U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Geologic map of the McCoy Peak quadrangle, southern Cascade Range, Washington

by

Donald A. Swanson[1]

Open-File Report 92-336

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

CONTENTS

INTRODUCTION 1
ACKNOWLEDGMENTS 1
ROCK TERMINOLOGY AND CHEMICAL CLASSIFICATION 2
GENERAL GEOLOGY 6
TERTIARY ROCKS OLDER THAN INTRUSIVE SUITE OF KIDD CREEK 7
Volcaniclastic rocks 7
Chaotic volcanic breccia 8
Vitroclastic dacite and andesite breccia 9
Volcanic centers 10
Regional dike swarm 11
Age 13
INTRUSIVE SUITE OF KIDD CREEK 13
Dikes 14
Sills 16
Relation of dikes and sills 16
Hornblende quartz diorite and granodiorite of McCoy Creek 17
Geometry of body 17
Evidence relating the McCoy Creak intrusion and the Kidd Creek intrusive suite 18
Relation of McCoy Creek intrusion to the radial dike and sill swarm 18
Age of intrusive suite of Kidd Creek 21
STRUCTURE 21
Folds 21
Faults 22
Jumbo Creek zone 23
QUATERNARY BASALT AND BASALTIC ANDESITE 23
THICKNESS OF OLIGOCENE AND MIOCENE CRUST 25
DESCRIPTION OF MAP UNITS 27
REFERENCES CITED 33
CORRELATION OF MAP UNITS 35
EXPLANATION OF MAP SYMBOLS 36

FIGURES

1. Map showing location of McCoy Peak quadrangle relative to other quadrangles and the Southern Washington Cascades Conductor 2
2. Map of McCoy Peak quadrangle, showing localities mentioned in text 3
3. Total alkali-silica classification diagram for rocks in McCoy Peak quadrangle 3
4. Plot of phenocryst assemblage vs. SiO_2 for rocks in McCoy Peak quadrangle 6
5. Locations of samples collected in McCoy Peak quadrangle 6
6. Alkali-lime classification diagram for Tertiary rocks in McCoy Peak quadrangle 7
7. Plot of FeO*/MgO vs. SiO_2 for rocks from McCoy Peak quadrangle 7
8. Plot of total alkalis vs. SiO_2 for rocks in McCoy Peak quadrangle 8
9. Plot of K_2O vs. SiO_2 for rocks from McCoy Peak quadrangle 8
10. Distrbution of pyroxene andesite and basaltic andesite dikes in French Butte, Greenhorn Buttes, Tower Rock, and McCoy Peak quadrangles 12
11. Rose diagrams of strikes of dikes and beds in McCoy Peak and other quadrangles 13
12. Plots of TiO_2, FeO*, and MnO vs. SiO_2 for rocks from McCoy Peak quadrangle 13
13. Generalized map showing distribution of intrusive suite of Kidd Creek 15
14. Comparison of analyses of Kidd Creek intrusive suite done in two laboratories 20
15. Comparison of adjusted analyses of Kidd Creek intrusive suite with those of McCoy Creek intrusion 20
16. Plot of glass vs. total olivine contents for high-K_2O olivine basalt in McCoy Peak and adjacent quadrangles 24
17. Plot of $Na_{6.0}$ and $Ca_{6.0}$ vs. crustal thickness (Plank and Langmuir, 1988) to compare thickness of Tertiary crust with that of other arcs 25

TABLES

1. Chemical analyses of rocks from McCoy Peak quadrangle 4
2. Chemical analyses from Link (1985) 19
3. Radiometric ages from the McCoy Peak quadrangle 22
4. Modes of young olivine basalt in McCoy Peak and adjacent quadrangles 24

PLATES

1. Geologic map of McCoy Peak quadrangle .... Separate sheet
2. Cross sections of McCoy Peak quadrangle .... Separate sheet

GEOLOGIC MAP OF THE McCOY PEAK QUADRANGLE, SOUTHERN CASCADE RANGE, WASHINGTON

By Donald A. Swanson

INTRODUCTION

The McCoy Peak 7.5-minute quadrangle is centered about 35 km northeast of Mount St. Helens and 25 km west of the crest of the Cascade Range in southern Washington (fig. 1). Geologic maps have recently been published for the adjoining Tower Rock, French Butte, and Greenhorn Buttes quadrangles (Swanson, 1989, 1991) and finished but not yet published for the Blue Lake quadrangle (D.A. Swanson, unpublished map, 1991).

The mapping and related geologic research are part of a project to tie the stratigraphy of the area near Mount St. Helens (Evarts and Ashley, 1984, 1990a, 1990b, 1991, in press a-d; Evarts and others, 1987; Swanson, 1989, 1991) into the now classic Tertiary stratigraphic section in the Mount Rainier-White Pass area as defined by Fiske and others (1963) and modified by Vance and others (1987). This work will establish an improved regional geologic framework for the southern Washington Cascades and complete a geologic transect across the west side of the Cascade Range (Swanson and Evarts, 1992). It will also support a prospective geophysical transect linking coastal Washington to the Columbia Plateau. In addition, the research will test whether a major electrical conductivity layer in the upper crust, the Southern Washington Cascades Conductor (SWCC) of Stanley and others (1987) has a recognizable influence on the geology of the area. The quadrangles being mapped lie within and astride the edge of the SWCC.

The McCoy Peak quadrangle straddles the major east-west drainage divide that separates the west-flowing Cispus and Lewis Rivers (fig. 2). Most of the quadrangle is north of the divide and is drained by the Cispus River, chiefly via two major tributaries, Yellowjacket and McCoy Creeks. South of the divide drainage into the Lewis River is via Straight, French, and Quartz Creeks. Langille Ridge, Juniper Ridge, and most of the Cispus-Lewis divide are part of the Dark Divide Roadless Area in Gifford Pinchot National Forest and are accessible only by trail.

The quadrangle is underlain chiefly by late Oligocene and early Miocene volcanic deposits, both lava flows and volcaniclastic rocks, that range from basaltic andesite to rhyolite but consist dominantly of basaltic andesite and andesite. Numerous dikes and sills, chiefly of andesite and low-SiO_2 dacite, cut the older rocks, and a major subvolcanic center with a radial dike and sill swarm first described in this paper occurs in the northern part of the quadrangle. Very low-grade (zeolite-facies) metamorphism pervades most of the Tertiary rocks and gives a greenish cast to many of the once-glassy volcaniclastic rocks. Propylitic alteration, local phyllic alteration, and sulfide mineralization affect two large areas and several smaller ones in the quadrangle. Quaternary flows and pyroclastic deposits, and Quaternary or Pliocene dikes, of olivine basalt and basaltic andesite occur in several places. Unconsolidated deposits related to at least one episode of late Pleistocene glaciation cover parts of the area. The quadrangle is downwind from Mount St. Helens, and tephra from eruptions of the past 50,000 years mantles most units (Mullineaux, 1986), particularly in the southwestern part of the area.

Bedrock exposures are limited in many places, owing to dense forest cover and locally thick glacial drift, but overall the number of exposures is much greater than farther west, because of less tephra cover. Many natural exposures occur along creeks and hillsides, particularly along the unforested upper parts of Langille and Juniper Ridges, and combined with road cuts permit adequate determination of most stratigraphic relations.

Only small-scale (1:100,000 and smaller) reconnaissance geologic work had been done in the quadrangle before this research, except for two thesis studies of the McCoy Creek mining district (Simon, 1972; Link, 1985). Chief among the reconnaissance mapping was that by Hammond (1980), Korosec (1987; included in Walsh and others, 1987), and J.G. Smith (unpublished map of the Yakima 2° sheet). The new geologic map agrees in general with these earlier studies but differs considerably in detail, particularly in the McCoy Creek area.

ACKNOWLEDGMENTS

I thank Chuyler Freeman (National Association of Geology Teachers fellow), Gary Stoopes, and Barbara White (my wife) for help in the field, and Jeff Marso for many discussions about the hornblende-bearing intrusive rocks. Barry Goldstein (University of Puget Sound) provided advice on the glacial history of the area. Continued discussions with Russ Evarts, Roger Ashley, and Jim Smith have taught me a lot about Cascade geology and on occasion have raised challenging alternative interpretations, and Russ

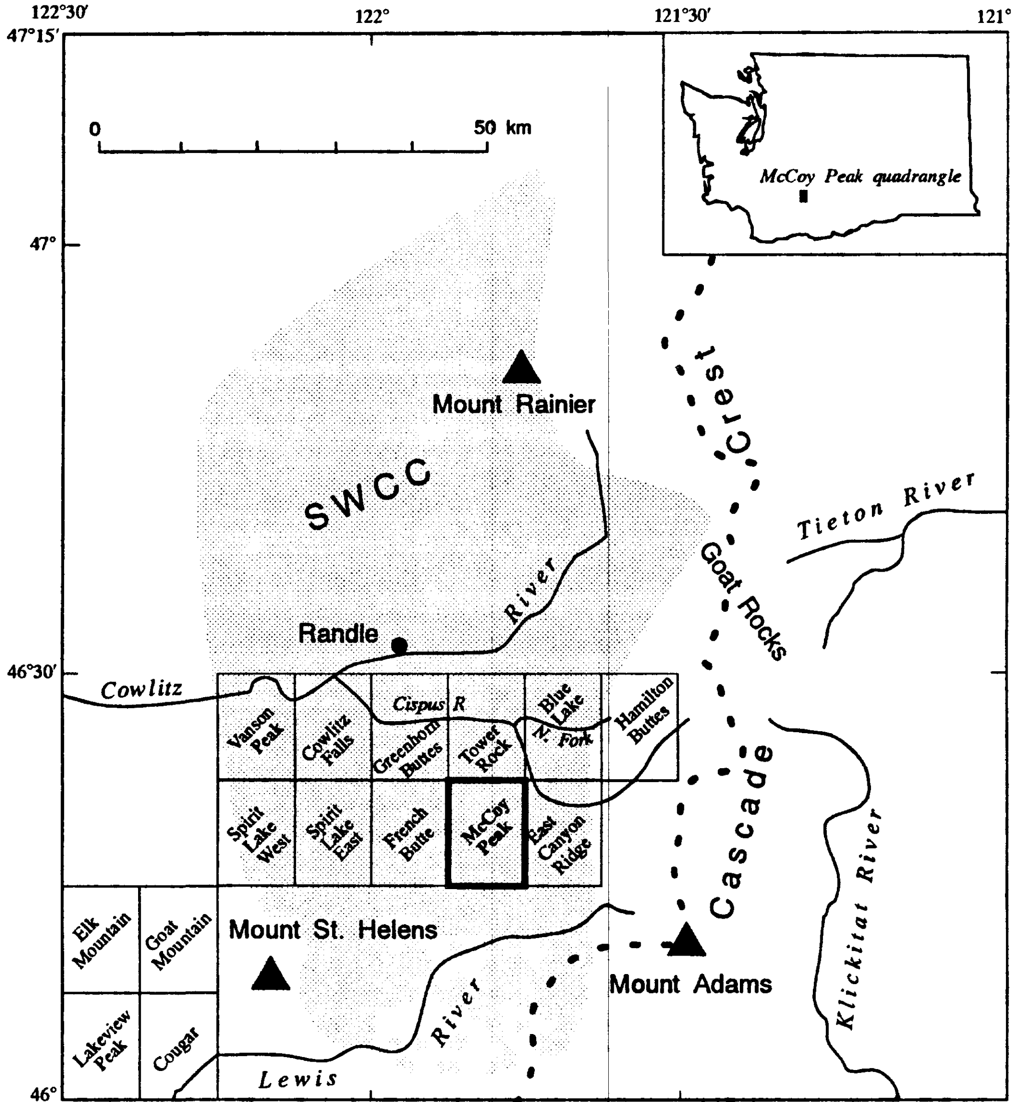


Figure 1. Index map showing location of McCoy Peak quadrangle relative to the three Holocene and late Pleistocene composite volcanoes in southern Washington; crest of Cascade Range; Pleistocene-Pliocene volcano at Goat Rocks; Southern Washington Cascades Conductor (SWCC; see text); and other 7-1/2′ quadrangles where 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° by me.

and Roger twice visited the mineralized areas, shared their expertise about them, and made incisive observations. John Link graciously provided a corrected version of the sample-locality map in his thesis (Link, 1985). Joe Vance (University of Washington) donated considerable time and effort to zircon fission-track dating. Eric Cheney (University of Washington) introduced me in 1986 to the intrusive suite of Kidd Creek and the Camp Creek mineralized area. Dick Moore and Dave Sherrod reviewed and improved the map and text.

ROCK TERMINOLOGY AND CHEMICAL CLASSIFICATION

I classified chemically analyzed samples according to recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks (Le Bas and others, 1986), which I slightly modified to include a field for rhyodacite (fig. 3). For the total alkali contents found, the analyzed rocks can be grouped under six names: *basalt* (<52 per cent SiO_2), *basaltic andesite* (52–57 per cent SiO_2), *andesite*

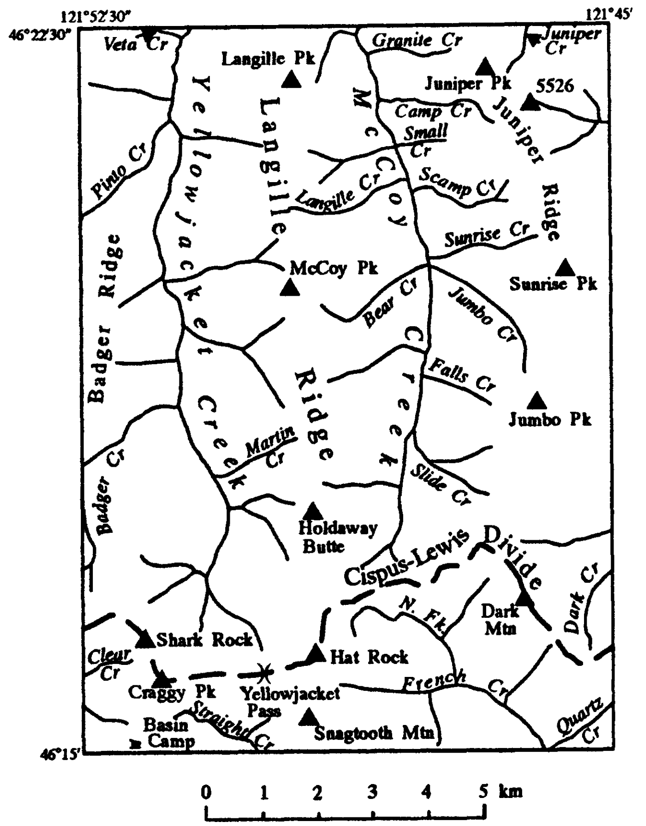


Figure 2. Map of McCoy Peak quadrangle showing locations of geographic features mentioned in text.

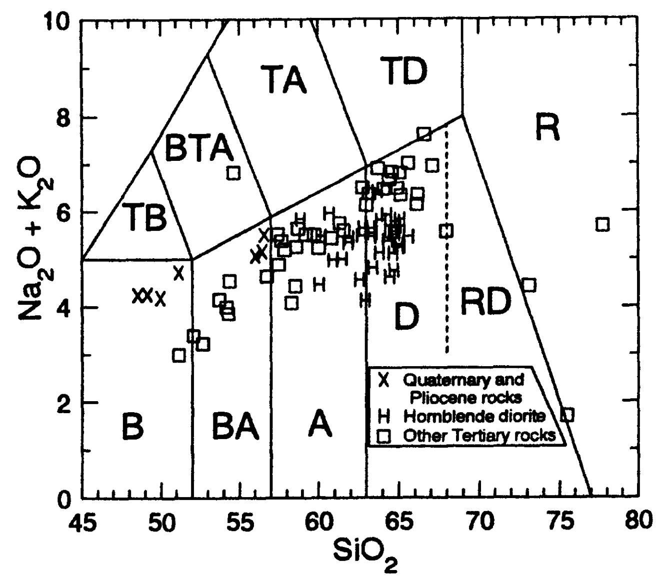


Figure 3. Total alkali-silica classification diagram for chemical analyses from the McCoy Peak quadrangle, modified from Le Bas and others (1986) to include field for rhyodacite. B, basalt; BA, basaltic andesite; A, andesite; D, dacite; RD, rhyodacite; R, rhyolite; TB, trachybasalt; BTA, basaltic trachyandesite; TA, trachyandesite; TD, trachydacite. Data from table 1. Sample in BTA field (table 1, no. 11) probably enriched in Na_2O during alteration. Hornblende diorite includes all samples in intrusive suite of Kidd Creek.

(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 the following rather consistent phenocryst assemblages (fig. 4), with minerals given in approximate order of decreasing abundance: *basalt*, ol ± pl ± cpx ± rare opx; *basaltic andesite*, pl ± cpx ± opx ± ol ± rare hb; *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 has been found only in intrusive rocks.

Samples for which thin sections but no chemical analyses were available could therefore be classified on the basis of their phenocryst assemblage and groundmass texture. In all, 232 samples from the McCoy Peak quadrangle were sectioned (fig. 5); of these, 83 were chemically analyzed (table 1). In addition, table 1 includes two chemical analyses previously published by Korosec (1987).

The Tertiary suite is calcic (Peacock, 1931), with an alkali-lime index of about 62.3 (fig. 6), similar to that in the adjacent mapped quadrangles (Swanson, 1989, 1991). Most analyses of Tertiary rocks, except for those of the hornblende diorite and related rocks in the intrusive suite of Kidd Creek (Marso and Swanson, 1992), are tholeiitic on a plot of FeO*/MgO vs. SiO_2 (fig. 7), according to the classification of Miyashiro (1974). This pattern is similar to that in the adjacent mapped quadrangles. However, five of the seven analyses of young flows and dikes are calc-alkaline (fig. 7), in contrast to the dominantly tholeiitic character of young basalt in previously mapped quadrangles. A plot of total alkalis vs. SiO_2 (fig. 8) shows that most of the analyses are subalkaline, regardless of the classification used (that of Macdonald and Katsura [1964] or Irvine and Baragar [1971]). Four analyses of young rocks are marginally alkaline.

A diagram of K_2O vs. SiO_2 shows that most rocks 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 IUGS terminology); the rest are low-K types (fig. 9).

