Subchron, 1.77–1.95 Ma; Reunion Subchron, 2.14–2.15 Ma) or to a pre-Matuyama (>2.6 Ma) period of normal polarity (Berggren and others, 1995; Cande and Kent, 1992, 1995; Izett and Obradovich, 1994; Mead, 1996).

Finally, the heart of Goat Rocks volcano, in the basin of Upper Lake Creek just east of the quadrangle, is so deeply eroded that considerable time and erosive power seem required to reduce the edifice so drastically in a few hundred thousand years. If a substantial part of the main edifice were younger than Hayden Creek, the problem of enough time and power would be greatly exacerbated.

Flows possibly younger than Hayden Creek Drift—Several flows are or may be younger than the rest of the section and could postdate the Hayden Creek. One set of flows (map unit Qgrh) comprises hornblende-porphyritic, normally magnetized flows, three remnants of which hang on the southeast side of Angry Mountain. An andesite flow (table 1, no. 7) forms a bench against Tertiary andesite about 200 m above the modern course of Middle Fork Johnson Creek. This is well within the valley thought to have been excavated or at least greatly widened by glaciers of Hayden Creek age. A silicic dacite flow (table 1, no. 28) occupies a channel eroded about 250 m into map unit Qgr_3 about 300 m above the valley floor. The third remnant is a rhyodacite flow and attached feeder plug (or perhaps a platy intracanyon flow) (table 1, no. 31) 1 km west of Heart Lake. This flow rests directly on reversed flows yet partly mantles the side of the modern canyon.

These three lava-flow remnants might have survived erosion during Hayden Creek time. They could have entered a pre-Hayden Creek valley and be only leftovers from those events. Perhaps equally possible, they could have flowed down a canyon after the Hayden Creek glacier had receded, only to have been almost totally removed by later erosion, particularly during Evans Creek time. This possibility requires much (too much?) erosion since the Hayden Creek. On this basis I favor a pre-Hayden Creek age but cannot discount a younger one.

The dacite of Jordan Creek (map unit Qdj; table 1, nos. 27 and 29–30) is more likely to be of post-Hayden Creek age than unit Qgrh. It occurs low in the valley of Middle Fork Johnson Creek, only 150 m above the modern stream. The vent location for this flow is uncertain but is probably in the Goat Rocks center (Swanson, 1996). The dacite is chemically similar to the two most silicic flows of unit Qgrh (table 1, compare nos. 27 and 29–30 with nos. 28 and 31) but lacks hornblende phenocrysts and so cannot be a direct correlative. Even this flow is overlain by till of Evans Creek age.

The third unit that may be younger than Hayden Creek is the andesite of Clear Fork Cowlitz River (map unit Qacf), which occurs in two small outcrop areas in the extreme northeast corner of the quadrangle. The vent for this flow is on the ridge just north of Coyote Lake 1 km southeast of Lost Hat Lake (Ellingson, 1968, 1972; Hammond, 1980; Swanson and Clayton, 1983). This vent is peripheral to Goat Rocks volcano itself but can be considered as part of the Goat Rocks volcanic center in the broad sense. The flow ends along the Clear Fork Cowlitz opposite the mouth of Cortright Creek, 8 km northwest of its outcrops in the quadrangle. The andesite may have ponded against a levee of its own making or perhaps against a remnant of the Hayden Creek glacier remaining in the Cowlitz valley, as suggested by Hammond (1980). Another possibility is that ancestral Cortright Creek was such a raging torrent that the flow was continually disrupted as it slowly poured into the creek. The terminus in this interpretation would reflect the dynamic interplay of water and lava, not static ponding against a topographic barrier. The andesite flow is overlain by till of Evans Creek age along its entire length. Striking long columns characterize the flow and are the object of the Palisades Viewpoint along U.S. Highway 12.

Just south and east of the quadrangle obviously post-Hayden Creek (but pre-Evans Creek) andesite flows (the andesite of Old Snowy Mountain) were erupted from the Old Snowy Mountain-Ives Peak area in the Goat Rocks volcanic center, somewhat south of the core of Goat Rocks volcano itself. They occupy the floor of the modern Cispus River and Goat Creek in the eastern part of the Hamilton Buttes quadrangle (Swanson, 1996). Several flows of the andesite of Old Snowy Mountain moved down Upper Lake Creek, though none is left in the Packwood Lake quadrangle; a remnant occurs only 250 m east of the quadrangle, barely 20 m above modern creek level. These flows show clearly that the Goat Rocks volcanic center was active in post-Hayden Creek time, whether or not the flows of map units Qgrh and Qdj are of that vintage.

