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# Geologic maps of the French Butte and Greenhorn Buttes quadrangles, Washington

by

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# GEOLOGIC MAPS OF THE FRENCH BUTTE AND GREENHORN BUTTES QUADRANGLES, WASHINGTON

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## INTRODUCTION

The French Butte and Greenhorn Buttes 7.5-minute quadrangles are in the Cascade Range in southern Washington, about 15-20 km northeast of Mount St. Helens and 30-35 km west of the Cascade Crest (Fig. 1). The two quadrangles adjoin the east sides of the Spirit Lake East and Cowlitz Falls quadrangles recently mapped by Evarts and Ashley (in press a, b). The extreme southwest corner of the French Butte quadrangle is in the area devastated by the May 18, 1980, eruption of Mount St. Helens. The French Butte quadrangle includes a major east-trending divide that separates the Cispus-Cowlitz river system to the north from the Lewis system to the south (Fig. 1).

The quadrangles are underlain chiefly by Miocene volcanic rocks ranging from olivine basalt to rhyodacite or rhyolite, cut locally by subvolcanic intrusions and unconformably overlain in a few places by flows of Quaternary olivine basaltic andesite and andesite. Low-grade hydrothermal alteration pervades the Tertiary rocks and gives a greenish cast to many of the once-glassy volcaniclastic rocks. Unconsolidated deposits related to at least two episodes of late Pleistocene glaciation cover parts of the area (Crandell and Miller, 1974). Tephra from eruptions of Mount St. Helens during the past 50,000 yrs mantles all units (Mullineaux, 1986). In general the tephra cover thins northeastward, away from the dominant axis of fallout. The tephra was not mapped owing to its ubiquitous presence.

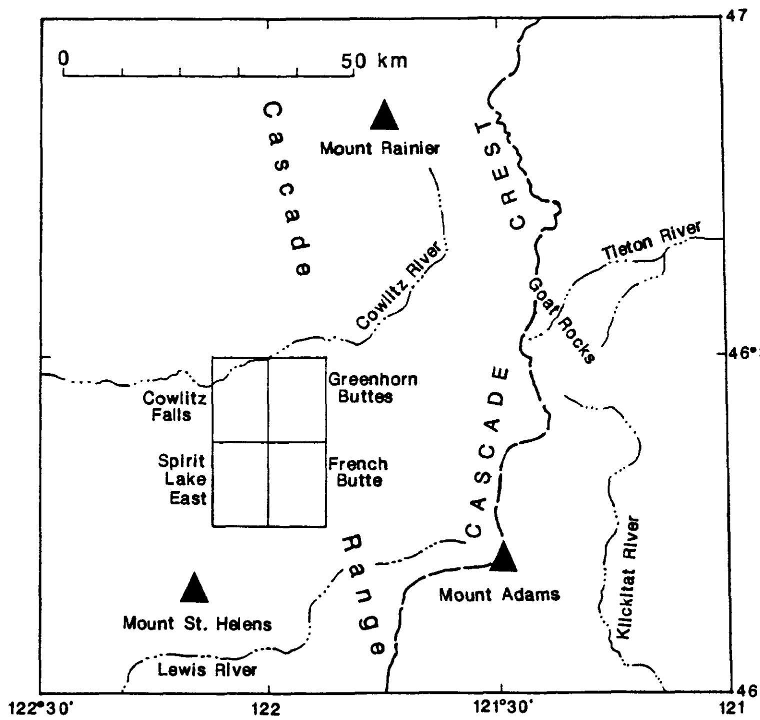



Figure 1. Locations of French Butte and Greenhorn Buttes quadrangles (this report), Spirit Lake East and Cowlitz Falls quadrangles (Evarts and Ashley, in press a, b), and major volcanoes in southern Washington Cascades.

Bedrock exposures are relatively limited owing to the thick surficial cover and dense forest (broken by numerous clearcuts). However, numerous small perennial and annual streams provide adequate to excellent local exposures and, together with intervening cliffs and ridge-top outcrops, allow stratigraphic relations to be determined with few exceptions. Most such streams were traversed during the mapping. Numerous logging roads afford exposures as well as reasonably good access. The southeast corner of the French Butte quadrangle is relatively difficult to reach, however; mapping there is incomplete.

These geologic maps, together with those of Evarts and Ashley (in press a, b), are the first to be prepared at a scale of 1:24,000 in the predominately Tertiary part of the southern Washington Cascades. They initiate a series of maps to be completed during the next several years as part of a project to tie mapping in the Mount St. Helens area by Evarts and Ashley (1984, in press a, b) and Evarts and others (1987) into the now-classic Tertiary stratigraphic section (Ohanapecosh, Stevens Ridge, and Fifes Peak Formations, in ascending order) defined by Fiske and others (1963) in Mount Rainier National Park and adjacent areas. These stratigraphic names have been used, sometimes in modified form, by most later workers (Hammond, 1980; Swanson and Clayton, 1983; Vance and others, 1987) in areas near Mount Rainier and have been tentatively extended throughout the southern Washington Cascades during reconnaissance work with little intervening detailed mapping (Wise, 1970; Hammond, 1980). For example, Hammond (1980) assigned most of the bedrock in the French Butte and Greenhorn Buttes quadrangles to the Ohanapecosh and Stevens Ridge Formations on the basis of reconnaissance mapping. One of the objects of my work is to place the stratigraphy of Fiske and others (1963) into a well-controlled regional context that will result from pooling the work by Evarts and Ashley with that of the current study to provide a geologic transect across the southern Washington Cascades. It is too early in the study to assess the regional stratigraphic relations, although it is clear that the rocks in the French Butte and Greenhorn Buttes quadrangles are considerably younger that those assigned to the Ohanapecosh Formation near Mount Rainier (Vance and others, 1987).

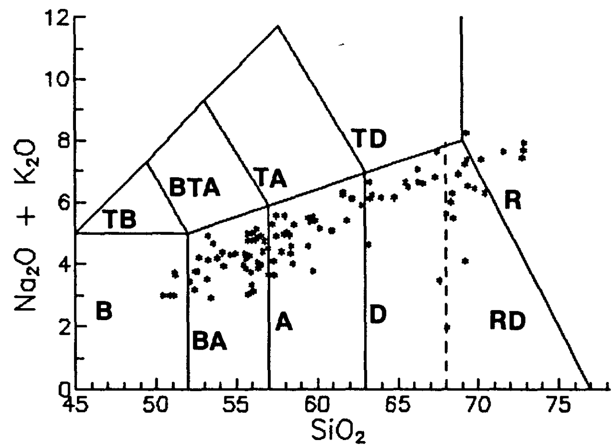



Figure 2. Chemical analyses of Tertiary volcanic rocks in the French Butte and Greenhorn Buttes quadrangles plotted on total alkali-silica classification diagram, modified from Le Bas and others (1986) to include a field for rhyodacite. B, basalt; BA, basaltic andesite; A, andesite; D, dacite; RD, rhyodacite; R, rhyolite; TB, trachybasalt; BTA, basaltic trachyandesite; TA, trachyandesite; TD, trachydacite. Data from tables 1 and 2.

## ACKNOWLEDGMENTS

I appreciate the field assistance of Mark Heckman, Gary Stoopes, Kent Syverson, and Rick Wessels (all National Association of Geology Teachers fellows), Jack Kleinman and Stoopes (Cascades Volcano Observatory), and Barbara White (my wife). I am indebted to Russ Evarts, Roger Ashley, and Jim Smith for enlightening discussions about the bedrock geology of the area. Evarts and Ashley worked closely with me to resolve small differences along quadrangle boundaries and to make our independent mapping efforts truly collaborative. Willie Scott illuminated the Quaternary geology during a two-day field trip with Evarts and me, and later corrected some of my mistakes in interpreting the glacial deposits. Smith and Evarts provided unpublished K-Ar ages, and Evarts permitted use of several unpublished chemical analyses. Mike Korosec (Washington Department of Natural Resources, Division of Geology and Earth Resources) furnished unpublished field sheets and related chemical analyses from his reconnaissance work for preparation of the new geologic map of Washington. Russ Evarts and Willie Scott reviewed and greatly improved the manuscript and map.

## ROCK TERMINOLOGY

Chemically analyzed samples are classified according to the recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks (Le Bas and others, 1986), modified to include a field for rhyodacite (Fig. 2). 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* (57-63 per cent $SiO_2$), *dacite* (63-68 per cent $SiO_2$), *rhyodacite* (generally between 68 and about 72 percent $SiO_2$, but see Figure 2), and *rhyolite* (generally greater than about 72 percent $SiO_2$, but see Figure 2). These samples have the following rather consistent phenocryst assemblages (Fig. 3), with minerals given in approximate order of decreasing abundance: *basalt*, ol ± cpx ± pl; *basaltic andesite*, pl ± cpx ± hyp ± ol; *andesite*, pl ± cpx ± hyp ± rare olivine ± hb; *dacite*, similar assemblage as that for andesite (except for rare quartz) but hypersthene is less common and the groundmass texture is commonly snowflaked; *rhyodacite* and *rhyolite*, generally nearly aphyric with pl > cpx. Samples with thin sections but no chemical analysis could therefore be classified on the basis of their phenocryst assemblage and groundmass texture. In all, 379 samples from the two quadrangles were sectioned (Fig. 4); of these, 114 were chemically analyzed (Fig. 5; Tables 1 and 2).

## GENERAL GEOLOGY

The rocks in the two quadrangles are mostly lower owing to hydrothermal alteration related to the presumed vent. The basalt of Twelvemile Creek is the

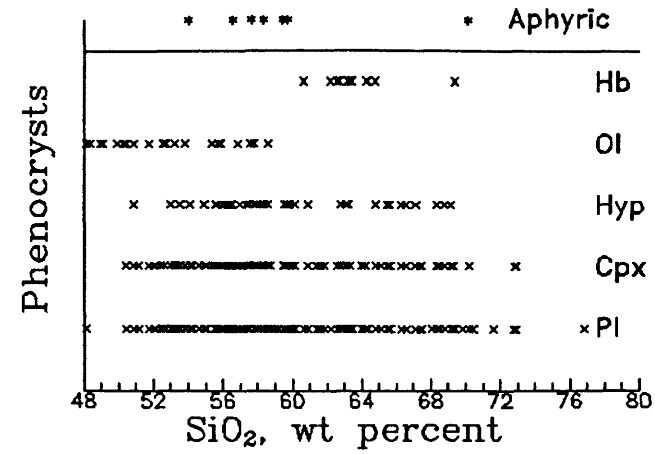
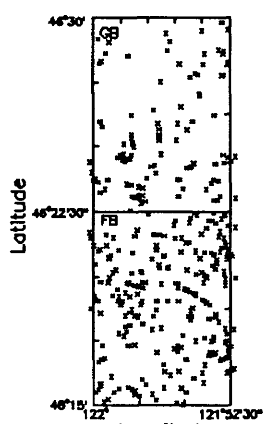



Figure 3. Plot of phenocryst assemblage vs $SiO_2$ for Tertiary rocks chiefly from French Butte and Greenhorn Buttes quadrangles but including some from Tower Rock, McCoy Peak, Mt. Rainier 3 SW, and Mt. Rainier 3 SE quadrangles. x, phenocryst observed in thin section. Hb, hornblende; Ol, olivine; Hyp, hypersthene; Cpx, calcic clinopyroxene; Pl, plagioclase. Several aphyric samples also shown.



