U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Geologic map of the East Canyon Ridge quadrangle, southern Cascade Range, Washington

by

Donald A. Swanson[1]

Open-File Report 94–591

[1]U.S. Geological Survey, Department of Geological Sciences AJ-20, University of Washington, Seattle, Washington 98195

CONTENTS

FIGURES

TABLES

PLATES

Geologic map of the East Canyon Ridge quadrangle, southern Cascade Range, Washington

by Donald A. Swanson

INTRODUCTION

The East Canyon Ridge 7.5–minute quadrangle is centered about 40 km east-northeast of Mount St. Helens, 15 km northwest of Mount Adams, and 12 km west of the crest of the Cascade Range in southern Washington (fig. 1). It is the most recent in 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, and Blue Lake quadrangles (Swanson, 1989, 1991, 1992, 1993) and finished but not yet compiled for the Hamilton Buttes quadrangle (D.A. Swanson, unpublished mapping, 1993). I plan to complete the mapping of the Tertiary rocks in the Green Mountain quadrangle in 1994; Hildreth and Fierstein (in press) have already mapped the Quaternary rocks there. Also in 1994 I plan to map those parts of the Purcell Mountain and Packwood quadrangles that are south of the Cowlitz River. Richard B. Moore will be mapping north of the river, and a geologic map of the Randle quadrangle, prepared jointly with Moore and Carl Thornber, is nearly completed.

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 or early Oligocene. A primary goal has been to tie the Tertiary stratigraphy of the area near and west of Mount St. Helens (Evarts and Ashley, 1984, 1990a, 1990b, 1991, 1992, 1993a, 1993b, in press a and b; Evarts and others, 1987; Swanson, 1989, 1991, 1992, 1993) 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 the southern Washington Cascades and defining a geologic research corridor across the west side of the Cascade Range (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) 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 will provide geologic support for seismic and other geophysical surveys in a corridor linking coastal Washington with the Columbia Plateau, now planned for fiscal year 1995 and possibly 1996 (Wells and others, 1993). Detailed field work is testing 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 quadrangles that I have studied lie either within the SWCC or astride its margin.

The East Canyon Ridge quadrangle drains principally into the Cispus River (fig. 2), a trunk stream carrying water from the north side of Mount Adams and the west side of the rugged Goat Rocks Wilderness into the Cowlitz River. The Lewis River drains the southern part of the quadrangle and flows directly into the Columbia River. East Canyon Creek is a major stream in the quadrangle; for this paper, it is divided into upper and lower segments, the upper flowing along strike to about the mouth of Summit Prairie Creek and the lower segment flowing across structure from there to its mouth at the Cispus River.

Roads follow most major drainages in the quadrangle, and logging roads in various conditions climb some steep slopes. Many of the roads are not shown on the quadrangle map. Access is by foot trail in the upper Summit Prairie Creek–Quartz Creek–Pin Creek area. The west and northeast parts of East Canyon Ridge have neither roads nor trails.

Oligocene and early Miocene volcaniclastic and volcanic rocks, mainly of basaltic andesite and andesite composition (table 1), underlie most of the quadrangle. Many Tertiary intrusions, mostly sill-like and commonly silicic, cut the layered rocks. Pleistocene dacite flows barely entered the eastern part of the quadrangle from nearby vents. Late Pleistocene basalt issued, typically explosively, from several vents near Spud Hill. Late Pleistocene basalt and basaltic andesite flooring the Cispus valley was erupted from north of Mount Adams.

Glacial drift covers large areas, but generally bedrock crops out along creeks, steep slopes, and ridges. The bedrock mapping involved traverses along most drainages, large and small; such work finds many exposures, even in densely forested terrain. The area is downwind from Mount St. Helens but so far away that tephra is less than a few centimeters thick and poses no problems for mapping bedrock.

Previous small-scale (1:100,000 and smaller) reconnaissance geologic mapping for regional purposes has included the East Canyon Ridge quadrangle, mainly by Hammond (1980), Korosec (1987), and J.G. Smith (1993 and an unpublished map of the Yakima 2–degree sheet). A 1:24,000–scale map accompanies Harle's (1974) thesis study of the Council Bluff area.

ACKNOWLEDGMENTS

Wes Hildreth, Willie Scott, and Richard Waitt offered needed advice for interpreting several features along the Cispus valley. Mike Korosec kindly provided field maps and chemical analyses that he used in preparing his regional geo-

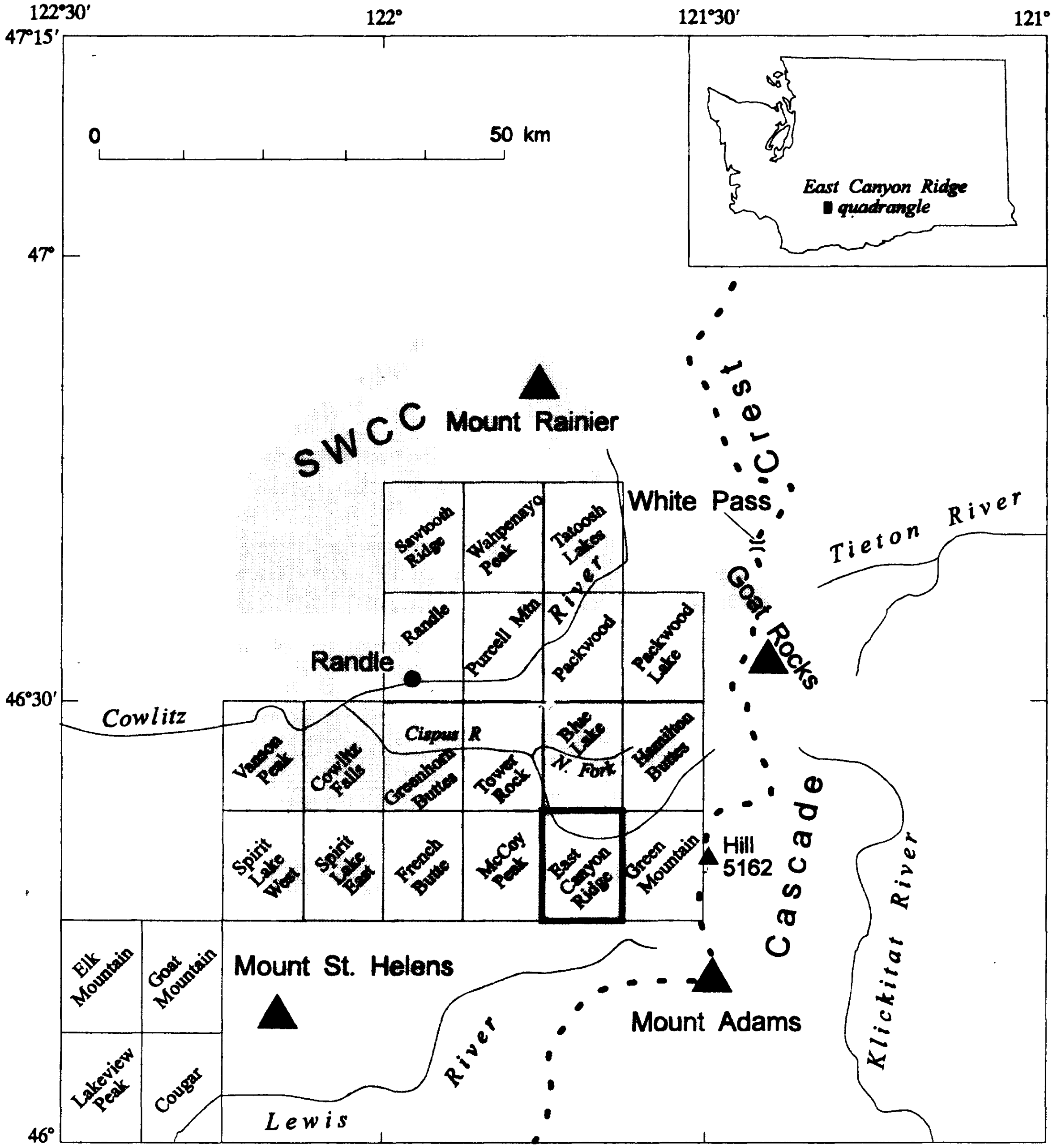


Figure 1. Index map showing location of East Canyon Ridge quadrangle relative to the three Holocene and late Pleistocene composite volcanoes in southern Washington, crest of Cascade Range, Pleistocene-Pliocene volcano at Goat Rocks, Southern Washington Cascades Conductor (SWCC: see text), and other 7-1/2' 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.

logic map (scale 1:100,000; Korosec, 1987). Rick Conrey and Paul Hammond arranged for several chemical analyses. Russ Evarts made valuable comments during a field trip in 1992. Mac Rutherford (Brown University) and his students, Sarah Kirn and Eric Tohver, helped me find the Kidd Creek dikes cutting the rhyolite of Spud Hill and had valuable comments to make about the rhyolite. Barbara White (my wife) provided logistic help on several long traverses. Three programs within the U.S. Geological Survey have supported my research—National Cooperative Geologic Mapping (the principal sponsor), National Earthquake Hazards Reduction, and Deep Crustal Studies. Wendell Duffield and Norman Banks reviewed and improved the map and text.

ROCK TERMINOLOGY AND CHEMICAL CLASSIFICATION

For consistency, this section follows exactly the format of comparable sections in previous open-file reports, including all of the figures. This consistency enables ready comparison with data in the other reports.

I followed the same classification scheme used in previous open-file reports—the IUGS system (Le Bas and others,

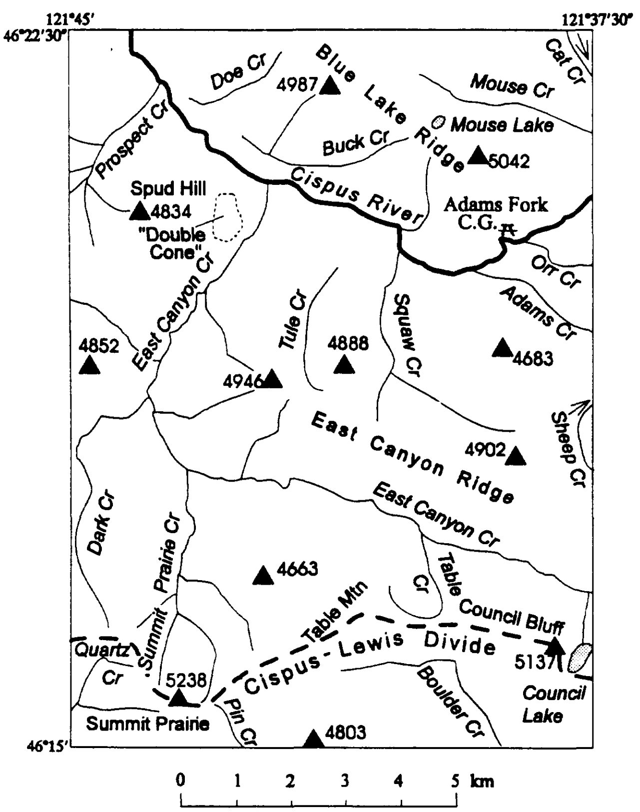


Figure 2. Map of East Canyon Ridge quadrangle showing locations of geographic features mentioned in text.

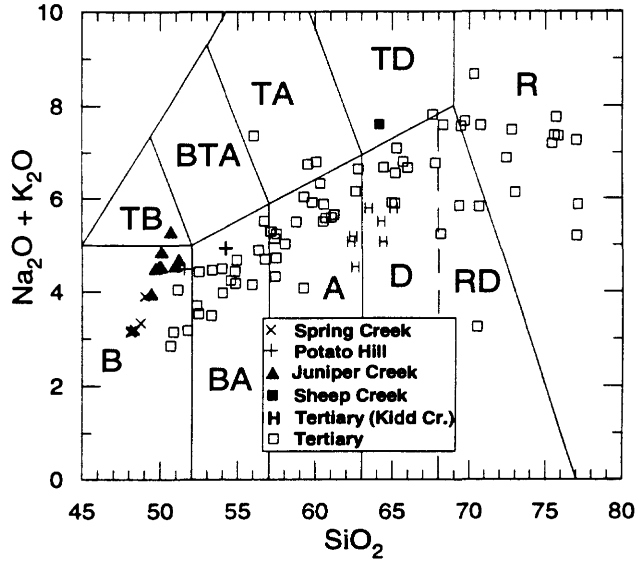


Figure 3. Total alkali-silica classification diagram for chemical analyses from the East Canyon Ridge quadrangle, modified from Le Bas and others (1986) to include field for rhyodacite. B, basalt; BA, basaltic andesite; A, andesite; D, dacite; RD, rhyodacite; R, rhyolite; TB, trachybasalt; BTA, basaltic 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). Extreme values of alkalies represent altered rocks either enriched or depleted in Na_2O. Quaternary rocks, in order of increasing age, are: basalt of Spring Creek (map unit Qbs), basalt of Juniper Creek (map unit Qbj) and its chemical correlatives (map units Qbe and Qbws), basalt and basaltic andesite of Potato Hill (map unit Qbap), and dacite of Sheep Creek (map unit Qds).

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 per cent SiO_2), *basaltic andesite* (52–57 per cent SiO_2), *andesite* (57–63 per cent SiO_2), *dacite* (63–68 per cent 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). These samples 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 rare quartz and no olivine), 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. Hornblende occurs only in the intrusive suite of Kidd Creek, the composition of which is silicic andesite and dacite (Marso and Swanson, 1992).

Several samples show evidence of alkali removal during alteration. Sample 85 (table 1; $Na_2O + K_2O = 3.24$; $SiO_2 = 70.50$) is a hydrated ash-flow tuff that probably lost both Na_2O and K_2O during alteration. Samples 96 ($Na_2O + K_2O = 5.20$; $SiO_2 = 77.01$) and 97 ($Na_2O + K_2O = 5.87$; $SiO_2 = 77.11$) probably lost Na_2O during hydration. In general the wide scatter in amounts of total alkalies at high silica contents may reflect gains and(or) losses during hydration. Sample 36 ($Na_2O + K_2O = 7.36$; $SiO_2 = 56.04$) plots well inside the trachyandesite field for no obvious petrographic reason; the analysis is being redone, for the values for CaO and Na_2O could have been interchanged inadvertently during tabulation in the laboratory.

Samples with thin sections but no chemical analyses can be roughly classified by their phenocryst assemblages and groundmass textures (fig. 4). In all, 124 samples from the East Canyon quadrangle were sectioned (fig. 5); of these, 86 samples were chemically analyzed (table 1). In addition, table 1 includes five chemical analyses previously published by Korosec (1987) and three analyses from Hammond and Korosec (1983). These additional analyses, as well as the three indicated in table 1, were done in the XRF laboratory of the Geology Department at Washington State University.

The Tertiary suite is calcic (Peacock, 1931). Its alkali-lime index is about 61.8 (fig. 6), slightly less than the range of 62.3–63.1 in the previously mapped quadrangles. This difference is probably not significant.

Most of the chemically analyzed Tertiary rocks, except those of the hornblende-bearing intrusive suite of Kidd Creek (H in figure 7) and a few others, are tholeiitic on a plot of FeO*/ MgO vs. SiO_2, according to the classification