Dikes—Six fresh, normally magnetized dikes of pyroxene andesite or mafic dacite similar to the flows from Goat Rocks volcano were recognized in the quadrangle, and more occur just east of the map area in the Old Snowy Mountain quadrangle. Four of the dikes—three northwest of Johnson Peak and one west of Jordan Basin—cut the magnetically reversed flows and so belong to the upper normal section. The other two dikes, west of Jordan Basin, cut only Tertiary andesite and could be related to the lower normal unit, though it seems more likely that they are younger.

All of the dikes are vertical, horizontally columnar, and 2–4 m wide. They are readily recognized by their dark, woodpile-stacked columns that stand out starkly in the mountain meadows. No evidence was found that the dikes vented, but all are glassy and probably are within a few tens of meters of the paleosurface.

The dikes are part of a radial swarm around Goat Rocks volcano. This swarm, shown on the generalized map of Swanson and Clayton (1983), focuses on the basin of Upper Lake Creek and is one of the reasons for believing that the core of Goat Rocks volcano was centered here.

Andesite of Angry Mountain—Two small remnants of what is probably one columnar vitrophyric andesite flow cap the northwestern part of Angry Mountain. The flow is reversely magnetized. It contains scattered clots of gabbro and diorite. No source vent for the flow has been identified. The rock more closely resembles the flows from Goat Rocks volcano than any other in the quadrangle and may be an outlier of map unit Qgr_2.

If the andesite flow was indeed erupted from the volcano, what path did it take to get here? The base of the highest cap is at about 5200 ft elevation. The nearest remnant of unit Qgr_2 is about 4 km farther east (2 km west of Heart Lake), at an elevation of 4400–6000 ft. If the andesite of Angry Mountain once connected to the Heart Lake remnant, it would be at most 800 ft (240 m) below any possible correlative flow, assuming no erosion. The resulting maximum straight-line gradient, about 60 m/km, is less than that of much of the section of intracanyon flows but is nonetheless quite high. Given a lessening of stream gradient away from the Goat Rocks center, the andesite of Angry Mountain could reasonably have been once connected, by an unknown though probably fairly straight course, to the Heart Lake remnant.

QUATERNARY SEDIMENTARY DEPOSITS

Glacial deposits—Drift, chiefly till but including probable glaciofluvial deposits in valleys, is extensive in the quadrangle. The thickness of weathering rinds on andesite stones in the drift was examined in many places and is less than 1 mm consistently. This evidence indicates that the drift is of Evans Creek age, about 20 ka.

Many small lakes and ponds in the quadrangle result from glaciation. Heart Lake, Lost Lake, Lost Hat Lake, and unnamed ponds on Beargrass Butte, Angry Mountain, and Snyder Mountain all occupy cirques of Evans Creek age.

Landslide deposits (map unit Qls)—Landslides are common and responsible for the two largest lakes in the quadrangle, Packwood Lake and Glacier Lake.

Another small pond, Beaver Lake along Coal Creek in the northeast corner of the quadrangle, may be trapped by a rock-fall or debris-flow deposit from the steep valley sides. Distant observations from the north of this area in June 1996 noted several large debris flows from both the east and west sides of Coal Creek that resulted from exceptionally heavy rainfall in early February. One or more similar debris flows might have formed Beaver Lake.

Packwood Lake landslide—The slide that dammed Lake Creek to form Packwood Lake involved both volcaniclastic rocks interbedded with silicic sills of unit Tri and overlying andesite flows from Goat Rocks volcano. Blocks of all lithologies can be easily observed along the foot trail to the lake and along the aqueduct and associated access trail north of the lake.

The landslide covers about 5.5 km^2 and probably has a volume of 0.6–1 km^3, though the preexisting topography is too poorly known to make this a firm estimate. The landslide swept eastward across the creek and rode up the opposite valley wall at least 120 m before turning downstream. It eventually transformed into a debris flow that doubtless reached the Cowlitz River. Unmapped probable remnants of the debris flow occur along Lake Creek well into the Ohanapecosh Hot Springs quadrangle.