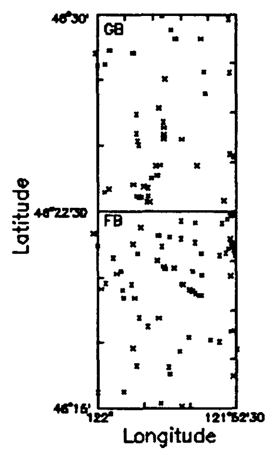




Figure 4 (left). Map showing distribution of 379 sample localities in and just outside the French Butte (FB) and Greenhorn Buttes (GB) quadrangles. Thin sections examined from each sample.

Figure 5 (right). Map showing distribution of 114 chemically analyzed samples in and just outside the French Butte (FB) and Greenhorn Buttes (GB) quadrangles. Includes locations of samples analyzed by R. C. Evarts and R. P. Ashley (written commun., 1988) and M. A. Korosec (written commun., 1987).

most mafic Tertiary Miocene basaltic andesite and andesite lava flows and andesitic to dacitic volcaniclastic deposits. Less abundant lithologies include flows and clastic rocks of basalt, dacite, and rhyodacite, and rhyolite. The Tertiary section is at least 1.2 km thick. The rocks are gently folded along north- to north-northwest-trending axes and cut by minor strike-slip shears mostly trending northwest. Pleistocene olivine basaltic andesite and andesite lava flows unconformably overlie the Tertiary rocks in the southeast part of the French Butte quadrangle.

## TERTIARY ROCKS

The basalt of Twelvemile Creek is probably the oldest unit in the two quadrangles, despite its occurrence along the trough of the Elk Creek syncline. No radiometric ages are available for it, but field relations suggest the unit is older than welded tuff of unit Ttv dated as 23.3 ± 1.8 Ma (Table 3, no. 1A). The basalt crops out in the central part of the French Butte quadrangle and apparently underlies unconformably andesite and basaltic andesite lava flows and dacitic volcaniclastic rocks (see cross section B-B'). Volcaniclastic rocks (unit Ttv) in the small exposure surrounded by basalt along Twelvemile Creek itself consist of bedded sandstone derived from erosion of the basalt and are not related to the more silicic tuffaceous units higher in section. The basalt probably erupted locally, because the stack of thin flows is cut by at least one petrographically similar dike in a cliff just south of the mouth of Twelvemile Creek. The basalt is more highly altered than most other rocks in the area, perhaps unit in either quadrangle (Tables 1 and 2).

The overlying Tertiary section consists of interbedded lava flows and volcaniclastic rocks in roughly equal proportions. Few individual lava flows or ash-flow tuffs have more than local significance. Many such units probably never extended far owing to small volume or confinement to channels. The lava flows and ash-flow tuffs typically lack distinctive characteristics and hence cannot be mapped separately. For the most part, these units form a conformable or only locally disconformable section that probably records deposition on broad aprons between vent areas. Such an interpretation accounts for the readily traceable though discontinuous units in the Iron Creek and Pinto Creek valleys, where only local vent areas (such as unit Tav 1 km south of Pinto Rock) mar the otherwise overall "layer-cake" stratigraphy.

Locally, however, vent and near-vent deposits dominate the section. The most prominent example is the bedded breccia of Pinto Rock, whose coarseness, poor sorting, and steep dips of as much as 32° clearly define a major eruptive center or centers elongate northward. The basalt and basaltic andesite of Huffaker Mountain probably occur on the east flank of a