Table 1. Chemical analyses from the East Canyon Ridge 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	Qbs	92-009	47.8	1.41	16.7	2.84	8.33	0.18	9.18	9.95	2.82	0.29	0.20	0.33	0.10	0.00	100.13	48.08	1.42	16.80	10.95	0.18	9.23	10.01	2.84	0.29	0.20	3.13	1.19	121	39.60	46	19.97
2	Qbs	90-122	47.9	1.44	16.5	1.51	9.71	0.18	8.91	10.20	2.86	0.29	0.18	0.12	0.15	0.00	99.95	48.13	1.45	16.58	11.12	0.18	8.95	10.25	2.87	0.29	0.18	3.16	1.24	121	43.92	46	21.74
3	Qbs	92-006	47.9	1.41	16.6	4.69	6.85	0.19	8.64	10.30	2.86	0.27	0.17	0.09	0.12	0.00	100.09	48.18	1.42	16.70	11.14	0.19	8.69	10.36	2.88	0.27	0.17	3.15	1.28	121	40.30	46	20.15
4	Qbs	90-083	48.4	1.57	16.8	2.04	9.59	0.19	7.70	10.70	2.97	0.20	0.16	0.14	0.06	0.00	100.52	48.34	1.57	16.78	11.41	0.19	7.69	10.69	2.97	0.20	0.16	3.17	1.48	121	44.20	46	21.63
5	Qbs	92-003	48.0	1.47	16.9	2.74	8.69	0.18	7.85	10.30	2.93	0.24	0.17	0.25	0.10	0.00	99.82	48.39	1.48	17.04	11.25	0.18	7.91	10.38	2.95	0.24	0.17	3.20	1.42	121	42.56	46	20.30
6	Qbs	92-004	48.6	1.50	16.7	1.68	9.20	0.18	8.19	10.30	2.98	0.34	0.21	0.21	0.05	0.00	100.14	48.74	1.50	16.75	10.74	0.18	8.21	10.33	2.99	0.34	0.21	3.33	1.31	121	40.40	46	20.26
7	Qbs	HK93	47.8	1.65	16.4	11.08	0.00	0.18	7.22	10.35	3.51	0.30	0.19	0.33	0.00	0.00	99.05	49.00	1.69	16.81	10.22	0.18	7.40	10.60	3.60	0.31	0.19	3.90	1.38	121	43.47	46	21.56
8	Qbe	88-045	49.5	1.34	15.7	2.41	6.38	0.14	9.59	9.83	3.03	1.45	0.51	0.13	0.06	0.01	100.08	49.68	1.34	15.76	8.58	0.14	9.62	9.87	3.04	1.46	0.51	4.50	0.89	121	42.63	46	20.82
9	Qbws	85-029	49.5	1.28	16.2	2.83	6.02	0.15	8.60	10.00	3.30	1.20	0.38	0.06	0.00	0.00	99.52	49.91	1.29	16.33	8.64	0.15	8.67	10.08	3.33	1.21	0.38	4.54	1.00	121	44.47	46	20.33
10	Qbws[1]	85-029																50.01	1.29	16.47	8.34	0.15	8.86	9.95	3.32	1.23	0.38	4.54	0.94	121	44.47	46	20.33
11	Qbws	HK92	49.0	1.25	17.0	8.34	0.00	0.14	8.15	9.68	3.45	1.30	0.34	0.44	0.00	0.00	99.06	50.06	1.28	17.41	7.68	0.14	8.33	9.90	3.53	1.33	0.35	4.86	0.92	121	44.46	46	20.34
12	Qbws	92-079	49.0	1.31	16.6		6.78	0.16	8.87	10.10	2.83	1.10	0.41	0.35	0.18	0.00	97.69	50.43	1.35	17.09	6.98	0.16	9.13	10.40	2.91	1.13	0.42	4.04	0.76	121	44.54	46	20.80
13	Ta	92-098	49.0	1.09	18.1	5.17	4.62	0.18	5.75	10.50	2.46	0.30	0.18	1.06	1.18	0.22	99.81	50.60	1.13	18.69	9.58	0.19	5.94	10.84	2.54	0.31	0.19	2.85	1.61	121	44.46	46	16.64
14	Qbe	HK94	49.5	1.35	15.8	8.26	0.00	0.13	8.56	9.40	3.76	1.40	0.35	0.42	0.00	0.05	98.89	50.67	1.38	16.15	7.62	0.13	8.77	9.63	3.85	1.43	0.36	5.29	0.87	121	42.63	46	20.82
15	Ta	92-063	49.1	1.15	18.7	4.70	3.86	0.21	5.62	10.50	2.61	0.42	0.19	0.73	1.47	0.02	99.28	50.83	1.19	19.36	8.38	0.22	5.82	10.87	2.70	0.43	0.20	3.14	1.44	121	42.99	46	15.43
16	Qbe	92-027	49.9	1.21	15.1	3.98	4.14	0.13	9.29	9.62	3.04	1.42	0.51	0.50	0.53	0.00	99.37	50.95	1.24	15.42	7.88	0.13	9.49	9.82	3.10	1.45	0.52	4.55	0.83	121	42.82	46	20.51
17	Ta	92-034	49.3	1.20	20.3	5.20	2.65	0.21	4.47	9.56	3.01	0.89	0.23	0.90	1.70	0.25	99.87	51.09	1.24	21.04	7.60	0.22	4.63	9.91	3.12	0.92	0.24	4.04	1.64	121	43.37	46	16.97
18	Qbe	92-033	50.8	1.37	16.3	2.23	6.13	0.14	8.31	9.16	3.35	1.30	0.45	0.18	0.09	0.00	99.81	51.15	1.38	16.41	8.19	0.14	8.37	9.22	3.37	1.31	0.45	4.68	0.98	121	42.59	46	20.27
19	Qbap	92-044	51.0	1.60	16.4	1.88	7.76	0.16	6.92	8.73	3.47	0.97	0.31	0.13	0.13	0.00	99.46	51.51	1.62	16.56	9.55	0.16	6.99	8.82	3.50	0.98	0.31	4.48	1.37	121	37.59	46	20.70
20	Ta	92-100	50.9	1.03	17.2	3.18	6.01	0.17	5.99	10.90	2.31	0.81	0.19	0.71	0.49	0.11	100.00	51.74	1.05	17.48	9.02	0.17	6.09	11.08	2.35	0.82	0.19	3.17	1.48	121	39.28	46	15.13
21	Tai	92-072	49.8	1.29	17.7	5.15	4.05	0.19	4.39	9.39	2.85	0.68	0.23	1.10	2.03	0.68	99.53	52.31	1.35	18.59	9.12	0.20	4.61	9.86	2.99	0.71	0.24	3.71	1.98	121	42.83	46	17.87
22	Ta	92-096	50.5	1.29	18.2	5.30	3.16	0.16	4.99	9.62	2.61	0.79	0.21	1.01	1.42	0.16	99.42	52.44	1.34	18.90	8.23	0.17	5.18	9.99	2.71	0.82	0.22	3.53	1.59	121	42.99	46	17.33
23	Tai	92-030	48.6	1.98	15.8	3.96	7.24	0.26	3.03	7.73	3.94	0.16	0.36	3.17	0.77	2.63	99.63	52.45	2.14	17.05	11.66	0.28	3.27	8.34	4.25	0.17	0.39	4.42	3.57	121	41.35	46	19.84
24	Tai	92-050	50.5	1.53	16.9	6.09	3.88	0.21	4.20	8.55	3.00	0.31	0.28	1.24	2.55	0.04	99.28	53.25	1.61	17.82	9.87	0.22	4.43	9.02	3.16	0.33	0.30	3.49	2.23	121	42.25	46	17.83
25	Ta	92-011	52.1	1.16	18.3	3.94	5.08	0.16	3.86	8.99	3.55	0.81	0.21	1.29	0.23	0.07	99.75	53.29	1.19	18.72	8.82	0.16	3.95	9.20	3.63	0.83	0.21	4.46	2.23	121	40.70	46	21.24
26	Ta	92-077	52.5	1.36	18.6	4.34	4.54	0.15	3.13	8.53	3.53	0.84	0.20	1.22	0.24	0.00	99.18	53.96	1.40	19.12	8.68	0.15	3.22	8.77	3.63	0.86	0.21	4.49	2.70	121	44.19	46	20.63
27	Tai	92-023	52.2	1.30	16.7	3.74	5.47	0.15	4.78	8.62	2.80	1.04	0.24	1.37	1.24	0.08	99.73	54.00	1.34	17.28	9.14	0.16	4.94	8.92	2.90	1.08	0.25	3.97	1.85	121	43.95	46	19.92
28	Qbap	88-071	53.8	1.33	16.1	1.87	6.59	0.14	6.53	7.97	3.48	1.40	0.31	0.37	0.14	0.00	100.03	54.16	1.34	16.21	8.33	0.14	6.57	8.02	3.50	1.41	0.31	4.91	1.27	121	38.78	46	20.21
29	Qbap	92-010	53.6	1.32	16.4	1.72	6.67	0.14	6.25	7.76	3.48	1.37	0.32	0.51	0.25	0.00	99.79	54.22	1.34	16.59	8.31	0.14	6.32	7.85	3.52	1.39	0.32	4.91	1.31	121	39.80	46	20.02
30	Qbap	92-005	53.8	1.33	16.4	1.58	6.78	0.14	6.24	7.77	3.47	1.42	0.32	0.46	0.18	0.00	99.89	54.29	1.34	16.55	8.28	0.14	6.30	7.84	3.50	1.43	0.32	4.93	1.31	121	40.30	46	20.29
31	Tai	92-028	53.6	1.61	15.9	3.42	7.18	0.19	4.14	8.17	3.54	0.63	0.24	0.54	0.49	0.04	99.69	54.54	1.64	16.18	10.44	0.19	4.21	8.31	3.60	0.64	0.24	4.24	2.48	121	40.53	46	19.65
32	Tai	92-069	53.7	1.54	17.2	3.94	5.33	0.38	3.25	8.40	3.36	0.98	0.30	0.70	0.70	0.00	99.78	54.80	1.57	17.55	9.06	0.39	3.32	8.57	3.43	1.00	0.31	4.43	2.73	121	41.11	46	16.52
33	Ta	92-097	54.0	1.25	18.6	3.32	4.76	0.14	3.46	8.88	3.28	0.83	0.29	0.52	0.53	0.00	99.86	54.83	1.27	18.89	7.87	0.14	3.51	9.02	3.33	0.84	0.29	4.17	2.24	121	43.26	46	16.78
34	Tai	92-052	52.3	1.51	17.0	2.95	5.66	0.11	2.77	8.48	3.20	1.25	0.31	0.73	0.66	2.89	99.82	54.91	1.59	17.85	8.73	0.12	2.91	8.90	3.36	1.31	0.33	4.67	3.00	121	40.51	46	17.50
35	Tai	92-045	54.2	1.21	17.1	4.19	4.34	0.15	3.55	8.36	3.13	0.89	0.24	1.28	1.10	0.00	99.74	55.91	1.25	17.64	8.37	0.15	3.66	8.62	3.23	0.92	0.25	4.15	2.28	121	42.63	46	18.53
36	Tai	90-121	53.3	1.89	16.4	3.53	5.68	0.24	3.44	3.65	5.52	1.48	0.34	2.79	0.89	0.83	99.98	56.04	1.99	17.24	9.31	0.25	3.62	3.84	5.80	1.56	0.36	7.36	2.57	121	44.36	46	20.18
37	Tai	92-061	55.6	1.59	16.1	2.80	6.66	0.18	3.58	7.32	3.92	0.90	0.34	0.60	0.37	0.00	99.96	56.33	1.61	16.31	9.30	0.18	3.63	7.42	3.97	0.91	0.34	4.88	2.56	121	44.42	46	15.68
38	Ta	92-038	54.2	1.44	16.8	5.28	3.42	0.17	3.26	6.01	4.39	0.88	0.26	2.14	1.24	0.00	99.49	56.71	1.51	17.58	8.55	0.18	3.41	6.29	4.59	0.92	0.27	5.51	2.51	121	41.26	46	19.16
39	Ta	92-056	56.2	1.07	17.5	2.98	4.97	0.15	3.98	7.66	3.25	1.39	0.21	0.22	0.22	0.01	99.81	56.73	1.08	17.67	7.72	0.15	4.02	7.73	3.28	1.40	0.21	4.68	1.92	121	43.78	46	15.38
40	Taid	92-076	55.8	0.91	20.5	2.22	3.53	0.12	1.67	7.77	4.18	0.98	0.27	1.15	0.58	0.02	99.70	57.10	0.93	20.98	5.66	0.12	1.71	7.95	4.28	1.00	0.28	5.28	3.31	121	44.71	46	18.50
41	Ta	92-057	55.3	1.35	17.0	5.23	2.93	0.32	3.00	6.77	3.79	1.32	0.25	0.56	1.23	0.22	99.27	57.17	1.40	17.57	7.89	0.33	3.10	7.00	3.92	1.36	0.26	5.28	2.55	121	44.75	46	15.26
42	Tai	92-058	56.3	1.36	16.3	3.28	5.43	0.14	3.61	6.70	3.55	1.49	0.31	0.40	0.69	0.00	99.56	57.37	1.39	16.61	8.54	0.14	3.68	6.83	3.62	1.52	0.32	5.14	2.32	121	43.63	46	15.35
43	Ta	MK85627	57.2	1.12	19.1	3.68	4.22	0.14	2.28	7.72	3.25	1.05	0.25				99.99	57.38	1.12	19.19	7.56	0.14	2.29	7.75	3.26	1.05	0.25	4.32	3.30	121	42.85	46	17.28
44	Tai	92-029	56.5	1.42	16.6	3.22	5.24	0.16	3.40	7.25	3.60	1.04	0.24	0.44	0.57	0.00	99.68	57.45	1.44	16.88	8.27	0.16	3.46	7.37	3.66	1.06	0.24	4.72	2.39	121	40.36	46	19.24
45	Tai	92-060	56.9	1.55	16.5	2.76	6.20	0.17	2.73	6.97	4.09	1.09	0.30	0.55	0.20	0.00	100.01	57.48	1.57	16.67	8.77	0.17	2.76	7.04	4.13	1.10	0.30	5.23	3.18	121	43.83	46	15.82
46	Ta	92-022	54.3	1.05	16.5	4.26	2.12	0.09	3.60	7.06	3.25	1.44	0.31	3.89	1.52	0.05	99.44	58.04	1.12	17.64	6.36	0.10	3.85	7.55	3.47	1.54	0.33	5.01	1.65	121	38.18	46	21.46
47	Ta	85-076	57.8	1.07	16.9	2.67	4.46	0.12	3.38	6.54	3.66	1.75	0.29	0.33	0.65	0.11	99.73	58.76	1.09	17.18	6.98	0.12	3.44	6.65	3.72	1.78	0.29	5.50	2.03	121	38.20	46	16.28
48	Ta	92-008	56.7	1.46	16.3	3.04	4.62	0.12	2.77	6.87	3.09	0.81	0.28	2.17	0.40	0.91	99.54	59.21	1.52	17.02	7.68	0.13	2.89	7.17	3.23	0.85	0.29	4.07	2.66	121	40.16	46	21.14
49	Ta	92-016	57.1	1.88	14.7	3.93	5.42	0.18	2.88	4.42	3.99	1.82	0.43	2.52	0.32	0.08	99.67	59.26	1.95	15.26	9.30	0.19	2.99	4.59	4.14	1.89	0.45	6.03	3.11	121	43.14	46	22.20
50	Tai	92-051	57.6	1.40	16.1	4.67	3.57	0.20	2.64	4.19	4.82	1.71	0.37	1.77	0.69	0.05	99.78	59.50	1.45	16.63	8.03	0.21	2.73	4.33	4.98	1.77	0.38	6.75	2.94	121	40.95	46	18.50
51	Ta	92-068	59.0	1.38	16.5	3.57	4.09	0.23	2.29	5.64	4.53	1.30	0.51	0.37	0.36	0.00	99.77	59.79	1.40	16.72	7.40	0.23	2.32	5.72	4.59	1.32	0.52	5.91	3.19	121	42.03	46	16.25
52	Tdi	92-049	58.2	1.16	16.3	5.42	1.90	0.14	2.63	4.83	4.46	2.12	0.31	0.83	1.14	0.02	99.46	60.04	1.20	16.82	6.99	0.14	2.71	4.98	4.60	2.19	0.32	6.79	2.58	121	42.01	46	18.58
53	Ta	92-021	58.1	0.87	17.6	3.13	2.73	0.09	2.72	5.06	4.94	1.15	0.25	2.33	0.29	0.30	99.56	60.32	0.90	18.27	5.76	0.09	2.82	5.25	5.13	1.19	0.26	6.32	2.04	121	38.37	46	22.07
54	Ta	92-065	59.6	0.98	16.5	3.32	3.71	0.12	2.99	5.95	3.74	1.68	0.26	0.37	0.41	0.02	99.65	60.50	0.99	16.75	6.80	0.12	3.03	6.04	3.80	1.71	0.26	5.50	2.24	121	42.19	46	16.38
55	Tai	92-059	59.3	1.39	15.8	2.83	4.65	0.19	2.29	5.38	4.69	1.06	0.66	1.22	0.32	0.00	99.78	60.54	1.42	16.13	7.35	0.19	2.34	5.49	4.79	1.08	0.67	5.87	3.14	121	43.76	46	15.66

Table 1. Chemical analyses from the East Canyon Ridge 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
56	Ta	92-066	59.6	0.97	16.4	3.08	3.79	0.12	3.07	5.78	3.73	1.75	0.27	0.43	0.69	0.02	99.70
57	Ta	92-101	60.0	0.83	16.8	2.84	3.70	0.13	2.63	5.98	3.62	1.87	0.20	0.59	0.51	0.02	99.72
58	Ta	92-087	60.1	1.00	16.0	3.17	3.77	0.12	2.89	5.61	3.75	1.79	0.33	0.43	0.55	0.03	99.54
59	Ta	92-064	60.0	0.95	16.2	3.40	3.11	0.12	2.67	6.11	3.69	1.85	0.26	0.43	0.48	0.22	99.49
60	Thd	88-001	60.4	0.74	16.7	3.24	1.96	0.09	3.03	6.03	3.71	1.20	0.19	1.18	0.80	0.00	99.27
61	Thd	MK10841	62.3	0.74	16.9	2.67	3.06	0.11	3.07	5.84	3.62	1.55	0.18				100.00
62	Thd	92-024	59.7	0.84	16.9	3.23	2.13	0.10	1.92	6.45	4.12	0.19	0.24	1.62	0.57	1.45	99.46
63	Ta	92-062	61.1	0.91	16.0	4.26	2.07	0.10	2.13	5.27	3.61	2.39	0.21	0.49	0.89	0.08	99.51
64	Tai	92-046	60.5	1.46	14.8	5.43	2.10	0.26	2.15	3.23	5.81	0.59	0.60	1.44	1.09	0.00	99.46
65	Thd	85-087	60.6	0.70	16.0	2.45	2.29	0.09	2.95	4.94	3.81	1.72	0.18	1.92	0.91	1.34	99.90
66	Qds	92-041	63.6	0.99	15.9	2.15	3.46	0.10	1.50	3.82	4.49	3.05	0.28	0.14	0.10	0.00	99.58
67	Thd	92-053	62.6	0.69	16.8	3.27	1.53	0.08	2.18	5.02	4.04	1.32	0.19	0.78	0.73	0.00	99.23
68	(Thd)[3]	MK98435	64.3	0.70	16.5	2.45	2.81	0.08	2.70	5.28	3.67	1.38	0.17				100.00
69	Tdtm	85-073	63.0	0.99	15.4	3.26	2.87	0.17	1.63	3.88	4.85	1.68	0.37	0.29	0.73	0.01	99.13
70	Tdtm[2]	85-074															
71	(Thd)[3]	92-083	63.2	0.64	16.3	3.04	1.42	0.07	2.33	4.62	4.04	1.58	0.17	1.01	0.73	0.00	99.15
72	Tdtm[2]	85-073															
73	Tdi	92-036	63.1	0.88	15.7	5.12	0.85	0.13	1.36	3.53	4.58	1.76	0.29	0.93	1.26	0.02	99.51
74	Tdtm	92-086	64.0	0.99	15.5	4.19	1.72	0.14	0.96	3.65	4.93	2.02	0.36	0.63	0.48	0.01	99.58
75	Tai	92-070	63.6	0.88	14.8	4.89	1.48	0.13	1.62	3.02	4.66	1.92	0.29	0.85	1.43	0.00	99.57
76	Tdi	92-048	64.4	0.84	15.4	2.97	2.51	0.15	1.32	3.49	4.78	1.73	0.28	0.89	0.76	0.08	99.60
77	Tdi	92-088	66.4	0.60	15.4	3.19	1.78	0.16	0.92	2.19	5.58	2.10	0.21	0.55	0.36	0.00	99.44
78	Tdi	92-082	64.9	0.59	15.0	1.21	3.12	0.12	0.78	3.46	4.51	1.97	0.18	1.52	0.35	1.67	99.38
79	Trd	92-018	63.9	0.45	15.2	1.65	1.82	0.07	1.24	4.53	3.06	1.85	0.16	2.21	0.58	2.82	99.54
80	Tdi	92-080	66.8	0.60	15.2	2.47	2.17	0.12	0.85	2.21	5.44	1.99	0.19	1.20	0.20	0.00	99.44
81	Tdi	MK85623	69.2	0.62	15.4	2.30	2.64	0.14	0.72	3.00	3.93	1.90	0.17				100.02
82	Trd	92-091	68.2	0.52	14.9	2.72	1.29	0.07	0.74	2.43	4.54	2.89	0.14	0.47	0.52	0.12	99.55
83	Tri	92-047	67.9	0.58	14.9	3.07	1.40	0.12	0.75	1.33	4.98	2.50	0.18	1.30	0.35	0.00	99.36
84	Tri	92-035	68.6	0.44	14.9	3.52	0.46	0.09	0.57	0.74	6.05	2.41	0.13	0.87	0.51	0.00	99.29
85	Ttv	85-078	62.8	0.67	13.6	5.09	0.01	0.12	0.80	3.46	1.66	1.23	0.15	5.53	4.03	0.00	99.15
86	Trcb	92-090	68.7	0.71	13.7	5.49	0.03	0.06	0.29	2.95	3.01	2.65	0.20	0.94	0.53	0.00	99.26
87	Trcb	85-075	69.1	0.50	14.9	3.46	0.11	0.03	0.17	2.20	4.54	2.87	0.15	0.40	0.66	0.07	99.16
88	Tris	92-037	71.1	0.26	14.9	1.94	0.81	0.06	0.39	2.03	4.29	2.47	0.09	0.74	0.39	0.00	99.47
89	Trcb	92-094	71.7	0.49	14.6	1.90	0.16	0.02	0.17	2.10	4.46	2.91	0.15	0.57	0.36	0.03	99.62
90	Tris	85-080	70.3	0.27	14.6	2.57	0.10	0.06	0.16	2.48	3.52	2.39	0.09	1.55	0.32	0.84	99.25
91	Tris	85-031	74.3	0.12	14.1	0.59	0.61	0.07	0.26	1.31	4.32	2.77	0.09	0.46	0.29	0.01	99.30
92	Tris	92-078	74.5	0.12	14.1	0.91	0.35	0.06	0.25	1.00	4.45	2.82	0.09	0.69	0.29	0.00	99.63
93	Tris	92-031	74.4	0.12	14.2	0.62	0.68	0.04	0.25	0.33	4.66	2.97	0.08	0.85	0.31	0.01	99.52
94	Tris	92-026	74.2	0.13	14.3	0.75	0.72	0.06	0.24	0.23	4.79	2.41	0.09	0.93	0.31	0.00	99.16
95	Tris	92-081	75.3	0.11	13.8	1.04	0.14	0.04	0.15	0.11	4.50	2.61	0.08	0.90	0.17	0.00	98.95
96	Tris	85-081	74.1	0.16	14.8	1.94	0.06	0.06	0.10	0.10	2.08	2.92	0.09	3.03	0.36	0.00	99.80
97	Tris	MK85622	77.1	0.11	14.6	0.43	0.49	0.08	0.02	1.30	3.03	2.84	0.08				100.02

Map No.	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
56	60.66	0.99	16.69	6.68	0.12	3.12	5.88	3.80	1.78	0.27	5.58	2.14	121	42.12	46	15.87
57	61.03	0.84	17.09	6.36	0.13	2.68	6.08	3.68	1.90	0.20	5.58	2.38	121	37.66	46	15.35
58	61.19	1.02	16.29	6.74	0.12	2.94	5.71	3.82	1.82	0.34	5.64	2.29	121	40.42	46	16.56
59	61.21	0.97	16.53	6.29	0.12	2.72	6.23	3.76	1.89	0.27	5.65	2.31	121	41.61	46	15.02
60	62.29	0.76	17.22	5.03	0.09	3.12	6.22	3.83	1.24	0.20	5.06	1.61	121	38.27	46	20.49
61	62.44	0.74	16.94	5.48	0.11	3.08	5.86	3.63	1.55	0.18	5.18	1.78	121	38.05	46	38.05
62	62.52	0.88	17.70	5.27	0.10	2.01	6.75	4.31	0.20	0.25	4.51	2.62	121	43.95	46	19.92
63	62.59	0.93	16.39	6.05	0.10	2.18	5.40	3.70	2.45	0.22	6.15	2.77	121	44.39	46	15.68
64	62.77	1.51	15.35	7.25	0.27	2.23	3.35	6.03	0.61	0.62	6.64	3.25	121	42.65	46	18.62
65	63.46	0.73	16.76	4.71	0.09	3.09	5.17	3.99	1.80	0.19	5.79	1.52	121	40.07	46	21.07
66	64.16	1.00	16.04	5.44	0.10	1.51	3.85	4.53	3.08	0.28	7.61	3.60	121	37.70	46	18.54
67	64.28	0.71	17.25	4.59	0.08	2.24	5.15	4.15	1.36	0.20	5.50	2.05	121	40.08	46	19.00
68	64.42	0.70	16.54	5.03	0.08	2.71	5.29	3.68	1.38	0.17	5.06	1.86	121	38.84	46	20.25
69	64.43	1.01	15.75	5.94	0.17	1.67	3.97	4.96	1.72	0.38	6.68	3.56	121	41.16	46	16.12
70	64.97	1.04	15.90	6.17	0.14	1.64	3.90	4.30	1.61	0.32	5.91	3.76	121	41.13	46	16.40
71	65.08	0.66	16.79	4.28	0.07	2.40	4.76	4.16	1.63	0.18	5.79	1.78	121	42.33	46	19.81
72	65.18	1.03	15.83	5.97	0.17	1.59	4.01	4.25	1.64	0.32	5.89	3.75	121	41.16	46	16.12
73	65.19	0.91	16.22	5.64	0.13	1.41	3.65	4.73	1.82	0.30	6.55	4.01	121	42.32	46	19.08
74	65.28	1.01	15.81	5.60	0.14	0.98	3.72	5.03	2.06	0.37	7.09	5.72	121	41.80	46	15.57
75	65.70	0.91	15.29	6.08	0.13	1.67	3.12	4.81	1.98	0.30	6.80	3.63	121	43.16	46	16.68
76	66.00	0.86	15.78	5.31	0.15	1.35	3.58	4.90	1.77	0.29	6.67	3.93	121	42.79	46	19.22
77	67.61	0.61	15.68	4.74	0.16	0.94	2.23	5.68	2.14	0.21	7.82	5.06	121	41.78	46	17.62
78	67.80	0.62	15.67	4.40	0.13	0.81	3.61	4.71	2.06	0.19	6.77	5.40	121	44.30	46	20.33
79	68.15	0.48	16.21	3.52	0.07	1.32	4.83	3.26	1.97	0.17	5.24	2.67	121	39.56	46	21.92
80	68.31	0.61	15.54	4.49	0.12	0.87	2.26	5.56	2.03	0.19	7.60	5.17	121	43.78	46	19.83
81	69.34	0.62	15.44	4.72	0.14	0.72	3.01	3.94	1.90	0.17	5.84	6.54	121	43.82	46	19.92
82	69.47	0.53	15.18	3.81	0.07	0.75	2.48	4.62	2.94	0.14	7.57	5.05	121	37.62	46	16.35
83	69.71	0.60	15.30	4.27	0.12	0.77	1.37	5.11	2.57	0.18	7.68	5.55	121	43.13	46	19.14
84	70.32	0.45	15.27	3.72	0.09	0.58	0.76	6.20	2.47	0.13	8.67	6.36	121	42.20	46	19.28
85	70.50	0.75	15.27	5.15	0.13	0.90	3.88	1.86	1.38	0.17	3.24	5.74	121	38.48	46	17.30
86	70.65	0.73	14.09	5.11	0.06	0.30	3.03	3.10	2.73	0.21	5.82	17.14	121	38.85	46	16.58
87	70.74	0.51	15.25	3.30	0.03	0.17	2.25	4.65	2.94	0.15	7.59	18.96	121	38.39	46	16.47
88	72.44	0.26	15.18	2.60	0.06	0.40	2.07	4.37	2.52	0.09	6.89	6.55	121	41.18	46	19.54
89	72.81	0.50	14.83	1.90	0.02	0.17	2.13	4.53	2.96	0.15	7.48	11.00	121	38.03	46	16.28
90	73.01	0.28	15.16	2.51	0.06	0.17	2.58	3.66	2.48	0.09	6.14	15.08	121	40.98	46	19.45
91	75.45	0.12	14.32	1.16	0.07	0.26	1.33	4.39	2.81	0.09	7.20	4.39	121	43.92	46	20.39
92	75.59	0.12	14.31	1.19	0.06	0.25	1.01	4.52	2.86	0.09	7.38	4.68	121	44.40	46	20.73
93	75.70	0.12	14.45	1.26	0.04	0.25	0.34	4.74	3.02	0.08	7.76	4.95	121	41.63	46	20.01
94	75.83	0.13	14.61	1.43	0.06	0.25	0.24	4.90	2.46	0.09	7.36	5.81	121	44.68	46	21.63
95	77.01	0.11	14.11	1.10	0.04	0.15	0.11	4.60	2.67	0.08	7.27	7.17	121	43.45	46	21.35
96	77.01	0.17	15.38	1.88	0.06	0.10	0.10	2.16	3.03	0.09	5.20	18.06	121	41.44	46	19.37
97	77.11	0.11	14.55	0.88	0.08	0.02	1.30	3.03	2.84	0.08	5.87	43.85	121	43.78	46	20.40