Rising water behind the landslide dam inundated a forest. Two standing snags of this forest appear above lake level northwest of the island (Agnes Island on Forest Service maps) during low-water season (early autumn). In 1988 R.L. Schuster (written and oral commun., 1993 and 1994) sampled wood from the outer part of each snag (no bark was preserved) and obtained ^{14}C ages of about 970 ± 60 yr and 1140 ± 60 yr for the two snags. Schuster believes the younger age could reflect erosion of rings, so he prefers the older age.

Upstream from the lake is a deposit of mud that can be treacherous to walk on owing to its saturated, thixotropic properties. The mud is laminated in many creek banks. It seems likely that the mud is lake sediment deposited behind the landslide dam before the dam was overtopped and water level dropped to its present position (maintained slightly higher than its natural level by a low dam). This mud is crudely mapped as unit Qs; its upstream limit is shown only schematically on the geologic map. The mud would be a good place to search for organic material to check the radiocarbon ages of the snags.

Glacier Lake landslide—The gravitational failure of northeast-dipping, fine-grained volcanic sandstone and tuff led to a landslide that dammed Glacier Creek and formed Glacier Lake. The lake currently occupies a closed basin and drains underground through the slide deposit, emerging at the surface in a large spring near the toe of the slide more than 1 km downstream (the drainage shown on the topographic map reflects surface runoff rather than lake water). Comparatively few trees grow on the deposit near the lake, owing to its rocky and permeable nature.

Glacier Lake is unlike other lakes in the mapped quadrangles, because a large log raft floats on its surface, its location varying with the wind. In this respect the lake is a miniature Spirit Lake near Mount St. Helens. Perhaps many of the logs in this raft are trees swept up by the slide and carried into the lake. The floating logs suggest that the landslide is relatively young. In 1988 R.L. Schuster sampled wood from a barkless snag in the lake and obtained a ^{14}C age of 660 ± 60 yr (written commun., 1993).

A deposit of well laminated or varved mud (map unit Qs) occurs upstream and along the east margin of the lake. The deposit is at least 7 m thick. It most likely is sediment deposited during the high stand of the lake before its underground outlet was established and water level dropped to a stable height.

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. Mostly Holocene and very late Pleistocene. Locally includes colluvium, 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 especially drift

Qf **Alluvial fan deposits (Holocene or Pleistocene)**—Poorly bedded and sorted alluvial deposits, in part debris flows, at mouths of two small tributaries of Upper Lake Creek. Holocene or very late Pleistocene. May include 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. Mostly Holocene and very late Pleistocene. Packwood Lake formed behind large landslide probably 1100–1200 radiocarbon years ago. Glacier Lake was dammed by slide deposit perhaps about 650 radiocarbon years age and now drains underground through the slide deposit. (Ages from R.L. Schuster, written commun., 1994). Locally includes colluvium, particularly talus, and drift

Qs **Lake mud (Holocene and Pleistocene)**—Massive to thinly stratified, unconsolidated mud and less abundant fine-grained sand upstream from both Glacier and Packwood Lakes. Interpreted as deposits from high stand of each landslide-dammed lake before present outlets formed. Mud deposit near Glacier Lake is particularly well bedded, perhaps varved. Deposit along low-gradient Upper Lake Creek probably includes modern deltaic silt; contact with fine-grained fluvial alluvium shown only schematically on map. At least 7 m thick at Glacier Lake and 4 m at Packwood Lake

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 possibly a relatively old landslide deposit west and southwest of Packwood Lake

YOUNG LAVA FLOWS AND RELATED DEPOSITS

Qacf **Andesite of Clear Fork Cowlitz River (Pleistocene)**—Gray, fine-grained flow with sparse, small, generally oxidized hornblende phenocrysts. Underlies two small areas along northeast edge of map area. Erupted from vent on ridge just north of Coyote Lake 1 km southeast of Lost Hat Lake (Ellingson, 1968, 1972; Hammond, 1980; Swanson and Clayton, 1983). Flowed along ancestral Clear Fork Cowlitz River and ponded to become strikingly columnar, as seen from scenic Palisades Viewpoint on Highway 12 (White Pass highway). Silicic andesite chemically (Clayton, 1983, p. 200, sample CFCCF-1). Occupies U-shaped valley probably carved by glacier of Hayden Creek age. Overlain by till of Evans Creek Drift