## Table 1. Chemical Analyses from the French Butte Quadrangle, Washington

| Map No. | Map Unit | Field No. | Original Analysis SiO2 | TiO2 | Al2O3 | Fe2O3 | FeO | MnO | MgO | CaO | Na2O | K2O | P2O5 | H2O+ | H2O- | CO2 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Tbt | 86-032 | 49.0 | 0.92 | 18.6 | 4.74 | 4.08 | 0.18 | 6.29 | 10.80 | 2.41 | 0.49 | 0.12 | 0.83 | 2.06 | 0.06 | 100.58 |
| 2 | Tbt | 8C-047 | 49.9 | 0.93 | 18.8 | 4.46 | 4.52 | 0.11 | 6.51 | 10.20 | 2.41 | 0.54 | 0.12 | 0.66 | 1.18 | 0.04 | 100.41 |
| 3 | 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 |
| 4 | Ta | 86-191 | 49.3 | 1.29 | 17.5 | 5.98 | 3.38 | 0.24 | 4.63 | 8.54 | 3.16 | 0.39 | 0.21 | 1.84 | 3.34 | 0.02 | 99.82 |
| 5 | Tbpr | 86-132 | 51.0 | 1.28 | 18.7 | 4.84 | 4.28 | 0.18 | 3.79 | 8.92 | 3.25 | 0.84 | 0.19 | 1.25 | 1.67 | 0.02 | 100.21 |
| 6 | Tai | 86-126 | 51.9 | 1.21 | 18.5 | 3.31 | 5.59 | 0.16 | 4.36 | 9.30 | 3.02 | 0.43 | 0.17 | 0.98 | 1.20 | 0.00 | 100.13 |
| 7 | Ta | 86-189 | 51.5 | 1.30 | 18.2 | 4.46 | 3.83 | 0.33 | 3.11 | 9.49 | 3.63 | 1.14 | 0.23 | 0.58 | 1.04 | 0.92 | 99.76 |
| 8 | Ta | 86-163 | 52.4 | 1.64 | 16.4 | 4.72 | 5.65 | 0.17 | 3.86 | 8.67 | 3.28 | 0.81 | 0.24 | 0.72 | 1.19 | 0.00 | 99.75 |
| 9 | Ta | 3FB-VO3 | 53.0 | 1.75 | 15.9 | 4.24 | 6.63 | 0.17 | 4.12 | 8.07 | 3.40 | 0.88 | 0.23 | 0.30 | 0.98 | 0.00 | 99.67 |
| 10 | Ta | 86-114 | 53.6 | 1.78 | 15.8 | 4.56 | 6.61 | 0.20 | 4.05 | 8.31 | 3.46 | 0.88 | 0.23 | 0.35 | 0.29 | 0.00 | 100.12 |
| 11 | Tai | 86-112 | 52.5 | 1.59 | 17.0 | 4.83 | 4.65 | 0.18 | 3.48 | 7.92 | 3.41 | 0.71 | 0.30 | 1.44 | 1.99 | 0.02 | 100.02 |
| 12 | Qbbr | 86-165 | 55.0 | 1.17 | 17.8 | 2.77 | 4.42 | 0.11 | 5.50 | 7.53 | 4.19 | 0.84 | 0.34 | 0.32 | 0.07 | 0.00 | 100.06 |
| 105 | Ta | 8R82 | 53.9 | 1.20 | 16.8 | 3.30 | 4.90 | 0.14 | 4.80 | 8.40 | 3.10 | 0.75 | 0.24 | 0.70 | 1.40 | 0.02 | 99.65 |
| 13 | Ta | 86-149 | 54.3 | 1.63 | 17.0 | 2.92 | 6.16 | 0.15 | 3.15 | 8.24 | 3.58 | 0.68 | 0.29 | 1.32 | 0.38 | 0.03 | 99.83 |
| 14 | Tai | 3FB-VO5 | 54.0 | 1.11 | 16.9 | 2.69 | 5.32 | 0.14 | 4.27 | 8.70 | 3.08 | 1.00 | 0.18 | 0.09 | 0.89 | 1.18 | 99.55 |
| 15 | Ta | 86-148 | 54.2 | 1.63 | 16.9 | 4.69 | 4.37 | 0.17 | 2.62 | 8.09 | 3.37 | 1.48 | 0.29 | 0.67 | 0.53 | 0.94 | 99.95 |
| 16 | Ta | 87-048 | 54.0 | 1.06 | 16.9 | 4.03 | 4.16 | 0.14 | 4.40 | 8.16 | 3.20 | 0.92 | 0.16 | 0.38 | 1.80 | 0.00 | 99.31 |
| 17 | Qbbr | 85-006 | 55.6 | 1.19 | 18.3 | 2.80 | 4.26 | 0.10 | 4.93 | 7.28 | 4.30 | 0.75 | 0.30 | 0.45 | 0.37 | 0.00 | 100.63 |
| 18 | Ta | 86-093 | 54.9 | 1.83 | 15.7 | 4.02 | 6.01 | 0.17 | 3.46 | 7.46 | 3.39 | 1.29 | 0.32 | 0.59 | 0.58 | 0.00 | 99.72 |
| 19 | Tai | 87-236 | 53.9 | 1.32 | 16.6 | 5.28 | 4.43 | 0.20 | 3.30 | 6.68 | 3.90 | 0.92 | 0.24 | 0.54 | 1.64 | 0.09 | 99.04 |
| 20 | Ta | 86-029 | 53.7 | 1.07 | 16.5 | 3.02 | 4.96 | 0.16 | 4.24 | 9.26 | 2.77 | 0.22 | 0.19 | 1.85 | 1.53 | 0.02 | 99.49 |
| 21 | Tafb | 85-012 | 55.2 | 1.16 | 18.4 | 4.07 | 4.20 | 0.19 | 2.72 | 7.78 | 3.81 | 0.88 | 0.18 | 0.53 | 0.77 | 0.05 | 99.94 |
| 22 | Ta | 87-047 | 53.9 | 1.62 | 16.4 | 5.85 | 3.46 | 0.14 | 2.90 | 6.98 | 3.50 | 1.42 | 0.28 | 0.49 | 1.79 | 0.02 | 98.75 |
| 23 | Tbfb | 86-101 | 55.4 | 1.55 | 16.8 | 2.88 | 6.16 | 0.15 | 3.03 | 7.52 | 3.85 | 0.94 | 0.31 | 0.93 | 0.44 | 0.00 | 99.96 |
| 24 | Ta | 5FB-VO8 | 55.1 | 0.97 | 15.9 | 3.07 | 4.80 | 0.19 | 4.94 | 9.14 | 2.78 | 0.99 | 0.18 | 0.76 | 0.79 | 0.79 | 100.40 |
| 25 | Ta | 86-021 | 55.3 | 1.35 | 16.7 | 3.76 | 4.76 | 0.21 | 3.15 | 7.85 | 3.60 | 1.22 | 0.27 | 0.48 | 0.97 | 0.34 | 99.96 |
| 106 | Ta | 7R22 | 55.7 | 0.83 | 16.4 | 3.60 | 4.40 | 0.13 | 5.10 | 8.50 | 3.10 | 0.80 | 0.25 | 0.97 | 0.92 | 0.14 | 100.84 |
| 26 | Qbl | 87-235 | 56.3 | 1.04 | 17.3 | 2.22 | 4.54 | 0.12 | 4.80 | 7.60 | 3.90 | 1.08 | 0.34 | 0.13 | 0.11 | 0.08 | 99.56 |
| 27 | Ta | 86-062 | 55.9 | 0.98 | 15.9 | 2.94 | 5.02 | 0.13 | 5.01 | 8.78 | 2.49 | 1.10 | 0.18 | 1.00 | 0.77 | 0.28 | 100.48 |
| 28 | Ta | 86-185 | 56.2 | 1.89 | 15.3 | 4.64 | 5.27 | 0.21 | 2.91 | 6.69 | 3.64 | 1.56 | 0.35 | 0.69 | 0.66 | 0.01 | 100.02 |
| 29 | Ta | 86-011 | 56.2 | 1.07 | 16.2 | 3.48 | 4.45 | 0.14 | 4.48 | 8.15 | 2.93 | 1.10 | 0.19 | 0.57 | 1.08 | 0.03 | 100.07 |
| 30 | Ta | 86-190 | 56.3 | 1.65 | 16.3 | 4.21 | 4.90 | 0.22 | 2.72 | 6.37 | 4.20 | 1.24 | 0.29 | 0.73 | 0.66 | 0.00 | 99.79 |
| 31 | Qbl | 87-232 | 56.8 | 1.02 | 17.3 | 2.34 | 4.49 | 0.11 | 4.40 | 7.08 | 4.00 | 1.06 | 0.32 | 0.10 | 0.22 | 0.01 | 99.25 |
| 32 | Qbbr | 86-154 | 57.5 | 1.05 | 17.5 | 3.23 | 3.76 | 0.11 | 4.05 | 7.27 | 3.88 | 1.14 | 0.35 | 0.36 | 0.08 | 0.00 | 100.28 |
| 33 | Ta | 86-188 | 56.8 | 1.98 | 15.4 | 4.45 | 4.86 | 0.22 | 2.69 | 6.14 | 4.07 | 1.37 | 0.39 | 0.49 | 1.08 | 0.00 | 99.94 |
| 34 | Ta? | 87-069 | 56.7 | 1.04 | 18.1 | 2.75 | 4.13 | 0.12 | 2.60 | 6.98 | 3.80 | 1.00 | 0.32 | 1.38 | 0.19 | 0.00 | 99.11 |
| 35 | Ta | 85-001 | 56.7 | 1.29 | 19.5 | 2.89 | 2.20 | 0.17 | 1.71 | 8.57 | 3.28 | 0.95 | 0.20 | 0.78 | 0.58 | 0.05 | 98.87 |
| 36 | Ta | 86-081 | 57.6 | 1.34 | 16.2 | 2.54 | 5.60 | 0.15 | 2.92 | 6.66 | 4.26 | 0.95 | 0.33 | 1.25 | 0.44 | 0.03 | 100.27 |
| 37 | Tai | 86-119 | 58.6 | 1.23 | 17.2 | 2.01 | 5.18 | 0.15 | 2.18 | 6.47 | 4.10 | 1.17 | 0.26 | 1.16 | 0.14 | 0.00 | 99.85 |
| 107 | Ta | MK85638 | 59.5 | 1.21 | 15.6 | 3.97 | 4.55 | 0.13 | 3.84 | 7.20 | 2.59 | 1.16 | 0.24 | | | | 99.99 |
| 38 | Ta | 86-186 | 57.7 | 1.22 | 17.3 | 4.33 | 2.62 | 0.17 | 1.30 | 6.75 | 4.09 | 1.26 | 0.26 | 1.01 | 1.44 | 0.32 | 99.77 |
| 39 | Tai | 86-187 | 58.0 | 1.24 | 17.2 | 4.79 | 2.55 | 0.17 | 1.44 | 6.44 | 3.99 | 1.24 | 0.26 | 1.08 | 1.45 | 0.10 | 99.95 |
| 40 | Tbpr | 85-011 | 58.5 | 1.02 | 17.6 | 3.61 | 2.52 | 0.14 | 2.67 | 6.37 | 3.77 | 1.25 | 0.19 | 0.60 | 1.33 | 0.02 | 99.59 |
| 41 | Ta | 86-082 | 60.5 | 1.52 | 14.9 | 4.72 | 3.82 | 0.15 | 1.85 | 4.59 | 4.38 | 1.83 | 0.41 | 0.59 | 0.50 | 0.00 | 99.76 |
| 42 | Ta | 86-151 | 59.4 | 1.42 | 14.8 | 4.39 | 3.93 | 0.17 | 1.58 | 4.76 | 4.14 | 1.88 | 0.37 | 0.99 | 0.77 | 1.18 | 99.78 |
| 43 | Ta | 86-150 | 60.5 | 1.34 | 15.2 | 4.04 | 3.74 | 0.17 | 1.95 | 4.52 | 4.37 | 1.56 | 0.37 | 1.20 | 0.89 | 0.01 | 99.86 |
| 44 | Tdpp | 86-142 | 60.9 | 0.84 | 16.8 | 3.85 | 2.43 | 0.14 | 1.84 | 5.22 | 4.45 | 1.54 | 0.21 | 0.78 | 0.76 | 0.00 | 99.76 |
| 45 | Tbd | 86-199 | 60.3 | 0.66 | 17.1 | 4.33 | 0.86 | 0.07 | 2.43 | 4.93 | 4.43 | 1.23 | 0.16 | 1.03 | 1.83 | 0.00 | 99.36 |
| 46 | Ta | 8E146A | 60.3 | 1.10 | 14.6 | 2.20 | 5.20 | 0.14 | 2.10 | 5.30 | 3.80 | 0.61 | 0.31 | 2.70 | 1.20 | 0.02 | 99.58 |