Table 1. Chemical analyses from the McCoy Peak 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	Qbbc	90-051	48.3	1.96	15.7	2.43	7.98	0.15	9.54	9.16	3.19	1.02	0.37	0.20	0.18	0.00	100.18	48.51	1.97	15.77	10.21	0.15	9.58	9.20	3.20	1.02	0.37	4.23	1.07	121	51.66	46	15.22
2	QTob	87-082	48.2	1.72	16.4	2.69	7.39	0.16	8.00	9.28	3.40	0.76	0.38	0.26	0.56	0.00	99.20	49.13	1.75	16.72	10.00	0.16	8.15	9.46	3.47	0.77	0.39	4.24	1.23	121	51.28	46	15.94
3	Qbj	90-078	49.8	1.25	16.1	2.70	6.36	0.15	8.97	10.10	2.97	1.18	0.39	0.04	0.04	0.00	100.05	49.95	1.25	16.15	8.82	0.15	9.00	10.13	2.98	1.18	0.39	4.16	0.98	121	45.16	46	22.36
4	Qbj?	90-023	50.7	1.17	16.6	4.33	3.91	0.12	8.98	8.81	3.65	1.01	0.35	0.15	0.15	0.00	99.93	51.11	1.18	16.73	7.87	0.12	9.05	8.88	3.68	1.02	0.35	4.70	0.87	121	46.70	46	18.62
85	Tg	86-170	50.1	1.11	18.2	3.89	5.32	0.16	5.71	10.80	2.52	0.41	0.13	1.44	0.36	0.09	100.24	51.14	1.13	18.58	9.00	0.16	5.83	11.02	2.57	0.42	0.13	2.99	1.54	121	52.46	46	17.26
5	Tg	87-073	49.9	0.94	17.6	3.67	5.32	0.15	5.40	9.82	2.80	0.46	0.16	2.21	0.59	0.28	99.30	52.06	0.98	18.36	9.00	0.16	5.63	10.24	2.92	0.48	0.17	3.40	1.60	121	51.55	46	16.28
6	Tg	90-095	51.3	0.98	17.4	3.46	5.12	0.16	5.99	10.00	2.60	0.55	0.18	2.45	0.55	0.00	100.74	52.67	1.01	17.87	8.45	0.16	6.15	10.27	2.67	0.56	0.18	3.23	1.37	121	50.88	46	15.71
7	Ta	90-091	52.8	1.38	17.2	4.38	4.66	0.19	4.90	8.83	3.13	0.95	0.28	0.77	1.15	0.00	100.62	53.73	1.40	17.50	8.75	0.19	4.99	8.99	3.19	0.97	0.28	4.15	1.76	121	49.45	46	20.30
8	Ta	86-153	53.0	1.13	18.1	4.23	4.10	0.16	4.12	9.26	3.10	0.80	0.20	0.84	0.92	0.20	100.16	54.20	1.16	18.51	8.09	0.16	4.21	9.47	3.17	0.82	0.20	3.99	1.92	121	52.35	46	20.77
9	Ta	90-102	53.1	1.81	16.4	5.67	4.80	0.22	3.77	8.61	3.45	0.32	0.24	1.35	0.61	0.02	100.37	54.28	1.85	16.76	10.12	0.22	3.85	8.80	3.53	0.33	0.25	3.85	2.63	121	47.35	46	19.25
10	Ta	90-020	53.2	1.91	16.2	5.02	5.02	0.16	3.84	8.25	3.23	1.20	0.31	0.64	0.95	0.00	99.93	54.38	1.95	16.56	9.75	0.16	3.92	8.43	3.30	1.23	0.32	4.53	2.48	121	47.84	46	16.88
11	Ta	86-152	52.4	1.53	20.3	3.92	2.75	0.27	2.36	5.87	4.94	1.60	0.37	2.85	0.87	0.00	100.03	54.63	1.60	21.16	6.55	0.28	2.46	6.12	5.15	1.67	0.39	6.82	2.66	121	52.41	46	20.88
12	QTba	90-064	55.6	1.16	17.7	2.47	4.95	0.11	4.46	7.63	3.78	1.23	0.42	0.32	0.22	0.01	100.06	56.01	1.17	17.83	7.23	0.11	4.49	7.69	3.81	1.24	0.42	5.05	1.61	121	50.79	46	21.35
13	QTba	90-049	55.9	1.14	17.4	3.54	3.87	0.11	4.33	7.62	3.80	1.28	0.41	0.16	0.26	0.00	99.82	56.44	1.15	17.57	7.12	0.11	4.37	7.69	3.84	1.29	0.41	5.13	1.63	121	50.73	46	21.67
86	Qbbr	88-008[1]																55.81	1.23	17.28	6.99	0.11	4.67	7.60	4.64	1.22	0.44	5.86	1.50	121	51.40	46	21.55
14	Qbbr	MK85915	56.0	1.11	17.0	7.54		0.12	4.61	7.52	4.01	1.43	0.43				99.77	56.56	1.12	17.17	6.86	0.12	4.65	7.59	4.05	1.44	0.43	5.49	1.48	121	51.65	46	20.78
15	Ta	90-097	55.2	1.00	17.5	4.19	3.36	0.13	3.85	7.80	3.25	1.26	0.17	1.78	0.59	0.16	100.24	56.74	1.03	17.99	7.33	0.13	3.96	8.02	3.34	1.30	0.17	4.64	1.85	121	51.37	46	15.78
16	Ta	MK85913	56.8	1.55	17.1	9.22		0.19	2.07	7.12	4.13	1.33	0.36				99.83	57.44	1.57	17.24	8.39	0.19	2.09	7.20	4.17	1.34	0.36	5.51	4.01	121	52.38	46	20.56
17	Tdi	90-056	56.1	1.46	16.0	3.59	5.17	0.15	3.41	7.00	3.62	1.14	0.28	1.26	0.34	0.01	99.53	57.50	1.50	16.40	8.61	0.15	3.50	7.17	3.71	1.17	0.29	4.88	2.46	121	50.05	46	17.53
18	Ta	90-074	56.6	1.66	16.1	4.81	4.14	0.17	3.00	6.60	4.18	1.09	0.28	0.38	0.79	0.00	99.80	57.67	1.69	16.40	8.63	0.17	3.06	6.72	4.26	1.11	0.29	5.37	2.82	121	49.02	46	19.15
19	Tdi	90-052	57.2	1.26	16.4	4.38	4.40	0.16	3.42	6.73	3.72	1.41	0.21	0.43	0.16	0.00	99.88	57.86	1.27	16.59	8.44	0.16	3.46	6.81	3.76	1.43	0.21	5.19	2.44	121	52.05	46	15.56
20	Tai	90-096	56.8	1.07	17.1	1.92	5.68	0.13	3.31	7.41	3.01	0.97	0.20	1.86	0.58	0.17	100.21	58.31	1.10	17.56	7.61	0.13	3.40	7.61	3.09	1.00	0.21	4.09	2.24	121	51.43	46	16.01
21	Tdi	90-080	55.2	1.32	16.7	2.99	4.27	0.16	1.98	7.33	3.30	0.88	0.43	3.77	0.77	0.13	99.23	58.56	1.40	17.72	7.38	0.17	2.10	7.78	3.50	0.93	0.46	4.43	3.52	121	45.20	46	21.52
22	Tbh	90-043	57.4	1.28	16.8	2.59	5.39	0.16	2.50	6.69	4.03	1.11	0.22	0.54	0.66	0.00	99.37	58.62	1.31	17.16	7.89	0.16	2.55	6.83	4.12	1.13	0.22	5.25	3.09	121	49.40	46	15.52
23	Tvb	87-088	55.5	1.08	18.9	2.95	2.92	0.11	1.40	6.32	4.00	1.32	0.32	3.62	0.59	0.21	99.24	58.72	1.14	20.00	5.89	0.12	1.48	6.69	4.23	1.40	0.34	5.63	3.98	121	51.24	46	16.72
24	Thd	90-072	57.9	0.91	17.0	3.00	3.06	0.10	4.14	6.53	4.43	1.28	0.29	1.00	0.19	0.00	99.83	58.88	0.93	17.29	5.86	0.10	4.21	6.64	4.50	1.30	0.29	5.81	1.39	121	49.47	46	19.68
25	Tasr	87-079	57.6	1.46	16.4	4.84	3.22	0.17	2.40	5.86	4.30	1.06	0.46	0.41	1.09	0.00	99.27	59.21	1.50	16.86	7.79	0.17	2.47	6.02	4.42	1.09	0.47	5.51	3.15	121	52.25	46	17.92
26	Tai	90-067	58.7	1.49	16.4	2.95	4.65	0.17	2.28	6.14	4.15	1.25	0.39	0.90	0.21	0.00	99.68	59.73	1.52	16.69	7.43	0.17	2.32	6.25	4.22	1.27	0.40	5.49	3.20	121	49.65	46	21.71
27	Tai	85-069	58.2	0.96	16.8	4.09	2.98	0.13	2.90	6.08	3.70	1.36	0.20	1.36	0.62	0.01	99.39	60.01	0.99	17.32	6.87	0.13	2.99	6.27	3.81	1.40	0.21	5.22	2.30	121	51.03	46	16.63
28	Thd	90-066	56.4	0.89	17.1	3.15	2.54	0.09	2.83	6.86	3.45	0.72	0.23	3.06	2.49	0.01	99.82	60.04	0.95	18.20	5.72	0.10	3.01	7.30	3.67	0.77	0.24	4.44	1.90	121	50.36	46	19.25
29	Thd	90-088	57.8	0.89	16.9	2.87	2.99	0.10	3.52	5.82	4.18	1.06	0.23	2.06	0.78	0.02	99.22	60.16	0.93	17.59	5.80	0.10	3.66	6.06	4.35	1.10	0.24	5.45	1.58	121	49.40	46	21.03
30	Thd	87-127	58.3	0.86	17.9	4.13	1.63	0.10	2.40	5.24	4.60	1.10	0.22	1.17	1.22	0.17	99.04	60.69	0.90	18.63	5.56	0.10	2.50	5.45	4.79	1.15	0.23	5.93	2.22	121	49.50	46	20.94
31	Ta	90-024	59.0	1.44	15.7	4.91	2.76	0.21	2.15	5.67	4.00	1.27	0.46	1.41	0.44	0.12	99.54	60.78	1.48	16.17	7.40	0.22	2.21	5.84	4.12	1.31	0.47	5.43	3.34	121	48.58	46	19.69
32	Thd	90-087	58.4	0.86	16.7	2.65	3.24	0.10	3.48	5.79	4.47	0.28	0.19	2.41	0.27	1.16	100.00	60.90	0.90	17.41	5.87	0.10	3.63	6.04	4.66	0.29	0.20	4.95	1.62	121	48.71	46	21.76
33	Tasr	90-124	60.3	1.26	16.0	2.20	5.08	0.18	2.17	5.37	4.37	1.28	0.35	1.18	0.24	0.02	100.00	61.32	1.28	16.27	7.18	0.18	2.21	5.46	4.44	1.30	0.36	5.75	3.25	121	52.00	46	16.70
34	Thd	89-078	58.0	0.76	17.4	3.06	2.05	0.08	2.25	6.15	4.00	0.69	0.19	3.70	1.26	0.00	99.59	61.49	0.81	18.45	5.09	0.08	2.39	6.52	4.24	0.73	0.20	4.97	2.14	121	51.16	46	22.08
35	Tasr	87-072	59.9	1.22	15.8	2.71	4.63	0.15	2.40	5.00	4.30	1.14	0.32	1.42	0.62	0.00	99.61	61.57	1.25	16.24	7.26	0.15	2.47	5.14	4.42	1.17	0.33	5.59	2.94	121	51.52	46	16.26
36	Thd	90-032	59.5	0.86	17.3	3.36	2.14	0.08	2.83	5.15	4.13	0.98	0.21	1.75	1.15	0.31	99.75	61.85	0.89	17.98	5.37	0.08	2.94	5.35	4.29	1.02	0.22	5.31	1.82	121	45.58	46	20.37
37	Thd	90-118	60.3	0.75	17.3	3.34	1.85	0.09	2.65	5.99	3.89	1.38	0.18	1.89	0.46	0.00	100.07	61.92	0.77	17.76	4.99	0.09	2.72	6.15	3.99	1.42	0.18	5.41	1.83	121	45.01	46	20.10
38	Thd	90-110	59.2	0.82	16.3	2.75	2.56	0.11	2.52	6.13	3.32	0.97	0.21	2.22	0.35	2.04	99.50	62.57	0.87	17.23	5.32	0.12	2.66	6.48	3.51	1.03	0.22	4.53	2.00	121	45.47	46	20.75
39	Thd	90-073	60.6	0.77	17.0	2.22	2.89	0.08	2.70	5.13	4.22	1.05	0.20	2.42	0.43	0.11	99.82	62.71	0.80	17.59	5.06	0.08	2.79	5.31	4.37	1.09	0.21	5.45	1.81	121	48.60	46	20.14
40	Ta	88-011	60.3	1.22	14.7	2.88	4.52	0.18	1.71	4.28	4.70	1.54	0.35	2.85	0.28	0.00	99.51	62.75	1.27	15.30	7.40	0.19	1.78	4.45	4.89	1.60	0.36	6.49	4.16	121	51.20	46	22.41
41	Thd	87-131	60.4	0.86	16.1	4.35	1.52	0.09	2.60	5.06	4.20	1.20	0.24	0.66	1.53	0.00	98.81	62.80	0.89	16.74	5.65	0.09	2.70	5.26	4.37	1.25	0.25	5.61	2.09	121	52.20	46	19.93
42	Thd	90-008	60.5	0.82	16.9	1.75	3.44	0.26	2.64	5.88	3.60	0.34	0.21	2.04	0.32	1.55	100.25	62.91	0.85	17.57	5.21	0.27	2.75	6.11	3.74	0.35	0.22	4.10	1.90	121	46.70	46	19.72
43	Ta	90-109	62.0	0.89	15.6	4.06	2.43	0.14	1.83	4.93	3.55	2.48	0.89	0.82	0.95	0.05	100.62	63.01	0.90	15.85	6.18	0.14	1.86	5.01	3.61	2.52	0.90	6.13	3.32	121	45.11	46	19.18
44	Tdi	87-085	61.2	1.18	15.5	2.81	4.01	0.20	2.30	3.42	5.10	1.06	0.38	1.73	0.17	0.21	99.27	63.17	1.22	16.00	6.75	0.21	2.37	3.53	5.26	1.09	0.39	6.36	2.85	121	50.80	46	17.20
45	Thd	87-133	60.0	0.66	16.7	3.11	1.77	0.09	2.10	5.32	4.10	1.12	0.24	2.56	1.20	0.00	98.97	63.22	0.70	17.60	4.82	0.09	2.21	5.61	4.32	1.18	0.25	5.50	2.18	121	51.40	46	19.38
46	Thd	87-122	60.6	0.72	16.6	3.78	1.54	0.10	2.70	4.62	4.10	1.28	0.20	1.12	1.29	0.02	98.67	63.22	0.75	17.32	5.15	0.10	2.82	4.82	4.28	1.34	0.21	5.61	1.83	121	49.40	46	19.82
47	Thd	90-107	61.4	0.69	16.7	3.30	1.64	0.08	2.54	5.58	3.66	1.62	0.18	1.06	1.55	0.00	100.00	63.26	0.71	17.21	4.75	0.08	2.62	5.75	3.77	1.67	0.19	5.44	1.81	121	46.25	46	18.98
48	Thdm	90-001	62.1	0.75	17.0	2.94	3.23	0.02	2.40	4.26	3.64	1.77	0.20	1.07	0.25	0.00	99.63	63.36	0.77	17.34	5.99	0.02	2.45	4.35	3.71	1.81	0.20	5.52	2.45	121	47.96	46	21.46
49	Thd	89-094	61.5	0.66	16.9	3.17	1.77	0.10	2.77	5.62	3.81	0.83	0.17	1.25	1.27	0.00	99.82	63.41	0.68	17.43	4.77	0.10	2.86	5.79	3.93	0.86	0.18	4.78	1.67	121	46.04	46	22.03
50	Thd	88-009	61.6	0.74	16.8	4.03	1.06	0.06	2.19	4.31	4.79	1.40	0.18	1.41	0.98	0.02	99.57	63.66	0.76	17.36	4.84	0.06	2.26	4.45	4.95	1.45	0.19	6.40	2.14	121	51.92	46	22.27
51	Td	90-062	60.2	0.98	15.4	2.78	3.40	0.15	1.26	3.69	3.53	2.99	0.36	2.02	0.43	2.24	99.43	63.73	1.04	16.30	6.25	0.16	1.33	3.91	3.74	3.17	0.38	6.90	4.68	121	47.20	46	16.07
52	Thd	90-026	61.3	0.74	16.7	2.64	2.30	0.08	2.07	5.42	3.78	1.12	0.20	1.60	0.46	1.36	99.77	63.80	0.77	17.38	4.87	0.08	2.15	5.64	3.93	1.17	0.21	5.10	2.26	121	48.62	46	19.77
53	Thd	90-070	61.1	0.71	16.2	3.00	2.11	0.09	2.58	4.40	4.82	0.71	0.18	1.87	0.41	1.48	99.66	63.91	0.74	16.95	5.03	0.09	2.70	4.60	5.04	0.74	0.19	5.78	1.86	121	48.83	46	21.38
54	Tai	90-036	61.2	0.92	15.6	4.90	0.99	0.12	1.37	4.38	4.53	1.65	0.35	1.00	2.11	0.30	99.42	64.07	0.96	16.33	5.65	0.13	1.43	4.59	4.74	1.73	0.37	6.47	3.94	121	46.73	46	17.24
55	Thd	90-061	61.8	0.70	16.2	3.92	0.96	0.07	2.39	4.66	4.02	1.65	0.17	1.33	1.74	0.04	99.65	64.28	0.73	16.85	4.67	0.07	2.49	4.85	4.18	1.72	0.18	5.90	1.88	121	47.28	46	16.25
56	Thd	85-051	62.0	0.68	16.9	2.84	1.90	0.07	2.02	4.94	3.96	1.20	0.18	2.11	0.53	0.27	99.60	64.31	0.71	17.53	4.63	0.07	2.10	5.12	4.11	1.24	0.19	5.35	2.20	121	50.20	46	17.94

Table 1 (cont.). Chemical analyses from the McCoy Peak 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
57	Td	90-090	62.6	0.94	15.7	4.11	1.84	0.11	1.43	4.17	4.14	2.33	0.22	1.19	0.40	0.77	99.95
58	Thd	89-060	60.3	0.64	16.4	2.41	2.08	0.05	2.06	5.38	3.60	0.70	0.19	2.33	0.88	2.45	99.47
59	Thd	90-106	62.6	0.70	16.5	2.91	1.88	0.07	2.16	4.94	4.02	1.38	0.18	1.56	0.83	0.14	99.87
60	Tbh	90-048	62.7	1.05	14.6	1.48	5.09	0.14	1.35	3.81	4.64	1.99	0.34	1.71	0.40	0.00	99.30
61	Thdm	90-117	63.4	0.75	17.1	2.44	2.65	0.02	2.41	4.35	3.62	1.37	0.19	1.21	0.03	0.00	99.54
62	Thd	90-058	62.6	0.71	16.6	3.39	1.36	0.09	2.15	4.65	4.18	1.18	0.20	1.31	0.77	0.43	99.62
63	Thd	89-095	62.2	0.70	16.5	2.56	2.47	0.10	2.28	4.83	3.74	0.81	0.21	2.41	0.77	0.16	99.74
64	Thd	87-124	62.2	0.58	15.9	2.86	1.84	0.09	2.90	4.46	3.80	1.46	0.22	2.03	0.44	0.02	98.80
65	Thd	90-113	61.5	0.64	15.9	2.65	1.83	0.07	2.46	4.51	3.85	1.62	0.16	2.01	0.53	1.01	98.74
66	Thd	90-022	62.3	0.71	15.9	2.75	2.08	0.08	2.34	4.63	4.30	1.11	0.16	1.94	0.51	0.59	99.40
67	Ta	90-093	62.6	0.99	14.5	4.10	2.70	0.17	1.36	3.84	4.32	1.93	0.32	1.09	1.45	0.41	99.78
68	Thd	90-069	62.8	0.70	16.3	2.10	2.52	0.08	2.25	4.83	3.60	1.50	0.17	1.84	0.25	1.03	99.97
69	Thd	90-079	62.0	0.64	16.4	2.22	2.23	0.07	1.88	5.01	4.41	0.56	0.17	2.04	0.55	1.56	99.74
70	Td	87-145	62.4	1.06	14.4	5.07	1.49	0.16	1.50	3.42	4.40	2.12	0.38	0.48	1.47	0.03	98.38
71	Thd	90-038	62.0	0.71	16.4	3.53	1.44	0.07	0.74	5.55	3.72	1.27	0.19	1.29	1.54	1.33	99.78
72	Thd	88-007	63.4	0.67	16.3	2.49	2.07	0.08	2.15	4.67	4.16	1.49	0.17	1.47	0.27	0.00	99.39
73	Tai	90-076	62.6	0.95	15.4	4.45	2.00	0.14	1.57	3.13	4.62	1.47	0.26	1.95	1.00	0.15	99.69
74	Thd	90-116	62.5	0.68	16.4	1.88	2.58	0.08	1.89	4.54	4.46	0.97	0.19	2.03	0.11	1.30	99.61
75	Thd	90-114	63.2	0.65	16.1	2.87	1.49	0.07	1.68	5.17	3.59	1.65	0.16	1.58	0.47	1.04	99.72
76	Td	87-144	63.3	0.84	15.9	4.09	1.45	0.12	0.55	3.56	5.00	1.76	0.32	0.04	1.44	0.00	98.37
77	Tvdh	90-059	62.9	0.81	15.1	1.82	3.50	0.14	1.25	3.71	4.72	1.12	0.23	3.11	0.90	0.00	99.31
78	Tvdh	90-075	63.2	0.80	15.1	1.68	3.65	0.14	1.24	3.56	4.89	1.17	0.23	3.03	0.84	0.00	99.53
79	Tai	90-037	64.4	0.64	16.1	5.00	0.35	0.09	0.51	2.56	4.86	2.50	0.18	0.65	1.39	0.42	99.65
80	Td	87-146	65.0	0.76	14.5	4.29	1.70	0.17	0.90	2.96	4.80	1.94	0.26	0.48	1.26	0.00	99.02
81	Td	90-025	65.7	0.79	15.2	3.50	1.93	0.10	1.18	3.02	4.53	0.85	0.24	1.60	0.66	0.16	99.46
82	Ttv	90-010	68.9	0.47	14.0	0.82	2.06	0.13	0.79	2.92	2.10	2.07	0.08	2.19	0.57	2.17	99.27
83	Ttv	90-016	66.8	0.18	12.6	0.57	1.15	0.02	0.46	5.25	1.15	0.36	0.05	8.10	2.58	0.63	99.90
84	Tr	90-040	75.0	0.23	10.8	1.46	0.53	0.08	0.44	2.50	2.58	2.90	0.05	0.78	0.72	1.26	99.33

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
57	64.42	0.97	16.16	5.70	0.11	1.47	4.29	4.26	2.40	0.23	6.66	3.87	121	49.82	46	20.51
58	64.44	0.68	17.53	4.54	0.05	2.20	5.75	3.85	0.75	0.20	4.60	2.06	121	46.58	46	22.15
59	64.50	0.72	17.00	4.64	0.07	2.23	5.09	4.14	1.42	0.19	5.56	2.08	121	45.27	46	19.37
60	64.61	1.08	15.05	6.62	0.14	1.39	3.93	4.78	2.05	0.35	6.83	4.76	121	49.07	46	16.13
61	64.66	0.76	17.44	4.94	0.02	2.46	4.44	3.69	1.40	0.19	5.09	2.01	121	47.57	46	20.84
62	64.69	0.73	17.15	4.56	0.09	2.22	4.81	4.32	1.22	0.21	5.54	2.05	121	49.08	46	17.04
63	64.69	0.73	17.16	4.97	0.10	2.37	5.02	3.89	0.84	0.22	4.73	2.09	121	45.94	46	22.28
64	64.78	0.60	16.56	4.59	0.09	3.02	4.64	3.96	1.52	0.23	5.48	1.52	121	49.49	46	20.47
65	64.79	0.67	16.75	4.44	0.07	2.59	4.75	4.06	1.71	0.17	5.76	1.71	121	45.80	46	20.51
66	64.84	0.74	16.55	4.74	0.08	2.44	4.82	4.48	1.16	0.17	5.63	1.95	121	47.00	46	18.67
67	64.92	1.03	15.04	6.63	0.18	1.41	3.98	4.48	2.00	0.33	6.48	4.70	121	51.34	46	15.17
68	64.98	0.72	16.87	4.56	0.08	2.33	5.00	3.73	1.55	0.18	5.28	1.96	121	49.06	46	21.18
69	65.01	0.67	17.20	4.43	0.07	1.97	5.25	4.62	0.59	0.18	5.21	2.25	121	45.88	46	21.73
70	65.07	1.11	15.02	6.32	0.17	1.56	3.57	4.59	2.21	0.40	6.80	4.05	121	51.94	46	19.05
71	65.08	0.75	17.21	4.85	0.07	0.78	5.83	3.90	1.33	0.20	5.24	6.24	121	45.98	46	18.41
72	65.09	0.69	16.73	4.43	0.08	2.21	4.79	4.27	1.53	0.17	5.80	2.01	121	51.78	46	20.94
73	65.11	0.99	16.02	6.25	0.15	1.63	3.26	4.81	1.53	0.27	6.33	3.82	121	47.99	46	18.38
74	65.12	0.71	17.09	4.45	0.08	1.97	4.73	4.65	1.01	0.20	5.66	2.26	121	46.96	46	21.73
75	65.60	0.67	16.71	4.23	0.07	1.74	5.37	3.73	1.71	0.17	5.44	2.42	121	45.54	46	19.94
76	65.61	0.87	16.48	5.32	0.12	0.57	3.69	5.18	1.82	0.33	7.01	9.33	121	51.71	46	19.04
77	66.13	0.85	15.88	5.40	0.15	1.31	3.90	4.96	1.18	0.24	6.14	4.11	121	49.04	46	18.23
78	66.18	0.84	15.81	5.41	0.15	1.30	3.73	5.12	1.23	0.24	6.35	4.16	121	48.85	46	18.00
79	66.60	0.66	16.65	5.02	0.09	0.53	2.65	5.03	2.59	0.19	7.61	9.51	121	45.65	46	15.08
80	67.11	0.78	14.97	5.74	0.18	0.93	3.06	4.96	2.00	0.27	6.96	6.17	121	51.96	46	19.03
81	67.95	0.82	15.72	5.25	0.10	1.22	3.12	4.69	0.88	0.25	5.56	4.31	121	48.66	46	19.73
82	73.10	0.50	14.85	2.97	0.14	0.84	3.10	2.23	2.20	0.08	4.42	3.54	121	47.35	46	19.90
83	75.45	0.20	14.23	1.88	0.02	0.52	5.93	1.30	0.41	0.06	1.71	3.62	121	47.28	46	18.78
84	77.78	0.24	11.20	1.91	0.08	0.46	2.59	2.68	3.01	0.05	5.68	4.19	121	48.49	46	15.53

X-ray fluorescence analyses, except those prefixed by MK, done in U.S. Geological Survey laboratories in Menlo Park, Calif. (analyst Marsha Dyslin) and Denver, Colo. (analysts J.E. Taggart, A.J. Bartel, and D.F. Siems)
FeO and CO_2 analyses done in U.S. Geological Survey laboratories in Menlo Park (analysts S.F. Bader, J. Consul, N.H. Elsheimer, L. Espos, and K. Lewis) and Denver (analyst E. Brandt)
Water analyses done in U.S. Geological Survey laboratory in Menlo Park (analysts S.F. Bader, J. Consul, N.H. Elsheimer, L. Espos, and K. Lewis)
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
[1]*Analyses done at Washington State University by R.M. Conrey and Diane Johnson, using XRF techniques*

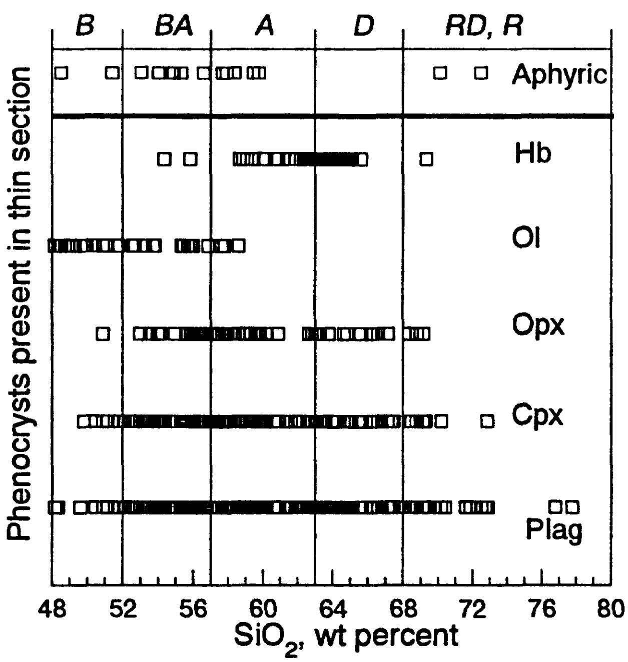


Figure 4. Plot of phenocryst assemblage vs. SiO_2 for 252 porphyritic and 15 nonporphyritic Tertiary rocks, chiefly in McCoy Peak, Tower Rock, French Butte, and Greenhorn Buttes quadrangles but including a few from other quadrangles. □, phenocryst observed in thin section; Hb, hornblende; Ol, olivine; Opx, orthopyroxene; Cpx, clinopyroxene; Plag, plagioclase. Rock types along top edge from figure 3.