Qdj **Dacite of Jordan Creek (Pleistocene)**—Gray to pink, moderately to highly pyroxene-plagioclase-porphyritic, silicic dacite flow that forms crest of ridge north of Jordan Creek and spills into valley of Middle Fork Johnson Creek. About 60 m thick. Columnar basal zone several meters thick but otherwise platy. Contains crystalline clots of plagioclase and two pyroxenes 1–2 mm in diameter. Scattered xenocrysts of quartz. Chemically a dacite to rhyodacite with 67–68 percent SiO_2 (table 1, nos. 27 and 29–30). Probably an intracanyon flow erupted from Goat Rocks volcanic center; chemically resembles some late-stage hornblende-bearing flows from Goat Rocks (table 1, nos. 28 and 31). Normal magnetic polarity. Covered with Evans Creek Drift. Likely younger than Hayden Creek Drift, because flow occurs in U-shaped valley probably eroded during Hayden Creek time

Qaa **Andesite of Angry Mountain (Pleistocene)**—Vitrophyric andesite (table 1, no. 11) in two small outcrops on northwestern crest of Angry Mountain. Columnar, with some columns more than 3 m long and 40 cm in diameter; many are subhorizontal. Phenocrysts are hypersthene, augite, plagioclase, and perhpas hornblende (oxidized to opacite). Sparse gabbroic, probably cognate, inclusions less than 1 cm in diameter. Magnetic polarity of northern cap is reversed; that of southern outcrop not determined, because columns are loose and probably rotated. Interpreted as two remnants of one flow, vent location for which is unknown. Resembles many flows from Goat Rocks volcanic center and may be erosional outlier of unit Qgr_2, though elevation of 5200 ft is quite high relative to that of nearest potential upstream equivalent (about 5800 ft nearly 4 km farther east along Angry Mountain)

Andesite and dacite lava flows and laharic breccia of Goat Rocks volcano (Pleistocene)—Mostly two pyroxene-plagioclase-phyric or, more commonly, vitrophyric lava flows that erupted from Goat Rocks volcano (Ellingson, 1968) and advanced down ancestral valleys and canyons radiating from the volcano. Some flows contain phenocrysts of hornblende, and most carry cognate(?) inclusions of gabbro or diorite, commonly 2–4 cm in diameter and subspheriodal in shape. Rubbly basal and upper zones. Thicknesses of single flows typically several tens of meters. Flows commonly separated by thin debris-flow deposits or, in higher proximal areas, possibly by till. Center of volcano, and probably its main vent area, lies 2–4 km east of Johnson Peak, as judged by locus of radial dike swarm (Swanson and Clayton, 1983). Chiefly silicic andesite and mafic dacite (table 1). Subdivided into four stratigraphic units on basis of magnetic polarity and erosional relations:

Qgrh **Late-stage hornblende andesite and dacite**—Normally magnetized hornblende-pyroxene-plagioclase-porphyritic lava flows in drainage of Middle Fork Johnson Creek. Flows erosionally overlie, and occupy canyons eroded tens to hundreds of meters into, older products of Goat Rocks volcano as well as Tertiary rocks. Remnants occur in three areas. Rhyodacite flow (table 1, no. 31) 1 km west of Heart Lake is connected to vertically platy feeder plug (or possibly a canyon fill) cutting reversely magnetized flows of unit Qgr_2. Silicic dacite flow (table 1, no. 28) occupies canyon eroded 250 m into rocks of normally magnetized unit Qgr_3 2.3 km west of Heart Lake. Remnant of andesitic intracanyon flow (table 1, no. 7) hangs on valley wall nearly 500 m below crest of Angry Mountain, 3 km west of Heart Lake. Dacite of Juniper Creek, though not hornblende-phyric, may be downstream equivalent of this late-stage unit. Age is probably post-Hayden Creek Drift, because intracanyon flows occupy U-shaped valley probably carved during that glaciation

Qgr_3 Upper normally magnetized lava flows—More than 450 m of dominantly vitrophyric, cognate-inclusion-bearing andesite and dacite flows filling canyons incised into older units, including older flows from Goat Rocks volcano. Unit occurs in distal areas of volcano (Snyder Mountain, Angry Mountain, ridge south of Lost Creek, and on ridge crest 1 km southeast of Lost Lake) but has been removed by erosion from proximal areas. Flows follow paleovalleys but not modern valleys and so are older than Hayden Creek Drift (probably about 0.14 Ma). They overlie reversely magnetized rocks of dated unit Qgr_2 and so are younger than about 0.78 Ma. Deep, steep-sided canyons were eroded into reversed flows and filled by unit, perhaps during one or more periods of pre-Hayden Creek glaciation. Includes normally magnetized dikes that cut rocks as young as unit Qgr_2 north of Johnson Peak and on ridge separating Jordan and Middle Fork Johnson Creeks. These dikes form part of radial swarm around Goat Rocks volcano (Swanson and Clayton, 1983)