| Map No. | Map Unit | Field No. | Recalculated H2O- and CO2-free to 100 percent, with iron as FeO SiO2 | TiO2 | Al2O3 | FeOT | MnO | MgO | CaO | Na2O | K2O | P2O5 | Na2O+K2O | FeOT/MgO | Longitude Deg | Longitude Min | Latitude Deg | Latitude Min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Tbt | 86-032 | 50.43 | 0.95 | 19.14 | 8.59 | 0.19 | 6.47 | 11.12 | 2.48 | 0.50 | 0.12 | 2.98 | 1.33 | 121 | 57.750 | 46 | 18.468 |
| 2 | Tbt | 8C-047 | 50.88 | 0.95 | 19.17 | 8.70 | 0.14 | 6.64 | 10.40 | 2.46 | 0.55 | 0.12 | 3.01 | 1.31 | 121 | 58.020 | 46 | 19.212 |
| 3 | Tg | 86-170 | 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 | 52.458 | 46 | 17.262 |
| 4 | Ta | 86-191 | 52.44 | 1.37 | 18.61 | 9.32 | 0.26 | 4.92 | 9.08 | 3.36 | 0.41 | 0.22 | 3.77 | 1.89 | 121 | 54.408 | 46 | 19.314 |
| 5 | Tbpr | 86-132 | 52.69 | 1.32 | 19.32 | 8.93 | 0.19 | 3.92 | 9.22 | 3.36 | 0.87 | 0.20 | 4.23 | 2.28 | 121 | 54.720 | 46 | 21.330 |
| 6 | Tai | 86-126 | 53.17 | 1.24 | 18.95 | 8.78 | 0.16 | 4.47 | 9.53 | 3.09 | 0.44 | 0.17 | 3.53 | 1.96 | 121 | 54.372 | 46 | 20.082 |
| 7 | Ta | 86-189 | 53.22 | 1.34 | 18.81 | 8.10 | 0.34 | 3.21 | 9.81 | 3.75 | 1.18 | 0.24 | 4.93 | 2.52 | 121 | 54.702 | 46 | 19.380 |
| 8 | Ta | 86-163 | 53.82 | 1.68 | 16.84 | 10.17 | 0.17 | 3.96 | 8.90 | 3.37 | 0.83 | 0.25 | 4.20 | 2.57 | 121 | 52.770 | 46 | 20.070 |
| 9 | Ta | 3FB-VO3 | 54.10 | 1.79 | 16.23 | 10.66 | 0.17 | 4.21 | 8.24 | 3.47 | 0.90 | 0.23 | 4.37 | 2.53 | 121 | 57.882 | 46 | 16.626 |
| 10 | Ta | 86-114 | 54.13 | 1.80 | 15.96 | 10.82 | 0.20 | 4.09 | 8.39 | 3.49 | 0.89 | 0.23 | 4.38 | 2.65 | 121 | 55.542 | 46 | 17.190 |
| 11 | Tai | 86-112 | 54.64 | 1.65 | 17.69 | 9.37 | 0.19 | 3.62 | 8.24 | 3.55 | 0.74 | 0.31 | 4.29 | 2.59 | 121 | 55.530 | 46 | 21.468 |
| 12 | Qbbr | 86-165 | 55.34 | 1.18 | 17.91 | 6.95 | 0.11 | 5.53 | 7.58 | 4.22 | 0.85 | 0.34 | 5.07 | 1.26 | 121 | 52.758 | 46 | 17.970 |
| 105 | Ta | 8R82 | 55.45 | 1.23 | 17.28 | 8.10 | 0.14 | 4.94 | 8.64 | 3.19 | 0.77 | 0.25 | 3.96 | 1.64 | 122 | 0.000 | 46 | 15.600 |
| 13 | Ta | 86-149 | 55.52 | 1.67 | 17.38 | 8.99 | 0.15 | 3.22 | 8.42 | 3.66 | 0.70 | 0.30 | 4.36 | 2.79 | 121 | 52.668 | 46 | 21.180 |
| 14 | Tai | 3FB-VO5 | 55.60 | 1.14 | 17.40 | 7.97 | 0.14 | 4.40 | 8.96 | 3.17 | 1.03 | 0.19 | 4.20 | 1.81 | 121 | 59.610 | 46 | 19.782 |
| 15 | Ta | 86-148 | 55.68 | 1.67 | 17.36 | 8.82 | 0.17 | 2.69 | 8.31 | 3.46 | 1.52 | 0.30 | 4.98 | 3.28 | 121 | 52.710 | 46 | 21.312 |
| 16 | Ta | 87-048 | 55.83 | 1.10 | 17.47 | 8.05 | 0.14 | 4.55 | 8.44 | 3.31 | 0.95 | 0.17 | 4.26 | 1.77 | 121 | 52.806 | 46 | 22.350 |
| 17 | Qbbr | 85-006 | 55.86 | 1.20 | 18.39 | 6.81 | 0.10 | 4.95 | 7.31 | 4.32 | 0.75 | 0.30 | 5.07 | 1.38 | 121 | 53.376 | 46 | 17.538 |
| 18 | Ta | 86-093 | 55.93 | 1.86 | 16.00 | 9.81 | 0.17 | 3.53 | 7.60 | 3.45 | 1.31 | 0.33 | 4.76 | 2.78 | 121 | 56.382 | 46 | 20.442 |
| 19 | Tai | 87-236 | 56.01 | 1.37 | 17.25 | 9.54 | 0.21 | 3.43 | 6.94 | 4.05 | 0.96 | 0.25 | 5.01 | 2.78 | 121 | 58.632 | 46 | 15.642 |
| 20 | Ta | 86-029 | 56.06 | 1.12 | 17.23 | 8.02 | 0.17 | 4.43 | 9.67 | 2.89 | 0.23 | 0.20 | 3.12 | 1.81 | 121 | 58.182 | 46 | 19.722 |
| 21 | Tafb | 85-012 | 56.22 | 1.18 | 18.74 | 8.01 | 0.19 | 2.77 | 7.92 | 3.88 | 0.90 | 0.18 | 4.78 | 2.89 | 121 | 56.520 | 46 | 21.180 |
| 22 | Ta | 87-047 | 56.23 | 1.69 | 17.11 | 9.10 | 0.15 | 3.03 | 7.28 | 3.65 | 1.48 | 0.29 | 5.13 | 3.00 | 121 | 52.710 | 46 | 22.380 |
| 23 | Tbfb | 86-101 | 56.36 | 1.58 | 17.09 | 8.90 | 0.15 | 3.08 | 7.65 | 3.92 | 0.96 | 0.32 | 4.88 | 2.89 | 121 | 56.112 | 46 | 21.552 |
| 24 | Ta | 5FB-VO8 | 56.37 | 0.99 | 16.27 | 7.74 | 0.19 | 5.05 | 9.35 | 2.84 | 1.01 | 0.18 | 3.86 | 1.53 | 121 | 58.062 | 46 | 21.282 |
| 25 | Ta | 86-021 | 56.55 | 1.38 | 17.08 | 8.32 | 0.21 | 3.22 | 8.03 | 3.68 | 1.25 | 0.28 | 4.93 | 2.58 | 121 | 58.098 | 46 | 17.298 |
| 106 | Ta | 7R22 | 56.58 | 0.84 | 16.66 | 7.76 | 0.13 | 5.18 | 8.63 | 3.15 | 0.81 | 0.25 | 3.96 | 1.50 | 122 | 0.228 | 46 | 21.672 |
| 26 | Qbl | 87-235 | 56.86 | 1.05 | 17.47 | 6.60 | 0.12 | 4.85 | 7.68 | 3.94 | 1.09 | 0.34 | 5.03 | 1.36 | 121 | 56.088 | 46 | 16.302 |
| 27 | Ta | 86-062 | 56.96 | 1.00 | 16.20 | 7.82 | 0.13 | 5.10 | 8.95 | 2.54 | 1.12 | 0.18 | 3.66 | 1.53 | 121 | 57.852 | 46 | 20.910 |
| 28 | Ta | 86-185 | 57.23 | 1.92 | 15.58 | 9.62 | 0.21 | 2.96 | 6.81 | 3.71 | 1.59 | 0.36 | 5.30 | 3.25 | 121 | 55.020 | 46 | 19.530 |
| 29 | Ta | 86-011 | 57.32 | 1.09 | 16.52 | 7.73 | 0.14 | 4.57 | 8.31 | 2.99 | 1.12 | 0.19 | 4.11 | 1.69 | 121 | 58.968 | 46 | 20.148 |
| 30 | Ta | 86-190 | 57.46 | 1.68 | 16.64 | 8.87 | 0.22 | 2.78 | 6.50 | 4.29 | 1.27 | 0.30 | 5.56 | 3.19 | 121 | 54.450 | 46 | 19.326 |
| 31 | Qbl | 87-232 | 57.61 | 1.03 | 17.55 | 6.60 | 0.11 | 4.46 | 7.18 | 4.06 | 1.08 | 0.32 | 5.14 | 1.48 | 121 | 55.458 | 46 | 15.078 |
| 32 | Qbbr | 86-154 | 57.78 | 1.06 | 17.58 | 6.70 | 0.11 | 4.07 | 7.31 | 3.90 | 1.15 | 0.35 | 5.05 | 1.65 | 121 | 53.898 | 46 | 17.610 |
| 33 | Ta | 86-188 | 58.00 | 2.02 | 15.73 | 9.06 | 0.22 | 2.75 | 6.27 | 4.16 | 1.40 | 0.40 | 5.56 | 3.29 | 121 | 54.822 | 46 | 19.458 |
| 34 | Ta? | 87-069 | 58.29 | 1.07 | 18.61 | 6.79 | 0.12 | 2.67 | 7.18 | 3.91 | 1.03 | 0.33 | 4.94 | 2.54 | 121 | 52.650 | 46 | 16.242 |
| 35 | Ta | 85-001 | 58.35 | 1.33 | 20.07 | 4.94 | 0.17 | 1.76 | 8.82 | 3.38 | 0.98 | 0.21 | 4.36 | 2.81 | 121 | 55.050 | 46 | 17.700 |
| 36 | Ta | 86-081 | 58.60 | 1.36 | 16.48 | 8.03 | 0.15 | 2.97 | 6.78 | 4.33 | 0.97 | 0.34 | 5.30 | 2.70 | 121 | 57.300 | 46 | 18.138 |
| 37 | Tai | 86-119 | 59.58 | 1.25 | 17.49 | 7.11 | 0.15 | 2.22 | 6.58 | 4.17 | 1.19 | 0.26 | 5.36 | 3.20 | 121 | 55.380 | 46 | 19.728 |
| 107 | Ta | MK85638 | 59.74 | 1.21 | 15.66 | 8.14 | 0.13 | 3.86 | 7.23 | 2.60 | 1.16 | 0.24 | 3.76 | 2.11 | 121 | 57.630 | 46 | 21.900 |
| 38 | Ta | 86-186 | 59.75 | 1.26 | 17.91 | 6.75 | 0.18 | 1.35 | 6.99 | 4.24 | 1.30 | 0.27 | 5.54 | 5.00 | 121 | 54.996 | 46 | 19.518 |
| 39 | Tai | 86-187 | 59.89 | 1.28 | 17.76 | 7.08 | 0.18 | 1.49 | 6.65 | 4.12 | 1.28 | 0.27 | 5.40 | 4.75 | 121 | 54.918 | 46 | 19.494 |
| 40 | Tbpr | 85-011 | 60.14 | 1.05 | 18.09 | 5.93 | 0.14 | 2.74 | 6.55 | 3.88 | 1.28 | 0.20 | 5.16 | 2.16 | 121 | 55.500 | 46 | 19.746 |
| 41 | Ta | 86-082 | 61.61 | 1.55 | 15.17 | 8.22 | 0.15 | 1.88 | 4.67 | 4.46 | 1.86 | 0.42 | 6.32 | 4.37 | 121 | 56.700 | 46 | 18.438 |
| 42 | Ta | 86-151 | 61.62 | 1.47 | 15.35 | 8.17 | 0.18 | 1.64 | 4.94 | 4.29 | 1.95 | 0.38 | 6.24 | 4.98 | 121 | 52.542 | 46 | 21.000 |
| 43 | Ta | 86-150 | 62.14 | 1.38 | 15.61 | 7.58 | 0.17 | 2.00 | 4.64 | 4.49 | 1.60 | 0.38 | 6.09 | 3.79 | 121 | 52.602 | 46 | 21.030 |
| 44 | Tdpp | 86-142 | 62.24 | 0.86 | 17.17 | 6.03 | 0.14 | 1.88 | 5.34 | 4.55 | 1.57 | 0.21 | 6.12 | 3.21 | 121 | 53.268 | 46 | 22.062 |
| 45 | Tbd | 86-199 | 62.77 | 0.69 | 17.80 | 4.95 | 0.07 | 2.53 | 5.13 | 4.61 | 1.28 | 0.17 | 5.89 | 1.96 | 121 | 53.052 | 46 | 20.940 |
| 46 | Ta | 8E146A | 63.18 | 1.15 | 15.30 | 7.52 | 0.15 | 2.20 | 5.55 | 3.98 | 0.64 | 0.32 | 4.62 | 4.62 | 121 | 59.802 | 46 | 19.542 |