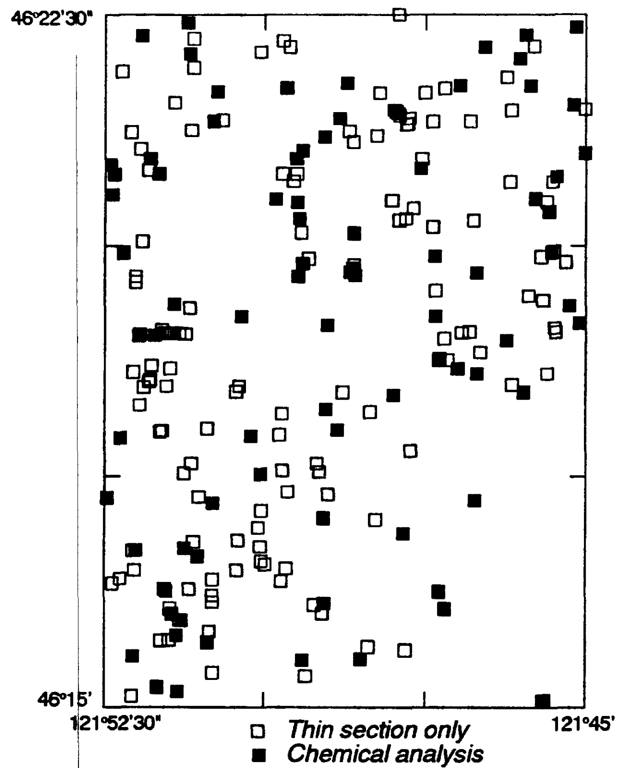


Figure 5. Map showing distribution of 234 sample localities in McCoy Peak quadrangle, including two localities for samples collected by Korosec (1987) and listed in table 1.

At SiO_2 = 57.5 percent (a value used by Gill [1981] to compare andesitic arcs throughout the world), the host rock for the intrusive suite of Kidd Creek, and the suite itself, have an average K_2O content ($K_{57.5}$) of 1.17 and 0.76 respectively. The average FeO*/MgO ratio (FeO*/$Mg_{57.5}$) for each data set is 2.80 and 1.60, respectively. The values for $K_{57.5}$ and FeO*/$Mg_{57.5}$ were obtained by linear regression of the data in figures 9 and 7, respectively. These values are within the range given by Gill (1981, table 7.1 and appendix) for volcanic arcs and are similar to those in the neighboring mapped quadrangles (Swanson, 1989, 1991). However, the FeO*/$Mg_{57.5}$ value is rather high. This observation is discussed in the section, "Thickness of Oligocene and Miocene crust."

GENERAL GEOLOGY

The rocks in the quadrangle are mostly late Oligocene and early Miocene basaltic andesitic and andesite lava flows, and andesitic and dacitic volcaniclastic deposits. Rhyolite flows occur but are uncommon. Flows of andesite and basaltic andesite dominate the section except in the northern third of the quadrangle, where well-bedded subaerial volcaniclastic deposits, mostly of fluvial origin, prevail. The flows are intruded by numerous dikes, some of which probably fed flows. The dikes box the compass, but one trend, roughly east-west, is especially notable in the southern part of the quadrangle and is part of a regional swarm (Swanson, 1990).

The Tertiary section in general dips west-southwestward, toward the trough of the Pole Patch syncline just west of the quadrangle (Swanson, 1989), as does the section in the Tower Rock quadrangle to the north. However, attitudes in the southern half of the quadrangle are complex and in places unpredictable, probably because of the proximity to vent areas. A possibility exists that an angular unconformity separates a more steeply dipping section dominated by volcaniclastic rocks from a younger, gentler-dipping section dominated by lava flows. Definitive evidence for such an unconformity has not been found, however.

Outcrops in the northeastern part of the quadrangle expose the core of a subvolcanic intrusive complex of hornblende diorite and related rocks, which is the focus for

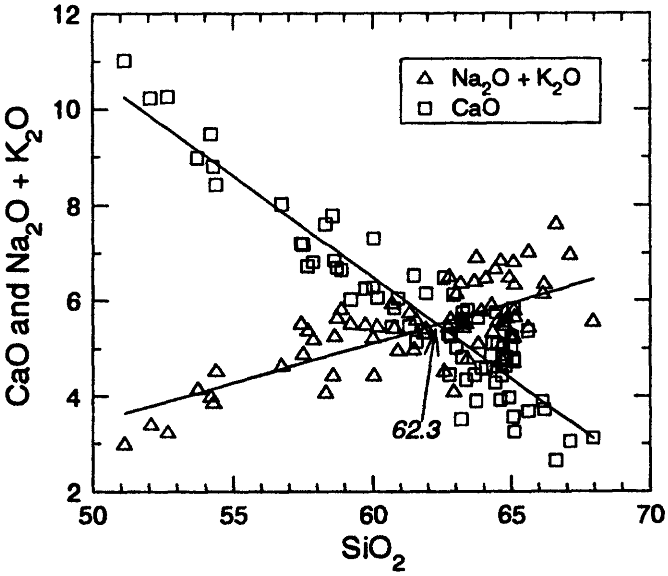


Figure 6. Plots of CaO and (Na_2O + K_2O) vs. SiO_2 for all analyzed Tertiary rocks in McCoy Peak quadrangle. Linear regressions of both plots cross at SiO_2 content of 62.3, indicating slightly calcic suite in terminology of Peacock (1931). Analysis no. 11 (table 1) and the three analyses with SiO_2 greater than 70 percent not included, because significant alteration affects alkali contents.

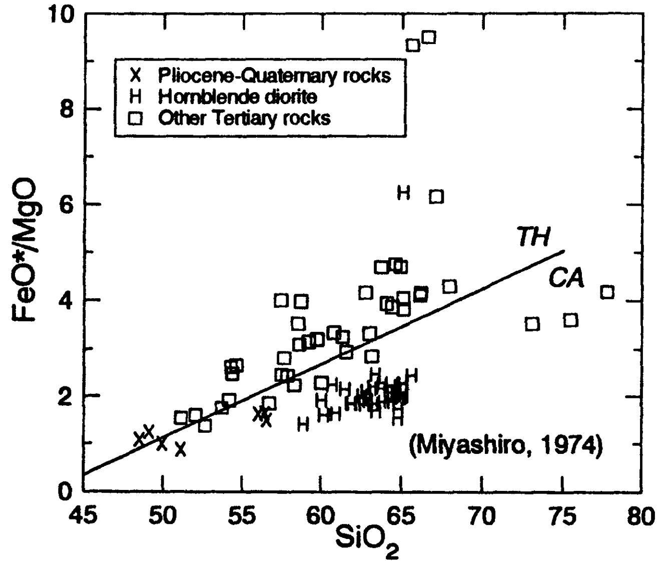


Figure 7. Plot of FeO*/MgO vs. SiO_2 for chemically analyzed rocks from McCoy Peak quadrangle. Subdivision into tholeiitic (TH) and calc-alkaline (CA) suites after Miyashiro (1974). Most Tertiary rocks are tholeiitic, but the hornblende diorite in the intrusive suite of Kidd Creek is calc-alkaline. Young basalt and basaltic andesite lie close to the boundary between the two suites. Both samples with FeO*/MgO > 9 (table 1, nos. 76 and 79) have high Fe_2O_3/FeO* ratios and low MgO contents. For linear regression (not shown) to obtain FeO*/$Mg_{57.5}$, the two values of FeO*/MgO greater than 9 and the value of 6.24 were not used.

a radial swarm of dikes and sills; representatives of this swarm are abundant in both the Tower Rock and the McCoy Peak quadrangles (Swanson, 1991; this paper). The age of the intrusive complex is probably about 13.5–10.5 Ma, several million years younger than any of the erupted rocks in the Tertiary section. Rocks in the complex are characteristically low in FeO*, TiO_2, and MnO and thereby chemically distinct from the older rocks. The complex was intruded following a period of folding and erosion, and little if any folding occurred after the intrusive episode was complete. A possible fault paralleling Jumbo Creek may be coeval with, or younger than, the intrusive complex; a few other faults, tentatively interpreted as minor structures, are younger.

Two Quaternary flows of olivine basalt and one of basaltic andesite occur in the quadrangle. At least one other olivine basalt flow is inferred on the basis of float, although no outcrop has been found. One of the flows of olivine basalt is in the northeast corner of the quadrangle, one in the southwest corner, and one (the inferred flow) is halfway between; all cover small areas and are relatively rich in K_2O. The flow in the northeast corner, the basalt of Juniper Creek, includes deposits from its vent, a hydromagmatic cone. The basaltic andesite of Badger Ridge (0.65 Ma) was erupted in the French Butte quadrangle (Swanson, 1989); it is much more extensive than the olivine basalt and covers about 1.5 km^2 along the west edge of the quadrangle. Two fresh dikes, one of olivine basalt and the other of basaltic andesite, are probably of Pleistocene or Pliocene age.

TERTIARY ROCKS OLDER THAN INTRUSIVE SUITE OF KIDD CREEK

Volcaniclastic rocks—Most of the volcaniclastic rocks north of Jumbo Creek and east of Langille Ridge (fig. 2) are moderately- to well-bedded and sorted sandstone and siltstone, probably deposited in aprons away from centers of active volcanism. Common channels and local erosional unconformities testify to a rather high-energy fluvial environment. Relatively thin (1–3 m thick) diamictites are common and interpreted as distal facies of lahars and other types of volcanic debris flows. Thick, coarse laharic breccia is not as common as farther south along strike in the quadrangle, an area presumably closer to active volcanic centers. Fossil plant material, mainly fragments of trunks and limbs, is abundant in places. Particularly good places

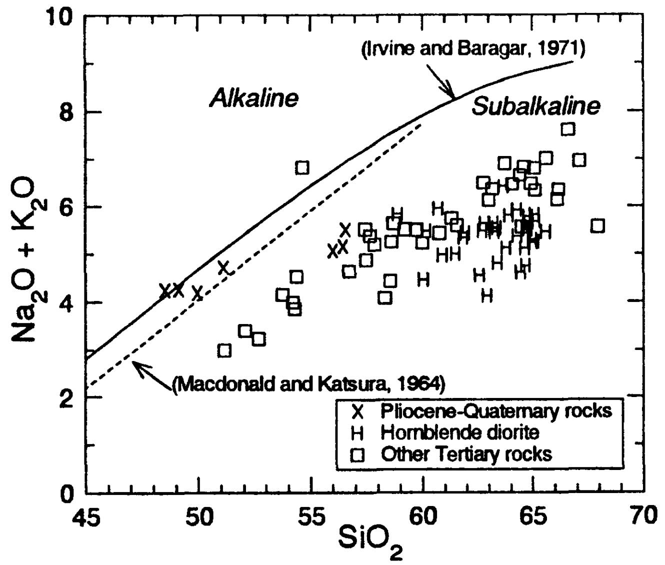


Figure 8. Plot of (Na_2O + K_2O) vs. SiO_2 showing boundary between subalkaline and alkaline suites after Macdonald and Katsura (1964) and Irvine and Baragar (1971). Several young basalt samples are marginally alkaline. Tertiary sample in alkaline field (table 1, no. 11) probably enriched in Na_2O during alteration.

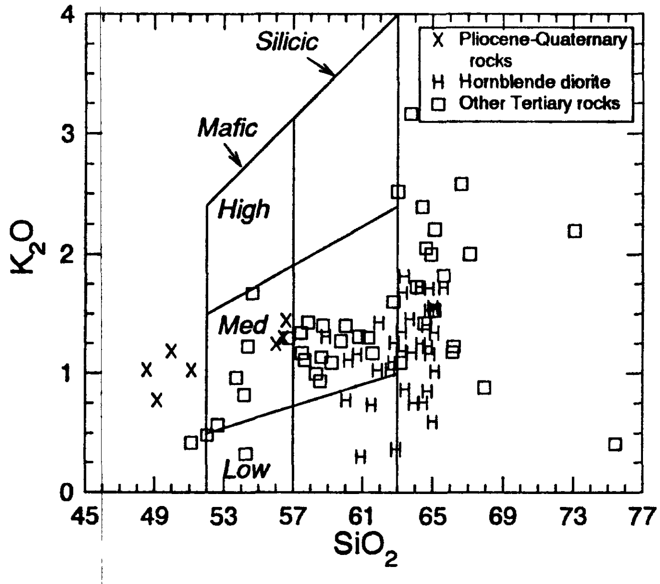


Figure 9. Plot of K_2O vs. SiO_2 for rocks from the McCoy Peak quadrangle. Fields modified from Gill (1981), so that mafic andesite (basaltic andesite in IUGS terminology used in this paper) extends down to 52 percent. For linear regression (not shown) to obtain $K_{57.5}$ (see text), SiO_2 content of 75.45 was not used.

to observe these features are just southeast of Point 5526 on Juniper Ridge and just southwest of Sunrise Peak.

A larger proportion of the volcaniclastic section west of Langille Ridge and north of McCoy Peak consists of pumice-lapilli tuff and pumice-lithic-lapilli tuff, although deposits clearly of fluvial origin are common and perhaps even dominant. The pumice-bearing rocks are mostly ash-flow tuff, in places welded but generally nonwelded; the vitrophyric base of one welded tuff is indicated on the map, although it is much less obvious than in the adjoining French Butte quadrangle. Distal lahar deposits are more common than in the northeastern part of the quadrangle, but very thick, coarse deposits are uncommon. One particularly good leaf-fossil locality occurs low on the west side of Langille Ridge (fig. 2; locality available from the author); fossils examined by Jack Wolfe (U.S. Geological Survey) include new species as well as recognizable ones that Wolfe considers more likely to be of late Oligocene than early Miocene age (J.A. Wolfe, personal commun., 1991). This westward and up-section facies change is very gradual, and interbedding of all rock types occurs throughout the section anywhere in the northern third of the quadrangle. Such a gradual change also characterizes the volcaniclastic rocks in the Tower Rock quadrangle (Swanson, 1991).

South of Jumbo Creek and McCoy Peak, many of the volcaniclastic rocks are coarser and less well bedded and sorted than those farther north. Thin andesitic diamictites interpreted as lahars are more common, as are poorly sorted volcanic breccia and lithic-lapilli tuff that contain a variety of clasts and probably were deposited by lithic pyroclastic flows. Fluvial sandstone and other well-sorted deposits also occur but in greatly reduced proportion compared to the section farther north. These observations are consistent with relative proximity to eruptive centers, as independently judged by the prevalence of lava flows, dike concentrations, other andesite intrusions, and attitudes inconsistent with the regional structure. Pumice-bearing tuff is not common, although quartz-phyric rhyolitic ash-flow tuff (the only quartz-phyric tuff in the quadrangle) occurs at two localities south of Jumbo Creek (plate 1, nos. 82 and 83), and several pumice-bearing lithic diamictites that are probably pyroclastic-flow deposits occur at Hat Rock and in upper Yellowjacket and McCoy Creek basins, particularly along the divide between McCoy and French Creeks where the rocks are exposed in road cuts.

Chaotic volcanic breccia—Very thick, poorly bedded to nonbedded volcanic breccia crops out around Holdaway Butte and in the Shark Rock-Craggy Peak area (unit Tvb on plate 1). Similar breccia occurs below Kirk Rock, in the French Butte quadrangle 1.4 km west of Shark Rock (hill 5597 on the quadrangle map); the mapped part of the unit west of Shark Rock belongs to the Kirk Rock pile.

The accumulations are remarkably thick, more than 350 m below Holdaway Butte, 500 m below Shark Rock and Craggy Peak, and 300 m below Kirk Rock. The margins of the unit are indistinct and in places arbitrarily portrayed on plate 1, but the lack of internal continuity, except for local lava flows and very local bedding, distinguishes the unit from the rest of the volcaniclastic section.

The breccia consists of angular andesitic clasts as much as 1 m or more in diameter that form a disrupted framework separated by finer matrix of similar lithic content. Hydrothermal alteration is common and in many places obscures primary textures, as does the intense propylitization and sulfide mineralization in Yellowjacket Creek basin. In places in the propylitized rocks, the clasts have dark reaction rims with the matrix that simulate quenched margins; a good place to see this relation is at an elevation of 3100 ft along the creek 1.3 km north-northeast of the high point at the south end of Shark Rock, below an abandoned logging road (not shown on map).

At least one tabular body of andesite occurs within the breccia 1 km northeast of Shark Rock. Whether it is a flow or an intrusion could not be determined with certainty. The body is shown as an intrusion on plate 1 because of its blocky jointing and lack of vesicularity, but this evidence is not convincing. The gourd-shaped andesite intrusion centered 0.8 km northeast of Craggy Peak could in reality be two tabular sills or flows; exposures are too poor to make a clear identification. These uncertainties are significant, because if the bodies are indeed flows, they would suggest that the breccia was emplaced in stages separated by periods of effusion.

The limited areal distribution and great thickness of the three piles of volcanic breccia suggest that each occurs in a crater or small caldera 1–2 km across. Possibly all three are remnants of one large caldera fill; local dips are variable, but considerations of the west-southwest regional dip readily permit at least the correlation of the Holdaway Butte and Shark Rock-Craggy Peak piles.

Several unanswered questions are raised by the interpretation of the piles as crater or caldera fills. One is why so much of the breccia is matrix supported; talus, which would be expected to fill craters, is generally framework supported. One way around this dilemma is to ascribe the origin of the breccia to explosions, whose deposits in a proximal environment would commonly be chaotic. Another way is to call upon a mix of debris flows, talus, and explosion debris.

Another question concerns the duration of emplacement of the breccia. Did emplacement take a geologically short period of time (weeks to tens of years) or much longer (hundreds to thousands of years)? If the andesite bodies are indeed flows, several periods of effusion are indicated. I favor a geologically short period of time, because of the chaotic nature of the three piles; this interpretation is the main reason that I believe the andesite bodies are intrusive rather than extrusive.

Still another important question regards the origin of the depression(s) filled by the breccia. Are the depressions really one or more craters or calderas, or are they one or more deep canyons eroded into the underlying rocks and filled by thick debris flows? I view canyons as less likely than craters, because no evidence exists elsewhere to suggest a period of such pronounced erosion during accumulation of the Tertiary section. Indeed, the concentrations of dikes and flows surrounding the breccia imply nearby volcanoes and hence the proper setting for one or more collapse or explosion depressions to form.

In short, the thick piles of breccia are enigmatic and deserve more careful study. They probably record the filling of one or more craters or small calderas, but the evidence for this origin is circumstantial and unconvincing.

Vitroclastic dacite and andesite breccia—Vitroclastic dacite breccia, poorly sorted and bedded, forms steep slopes and cliffs 1 km northeast of Holdaway Butte, along the northeast edge of one of the thick piles of volcanic breccia (unit Tvdh on plate 1). Clasts in the vitroclastic breccia are or once were glassy to very fine-grained. A quenched rim surrounds many of the clasts, and perlitic cracks are abundant. The clasts typically have closely spaced, hackly jointing and other features that resemble those described for subaqueous rhyolite by Kano and others (1991). The breccia is generally framework supported, although locally matrix separates the larger clasts. The matrix is simply a finer-grained version of the blocks and is palagonitized in places. The crude bedding defines an antiform whose crestline trends northwest. Dips are steep, generally greater than 20°.

These characteristics indicate the interaction of dacite lava with water, presumably in a depression at least 120 m deep. The location of this depression—partly nested within the thicker volcanic breccia, itself probably a crater filling—suggests renewed crater formation. Possibly dacite lava rose into a crater lake, quenched, and fragmented, much as does basaltic lava during subglacial eruptions. Pillows did not form owing to the relatively high viscosity of the high-silica dacite lava (table 1, nos. 77–78), but otherwise the structures resemble those of subglacial basalt flows and coarse hyaloclastite, such as described by Hammond (1987) for late Quaternary basalt in the nearby Lone Butte-Crazy Hills area. Zones of devitrification and hydrothermal alteration in the hydroclastic breccia might have been induced by hot water during cooling of the pile.