Qgr_2 Reversely magnetized lava flows—Valley-filling flows totaling more than 500 m thick, dominantly vitrophyric, inclusion-bearing, and, except for reversed magnetic polarity, indistinguishable physically and chemically (table 1) from older and younger flows of Goat Rocks volcano. Less extensive distally than unit Qgr_3 but nonetheless present 500 m southeast of Lost Lake and along ridge between Mosquito Lake and Lost Creek. Erosional unconformity with Tertiary rocks strikingly revealed at west end of Jordan Basin, as can be seen from Goat Ridge just south of quadrangle. Regional work shows that Tieton Andesite, an 80-km-long flow that reached outskirts of Yakima (Swanson and others, 1989, p. 25; Sparks and others, 1993), is part of this unit; Tieton Andesite has an unpublished K-Ar age of 1 ± 0.1 Ma (oral communication from S.M. Farooqui in 1977, as reported by Swanson [1978])

Qgr_1 Lower normally magnetized flows—Valley-filling vitrophyric andesite and dacite flows and laharic breccia underlying unit Qgr_2 and erosionally overlying Tertiary rocks. In quadrangle occurs only in upper Middle Fork Johnson Creek, in one small area in Jordan Basin along east edge of map area, and about 2.5 km southeast of south end of Packwood Lake, but more extensive just east of quadrangle. More altered than most younger rocks, as noted by Swanson and Clayton (1983); quartz and opal common in breccia along Middle Fork Johnson Creek 500–700 m southwest of Heart Lake. Age uncertain. Normal magnetic polarity is consistent with pre-Matuyama age (i.e., about 2.6 Ma) or with one of the relatively brief periods of normal polarity within the Matuyama (Jaramillo [0.99–1.07 Ma], Cobb Mountain [1.21–1.24 Ma], Olduvai [1.77–1.95 Ma], or Reunion [2.14–2.15 Ma]) (ages are latest best estimates of Berggren and others [1995]; see also Cande and Kent [1992, 1995]; Izett and Obradovich [1994]; Mead [1996])

INTRUSIVE ROCKS

Tgl Gabbro of Lake Creek (Miocene or Oligocene)—Non-porphyritic, even-grained, hypidiomorphic to subophitic, two-pyroxene gabbro or mafic diorite forming much of ridge between Lake and Lost Creeks. Contains several percent groundmass quartz. One chemical analysis shows an unusually sodic, basaltic trachyandesite composition (table 1, no. 3). Another, fresher rock (table 1, no. 33) has a more normal basaltic or basaltic andesite composition. Fundamentally has sill-like form, with roof of units Tqt and Ttv preserved along much of ridge. More than 550 m thick. Locally has subvertical contacts, with scabs of hornfelsed tuff clinging to steep faces; good place to observe such relations is along contact 250 m east of site of analyzed sample 3. Quenched along contacts but elsewhere typically has grain size of 1–1.5 mm. Intrudes rocks as young as unit Tqt (about 24.8 Ma)

Tqdb Quartz diorite of Beargrass Butte (Miocene or Oligocene)—Complex intrusion of quartz diorite, andesite, and hornblende dacite forming Beargrass Butte. Two chemical analyses are andesite (table. 1, no. 34) and dacite (no. 35). Body may be fundamentally a sill at least 500 m thick, but contact relations are complex and indicate considerable cross-cutting of host rock. Marginal zones locally comprise narrow dikes between screens of host rock, as seen 1.2 km northwest of summit of Beargrass Butte and 0.7–1 km west of summit. Relations of hornblende-bearing rocks to rest of intrusion unclear. They are scattered through intrusion, having been found in several places on steep north side, in summit area, and best exposed in bed of Coal Creek 800 m downstream from Beaver Lake (table 1, no. 35). Locally as coarse as 2 mm. Contains scattered plagioclase phenocrysts in all rocks and plagioclase plus hornblende in the hornblende-bearing rocks. Quartz ubiquitous in wholly crystalline groundmass. Cuts rocks as young as unit Tqt