## Table 1. Chemical Analyses from the French Butte Quadrangle, Washington (cont.)

| Map No. | Map Unit | Field No. | Original Analysis SiO2 | TiO2 | Al2O3 | Fe2O3 | FeO | MnO | MgO | CaO | Na2O | K2O | P2O5 | H2O+ | H2O- | CO2 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 | Tbd | 85-048 | 60.7 | 0.68 | 16.1 | 4.17 | 0.95 | 0.08 | 2.97 | 4.18 | 4.53 | 1.85 | 0.18 | 1.13 | 1.85 | 0.00 | 99.37 |
| 48 | Tbd | 85-047B | 61.1 | 0.67 | 16.9 | 4.16 | 1.00 | 0.09 | 2.42 | 4.28 | 4.91 | 1.09 | 0.16 | 1.05 | 1.81 | 0.00 | 99.64 |
| 49 | Tdi | 87-237 | 61.5 | 0.88 | 15.6 | 4.81 | 1.28 | 0.17 | 1.90 | 4.26 | 4.30 | 1.62 | 0.30 | 0.87 | 1.34 | 0.22 | 99.05 |
| 50 | Ta | 86-094 | 62.7 | 1.22 | 14.0 | 3.62 | 3.39 | 0.12 | 1.42 | 4.40 | 3.60 | 2.33 | 0.32 | 0.83 | 1.15 | 0.29 | 99.39 |
| 51 | Ttv | 86-121 | 66.3 | 0.84 | 15.1 | 4.03 | 0.89 | 0.15 | 0.80 | 2.89 | 4.66 | 2.83 | 0.20 | 0.63 | 0.58 | 0.00 | 99.90 |
| 52 | Ttv | 3FB-VO6 | 62.1 | 0.73 | 13.8 | 3.04 | 2.30 | 0.11 | 1.16 | 5.63 | 2.08 | 1.11 | 0.18 | 4.74 | 1.76 | 0.00 | 98.74 |
| 53 | Ttv | 86-200 | 57.4 | 0.61 | 14.0 | 3.57 | 0.68 | 0.07 | 1.56 | 5.09 | 0.86 | 0.79 | 0.11 | 9.13 | 5.57 | 0.00 | 99.44 |
| 54 | Ttv | 86-130 | 64.0 | 0.67 | 14.4 | 2.33 | 2.00 | 0.09 | 1.13 | 3.54 | 3.85 | 1.77 | 0.14 | 4.15 | 1.45 | 0.00 | 99.52 |
| 55 | Ttv | 86-097 | 64.7 | 0.67 | 14.6 | 2.10 | 2.14 | 0.09 | 1.07 | 3.35 | 4.13 | 1.80 | 0.13 | 3.92 | 0.76 | 0.00 | 99.46 |
| 56 | Ttv | 86-145 | 64.1 | 0.82 | 14.1 | 2.11 | 2.37 | 0.10 | 1.11 | 3.78 | 3.90 | 1.23 | 0.19 | 3.98 | 1.76 | 0.00 | 99.55 |
| 57 | Ttv | 86-125 | 65.6 | 0.64 | 14.4 | 2.14 | 2.04 | 0.09 | 0.92 | 3.05 | 4.19 | 2.39 | 0.13 | 3.42 | 0.43 | 0.00 | 99.44 |
| 58 | Ttv | 86-116 | 67.6 | 0.74 | 14.2 | 4.54 | 0.58 | 0.09 | 0.74 | 2.50 | 4.53 | 2.52 | 0.16 | 0.64 | 0.90 | 0.00 | 99.74 |
| 59 | Ttv | 86-092 | 66.5 | 0.77 | 13.6 | 3.12 | 2.13 | 0.08 | 0.86 | 1.19 | 4.71 | 3.20 | 0.17 | 0.95 | 0.24 | 0.01 | 97.53 |
| 60 | Ttv | 86-141 | 67.5 | 0.78 | 14.4 | 3.71 | 0.96 | 0.07 | 0.82 | 2.14 | 4.49 | 2.71 | 0.18 | 0.82 | 0.77 | 0.00 | 99.35 |
| 61 | Tbd | 86-042 | 67.6 | 0.47 | 15.3 | 2.23 | 1.18 | 0.06 | 1.34 | 3.07 | 3.23 | 3.11 | 0.10 | 1.46 | 0.32 | 0.03 | 99.50 |
| 62 | Td | 87-234 | 67.4 | 0.58 | 15.4 | 4.66 | 0.14 | 0.06 | 0.10 | 2.26 | 4.40 | 1.80 | 0.23 | 1.16 | 0.62 | 0.08 | 98.89 |
| 63 | Ttv | 86-147 | 68.8 | 0.77 | 14.2 | 3.57 | 0.66 | 0.08 | 0.58 | 2.29 | 4.76 | 2.48 | 0.18 | 0.78 | 0.48 | 0.00 | 99.63 |
| 64 | Trda | 86-017 | 70.0 | 0.43 | 13.9 | 3.57 | 0.38 | 0.05 | 0.61 | 1.66 | 4.13 | 3.31 | 0.08 | 0.58 | 0.34 | 0.00 | 99.04 |
| 65 | Trda | 86-051 | 71.0 | 0.62 | 13.5 | 4.20 | 0.26 | 0.02 | 0.26 | 0.77 | 4.21 | 3.03 | 0.14 | 0.90 | 0.34 | 0.00 | 99.25 |
| 66 | Trda | 86-046 | 74.5 | 0.55 | 11.7 | 5.04 | 0.15 | 0.08 | 0.21 | 0.45 | 3.82 | 0.91 | 0.12 | 1.16 | 0.37 | 0.00 | 99.06 |

| Map No. | Recalculated H2O- and CO2-free to 100 percent, with iron as FeO SiO2 | TiO2 | Al2O3 | FeOT | MnO | MgO | CaO | Na2O | K2O | P2O5 | Na2O+K2O | FeOT/MgO | Longitude Deg | Longitude Min | Latitude Deg | Latitude Min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 | 63.25 | 0.71 | 16.78 | 4.90 | 0.08 | 3.09 | 4.36 | 4.72 | 1.93 | 0.19 | 6.65 | 1.59 | 121 | 53.412 | 46 | 20.832 |
| 48 | 63.41 | 0.70 | 17.54 | 4.92 | 0.09 | 2.51 | 4.44 | 5.10 | 1.13 | 0.17 | 6.23 | 1.96 | 121 | 52.542 | 46 | 20.820 |
| 49 | 63.97 | 0.92 | 16.23 | 5.83 | 0.18 | 1.98 | 4.43 | 4.47 | 1.69 | 0.31 | 6.16 | 2.94 | 121 | 56.580 | 46 | 15.180 |
| 50 | 64.80 | 1.26 | 14.47 | 6.87 | 0.12 | 1.47 | 4.55 | 3.72 | 2.41 | 0.33 | 6.13 | 4.67 | 121 | 56.352 | 46 | 20.322 |
| 51 | 67.45 | 0.85 | 15.36 | 4.60 | 0.15 | 0.81 | 2.94 | 4.74 | 2.88 | 0.20 | 7.62 | 5.68 | 121 | 54.702 | 46 | 22.080 |
| 52 | 67.55 | 0.79 | 15.01 | 5.48 | 0.12 | 1.26 | 6.12 | 2.26 | 1.21 | 0.20 | 3.47 | 4.35 | 121 | 58.680 | 46 | 19.518 |
| 53 | 68.03 | 0.72 | 16.59 | 4.61 | 0.08 | 1.85 | 6.03 | 1.02 | 0.94 | 0.13 | 1.96 | 2.49 | 121 | 52.950 | 46 | 21.102 |
| 54 | 68.31 | 0.72 | 15.37 | 4.38 | 0.10 | 1.21 | 3.78 | 4.11 | 1.89 | 0.15 | 6.00 | 3.62 | 121 | 54.372 | 46 | 20.922 |
| 55 | 68.41 | 0.71 | 15.44 | 4.26 | 0.10 | 1.13 | 3.54 | 4.37 | 1.90 | 0.14 | 6.27 | 3.77 | 121 | 56.688 | 46 | 21.600 |
| 56 | 68.48 | 0.88 | 15.06 | 4.56 | 0.11 | 1.19 | 4.04 | 4.17 | 1.31 | 0.20 | 5.48 | 3.83 | 121 | 55.512 | 46 | 22.152 |
| 57 | 68.78 | 0.67 | 15.10 | 4.16 | 0.09 | 0.96 | 3.20 | 4.39 | 2.51 | 0.14 | 6.90 | 4.33 | 121 | 54.828 | 46 | 20.250 |
| 58 | 69.16 | 0.76 | 14.53 | 4.78 | 0.09 | 0.76 | 2.56 | 4.63 | 2.58 | 0.16 | 7.21 | 6.29 | 121 | 55.848 | 46 | 20.358 |
| 59 | 69.26 | 0.80 | 14.16 | 5.14 | 0.08 | 0.90 | 1.24 | 4.91 | 3.33 | 0.18 | 8.24 | 5.71 | 121 | 56.760 | 46 | 20.658 |
| 60 | 69.31 | 0.80 | 14.79 | 4.42 | 0.07 | 0.84 | 2.20 | 4.61 | 2.78 | 0.18 | 7.39 | 5.26 | 121 | 52.980 | 46 | 22.224 |
| 61 | 69.35 | 0.48 | 15.70 | 3.27 | 0.06 | 1.37 | 3.15 | 3.31 | 3.19 | 0.10 | 6.50 | 2.39 | 121 | 58.722 | 46 | 20.250 |
| 62 | 69.80 | 0.60 | 15.95 | 4.49 | 0.06 | 0.10 | 2.34 | 4.56 | 1.86 | 0.24 | 6.42 | 44.90 | 121 | 56.130 | 46 | 16.572 |
| 63 | 70.20 | 0.79 | 14.49 | 3.95 | 0.08 | 0.59 | 2.34 | 4.86 | 2.53 | 0.18 | 7.39 | 6.69 | 121 | 52.818 | 46 | 21.480 |
| 64 | 71.60 | 0.44 | 14.22 | 3.67 | 0.05 | 0.62 | 1.70 | 4.22 | 3.39 | 0.08 | 7.61 | 5.92 | 121 | 58.632 | 46 | 19.218 |
| 65 | 72.75 | 0.64 | 13.83 | 4.14 | 0.02 | 0.27 | 0.79 | 4.31 | 3.10 | 0.14 | 7.41 | 15.33 | 121 | 59.982 | 46 | 21.198 |
| 66 | 76.78 | 0.57 | 12.06 | 4.83 | 0.08 | 0.22 | 0.46 | 3.94 | 0.94 | 0.12 | 4.88 | 21.95 | 121 | 59.160 | 46 | 20.748 |

*X-ray fluorescence analyses done in U.S. Geological Survey laboratories in Menlo Park, Calif., (analyst Marsha Dyslin) and Denver, Colo., (analysts J. Taggart, A.J. Bartel, and D. Siems)*
*FeO and carbon dioxide analyses done in U.S. Geological Survey laboratories in Menlo Park (analyst J. Consul) and Denver (Analyst E. Brandt)*
*Water (both plus and minus) analyses done in U.S. Geological Survey laboratory in Menlo Park (analysts L. Espos and J. Consul)*
*Analyses with field numbers prefaced by MK from Korosec (1987); by 3, 5, 7, 8R, or 8E from R.C. Evarts and R.P. Ashley (written commun., 1988); and by 85, 86, or 87 from this study*