Vitroclastic dacite breccia (unit Tbh on plate 1; table 1, no. 60) forms steep cliffs at Hat Rock. Clasts are quenched and jointed as near Holdaway Butte, but at Hat Rock both broken and intact small pillows, some partly drained, also occur. In places the clasts and pillow fragments lie in a yellow palagonite matrix. The deposit fills one or more steep-walled, rather flat-floored depressions somewhat more than 60 m deep. The flat base of the hyaloclastite is well exposed along the base of the cliff encompassing much of Hat Rock.

The contact of the hyaloclastite and the wallrock (a lithic-lapilli tuff) of the depression (or at least the largest of multiple depressions) is well exposed at the south end of the west face of Hat Rock itself, where it can be traced from subhorizontal to subvertical. A gully has been eroded along the steep northwest-striking contact, and fragments of the lapilli tuff cling to the nearly vertical face of the hyaloclastite fill and are columnar as if baked against the contact. Blocks of the lapilli tuff also occur within the hyaloclastite. Clasts in the hyaloclastite are on average larger toward the top of the deposit, and what appear to be discontinuous lobes of lava are more abundant and larger higher in the section. Thin subaerial lava flows (unit Ta on plate 1) cap the section and, if related to the hyaloclastite as suggested by the seemingly gradational contacts with it, record the maximum surface level of the water that caused the quenching, if the concept of lava deltas is applicable in this setting (Fuller, 1931; Jones and Nelson, 1970; Furnes and Sturt, 1976). Discontinuous exposures show that the northeast side of Hat Rock is also along a steep contact between hyaloclastite and lapilli tuff. The hyaloclastite merges gradually eastward into a vitrophyric dacite flow, which is exposed along the ridge crest at about 5000 ft elevation at the east end of the outcrop area of the unit.

Possibly another filled depression occurs just south of Hat Rock, but all exposed contacts are subhorizontal. The map pattern suggests that the northwest contact of this exposure is steep.

Hydroclastic andesite breccia (unit Tbh in plate 1; table 1, no. 22) forms most of Snagtooth Mountain 1 km south of Hat Rock. Except for its composition, the 60–70-m-thick, cliff-forming rock resembles that at Hat Rock in most respects. However, it is less thoroughly brecciated and in places merges either upward or laterally into flowlike masses many meters across that are quenched and closely jointed but not heavily brecciated. Crude vertical columns, best seen from a distance, characterize the unit and typically are wider near the base of the cliff and narrower near the top. Generally the base of the unit, which is everywhere breccia, is subhorizontal and rests on lithic-lapilli tuff or diamictite. Lateral margins of the unit on Snagtooth are not preserved.

Taken together, the Hat Rock and Snagtooth vitric breccia reflect quenching of lava by water, but the nature of the depressions in which water was present is unclear. Likely choices are gorges eroded into the underlying pyroclastic flow or small craters. I favor gorges over craters, because of the geometry and the lack of any crater-fill material supplied by mass wasting of the walls. Both of these units, with thin overlying andesite flows, cap the local section, and the comparative freshness of the glassy rocks raises the possibility that they are considerably younger than the underlying rocks. However, a significant age difference is not required; gorges commonly form in pyroclastic flows within a few years to decades after emplacement. Moreover, a clastic dike of green lithic-lapilli tuff, probably formed by loading of the underlying lapilli tuff, cuts the vitric breccia on the north side of Snagtooth Mountain (shown as a dike of map unit Ttv on plate 1); this relation implies that the tuff was not lithified when the breccia was formed and hence was likely not much older. Finally, the great thickness (more than 90 m) of an andesite or basaltic andesite flow 1 km east-northeast of Hat Rock along the same ridge implies considerable relief in this general area before formation of the vitric breccia.

Whether the hydroclastic breccia northeast of Holdaway Butte, at Hat Rock, and at Snagtooth are related genetically is a open question. No similar rocks have been found in the other mapped quadrangles (including the unpublished but completed Blue Lake quadrangle), and why three occurrences of similar material are so close together is puzzling. My feeling is that the Hat Rock and Snagtooth bodies probably formed at about the same time but from chemically distinct flows, and that the breccia northeast of Holdaway Butte is unrelated to the other two.

Volcanic centers—Concentrations of andesitic dikes, and local quaquaversal dips in lava flows, indicate the presence of several extrusive centers in the southern half of the quadrangle. One of the most obvious vent areas is in the headwaters of the north fork of Slide Creek (fig. 2) 1 km southwest of Jumbo Peak. Here, crudely bedded, welded, andesitic spatter and agglutinate define at least two low cones that merge downward and outward into andesitic breccia. Just upslope (up dip) from the cones, welded spatter is plastered on the walls of a crater more than

100 m deep, and a thick flow fills the crater. The geometry of the area suggests that the crater is centered west or southwest of the present exposures, perhaps at a swarm of northwest-striking dikes exposed on the divide between the two forks of Slide Creek or at a complex intrusion (in unit Tai) exposed in road cuts just south of the mouth of Slide Creek. This intrusion consists of many dikes of different strikes (60°–75° is most common), smaller irregular masses of columnar andesite, and wallrock(?) screens of coarse breccia that could in fact be vent breccia.

Across McCoy Creek west of the filled crater, steeply north-dipping flows on Langille Ridge and its spurs are plainly evident and define the north flank of another volcanic center, riddled with dikes and irregular andesitic intrusions. Most of the dikes strike northwest, but several have other orientations that crudely define a radial swarm centered in this general area. This center is adjacent to, and perhaps a part of, the crater complex filled by volcanic breccia and hydroclastic dacite breccia northeast of Holdaway Butte.

A concentration of dikes 1.5 km northwest of Dark Mountain probably indicates a volcanic center, possibly parasitic to the major center on Langille Ridge. This possibility is suggested by the east and southeast dips in the lava flows—an anomaly relative to the regional north-northwest strike that can be explained if the flows are on the east and southeast flank of a large volcano. An apparent south-southeast dip of 5° was observed on the west side of Dark Mountain from the ridge crest east of Hat Rock; this apparent dip, not shown on the map because the strike could not be adequately defined, suggests that Dark Mountain too is on the flank of the Langille Ridge center or a center related to the complex intrusion just south of the mouth of Slide Creek.

Numerous dikes on and west of Dark Mountain may indicate proximity to another volcano, and dikes on the ridge separating Badger and Yellowjacket Creeks display a broadly radial pattern suggestive of a center. At neither locality are remains of a volcanic edifice related to the dikes preserved; they have been removed by erosion if once present.

Andesitic intrusions wider than single dikes are scattered throughout the quadrangle. Many are decidedly elongate and have complex internal jointing suggesting multiple dikelike injections; a well-exposed example of such a body, although not as elongate as some, is the body just south of the mouth of Slide Creek. Some or all of these intrusions could be subvolcanic bodies. Certainly in some way they are likely to be associated with volcanic centers, but whether they actually fed lava to the surface themselves or were injected laterally from major feeding conduits is unknown.

Probably more pyroxene andesite eruptive centers occur in the southern half of the McCoy Peak quadrangle than in the rest of the mapped quadrangles combined, to judge from the distribution of pyroxene andesite dikes in the mapped area (fig. 10*A*). This figure does not show the locations of andesitic intrusions larger than single dikes and so is slightly misleading, because a few larger andesitic intrusions in the other quadrangles (such as Greenhorn Buttes themselves) were probably associated with volcanoes. Moreover, an older part of the section is exposed in the southern half of the McCoy Peak quadrangle than in the French Butte and Greenhorn Buttes quadrangles, so that more dikes are likely to be exposed by erosion. Nonetheless, the overall pattern is clear. Of 475 pyroxene andesite dikes for which strikes could be measured, 308 of them occur in the McCoy Peak quadrangle, most of them in the southern half.

Regional dike swarm—Most dikes in and south of the headwaters of Yellowjacket and McCoy Creeks strike roughly west or, more commonly, a few degrees north of due west and form part of a regional swarm of dikes previously described (Swanson, 1989, 1990, 1991). The mean strike of the 318 mapped pyroxene andesite dikes in the quadrangle is about 280° (fig. 11*A*), very similar to that of dikes in the swarm in the other quadrangles (fig. 11*B*, *C*; Swanson, 1989, 1991), despite the obvious concentration of dikes of various orientations around the eruptive centers. This illustrates how dominant the regional swarm is. Another idea of the dominance is to compare figures 10*A* and *B*; a large proportion of the mapped pyroxene andesite dikes belongs to the regional swarm.

Most of the dikes in the regional swarm are vertical to subvertical. The dikes strike at a high angle to the regional strike of the host rock (about 340°; fig. 11 *D*) and so would not be recognizably tilted during folding. Hence the age of the regional swarm relative to regional tilting cannot be determined. By contrast, many dikes trending at low angles to the regional strike dip about 70° east, probably because they were intruded before regional westward tilting (on the assumption that dips were originally subvertical).

Dikes of pyroxene andesite are consistently older than those of hornblende dacite and diorite wherever intersections were found. However, only two such intersections were seen involving pyroxene andesite dikes of the regional trend; both intersections are within the volcanic center on Langille Ridge, where the orientation of the pyroxene andesite dikes could reflect local rather than regional stress

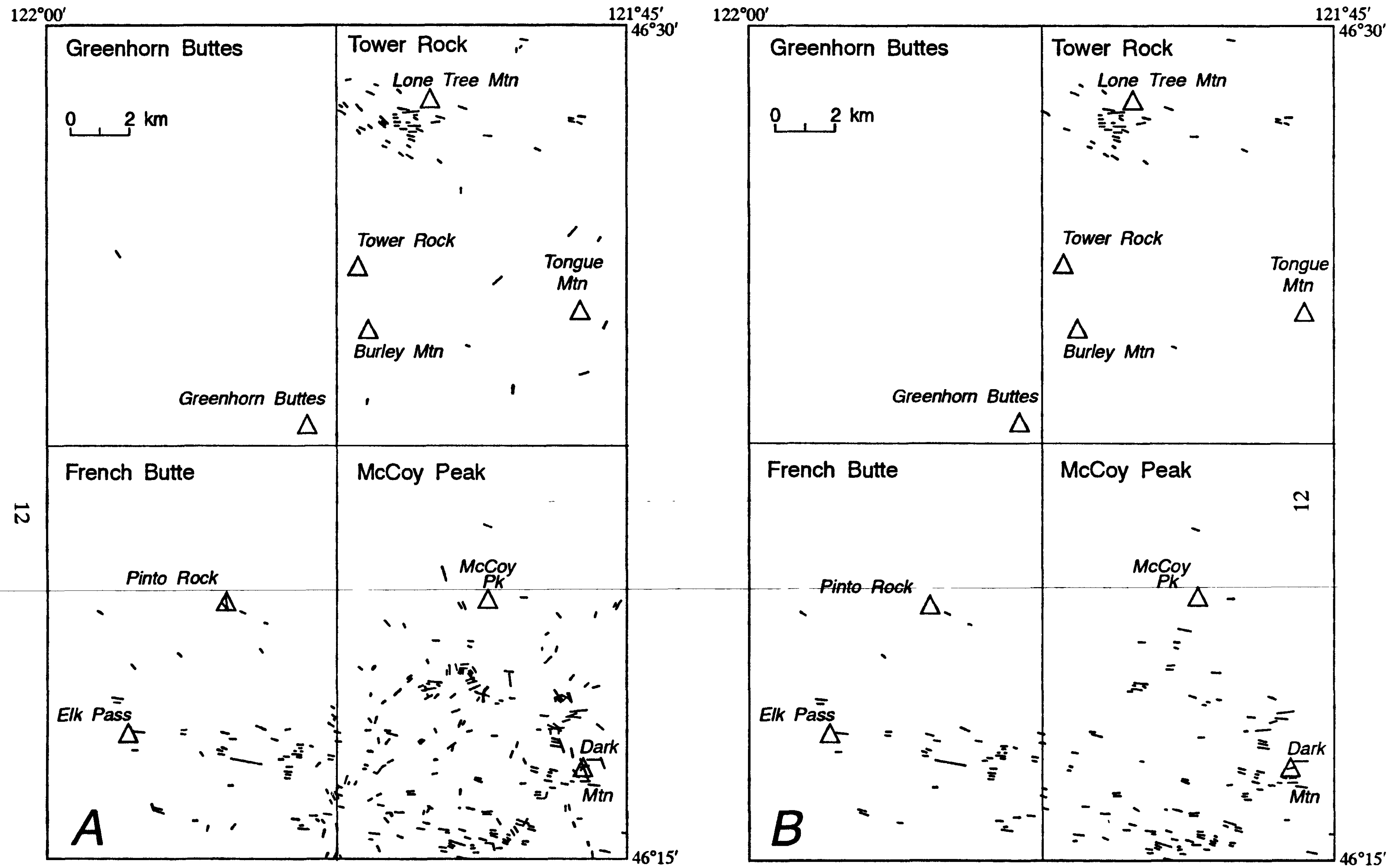


Figure 10. Generalized distribution of 475 pyroxene andesite and basaltic andesite dikes in French Butte, Greenhorn Buttes, Tower Rock, and McCoy Peak quadrangles. Only those dikes are shown for which strike could be measured. Larger intrusions, even those consisting of multiple dikelike intrusions, are not plotted. A, all dikes, both those in regional swarm and those related to local centers. B, only dikes in regional swarm, defined by criterion that strike is between about 260 and 300 degrees. Note concentration of dikes in two broad areas, on Lone Tree Mountain in Tower Rock quadrangle and in southern part of French Butte and especially McCoy Peak quadrangles. Sixty-five percent of dikes are in McCoy Peak quadrangle.

12

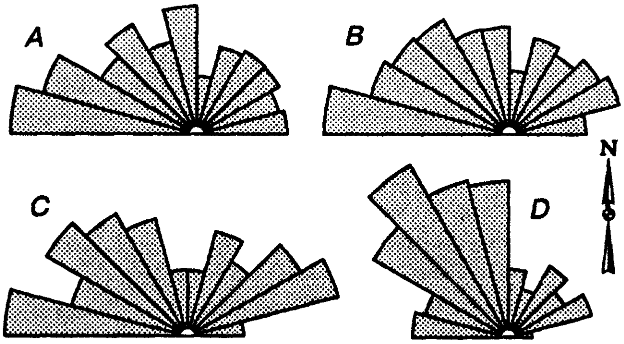


Figure 11. Equiarea rose diagrams in 15° increments of strikes of pyroxene andesite dikes and volcaniclastic beds. *A*, 318 dikes in McCoy Peak quadrangle (mean direction, 279.8°; s.d, 42.2°). *B*, 566 dikes, mostly in French Butte, Greenhorn Buttes, Tower Rock, and McCoy Peak quadrangles but including a few in adjacent quadrangles (mean direction, 277.7°; s.d., 42.0°). *C*, 248 dikes in all quadrangles except McCoy Peak (mean direction, 275°; s.d., 41.7°). *D*, 206 strikes of bedding in McCoy Peak quadrangle (mean direction, 341.5°; s.d., 41.7°).

and hence strike west only fortuitously. Therefore, the age relation between the regional swarm and the hornblende-bearing dikes can not be convincingly demonstrated. Nonetheless, the consistently greater degree of alteration argues for the regional swarm being older, as does its petrographic and chemical similarity to the pyroxene andesite dikes known to predate the hornblende-bearing dikes.

Age—No radiometric ages exist for rocks in the quadrangle older than the intrusive suite of Kidd Creek. Projection along strike from dated rocks in the Tower Rock and Greenhorn Buttes quadrangles suggests that the section is between about 30 Ma and 18.5 Ma (Swanson, 1991, tables 2 and 3), becoming younger from east to west. This is broadly consistent with the age of the fossil plants (more likely late Oligocene than early Miocene; see section on "Volcaniclastic rocks") low on the west side of Langille Ridge, because linear extrapolation between the bounding radiometric ages would suggest an age of 22–26 Ma for the fossils compared to the accepted age of 23.7 Ma for the Miocene-Oligocene boundary (Palmer, 1983).

INTRUSIVE SUITE OF KIDD CREEK

The term *intrusive suite of Kidd Creek* (Marso and Swanson, 1992) is used for a widespread, chemically related suite of hornblende-plagioclase-phyric silicic andesite, mafic dacite, microdiorite, diorite, and quartz diorite dikes, sills, and larger stocklike bodies that occurs in the Tower Rock, McCoy Peak, French Butte, Blue Lake,

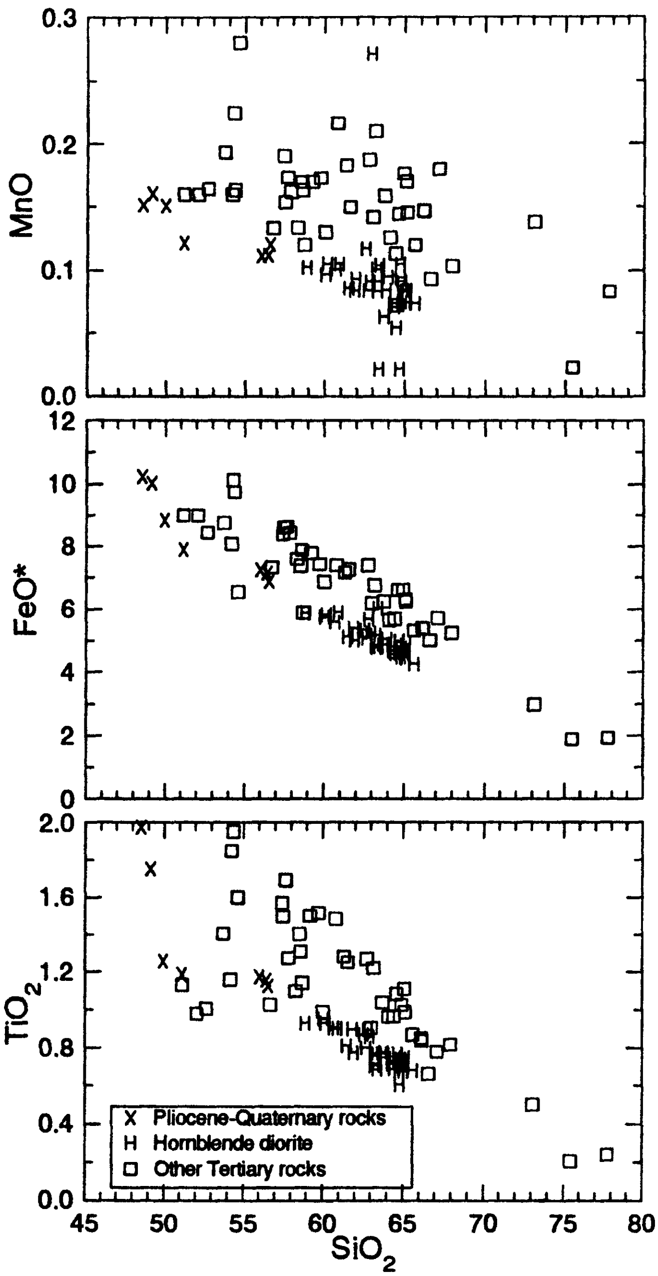


Figure 12. Plots of TiO_2, FeO*, and MnO vs. SiO_2 for all analyzed rocks in McCoy Peak quadrangle. Note that hornblende diorite and related rocks of Kidd Creek intrusive suite are chemically distinct from most other rocks in quadrangle.

and East Canyon Ridge quadrangles. For brevity, I generally use the terms hornblende diorite, hornblende microdiorite, and hornblende dacite, depending on grain size, while recognizing that the compositions straddle formal classification boundaries. The suite is characterized by relatively low contents of TiO_2, FeO*, and MnO (fig. 12) compared to other Tertiary rocks in the area.

The name, Kidd Creek, was first suggested in about 1981 by Prof. Eric Cheney (University of Washington) and a student of his, R.M. Nichols, to distinguish these comparatively fresh intrusions from the mineralized hornblende quartz diorite and granodiorite of McCoy Creek. Link (1985) was the first to use the term in a formal report. I include within the Kidd Creek all of the hornblende-phyric intrusive rocks in adjacent quadrangles (Swanson, 1989, 1991). Field relations and chemical compositions presented in this report and by Link (1985) indicate to me that the McCoy Creek body is also part of the Kidd Creek suite, and that it is more highly altered and mineralized because it forms the subvolcanic roots of a large volcano, all eruptive remnants of which have been eroded away.

Dikes—More than 140 dikes of hornblende dacite and microdiorite occur in the quadrangle, mostly in the northern half but extending as far south as the North Fork of French Creek (fig. 2), 2.2 km north of the southern edge of the quadrangle. The dikes are best exposed high along Langille and Juniper Ridges (fig. 2); relatively few crop out low in the valleys, owing at least in part to the poorer exposures there. Note that the hornblende-bearing dikes are shown on plate 1 by a different symbol from those of other dikes (see explanation of map symbols).

The dikes are typically 1–2 m wide, but some are as wide as 10 m or more. Each dike has chilled margins and a coarser-grained interior, generally lacking vesicles. Needlelike hornblende phenocrysts in a few chilled margins are weakly aligned parallel to the dike margin and plunge obliquely toward the Camp Creek area; generally, however, no preferred orientation of phenocrysts is evident. Most of the dikes are columnar perpendicular to their contacts.

Most of the dikes can be traced only a few tens of meters before ending or disappearing beneath overburden, but several on Langille Ridge can be recognized for several hundred meters along strike. The dike cutting Jumbo Peak is exposed for about 600 m, as is an east-striking dike connecting two larger intrusions in the headwaters of Jumbo Creek. Five dike segments form a right-stepping, north trend for 2 km south of Falls Creek (fig. 2), and a sixth segment occurs along the approximate extension of this trend (but in a left-stepping sense) 2.5 km farther south along the North Fork of French Creek (fig. 2). These six segments may be parts of the same dike.

Most of the dikes are subvertical, even those that cross the strike of the dipping host rock at low angles. A similar geometric relation was found in the Tower Rock quadrangle (Swanson, 1991). This relation implies that the dikes are younger than the age of tilting, on the assumption that they were nearly vertical when emplaced.

Exceptions to this geometric relation are rare but obvious. Northwest-striking dikes just southwest of the mouth of Granite Creek dip about 50°–60° west and, within a few tens of meters, bend into sills in the bedded, 35°-dipping volcaniclastic section. A well-exposed 6-m-wide dike cutting the vitric dacite breccia northeast of Holdaway Butte dips only 60°–70° east-southeast, as indicated by direct measurements and by its map pattern. Southward projection of the dike at this dip across spotty exposures in dense slide alder meets a dike east of Holdaway Butte with a similar dip. The map pattern suggests that this dike maintains its eastward inclination for at least 1.5 km of strike length.