Tg **Gabbro (Miocene or Oligocene)**—Intrusion of medium-grained two-pyroxene gabbro or diorite along Lake Creek in northwest corner of quadrangle. Similar to unit Tgl but unconnected to it at present level of exposure. Probably cuts units Tip and Tri but relations uncertain

Tip **Glomeroporphyritic sill complex of Packwood (Miocene or Oligocene)**—Plagioclase glomeroporphyritic andesite and microdiorite forming columnar sills intruding unit Ttv northeast of Lake Creek and extending northwestward into 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 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 nearly aphyric rhyolite. Probably cut by unit Tgl. May grade into unit Tri; many outcrops could be assigned to either unit

Tri **Sill complex of dacite, rhyodacite, and related fine-grained quartz diorite and granodiorite (Miocene or Oligocene)**—Columnar, tan- to buff-weathering, sparsely to moderately plagioclase-porphyritic silicic sills in northwestern part of quadrangle. 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 in adjacent Packwood quadrangle range from mafic dacite to silicic rhyodacite. May grade into unit Tip; many outcrops could be assigned to either unit

Tdlh **Silicic dikes and sills of Lost Hat Lake (Miocene or Oligocene)**—White to gray, fine-grained, sparsely plagioclase-hornblende porphyritic dacite dikes and sills cutting unit Ttv near Lost Hat Lake. Light color makes unit stand out in cliffs and alpine meadows. Dikes are 1–3 m wide and trend roughly west. Sills are 1–6 m thick. Hornblende altered to green clay and oxides. The one chemical analysis available, from just east of quadrangle, is of dacite composition (66 percent SiO_2). Age relative to other intrusive units unknown

Taih **Sills of Hugo Lake (Miocene or Oligocene)**—Highly and commonly coarsely plagioclase-phyric basalt, basaltic andesite, and lesser diabase and microdiorite forming several sills cutting arkose of Chambers Creek and stratigraphically higher volcaniclastic rocks. Northern end of swam prominent in Hamilton Buttes quadrangle (Swanson, 1996). Typically columnar jointed and 4–7 m thick. Phenocrysts of plagioclase 3–6 mm long, and a few glomerocrysts as much as 10 mm or more across, form 10–30 volume per cent of rock. Phenocrysts of pyroxene (both hypersthene and augite) generally make up a few per cent. From glassy (now devitrified) or very fine-grained margins, grain size increases toward interior, reaching 1–2 mm in coarsest microdiorite. Chemical analysis is basaltic (table 1, no. 2); other analyses in Hamilton Buttes quadrangle range from basaltic to mafic andesite (Swanson, 1996). The more mafic rocks commonly have high contents of Al_2O_3 and CaO, suggestive of plagioclase accumulation. Several dikes of unit Tai are highly plagioclase porphyritic and are likely related to the sills of Hugo Lake; an example is analysis 1 in table 1

Tai **Andesite and basaltic andesite intrusions (Miocene and Oligocene)**—Dikes, sills, and fewer small hypabyssal intrusions of aphyric and one- or two-pyroxene-plagioclase-phyric basaltic andesite and andesite. Typically fine- to medium-grained and texturally resembles lava flows (map unit Ta). Sills have columnar jointing normal to contacts, quenched margins, and thicknesses of 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 map unit Ta, but many dikes could be younger and have fed flows now eroded away. Compositions range from basalt to silicic andesite (table 1, nos. 1, 4–5, 13; no. 1 probably represents a dike of unit Taih). Portrayal of dike swarm opposite mouth of Deception Creek greatly simplifies very complicated, dike-on-dike area that may actually be one intrusive body with numerous pulses of injection. These dikes, and others on Angry

Mountain, may be related to Angry Mountain eruptive center

LAVA FLOWS AND VOLCANICLASTIC ROCKS

Ttv Volcaniclastic rocks (Oligocene and Eocene)—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. However, well-bedded sandstone dominates the section in the quadrangle, although lithic diamictite and tuffaceous rocks are prominent in younger part of section. 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 cross bedding, channels, and both normal and inverse size grading common. Clasts are almost entirely of volcanic derivation, chiefly basaltic andesite and andesite but including more silicic rock types. Some beds low in the section are mixtures of volcanic and arkosic detritus. Fossil wood, chiefly 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. 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. Uncommonly welded. 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, but air-fall tuff interbedded with middle part of arkose of Chambers Creek (map unit Tsc) in Hamilton Buttes quadrangle (Swanson, 1996) yielded zircon fission-track age of 35.9 ± 0.7 Ma (Winters, 1984), late Eocene according to Cande and Kent (1992) and Odin and others (1991). Top of unit could be early Miocene age, but unit Tqt, near top of section, is late Oligocene.