## Table 2. Chemical analyses from the Greenhorn Buttes Quadrangle, Washington

| Map | Map | Field | | | | | | Original Analysis | | | | | | | | | Recalculated H2O- and CO2-free to 100 percent, with iron as FeO | | | | | | | | | | | | | Longitude | | Latitude | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Unit | No. | SiO2 | TiO2 | Al2O3 | Fe2O3 | FeO | MnO | MgO | CaO | Na2O | K2O | P2O5 | H2O+ | H2O- | CO2 | Total | SiO2 | TiO2 | Al2O3 | FeOT | MnO | MgO | CaO | Na2O | K2O | P2O5 | Na2O+K2O | FeOT/MgO | Deg | Min | Deg | Min |
| 108 | Tbhm | MK8565 | 50.9 | 1.51 | 20.0 | 4.50 | 5.15 | 0.17 | 4.24 | 9.57 | 3.55 | 0.15 | 0.23 | | | | 99.97 | 51.15 | 1.52 | 20.10 | 9.22 | 0.17 | 4.26 | 9.62 | 3.57 | 0.15 | 0.23 | 3.72 | 2.17 | 121 | 56.520 | 46 | 29.952 |
| 102 | Tbhm | 2E106 | 51.0 | 1.00 | 18.8 | 4.00 | 5.30 | 0.17 | 6.10 | 9.70 | 3.10 | 0.56 | 0.32 | 0.58 | 0.52 | 0.02 | 101.47 | 51.18 | 1.00 | 18.87 | 8.93 | 0.17 | 6.12 | 9.73 | 3.11 | 0.56 | 0.32 | 3.67 | 1.46 | 122 | 0.120 | 46 | 28.512 |
| 67 | Ta | 87-062 | 50.2 | 1.54 | 18.6 | 5.00 | 4.59 | 0.16 | 3.60 | 9.60 | 3.10 | 0.22 | 0.20 | 0.32 | 1.84 | 0.00 | 98.97 | 52.12 | 1.60 | 19.31 | 9.44 | 0.17 | 3.74 | 9.97 | 3.22 | 0.23 | 0.21 | 3.45 | 2.52 | 121 | 56.700 | 46 | 26.418 |
| 103 | Tbhm | 1E20 | 51.5 | 0.94 | 20.7 | 3.00 | 4.80 | 0.15 | 3.60 | 10.60 | 2.80 | 0.35 | 0.14 | 0.33 | 0.97 | 0.05 | 99.93 | 52.40 | 0.96 | 21.06 | 7.63 | 0.15 | 3.66 | 10.79 | 2.85 | 0.36 | 0.14 | 3.21 | 2.08 | 121 | 59.988 | 46 | 28.062 |
| 68 | Tbhm | 87-066 | 51.4 | 1.12 | 18.1 | 3.64 | 5.15 | 0.17 | 5.10 | 9.54 | 3.00 | 0.68 | 0.20 | 0.46 | 0.81 | 0.00 | 99.37 | 52.59 | 1.15 | 18.52 | 8.62 | 0.17 | 5.22 | 9.76 | 3.07 | 0.70 | 0.20 | 3.77 | 1.65 | 121 | 59.364 | 46 | 28.644 |
| 69 | Ta | 87-054 | 51.7 | 1.04 | 16.4 | 4.40 | 4.85 | 0.18 | 6.30 | 8.38 | 3.40 | 0.62 | 0.22 | 0.37 | 1.43 | 0.07 | 99.36 | 53.27 | 1.07 | 16.90 | 9.08 | 0.19 | 6.49 | 8.63 | 3.50 | 0.64 | 0.23 | 4.14 | 1.40 | 121 | 56.472 | 46 | 25.890 |
| 109 | Ta | MK8569 | 53.2 | 1.14 | 18.8 | 4.22 | 4.83 | 0.19 | 4.81 | 9.79 | 2.70 | 0.19 | 0.15 | | | | 100.03 | 53.42 | 1.14 | 18.87 | 8.65 | 0.19 | 4.83 | 9.83 | 2.71 | 0.19 | 0.15 | 2.90 | 1.79 | 121 | 57.882 | 46 | 26.178 |
| 70 | Ta | 87-055 | 51.1 | 1.32 | 17.2 | 5.81 | 3.38 | 0.26 | 4.20 | 8.04 | 3.30 | 1.16 | 0.24 | 0.46 | 2.28 | 0.00 | 98.75 | 53.55 | 1.38 | 18.02 | 9.03 | 0.27 | 4.40 | 8.42 | 3.46 | 1,22 | 0.25 | 4.67 | 2.05 | 121 | 56.382 | 46 | 25.344 |
| 71 | Ta | 87-162 | 51.9 | 1.56 | 16.5 | 3.94 | 5.54 | 0.16 | 3.70 | 8.78 | 3.30 | 0.46 | 0.26 | 0.99 | 1.73 | 0.00 | 98.82 | 54.23 | 1.63 | 17.24 | 9.50 | 0.17 | 3.87 | 9.17 | 3.45 | 0.48 | 0.27 | 3.93 | 2.45 | 121 | 54.258 | 46 | 27.798 |
| 72 | Tbhm | 87-063 | 53.6 | 1.14 | 18.4 | 3.49 | 4.29 | 0.16 | 4.10 | 8.24 | 3.60 | 0.64 | 0.22 | 0.21 | 1.14 | 0.00 | 99.23 | 54.96 | 1.17 | 18.87 | 7.62 | 0.16 | 4.20 | 8.45 | 3.69 | 0.66 | 0.23 | 4.35 | 1.81 | 121 | 58.092 | 46 | 28.530 |
| 73 | Tagc | 87-170 | 53.6 | 1.28 | 15.7 | 3.83 | 5.51 | 0.15 | 4.60 | 8.18 | 3.00 | 0.70 | 0.18 | 0.77 | 1.27 | 0.00 | 98.77 | 55.63 | 1.33 | 16.30 | 9.29 | 0.16 | 4.77 | 8.49 | 3.11 | 0.73 | 0.19 | 3.84 | 1.95 | 121 | 52.848 | 46 | 24.666 |
| 74 | Tabc | 87-007 | 53.8 | 1.62 | 16.6 | 4.47 | 5.43 | 0.19 | 2.90 | 7.14 | 3.50 | 1.10 | 0.28 | 1.63 | 0.36 | 0.10 | 99.12 | 55.71 | 1.68 | 17.19 | 9.78 | 0.20 | 3.00 | 7.39 | 3.62 | 1.14 | 0.29 | 4.76 | 3.26 | 121 | 59.382 | 46 | 23.376 |
| 110 | Ta | MK85620 | 55.5 | 1.21 | 18.2 | 4.41 | 5.06 | 0.17 | 3.68 | 8.60 | 2.79 | 0.23 | 0.16 | | | | 100.01 | 55.74 | 1.22 | 18.28 | 9.05 | 0.17 | 3.70 | 8.64 | 2.80 | 0.23 | 0.16 | 3.03 | 2.45 | 121 | 54.390 | 46 | 29.082 |
| 75 | Tagc | 87-169 | 52.9 | 1.14 | 15.8 | 5.30 | 3.48 | 0.19 | 4.40 | 8.22 | 2.70 | 0.82 | 0.20 | 0.69 | 3.06 | 0.00 | 98.90 | 55.91 | 1.20 | 16.70 | 8.72 | 0.20 | 4.65 | 8.69 | 2.85 | 0.87 | 0.21 | 3.72 | 1.88 | 121 | 52.590 | 46 | 24.582 |
| 111 | Ta | MK8571 | 55.7 | 1.22 | 18.0 | 4.38 | 5.02 | 0.16 | 3.56 | 8.51 | 3.02 | 0.28 | 0.16 | | | | 100.01 | 55.94 | 1.23 | 18.08 | 8.98 | 0.16 | 3.58 | 8.55 | 3.03 | 0.28 | 0.16 | 3.31 | 2.51 | 121 | 56.328 | 46 | 27.540 |
| 76 | Ta | 87-199 | 54.3 | 0.96 | 15.9 | 2.86 | 5.01 | 0.15 | 5.60 | 7.84 | 2.90 | 1.00 | 0.16 | 0.58 | 1.51 | 0.08 | 98.85 | 56.33 | 1.00 | 16.49 | 7.87 | 0.16 | 5.81 | 8.13 | 3.01 | 1.04 | 0.17 | 4.05 | 1.35 | 121 | 57.912 | 46 | 25.464 |
| 77 | Ta | 87-049 | 54.7 | 0.90 | 16.6 | 3.78 | 3.91 | 0.13 | 4.70 | 8.64 | 2.90 | 0.94 | 0.14 | 0.49 | 1.34 | 0.04 | 99.21 | 56.42 | 0.93 | 17.12 | 7.54 | 0.13 | 4.85 | 8.91 | 2.99 | 0.97 | 0.14 | 3.96 | 1.55 | 121 | 58.068 | 46 | 23.550 |
| 104 | Ta | 1E19 | 55.3 | 1.00 | 17.7 | 3.90 | 3.70 | 0.14 | 4.00 | 7.80 | 3.20 | 1.10 | 0.21 | 0.40 | 0.30 | 0.04 | 98.79 | 56.63 | 1.02 | 18.12 | 7.38 | 0.14 | 4.10 | 7.99 | 3.28 | 1.13 | 0.22 | 4.41 | 1.80 | 121 | 59.610 | 46 | 28.098 |
| 78 | Ta | 86-066 | 53.4 | 1.22 | 17.8 | 3.20 | 4.30 | 0.18 | 3.38 | 6.26 | 3.84 | 0.61 | 0.26 | 3.42 | 1.36 | 0.12 | 99.35 | 56.73 | 1.30 | 18.91 | 7.63 | 0.19 | 3.59 | 6.65 | 4.08 | 0.65 | 0.28 | 4.73 | 2.13 | 121 | 57.888 | 46 | 23.088 |
| 79 | Ta | 87-105 | 55.7 | 1.08 | 17.1 | 3.63 | 4.18 | 0.13 | 3.90 | 7.86 | 3.50 | 0.90 | 0.18 | 0.82 | 0.39 | 0.00 | 99.37 | 56.96 | 1.10 | 17.49 | 7.61 | 0.13 | 3.99 | 8.04 | 3.58 | 0.92 | 0.18 | 4.50 | 1.91 | 121 | 55.794 | 46 | 29.082 |
| 112 | Ta | MK85629 | 57.1 | 1.07 | 17.5 | 3.82 | 4.38 | 0.14 | 4.03 | 8.18 | 3.10 | 0.53 | 0.18 | | | | 100.03 | 57.30 | 1.07 | 17.56 | 7.83 | 0.14 | 4.04 | 8.21 | 3.11 | 0.53 | 0.18 | 3.64 | 1.94 | 121 | 56.010 | 46 | 29.412 |