X-ray fluorescence analyses, except those otherwise indicated, done in U.S. Geological Survey laboratory in Denver, Colo. (lab chief, D.F. Siems

FeO, CO_2, and water done in U.S. Geological Survey laboratory in Menlo Park, Calif. (analysts, N.H. Elsheimer and S.F. Bader) and Denver, Colo. (analysts, T.R. Peacock and Z.A. Brown)

Analyses for field numbers prefixed by MK given in Korosec (1987) and done at Washington State University using XRF techniques; sample locations transferred from Korosec's field map may be slightly in error

Analyses for field numbers prefixed by HK given in table 2 of Hammond and Korosec (1983) and done at Washington State University using XRF techniques; sample locations approximately located

[1] *Analysis done at Washington State University by R.M. Conrey and Diane Johnson using XRF techniques*

[2] *Analysis done at Washington State University using XRF techniques courtesy of P.E. Hammond*

[3] *Sample collected from landslide block derived from unit Thd*

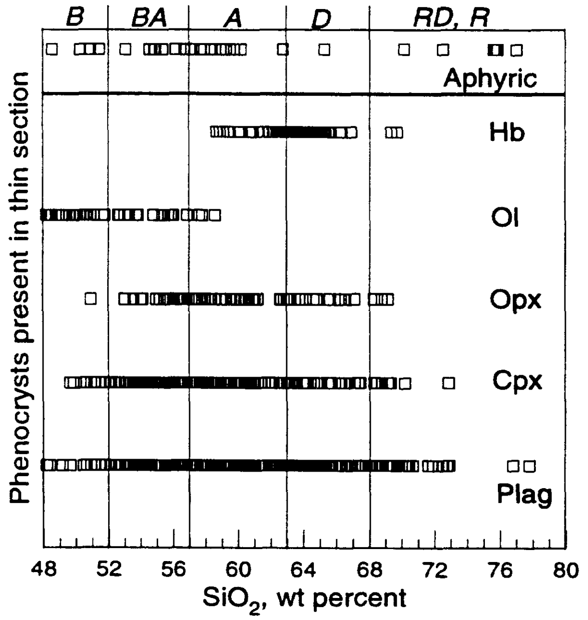


Figure 4. Plot of phenocryst assemblage vs. SiO_2 for 362 porphyritic and 28 non-porphyritic Tertiary rocks, chiefly in the six mapped quadrangles but including a few in other quadrangles. □, phenocryst observed in thin section; Hb, hornblende; Ol, olivine; Opx, orthopyroxene; Cpx, clinopyroxene; Plag, plagioclase. Rock types along top edge from figure 3. Revised from less complete version in Swanson (1993). Modal amont of phenocrysts ranges widely to a maximum of nearly 50 percent; typical values are 5–20 percent.

of Miyashiro (1974). This pattern resembles that in the adjacent quadrangles.

Both tholeiitic and calc-alkaline suites characterize the Quaternary rocks (fig. 7). The seven analyses of the basalt of Spring Creek (map unit Qbs; a low-K basalt; table 1, nos. 1–7) are tholeiitic, as is the dacite of Sheep Creek (map unit Qds). In contrast, all eight analyses of the relatively high-K basalt of Juniper Creek and related basalt (nos. 8–12, 14, 16, and 18; map units Qbj,. Qbe, and Qbws) are calc-alkaline, as is the basaltic andesite of Potato Hill. Only the Juniper Creek was erupted within the area of the quadrangle.

Most of the analyses are subalkaline on a plot of total alkalies vs. SiO_2 (fig. 8; Macdonald and Katsura, 1964; Irvine and Baragar, 1971). Three of the Tertiary samples are mildly alkalic according to both definitions. One of these (no. 36) is being reanalyzed (see discussion above). Each of the other two analyses (no. 11 and 14), both from Hammond and Korosec (1983), are high in Na_2O, possibly reflecting poor analyses; no samples or thin sections are available for examination. The basalt of Juniper Creek is slightly alkalic in the usage of Macdonald and Katsura (1964).

A plot of K_2O vs. SiO_2 (fig. 9) shows that most samples with SiO_2 between 52 and 63 percent are medium-K mafic and silicic andesite according to Gill (1981; basaltic andesite and andesite, respectively, in the IUGS terminology used here). This diagram nicely distinguishes the basalt of Spring Creek (map unit Qbs) from the basalt of Juniper Creek and related basalt (map units Qbe and Qbws; for analysis of sample from map unit Qbj, see Swanson [1993, table 1, no. 5–6]). Note that the dacite of Sheep Creek (map unit Qds) is quite potassic. One sample of the Kidd Creek intrusive suite (table 1, no. 62) is very low in K_2O, almost surely because

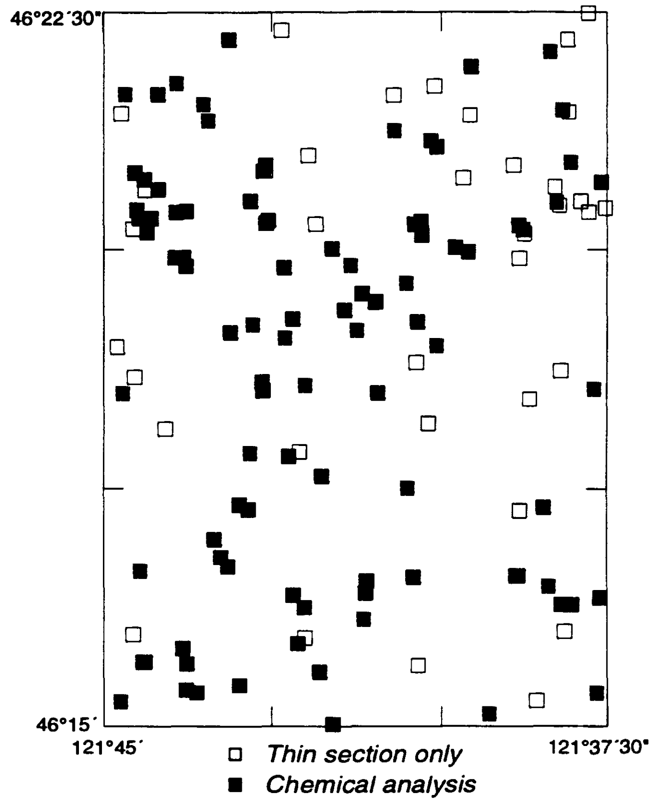


Figure 5. Map showing distribution of 132 sample localities in East Canyon Ridge quadrangle, including localities for samples collected by Hammond and Korosec (1983) and Korosec (1987) and listed in table 1.

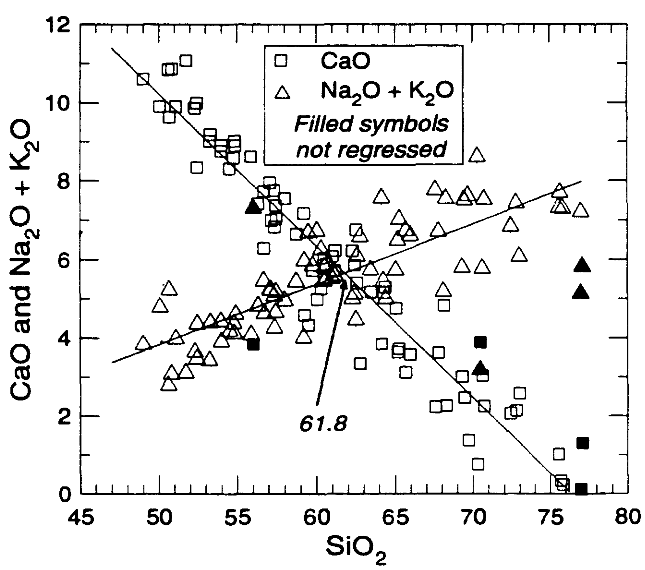


Figure 6. Plots of CaO and (Na_2O + K_2O) vs. SiO_2 for all analyzed Tertiary rocks in East Canyon Ridge quadrangle. Linear regressions of both plots cross at SiO_2 content of 61.8, indicating slightly calcic suite in terminology of Peacock (1931). Filled symbols probably represent highly altered rocks and are excluded from regressions.

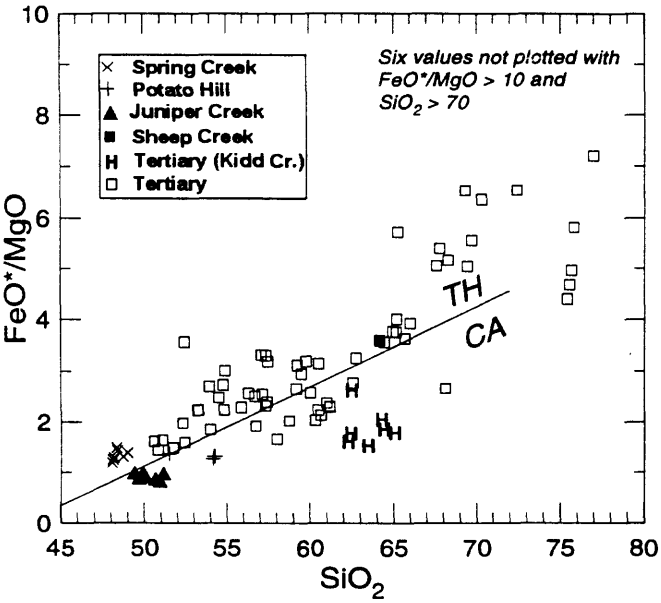


Figure 7. Plot of FeO*/MgO vs. SiO_2 for all chemically analyzed Tertiary and Quaternary rocks from East Canyon Ridge quadrangle. Subdivision into tholeiitic (TH) and calc-alkaline (CA) suites after Miyashiro (1974). Most Tertiary rocks are tholeiitic, but the hornblende diorite in the intrusive suite of Kidd Creek is clearly calc-alkaline, as are some of the older rocks. Quaternary lava flows are both tholeiitic and calc-alkaline. Basalt of Juniper Creek and its chemical correlatives, and basalt and basaltic andesite of Potato Hill, are slightly calc-alkaline, whereas basalt of Spring Creek is tholeiitic (it has both higher FeO* and lower MgO than the Juniper Creek analyses [table 1]), as is dacite of Sheep Creek. See caption of figure 3 for map-unit symbols of Quaternary rocks.

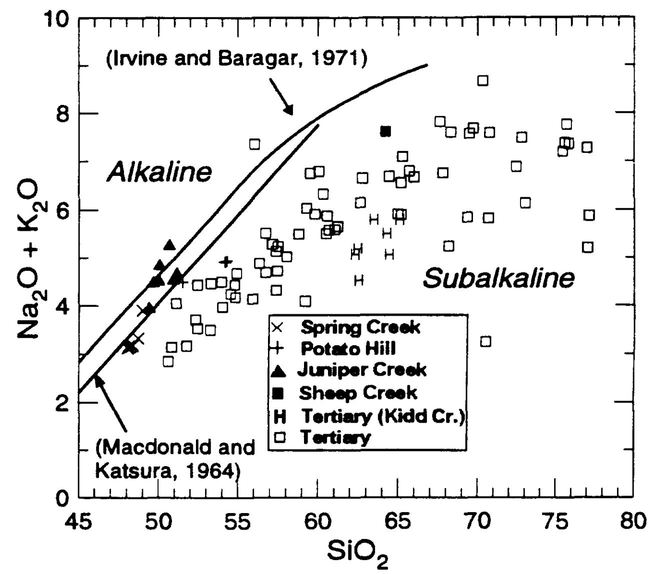


Figure 8. Plot of ($Na_2O + K_2O$) vs. SiO_2 for all chemically analyzed Tertiary and Quaternary rocks in the East Canyon Ridge quadrangle. Boundaries shown between subalkaline and alkaline suites after Macdonald and Katsura (1964) and Irvine and Baragar (1971). Basalt of Juniper Creek is marginally alkaline. Tertiary sample (table 1, no. 36) in alkaline field probably enriched in both Na_2O and K_2O during alteration. Spring Creek sample (table 1, no., 7) in alkaline field of Macdonald and Katsura probably reflects incorrect Na_2O content. See caption of figure 3 for map-unit symbols of Quaternary rocks.

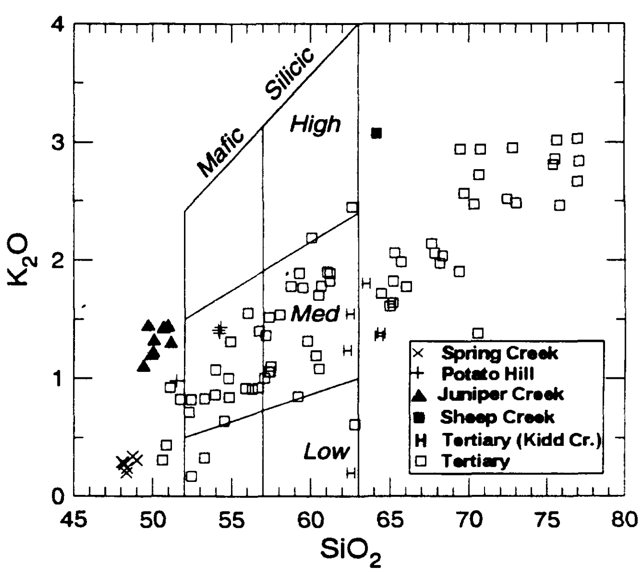


Figure 9. Plot of K_2O vs. SiO_2 for all chemically analyzed Tertiary and Quaternary rocks from the East Canyon Ridge quadrangle. Fields modified from Gill (1981), so that mafic andesite (basaltic andesite in IUGS terminology used in this paper) extends down to 52 percent. Both samples with exceptionally low K_2O content at 62–63 percent SiO_2 (table 1, no. 62 and 64) may have had Na_2O added at the expense of K_2O during alteration. Note potassic nature of dacite of Sheep Creek and distinctly different fields for basalt of Juniper Creek (and its chemical correlatives) and low-K basalt of Spring Creek. See caption of figure 3 for map-unit symbols of Quaternary rocks.

of leaching during alteration; however, I didn't recognize any unusual degree of alteration in thin section, and in fact some hornblende is still fresh.

GEOLOGIC OVERVIEW OF QUADRANGLE

Bedded volcaniclastic rocks of Oligocene and Miocene age underlie most of the quadrangle. They range from siltstone to diamictite and are most typically volcanic sandstone and fine-grained conglomerate. The rocks are generally well bedded and display lensing, channeling, and other features indicative of a fluvial environment. Lithic-lapilli tuff and pumiceous tuff—both generally of ashflow origin—and tuff are most common high in the section, on the south flank of East Canyon Ridge, and south of East Canyon Creek.

Flows of andesite, basaltic andesite, and basalt, ranging from nonporphyritic to highly plagioclase phyric, occur throughout the quadrangle and dominate the younger part of the section south of upper East Canyon Creek. Dacite or more silicic flows are uncommon, occurring with certainty only on Council Bluff, except for the Quaternary dacite of Olallie Lake (map unit Qdo) and dacite of Sheep Creek (map unit Qds) along the east edge of the quadrangle.

Volcaniclastic rocks are more common in the East Canyon Ridge and Blue Lake quadrangles than in the other mapped quadrangles farther west, where andesite and basaltic andesite lava flows predominate. This distribution may simply reflect a difference in age; most of the section in the East Canyon Ridge and Blue Lake quadrangles is older than that farther west, and apparently the lower part of the section is composed mostly of volcaniclastic rocks. Coeval lateral variation cannot be discounted, however.

Irregular but locally sill-like intrusions of rhyolite, dacite, hornblende microdiorite (and related rocks of different grain size) are common in the northern two-thirds of the quadrangle. Silicic intrusions are far more voluminous than in the other mapped quadrangles. The rhyolite intrusion of Spud Hill (map unit Tris) is probably a large intrusive dome (cryptodome) that punched through and tilted host rock along its western boundary; it has a high-SiO_2-rhyolite composition, unusual for the Cascades. The hornblende-bearing sills belong to the *intrusive suite of Kidd Creek* of Marso and Swanson (1992), which is particularly striking in the Tower Rock and McCoy Peak quadrangles. One large intrusion of microdiorite cuts volcaniclastic rocks near the mouth of Dark Creek, and two small plugs(?) crop out near Summit Prairie. Dikes of andesite and basaltic andesite are common only south of upper East Canyon Creek; many strike about east or slightly north of east and belong to the regional dike swarm first recognized farther west (Swanson, 1990).

Most of the quadrangle is on the southwest limb of the Bishop Ridge anticline, whose crest line just crosses the extreme northeast corner. The anticline is best defined in the Blue Lake quadrangle and appears to plunge out southeastward in the Green Mountain quadrangle. The Table Mountain syncline, a broad structure with a poorly defined troughline, warps the lava flows south of upper East Canyon Creek. The syncline is so gentle that I overlooked it while mapping the McCoy Peak quadrangle, and indeed it reaches only about 1 km or less into that quadrangle. From relations in the other quadrangles, I infer that the folding mostly or entirely predates 12 Ma, the age of the intrusive suite of Kidd Creek; no definitive evidence of this age relation was discovered in the East Canyon Ridge quadrangle.

During the late Pleistocene, at least six vents in the northwestern part of the quadrangle erupted the moderate-K_2O, olivine-bearing basalt of Juniper Creek (map unit Qbj) and its correlatives (map units Qbe and Qbws); all but one of these vents formed by phreatomagmatic (hydromagmatic) activity, probably adjacent to the Hayden Creek glacier in the Cispus valley. Hildreth and Fierstein (in press) and Hildreth and Lanphere (in press) showed that, before those eruptions, a 381-ka dacite flow—the dacite of Olallie Lake (map unit Qdo)—just crossed into the quadrangle from its probable vent 3 km farther southeast. Later a 246-ka dacite flow—the dacite of Sheep Creek (Qds)—moved down ancestral Sheep Creek, eroded into the earlier dacite flow, from a vent in the Mount Adams volcanic field. About 111 ka, Potato Hill, a cone on the Cascade Crest just north of hill 5162 (fig. 1), sent basaltic andesite and basalt flows (map unit Qbap) into the glacially carved Cispus River valley (Hildreth and Fierstein, in press; Hildreth and Lanphere, in press). Possibly about 21–40 ka (Hildreth and Fierstein, in press; Swanson, 1993), after the six vents had erupted, the basalt of Spring Creek (map unit Qbs) entered the Cispus valley from its vent near Potato Hill, flowed across the quadrangle, and advanced nearly 14 km farther downstream to a point nearly 40 km from its vent.

TERTIARY ROCKS OLDER THAN INTRUSIVE SUITE OF KIDD CREEK

Volcaniclastic rocks (map unit Ttv)—The oldest rocks in the quadrangle, well exposed along the crestline of the Bishop Ridge anticline in the Blue Lake and Green Mountain quadrangles but only poorly so in the East Canyon Ridge, include 1) epiclastic rocks such as volcanic sandstone and conglomerate, which were eroded from preexisting 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, which were deposited directly by eruption-related processes, and 3) lithic and(or) pumiceous diamictite whose origin is uncertain but most likely represents lahars fed either directly by eruptions or by later erosional processes. These rock types are the most common throughout the section.

The epiclastic suite consists entirely of clasts either eroded from slightly older Cascade volcanic rocks or reworked from deposits of contemporary eruptions. Clasts range in grain size from silt to gravel but are predominantly coarse sand. Wide ranges in degree of sorting and rounding characterize the deposits; in many places, well-sorted volcanic sandstone is interbedded with poorly sorted rocks including even diamictite with a matrix-supported framework. Beds range in thickness from less than 1 cm to more than 50 cm, averaging a few centimeters. Channels and lensoid beds are especially common. Cross bedding is locally apparent and typically indicates a general east to west transport direction (with considerable variation), as found by Stine (1987) and Winters (1984) farther northeast. Woody material, generally poorly preserved, occurs in many beds and along bedding planes. The most accessible example of epiclastic deposits is a photogenic roadcut 600 m south-southwest of Point 4834 on Spud Hill, where steeply tilted fine-grained volcanic sandstone dominates but mudstone also is abundant.

The pyroclastic suite is dominated by lithic-lapilli tuff and lithic-pumice lapilli tuff, most of which is probably of ash-flow origin. Welding is uncommon, however, and distinguishing a nonwelded primary pyroclastic flow from a pumiceous or even lithic lahar is difficult. Lithic-lapilli tuff and pumice-lapilli tuff commonly intertongue with other volcaniclastic deposits, and they dominate the younger part of the section. Many of these rocks were probably emplaced as pyroclastic flows, particularly those containing charred wood (commonly seen), although some could be debris flows. Air-fall tuff is likewise difficult to distinguish from epiclastic mudstone, and in fact much of the mudstone could be reworked or even *in situ* tuff. Roadcuts expose fine examples of lithic-pumice-lapilli tuff almost certainly of ash-flow origin on the southeast end of East Canyon Ridge near and southwest of the site of K-Ar age 1A. Farther along the same road (FS 2328), at the site of the small fault 800 m south-southwest of Point 4902, several logs with rootballs still attached directly underlie an ash-flow tuff. The logs are aligned east-west, and the rootballs are at the west end of each log; apparently the ash flow was traveling eastward when it knocked over the forest, leaving the logs as "weather vanes." One of these logs is nearly 1.2 m in diameter and about 9 m long; others are 60 cm in diameter and at least 3 m long. (Gregory Nimz, an undergraduate at the University of Washington in the early 1980s, first made these observations in an unpublished report.)