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

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. Lithic inclusions several centimeters in diameter locally abundant. 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 more than 60 m in places. Rhyolitic composition (table 1, nos. 32 and 38), as well as two other analyses in neighboring Packwood quadrangle). Outstanding marker unit in northern part of quadrangle and adjacent Ohanapecosh Hot Springs quadrangle. Two ages available for unit, both from prominent cut along U.S. 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 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)

Tbg Breccia of Glacier Lake (Oligocene)—Breccia of volcanic rock fragments forming deposit more than 240 m thick best exposed in southwest-facing cliff on ridge just southeast of Glacier Lake. Bedding absent in most places and vague in others, except for tuff beds toward top of section. Crude partings in breccia, defined by joints and some elongate clasts, simulate bedding in places and suggest vague north to northeast dip of about 30°. Clasts are as large as 4–6 m across, though generally 0.5–1 m maximum, and generally angular. Mostly framework disrupted but local pockets a few meters across are framework supported. Interpreted as crater filling, or very proximal near-vent deposit, of Angry Mountain center. Contacts only approximate; unit may well extend north of lake and Glacier Creek. Thick lava flows surround unit, but nowhere was contact seen

Ta **Andesite, basaltic andesite, and basalt lava flows (Oligocene)**—Fine- to medium-grained, highly plagioclase-phyric (>20 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 on Angry Mountain (an old eruptive center), on ridge between Middle Fork Johnson and Jordan Creeks (part of Angry Mountain center), and along both sides of Upper Lake Creek. 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 plagioclase-hypersthene-clinopyroxene (minerals 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. The one chemical analysis from quadrangle is mafic dacite (table 1, no. 20), but probably most flows are basaltic andesite and andesite, to judge from more extensive chemical data in previously mapped quadrangles. Dikes and other intrusions of map unit Tai probably fed some flows in this unit. Interbedded with volcaniclastic rocks (map unit Ttv) and includes volcaniclastic beds too thin to map separately

Trj **Rhyodacite of Jennings Creek (Oligocene)**—Fine-grained, gray to blue-gray, moderately plagioclase-phyric rhyodacite (table 1, no. 36) lava flow forming circular hill in headwaters of Jennings Creek. Plagioclase is milky. Calcite veins cut rock. Strong normal magnetic polarity. Oxidized in places. Probably vent area, but glaciation has removed any tephra once present. Interpreted as part of Tertiary section, but could be younger, perhaps Pliocene or Pleistocene, as suggested by J.G. Smith (oral commun., 1987)

Trd **Rhyodacite dome (Oligocene)**—Platy, rather fine-grained, sparsely plagioclase-phyric rhyodacite (table 1, no. 37) forming steep slope between Packwood Lake and Mosquito Lake. Tan to buff weathering. Disintegrates to form extensive scree slopes because of platy jointing. Contains oxidized pyrite in places, and locally is strongly altered hydrothermally. Could be plug or other intrusion but interpreted as extrusive dome in section composed dominantly of andesite

ARKOSE AND RELATED SEDIMENTARY ROCKS

Tsc **Arkose of Chambers Creek (Oligocene and Eocene)**—Well-bedded, typically micaceous arkose and lesser pebble conglomerate, siltstone, and mudstone. Channels, cross bedding, and ripple marks common. Designated as the *Chambers Creek beds* by Winters (1984), who provides thorough description of unit. Some beds mixed with volcaniclastic detritus, and many pebbles in conglomerate are locally derived. Interbedded with volcanic sandstone of unit Ttv. Paleocurrent directions in arkose indicate westward and southwestward river transport. Heavy mineral suite indicates provenance in moderate-grade metamorphic rocks of northern or northeastern Washington. Generalized map portrayal greatly simplifies complex interbedding and mixing with volcaniclastic detritus of unit Ttv. More extensively esposed in Hamilton Buttes quadrangle (Swanson, 1996)