| 80 | Ta | 87-030 | 56.0 | 1.22 | 16.9 | 3.89 | 4.05 | 0.11 | 3.30 | 7.38 | 3.40 | 1.38 | 0.20 | 0.30 | 0.88 | 0.00 | 99.01 | 57.47 | 1.25 | 17.34 | 7.75 | 0.11 | 3.39 | 7.57 | 3.49 | 1.42 | 0.21 | 4.91 | 2.29 | 121 | 56.790 | 46 | 24.240 |
| 81 | Ta | 86-058 | 56.7 | 1.18 | 16.1 | 3.49 | 4.60 | 0.13 | 4.07 | 7.63 | 3.04 | 1.29 | 0.23 | 0.61 | 0.62 | 0.04 | 99.73 | 57.79 | 1.20 | 16.41 | 7.89 | 0.13 | 4.15 | 7.78 | 3.10 | 1.31 | 0.23 | 4.41 | 1.90 | 121 | 57.198 | 46 | 22.890 |
| 82 | Ta | 87-040 | 56.0 | 1.14 | 16.7 | 4.36 | 3.44 | 0.10 | 3.40 | 6.98 | 3.30 | 1.48 | 0.20 | 0.43 | 1.31 | 0.01 | 98.85 | 57.93 | 1.18 | 17.28 | 7.62 | 0.10 | 3.52 | 7.22 | 3.41 | 1.53 | 0.21 | 4.95 | 2.16 | 121 | 57.330 | 46 | 23.412 |
| 83 | Ta | 87-052 | 55.8 | 1.24 | 15.9 | 4.59 | 3.47 | 0.18 | 3.60 | 6.96 | 3.30 | 1.50 | 0.24 | 0.59 | 1.21 | 0.02 | 98.60 | 57.93 | 1.29 | 16.51 | 7.90 | 0.19 | 3.74 | 7.23 | 3.43 | 1.56 | 0.25 | 4.98 | 2.11 | 121 | 57.078 | 46 | 23.778 |
| 84 | Ta | 87-058 | 56.7 | 1.30 | 16.8 | 3.98 | 4.25 | 0.13 | 2.90 | 6.70 | 3.80 | 1.10 | 0.26 | 0.30 | 1.06 | 0.00 | 99.28 | 58.14 | 1.33 | 17.23 | 8.03 | 0.13 | 2.97 | 6.87 | 3.90 | 1.13 | 0.27 | 5.02 | 2.70 | 121 | 56.400 | 46 | 25.248 |
| 85 | Tai | 87-038 | 56.4 | 1.00 | 17.0 | 5.06 | 2.27 | 0.12 | 3.60 | 7.08 | 3.30 | 1.12 | 0.16 | 0.45 | 1.73 | 0.03 | 99.32 | 58.38 | 1.04 | 17.60 | 7.06 | 0.12 | 3.73 | 7.33 | 3.42 | 1.16 | 0.17 | 4.58 | 1.89 | 121 | 53.178 | 46 | 22.938 |
| 113 | Ta | MK85636 | 58.3 | 1.12 | 17.1 | 3.71 | 4.24 | 0.15 | 3.56 | 7.68 | 2.79 | 1.21 | 0.20 | | | | 100.06 | 58.48 | 1.12 | 17.15 | 7.59 | 0.15 | 3.57 | 7.70 | 2.80 | 1.21 | 0.20 | 4.01 | 2.13 | 121 | 56.730 | 46 | 23.880 |
| 86 | Ta | 87-022 | 58.0 | 1.62 | 15.8 | 3.47 | 4.63 | 0.16 | 2.50 | 5.86 | 4.10 | 1.26 | 0.52 | 0.37 | 0.81 | 0.00 | 99.10 | 59.45 | 1.66 | 16.19 | 7.94 | 0.16 | 2.56 | 6.01 | 4.20 | 1.29 | 0.53 | 5.49 | 3.10 | 121 | 59.628 | 46 | 23.238 |
| 87 | Tabc | 86-054 | 57.9 | 1.66 | 15.3 | 5.49 | 3.72 | 0.20 | 2.54 | 6.34 | 3.30 | 1.18 | 0.32 | 1.63 | 0.50 | 0.15 | 100.23 | 59.45 | 1.70 | 15.71 | 8.89 | 0.21 | 2.61 | 6.51 | 3.39 | 1.21 | 0.33 | 4.60 | 3.41 | 121 | 54.588 | 46 | 24.228 |
| 88 | Ta | 87-057 | 58.2 | 1.30 | 16.0 | 3.81 | 4.07 | 0.15 | 2.60 | 5.92 | 3.90 | 1.36 | 0.32 | 0.33 | 0.99 | 0.00 | 98.95 | 59.85 | 1.34 | 16.45 | 7.71 | 0.15 | 2.67 | 6.09 | 4.01 | 1.40 | 0.33 | 5.41 | 2.89 | 121 | 56.400 | 46 | 25.440 |
| 89 | Ta | 86-068 | 59.4 | 1.05 | 16.1 | 3.30 | 3.75 | 0.10 | 2.85 | 6.14 | 3.31 | 1.66 | 0.22 | 0.78 | 1.16 | 0.08 | 99.90 | 60.89 | 1.08 | 16.50 | 6.89 | 0.10 | 2.92 | 6.29 | 3.39 | 1.70 | 0.23 | 5.09 | 2.36 | 121 | 57.780 | 46 | 23.070 |
| 90 | Ta | 86-057 | 59.7 | 1.17 | 15.9 | 4.71 | 2.10 | 0.13 | 2.17 | 5.61 | 3.45 | 1.79 | 0.25 | 0.88 | 1.69 | 0.08 | 99.63 | 61.86 | 1.21 | 16.47 | 6.57 | 0.13 | 2:25 | 5.81 | 3.57 | 1.85 | 0.26 | 5.42 | 2.92 | 121 | 57.282 | 46 | 23.112 |
| 91 | Ta | 87-172 | 61.1 | 1.10 | 14.8 | 1.47 | 5.97 | 0.16 | 1.40 | 4.44 | 4.30 | 1.60 | 0.34 | 2.11 | 0.20 | 0.00 | 98.99 | 63.30 | 1.14 | 15.33 | 7.55 | 0.17 | 1.45 | 4.60 | 4.45 | 1.66 | 0.35 | 6.11 | 5.21 | 121 | 52.932 | 46 | 29.820 |
| 92 | Td | 87-194 | 63.7 | 0.90 | 15.2 | 3.92 | 2.01 | 0.15 | 1.20 | 3.80 | 4.50 | 1.94 | 0.32 | 0.42 | 1.67 | 0.02 | 99.75 | 65.50 | 0.93 | 15.63 | 5.69 | 0.15 | 1.23 | 3.91 | 4.63 | 1.99 | 0.33 | 6.62 | 4.63 | 121 | 57.780 | 46 | 25.008 |
| 93 | Td | 87-197 | 63.8 | 0.96 | 14.9 | 4.61 | 1.87 | 0.12 | 1.20 | 3.58 | 4.50 | 1.80 | 0.30 | 0.42 | 0.96 | 0.09 | 99.11 | 65.65 | 0.99 | 15.33 | 6.20 | 0.12 | 1.23 | 3.68 | 4.63 | 1.85 | 0.31 | 6.48 | 5.04 | 121 | 57.840 | 46 | 25.158 |
| 94 | Td | 87-053 | 64.6 | 0.96 | 15.3 | 4.45 | 1.30 | 0.10 | 0.75 | 3.30 | 4.80 | 2.06 | 0.30 | 0.62 | 0.64 | 0.00 | 99.18 | 66.28 | 0.98 | 15.70 | 5.44 | 0.10 | 0.77 | 3.39 | 4.92 | 2.11 | 0.31 | 7.04 | 7.06 | 121 | 54.168 | 46 | 26.982 |
| 95 | Tdbm | 87-094 | 63.8 | 1.00 | 14.4 | 1.56 | 3.89 | 0.11 | 1.20 | 3.80 | 3.90 | 2.50 | 0.26 | 2.32 | 0.47 | 0.00 | 99.21 | 66.28 | 1.04 | 14.96 | 5.50 | 0.11 | 1.25 | 3.95 | 4.05 | 2.60 | 0.27 | 6.65 | 4.40 | 121 | 56.394 | 46 | 25.662 |
| 96 | Tdbm | 85-014 | 64.1 | 0.91 | 14.5 | 1.35 | 3.86 | 0.10 | 1.18 | 3.82 | 4.00 | 2.36 | 0.25 | 2.44 | 0.33 | 0.00 | 99.20 | 66.56 | 0.94 | 15.06 | 5.28 | 0.10 | 1.23 | 3.97 | 4.15 | 2.45 | 0.26 | 6.60 | 4.29 | 121 | 55.422 | 46 | 25.242 |
| 97 | Td | 87-175 | 65.3 | 0.86 | 15.3 | 3.82 | 1.14 | 0.18 | 0.60 | 3.28 | 4.70 | 1.88 | 0.28 | 0.75 | 0.57 | 0.00 | 98.66 | 67.35 | 0.89 | 15.78 | 4.72 | 0.19 | 0.62 | 3.38 | 4.85 | 1.94 | 0.29 | 6.79 | 7.61 | 121 | 52.860 | 46 | 27.780 |
| 114 | Tdbm | MK85635 | 67.9 | 0.92 | 14.8 | 2.68 | 3.07 | 0.11 | 1.07 | 3.73 | 3.19 | 2.40 | 0.22 | | | | 100.09 | 68.02 | 0.92 | 14.83 | 5.49 | 0.11 | 1.07 | 3.74 | 3.20 | 2.40 | 0.22 | 5.60 | 5.12 | 121 | 55.422 | 46 | 25.242 |
| 98 | Ttv | 86-073 | 63.5 | 0.71 | 13.2 | 2.52 | 2.52 | 0.09 | 0.89 | 4.72 | 2.79 | 0.98 | 0.15 | 5.88 | 1.48 | 0.00 | 99.43 | 69.16 | 0.77 | 14.38 | 5.22 | 0.10 | 0.97 | 5.14 | 3.04 | 1.07 | 0.16 | 4.11 | 5.38 | 121 | 57.660 | 46 | 23.052 |
| 99 | Td | 87-029 | 68.7 | 0.84 | 13.5 | 4.53 | 0.46 | 0.07 | 0.50 | 3.02 | 3.80 | 2.34 | 0.24 | 0.40 | 0.50 | 0.00 | 98.90 | 70.43 | 0.86 | 13.84 | 4.65 | 0.07 | 0.51 | 3.10 | 3.90 | 2.40 | 0.25 | 6.29 | 9.12 | 121 | 56.652 | 46 | 24.270 |
| 100 | Td | 86-056C | 71.0 | 0.44 | 13.2 | 3.19 | 0.45 | 0.08 | 0.64 | 1.22 | 4.24 | 3.24 | 0.08 | 0.80 | 0.58 | 0.00 | 99.16 | 72.85 | 0.45 | 13.54 | 3.41 | 0.08 | 0.66 | 1.25 | 4.35 | 3.32 | 0.08 | 7.67 | 5.17 | 121 | 57.390 | 46 | 22.872 |
| 101 | Td | 87-051 | 71.6 | 0.44 | 13.8 | 2.55 | 0.73 | 0.05 | 0.20 | 1.28 | 4.70 | 3.06 | 0.10 | 0.39 | 0.19 | 0.00 | 99.09 | 72.87 | 0.45 | 14.05 | 3.08 | 0.05 | 0.20 | 1.30 | 4.78 | 3.11 | 0.10 | 7.90 | 15.40 | 121 | 57.540 | 46 | 23.460 |