All of the bedded rocks in the quadrangle were apparently deposited in lowlands rather than on the flanks of cones. This conclusion, also reached for the rocks in the Blue Lake quadrangle (Swanson, 1993) and the adjacent Hamilton Buttes quadrangle (Stine, 1987), is supported by the observation that bedding attitudes are nearly everywhere consistent with local structure and hence were probably subhorizontal when deposited. Moreover, 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). I found no evidence of large Tertiary volcanic centers in the quadrangle, although the numerous dikes, local cinder, and thick section of lava flows south of upper East Canyon Creek (see following section) suggest at least small vents high in the section. The thick accumulation of alluvial-apron volcaniclastic rocks in the quadrangle, perhaps 4.5–5 km (see later section on folds, and not including the thickness of overlying lava flows), is consistent with the notion of syndepositional subsidence, an idea suggested and elaborated on in my discussion of the Blue Lake quadrangle (Swanson, 1993) and in Evarts and Swanson (1994) and Swanson (1994).

Lava flows and domes—A section of gently dipping lava flows (map units Ta and Tdtm) nearly 300 m thick holds up a high, rather flat upland south of upper East Canyon Creek. The flows range in composition from basalt to mafic dacite. Some of the basalt is recognizable as such in the field, because it carries red pseudomorphs (smectite + hematite) of olivine phenocrysts, together with ubiquitous phenocrysts of plagioclase. However, consistently determining the composition of the flows is difficult in the field, so no attempt was made to discriminate them on the basis of composition. I mapped the dacite flow capping Table Mountain (map unit Tdtm) solely by its geomorphic prominence; the physical character of the flow resembles that of many andesite flows.

This section of lava flows is part of a continuous belt of similar rocks that extends westward across the southern parts of the McCoy Peak and French Butte quadrangles. It probably warrants a name, and indeed Hammond (1980) and Korosec (1987) assigned these flows to the *lava flows of Council Bluff.* There is some confusion as to where the base of this unit should be placed, however. Moreover, Hammond and Korosec included rhyolite in the unit that I believe should be separated out. My reconnaissance in the Lewis River drainage suggests that the unit loses definition there and becomes extensively interbedded with volcaniclastic rocks of various types. Hence I have not used their unit name on this or previous maps but instead am delaying assigning a new or restricted name until my mapping is complete and the contact relations better understood.

Attitudes are generally consistent with the Table Mountain syncline, but some differences in the Summit Prairie area suggest remnants of one or more eroded cones. Oxidized scoria crops out at about 1,460 m (4,800 ft) along Summit Prairie Creek and could be near-vent cinder rather than slaggy flow-top rubble. A thin flow with wispy internal structure suggestive of a non-homogenized and hence near-vent spatter-fed flow crops out near the trail 800 m northwest of Point 5238.

The abundance of dikes in this area also suggests one or more vents. In general, dikes are most common in areas underlain by lava flows throughout all of the quadrangles mapped and less common in areas underlain by volcaniclastic rocks. This "guilt by association" suggests that the dikes are related to the particular section of flows that they cut, or to its eroded upper part, .

The northern margin of the flow field is a series of north-facing (up-dip) cliffs and steep hillsides. I interpret this as an erosional feature caused by slope retreat resulting from landsliding as well as fluvial and glacial processes. No evidence of faulting was observed in this steep area.

Previous workers interpreted the lava flows to rest with angular unconformity on the volcaniclastic rocks, because dips on the south flank of East Canyon Ridge are much steeper than those within the flows themselves (Harle, 1974; Hammond, 1980). I disagree with this interpretation, for I found dips of intermediate value near or along the base of the cliff line. Moreover, flows, tuffs, and volcanic sandstone are obviously interbedded along the lower part of Summit Prairie Creek and southwest of the mouth of Dark Creek. The contact between andesite and underlying lapilli tuff is conformable along Table Creek at the base of the exposed andesite section. Consequently I view the section as concordant and portray it as such in Section C–C′. The apparent angular unconformity merely reflects a gradual lateral change in dip with distance from the axis of the Table Mountain syncline, not an abrupt up-section change as interpreted by Harle (1974) and Hammond (1980).

Two K-Ar ages (table 2, map no. 1A and 2A) should in theory provide additional evidence bearing on whether the contact is conformable or unconformable; however they do not. The ages clearly conflict with one another on stratigraphic grounds, for the younger age (about 20 Ma; map no. 1A) is from the older part of the section on the southeast end of East Canyon Ridge, and the older age (about 25.5 Ma; map no. 2A, located at the site of chemical analysis 43, to which it is connected by a leader on the geologic map) is from a stratigraphically higher part of the section near lower Summit Prairie Creek. There is no objective way to decide which if either of these two ages is most nearly correct. These ages show what so many other Tertiary ages in the southern Washington Cascades do; individual ages are in general unreliable, and it will take a large-scale project and many radiometric ages before some statistical consistency can be obtained and clearly incorrect ages discovered. Given the broad mid-Tertiary age of the section, it is probably better to have no radiometric ages than to have only a few, for the temptation for overinterpretation is strong and not easily avoided.

Near Council Lake at least two silicic lava flows or domes are interbedded with the more mafic lava flows. The most prominent, the rhyolite of Council Bluff (map unit Trcb; table 1, no. 86–87), forms the steep cliffs of Council Bluff itself. The rhyolite is at least 150 m thick. Andesite flows underlie the rhyolite, bank against its west flank, and overlie it at the site of the former lookout. Its thickness and local relief suggest the rhyolite is a dome. This body, and the older rhyodacite flow or dome (map unit Trd) just north of Council Lake, lie along the projected trend of the large rhyolite intrusion of Spud Hill (map unit Tris) and could conceivably be an extrusive equivalent.

Lava flows are distributed throughout the older part of the section, though far less abundantly than south of upper East Canyon Creek. Thin rubbly flows with associated fine-grained cinder crop out on Blue Lake Ridge west of Doe Creek. Dips in the cinder are contrary to the regional structure and probably signify the flank of a cone.

Along upper Buck Creek a sparsely plagioclase-phyric basaltic andesite (table 1, no. 25) forms a dip-slope outcrop of what I interpret as a lava flow. Its east margin is straight and faulted; an attitude on the fault indicates a west dip of 55°. Exposures are rather sparse in this area, and the basaltic andesite could well be an intrusion, not a flow.

Tabular bodies of andesite and basaltic andesite crop out in the Mouse and Cat Creek drainages, high on the north flank of East Canyon Ridge, and north of Spud Hill. Some or all of these bodies could be sills, although all are fine to medium grained, vesicular in places, and lack good columnar jointing such as that which characterizes many of the definite sills in the region.

Basaltic andesite (table 1, no. 26) and an associated dike occur in the roof of the rhyolite intrusion of Spud Hill. The basaltic andesite is rather coarse grained and could be called a microdiorite. It may be intrusive, perhaps part of a complex intrusion of which the dike is one component. However, I found enough vesicular rock to suggest that the basaltic andesite is best interpreted as one or more flows.

Intrusions—Numerous dikes, sills, and irregular intrusive bodies probably older than the intrusive suite of Kidd Creek occur in the quadrangle. In general only their ages relative to the host rock are known, and important age relations among different intrusions are completely unknown from the evidence in this quadrangle alone.

Dikes—About 60 different segments of dikes were mapped. They are most common along and south of upper East Canyon Creek but also crop out on the south flank of East Canyon Ridge, west of lower East Canyon Creek, and possibly about 400 m southeast of Mouse Lake. The dikes are typically a meter or two wide, columnar, and slightly vesicular with quenched margins. Most dip approximately normal to bedding, even where bedding is steep, so the dikes are probably older than the folding. Chemical analyses range from basaltic andesite to dacite; dikes of basalt probably also occur but were not analyzed. Most are basaltic andesite or andesite. The dikes typically carry moderately abundant phenocrysts of plagioclase and one or two pyroxenes, although some are sparsely porphyritic or even aphyric.

The dikes have a rather consistent east strike (figs. 10 and 11*B*), averaging about 260°, slightly less than the 280° orientation of so many dikes in the southern part of the McCoy Peak and French Butte quadrangles (Swanson, 1989, 1992). However, many dikes in the East Canyon Ridge quadrangle also have this strike; in fact, the dominant mode is 270–290° (fig. 11*B*). The east-striking dikes form what is apparently the east end of the regional swarm of pyroxene andesite dikes described by Swanson (1989, 1990, 1992) and shown in figure 10.

A remarkable, slightly arcuate dike cuts tuffaceous rocks on the west end of East Canyon Ridge. This dike forms a prominent lineament on air photos—the most prominent in any of the mapped quadrangles. Apparently this lineament was interpreted as a fault by Korosec (1987), perhaps based in part on an interpretation in the unpublished student project by Gregory Nimz mentioned earlier. However, nearly complete exposure along the trace of the dike shows that it is the cause of the lineament and that its host rock, though fractured in places near the contact, is not demonstrably faulted. The fracturing is pronounced only at an elevation of about 1,270 m (4,170 ft); elsewhere the wallrock to the dike is only slightly broken if at all. The dike itself is fractured in places but not segmented by faults. The dike is unusually thick for this area, at least 7 m near where the sample for analysis 35 was taken but narrowing to 4–5 m both north and south from there. The actual contact with the host rock was nowhere seen, so these thicknesses are certainly minimums. The dike is a basaltic andesite with considerable range in composition (table 1, no. 21 and 35). Two narrow northeast-trending dikes apparently intersect the main body, although the actual contacts were nowhere observed. One of these dikes has a strange, high-TiO_2 and high-FeO dacite composition (table 1, no. 64).

I interpret the fracturing associated with the dike as caused in part by brittle rupture during emplacement and in part by differential slip along the dike during folding. Such a thick, continuous, nearly vertical body would presumably have acted as a mechanical inhomogeneity in the layered host rocks as they were folded. Resulting differential stress could be reflected by the fracturing.

Plugs and other intrusions—Two small-diameter, vertically walled intrusions of andesite cut lava flows in the Summit Prairie area. Each has a once-glassy margin and a medium-grained interior. Each is relatively fresh compared to its host rock. The larger body has internal quenched contacts and a jointing pattern consistent with multiple injections of magma. These two bodies may be small plugs.

The basaltic andesite intrusion of Dark Creek (map unit Taid; table 1, no. 40) forms a prominent, rugged bluff overlooking the mouth of Dark Creek near the big bend of East

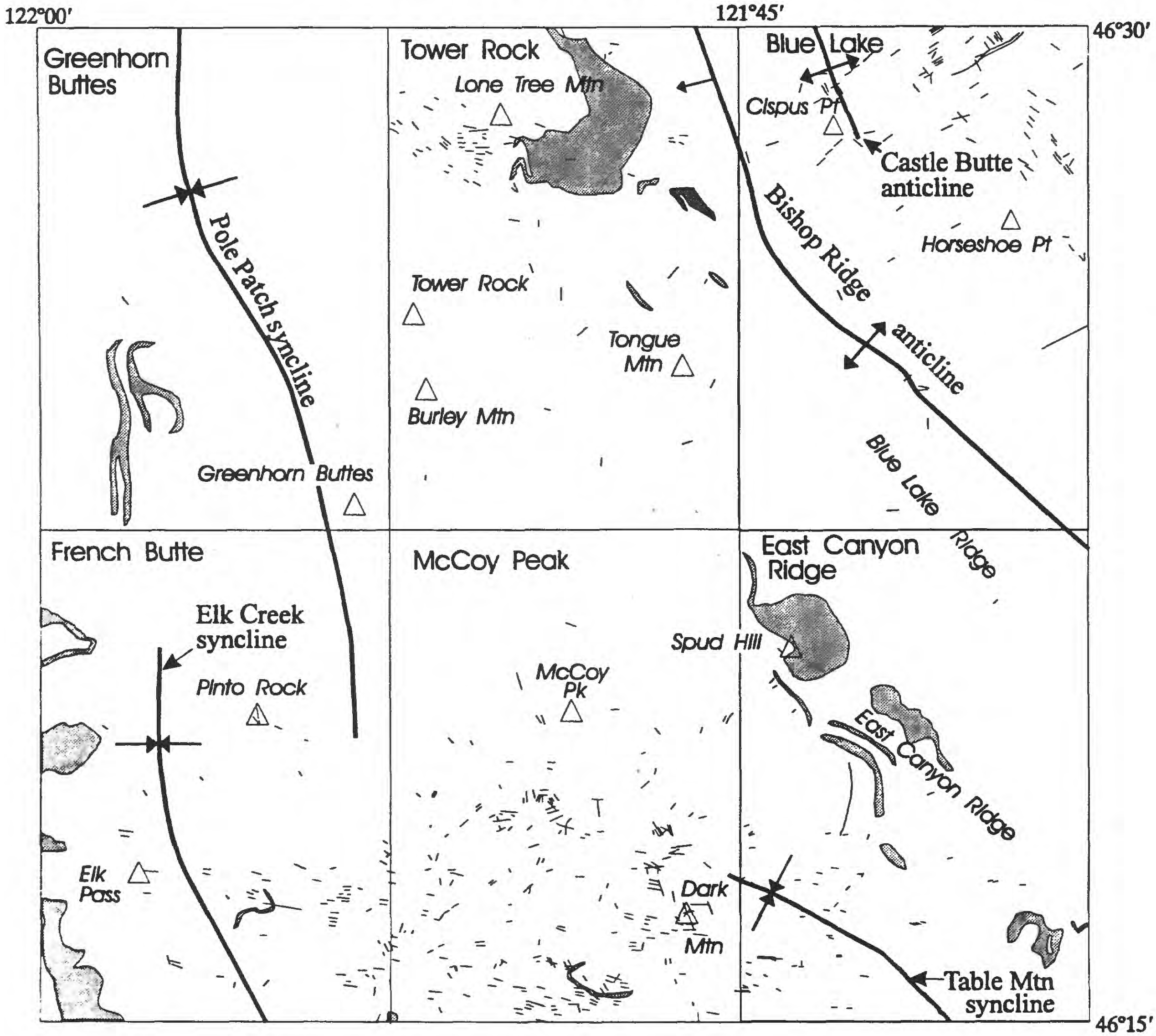


Figure 10. Generalized distribution of about 625 dikes (short lines) of pyroxene andesite and basaltic andesite (with minor basalt and dacite) in mapped quadrangles. Only those dikes are shown for which strike could be measured. Note regional swarm of roughly west-striking dikes in southern part of area and dike-poor zone farther north. Shaded, rhyolite and rhyodacite extrusions and intrusions; note belt of silicic rock from East Canyon Ridge to Lone Tree Mountain. Axial traces of major folds also shown; northwest part of Bishop Ridge anticline is west-facing monocline.

Canyon Creek. Its emplacement deformed as well as hornfelsed the country rock, as seen by the northerly strike and steepened dip along its northwest side. This body could well have formed a shallow reservoir for a volcano now eroded away. Another cross-cutting andesitic intrusion (table 1, no. 44) along Squaw Creek 1 km east-northeast of Point 4888 could likewise be such a reservoir.

Sill-like bodies of map unit Tai were mapped in the Tule Creek–Squaw Creek area. These bodies are medium grained, sparsely vesicular at most, and lack rubble typical of lava flows. The thickest body has nicely developed, straight columnar joints, in places 12 m long, normal to bedding in the country rock. I never found an exposed upper contact on one of these bodies and can only infer that they are sills.

Silicic intrusions—A belt of silicic sills and intrusive domes extends from the northwest corner of the quadrangle southeastward to upper East Canyon Creek, along the regional strike of the bedded rocks (fig. 10). This belt is by far the largest cluster of silicic intrusions in any of the quadrangles that I have mapped and suggests some sort of genetic tie among the intrusions. Furthermore, rhyodacite lava flows and domes crop out approximately along strike near Council Lake (map units Trcb and Trd) and in the Tower Rock quadrangle as far as 18 km from Spud Hill (the rhyodacite of Camp Creek east of Lone Tree Mountain [fig. 10; Swanson, 1991]). My field work in the Purcell Mountain quadrangle south of the Cowlitz River has found silicic rocks of similar field appearance and chemical composition along strike with the rhyodacite of Camp Creek. This makes the resulting zone at least 31 km long. And, in September 1994 Richard B. Moore showed me a sill of probable silicic composition approximately along strike with the belt about 9 km north of the Cowlitz River in the Purcell Mountain quadrangle; if this is indeed part of the silicic belt, the belt is at least 40 km long.The silicic bodies may all be about the same age, for they occur approximately along strike with one another, although some are intrusive and others extrusive. This belt stands out from the andesite that otherwise dominates the mapped quadrangles (fig. 10). Evarts and Swanson (1994) suggest that this zone may be roughly correlative to another similar zone just east of Mount St. Helens, which includes the rhyodacite of Strawberry Mountain and the dacite of Clearwater Creek in the French Butte quadrangle as well as farther west (Swanson, 1989; Evarts and Ashley, 1993a, b).

RHYOLITE INTRUSION OF SPUD HILL. The largest of these bodies is the rhyolite intrusion of Spud Hill (map unit Tris). This rhyolite and high-SiO_2 rhyolite (table 1, no. 91–92, 95, 97) forms a domelike mass whose roof is preserved but base not exposed. It is at least 800 m high and has a volume of more than 1 km^3.

Evidence that the Spud Hill body is at least partly intrusive was found in two areas, the top of the hill itself and along the west contact. The tuffaceous rocks and andesite capping Spud Hill, and the wallrock above the alluviated meadow just west of the hill, have been hornfelsed and locally deformed; note the northeast strike and southeast dip 400 m southeast of Point 4834. The contact is so tight that hand samples can easily be taken across it. Moreover, the rhyolite is very fine-grained, presumably chilled, against the andesite, which conversely shows no textural change at the contact; this relation is well exposed about 150 m southeast of Point 4834, where the contact dips about 18° northeast. The contact of the cap rock with the rhyolite is complex; multiple sills, dikes, and irregular pods of rhyolite intrude the host over a thickness of several meters. The host and the rhyolite are slickensided locally along this zone, probably a result of protoclastic intrusion. The rhyolite is fine grained everywhere but even finer near the contact. These observations indicate that the rhyolite intruded, heated, and deformed its roof. Were it otherwise, the volcaniclastic rocks and andesite would have to rest depositionally on the irregular surface of the rhyolite, yet no evidence for such deposition was found, such as pieces of rhyolite in the sediment.

The western contact of the rhyolite is exposed in a road cut 400 m south of Point 4834. Here the contact is clearly intrusive in a border zone about 100 m wide. The rhyolite consists of several dikelike bodies in contact with one another and, nearer the margin, with horses or screens of hornfelsed, broken and deformed coarse lithic-pumice-lapilli tuff. The rhyolite is broken too and apparently behaved in a brittle, protoclastic manner during the late stage of emplacement. The margin of the rhyolite dips about 85° northeast. Some of the dikelike bodies are much less deformed than the rest of the border zone and may indicate relatively late injection, after most of the protoclastic deformation had taken place.

I have outlined in detail the evidence for intrusion, because the overall shape and thickness (at least 800 m if not tilted, and about 1 km if tilted 40°, consonant with the dip of the host rock) suggest a dome. Perhaps the best interpretation for the form of the body is an intrusive dome or cryptodome, but also possible is an extrusive dome that lifted up and punched through its cap rock. Both kinds of domes have been observed to form in the past 50 years. Development of a cryptodome is well documented at Mount St. Helens in March–May 1980 (Lipman and others, 1981; Moore and Albee, 1981), and extrusion of a mostly capped dome (termed "roof mountain," a translated Japanese term, in the literature) was observed at Usu volcano in Japan in 1943–45 (Minikami and others, 1951). Still another possibility is simply a thick node along a basically sill-like body, such as those that commonly formed in sills of the intrusive suite of Kidd Creek in the other mapped quadrangles (Swanson, 1991, 1992, 1993); in the Kidd Creek sills, however, the node (or plug) generally occurs at the stubby end of the sill rather than at an intermediate location.

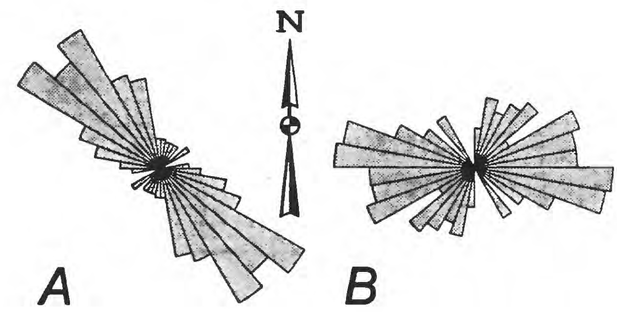


Figure 11. Equiarea rose diagrams in 10° increments showing strikes of volcaniclastic rocks and pyroxene andesite dikes in East Canyon Ridge quadrangle. *A*, 273 strikes of bedding (mean direction, 309.8°; s.d., 25.6°); *B*, 62 pyroxene andesite dikes (exclusive of long arcuate dike on west end of East Canyon Ridge); mean direction of 79.6° (s.d., 33.0°).

The rhyolite of Spud Hill is younger than its host rock but older than the post-folding intrusive suite of Kidd Creek (map unit Thd). At least two dikes of the Kidd Creek suite, each columnar and about 2 m thick, cut the rhyolite at about 4200 ft elevation 200 m north-northwest of the site of chemical analysis 91. These dikes strike about 270° and dip 50–60° south—an unusually shallow dip for dikes of the Kidd Creek suite that suggests influence by the already present massive rhyolite. The contact of map units Thd and Tris at the north end of the Spud Hill body is not exposed; probably the Kidd Creek is cross cutting there, too.

The Spud Hill is older than the Kidd Creek, but its relation to the age of folding is less clear. Map relations suggest that the body dips west with the host rock. Note how the cap rock connects to the marginal host rock on the west side of the body, and how the foliation and plunge of columns along the low eastern margin of the body indicate a west dip comparable to that of the host. However, this evidence is far from definitive. Clearly this body is a prime candidate for isotopic dating and for paleomagnetic study to determine the timing of its emplacement relative to folding. This would be desirable for helping to decipher its emplacement mechanism and to evaluate its unusually silicic composition in terms of the overall petrologic and tectonic development of the arc. An attempt to date zircon crystals in the rhyolite by the fission-track method proved fruitless, for no zircons were found in the heavy mineral separate (J.A. Vance, oral commun., 1991).