A wide, dike-on-dike composite body of hornblende diorite underlies McCoy Peak. The body is portrayed on plate 1 as a simple intrusion, but in reality it could be mapped as scores of dikes. I show only the most obvious dikes that form linear ridges near the summit. No internal screens of wallrock were found within the main body of the intrusion. Contacts with the host rock, and between dikes themselves, are subvertical. Internal jointing commonly crosses dike contacts and indicates that most or all of the body must have cooled together below the jointing temperature, rather than each dike cooling individually. Bedding in the country rock is upturned and even vertical in places along the northwest contact; such deformation implies forceful injection of a magma body wider than just a single dike. Moreover, the grain size is coarser than that of most dikes and compares to that of the sills. Consequently the McCoy Peak intrusion is apparently composite, formed by repeated injection of dikes that amalgamated into a single body, rose forcefully an unknown distance, and cooled as a unit.

Hornblende phenocrysts are typically fresh or only partly altered in dikes high on, and west of, Langille Ridge and in dikes east of McCoy Creek south of Jumbo Creek. In contrast, hornblende in dikes elsewhere in the quadrangle, most notably along Juniper Ridge, is typically altered mostly or completely to chlorite and carbonate. This pattern parallels that of propylitic alteration in the host rock, which is most intense in the Camp Creek-Juniper Ridge area. Owing to this alteration, the dikes on Juniper Ridge are not obviously hornblende bearing in the field, but thin sections reveal pseudomorphs of hornblende phenocrysts. Furthermore, the chemical compositions of these dikes (table 1, no. 49) and similar dikes within 2 km north of the quadrangle boundary (Swanson, 1991, table 1, nos. 65, 68, 74, 77, 86, and 90) are within the range of relatively fresh rocks of the intrusive suite, sharing the low contents of FeO*, TiO_2,

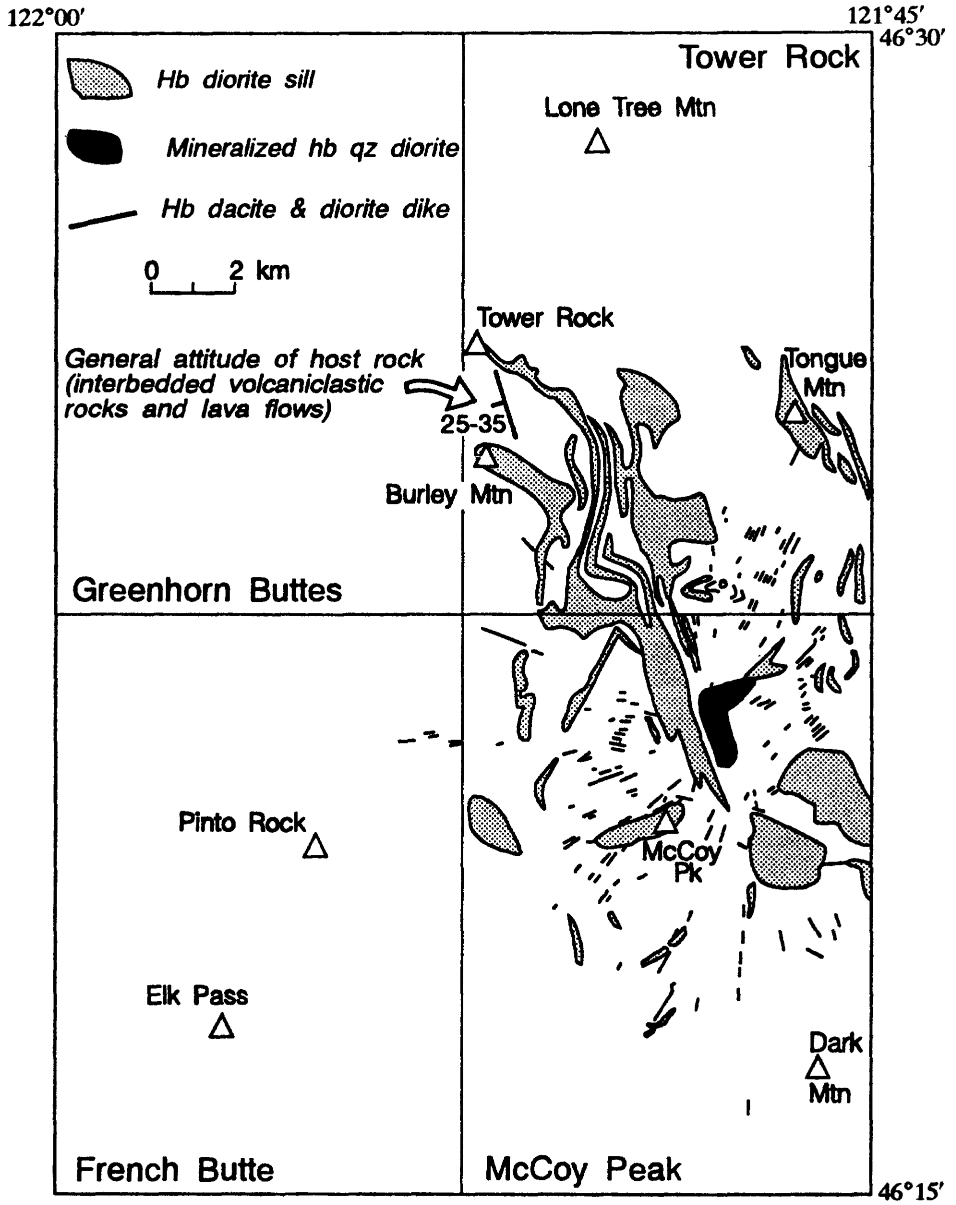


Figure 13. Generalized map showing distribution of intrusive suite of Kidd Creek in the four quadrangles indicated. Dikes radiate from mineralized McCoy Creek intrusion. Dikes occur preferentially in southwest and northeast quadrants, and sills in northwest and southeast quadrants.

and MnO that characterize the suite. For these reasons, the dikes in the Juniper Ridge area are included with the fresher dikes in the intrusive suite of Kidd Creek. The dikes along lower Sunrise Creek are especially highly altered, and their inclusion in the Kidd Creek is problematic; no samples were chemically analyzed, and petrographic examination found only suggestive but not definitive textural characteristics of the Kidd Creek suite.

The dikes as a whole form a radial pattern focused on the lower Camp Creek area (plate 1; fig. 13). Even if the dikes on Juniper Ridge are excluded, the radial pattern is obvious though missing its northeast sector. The radial pattern holds in the adjoining Tower Rock and French Butte quadrangles, although probably fewer than 60 dikes occur there. The map pattern of the swarm on the geologic maps (pl. 1; Swanson, 1991, pl. 1) is well defined and shows no evidence of post-emplacement tilting, which would have thrown the pattern into disarray. The pattern is therefore additional evidence that the dikes are younger than most or all of the tilting that characterizes the host rock. This pattern is further discussed in the section, "Relation of McCoy Creek intrusion to the radial dike and sill swarm."

Locally, dikes diverge from the radial pattern. North of Falls Creek, a small area contains dikes that strike northeast, oblique to the radial trend; these dikes may be related to the stocklike body along Jumbo Creek. A dike on Sunrise Peak and several along lower Sunrise Creek likewise fall outside the radial pattern and may have been fed from larger nearby intrusions. The east-striking dike in the headwaters of Jumbo Creek connects two larger intrusions and is probably related to them.

Sills—Sills of hornblende diorite and microdiorite are common in the volcaniclastic part of the section, as in the Tower Rock quadrangle (Swanson, 1991). The sills range in thickness from a few centimeters to more than 100 m. Single sills in the quadrangle have been traced for more than 2.5 km (the sill just west of Langille Peak), and composite bodies, for more than 3.5 km (the complex body between Langille Peak and McCoy Creek). In the Tower Rock quadrangle, single sills were traced along strike another 6 km, for a total strike length from north to south of more than 9.5 km. Sills underlie some of the highest peaks in the quadrangle: Juniper Peak, Sunrise Peak, and the unnamed peak a little over 5600 ft high just south of Jumbo Creek. Despite their prominence, however, the sills are not such dominant features of the landscape as they are in the Tower Rock quadrangle.

The sills have subplanar basal and upper contact zones that are quenched and roughly conformable with the bedding in the host rock. Local discordance is common, and along strike some sills locally cross bedding to follow higher or lower stratigraphic levels. Well-developed, even eye-catching columnar jointing typifies the sills. Commonly the columns are exactly perpendicular to the basal and upper contacts with the host rock, and their orientation can be used as a reliable indicator of the attitude of the sill if contacts are not exposed.

The thick bodies in the Sunrise Peak and Jumbo Creek areas are composite bodies made by repeated injections of magma in sill-like fashion. The thick body between Langille Peak and McCoy Creek is a similar composite sill and is especially striking. From the McCoy Creek road it appears to be bedded, but outcrop examination shows that the "bedding" is defined by sill contacts or planar joints normal to the columns.

Though sill-like, these composite bodies locally exhibit steep contacts with the wallrock. A good example is the southwest margin of the body along Jumbo Creek, where it contacts volcaniclastic rocks. Whether such steep contacts reflect only local cross-cutting of bedding or are more extensive at depth is not clear. I have portrayed the bodies in plate 2 as having concordant floors at depth, but this is speculative. What is beyond question is that at the level of exposure the bodies are fundamentally sill-like. The composite sills closely resemble those in the Tower Rock quadrangle, where the ends of some of the thicker sills are demonstrably cross-cutting but the overall geometry shows their fundamentally sill-like character (Swanson, 1991).

The south end of the body between Langille Peak and McCoy Creek is only schematically shown on plate 1. This area is poorly exposed, but traverses show repeated apparent interleaving of hornblende diorite and volcaniclastic rocks.

The thick body of hornblende microdiorite between Pinto and Yellowjacket Creeks is somewhat anomalous, because it is mostly in contact with lava flows rather than volcaniclastic rocks. Overall it appears sill-like on the basis of its map pattern and orientation of columnar jointing near its southeastern and northeastern margins, but the intrusion clearly crosses layering in the lava flows and so is partly stocklike. A few simple sills also occur mainly in lava flows; a prominent and well-exposed example is along the road just above the mouth of Martin Creek in the upper Yellowjacket Creek drainage (fig. 2; table 1, no. 56). A small, subequant, columnar-jointed intrusion across Yellowjacket Creek from there also intrudes lava flows; this is probably a cross-cutting body, although no definitive exposures were observed.

As in the Tower Rock quadrangle, the thicker bodies of hornblende diorite and microdiorite are more highly altered than are the thin sills and dikes, probably owing to alteration by circulating hot ground water during cooling.

The sills are younger than pyroxene andesite dikes that cut the section. For example road cuts and natural exposures a few hundred meters north of Martin Creek show a sill clearly cutting several dikes.

Relation of dikes and sills—Taken together, several observations in the McCoy Peak, Tower Rock, and French Butte quadrangles indicate that the dikes and sills are related to the same episode of magmatism. They have similar composition, mineral content, areal distribution, degree of alteration, age relative to the host rock, and probably age relative to folding. A few dikes cut a few sills, but in general the two are exclusive. Some dikes, such as those southwest of the mouth of Granite Creek, twist along strike into sills, and others along the margins of thick sills appear to blend into the sills as if they either fed or were fed by the sill.

An interesting dike-sill pattern is evident on a regional scale (fig. 13). Dikes are more common southwest and northeast of the Camp Creek area, and sills are more common southeast and especially northwest of that area. If the dikes and sills are genetically related, what accounts for this pattern?

I suggest that the regional structure of the well-bedded volcaniclastic host rock in the McCoy Peak and Tower Rock quadrangles controls the distribution of dikes and sills. The regional strike is north-northwest (mean direction is 344° for 431 measurements in the two quadrangles [fig. 12*D* and Swanson, 1991, fig. 10]), and the regional dip is 25°–35° west-southwest (fig. 13). Dikes intruded at high angles to the regional strike propagated outward from the center of the radial swarm and retained their subvertical attitude for long distances. In contrast, dikes initially intruded as subvertical sheets along the regional strike of the well-bedded volcaniclastic rocks eventually twisted into the bedding planes and became sills. Thus most of the sills can be viewed as shallow-dipping dikes that originated as members of the radial dike swarm.

The shallow-dipping dikes just southwest of the mouth of Granite Creek (see section on Dikes) may record the transition zone from dikes to sills. This area coincides with the generalized location of the transition zone inferred from map relations to be within a few hundred meters to perhaps 2 km from the focus of the radial swarm.

Even some dikes intruded *across* the regional strike may eventually have fed sills. A crude ring of sills encloses most of the dikes in the southwest and northeast quadrants of the radial swarm, some 4–7 km from the center of the swarm (fig. 13). No intersections of dikes and sills were seen in these areas, but an intriguing possibility is that the dikes may have ended as they turned into sills, perhaps as intrusion pressure diminished away from the center and magma stagnated at favorable bedding planes in the host rock.

A possible problem with the "radial sill swarm" hypothesis is that the volume of the sills is vastly greater than that of the dikes. Why, therefore, should the dikes and sills be considered equivalents? If the dikes are viewed as conduits, and the sills as reservoirs, then dikes could have transported a far larger volume of magma into the sills than can be accounted for by their narrow width. Also, some of the dikes could have supplied large volumes to eruptive vents on the ground surface, all evidence for which has been removed by erosion, whereas the sills stored magma without losing it to eruptions.

Far more sills occur in the northwest quadrant of the radial swarm than in the southeast quadrant. Perhaps this reflects the nature of the host rock, which consists chiefly of volcaniclastic rocks in the northwest quadrant and andesite flows in the southeast quadrant (plate 1; Swanson, 1991). Intrusion may have been favored into the volcaniclastic section. Perhaps, too, sills are abundant in the southeast quadrant below the level of exposure, if volcaniclastic rocks underlie the exposed lava flows there. More on this issue should be learned after mapping in the East Canyon Ridge quadrangle, scheduled for summer 1992.

Hornblende quartz diorite and granodiorite of McCoy Creek—This body (unit Thdm in plate 1) forms the core of the McCoy Creek district described by Link (1985). Much of it is in the phyllic and propylitic zones of a porphyry copper-molybdenum deposit with associated small gold-bearing veins. Link (1985) describes the deposit and alteration products in detail, and I concentrate here on placing the host intrusion in the geologic framework developed for the McCoy Peak and adjoining quadrangles.

Geometry of body—The intrusion has a boomerang shape in outcrop, about 2.2 km by 1.7 km maximum dimensions. These values differ from those given by Link (1985), whose map shows a much different distribution pattern partly controlled by faulting that I cannot confirm.

Link (1985) reports that drill-core data suggest that the intrusion, which he and Simon (1972) call a stock, dips steeply southwest. Such an attitude is consistent with a broadly sill-like form for the intrusion, following the regional west-southwest dip of 25°–35°. The outcrop pattern is also broadly compatible with such a geometry, or at least with a body whose top dips in accord with the bedding. In this interpretation, the exposures east of McCoy Creek are along a dip slope developed near the top of the intrusion, and the disappearance of the body along McCoy Creek is caused by the dip, not by a fault along the creek as suggested by Link (1985). The map pattern along the southeastern contact of the intrusion could be interpreted to indicate a steep margin, but exposures are poor between creeks and the contact could easily "vee" down the ridges from points where it crosses creeks.

Link (1985) mapped intrusive breccia discontinuously along the eastern margin of the intrusion. I was unable to confirm this identification but did find highly altered lithic-lapilli tuff in many places near the contact.

The intrusion is coarsely platy along Small Creek (fig. 2; called Eagle Creek by Link, 1985). The attitude of the platy joints is similar to that of the host rock (pl. 1). Platy joints paralleling contacts are common in sills of the Kidd Creek intrusive suite. This is weak evidence for a sill-like form for the McCoy Creek intrusion, or at least a top roughly concordant with bedding.

Evidence relating the McCoy Creek intrusion and the Kidd Creek intrusive suite—Several lines of evidence suggest that the McCoy Creek intrusion is related to the Kidd Creek intrusive suite. Field relations show an apparent gradation between the two units in upper Camp Creek. The contact between the two units shown on plate 1 is drawn simply at about the point above which hornblende pseudomorphs become evident in the field and phyllic alteration is absent. Nearly continuous exposures along the creek allow the gradation to be seen almost completely.

The body is at the focus of the radial dike swarm and may have a sill-like form, as do many of the Kidd Creek intrusions. This evidence is unconvincing but suggestive of a tie between the two.

The Kidd Creek dikes and sills and the McCoy Creek intrusion are the only hornblende-bearing intrusive suites in the five quadrangles mapped and are unlike any rock found by other workers in adjacent areas. This evidence is circumstantial but suggestive of a genetic tie.

Comparison of chemical compositions is an obvious way to test whether the two units could be equivalent. Given the distinctive composition of the Kidd Creek suite, chemical identity with the McCoy Creek intrusion would strongly imply genetic correlation. A meaningful comparison is not easy to make, however, owing to the possible effects of sulfide mineralization on the McCoy Creek body, particularly the addition of iron as pyrite. Nonetheless, the two analyses of the McCoy Creek intrusion (table 1, nos. 48 and 61) have contents of TiO_2 and MnO similar to those of the Kidd Creek suite, and the FeO* content of no. 61 is also similar. Two samples do not make a convincing case for correlation, however.

To test further the possible chemical similarity, I examined data in Link's thesis (1985). He gives 11 chemical analyses of what I interpret to be the McCoy Creek intrusion (table 2, nos. 1L–5L, 8L–9L, 11L–12L, 23L, and 25L). They closely resemble his analyses of what I have mapped as intrusions of the Kidd Creek suite (table 2, nos. 7L, 10L, 13L–19L, 21L–22L, 24L, 27L–29L). This similarity argues strongly for correlation of the units.

A major problem exists, however, when comparing the analyses in table 2 with those in table 1. Contents of SiO_2, TiO_2, and FeO* are far higher in table 2. The difference reflects analytical bias between the two laboratories involved (Washington State University for table 2 and U.S. Geological Survey for table 1) rather than actual differences, as indicated by the following discussion.

The analytical bias is clear if the Kidd Creek analyses are compared. Table 1 shows that compositions of Kidd Creek rocks near the McCoy Creek area are no different than those farther away, and the analyses in table 2 should therefore resemble those of the Kidd Creek suite as a whole. However, the analyses in table 2 for rocks that I mapped as Kidd Creek are actually much higher in SiO_2, TiO_2, and FeO* (fig. 14). Linear regressions through the Kidd Creek data sets show that, for comparable amounts of SiO_2, the contents of TiO_2 and FeO* are higher by about 0.07 percent and 1 percent, respectively, for analyses in table 2 than for those in table 1. (In the following discussion, I reduced the bias for FeO* from 1 percent to 0.7 percent, because the regression through the data from table 2 was skewed by three outliers of such high FeO* content that I suspect iron in the form of sulfide was added to the three samples.) MnO, another key oxide for identification of the Kidd Creek suite, may be higher by about 0.03 percent in the analyses of table 2.

I adjusted the analyses of the McCoy Creek intrusion in table 2 by the bias indicated by the regression in figure 14 and then compared them with the Kidd Creek and McCoy Creek analyses from table 1 (fig. 15). The data are "noisy" but show in general that the two units fall along a similar trend.

The chief "culprit" in causing the bias may be SiO_2. If the content of SiO_2 is reduced about 2 weight percent in the analyses of table 2, most of the other differences can be accounted for. This is a very large difference not easily explained. Conrey (1991, p. 162) found that analyses done in the same laboratory since Link's work are consistently high in SiO_2 relative to values obtained in other laboratories, but by only about 0.45 weight percent; he attributes the difference to the ways in which the fused beads for XRF analysis are prepared and corrected for matrix effects.

Whatever the reason, the analytical data in tables 1 and 3 clearly show biases that tend to obscure the chemical resemblance between the Kidd Creek intrusive suite and the McCoy Creek intrusion. When the biases are accounted for, the resemblance is clear, and this resemblance is further suggested by the internally consistent data in table 1 alone.