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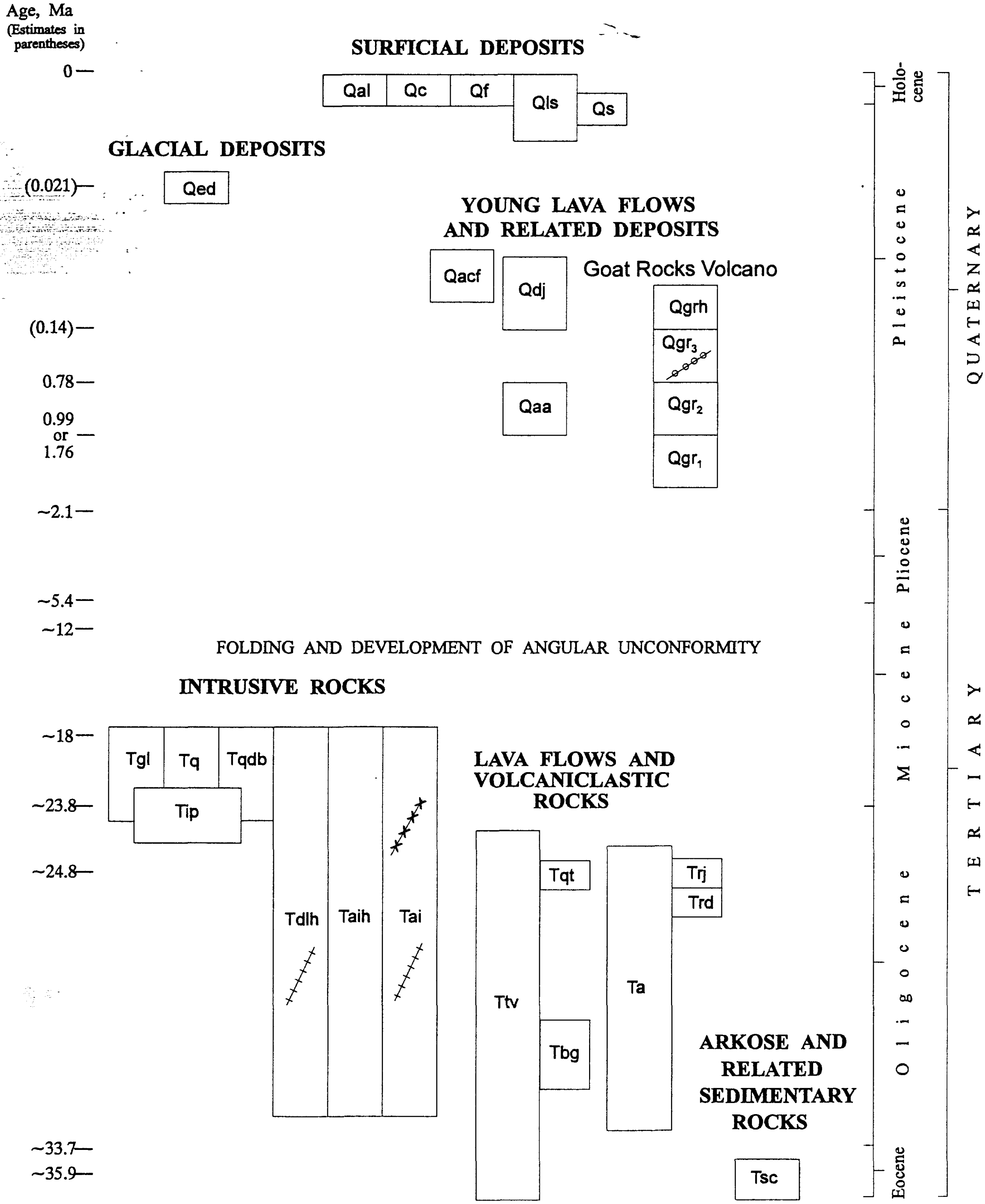
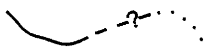
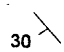
CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

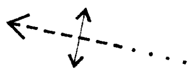

Contact, dashed where approximately located, queried where uncertain, dotted where concealed


Schematic contact between units Qs and Qal in Upper Lake Creek valley



Strike and dip of bedding and flow contacts

Folds, dashed where approximately located, dotted where concealed

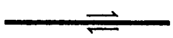

Trace of axis of anticline, showing direction of plunge

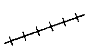

Trace of axis of syncline, showing direction of plunge

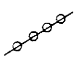
Faults, dashed where approximately located


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


Thrust fault, barbs on hanging wall


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


Dike of andesite and basaltic andesite of units Tai, Taih, and Tdlh


Dike of unit Qgr_3


Prominent thin sill of glomerophyric andesite on Coal Creek Mountain

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