Sills(?) of similar composition (map unit Tris; table 1, no. 88, 90, 93–94, 96) and physical appearance extend northwest and southeast from Spud Hill. No contacts were observed, but map patterns suggest tabular bodies with slightly cross-cutting relations to the host rocks. In detail the two least silicic analyses are from somewhat coarser and more porphyritic rocks than typify the Spud Hill in other places. Future work may be able to split this type of rock from the much greater volume of more silicic rock, which makes up all of Spud Hill and most of the sill-like bodies extending northwest and southeast from it.

OTHER SILICIC INTRUSIONS. One other thick sill of silicic dacite and rhyodacite composition (map unit Tdi; table 1, no. 73, 76–78, 80–81) is particularly prominent in the quadrangle. It projects across lower East Canyon Creek, and probably also across upper East Canyon Creek, with no need for offset by faults that could hypothetically follow the poorly exposed valley bottoms. It in essence *stitches together* the section across those valleys. Its upper quenched contact crops out 1.3 km northeast of Point 4663 south of upper East Canyon Creek and 800 m northwest of Point 4946 on East Canyon Ridge. Elsewhere the contact is not exposed, but outcrops near it consistently show hornfelsed host rock and a fine-grained marginal zone on the intrusion. The sill is nicely columnar, though in places the columns are more nearly vertical than perpendicular to the 30–35°–dipping bedding.

One other thin, poorly exposed rhyolite sill(?) crops out just north of the thick sill at the west end of East Canyon Ridge (map unit Tri; table 1, no. 84). An isolated body of similar composition occurs just south of the thick sill (map unit Tri, table 1, no. 83).

INTRUSIVE SUITE OF KIDD CREEK

Sills of hornblende microdiorite and mafic dacite (table 1, nos. 60–62, 65, 67–68, 71) are abundant north of upper East Canyon Creek. The most prominent, north of the mouth of Orr Creek, is readily visible when driving west along the road in the Cispus valley. The sill is at least 175 m thick, dips southwest 30–35°, and has shed extensive talus and landslide debris, including an old landslide (map unit Qols) on the valley floor north of Adams Creek (see section on landslide deposits).

The 60–70–m–thick sill on the northeast flank of East Canyon Ridge forms a long strike ridge whose top is exposed in several places along the creek following the contact. This sill fingers out abruptly along Squaw Creek, about where the rhyolite sill of map unit Tris does similarly; perhaps the earlier of the two sills (probably the rhyolite) influenced the positioning of the younger sill.

Another prominent sill, more than 190 m thick, underlies Point 4852 north of Dark Creek. The sill 1.5 km north of there is part of a much larger body that reaches far into the McCoy Peak quadrangle (Swanson, 1992).

These sills are representatives of the intrusive suite of Kidd Creek (Marso and Swanson, 1992), a chemically coherent assemblage of hornblende-bearing sills, dikes, and irregular bodies throughout a 500–km^2 area in the Cispus drainage basin (fig. 12). This suite, its radial dike swarm, and its general characteristics have been described in detail in previous open-file reports (Swanson, 1991, 1992, 1993); the dikes that cut the rhyolite of Spud Hill are representatives of the radial dike swarm. The chemical distinction found elsewhere between the suite and other Tertiary rocks (lower contents of TiO_2, FeO*, and MnO at equivalent SiO_2 content) also holds in the East Canyon Ridge quadrangle (fig. 13). Its age is poorly known but, from three zircon fission-track ages, is considered to be about 12 Ma (Swanson, 1992). I have previously inferred, from relations between subvertical dikes and moderately dipping host rock, that the Kidd Creek postdates most if not all of the folding in the area (Swanson, 1991, 1992). This interpretation has been verified paleomagnetically by Hagstrum and Swanson (in press), who found that "unfolding" of the observed, tightly clustered paleomagnetic directions markedly increases their scatter, so that it is statistically almost certain that the dikes and sills have not experienced post-emplacement tilt.

The far-flung distribution of the sills in the Blue Lake and East Canyon Ridge quadrangles suggests that not all of the suite is directly related to one volcano centered northeast of McCoy Peak (fig. 12). That almost certainly *is* a major subvolcanic center, but the distribution of the sills suggests either additional centers not defined by radial dikes or noneruptive intrusions.

STRUCTURE

Folds—The structure is dominated by the Bishop Ridge anticline (fig. 10; Swanson, 1993), whose axial trace crosses the extreme northeast corner of the quadrangle along Cat Creek. The notable uniformity in strikes reflects the dominance of this structure (fig. 11*A*). Dips on the southwest flank of the anticline are 30–35° in most places but lessen on the south flank of East Canyon Ridge near the trough of the Table Mountain syncline. The syncline is a shallow structure, difficult to define and extending only a short distance into the McCoy Peak quadrangle, where I did not recognize it previously (Swanson, 1992). That the structure is subtle is illustrated by Harle's (1974) designation of it as an *anticline*; he placed a synclinal troughline (his Boulder Creek syncline) just north of Table Mountain.

The stratigraphic thickness of the section can easily be estimated from this relatively simple structure. The distance between the crest of the Bishop Ridge anticline and the trough of the Table Mountain syncline is about 13 km. From this distance the thickness of section can be calculated as 6.5

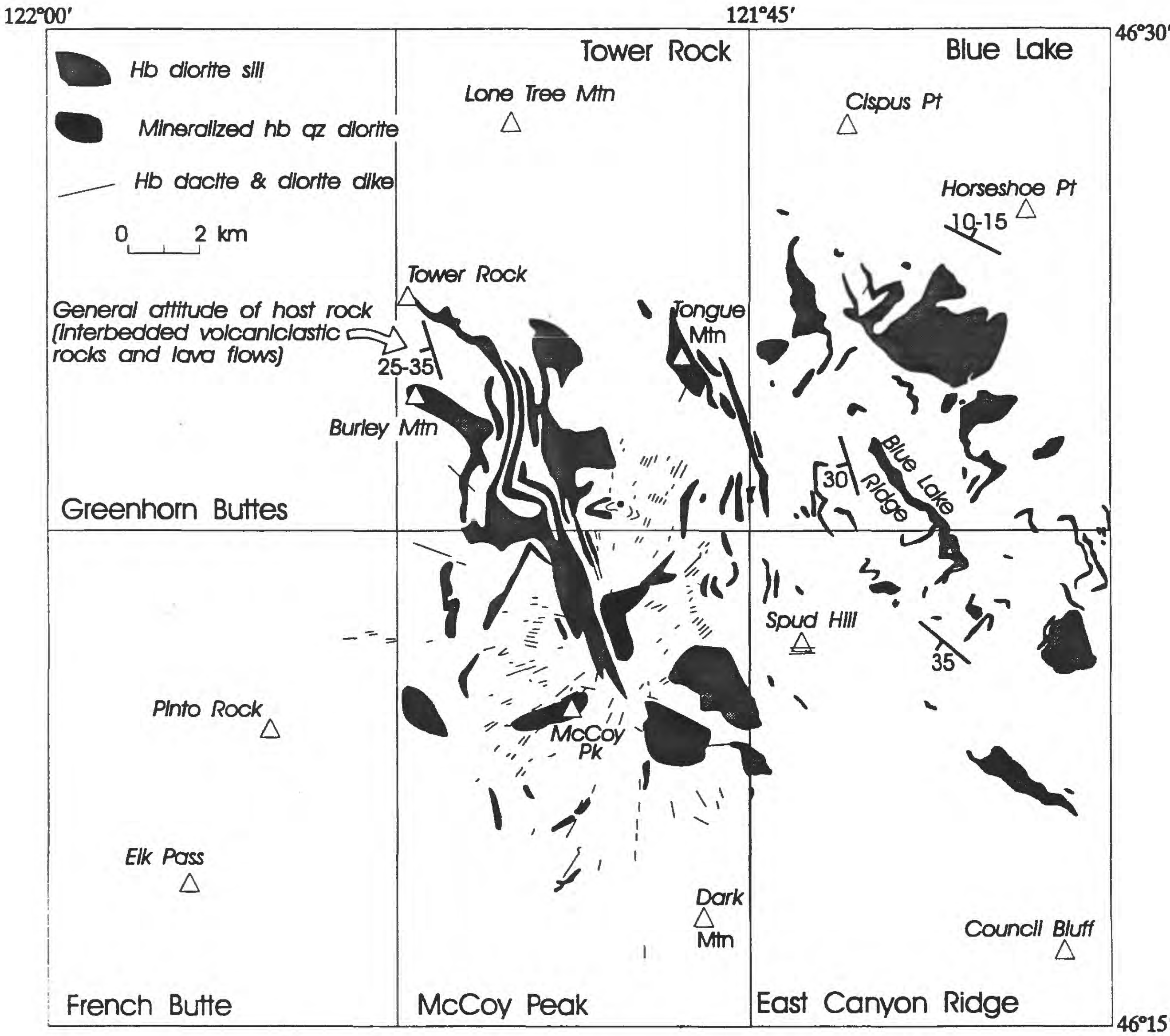


Figure 12. Generalized map showing distribution of intrusive suite of Kidd Creek in the mapped quadrangles. Dikes radiate from site of mineralized McCoy Creek intrusion, but none occurs in East Canyon Ridge quadrangle. Around the McCoy Creek area, dikes occur preferentially in southwest and northeast quadrants, and sills in northwest and southeast quadrants. In the Blue Lake and East Canyon Ridge quadrangles, however, sills are common northeast of the subvolcanic center and most likely record one or more separate foci of intrusion. General attitude of host rocks shown in four locations. The suite has been recognized slightly southeast of the northeast corner of the East Canyon Ridge quadrangle.

km for an average dip of 30°. This calculation does not take into account the shallower dip in the 3 km northeast of the synclinal troughline. An average dip of 10° for those 3 km and a 30° dip for the remaining 10 km result in a total calculated thickness of about 5.5 km. I conclude that the best thickness estimate is 6 ± 0.5 km. Of that thickness, sills account for 0.5 km at most, so that the true stratigraphic section is at least 5.5 ± 0.5 km. This is similar to the true thickness of about 5 ± 0.5 km that I previously calculated between the Bishop Ridge anticline and Pole Patch syncline in the Blue Lake, Tower Rock, and Greenhorn Buttes quadrangles (fig. 10; Swanson, 1993).

Faults and shear zones—No significant fault was identified in the quadrangle. Narrow shear zones or faults with small displacement found in several places show no systematic orientation or sense of displacement where that could be determined. The most conspicuous fault on the map, in the headwaters of Buck Creek, is interpreted from the map pattern and an observed shear surface dipping 55° west in a road cut at an elevation of 1,095 m (3,600 ft) just upstream from the site of analysis 25; slickensides on that surface plunge steeply down dip.

Previous workers in the area have mapped faults that I cannot confirm. Harle (1974) shows a north-striking fault, west side down, just west of Council Bluff. This fault would

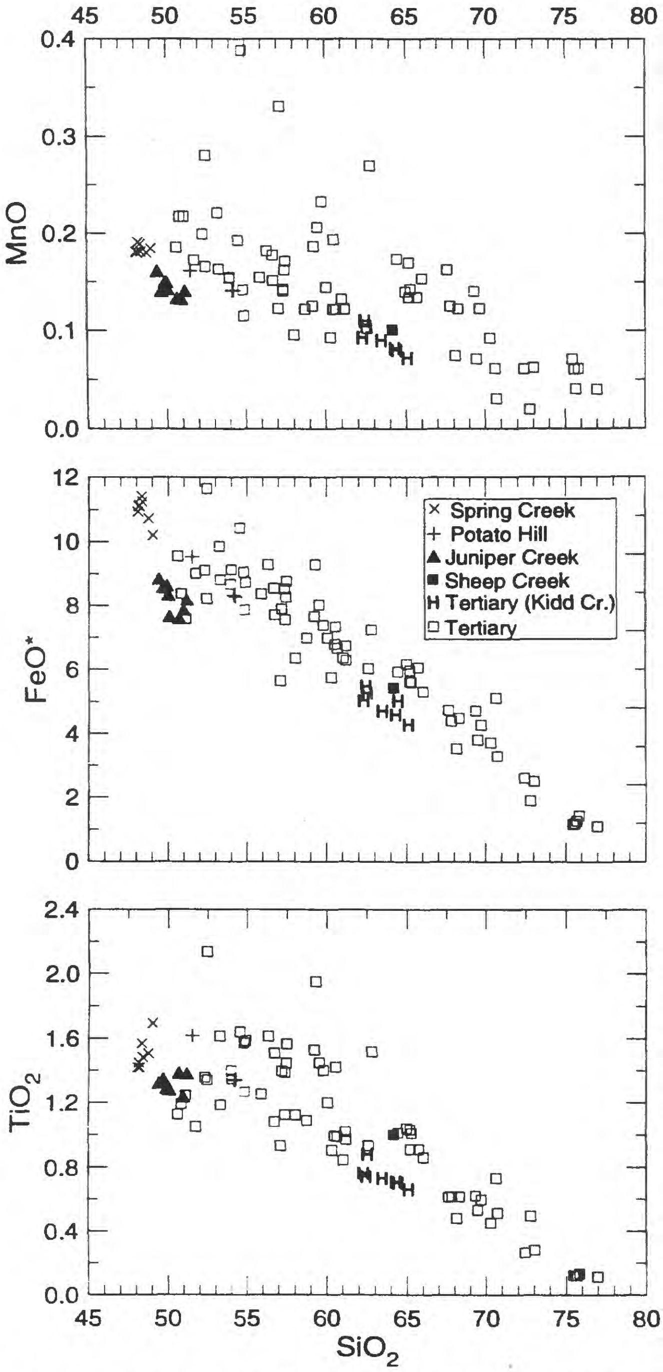


Figure 13. Plots of TiO_2, FeO*, and MnO vs. SiO_2 for all analyzed rocks in East Canyon Ridge quadrangle. Note that hornblende diorite and related rocks of Kidd Creek intrusive suite are chemically distinct from most other rocks in quadrangle. See caption of figure 3 for map-unit symbols of Quaternary rocks.

have to pass through the rhyolite of Council Bluff, where I saw no evidence of offset. Hammond (1980) mapped a north-striking normal fault, west side down, from Spud Hill south to the saddle between Table Mountain and Summit Prairie and thence southward beyond the quadrangle's southern margin. I looked for evidence for such a fault and found none; in fact, the projection of the dacite sill (map unit Tdi) across East Canyon Creek south of Spud Hill argues against much if any offset in the valley. Hammond (1980) shows two other faults, one north-striking west-down fault just east of the previously described one and another, striking northeast and east down, crossing upper East Canyon Creek across the projected extension of map unit Tdi. Korosec (1987) shows Hammond's first and second faults, and puts two north-striking faults across the east end of East Canyon Ridge. The western of these two faults appears to follow the arcuate dike so prominent on air photos but extends farther north. The eastern fault, east side down, passes over a saddle on East Canyon Ridge from upper East Canyon Creek down Tule Creek. My detailed work confirms none of these faults on East Canyon Ridge, which were mapped by Hammond and Korosec during only reconnaissance work. In each case my observations suggest that mapped units project across the proposed faults. In such forested terrain it is easy to miss exposures of fault planes and fault breccia or gouge, but there is nothing in the map pattern that requires faults of any magnitude.

Steep dips west of Spud Hill—An eye-catching road cut, often photographed, exposes bedded volcanic sandstone and mudstone at the site of analysis 78 about 600 m south-southwest of Point 4834. The volcaniclastic rocks dip 80° west and are cut by a small thrust fault dipping 27° south with offset of about 6 m. The sill of map unit Tdi intrudes the volcaniclastic rocks at the north end of the cut. Similarly the bedded rocks dip steeply along the next creek farther northwest as well as at several other sites near the road cut. Such steep attitudes do not characterize the volcaniclastic rocks beyond this area, however; instead they are confined to a narrow zone between two large intrusions, the rhyolite intrusion of Spud Hill and a hornblende microdiorite body that extends far into the McCoy Peak quadrangle.

I think it likely that the steep dips result from deformation caused by emplacement of one or both of these intrusions. In particular, the Spud Hill body demonstrably deforms its host rock, as described above. Moreover, volcanic sandstone dips steeply to vertically near the north margin of the large hornblende microdiorite sill 1.5 km inside the McCoy Peak quadrangle. I portrayed this relation as a fault on the McCoy Peak map but described in the text (Swanson, 1992, p. 23) how I thought that the steepened dip could be confined to that part of the section jacked up by the sill. I extend this interpretation to explain the steep dips near Spud Hill: deformation by intrusion, not regional faulting.

Pin Creek zone—Hammond (1980) portrayed the Pin Creek fault as extending from lower Pin Creek (along the Lewis River south of the quadrangle) northward to west of Davis Mountain, north of the Cowlitz River between Randle and Packwood. Korosec (1987) and Walsh and others (1987) show the fault (or fault zone) on their maps. In the quadrangle, the fault reaches from Spud Hill south to the saddle between Table Mountain and Summit Prairie and thence southward beyond the quadrangle's southern margin. Northward from Spud Hill the fault follows the Cispus River val-

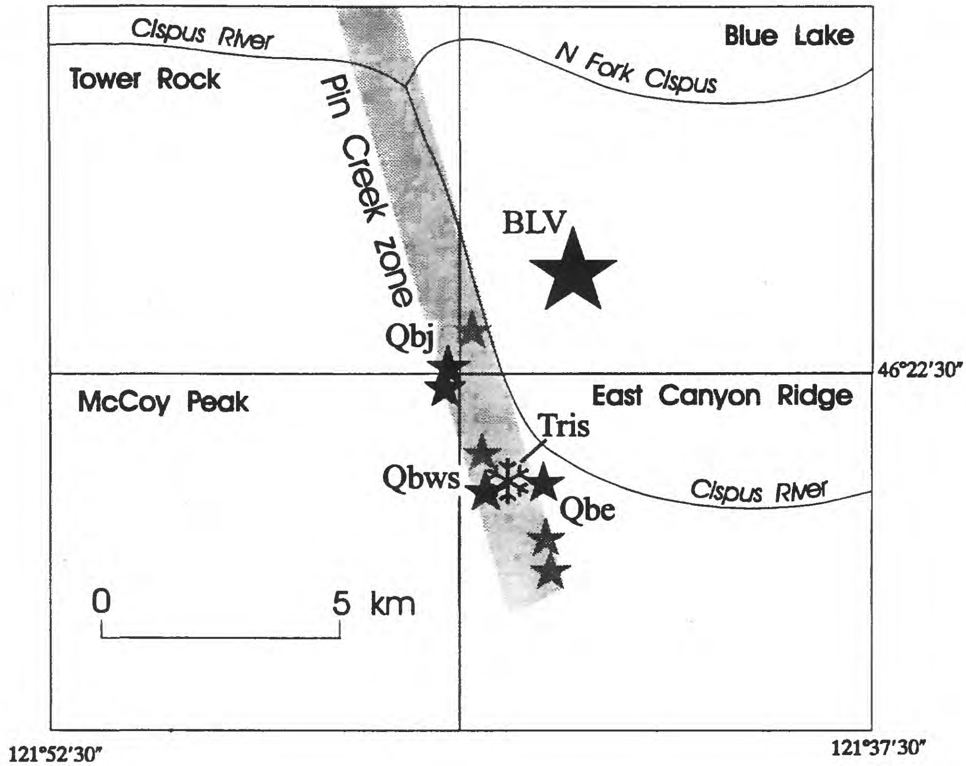


Figure 14. Map of parts of indicated quadrangles showing vents (stars, shaded where minor) for basalt of Juniper Creek and chemical correlatives relative to Pin Creek zone. BLV, Blue Lake volcano; Qbj, basalt of Juniper Creek; Qbe, basalt of East Canyon Creek; Qbws, basalt west of Spud Hill; Tris, rhyolite intrusion of Spud Hill (snowflake).

ley, leaves the valley near the mouth of the North Fork Cispus River, and eventually crosses the eastern limb of Lone Tree Mountain. Hammond portrays the rhyolite intrusion of Spud Hill as younger than the fault,. but conceivably the steep dips west of Spud Hill could be related to the fault.

I don't believe that the Pin Creek fault is a throughgoing structure. There is indeed evidence of faulting—mostly dextral slip as determined by roughness characteristics of fault planes rather than by offset strata—along what I called the *Pin Creek fault zone* in the northern part of the Tower Rock quadrangle (Swanson, 1991). This faulting does not exactly coincide with the Pin Creek fault as shown by previous workers; in particular it does not climb onto Bishop Mountain southeast of the mouth of the North Fork Cispus. South of the North Fork, however, I have found no evidence of faulting, despite considerable searching starting from my former premise that the fault system actually exists. Consequently I now use the term *Pin Creek zone* in a restricted sense to refer to the north-northwest-trending zone that includes faulting near the mouth of the North Fork Cispus River, several of the vents for the basalt of Juniper Creek and related basalt, the large rhyolite intrusion of Spud Hill, and the steep dips west of Spud Hill probably caused by the intrusion (fig. 14). Even the term *Pin Creek zone* is inappropriate, because Pin Creek itself is south of where I think the zone ends. Ultimately it may be best to drop the term entirely.

QUATERNARY LAVA FLOWS AND VENTS

Five different units of Quaternary volcanic rocks occur in the quadrangle, ranging from dacite to basalt in chemical composition. Four of the units were erupted outside the quadrangle, in the northern part of the Mount Adams volcanic field. The fifth unit has been subdivided into three map units, each erupted from specific vents in the northwest quarter of the quadrangle.

Dacite of Olallie Lake (map unit Qdo)—This flat-topped flow, called a coulee by Hildreth and Fierstein (in press), just entered the quadrangle from its probable vent near Takhlakh Lake, about 3 km east-northeast of Council Lake. It was erupted about 381 ± 5 ka (Hildreth and Fierstein, in press; Hildreth and Lanphere, in press) as a fairly extensive (4 km by 3 km in diameter) and thick (as much as 160 m) platy-jointed flow (Hildreth and Fierstein, in press). It now forms an upland in the Green Mountain quadrangle from which landslide debris cascades into Sheep Creek. Erosion cut through the flow to form ancestral Sheep Creek canyon. The flow is sparsely to moderately plagioclase phyric, distinctly less porphyritic than the dacite of Sheep Creek but otherwise resembling it.