Relation of McCoy Creek intrusion to the radial dike and sill swarm—The McCoy Creek intrusion is at the overall focus of the radial swarm of dikes and sills. Its composition is indistinguishable from that of the dikes and sills, and it seems to grade upward and(or) outward into at least one of the sills. Its alteration and mineralization indicate a site of extensive hydrothermal activity. Taken together, these relations imply that the intrusion occupies the core of a subvolcanic complex that injected magma into radial dikes and sills and that probably underlay a volcano, now completely eroded away. This conclusion is consistent with that of Link (1985, p. *v*), who wrote "comparison of

Table 2. Chemical analyses from Link (1985), with all iron as FeO* and normalized to 100 percent

Sample No.[1]	Map unit[2]	SiO_2	TiO_2	Al_2O_3	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Na_2O+ K_2O	FeO*/MgO
1L	Thdm	66.42	0.76	17.33	5.52	0.03	1.88	4.44	3.08	0.37	0.18	3.45	2.94
2L	Thdm	67.44	0.63	16.91	4.74	0.02	1.74	4.28	3.18	0.90	0.15	4.08	2.72
3L	Thdm	66.67	0.73	17.26	5.33	0.01	1.83	4.25	2.86	0.88	0.17	3.74	2.91
4L	Thdm	67.41	0.73	17.25	4.45	0.00	1.70	4.12	3.12	1.07	0.15	4.19	2.61
5L	Thdm[3]	69.58	0.56	16.22	4.00	0.02	1.43	4.41	3.12	0.52	0.14	3.64	2.79
6L	Thd	67.63	0.68	16.57	4.33	0.17	1.87	4.59	2.66	1.33	0.17	3.99	2.31
7L	Thd	65.00	0.80	17.60	5.49	0.15	1.92	4.59	3.12	1.15	0.18	4.27	2.87
8L	Thdm[3]	66.73	0.77	17.66	4.10	0.01	2.10	5.00	2.85	0.60	0.18	3.45	1.95
9L	Thdm[3]	66.46	0.66	17.12	4.80	0.01	1.69	4.92	3.21	0.96	0.16	4.17	2.83
10L	Thd	66.38	0.84	17.12	6.24	0.08	2.31	2.18	0.54	4.09	0.22	4.63	2.70
11L	Thdm	64.78	0.79	17.57	5.55	0.13	1.91	4.34	4.13	0.60	0.19	4.73	2.90
12L	Thdm	65.68	0.74	17.30	6.36	0.04	2.29	4.26	2.37	0.79	0.17	3.16	2.78
13L	Thd	66.52	0.67	17.09	4.51	0.08	1.62	4.65	3.42	1.28	0.16	4.70	2.78
14L	Thd	70.31	0.60	16.95	4.14	0.12	1.47	2.05	2.51	1.71	0.13	4.22	2.81
15L	Thd	65.62	0.71	17.16	7.06	0.09	1.83	3.30	2.38	1.66	0.19	4.03	3.87
16L	Thd	64.65	0.77	17.11	5.35	0.15	2.10	6.03	3.29	0.37	0.18	3.66	2.56
17L	Thd	66.02	0.72	16.89	4.96	0.10	1.65	5.08	3.27	1.12	0.18	4.39	3.00
18L	Thd?[4]	66.02	0.74	17.01	5.08	0.09	1.72	4.30	3.75	1.12	0.17	4.87	2.95
19L	Thd	64.10	0.92	17.02	6.24	0.10	2.90	3.97	3.29	1.16	0.30	4.45	2.15
20L	Ta	55.22	1.52	16.61	9.97	0.15	4.46	8.43	2.75	0.64	0.25	3.40	2.23
21L	Thd	66.69	0.68	16.34	5.02	0.09	2.16	4.21	3.42	1.22	0.17	4.64	2.33
22L	Thd	65.77	0.70	16.97	4.99	0.09	1.81	5.79	3.22	0.47	0.18	3.69	2.75
23L	Thdm[3]	65.66	0.61	16.80	4.68	0.10	2.16	5.36	3.11	1.35	0.16	4.46	2.16
24L	Thd	64.69	0.71	17.05	4.94	0.09	2.37	5.70	3.06	1.23	0.16	4.29	2.09
25L	Thdm[3]	63.90	0.75	17.44	5.39	0.12	2.34	6.19	2.59	1.10	0.19	3.69	2.31
26L	Ttv	56.70	1.29	18.97	10.34	0.19	2.87	5.96	2.65	0.92	0.10	3.58	3.60
27L	Thd	65.25	0.76	16.92	5.15	0.09	1.97	5.22	3.62	0.83	0.18	4.45	2.61
28L	Thd[5]	67.46	0.74	16.82	4.94	0.10	1.64	3.31	3.25	1.52	0.21	4.77	3.01
29L	Thd	66.39	0.64	16.56	4.51	0.09	1.81	5.49	3.09	1.25	0.17	4.34	2.49
30L	Ta	56.44	1.24	18.24	8.44	0.14	3.03	8.36	2.96	0.89	0.24	3.86	2.78

[1]*Samples are numbered consecutively as listed by Link (1985, tables A1 and A2); for example, 1L is same as Link's Stock 1, 10L is same as Dike Rock 1, and 30L is same as Ohp. Flow d*

[2]*Unit assignment is interpreted from my map on basis of locations shown on Link's plate 3 (augmented and corrected by John Link (written commun., 1992)*

[3]*In drill hole at following depths: 5L, -254 ft; 8L, -342 ft; 9L, -319 ft; 23L, -129 ft; 25L, -122.5 ft*

[4]*Along McCoy Peak trail south of Link's (1985) map area, at uncertain location not shown on map*

[5]*Must be block of unit Thd in landslide*

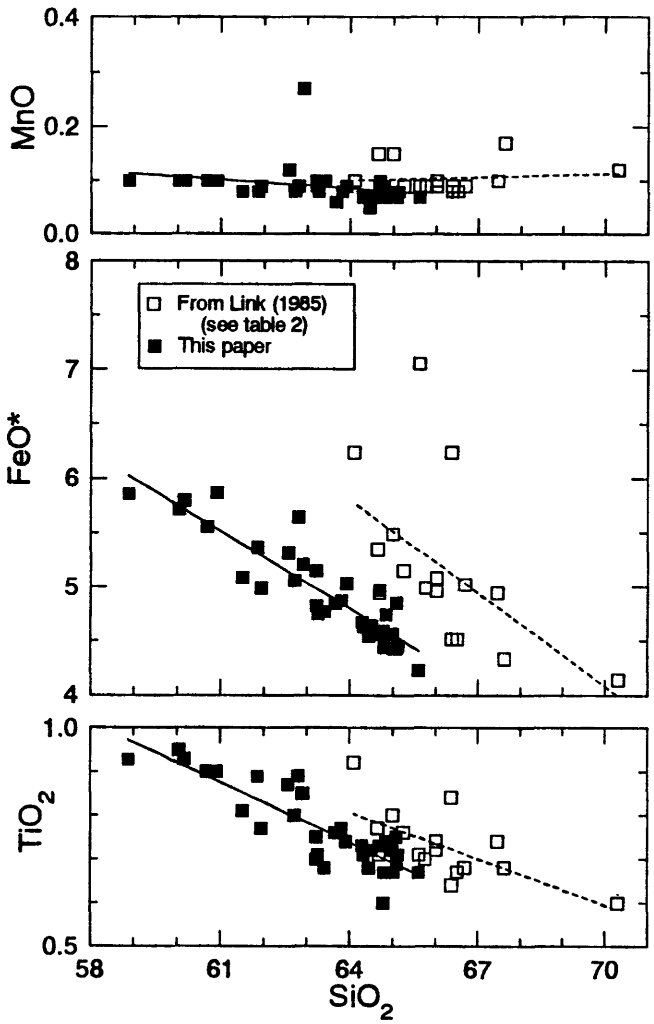


Figure 14. Comparison of analyses made in two laboratories (open symbol, Washington State University; closed, U.S. Geological Survey) for samples of Kidd Creek intrusive suite in McCoy Peak quadrangle. Note higher SiO_2 values for data in Link (1985; table 2 of this paper) than in those of table 1, and higher values of TiO_2, FeO*, and marginally of MnO at constant SiO_2. Linear regressions through both data sets shown. Approximate difference in regressions was used to adjust data in table 2 for plot in figure 15 (see text).

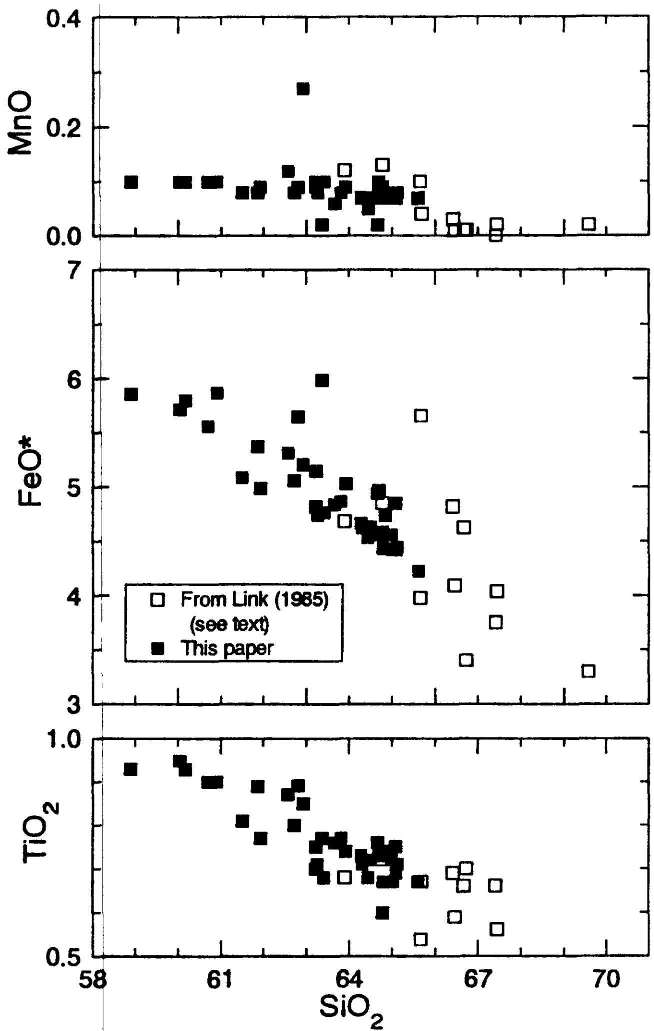


Figure 15. Comparison of analyses for McCoy Creek intrusion given in table 2, adjusted on basis of figure 14, with analyses of Kidd Creek intrusive suite and McCoy Creek intrusion given in table 1. No distinction can be made between the McCoy Creek and Kidd Creek compositions.

the rocks, mineralization, and alteration patterns of the McCoy Creek District with those found in porphyry-type systems in other tectonic environments suggests that the McCoy Creek pluton was emplaced into an island arc-type environment inboard from an active subduction zone."

The depth of the subvolcanic intrusive complex below the contemporary ground surface cannot readily be judged. Quenched margins and porphyritic textures indicate a shallow crustal level, as does the zeolite-facies metamorphism of the host rock. The widespread hydrothermal alteration and mineralization suggest extensive interaction with circulating ground water and hence a depth of no more than a few kilometers. A minimum depth of emplacement is simply the amount of present topographic relief, about 1 km. The stratigraphic thickness of about 3 km between the top of the intrusion and the top of the highest sill in the section farther west cannot be used as to estimate a minimum depth; the Kidd Creek suite apparently postdates most if not all of the folding in the area, and the section cannot simply be stacked above the Camp Creek area owing to the possibility of substantial erosion of the tilted rocks before intrusion of the Kidd Creek magma (see section on Structure, and also Swanson [1991]). Most likely the depth was 2–5 km.

Evidence presented in the section, "Geometry of body," suggests that the McCoy Creek intrusion has a broadly sill-like character, or at least an upper surface approximately concordant with the regional dip. However, that form does not readily square with the concept of a subvolcanic intrusion at the center of a large radial dike swarm. Perhaps the body is truly stocklike at depth, or perhaps it was emplaced as a sill above a small stock. Or, perhaps the magma-conduit system in the subvolcanic complex consisted of a stacked nest of sills, one of which is now exposed. The body is shown in plate 2 as a sill-like mass connected to a vertical feeding conduit from which other sills sprout; this form is reasonable in terms of current models of subvolcanic feeder systems beneath arc volcanoes. In reality, however, I believe that the true form of the McCoy Creek intrusion is open to considerable speculation.

Field evidence suggests that the McCoy Creek intrusion is somewhat older than some of the dikes and sills in the radial complex. A dike of propylitized, pyrite-bearing hornblende microdiorite cuts stockwork phyllic veining in the McCoy Creek intrusion in a roadcut 500 m south of the crossing of Camp Creek. This relation, pointed out by Roger Ashley and Russ Evarts, indicates that the dike is younger than the stockwork but older than some of the alteration and mineralization. Another possible dike, or younger phase of the intrusion, consists of unusually fresh quartz-bearing diorite containing relic hornblende in a road cut at the site of chemical analysis 12L (table 2). I interpret this body as part of the McCoy Creek intrusion owing to its outcrop width (at least 10 m) and lack of chilled margins or steep planar structures suggestive of a dike; Link (1985), however, interprets the body as a dike cutting the McCoy Creek intrusion. Both interpretations support the conclusion that intrusion, propylitic alteration, and mineralization and accompanying phyllic alteration overlapped in time—a reasonable consequence of repeated injections of magma at a long-lived magmatic center.

The mineralized joints in the hornfelsed wallrock of the McCoy Creek intrusion have dominantly northwest strikes similar to the regional strike of the tilted section (Simon, 1972, p. 24 and fig. 10). This similarity suggests that the mineralization follows joints that formed during folding and supports the interpretation that the Kidd Creek intrusive suite is mostly or wholly younger than the folding.

Age of intrusive suite of Kidd Creek—No reliable K-Ar ages are available for the Kidd Creek suite. Four ages of hornblende separates range from 15 to 25 Ma (Swanson, 1991, tables 2 and 3). On the other hand, three zircon fission-track ages, obtained on three of the four samples used for K-Ar determinations, have a much more restricted (and younger) range from 10.4 to 13.4 Ma (Swanson, 1991, tables 2 and 3). One of the samples dated by both methods is from a roadcut just south of Martin Creek along upper Yellowjacket Creek (table 3). Two zircon fission-track ages are pending, both for the McCoy Creek intrusion.

Armstrong and others (1976) obtained an age of 25.6 ± 0.9 Ma (corrected for new decay constants using the method of Dalrymple [1979]) for a "very fine-grained sericite concentrate" from the McCoy Creek intrusion. I cannot satisfactorily rationalize this age with the geologic relations or with the zircon fission-track ages. If the sericite age is correct, then the McCoy Creek intrusion cannot be related to the Kidd Creek intrusive suite, which elsewhere cuts rocks much younger than the sericite age, and the focus of the radial dike swarm on the Camp Creek area would have to be purely fortuitous. I cannot disprove the sericite age but believe the weight of the evidence supports a much younger age for the McCoy Creek intrusion.

STRUCTURE

Folds—The west-southwest-dipping section of late Oligocene and early Miocene rocks in the McCoy Peak quadrangle is on the east limb of the broad Pole Patch syncline, which, together with its possibly *en echelon* segment, the Elk Creek syncline (Swanson, 1989), dominates the structure of the French Butte, Greenhorn Buttes, Tower Rock, and McCoy Peak quadrangles. The trough of the Pole Patch syncline is just inside the French Butte quadrangle. The section exposed in the McCoy Peak quadrangle is about 5 km thick (pl. 2, B-B′), similar to that in the Tower Rock quadrangle; the east limb extends an unknown distance east of the quadrangle.

The strikes are relatively consistent (fig. 11D), and dips are generally 25°–35°. Attitudes are more variable than those in the other mapped quadrangles, however, owing at least in part to the presence of vent areas in the southern half of the quadrangle. The mean strike of about 342° is close to that of 346° for 225 readings in the Tower Rock quadrangle (Swanson, 1991) but somewhat more westerly than the mean of 357° for 183 measurements in the Greenhorn Buttes and French Butte quadrangles (Swanson, 1989). Overall the data from the four quadrangles illustrate the broadly consistent trend of the Pole Patch syncline and show that the syncline has a low plunge, if any.

Table 3. Radiometric ages from the McCoy Peak quadrangle

Map	Sample No.	Reference	Unit	Method[2]	K_2O (ave.)	^{40}Ar, mol/g	^{40}Ar, %[3]	Age, Ma
1A (56)	DS85-51	This paper[4]	Thd	K-Ar (HB)	0.237	5.279×10^{-12}	7.4	15.4 ± 1.3
Do	do	do[5]	do.	FT (zircon)	—	—	—	13.4 ± 1.3

[1]Map number, with number of corresponding chemical analysis in parentheses (table 1)
[2]K-Ar, potassium-argon; FT, fission track; HB, hornblende; WR, whole rock
[3]Percent radiogenic argon relative to total argon
[4]Hornblende K-Ar determinations by Robert J. Miller, U.S. Geological Survey, Menlo Park
[5]Zircon FT determination by Joseph A. Vance, University of Washington, Seattle

Most or all of the folding took place before intrusion of the suite of hornblende-bearing sills and dikes as indicated by the geometric relations of the dikes to tilted beds (see section on "Dikes"), the radial pattern of the dike swarm, and the orientation of mineralized joints associated with the McCoy Creek intrusion.

A shallow, west-northwest-trending syncline is defined by several attitudes in volcaniclastic rocks underlying Hat Rock. No other fold subsidiary to the Pole Patch structure is evident in the quadrangle.

Faults—No faults with demonstrably large displacement have been identified in the quadrangle, but several exposures show evidence of fault movement that could conceivably be part of larger but overlooked structures.

A low-angle fault is well exposed along the west side of Yellowjacket Creek about 800 m upstream from the mouth of Veta Creek (fig. 2). The fault plane, about 1 m above late-summer water level, has a shallow but variable dip that averages approximately horizontal. Gouge rests on the polished surface of the footwall, which is coarsely grooved along an azimuth of 300°. Asymmetric roughness on the fault plane suggests that the hanging wall moved westward, that is toward 300°. A dike of hornblende microdiorite cuts the fault and is therefore younger. The dike does not crop out in the well-exposed bed of the creek or east of the creek, however, and so the dike may be offset by another strand of the fault. A thin sill injected from the dike may be displaced 50–70 cm by another low-angle fault, although the apparent offset could be a primary irregularity along the margin of the sill. A thrust fault is exposed in this same zone but 10–20 m farther south. The thrust has a strike of 010°, a dip of 27°W, and cuts sandstone containing a piece of fossil wood offset about 1.5 m along the fault. The fine-grained, well-bedded volcanic sandstone, siltstone, and tuff strike north and dip steeply west at angles of 70° and more; probably the steep dip is related to the faulting.

Another low-angle fault crops out along a small tributary to Yellowjacket Creek about 2 km west-northwest of McCoy Peak. This fault has an undulatory plane with an overall northeast strike and a 15° south dip. Slickensides and accompanying asymmetric roughness on the fault plane indicate a normal sense of displacement. The magnitude of displacement is not discernible; the offset shown on plate 1 is highly interpretative. Several changes in lithology take place between the site of the fault and colluvial cover farther downstream, though contacts are not clearly exposed, and knots of bull quartz are common in the rocks; faults and hydrothermal fluids moving along them could account for these features.

Most other faults or shear zones in the quadrangle have dips generally greater than 70° and a wide range in strikes. One fault striking northwest about 600 m west of the mouth of Badger Creek offsets a red flow top about 3 m in a reverse sense. A northwest-striking fault dipping 83°SW cuts the andesite intrusive complex south of Slide Creek (fig. 2) in McCoy Creek valley; slickensides plunge steeply down the dip. About 700 m farther southeast, a nearly vertical west-striking fault slightly offsets the contact between breccia and an overlying flow in a north-down sense.

Simon (1972) mapped faults along parts of Camp, Scamp, and Jumbo Creeks, and Link (1985), Korosec (1987), and Walsh and others (1987) added faults along McCoy and Small Creeks. I could find no convincing evidence for these faults but did map small shears and faults along the northern margin of the McCoy Creek intrusion just south of, and along, Camp Creek. One of these faults is exposed at 3300 ft elevation at the Rust Adit (Link, 1985), where it is mineralized; the fault strikes about 030° and has a nearly vertical dip. Another mapped fault or shear zone cuts bleached lithic-lapilli tuff at an elevation of about 3140 ft in the bed of Camp Creek, the locality mentioned by Link (1985) as exposing the Camp Creek fault; this fault or shear zone strikes north and dips

10°–20°W. No post-mineralization displacement was recognized. Neither of the mapped faults can be traced from these exposures, and I found nothing in the field relations that demand much offset along them. Nonetheless,these and other faults and shear zones mapped by previous workers may be important features guiding mineralization; they simply don't influence the geology sufficiently to show at the scale of my mapping.

Jumbo Creek zone—Steeply dipping, locally vertical, volcaniclastic beds crop out along two small tributaries of Jumbo Creek west-southwest of Sunrise Peak. No faulting or notable shearing was observed at the two localities, only the southeasternmost of which is indicated on plate 1 with attitude symbols. They lie along a west-northwest-trending zone that includes, along Sunrise Creek, a narrow zone of shearing and a nearby dike of hornblende microdiorite with an anomalous northwest strike. In the headwaters of Jumbo Creek, the zone occurs along an abrupt change in lithology and dip magnitude (pl. 1). Link (1985), Korosec (1987), and Walsh and others (1987) placed a fault in this zone, and I follow suit, though I am not convinced from the meager evidence that a major fault is required. An abrupt monoclinal bend could give rise to similar field relations. Perhaps the steep dips, whether or not accompanied by faulting, result from intrusion and thickening of a sill; this scenario is portrayed on cross section *C–C'* (pl. 2), which shows faulting of the host rock but not the sill. The south side of the structure is downthrown, because the lava flows south of the zone dip less than the underlying volcaniclastic rocks at a similar elevation north of the zone.

A northwestward projection of the Jumbo Creek zone passes through the area of low-angle faulting along Yellowjacket Creek 800 m south of Veta Creek. On Langille Ridge volcaniclastic rocks are dominant northeast of the projected zone and lava flows are dominant southwest. The projected zone climbs the ridge near the relatively abrupt south end of the thick sill complex just west of McCoy Creek. These observations suggest that the Jumbo Creek zone crosses Langille Ridge. No evidence of shearing or faulting was noted along the projected zone on Langille Ridge, however, and field relations do not demand faulting.

Viewed from east of the quadrangle, the part of the Jumbo Creek zone in the East Canyon Ridge quadrangle resembles an angular unconformity; gently dipping lava flows and associated breccia appear to overlie steeply dipping volcaniclastic rocks. The critical area to test this idea (in the East Canyon Ridge quadrangle) has not yet been mapped. I found no convincing evidence for an angular unconformity in the McCoy Peak quadrangle, and in fact the seemingly interbedded nature of the lava flows and volcaniclastic rocks along McCoy Creek south of the Jumbo Creek zone argues against an angular unconformity.

QUATERNARY BASALT AND BASALTIC ANDESITE

The only known vent for young lava flows in the quadrangle is in the extreme northeast corner, where a tuff cone that erupted the basalt of Juniper Creek (unit Qbj in plate 1; Swanson, 1991) straddles the border with the Tower Rock quadrangle. The vent for the basaltic andesite of Badger Ridge (unit Qbbr) lies just west of the quadrangle border (Swanson, 1989), and vents for tiny remnants of the olivine basalt of Basin Camp (unit Qbbc) and the flow just north of Falls Creek (unit Qbj, shown queried) have not been found.

All of the young olivine basalt flows in the quadrangle are rather rich in K_2O and MgO (table 1, nos. 1, 3, and 4) and contain scattered flakes of red-brown biotite in the groundmass (table 4, cols. 2, 4, and 5). They constitute part of a suite of high-K and generally biotite-bearing (table 4) basalt that is distributed within a southwest-trending zone between Blue Lake volcano (in the Blue Lake quadrangle) and the Basin Camp area; the zone includes a vent area for very K_2O-rich olivine-clinopyroxene-phyric basalt (about 2.2 percent K_2O at 49.8 percent SiO_2) and olivine-bearing basaltic andesite about 3 km south of Snagtooth Mountain in the Quartz Creek Butte quadrangle. The age of the basalt of Juniper Creek is probably about 140 ka or somewhat younger, because it erupted on the side of the U-shaped Cispus River valley—sculpted by a glacier during Hayden Creek time—and may have interacted with remnant ice in the valley (Swanson, 1991). Blue Lake volcano is probably of about the same age, because it too formed partly under or along the margin of the glacier (D.A. Swanson, unpublished mapping), but whether all of the K_2O-rich units are of similar age is not known.