Dacite of Sheep Creek (map unit Qds)—This flow, erupted about 246 ± 4 ka (Hildreth and Fierstein, in press; Hildreth and Lanphere, in press), advanced down ancestral Sheep Creek canyon along and just east of the eastern edge of the quadrangle. The flow may once have extended to Adams Creek but now terminates in a waterfall on Sheep Creek at an elevation of 900 m (2,950 ft) just outside the quadrangle. Remnants of the flow were looked for but not found along Adams Creek. The flow is mafic dacite (table 1, no. 66), moderately plagioclase-two pyroxene phyric, generally crystalline, and only locally flow layered. The flow was mapped as the dacite of Ollalie Lake by Korosec (1987), but Hildreth and Fierstein (in press) separated it from the older, less porphyritic Ollalie Lake. The location of the vent is unknown but certainly southeast of the outcrop area and buried by younger rocks.

Basalt and basaltic andesite of Potato Hill (map unit Qbap)—About 111 ± 10 ka, flows of basalt and basaltic andesite erupted from Potato Hill, a prominent cone on the Cascade Crest 2 km north-northwest of hill 5162 (fig. 1; Hildreth and Fierstein, in press; Hildreth and Lanphere, in press). The flows poured into the Cispus valley 3–4 km upstream from the east edge of the quadrangle.

Three or more of these flows—each one olivine-bearing, sparsely plagioclase-clinopyroxene-phyric basalt and basaltic andesite—now crop out along the Cispus River from the east edge of the quadrangle to a point about 0.9 km downstream from the mouth of Squaw Creek. How much farther downriver the unit extends (or once extended) beyond its mapped limit is uncertain. Conceivably it occurs in the nearly inaccessible gorge walls along lower East Canyon Creek, though only the basalt of Spring Creek was identified on the rim of the gorge.

Hammond (1980) and Korosec (1987) did not distinguish the Potato Hill from the Spring Creek in the Cispus valley. Hildreth and Fierstein (in press), however, recognized that the flows from Potato Hill are distinct from the younger basalt of Spring Creek, for they carry plagioclase phenocrysts, are not generally diktytaxitic, and are markedly more silicic and otherwise different chemically.

The field appearance of the two units is in places similar, however, and care must be taken to distinguish the two. For example, the contact between the sites of analyses 1 (Spring Creek) and 29 (Potato Hill) between Adams and Squaw Creeks is very steep; the Spring Creek fills a gorge eroded into the Potato Hill, which here contains few plagioclase phenocrysts and is finely diktytaxitic. Initial observations were confusing, and it was only detailed searching that discovered the contact. The situation is similar 500 m downstream, where the Spring Creek forms the floor of the present Cispus gorge at the mouth of Squaw Creek, the Potato Hill forms the entire wall of the gorge only 100 m or less farther down the Cispus, and the field appearance of the two units is similar.

Perhaps the best place to view the unit is at the bridge across the Cispus River near Adams Fork Campground. Here one flow of distinctly plagioclase-olivine-phyric basaltic andesite (table 1, no. 28) crops out. This flow is more highly and coarsely porphyritic than those farther downstream. A good place to observe a basalt is at the site of analysis 19 near the east edge of the quadrangle. Here the Cispus cascades 6–8 m across a clinopyroxene-plagioclase-olivine-phyric flow, which has massive, wide columns but is missing its vesicular flow top owing to erosion.

The Cispus valley was apparently widened during the Hayden Creek Glaciation (probably about 140 ka), long before the Potato Hill was erupted. Whether the Potato Hill spread across the broad floor of the U-shaped valley or was confined to a channel along the Cispus is not clear, for nowhere can the Potato Hill be traced away from the modern Cispus owing to the cover of younger gravel and sand (map unit Qgs). Erosion by the Cispus had incised a 20–40–m–deep gorge into the Potato Hill by the time the basalt of Spring Creek was erupted.

Basalt of Juniper Creek (map unit Qbj) and related basalt—The basalt of Juniper Creek and its chemical correlatives, the basalt of East Canyon Creek (map unit Qbe) and the basalt west of Spud Hill (map unit Qbws) are the only Quaternary volcanic units that were erupted in the East Canyon Ridge quadrangle and adjacent parts of the McCoy Peak, Tower Rock, and Blue Lake Ridge quadrangles. The Juniper Creek itself has been described in detail in previous open-file reports (Swanson (1991, 1992, 1993). It is an intermediate-K_2O (1.2–1.4 percent, typically) basalt with numerous small olivine phenocrysts in a generally dark glassy groundmass. It and related basalt were erupted from several vents between lower East Canyon Creek and Blue Lake volcano, 5 km north of Spud Hill. Blue Lake volcano, by far the largest vent area, has a subglacial pedestal surmounted by subaerial flows and cinder. Most of the Juniper Creek and related rocks were erupted either under a glacier or in a wet environment that let to phreatomagmatic activity (Swanson, 1991, 1992, 1993). Many rocks of Juniper Creek affinity contain rare groundmass crystals of red-brown biotite and small xenoliths of multicrystalline vein quartz.

The basalt of Juniper Creek forms a tuff cone and two or three related lava flows and associated hyaloclastite in the extreme northwest corner of the East Canyon Ridge quadrangle and contiguous parts of the other three quadrangles. (Juniper Creek itself is just north of the northwest corner of the quadrangle.) The high point on the cone, in the McCoy Peak quadrangle, is at an elevation of about 1,090 m (3,570 ft). The cone consists of well-bedded, commonly well-sorted, cinder and black sideromelane sand, all of which is somewhat altered to palagonite. Surge beds, low-angle cross bedding, and shallow channels are common, and ballistic fragments of Tertiary rocks are sprinkled through the deposit. The remnant of the cone in the East Canyon Ridge quadrangle contains proportionally more cinder than do remnants in the other quadrangles and apparently records drier, less steam-rich explosions that alternated with the wetter, more powerful phreatomagmatic explosions.

The lava flows are thin except for one exposed along the crestline of the ridge extending northeast into the Blue Lake quadrangle. That outcrop ends in a cliff 40–60 m high overlooking the Cispus River. The basalt exposed in the cliff and adjacent steep slopes is glassy, hackly, dense, and closely resembles the thick subglacial flow on Blue Lake volcano. Subhorizontal columns 10–25 cm in diameter in the cliff form a complex entablaturelike body and suggest cooling against a steep surface, perhaps the side of a glacier. The flow underlies hyaloclastic debris from about 895 m (2,940 ft) down to about 825 m (2,700 ft).

***Basalt of East Canyon Creek* (map unit Qbe)**—Basaltic tephra and thin flows in several eroded tuff cones along lower East Canyon Creek chemically resemble (table 1, nos. 8, 14, 16, and 18) the basalt of Juniper Creek and are probably part of the same eruptive event, although they are designated as the *basalt of East Canyon Creek* on the map. All of these cones are dominated by glassy, sand-size, commonly palagonitized tephra that gives evidence of quenching by water. The cones are faintly bedded to well-bedded and contain abundant dense to moderately vesicular basaltic lapilli and blocks, generally poorly sorted.

Two tephra cones coalesce into a dumbbell-shaped, 200–m–high *double cone* at the east base of Spud Hill. The northern and southern points of the double cone are at elevations of about 798 m (2,618 ft) and 869 m (2,850 ft), respectively; the lowest point on the double cone is at about 670 m (2,200 ft). Hackly and radially jointed, pillowlike masses of quenched basalt cap thick, massive (owing to coeruptive slumping?), glassy tephra in a roadside quarry at the site of analyzed samples 8 and 14 near the north base of the double cone. However, most of each cone consists of hard, palagonite-cemented, crudely bedded lithic and glassy basaltic lapilli. A few white, lapilli-size xenoliths of the rhyolite of Spud Hill are scattered through the lapilli tuff. The deposits are best observed near the top of the highest cone; one of the basaltic lapilli from the summit was sampled for analysis 16.

The double cone has probably been eroded significantly, for the eastern part of the edifice appears to be missing and the remaining part of the edifice has been strongly modified. Crude attitudes suggest that both cones were centered east of their preserved remnants, beneath the gravel and sand of map unit Qgs. In fact, the two cones may really be erosional remnants of a single larger cone rather than two distinct centers. The exposures are simply too incomplete to piece together the former vent morphology precisely.

Boulders of diktytaxitic olivine basalt resembling the basalt of Spring Creek rest on the eroded surface of the double cone. Several can be seen in till or outwash gravel above the quarry face at the site of analyses 8 and 14, and I found one boulder at an elevation of 795 m (2,610 ft) on the northern ridge leading to the top of the southernmost cone. Many of the boulders are stream worn, and others are nicely faceted like till stones. It is unlikely that these boulders are xenoliths blasted out during phreatomagmatic eruptions that built the cone. Moreover, no boulders were seen within the deposits themselves, and the degree of erosion and other geomorphic arguments indicate that the basalt of Spring Creek is actually *younger* than the basalt of Juniper Creek and by extension also younger than the double cone. Most likely the Spring Creek(?) boulders were deposited by either the Evans Creek glacier or by outwash from the glacier.

At least two low, poorly exposed cones formed farther south along the east side of East Canyon Creek. Bedded and palagonitized black sand characterizes many of these exposures, where scattered cow-dung bombs and nonpalagonitized lapilli and blocks occur near vents. Lapilli-size lithic clasts of Tertiary rocks are sprinkled throughout all of the deposits, as are small xenoliths of vein quartz. In most places the bedding mantles the present hill slope developed in the Tertiary bedrock—good evidence that the cones were built in the preexisting valley.

***Basalt west of Spud Hill* (map unit Qbws)**—Another poorly exposed tuff cone mantles topography along a small tributary of Prospect Creek on the northwest flank of Spud Hill. This cone, included in the *basalt west of Spud Hill*, consists of poorly to well-bedded, glassy basaltic tephra of lapilli to sand size with palagonitic rinds, and an equal or even greater amount of lithic clasts derived from the Tertiary bedrock. The highest exposure is at an elevation of about 1,080 m (3,540 ft), and the cone extends at least as low as 915 m (3,000 ft). As along East Canyon Creek, this cone formed in a preexisting valley and records phreatomagmatic activity. Chemically the basaltic tephra is indistinguishable from the basalt of Juniper Creek (table 1, no. 12).

Oxidized cinder, thin flows, and rare spindle bombs and agglutinated spatter form a cinder cone in map unit Qbws just southwest of Spud Hill. The top of the cone is at an elevation of 1,335 m (4,380 ft), about 60 m above the saddle in the ridge south of Spud Hill, but its deposits mantle the east side of Prospect Creek valley below the saddle down to an elevation of about 1,160 m (3,800 ft). The deposits are similar chemically (table 1, no. 9–11) to the basalt of Juniper Creek and the basalt of East Canyon Creek, and I interpret them to be part of the same general eruptive event that formed all of the tuff cones. However, the eruption that produced the cinder cone obviously took place subaerially with minimal, if any, interaction with water.

Eruptive conditions—Most of the basalt of Juniper Creek and its chemical correlatives is the product of phreatomagmatic or subglacial eruptions. The lower part of Blue Lake volcano is subglacial (Swanson, 1993). The quenched, hackly, pillowlike masses of basalt exposed near the north base of the double cone indicate the presence of surface water, as does the hyaloclastite above the lava flow in the northwest corner of the quadrangle; whether these deposits formed beneath or alongside a glacier is unclear. All other eruptions except one were characterized by phreatomagmatic activity (in places interbedded with cinder) that produced quenched basaltic lapilli and sand, palagonite rinds and cement, local surge bedding, and lithic ballistic ejecta. The exception resulted in the subaerial cinder cone.

Elevations of the vents are consistent with these observations and point to the presence of a glacier in the Cispus valley as a possible cause of the phreatomagmatic activity. The cinder cone—the only vent showing no interaction with water—was formed above an elevation of about 1,275 m (4,180 ft), although its deposits mantle slopes down to 1,160 m (3,800 ft). All other vents are below 1,090 m (3,580 ft) (McCoy Peak quadrangle), 1,070 m (3,510 ft) (Tower Rock quadrangle), and 1,080 m (3,540 ft) (Blue Lake quadrangle, along the tributary to Prospect Creek). The top of the subglacial pedestal on Blue Lake volcano is at an elevation of about 1,040 m (3,400 ft), and it is 3 km downstream (and hence downglacier) from the other, slightly higher phreatomagmatic vents.

These observations are broadly consistent with the eruption of Juniper Creek magma into and along the edges of a valley glacier. Eruptions in from the edge of the glacier were subglacial (Blue Lake volcano and possibly the lower part of the double cone), and those near or just beyond the edge of the glacier were "wet" because of the presence of ponds, lakes, and abundant groundwater. The one eruption from a high area above the glacier produced the subaerial cinder cone.

The various vents were probably active at different times. All were erupted onto previously glaciated terrain that was presumably (but not certainly) eroded during advance of the Hayden Creek glacier. Blue Lake volcano may have erupted relatively soon after the glacier began its retreat. The transition from the subglacial pedestal to the subaerial cap is at about the elevation (1,040 m; 3,400 ft) of the top of the U-shaped valley profile, although till extends at least 60 m higher than that and shows that the glacier had once been thicker (Swanson, 1993, p. 18). The tuff cones near Juniper Creek and along the east side of East Canyon Creek must have been formed after the elevation of the surface of the glacier had dropped to no more than about 670–730 m (2,200–2,400 ft), because the flanks of the cones reach down to that elevation. Formation of the double cone may have taken place while ice was still present, though probably no higher than about 760 m (2,500 ft); some moving ice could help explain the apparent removal of the eastern part of the edifice. The phreatomagmatic deposits near Prospect Creek extend down to about 915 m (3,000 ft) and suggest an intermediate level for the glacier. However, lower Prospect Creek shows no sign of having been glaciated, so the elevation of the phreatomagmatic deposits may not provide a meaningful maximum limit for the level of the glacier.

How many vents for the Juniper Creek may have been under the glacier before being totally removed by ice erosion? All those preserved lie along the margins of the valley glacier or were apparently formed during glacier retreat. Conceivably early eruptions could have produced small subglacial edifices for which no evidence has been preserved.

Basalt of Spring Creek (map unit Qbs)—This low-K (table 1, nos. 1–7), diktytaxitic, olivine-phyric basalt occurs as remnants of an intracanyon flow or flows that issued from a low cone (hill 5162; fig. 1) on the Cascade crest north of Mount Adams (Hammond, 1980; Hildreth and Fierstein, in press) and flowed westward into the Cispus River valley as

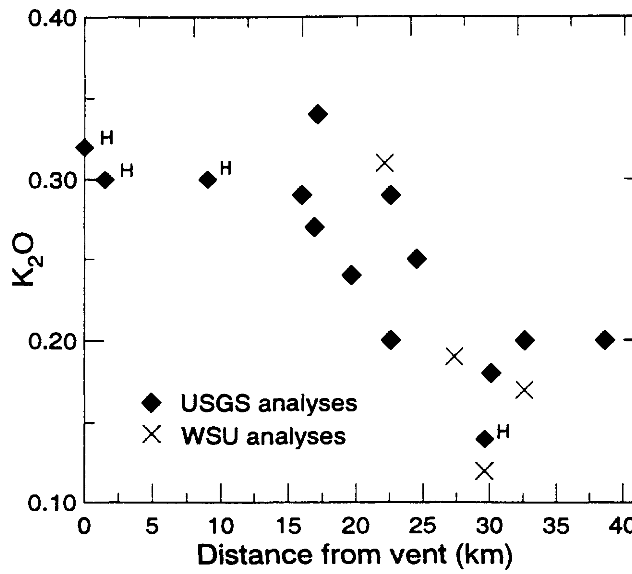


Figure 15. Plot of K_2O content of basalt of Spring Creek *vs.* distance from vent (hill 5162). Note apparent decrease of 0.1 percent or more in K_2O content from vent to farthest downstream outcrop. USGS, analyses done in U.S. Geological Survey laboratories in Menlo Park and Denver; diamonds labeled with H, USGS analyses courtesy of Wes Hildreth. WSU, analyses done at Washington State University.

well as eastward into the Klickitat River valley. Along the Cispus, the basalt probably underlies the entire valley floor as far downstream as Doe Creek. It filled and then spilled out of a 20–30-m–deep gorge eroded into the 111-ka basalt and basaltic andesite of Potato Hill (map unit Qbap). Downstream from Doe Creek the river has eroded completely through the flow and widened its channel considerably, but remnants of the flow hang on the sides of the valley as far downstream as the mouth of Dry Creek, about 15 river kilometers from the Blue Lake quadrangle (Swanson, 1991). The unit is equivalent to the "basalt of Hill 5162" of Hammond (1980) and is named for a creek just west of that hill.

The chemical composition of the basalt of Spring Creek is fairly constant along its entire length in the Cispus Valley (Swanson, 1991, 1993, table 1) and is readily distinguished from that of other young basalt in the area. Available analyses, however, suggest a slight decrease in K_2O content downstream between Squaw Creek (about 16 km from the vent along the course of the flow) and Dry Creek (about 38.6 km; fig. 15). To check this, I included four analyses supplied by Wes Hildreth (written commun., 1994); his analyses mimic and extend the trend back to the vent. Moreover, analyses done in the Washington State University laboratory likewise show the trend.

The change from K_2O values of about 0.30 to about 0.20 (or less) takes place gradationally between about 15 and 25 km from the vent. The gradational change makes it unlikely that two flows have been confused as one; otherwise, there would most likely be a sharp break between clusters of relatively high and low K_2O contents.

The chemical change cannot be explained simply by fractionation of olivine ("olivine control"); samples with high

Table 2. Radiometric ages from the East Canyon Ridge quadrangle

Map No.[1]	Sample No.	Reference	Unit	Method[2]	^{40}Ar, %[3]	Age
1A[4]	PEH-77-2 (SRL-4817)	Hammond (1980)	Ttv	K-Ar (plag)	—	19.4 ± 1.0 Ma 20.0 ± 1.0 Ma
2A (43)	MK85627	Phillips and others (1986)	Ta	K-Ar (WR)	72.2	25.5 ± 0.4 Ma
3A (2)		Hildreth and Fierstein (in press)	Qbs	^{14}C		21.5 ± 0.5 ka
Do.	DS92F–1	Swanson (1993)	do.	do.		41.1 ± 1.3 ka

[1]Map number, with number of chemical analysis from same locality in parentheses (table 1)
[2]K-Ar, potassium-argon; plag, plagioclase separate; WR, whole rock; ^{14}C, radiocarbon
[3]Percent radiogenic argon relative to total argon
[4]Location corrected from Hammond (1980) by Paul Hammond (written commun., 1994)

K_2O contain as much MgO (or more) as those with low K_2O. For example, Hildreth's sample 29.6 km from the vent has MgO = 8.82 and K_2O = 0.14, whereas his sample 1.5 km from the vent has MgO = 8.78 and K_2O = 0.30. Most likely the range in K_2O content reflects real variation in liquid composition.

Most basalt flows as long as the Spring Creek advance through a lengthening lava-tube system, so that lava erupted late is supplied to the flow front downstream from earlier lava. If this is true for the Spring Creek, then the early-erupted magma was richer in K_2O than the later magma.

Analysis 7 (table 1) has an unusually high content of Na_2O; it is an old XRF analysis (Hammond and Korosec, 1983) and may be in error. The high Na_2O content of this analysis accounts for the marginally alkalic point in figure 8.

Two radiocarbon ages have been obtained from material under the basalt in a prominent stream cut along the south side of Prospect Creek at the road crossing of FS 2801 (table 2). These ages are quite different from one another but provide a crude limit on the maximum age of the Spring Creek. One age, 21.5 ± 0.5 ka (radiocarbon years; USGS 2714), was obtained by Hildreth and Fierstein (in press) from organic-rich soil just under the basalt. The second age, 41.1 ± 1.3 ka (radiocarbon years; USGS 3278), was determined by Debbie Trimble (written commun., 1993) on carbonized rootlets(?) that I collected 30–50 cm below the base of the flow in colluvium or alluvium overridden by the basalt. Both ages *could* be correct; conceivably a soil developed about 21,500 years ago on a surficial deposit in which plants had been rooted 41,100 years ago. However, this scenario seems rather unlikely. Moreover, the dated soil was probably not pretreated before dating, because of the dispersed nature of the organic material in it, and so could be contaminated with younger carbon (Willie Scott, oral commun., 1993). If so, the age of 41.1 ka (perhaps itself a minimum because it is near the limit of reliable ^{14}C dating) would be closer to the real age of the soil. I favor this interpretation, because the geologic relations are best explained if the soil and basalt are approximately the same age. In either interpretation, the flow is younger than the soil.

Both radiocarbon ages are broadly consistent with stratigraphic relations along the Cispus River. The basalt of Spring Creek is overlain by thick outwash deposits of Evans Creek age (map unit Qgs in the East Canyon Ridge quadrangle) but overlies only thin soil and colluvium developed on older rocks (as at the radiocarbon locality or at the southeast end of the large patch of basalt opposite the mouth of East Canyon Creek) or gravel and sand deposits interpreted as bars along the ancestral Cispus (Swanson, 1991). These observations suggest that the Spring Creek was erupted before much if any outwash gravel had been deposited along the Cispus. Quaternary geologists believe it most likely that the Evans Creek Glaciation was near its peak about 21 ka (Willie Scott, oral commun., 1993), so that if the Spring Creek were of that age or younger it should overlie outwash gravel. Hence the Spring Creek is probably older than about 21 ka on stratigraphic grounds.

The Spring Creek filled and overtopped the gorge eroded into the flows of Potato Hill. It backed up Adams Creek for at least 1 km and probably nearly that far up East Canyon Creek.

The flow caps a small butte 250 m northwest of the mouth of Squaw Creek (table 1, no. 6). The butte stands 6–7 m above the surrounding surface and exposes squat vertical columns with no vesicular flow top or even any capping gravel of map unit Qgs. The butte suggests that the flow was considerably thicker than what would be expected from the elevation of today's valley floor, and that glaciofluvial erosion during Evans Creek time removed a large but unknown volume from the flow. Another possible explanation of the butte—a tumulus—is unlikely because the columns are vertical, not obliquely plunging as is typical in tumuli.