The high-K_2O basalt is fine-grained and rather glassy; modal glass averages 35 volume percent for the six samples in which glass could be counted separately (table 4, cols. 3–8). Total olivine content varies inversely with glass content (fig. 16); this variation shows that olivine was crystallizing during emplacement and cooling of the flows. Probably existing phenocrysts served as nuclei for some of this crystallization, because the three highest contents of olivine phenocrysts occur in the three most crystalline samples (table 4, cols. 4–5 and 7). In contrast to the high-K_2O suite, the low-K_2O olivine basalt of Spring Creek, a late Pleistocene flow in the Cispus Valley (fig. 1) just east and northeast of the quadrangle, is much more crystalline, averaging 13.4 volume percent glass (range

Table 4. Modes of young olivine basalt in McCoy Peak and adjacent quadrangles (*MP, McCoy Peak; TR, Tower Rock; ECR, East Canyon Ridge; BL, Blue Lake*)

Quadrangle	MP	TR	MP	MP	ECR[1]	BL[2]	ECR[3]	MP	MP
Map Unit	Qbj	Qbj	Qbj?	Qbbc	—	—	—	QTob	QTob
Sample No.	90-78	89-73	90-23	90-51	85-29	87	88-45	87-82	91-102
No. Points	1000	1000	1000	1000	1000	1011	1000	2000	1000
Phenocrysts									
Olivine	6.5	3.3	7.1	10.7	5.3	6.1	5.0	8.0	8.5
Groundmass									
Olivine	2.4	6.8	5.9	3.8	3.6	6.8	2.6	0.9	1.7
Plagioclase	5.4	26.6	34.5	35.4	17.9	25.9	13.6	4.6	19.9
Clinopyroxene	2.5	23.3	24.2	25.0	19.0	20.5	19.9	0.6	6.9
Opaque	2.1	4.2	1.6	6.9	5.7	6.1	9.0	0.2	6.2
Glass	—	35.8	26.3	17.4	47.3	33.4	49.7	—	56.8
Matrix[4]	81.1	—	—	—	—	—	—	85.7	—
Biotite	tr	—	0.4	0.8	1.2	1.1	0.2	—	—
Quartz inclusion	tr	—	—	—	—	—	—	—	—
Total Olivine	8.9	10.1	13.0	14.5	8.9	12.9	7.6	8.9	10.2

[1]Upper Spud Hill vent, chemically similar to basalt of Juniper Creek

[2]Blue Lake volcano, chemically similar to basalt of Juniper Creek

[3]Lower Spud Hill vent, chemically similar to basalt of Juniper Creek

[4]Matrix is mixture of crystals and glass too fine to count

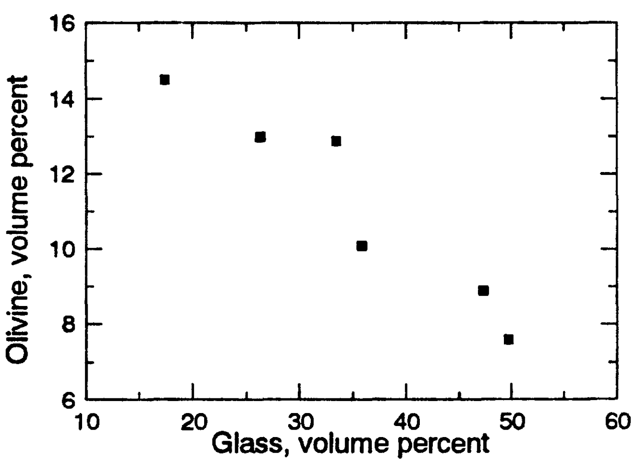


Figure 16. Plot of glass vs. total olivine contents for high-K_2O suite of late Pleistocene olivine basalt in McCoy Peak and adjacent quadrangles.

6.4–22.9) in six samples of the flow, and shows no systematic variation of olivine content (15.5 ± 2.3 volume percent) within the narrow range of crystallinity (Swanson, 1991, table 4, cols. 2–4 and 9–11).

The olivine basalt dike on the north face of Craggy Peak has decidedly less K_2O than do the olivine basalt flows in the quadrangle (table 1, no. 2); accordingly, it contains no biotite (table 4, col. 9). These differences indicate that it is not a feeder for the nearby basalt of Basin Camp. It is probably older than the basalt of Basin Camp, because deep erosion of Craggy Peak was required to expose the dike. Blocks of float in gully on west side of Craggy Peak are more crystalline than the dike on the north face of Craggy Peak but contain a similar amount of olivine phenocrysts (table 4, cols. 9 and 10); they probably record an unexposed extension of the dike.

The dike of basaltic andesite in Yellowjacket Creek valley is peculiar, because it has a low dip of only 60°–65° west. Its relation to the other young rocks in the region is unknown.

THICKNESS OF OLIGOCENE AND MIOCENE CRUST

Many chemical analyses of the Tertiary rocks have been obtained to support the detailed mapping of the four published quadrangles. The analyses are for rocks distributed throughout a section at least 5 km thick and spanning some 11.5 m.y. Examination of the entire data set indicates that a weak case can be made for a thinner crust during the late Oligocene and early Miocene than at present, and that the crust thickened during development of the mid-Tertiary section in southern Washington.

The FeO*/$Mg_{57.5}$ ratio of 2.76 for the Tertiary host rock in the McCoy Peak quadrangle, derived from figure 7 as earlier discussed, is rather high, just as it is in the Tower Rock quadrangle (Swanson, 1991). Gill (1981, p. 208) concluded that ratios greater than 2.5 "occur only at volcanic fronts, if at all, in volcanic arcs." The high ratios in the Tower Rock and McCoy Peak quadrangles are, strictly speaking, inconsistent with Gill's conclusion, for the volcanic front was probably located far west of the quadrangles during the Oligocene and early Miocene (Evarts and others, 1987; Walsh and others, 1987). However, Gill's conclusion is derived from his observation that such high FeO*/$Mg_{57.5}$ ratios reflect a crust that is less than 25 km thick (Gill, 1981, p. 208–216). Such a thickness is only about 55 percent that of the crust beneath the modern arc (44 km or more, as given in an oral presentation by Walter Mooney of the paper by Luetgert and others [1992]) and as such might seem in error. However, interpretation based on the work by Plank and Langmuir (1988) suggests that the Oligocene crust could indeed have been thinner than the present one.

In a world-wide survey of major-element chemistry of modern arc rocks, Plank and Langmuir (1988) found a linear relation between crustal thickness and the values of Na_2O and CaO (normalized to 6 percent MgO as $Na_{6.0}$ and $Ca_{6.0}$ respectively) in arc rocks resting on that crust (fig. 17). I determined the $Na_{6.0}$ and $Ca_{6.0}$ values for all of the Tertiary chemical analyses in the French Butte, Greenhorn Buttes, Tower Rock, and McCoy Peak quadrangles (except for the distinctly younger intrusive suite of Kidd Creek, which does not meet the screening criteria that Plank and Langmuir used, because no chemical analysis has >5.5 percent MgO). Those values, plotted in figure 17, suggest a crustal thickness of about 31±5 km (using an uncertainty of 5 km in crustal thickness, following Plank and Langmuir). Note that the $Na_{6.0}$ and $Ca_{6.0}$ values for the Quaternary rocks in the four quadrangles suggest much thicker crust, although that part of Plank and Langmuir's curve is relatively poorly defined (only two or three data points). In fact the calculated thickness is much too thick compared with the modern, seismically determined thickness of 40 km—a mismatch that illustrates a common problem when trying to interpret a specific situation in terms of a global average. Despite these uncertainties, a weak case can be made for a thinner crust during the late Oligocene and early Miocene than at present.

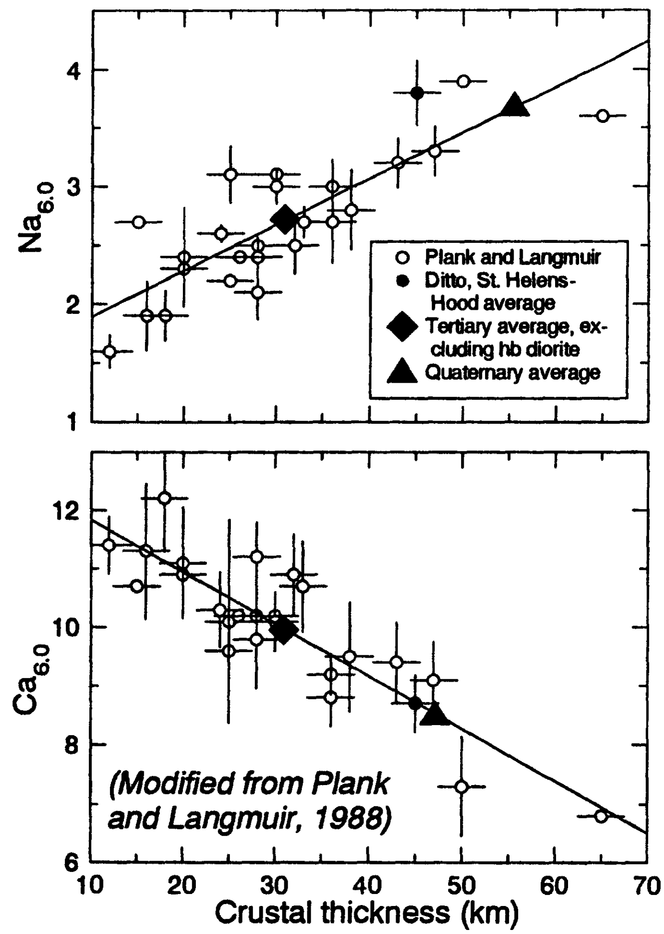


Figure 17. Plot of values of Na_2O and CaO at 6.0 percent MgO ($Na_{6.0}$ and $Ca_{6.0}$, respectively) vs. crustal thickness for suites of rocks from modern arc volcanoes, modified slightly from Plank and Langmuir (1988). Values of $Na_{6.0}$ and $Ca_{6.0}$ derived from linear regression of multiple analyses; values of crustal thickness based on seismic interpretations. Values of $Na_{6.0}$ and $Ca_{6.0}$ for middle Tertiary rocks (except intrusive suite of Kidd Creek and a few highly altered samples) and young lava flows that I have mapped are plotted along linear regression of data in Plank and Langmuir (1988). Note that apparent thickness of middle Tertiary crust is less than that of modern crust, but that apparent thickness of crust underlying young volcanic rocks (mostly late Pleistocene) is much greater than that indicated by modern seismic interpretations. See text.

Another equally crude comparison suggests that the crust thickened during the time that the rocks in the four mapped quadrangles were being erupted. In general the late Oligocene and early Miocene rocks decrease in age across the Tower Rock and McCoy Peak quadrangles into the central part of the Greenhorn Buttes and French Butte quadrangles, owing to their presence on the east flank of the Pole Patch syncline. A broad generality about arcs is that the proportion of calc-alkaline to tholeiitic rocks is thought to increase with increasing crustal thickness (Miyashiro, 1974; Gill, 1981; Coulon and Thorpe, 1981; Karig and Kay, 1981; Leeman, 1983). Examination of FeO*/MgO vs. SiO_2 plots (Swanson, 1989, fig. 11; Swanson, 1991, fig. 7; this paper, fig. 7) shows that the calc-alkaline series is represented by 35 percent of the analyses in the French Butte and Greenhorn Buttes quadrangles, where the rocks are younger, and 18 percent in the Tower Rock and McCoy Peak quadrangles, where the rocks are older. This pattern is consistent with thickening of the crust during the approximately 11.5 m.y. represented by the section. Furthermore, the roughly 12–Ma intrusive suite of Kidd Creek is decidedly calc-alkaline—even more so than most of the earlier Tertiary rocks—and might record still further crustal thickening. An important caveat to this reasoning is that in some arcs the tholeiitic and calc-alkaline series erupt side by side (Miller and others, 1992).

If the crust thickened during the 11.5–m.y. period, how much did it thicken? Simply on stratigraphic grounds the thickening could have been as much as 5 km, the amount of preserved section in the quadrangles (Swanson, 1991, this paper). Intrusions into the crust could also have caused thickening. Crisp (1984, p. 177 and 199) found that "the ratios of intrusive to extrusive volumes for intracontinental and island arc settings are between 4:1 and 16:1" and average about 10:1. This surprisingly high—and today still controversial—ratio would suggest a corresponding increase in crustal thickness owing to intrusion of sills of about 20 km, a value obtained by reducing the stratigraphic thickness by 60 percent to adjust for differences in specific gravity between intrusive and erupted rocks and multiplying by 10. The net crustal thickening of 25 km in only 11.5 m.y. is outrageous. The calculated amount of thickening would be much less if a large proportion of the intruded volume consisted of equidimensional bodies such as plutons rather than sills. How much less depends on the unknown ratio of sills to more equant bodies. In any case, Crisp's models suggest that the crust should thicken substantially by intrusion during active arc volcanism.

Another way to thicken the crust is by tectonism. The high electrical conductivity of the SWCC has been interpreted to reflect the presence of marine sedimentary rocks with saline pore fluids (Stanley and others, 1987), and the sedimentary rocks in turn have been interpreted as deposits of a forearc basin that was shoved eastward beneath the Cascades during subduction-related compression (Stanley and others, 1987). When the SWCC reached its present position is unclear. Possible thickening of the crust since the late Oligocene, and indeed between the late Oligocene and middle Miocene, is consistent with emplacement of the SWCC and with the broad folding along north-northwest-trending axes before intrusion of the Kidd Creek suite.

Comparison of the results of this study, which is limited to the quadrangles that I have mapped, with the pooled set of chemical analyses obtained by Russ Evarts and me for all of the quadrangles shown in figure 1 and others farther west, results in a different conclusion regarding thickening of the crust during the 35–18 m.y. period. Such pooling over a broad area does not show an increasingly large proportion of calc-alkaline rocks with decreasing age and hence does not support the interpretation of thickening crust with time. The discrepancy remains to be resolved between the limited but stratigraphically coherent data set on the east limb of the Pole Patch syncline and the pooled set that spans a longer period of time but also a much more widely distributed, less coherent stratigraphic section.

To summarize, the petrologic arguments allow no firm conclusions to be reached about changes in thickness of the crust. However, several independent though weak lines of evidence suggest that the crust thickened beneath the Cascade arc in southern Washington from late Oligocene to the present. At least some of this thickening reasonably took place between about 30 Ma and 18 Ma, the time during which the Tertiary volcanic rocks in the mapped quadrangles were forming; such thickening is suggested by the continuous section on the east flank of the Pole Patch syncline but is not suggested by a larger, more dispersed data set. Whether the thickening from the late Eocene to the present reflects deposition, intrusion, tectonism, or more likely a combination of all three cannot yet be read from the incomplete and confusing geologic record.

SURFICIAL DEPOSITS

Qal **Alluvium (Holocene and Pleistocene)**—Unconsolidated, moderately to well-sorted deposits of silt, sand, and gravel along major modern streams and on floors of some small cirques. Locally includes colluvium and drift

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

Qls **Landslide deposits (Holocene and Pleistocene)**—Diamictons produced by mass movement down slope. Includes both active and inactive slides. Generally results from movement of relatively dense and competent andesite and basalt lava flows or sills over clay-rich volcaniclastic rocks

Qhd **Hayden Creek Drift (Pleistocene)**—Till and outwash deposits containing numerous clasts with weathering rinds 1–2 mm thick in B soil horizon. Upper 0.5–1 m commonly deeply weathered. These features suggest correlation with Hayden Creek Drift (Crandell and Miller, 1974; Colman and Pierce, 1981). Age 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. Weathering-rind thickness not easily determined for many deposits in quadrangle, and some of these deposits could correlate with Evans Creek Drift, approximately 17–25 ka (Barnosky, 1984; Crandell, 1987)

BASALT AND BASALTIC ANDESITE FLOWS AND DIKES

Qbj **Basalt of Juniper Creek (Pleistocene)**—Aphyric to sparsely olivine-phyric, diktytaxitic olivine basalt forming tuff cone and associated thin flows in extreme northeastern corner of quadrangle. Characterized by high K_2O content (table 1, no. 3; Swanson, 1991, table 1, no. 10), and rare red-brown biotite in groundmass (table 4, col. 2). Contains rare small xenoliths of strained, corroded, multigranular quartz. Age not known but probably younger than Hayden Creek Drift in Cispus River valley east of quadrangle, because the flow mantles the side of a U-shaped valley eroded by a glacier in Hayden Creek time (Swanson, 1991). Possibly erupted during waning stage of Hayden Creek time, when retreating glacier still occupied Cispus River valley (see text). Degree of dissection indicates unit is older than basalt of Spring Creek (about 22 ka) along Cispus River (Swanson, 1991). Normal magnetic polarity. Map-unit symbol shown queried on north side of Falls Creek (fig. 2) west of Jumbo Peak, where concentration of angular blocks of aphyric to sparsely olivine-phyric basalt suggests presence of basalt beneath colluvium; included with unit Qbj because of presence of red-brown biotite (table 4, col. 4) and relatively high content of K_2O (table 1, no. 4), characteristics of unit Qbj farther north

Qbbc **Olivine basalt of Basin Camp (Pleistocene)**—Finely olivine-phyric basalt flow in small outcrop on ridge crest above trail north of Basin Camp (fig. 2) in southwest corner of quadrangle. Characterized by concave-upward joints whose strike is northeast, parallel to local trend of hillside; these joints suggest the flow followed a paleovalley parallel to the present ridge. Holocrystalline and intergranular, with locally flow-aligned plagioclase microlites. Contains scattered flakes of red-brown biotite (table 4, col. 5) and rather high contents of K_2O and MgO (table 1, no. 1), features typical of the basalt of Juniper Creek. This similarity weakly suggests an age similar to that of basalt of Juniper Creek. Normal magnetic polarity

QTob **Olivine basalt dike of Craggy Peak (Pleistocene or Pliocene)**—Vesicular dike 30 cm wide of finely olivine-phyric basalt cutting base of cliff at 5,000 ft elevation on north face of Craggy Peak. Glassy, with microlites of olivine, plagioclase, and clinopyroxene. Dike strikes

040° and is subvertical. Contains significantly less MgO and K_2O than do basalts of Juniper Creek and Basin Camp (table 1, no. 2). Angular blocks of similar basalt occur in gully just below trail on west side of Craggy Peak, along strike with dike, and suggest an unseen continuation of the dike (shown queried on map); no chemistry is yet available to check this interpretation, but the amount of olivine phenocrysts is similar to that of the dike (table 4, cols 9 and 10). Age uncertain but certainly no older than Pliocene, because freshness indicates that dike postdates burial metamorphism pervading host rock. Normal magnetic polarity

QTba **Basaltic andesite dike (Pleistocene or Pliocene)**—Fresh, vesicular dike of pale gray, sparsely clinopyroxene-phyric and glomerophyric basaltic andesite exposed in gullies above road along Yellowjacket Creek east of mouth of Pinto Creek in northwestern part of quadrangle. Map pattern indicates a general north strike, but trace is sinuous because dip is strangely low, 60°–65° west. Unusually wide, about 20 m, for dikes in Cascade Range. Vesicles are open and lined by cristobalite. Fresh groundmass glass between flow-aligned microlites of plagioclase. Phenocrysts are chiefly single crystals and clots of clinopyroxene but include rare orthopyroxene (especially as inclusions in sieved clinopyroxene) and an oxidized mafic mineral, probably olivine. Chemical composition (table 1, nos. 12 and 13) resembles that of samples collected by M. A. Korosec from basaltic andesite of Badger Ridge (table 1, no. 14; Korosec, 1987, table 2, unit Qvbd) but differs significantly from those of samples that I collected (Swanson, 1989, Table 1, nos. 12, 17, and 32). Petrographically unlike basalt of Badger Ridge. Probably older than Hayden Creek time but certainly no older than Pliocene, because freshness indicates that dike postdates burial metamorphism pervading host rock

Qbbr **Olivine-bearing basaltic andesite of Badger Ridge (Pleistocene)**—Olivine-bearing, aphyric or very sparsely porphyritic basaltic andesite and andesite erupted from eroded vent on Badger Ridge, 1 km west of quadrangle at lat 46°17'30". Contains fewer than 1 percent olivine and brown clinopyroxene phenocrysts mostly less than 1 mm in diameter. No plagioclase phenocrysts, except for rare highly zoned crystals 1–2 mm across. Light gray, sparkly appearance in field. Intergranular to intersertal texture, commonly with flow-aligned microlites that impart platy character to rock. Basaltic andesite and mafic andesite in composition (table 1, nos. 14 and 86; Swanson, 1989, table 1, nos. 12, 17, and 32). At least three flows were erupted, but only one found in quadrangle. Flows moved into and down ancestral Pinto Creek to its junction with Yellowjacket Creek. Normal magnetic polarity. Smooth glaciated surface. Whole-rock K-Ar age of 0.65 Ma (Swanson, 1989, table 3, no. 5A), courtesy of J. G. Smith

INTRUSIVE ROCKS

Thd **Hornblende diorite and related rocks (Miocene)**—Hornblende-clinopyroxene-plagioclase-phyric diorite, quartz diorite, dacite, and andesite forming sills, dikes, and irregularly shaped masses in northern two-thirds of quadrangle. Unit extends into French Butte and Tower Rock quadrangles (Swanson, 1991), as well as the Blue Lake and East Canyon Ridge quadrangles (D. A. Swanson, unpublished mapping), and forms the cogmagmatic "intrusive suite of Kidd Creek" of Marso and Swanson (1992). Grain size largely dependent on nature of body: andesite and dacite (rarely glassy) in dikes, thin sills, and chilled margins of larger bodies; and microdiorite and quartz microdiorite to diorite and quartz diorite in most sills and irregularly shaped masses. 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. Large body forming very steep area at north end of Badger Ridge contains only scattered small hornblende phenocrysts that are mostly resorbed or opacitized; body on Sunrise Peak is similar and contains quartz phenocrysts.