More evidence suggesting considerable erosion is the presence of high remnants of the flow in protected areas up Prospect Creek and along Blue Lake Creek in the Blue Lake quadrangle. Along Prospect Creek, the vesicular top of the Spring Creek occurs as high as 690 m (2,260 ft), and the base of the flow can be traced discontinuously through brush from about 640 m (2,100 ft) to the site of the radiocarbon analyses (597 m [1,960 ft]). Below the radiocarbon site, the flow extends down to about 580 m (1,900 ft) just above the flood plain of the Cispus. The total range in elevation is thus at least 110 m and indicates that the Spring Creek was quite thick at Prospect Creek. The range in elevation is still greater—about 145 m—in the Blue Lake Creek area (Swanson, 1993). These relations suggest that several tens of meters have been eroded off the unit, which is generally less than 50 m thick in any one exposure.

A profile drawn across the flow before erosion might well have been concave up for two reasons: breakouts farther downstream—leaving in essence sagged bath-tub rings along the valley sides, and contraction during cooling (the thicker the flow, the more it contracts). However, such processes probably could not account for the 50 m or more of missing thickness. Thus erosion, chiefly by outwash streams during ablation of the Evans Creek glacier, seems necessary to explain the observations.

QUATERNARY SEDIMENTARY DEPOSITS

Glacial deposits—As admitted in previous open-file reports, I have had difficulty distinguishing between drift of Hayden Creek (map unit Qhd) and Evans Creek (map unit Qed) ages. This quadrangle is no exception. Weathering-rind thicknesses are commonly definitive but in places ambiguous, in part because of the lack of proper lithologies among the stones for the thickness criterion to work. In general, however, a pattern emerged that seems reasonable.

Fine-grained, sparsely to moderately phyric andesitic stones in diamictons on valley floors generally have weathering rinds more than 1 mm thick, suggestive of drift of Hayden Creek age. Such drift occupies the valleys of Cat Creek, lower Mouse Creek, upper Dark Creek, and upper East Canyon Creek. No such drift was recognized low in the Cispus valley, perhaps because it has been eroded from the steep slopes or misidentified as colluvium. Several diamictons on the north flank of East Canyon Ridge are best explained as drift of Hayden Creek age.

Swampy terrain, many small ponds, one well-preserved moraine, and diamictons carrying andesite stones with little or no weathering rinds imply till of Evans Creek age in the flat upland east of Table Mountain. A lateral(?) moraine (map unit Qem) 1.5 km southwest of Council Lake contains stones of fresh vitrophyric andesite almost certainly derived from Mount Adams, although the Lewis River now separates the two areas. Deposits mapped as Evans Creek Drift north and west of Table Mountain are less surely till; they occur along a discontinuous bench and could be subdued landslide deposits derived from failure of andesite cliffs above, possibly along a volcaniclastic interbed. Relatively young-appearing diamictons along Mouse Creek are shown as drift of Evans Creek age but could well be older.

Gravel and sand (map unit Qgs) in various degrees of sorting and rounding overlie the basalt of Spring Creek. They probably represent fluvial deposits, as well as debris flows, that formed during retreat of ice during late Evans Creek time (Hildreth and Fierstein, in press). Clasts in the deposits are dominantly young basalt and andesite derived from the Mount Adams volcanic field but locally include Tertiary rocks as well. The morphologically distinct gravel of map unit Qg, deposited along streams draining into the Cispus, probably also has a similar origin. Gravel of map unit Qeo, which forms terraces downstream from the reach of valley underlain by the basalt of Spring Creek, is probably at least the partial equivalent of the gravel and sand of map unit Qgs, although it is partly derived from the erosionally retreating front of the Spring Creek flow.

Landslide deposits (map unit Qls)—Landslides are common in the quadrangle. I mapped only the largest. Some are active and others are not.

The broad slide on the south side of East Canyon Ridge is not active except locally but contains ponds in closed depressions. Linear ridges consisting of rotated blocks of bedded volcaniclastic rocks occupy the medial part of the landslide. Some of the blocks were rotated sufficiently to dip upslope, counter to the dip slope elsewhere on the ridge (see the attitudes shown on the map). This slide is joined along East Canyon Creek by another derived from andesite on the south side of the valley.

An active slide, with closed depressions and a drunken forest on its surface, spills into lower East Canyon Creek from its head at nearly 1,280 m (4,200 ft) south of Spud Hill. Slightly farther west, an older or less active slide starts at nearly 1,520 m (5,000 ft) along the Sunrise Peak trail and is truncated by the main slide.

***Old landslide* (map unit Qols)**—The remains of a large slide, now beheaded from its source, form the hill just west of Adams Fork Campground. The roughly 30–m–thick diamicton consists entirely of angular blocks of hornblende microdiorite. The microdiorite was mapped as *in situ* by Korosec (1987), but I could find no outcrop in which the microdiorite was not fragmental and blocks had not rotated. West of the summit are several closed or nearly closed depressions that dot a rather hummocky surface.

The apparent source of this old landslide or rockfall is the sill of hornblende microdiorite just to the north, which dips about 35° toward the valley and is sandwiched between relatively weak volcanic sandstone. The sill is highly jointed, forms unstable cliffs, and feeds several slides and rockfalls today. Most likely the slide came from an elevation of 1,160–1,340 m (3,800–4,400 ft) in the western part of the outcrop.

The age of this slide is unknown. It was likely in place before all of the surrounding gravel and sand had been deposited, because it was probably water carrying that detritus that eroded the gap that today separates the hill from the valley side. If so, the slide is at least as old as latest Pleistocene. The slide is surely no older than the most recent glacier that advanced this far down the Cispus, for the deposit is loose and would have been easily removed by the glacier. Whether the slide predates the basalt of Spring Creek cannot be determined.

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 drift

Qls **Landslide deposits (Holocene and Pleistocene)**—Diamictons produced by mass movement down slope. Includes both active and inactive slides. Many slides result from movement of relatively dense andesite and basalt flows or sills over clay-rich volcaniclastic rocks. Well-exposed active landslide with drunken forest spills into lower East Canyon Creek 1 km downstream from mouth of Dark Creek. This slide cuts an older slide, at the head of which blocks of hornblende diorite and volcanic sandstone have been disrupted and rotated but preserve internal contacts (see attitudes on geologic map). Large slide on south flank of East Canyon Ridge carries blocks of volcaniclastic rocks 100 m or more long that are back-rotated 50° from regional attitude (see geologic map). Mostly Holocene and very late Pleistocene. Locally includes colluvium and drift

Qf **Alluvial fan deposits (Holocene and Pleistocene)**—Local poorly bedded and sorted alluvial deposits, possibly debris flows, at mouths of small tributaries to Cispus River. Mostly Holocene and very late Pleistocene. Includes alluvium, colluvium, and possibly drift

Qols **Old landslide deposit (Pleistocene)**—Angular blocks of hornblende diorite forming thick diamicton underlying hill and hummocky apron just north and west of mouth of Adams Creek. Closed and nearly closed depressions on the apron and hill. Cispus River curves around the deposit. Interpreted as distal part of landslide from thick sill cropping out at southeast end of Blue Lake Ridge. This sill dips about 35° toward the valley and feeds several younger slides. Since the slide was emplaced, it has been separated from the valley wall by erosion, possibly during the time that gravel and sand of map unit Qgs were being deposited. Not clear if deposit is older or younger than adjacent basalt of Spring Creek. Initially interpreted as till, but monolithologic nature and extreme angularity of clasts argue for landslide

GLACIAL DEPOSITS

Qed **Evans Creek Drift (Pleistocene)**—Till, moraine, and outwash deposits, principally along Mouse Creek and south and west of Council Bluff. Slightly weathered to unweathered; most clasts in B soil horizon lack significant weathering rinds. However, unit along Mouse Creek contains some clasts with thicker weathering rinds that could be derived from local deposits of Hayden Creek Drift (map unit Qhd). Unit southwest of Council Lake contains unweathered stones of vitrophyric andesite probably erupted from Mount Adams (Hildreth and Fierstein, in press). Age is late Pleistocene, approximately 17–25 ka (Barnosky, 1984; Crandell, 1987). Queried where possibly of Hayden Creek age. Locally divided into:

Qem **Moraine deposit**—Morphologically distinct, 15–m–high ridge surrounded by till 1.5 km southwest of Council Lake. Contains stones of vitrophyric andesite probably from Mount Adams mixed with rounded pebbles and cobbles of nearby Tertiary rocks. No striae found on surfaces of stones; however, the stones of vitrophyre are highly jointed and probably break easily during transport by ice, so that striae are unlikely to be common

Qeo **Outwash deposits**—Unconsolidated, bedded, moderately sorted to well-sorted boulder to pebble gravel, sand, and silt forming fill in Cispus River valley opposite mouth of Prospect Creek. Several different terrace levels recognized (most obviously in the adjacent Tower Rock quadrangle (Swanson, 1991), presumably reflecting episodic glacier retreat. Deposited by meltwater streams draining glaciers in headwaters of Cispus River. Likely the downstream equivalent of gravel and sand map unit Qgs, but some could be younger and have been transported along the gorge eroded through map unit Qgs and into the underlying basalt of Spring Creek. Younger than the Spring Creek and so probably less than 21.5 ± 0.5 ka (radiocarbon years) (^{14}C date for soil at base of basalt of Spring Creek; see Hildreth and Fierstein [in press] and Swanson [1991]). Locally includes modern alluvium and colluvium

Qg **Gravel**—Deposits of subrounded to rounded boulder and cobble gravel in two patches along Prospect Creek. Poorly exposed. Interpreted as outwash deposits from glacier in McCoy Peak quadrangle (not mapped by Swanson {1992]). Lower patch of gravel contains clasts derived mainly from rhyolite intrusion of Spud Hill (map unit Tris) and other Tertiary rocks, as well as from basalt west of Spud Hill (map unit Qbws); few clasts of underlying basalt of Spring Creek. Upper patch along Prospect Creek could be older, perhaps related to deposition along margin of Hayden Creek glacier. Also includes gravel along Adams Creek, possibly a sidestream facies of the gravel and sand deposits of map unit Qgs

Qgs **Gravel and sand deposits (Pleistocene)**—Poorly to well-sorted, subangular to rounded fluvial gravel and sand above the basalt of Spring Creek in the Cispus River valley. Includes diamictons, probably deposited by debris flows. Blocks of Spring Creek and other young basalt and andesite 1–2 m in diameter common. Scattered clasts derived from Tertiary rocks. Thought to represent outwash from melting ice up Cispus drainage, especially up Spring Creek draining Mount Adams (in Green Mountain quadrangle), prior to marked incision into the underlying basalt of Spring Creek. Probably the upstream, less well-sorted and rounded equivalent of outwash deposits (map unit Qeo), at least the older part. Occurs as unmapped thin mantle and thicker patches on top of basalt of Spring Creek in Doe Creek–Buck Creek area. Locally includes alluvium

Qhd **Hayden Creek Drift (Pleistocene)**—Principally till but may include outwash and moraine deposits. Contains clasts with weathering rinds 1–2 mm thick in B soil horizon. Upper 0.5–1 m of deposit commonly weathered. These features suggest correlation with Hayden Creek Drift (Crandell and Miller, 1974; Colman and Pierce, 1981). Mapped along Cat Creek, Dark Creek, on north side of East Canyon Ridge, and on south side of upper East Canyon Creek valley. All of these identifications are tentative, owing to uncertainties in distinguishing till from old landslide or colluvial deposits. Age is late Pleistocene but otherwise uncertain; estimates range from about 60 ka (Crandell and Miller, 1974; Crandell, 1987) to 300 ka (Dethier, 1988). Colman and Pierce (1981) prefer age of about 140 ka on basis of thickness of weathering rinds on stones in the drift. Smooth elongate strike ridges probably reflecting glacial scour are visible from road north of Cispus River upstream from mouth of East Canyon Creek. Includes alluvium, colluvium, and possibly fan and landslide deposits

YOUNG LAVA FLOWS AND RELATED DEPOSITS

Qbs **Basalt of Spring Creek of Korosec (1987) (Pleistocene)**—Nonporphyritic to sparsely olivine-phyric, diktytaxitic olivine basalt along Cispus River valley. Equivalent to "basalt of Hill 5162" of Hammond (1980). Underlies valley floor (though largely covered by gravel and sand of map unit Qgs) from east edge of quadrangle to point just east of mouth of Prospect Creek. Occurs as terracelike erosional remnant along southeast edge of valley floor farther downstream. Fills 20–30–m–deep gorge eroded in basalt and basaltic andesite of Potato Hill (map unit Qbap) downstream from mouth of Adams Creek. Erupted from low cone forming knob 5162 (1.5 km southeast of Potato Hill in Glaciate Butte quadrangle) north of Mount Adams (fig. 1; Hammond, 1980; Hildreth and Fierstein, in press). Characterized by low K_2O content (0.12– 0.34 percent; Swanson [1991, 1992] and table 1), deep mauve clinopyroxene, and distinctive mode (Swanson, 1991, table 4). Occurs in valley probably carved largely by glacier of Hayden Creek age. Rests on organic-rich soil with age of 21.5 ± 0.5 ka radiocarbon years (Hildreth and Fierstein, in press) that contains roots with age of 41.1 ± 1.3 ka radiocarbon years (USGS lab number 3278, analysis by Debbie Trimble) at road crossing of Prospect Creek. Gravel derived from unit occurs in outwash deposits of Evans Creek Drift and as gravel and sand in map unit Qgs

Qbap **Basalt and basaltic andesite of Potato Hill (Pleistocene)**—Three or more lava flows, generally with small phenocrysts of plagioclase and olivine and uncommon clinopyroxene, in Cispus River valley from east edge of quadrangle to at least as far as 2 km downstream from mouth of Adams Creek. Recognized as distinct from the essentially aphyric, younger basalt of Spring Creek by Hildreth and Fierstein (in press). Flow exposed upstream from Adams Fork Campground is basalt (table 1, no. 19), but the three analyses from farther downstream—from one or more flows—are basaltic andesite (table 1, no. 28–30). Erupted from Potato Hill, prominent cone astride border of Green Mountain and Glaciate Butte quadrangles 2 km north-northwest of Hill 5162 (fig. 1). Hildreth and Fierstein (in press) and Hildreth and Lanphere (in press) report a K-Ar age of 111 ± 10 ka

Qbj **Basalt of Juniper Creek (Pleistocene)**—Aphyric to sparsely olivine-phyric, fine-grained to glassy olivine basalt forming tuff cone and associated lava flows in extreme northwestern corner of quadrangle. Bedding parallels topography and so dips toward Cispus valley. Characterized by moderately high K_2O content of 1.1–1.5 percent (Swanson, 1991, table 1, no. 10; Swanson, 1992, table 1, no. 3; Swanson, 1993, table 1, no. 6–7)), and rare red-brown biotite in groundmass (Swanson, 1992, table 4, col. 2). Contains rare small xenoliths of strained, corroded, multigranular quartz. Flows generally hackly jointed as in entablatures; water quenching is almost certain. Age not known but probably younger than most Hayden Creek Drift in Cispus River valley, because flow and cone mantle side of U-shaped valley eroded by glacier in Hayden Creek time (Swanson, 1993, plate 2, cross section C—A′). Possibly erupted during waning Hayden Creek time, when retreating glacier still occupied Cispus River valley (see text) and was able to quench the basalt. Degree of dissection indicates unit is older than basalt of Spring Creek and probably (but not certainly) basalt and basaltic andesite of Potato Hill

Qbe **Basalt of East Canyon Creek of Korosec (1987) (Pleistocene)**—Aphyric, fine-grained to glassy basalt forming several tephra cones on both sides of lower East Canyon Creek. Two cones form a dumbbell-shaped hill just west of the mouth of the creek, and at least two low, poorly exposed cones occur farther south along the east side of the creek. Most of each cone consists of faintly bedded to well-bedded, glassy, dense to moderately vesicular basaltic lapilli and blocks, generally poorly sorted. Lapilli-size lithic clasts of Tertiary rocks scattered throughout deposits. Bedded palagonitized black sand characterizes many of the exposures east of lower East Canyon Creek, where scattered cow-dung bombs and nonpalagonitized lapilli and blocks occur near vents. Hackly and radially jointed, pillow-like masses of quenched basalt cap thick, massive (slumped?) glassy tephra in roadside quarry at site of samples 8 and 14 (table 1). Cones apparently formed by phreatomagmatic explosions. Chemically indistinguishable (table 1, nos. 8, 14, 16, and 18) from basalt of Juniper Creek, though slightly more K_2O than most, and probably part of same eruptive episode. Contains scattered xenoliths of vein quartz, as does the Juniper Creek. Could be of subglacial origin

Qbws **Basalt west of Spud Hill (Pleistocene)**—Cinder cone on ridge crest and tuff cone along tributary of Prospect Creek. Cinder cone contains thin lava flows of aphyric, fine-grained basalt, is commonly oxidized, carries rare spindle bombs and spatter, and is crudely bedded and poorly sorted. Tuff cone contains palagonitized, glassy, finely olivine-phyric basaltic tephra and equally or more abundant clasts of Tertiary bedrock. Chemically indistinguishable (table 1, no. 9–12) from basalt of Juniper Creek and probably part of same eruptive episode. However, cinder cone clearly formed subaerially with little if any phreatomagmatic component. Apparently it was higher than top of glacier in Cispus valley. Equivalent to the basalt of Spud Hill of Hammond and Korosec (1983) and Korosec (1987)

Qds **Dacite of Sheep Creek of Hildreth and Fierstein (in press) (Pleistocene)**—Intracanyon lava flow of moderately porphyritic plagioclase-pyroxene dacite in Sheep Creek canyon along east-central border of quadrangle. Gray, not markedly flow layered. Generally crystalline but glassy near base and margins. Chemically a mafic dacite (table 1, no. 66). Caps ridge separating Sheep Creek and upper East Canyon Creek and extends downstream almost to Adams Creek. At least 70 m thick. Locally platy or columnar. Vent unknown but certainly southeast of outcrop area, buried by younger rocks. Hildreth and Fierstein (in press) and Hildreth and Lanphere (in press) report K-Ar age of 246 ± 4 ka for flow

Qdo **Dacite of Olallie Lake of Korosec (1987) (Pleistocene)**—Sparsely to moderately plagioclase-phyric dacite flow in one small patch along east edge of quadrangle adjacent to dacite of Sheep Creek, which occupies canyon partly eroded into unit. Hildreth and Fierstein (in press) report SiO_2 content of 66 percent and suggest that vent is beneath or near Takhlakh Lake, 3 km east-northeast of Council Lake. K-Ar age of 381 ± 5 ka (Hildreth and Fierstein, in press; Hildreth and Lanphere, in press)

INTRUSIVE ROCKS

Thd **Hornblende diorite and related rocks (Miocene)**—Hornblende-clinopyroxene-plagioclase-phyric diorite, quartz diorite, and fine-grained but holocrystalline variants of these rock types. Forms sills, locally cross-cutting bedding, intruding volcaniclastic rocks in northern half of quadrangle. Unit extends north and west for some distance and forms the comagmatic *intrusive suite of Kidd Creek* of Marso and Swanson (1992). Grain size largely depends on thickness of body: silicic andesite and dacite in thin sills and chilled margins of larger bodies, and microdiorite and quartz microdiorite to diorite and quartz diorite in thick sills. Average grain size of diorite reaches 1 mm but typically is 0.2–0.4 mm. Hornblende occurs in groundmass but chiefly as phenocrysts as long as 5 mm, with scattered megacrysts and clots to more than 1 cm in diameter. Hornblende phenocrysts form 1–5 percent of rock, clinopyroxene phenocrysts 1–3 percent, and plagioclase phenocrysts, about 5–15 (rarely 20) percent. Sparse orthopyroxene present in some samples. Quartz phenocrysts or xenocrysts, commonly partly resorbed, occur rather commonly in some bodies. Groundmass quartz present in some diorite and plentiful in quartz diorite. Inclusions of variously textured diorite, and clots of hornblende and plagioclase, fairly common. As in other mapped quadrangles, unit is chemically dacite and silicic andesite, with relatively low TiO_2, FeO*, and MnO (table 1, no. 60–62, 65, 67–68, 71) compared to host rocks at similar SiO_2 content. Generally fresher than host rock; hornblende is commonly unaltered. Age is about 12 Ma on basis of three zircon fission-track ages on members of the suite outside the quadrangle (Swanson, 1991, tables 2 and 3)

Tai **Andesite and basaltic andesite intrusions (Miocene and Oligocene)**—Dikes, sills, and fewer small subequant hypabyssal intrusions of aphyric and one- or two-pyroxene-plagioclase-phyric basaltic andesite and andesite. Fine- to medium-grained and texturally resembles lava flows (map unit Ta); some sills, such as those along upper Squaw Creek, could indeed be lava flows, for critical exposures of upper contacts are not exposed. Thick body between Tule and Squaw Creeks is rather dense and has wide columnar joints; it is interpreted as a sill although upper contact is not exposed. Dikes characterized by subhorizontal columnar jointing, quenched margins, steep contacts with host rocks, and widths of 1–5 m. No contact seen in quadrangle with map unit Thd, but elsewhere unit is older than the hornblende-bearing intrusions (Swanson, 1992). Typically more highly altered than map unit Thd. Probably in part feeders for flows of map unit Ta, but many dikes could be younger and have fed flows now eroded away. Most dikes are roughly perpendicular to bedding and would be vertical if host rock were tilted back to horizontal. Hence the dikes are probably older than the folding, a relation found in other mapped quadrangles (Swanson, 1991, 1992). The 2–km–long, gently curved dike 1.5 km east of mouth of Dark Creek forms prominent photolineament and is exposed nearly continuously. Dikes in Quartz Creek basin-Summit Prairie-Table Mountain area form part of regional swarm noted in McCoy Peak and French Butte quadrangles (Swanson, 1989, 1990, 1992). Two small, subequant intrusions of andesite in Summit Prairie area are likely small plugs of eroded cones; each has a glassy margin (not devitrified), is complexly jointed, and is markedly fresher than its host rock

Taid **Basaltic andesite intrusion of Dark Creek (Miocene)**—Fine- to medium-grained, holocrystalline (except for marginal zones), moderately to highly porphyritic, plagioclase-two pyroxene basaltic andesite or microdiorite (table 1, no. 40) forming imposing cliffs overlooking lower Dark Creek. Widely spaced, blocky jointing pattern. Cuts baked tuff and volcanic sandstone along northwest contact, where marginal part of intrusion is finely brecciated, perhaps protoclastically

Tqd **Quartz diorite (Miocene)**—Tiny outcrop of mineralized body on border with McCoy Peak quadrangle along branch of Prospect Creek 1.8 km south of northwest corner of quadrangle. Hypidiomorphic-granular texture, abundant interstitial quartz, moderately plagioclase and clinopyroxene phyric. Part of somewhat larger body in McCoy Peak quadrangle, where it was mapped as part of the diorite map unit (Tdi) and has an andesitic composition (Swanson, 1992, table 1, no. 21)

Tdi **Dacite sills (Miocene)**—One or more sills of coarse-grained andesite and microdiorite cropping out from just south of Spud Hill southeastward to valley of upper East Canyon Creek north of Table Mountain. Sparsely to moderately plagioclase and clinopyroxene phyric. Quartz occurs in groundmass of coarsest holocrystalline samples. Most samples are silicic dacite or rhyodacite (table 1, no. 73, 76–78, and 80–81); one is silicic andesite (table 1, no. 52).