Quartz phenocrysts or xenocrysts, commonly partly resorbed, occur in other bodies, too, especially east of McCoy Creek. Groundmass quartz present in some diorite and plentiful in quartz diorite. Inclusions of variously textured diorite, and clots of hornblende and plagioclase, fairly common. Chemically the unit is mafic dacite and silicic andesite, with characteristically low TiO_2, FeO*, and MnO (table 1; fig. 12) compared to other rocks in quadrangle. In general much fresher than host rock, and hornblende is commonly unaltered. Alteration is more intense near Camp Creek and on Juniper Ridge (fig. 2), however, where hornblende is almost totally altered to clay, chlorite, and carbonate, and disseminated sulfide mineralization is common. Large pluglike and irregular bodies are commonly more highly altered than thinner dikes and sills. Age is about 12 Ma on basis of several zircon fission-track ages from within and near the quadrangle (table 2; Swanson, 1991, tables 3 and 4). Many dikes and sills radiate from mineralized area near Camp Creek and may be related to the hornblende quartz diorite and granodiorite of McCoy Creek (unit Thdm; Link, 1985)

Thdm **Hornblende quartz diorite and granodiorite of McCoy Creek (Link, 1985) (Miocene)**—Medium- to coarse-grained, equigranular to hornblende- and plagioclase-phyric (less commonly quartz-phyric), white to dark-gray, altered (mostly propylitic but in places phyllic), commonly mineralized sill-like (possibly stocklike) body forming core of McCoy Creek mining district between Camp and Scamp Creeks in northeastern part of quadrangle. Quartz common in groundmass. Remnant texture commonly obscured by alteration minerals, chiefly quartz, sericite, carbonate, epidote, iron-titanium oxides, and sulfide minerals (Link, 1985). Chemically similar to unit Thd in terms of relatively low TiO_2, FeO*, and MnO, but contains more silicic compositions and possibly averages granodiorite in character (Link, 1985; table 2, nos. 48 and 61; table 3). Field relations suggest gradation into unit Thd in upper Camp Creek; contact shown on map is arbitrary. Considered as genetically related to unit Thd, possibly solidifying from a slightly earlier pulse of magma in a subvolcanic setting. About 12 Ma on basis of zircon fission-track ages (table 2)

Tai **Andesite and basaltic andesite intrusions (Miocene and Oligocene)**—Dikes and small, less common, subequant hypabyssal intrusions of aphyric and one- or two-pyroxene-plagioclase-phyric andesite and basaltic andesite. Includes dikes of dacite composition that resemble andesite in the field and thin section (table 1, nos. 54, 73, and 79). Fine-grained and texturally resembles lava flows (unit Ta). Dikes characterized by horizontal columnar jointing, quenched margins, steep contacts with host rocks, and widths of 1–5 m. Dike of dacite composition (table 1, no. 79) along Quartz Creek in southeast corner of quadrangle is at least 8 m wide. Local concentrations of dikes in upper Slide Creek drainage (fig. 2) 1–2 km northwest of Dark Mountain and on east side of Langille Ridge 1–2 km northeast of Holdaway Butte suggest former intrusive centers. Most dikes in and south of the headwaters of Yellowjacket and McCoy Creeks trend roughly east, part of a regional set of dikes noted previously (Swanson, 1990), which is most prominent in the southern part of the French Butte (Swanson, 1989) and McCoy Peak quadrangles. Large body just east of Shark Rock is medium to coarse grained and complexly columnar as if constructed by several pulses of magma. Body just south of mouth of Slide Creek, exposed in road cuts, consists of many dikes and irregular intrusions as well as coarse breccia that might be screens of wallrock. Older than unit Thd everywhere that units are in contact. Typically more highly altered than unit Thd (except in mineralized Camp Creek area) and so is probably everywhere older. Probably in part feeders for flows of unit Ta, but many dikes could be younger and have fed flows now eroded away

Tdi **Diorite and quartz-bearing diorite (Miocene)**—Medium- to coarse-grained, dark, hypidiomorphic-granular diorite in several bodies within northeast-trending zone along upper Yellowjacket and Clear Creeks in southwest part of quadrangle. Interstitial quartz. Large body of unit Tai just east of Shark Rock could be fine-grained equivalent of this unit. In places mineralized and propylitically altered. Includes weakly mineralized quartz-bearing diorite or quartz diorite along creek (named Prospect Creek on some Forest Service maps) 1.5 km southeast of Point 5526 in northeast corner of quadrangle; this body lies along projection of northeast-trending zone in southwest part of quadrangle. Three of the four chemical analyses of unit are remarkably similar to one another (table 1, nos. 17, 19, 21); the fourth (table 1, no. 44) is more heavily mineralized, and its more silicic composition may reflect presence of secondary quartz

Tg **Gabbro (Miocene)**—Medium- to coarse-grained, dark, hypidiomorphic-granular pyroxene gabbro occurring in three small bodies along northwest-trending alignment in southwestern part of quadrangle, between headwaters of Straight Creek and upper Badger Creek. On Shark Rock, unit cuts main intrusion (andesite of Shark Rock, unit Tasr), as shown in dynamited trail cuts. Small amount of interstitial quartz, and long apatite needles in groundmass. Chemical composition is basalt to very mafic basaltic andesite (table 1, nos. 5, 6, and 85)

Tasr **Andesite of Shark Rock (Miocene)**—Dark, very fine-grained to glassy, very slightly porphyritic andesite intrusions in southwestern part of quadrangle between middle Badger Creek and 1 km north of Yellowjacket Pass. Conchoidal fracture surfaces. Groundmass typically is tachylytic, with tiny plagioclase microlites commonly flow aligned. Sparse phenocrysts of plagioclase, brown clinopyroxene, and rare orthopyroxene less than 0.5 mm diameter. Inclusions of similar andesite occur at Shark Rock itself. Contacts with older rocks not observed, and unit could be series of domes rather than intrusions. Chemical analyses (table 1, nos. 25, 33, and 35) indicate andesite and silicic andesite composition

LAVA FLOWS AND VOLCANICLASTIC ROCKS

Tbpr **Bedded breccia of Pinto Rock (Miocene)**—Lithic breccia, lapilli tuff, and tuff of andesite and basaltic andesite composition capping section in northwest corner of quadrangle. Widely exposed in adjoining French Butte and Greenhorn Buttes quadrangles (Swanson, 1989), where it is related to a north-trending vent complex best exposed in the prominent monolith, Pinto Rock

Ttv **Volcaniclastic rocks (Miocene and Oligocene)**—Lithic- and lesser pumice-lapilli tuff, fine-grained tuff, and bedded conglomerate, sandstone, siltstone, and lithic diamictite containing volcanic-derived clasts. Typically green but locally buff, white, or mauve. Different rock types interbedded at all scales, and attempts to map them separately proved unworkable. In general, however, lapilli tuff and tuff are most abundant in central and western parts of quadrangle (in the middle and upper part of the stratigraphic section) and epiclastic rocks are most abundant in the northeastern part of the quadrangle (lower part of section). Well-bedded, mostly epiclastic rocks are especially abundant on either side of Juniper Ridge and just south of Sunrise Peak.

Pumice- and pumice-lithic-lapilli tuff, common farther west in the Greenhorn Buttes and French Butte quadrangles (Swanson, 1989), is much less abundant in the McCoy Peak quadrangle, as also in the Tower Rock quadrangle (Swanson, 1991). It is probably of ash-flow origin. Welding occurs but is not common. One prominent basal vitrophyre of a welded tuff occurs in northwest corner of quadrangle (shown on plate 1) and more obviously in adjacent French Butte quadrangle. Columnar welded tuff occurs in the mineralized area of upper Yellowjacket Creek, along a small creek 350 m southeast of elevation check point 2837 and 1.3 km south of Martin Creek (fig. 2). Another welded(?) tuff is exposed in cut along Pinto Creek road just north of southern switchback above Yellowjacket Creek. 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. Two prominent exposures of quartz-phyric rhyolitic ash-flow tuff occur low in the McCoy Creek drainage, one in road cut at site of chemical analysis 82 and the other along the small creek just north of Falls Creek (fig. 2; analysis 83). The ash-flow tuff could not be traced laterally from either exposure. The two exposures may be in the same ash-flow tuff, because I have found no other quartz-phyric tuff in the quadrangle. Samples of the tuff near Falls Creek contain scattered small phenocrysts of brown biotite, however, whereas samples from the other site do not.

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 entirely of volcanic derivation, chiefly basaltic andesite and andesite but including dacite. Fössil 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. Probably mostly of debris-flow origin.

Steep dips in unit 1 km southwest of Jumbo Peak occur in welded andesitic spatter and agglutinate that define remnants of two or more cones, probably part of a vent complex that erupted nearby andesite flows of unit Ta.

Unit locally includes andesite flows too thin to map separately and a 4–5–m–wide dike of lithic-lapilli tuff on north side of Snagtooth Mountain

Ta **Andesite and basaltic andesite lava flows (Miocene and Oligocene)**—Fine- to medium-grained, highly phyric (>20 percent) to slightly phyric (<5 percent), darkly hued, lava flows and associated basal and flow-top breccia of andesite and basaltic andesite. 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-hyper- sthene and plagioclase-hypersthene-clinopyroxene. Rare phenocrysts of olivine (typically altered to clay). Groundmass texture chiefly fine-grained intersertal or intergranular, with flow-aligned microlites common; very fine-grained pilotaxitic texture characterizes more silicic rocks. Fresh glass uncommon; glass generally altered to clay minerals. Compositions range from mafic basaltic andesite to dacite (table 1). Dacite included in the unit resembles andesite in the field and generally in thin section and so was not mapped separately; it probably makes up less than 20 percent of the unit. In general basaltic andesite is more highly porphyritic than andesite, but exceptions are common. Andesite and basaltic andesite are interbedded and cannot be mapped separately short of analyzing each flow. Dikes and other intrusions of unit Tai probably fed some flows in this unit. Interbedded extensively with volcaniclastic rocks (unit Ttv) and includes some volcaniclastic beds too thin to map separately. Flows dominate section in southern two-thirds of quadrangle. Flows in Jumbo Peak-Dark Mountain-upper Quartz Creek area included in the "lava flows of Council Bluff" by Hammond (1980) and "volcanic rocks of Council Bluff" by Korosec (1987), which east and south of quadrangle have yielded whole-rock K-Ar ages of about 26 Ma (Laursen and Hammond, 1979; Phillips and others, 1986; summarized in Korosec, 1987, table 1, nos. 24 and 26). Thick piles of generally thin lava flows in this area, on Langille Ridge north of Holdaway Butte, and on ridge between Badger and Yellowjacket Creeks suggest local eruptive centers near there

Td **Dacite flows (Miocene and Oligocene)**—Aphyric to moderately plagioclase-phyric, commonly platy and prominently flow-layered, flows in four areas: upper French Creek, just southeast and northwest of McCoy Peak, 1.4 km northwest of Holdaway Butte, and high in section on Badger Ridge (fig. 2). Easily confused with andesite in field, and probably many other dacite flows have been included in unit Ta because their dacitic character went unrecognized in the field. For example, analysis 43 was obtained from a very thick prominent flow that looks like andesite but has a dacite composition. Even in thin section no distinction can be made between such dacite and andesite flows. Flows mapped as dacite (unit Td) generally have contorted flow layering that serves as guide to silicic composition. However, without chemical analyses even most of these flows would have been included in unit Ta

Tvdh **Vitric dacite breccia northeast of Holdaway Butte (Miocene and Oligocene)**—Vitroclastic breccia or hyaloclastite of sparsely and finely plagioclase- and clinopyroxene-phyric dacite. Clasts typically 1–5 cm in diameter but reach 2 m rarely; typically have quenched margins and shattered appearance. Perlitic cracks numerous. Most glass devitrified. Palagonitic matrix in places. Deposit is poorly sorted and crudely bedded with northwest strike and steep dips either southwest or northeast. At least 120 m thick, possibly because unit fills a valley, crater, or other depression. Margins unexposed, but body may grade outward into either nonglassy or hydrothermally altered glassy breccia. Crude bedding and divergent dips imply chaotic emplacement mechanism. Dacite composition (table 1, nos. 77–78)

Tbh **Hydroclastic breccia and lava flows of Hat Rock and Snagtooth Mountain (Miocene and Oligocene)**—Cliff-forming units of glassy, finely and sparsely plagioclase-phyric to aphyric and clastic debris and associated lava flows on Snagtooth Mountain and Hat Rock. Consists of one or more flows with hackly or finely columnar jointing, as in entablatures of some basalt flows. Water-quenched, and interlayered with or laterally gradational into dominant hydroclastic breccia consisting of angular glassy blocks resembling the flows. Pillow fragments and drained pillows in places in the breccia, but most clasts are simply quenched blocks. On southwest side of Hat Rock, and probably on northeast side, hydroclastic breccia fills a steep-walled gorge eroded in lithic-lapilli tuff; clasts of the tuff occur in the outer part of the breccia. Unit ranges from andesite (Snagtooth Mountain; table 1, no. 22) to dacite (Hat Rock; table 1, no. 60); this suggests that the two deposits are not products of same event. Presumably formed by quenching of lava flows by water in valley or crater

Tvb **Volcanic breccia (Oligocene)**— Coarse lithic-lapilli tuff, lithic breccia, and other diamictites surrounding Holdaway Butte and Craggy Peak and occurring 1 km northeast of Shark Rock. Also occurs just west of Shark Rock, at east end of thick deposit surrounding Kirk Rock in southeast corner of French Butte quadrangle (D. A. Swanson, unpublished mapping). Thickness is more than 500 m below Shark Rock and Craggy Peak and more than 350 m below Holdaway Butte. Typically unbedded and chaotic, with disrupted framework; local bedding is discontinuous and indistinct. Clasts are of many different types but entirely of volcanic origin. Clasts vary from less than 1 cm to more than 1 m in diameter and are typically angular to subangular. Locally intense propylitic alteration, especially in mineralized area northeast of Shark Rock. Margins arbitrary and uncertain; may grade outward into layered deposits, may be confined within craters, or may do both depending on geometry of body. Origin obscure but most likely some kind of crater or caldera fill. Could be early Miocene in age

Tr **Rhyolite flows (Oligocene)**— Sparsely and finely plagioclase-phyric, flow-layered, green to pink rhyolite flow and related(?) dike 1 km east-northeast of Snagtooth Mountain, and a similar flow in southwest corner of quadrangle. Flow layering is commonly swirled. Groundmass typically has snowflake texture and contains small quartz-feldspar devitrification patches. Chemical analysis of flow east of Snagtooth Mountain is high-SiO_2 rhyolite (77–78 percent SiO_2; table 1, no. 84)

REFERENCES CITED

Armstrong, R.L., Harakal, J.E., and Hollister, V.F., 1976, Age determinations of late Caenozoic porphyry copper deposits of the North American Cordillera: Transactions/Section B of the Institution of Mining and Metallurgy, v. 85, p. B239–B244.

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.

Conrey, R.M., 1991, Geology and petrology of the Mt. Jefferson area, High Cascade Range, Oregon: Pullman, Washington State University, Ph.D. dissertation, 357 p.

Coulon, C., and Thorp, R.S., 1981, Role of continental crust in petrogenesis of orogenic volcanic associations: Tectonophysics, v. 77, p. 79–93.

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.

Crisp, J.A., 1984, Rates of magma emplacement and volcanic output: Journal of Volcanology and Geothermal Research, v. 20, p. 177–211.

Dalrymple, G.B., 1979, Critical tables for conversion of K-Ar ages from old to new constants: Geology, v. 7, p. 558–560.

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.

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.

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.

Evarts, R.C., and Ashley, R.P., in press a, 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., in press b, 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 c, 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 d, 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., 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.

Fuller, R.E., 1931, The aqueous chilling of basaltic lava on the Columbia River Plateau: American Journal of Science, v. 21, p. 281–300.

Furnes, Harald, and Sturt, B.A., 1976, Beach/shallow marine hyaloclastite deposits and their geological significance—an example from Gran Canaria: Journal of Geology, v. 84, p. 439–453.

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

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

Hammond, P.E., 1987, Lone Butte and Crazy Hills: subglacial volcanic complexes, Cascade Range, Washington, *in* Hill, M.L, ed., Cordilleran Section of the Geological Society of America: Geological Society of America Centennial Field Guide, v. 1, p. 339–344.

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.

Jones, J.G., and Nelson, P.H.H., 1970, The flow of basalt lava from air into water—its structural expression and stratigraphic significance: Geological Magazine, v. 107, p. 13–19.

Kano, Kazuhiko, Takeuchi, Keiji, Yamamoto, Takahiro, and Hoshizumi, Hideo, 1991, Subaqueous rhyolite block lavas in the Miocene Ushikiri Formation, Shimane Peninsula, SW Japan: Journal of Volcanology and Geothermal Research, v. 46, p. 241–253.

Karig, D.E., and Kay, R.W., 1981, Fate of sediments on the descending plate at convergent margins: Philosophical Transactions of the Royal Society of London, series A, v. 301A, p. 233–251.

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.

Laursen, J.M., and Hammond, P.E., 1979, Summary of radiometric ages of Washington rocks, July 1972 through December 1976: Isochron/West, no. 24, p. 3–24.

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.

Leeman, W.P., 1983, The influence of crustal structure on compositions of subducted-related magmas: Journal of Volcanology and Geothermal Research, v. 18, p. 561–588.

Link, J.E., 1985, Gold and copper mineralization in the McCoy Creek district, Skamania County, Washington: Pullman, Washington State University, M.S. thesis, 164 p.

Luetgert, J., Mooney, W.D., Criley, E., Keller, G.R., Gridley, J., Miller, K., Trehu, A., Nabelek, J., Smithson, S.B., Humphreys, C., Christensen, N.I., Clowes, R., and Asudeh, I., 1992, Crustal velocity structure of the Pacific NW: the 1991 seismic refraction/wide-angle reflection experiment [abst.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 66.

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, D.M., Langmuir, C.H., Goldstein, S.L., and Franks, A.L., 1992, The importance of parental magma composition to calc-alkaline and tholeiitic evolution: evidence from Umnak Island in the Aleutians: Journal of Geophysical Research, v. 97, p. 321–343.

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

Mullineaux, D.R., 1986, Summary of pre–1980 tephra-fall deposits erupted from Mount St. Helens, Washington state, USA: Bulletin of Volcanology, v. 48, p. 17–26.

Palmer, A.R., 1983, The Decade of North American Geology 1983 geologic time scale: Geology, v. 11, p. 503–504.

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.

Plank, Terry, and Langmuir, C.H., 1988, An evaluation of the global variations in the major element chemistry of arc basalts: Earth and Planetary Science Letters, v. 90, p. 349–370.

Simon, R.S., 1972, Geology of the Camp Creek area, northern Skamania County, Washington: Seattle, University of Washington, M.S. thesis, 33 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.

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.

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

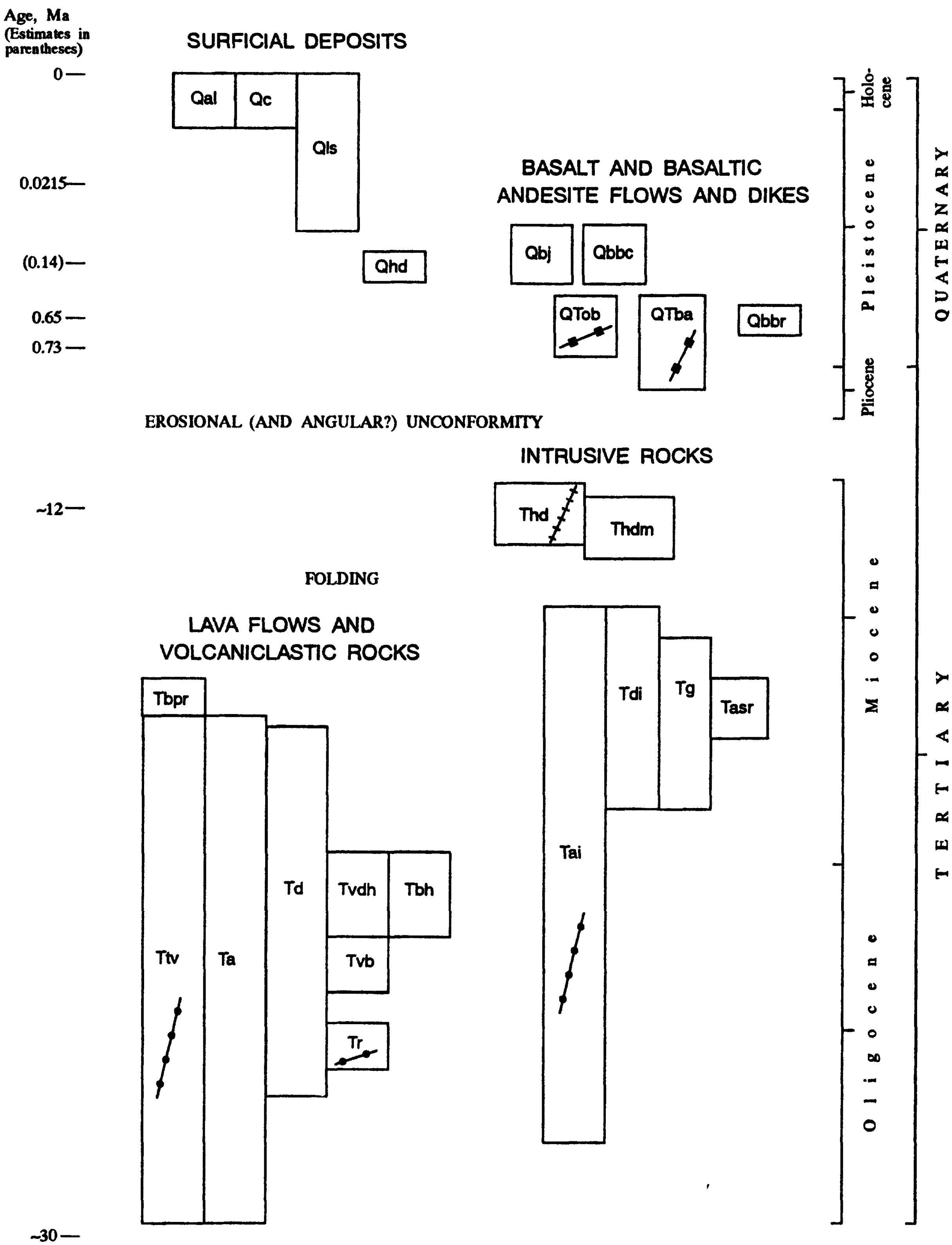
Swanson, D.A., 1991, Geologic map of the Tower Rock quadrangle, southern Cascade Range, Washington: U.S. Geological Survey Open-File Report 91–314, scale 1:24,000.

Swanson, D.A., and Evarts, R.C., 1992, Tertiary magmatism and tectonism in an E–W transect across the Cascade arc 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.

Walsh, T.J., Korosec, M.A., Phillips, W.M., Logan, R.L., and Schasse, H.W., 1987, Geologic map of Washington—southwest quadrant: Washington Division of Geology and Earth Resources, Geologic Map GM–34, scale 1:250,000.

CORRELATION OF MAP UNITS



EXPLANATION OF MAP SYMBOLS

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

Strike and dip of bedding and flow contacts

30 — Inclined

Vertical

Horizontal

16 — Attitude of prominent joint set in intrusive body

Trough of syncline. Shown only in south-central part of map near Hat Rock

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

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

40 — Direction and magnitude of dip of fault plane

Thrust fault; barbs on upper plate

Prominent basal vitrophyre of welded ash-flow tuff; queried where lateral extent uncertain

Dikes, queried where location uncertain

Olivine basalt and basaltic andesite of units Qob and QTba

Hornblende diorite and related rocks of unit Thd

Dike in unit Ta, except one dike of unit Ttv on Snagtooth Mountain

Area of sulfide mineralization

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

1 — Basalt

11 — Basaltic andesite

23 — Andesite

45 — Dacite

82 — Rhyodacite and rhyolite

5L — Site of chemically analyzed sample of Link (1985), with map number. See table 2

1A — Site of radiometrically dated sample, with map number. Number refers to table 3