Tri **Rhyodacite sills (Miocene)**—Two thin sills(?) of moderately plagioclase phyric rhyodacite on east end of East Canyon Ridge (table 1, no. 83–84). The southernmost sill has groundmass quartz and an altered mafic mineral that could be hornblende. Difficult to distinguish from andesite or mafic dacite in the field. Possibly offshoots from the larger dacite sill (map unit Tdi) in the area

Tris **Rhyolite intrusion of Spud Hill (Miocene)**—White to light gray, aphyric, fine-grained (commonly with snowflake texture), locally flow-layered rhyolite forming most of Spud Hill. Closely spaced platy jointing along flow layers contributes to extensive accumulations of scree. Roof of hornfelsed volcaniclastic rocks and andesite preserved on top of Spud Hill. Northwest-trending, intrusive (protoclastic?) contact with volcanic sandstone exposed in road cut 400 m south of Point 4834. Possibly an intrusive dome (cryptodome). Similar rhyolite forms sill (possibly flow) north of Prospect Creek and 3.5–km–long, slightly discordant body between lower East Canyon Creek and Squaw Creek. Rhyolite and high-SiO_2 rhyolite composition (table 1, no. 90–97). Includes slightly plagioclase-phyric rhyolite that seems part of body between Tule and Squaw Creeks (table 1, no. 88). Many samples relatively fresh; see contents of water and CO_2 in table 1. Cut by dikes of intrusive suite of Kidd Creek (map unit Thd) high on south flank of Spud Hill. Not enough zircon in mineral separates to obtain a fission-track date (J.A. Vance, oral commun., 1991). Unclear if unit predates or postdates folding. Could be related to rhyolite flow on Council Bluff (map unit Trcb), along projected trend of intrusion

LAVA FLOWS AND VOLCANICLASTIC ROCKS

Ttv **Volcaniclastic rocks (Miocene and Oligocene)**—Bedded conglomerate, sandstone, siltstone, and lithic diamictite containing volcanic-derived clasts, as well as lithic- and lesser pumice-lapilli tuff and fine-grained tuff. Typically brown to buff, with the tuffaceous rocks generally green and locally white or mauve. Different rock types are interbedded at all scales, and attempts to map them separately proved unworkable. However, well-bedded, chiefly epiclastic rocks are most common in the quadrangle on Blue Lake Ridge and south of Spud Hill, and tuffaceous rocks, especially ash-flow tuff, are most common on East Canyon Ridge. Hammond (1980) and Korosec (1987) assigned most of unit in quadrangle to Ohanapecosh Formation, but each separated out the tuffaceous rocks on East Canyon Ridge and assigned them to the Stevens Ridge 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 entirely of volcanic derivation, chiefly basaltic andesite and andesite but including more silicic rock types. Fossil wood, chiefly stems and twigs, 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 origin.

Pumice- and pumice-lithic-lapilli tuff is probably of pyroclastic-flow origin. Welding occurs but is not common. Good examples of ash-flow tuff are in road cuts at the east end of East Canyon Ridge Thickness of single lapilli-tuff beds ranges 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. Log molds occur in or at base of one pumice-lithic-lapilli tuff on East Canyon Ridge 800 m south-southwest of Point 4902. The one pumice-lapilli tuff chemically analyzed is strongly hydrated but clearly silicic (table 1, no. 85). K-Ar age of 19.7 ± 1.0 Ma (average of two ages) obtained by Hammond (1980) from site 800 m south-southeast of Point 4902 (1A on geologic map and in table 2)

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

Ta **Andesite, basaltic andesite, and basalt lava flows (Miocene and Oligocene)**—Fine- to medium-grained, highly 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. 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 (with minerals listed in decreasing order of abundance) is plagioclase-clinopyroxene, followed by plagioclase-clinopyroxene-hypersthene and plagioclase-hypersthene-clinopyroxene. Phenocrysts of olivine (typically pseudomorphed by hematite and smectite) common in basalt. One exceptionally coarsely porphyritic basalt is in road cut at site of analysis 17; plagioclase phenocrysts 2 cm long are abundant, as are smaller red pseudomorphs of smectite and hematite after olivine. Groundmass texture chiefly fine-grained intersertal or intergranular, with flow-aligned microlites common; very fine-grained pilotaxitic texture characterizes the more silicic rocks. Glass generally altered to clay minerals. Compositions range from basalt to silicic andesite (table 1). In general basalt and basaltic andesite are more highly porphyritic than andesite, but exceptions are common. Flows of different compositions are interbedded and cannot be mapped separately short of analyzing each flow. Dikes and other intrusions of map unit Tai probably fed some flows in this unit. Interbedded extensively with volcaniclastic rocks (map unit Ttv) and includes some volcaniclastic beds too thin to map separately. Unit south of upper East Canyon Creek called *lava flows of Council Bluff* by Hammond (1980) and *volcanic rocks of Council Bluff* by Korosec (1987). One K-Ar age of 25.5 ± 0.4 Ma obtained by Phillips and others (1986) at site 1.2 km south-southeast of mouth of Summit Prairie Creek (see 2A on geologic map and in table 2)

Tdtm **Dacite of Table Mountain (Miocene)**—Very sparsely and finely plagioclase-orthopyroxene-clinopyroxene-phyric mafic dacite lava flow (table 1, no. 69–70, 72, 74) that caps section and is probably the youngest erupted Tertiary rock in quadrangle. Groundmass contains flow-aligned microlites in matrix of glass or very fine-grained crystals. Probably one flow more than 60 m thick. Unit would not be distinctive from other flows in area were it not forming isolated Table Mountain

Tbd **Bouldery diamictite on Council Bluff (Miocene)**—Poorly sorted deposit of sparsely-moderately plagioclase-phyric dacite(?) or rhyolite(?) blocks and boulders in fine-grained, oxidized matrix. Blocks are as much as 1.5 m in diameter and resemble rhyolite of Council Bluff (map unit Trcb) in field appearance. No thin section or chemical analysis. Rests on map unit Trcb, a relation best seen near northeast end of exposure. Oxidized matrix suggests hot emplacement. Could be lithic pyroclastic flow from dome of map unit Trcb or perhaps remnant of a fragmental carapace on the dome

Trcb **Rhyolite of Council Bluff**—Pink, white, or light gray, sparsely-moderately plagioclase-phyric, commonly flow-layered rhyolite. Layering contorted on all scales, as can be seen through binoculars on face of Council Bluff. Fine-grained groundmass, commonly with flow-aligned microlites of plagioclase. Maximum thickness at least 150 m. Probably one or more flows or domes or both. Along projected trend of rhyolite intrusion of Spud Hill (map unit Tris) and chemically similar (table 1, no. 86–87, 89) to more mafic parts of that intrusion. Note: the site of the former lookout on Council Bluff is in an overlying andesite flow (table 1, no. 47), not the rhyolite of Council Bluff

Trd **Rhyodacite lava flows and domes**—Light gray, fine-grained rhyodacite in thin flow along Mouse Creek and >60–m-thick flow or dome along outlet creek to Council Lake. The thick flow or dome is moderately and finely plagioclase phyric (table 1, no. 82); the thin flow is nearly aphyric (table 1, no. 79). Each rhyodacite body has a fine-grained groundmass with snowflake texture

REFERENCES CITED

Barnosky, C. W., 1984, Late Pleistocene and early Holocene environmental history of southwestern Washington State, U.S.A.: Canadian Journal of Earth Sciences, v. 21, p. 619–629.

Colman, S. M., and Pierce, K. L., 1981, Weathering rinds on andesitic and basaltic stones as a Quaternary age indicator, western United States: U.S. Geological Survey Professional Paper 1210, 56 p.

Crandell, D. R., 1987, Deposits of pre–1980 pyroclastic flows and lahars from Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1444, 91 p.

Crandell, D. R., and Miller, R. D., 1974, Quaternary stratigraphy and extent of glaciation in the Mount Rainier region, Washington: U.S. Geological Survey Professional Paper 847, 59 p.

Dethier, D. P., 1988, The soil chronosequence along the Cowlitz River, Washington: U.S. Geological Survey Bulletin 1590–F, p. F1–F47.

Evarts, R.C., and Ashley, R.P., 1984, Preliminary geologic map of the Spirit Lake quadrangle, Washington: U.S. Geological Survey Open-File Report 84–480, scale 1:48,000.

Evarts, R.C., and Ashley, R.P., 1990a, Preliminary geologic map of the Cougar quadrangle, Cowlitz and Clark Counties, Washington: U.S. Geological Survey Open-File Report 90–631, scale 1:24,000, 40 p.

Evarts, R.C., and Ashley, R.P., 1990b, Preliminary geologic map of the Goat Mountain quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 90–632, scale 1:24,000, 47 p.

Evarts, R.C., and Ashley, R.P., 1991, Preliminary geologic map of the Lakeview Peak quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 91–289, scale 1:24,000, 35 p.

Evarts, R.C., and Ashley, R.P., 1992, Preliminary geologic map of the Elk Mountain quadrangle, Cowlitz County, Washington: U.S. Geological Survey Open-File Report 92–362, scale 1:24,000, 44 p.

Evarts, R.C., and Ashley, R.P., 1993a, Geologic map of the Spirit Lake East quadrangle, Skamania County, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1679, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., 1993b, Geologic map of the Vanson Peak quadrangle, Lewis, Cowlitz, and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1680, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., in press a, Geologic map of the Spirit Lake West quadrangle, Skamania and Cowlitz Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1681, scale 1:24,000.

Evarts, R.C., and Ashley, R.P., in press b, Geologic map of the Cowlitz Falls quadrangle, Lewis and Skamania Counties, Washington: U.S. Geological Survey Geologic Quadrangle Map GQ–1682, scale 1:24,000.

Evarts, R.C., and Swanson, D.A., 1994, Geologic transect across the Tertiary Cascade volcanic arc, southern Washington, *in* Swanson, D.A., and Haugerud, R.A., eds., Geologic field trips in the Pacific Northwest: 1994 Annual Meeting, Geological Society of America, Seattle, Washington, v. 2, p. 2H1–2H31.

Evarts, R.C., Ashley, R.P., and Smith, J.G., 1987, Geology of the Mount St. Helens area: record of discontinuous volcanic and plutonic activity in the Cascade arc of southern Washington: Journal of Geophysical Research, v. 92, p. 10,155–10,169.

Fiske, R.S., Hopson, C.A., and Waters, A.C., 1963, Geology of Mount Rainier National Park, Washington: U.S. Geological Survey Professional Paper 444, 93 p.

Gill, J.B., 1981, Orogenic andesites and plate tectonics: Springer Verlag, New York, 390 p.

Hagstrum, J.T., and Swanson, D.A., in press, Paleomagnetism of the Miocene intrusive suite of Kidd Creek: implications for the timing of deformation in the Cascade arc, southern Washington [abs.]: Eos, Transactions of the American Geophysical Union.

Hammond, P. E., 1980, Reconnaissance geologic map and cross sections of southern Washington Cascade Range: Portland, Oregon, Publications of Department of Earth Science, scale 1:125,000.

Hammond, P.E., and Korosec, M.A., 1983, Geochemical analyses, age dates, and flow-volume estimates for Quaternary volcanic rocks, southern Cascade Mountains, Washington: Washington Division of Geology and Earth Resources Open-File Report 83–13, 36 p.

Harle, D.S., 1974, Geology of Babyshoe Ridge area, southern Cascades, Washington: Corvallis, Oreg., Oregon State Univ., M.S. thesis, 71 p.

Hildreth, Wes, and Fierstein, Judy, in press, Geologic map of the Mount Adams volcanic field, Cascade Range of southern Washington: U.S. Geological Survey Miscellaneous Geologic Investigations Map.

Hildreth, Wes, and Lanphere, M.A. in press, Potassium-argon geochronology of a basalt-andesite-dacite arc system: the Mount Adams volcanic field, Cascade Range of southern Washington: Geological Society of America Bulletin.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common igneous rocks: Canadian Journal of Earth Sciences, v. 8, p. 523–548.

Korosec, M.A., 1987, Geologic map of the Mount Adams quadrangle, Washington: Washington Division of Geology and Earth Resources Open-File Report 87–5, 39 p.

Le Bas, M.J., Le Maitre, R.W., Streckeisen, A., and Zenettin, B., 1986, A chemical classification of volcanic rocks based on the total alkali-silica diagram: Journal of Petrology, v. 27, p. 745–750.

Lipman, P.W., Moore, J.G., and Swanson, D.A., 1981, Bulging of the north flank before the May 18 eruption—geodetic data, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 143–155.

Macdonald, G.A., and Katsura, T., 1964, Chemical composition of Hawaiian lavas: Journal of Petrology, v. 5, p. 82–133.

Marso, J.N., and Swanson, D.A., 1992, The intrusive suite of Kidd Creek: a middle Miocene magmatic event in the Cascade arc of southern Washington [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 67.

Miller, R.B., 1989, The Mesozoic Rimrock Lake inlier, southern Washington Cascades—implications for the basement to the Columbia embayment: Geological Society of America Bulletin, v. 101, p. 1289–1305.

Minikami, T., Ishikawa, T., and Yagi, K., 1951, The 1944 eruption of Volcano Usu in Hokkaido, Japan: Bulletin Volcanologique, series 2, v. 11, p. 45–157.

Miyashiro, A., 1974, Volcanic rock series in island arcs and active continental margins: American Journal of Science, v. 274, p. 321–355.

Moore, J.G., and Albee, W.C., 1981, Topographic and structural changes, March–July 1980—photogrammetric data, *in* Lipman, P.W., and Mullineaux, D.R., eds., The 1980 eruptions of Mount St. Helens, Washington: U.S. Geological Survey Professional Paper 1250, p. 123–134.

Peacock, M.A., 1931, Classification of igneous rock series: Journal of Geology, v. 39, p. 54–67.

Phillips, W.M., Korosec, M.A., Schasse, H.W., Anderson, J.L., and Hagen, R.A., 1986, K-Ar ages of volcanic rocks in southwest Washington: Isochron/West, no. 47, p. 18–24.

Smith, J.G., 1993, Geologic map of upper Eocene to Holocene volcanic and related rocks in the Cascade Range, Washington: U.S. Geological Survey Miscellaneous Investigations Map I–2005, scale 1:500,000, 19 p

Stanley, W.D., Finn, Carol, and Plesha, J.L., 1987, Tectonics and conductivity structures in the southern Washington Cascades: Journal of Geophysical Research, v. 92, p. 10,179–10,193.

Stanley, W.D., Gwilliam, W.J., Latham, Gary, and Westhusing, Keith, 1992, The southern Washington Cascades conductor—a previously unrecognized thick sedimentary sequence?: American Association of Petroleum Geologists Bulletin, v. 76, p. 1569–1585.

Stine, C.M., 1987, Stratigraphy of the Ohanapecosh Formation north of Hamilton Buttes, south-central Washington: Portland, Oreg., Portland State University, M.S. thesis, 83 p.

Swanson, D.A., 1978, Geologic map of the Tieton River area, Yakima County, south-central Washington: U.S. Geological Survey Miscellaneous Field Studies Map MF–968, scale 1:48,000.

Swanson, D.A., 1989, Geologic maps of the French Butte and Greenhorn Buttes quadrangles, Washington: U.S. Geological Survey Open-File Report 89–309, scale 1:24,000, 25 p.

Swanson, D.A., 1990, Trends of middle Tertiary dikes in and north of the Dark Divide Roadless Area, southern Washington Cascades [abs.]: Eos, Transactions of the American Geophysical Union, v. 71, p. 1,144.

Swanson, D.A., 1991, Geologic map of the Tower Rock quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 91–314, scale 1:24,000, 26 p.

Swanson, D.A., 1992, Geologic map of the McCoy Peak quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 92–336, scale 1:24,000, 36 p.

Swanson, D.A., 1993, Geologic map of the Blue Lake quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 93–297, scale 1:24,000, 34 p.

Swanson, D.A., 1994, Coeval volcanism and subsidence about 36 million years ago in the Cascade arc, southern Washington [abs.]: Geological Society of America Abstracts with Programs, v. 26, no. 7.

Swanson, D.A., and Evarts, R.C., 1992, Tertiary magmatism and tectonism in an E–W transect across the Cascade Range in southern Washington [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 84.

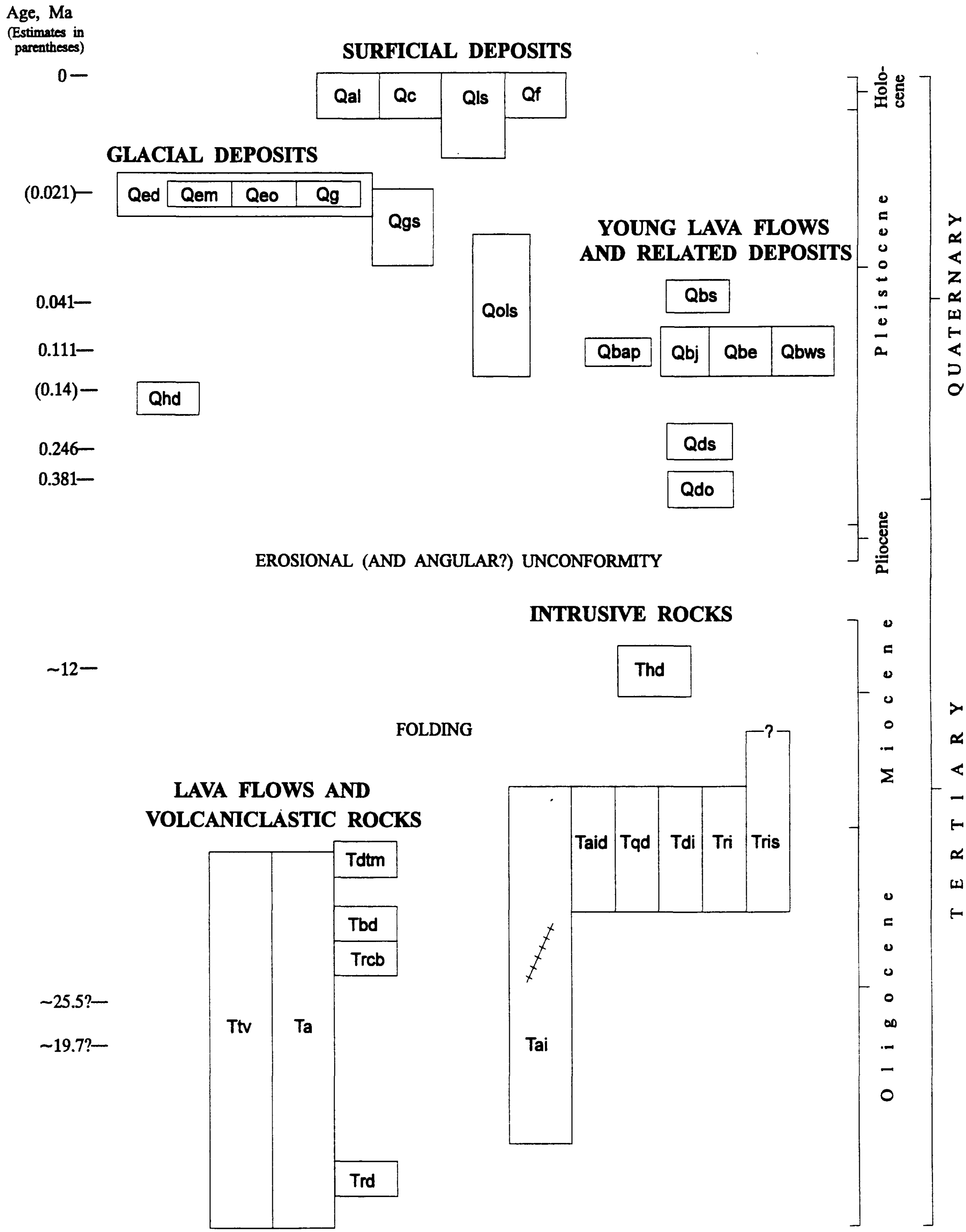
Vance, J.A., Clayton, G.A., Mattinson, J.M., and Naeser, C.W., 1987, Early and middle Cenozoic stratigraphy of the Mount Rainier–Tieton River area, southern Washington Cascades: Washington Division of Geology and Earth Resources Bulletin 77, p. 269–290.

Waters, A.C., 1961, Keechelus problem, Cascade Mountains, Washington: Northwest Science, v. 35, p. 39–57.

Wells, R.E., and others, 1993, CASCADIA: Regional lithospheric studies of the Pacific Northwest: U.S. Geological Survey Open-File Report 93–706, 39 p.

Winters, W.J., 1984, Stratigraphy and sedimentology of Paleogene arkosic and volcaniclastic strata, Johnson Creek–Chambers Creek area, southern Cascade Range, Washington: Portland, Oreg., Portland State University, M.S. thesis, 162 p.

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

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

Strike and dip of bedding and flow contacts

Dip amount and direction of intrusive contact

Attitude of prominent joint set in intrusive body

Folds, dashed where approximately located, dotted where concealed

Trace of axis of anticline

Trace of axis of syncline

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

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

Direction and magnitude of dip of fault plane

Fault or shear zone; arrows indicate sense of lateral displacement

Dike of unit Thd on Spud Hill

Dike of andesite and basaltic andesite of units Ta and Tai; queried where identification uncertain

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

Basalt

Basaltic andesite

Andesite

Dacite

Rhyodacite and rhyolite

Site of radiometrically dated sample listed in table 2