*X-ray fluorescence analyses done in U.S. Geological Survey laboratories in Menlo Park, Calif., (analyst Marsha Dyslin) and Denver, Colo., (analysts J. Taggart, A.J. Bartel, and D. Siems)*
*FeO and carbon dioxide analyses done in U.S. Geological Survey laboratories in Menlo Park (analyst J. Consul) and Denver (analyst E. Brandt)*
*Water analyses (both plus and minus) done in U.S. Geological Survey laboratory in Menlo Park (analysts L. Espos and J. Consul)*
*Analyses with field numbers prefaced by MK from Korosec (1987); by 1E or 2E from R.C. Evarts and R.P. Ashley (written commun., 1988); and by 85, 86, or 87 from this study*

Table 3. Radiometric Ages for Rocks in the French Butte and Greenhorn Buttes Quadrangles, Southern Cascades of Washington

| Map No. | Map Unit | Longitude | Latitude | Age (Ma) | Reference |
|---|---|---|---|---|---|
| 1A[a] | Ttv | 121°58.68′ | 46°19.52′ | 23.3±1.8 | Evarts and Ashley (in press, a) |
| 2A[b] | Tbhm | 121°59.99′ | 46°28.06′ | 23.3±0.8 | Evarts and others (1987) |
| 3A[b] | Ttv | 121°54.50′ | 46°22.68′ | 18.4±0.3 | Hammond (1980) |
| | | | | 18.9±0.3 | do. |
| 4A[c] | Tdbm | 121°55.42′ | 46°25.25′ | 15.7±0.2 | Phillips and others (1986); Korosec (1987) |
| 5A[c] | Qbbr | 121°53.62′ | 46°18.11′ | 0.65±0.017 | J. G. Smith (written commun., Sept. 1986) |

[a]Six-step $Ar^{40}$-$Ar^{39}$ plateau age on plagioclase separate
[b]Standard K-Ar method on plagioclase separate
[c]Standard K-Ar method on whole rock

large shield or lava cone (Evarts and Ashley, in press b), although dips in the unit are in the same direction as, and only slightly steeper than, those of nearby units that probably were deposited at the foot of the volcano. An eruptive center probably accounts for the prominent, steeply dipping section of thin basaltic andesite flows 2.5 km southwest of Elk Pass. An unmapped cinder bed, cut by a dike in a road cut 3.2 km due east of Elk Pass, is possibly part of a vent for some of the nearby andesite flows. Iron Creek Butte may be another andesitic center, as judged from its concentration of lava flows surrounded by tuffaceous rocks.

Some or all of the small intrusive bodies in the two quadrangles many have fed eruptions. All were emplaced at shallow depth, as shown by their generally fine grain size (even glassy in places) and quenched margins. Good examples are the andesite intrusion at Greenhorn Buttes, basaltic andesite bodies 1.2 km north and 2.2 km southeast of French Butte, and relatively coarse-grained basaltic andesite intrusions 1.5 km west-northwest of the mouth of Wakepish Creek and near the south edge of the French Butte quadrangle west of Elk Creek. The ages of these intrusions are unknown. The Greenhorn Buttes intrusions cuts rocks interbedded with an ash-flow tuff K-Ar dated at about 18.5 Ma (Table 3, no. 3A), and the body near Wakepish Creek cuts rocks dated at about 23.3 Ma (Table 3, no. 1A). How much younger the intrusions are than their wallrock is an important unanswered question.

Examples of relatively widespread units of silicic lava flows include the dacite of Clearwater Creek and the rhyodacite of Strawberry Mountain, both of which are extensive farther west in the Spirit Lake East quadrangle (Evarts and Ashley, in press a) and probably were erupted there. However, a quartz-phyric dome (unit Tqd) 2 km due west of Elk Pass could denote a vent for the Clearwater Creek unit.

Another extensive silicic unit, the dacite of Bluff Mountain, apparently flowed along a narrow northeast-trending gorge cut into volcaniclastic rocks in the central part of the Greenhorn Buttes quadrangle. This flow is the youngest dated Tertiary unit in the two quadrangles, with a K-Ar age of 15.7 ± 0.2 Ma (Table 3, no. 4A), and apparently reflects volcanic activity following a period of erosion of unknown duration. The gorge that it followed must have drained northeastward, because the base of the flow descends in that direction, even on the northeast limb of the syncline. In fact, the base of the flow is about 120 m lower at the south end of Bluff Mountain than it is 2.5 km southwestward, toward the trough of the syncline. The intracanyon flow crosses the trough of the Pole Patch syncline at a high angle. This arrangement implies one of two relations: either the flow is younger than the syncline (which did not control topography so that the paleodrainage crossed rather than followed its trough) and rests with both angular and erosional discordance on the underlying rocks; or the flow is older than the syncline but shows no evidence of folding owing to the overwhelming effect of the obvious erosional unconformity. Exposures are not adequate to separate the effects of a possible angular unconformity from those of the erosional unconformity and hence to determine whether the flow is younger or older than the folding. The flow also obliquely crosses the course of the modern Cispus River; clearly the Cispus does not follow the middle Miocene drainage system reflected by the dacite-filled gorge.

## PLEISTOCENE VOLCANIC ROCKS

No evidence exists for volcanic activity in the mapped area following eruption of the dacite of Bluff Mountain until olivine basaltic andesite and andesite flows were erupted in the French Buttes quadrangle in the Quaternary. Both Quaternary units, the olivine-bearing basaltic andesite of Badger Ridge and the olivine andesite of The Loaf, have been glaciated and have normal magnetic polarity. A flow on Badger Ridge has a K-Ar age of about 0.65 Ma (Table 3, no. 54). The similar degree of erosion of both units weakly suggests that they are about the same age, and the similar range of chemical compositions within each unit (compare analyses 12, 17, 26, 31, and 32, Table 1) could be taken as evidence that the two units are genetically related.

The two units were apparently erupted on either side of the Cispus-Lewis drainage divide (nearby Badger Peak is on the east-west divide) and sent flows downslope from the divide, whose development therefore predates 0.65 Ma. The vent for the Badger Ridge flows is filled with a plug on Badger Ridge; the vent for the olivine andesite of The Loaf is not exposed, although olivine-bearing spatter occurs just under the flow at one location 2 km south-southeast of The Loaf. Both units are bounded by high cliffs and have clearly experienced significant reduction in outcrop area by erosion. Most likely, the present topography, in which the Pleistocene flows stand high above the Miocene rocks, results from inversion and glacial scour in the Elk Creek, Pinto Creek, and Yellowjacket Creek (just east of Badger Ridge) drainages. However, a puzzling aspect of this interpretation is that the Miocene lava flows seemingly are as resistant to erosion as are the Pleistocene flows; in fact, both readily form cliffs in the two quadrangles. Perhaps the Pleistocene flows were erupted on flat ridge crests and built topographic highs owing to relatively low fluidity; where lava dribbled into flanking valleys, later erosion and glacial scour removed it. Another possibility is that the valleys were occupied by ice when the eruptions occurred. Recent compilations of ages of glaciation and low ocean temperatures are consistent with the possibility of glaciers occupying valleys in the Cascades about 0.65 Ma (Imbrie and Imbrie, 1980; Johnson, 1982; Richmond and Fullerton, 1986).

The flows of Badger Ridge and The Loaf lie along the northeast-trending Tumtum-Badger Ridge line of Quaternary vents that bounds most Quaternary activity in the southern Cascades of Washington (Swanson, 1989). Northwest of the line, only two Quaternary vents not associated with Mount St. Helens and its lineaments (Evarts and others, 1987) occur. Southeast of the line, Quaternary vents are scattered throughout the region. The line itself connects isolated vents seemingly not a part of the scatter to the southeast. The significance of the line remains obscure.

## STRUCTURE

### FOLDS

The Pole Patch syncline dominates the structure of the area. It is relatively well defined throughout most of its extent; only in the poorly exposed area north of the Cispus River does it become indistinct. The syncline clearly predates the flows of Badger Ridge; its relation to the 15.7-Ma dacite of Bluff Mountain is uncertain, as described above. The syncline is asymmetric; its east limb generally dips more than 10° within 1-2 km of its trough, whereas its west limb dips less than 10° within 4-6 km of its trough. Whether the syncline plunges is not clear; if it does, the plunge direction is probably northward.

The Elk Creek syncline is less well defined than the Pole Patch syncline. Nonetheless, attitudes in the Elk Creek and upper Iron Creek drainages are consistent with the presence of such a structure. Its plunge, if any, is indefinite. Several west dips beyond the north end of the Elk Creek syncline suggest that the syncline extends nearly to the Greenhorn Buttes quadrangle; however, I interpret the dips to reflect rotation in landslide blocks rather than tectonic deformation.

In regional perspective, the two synclines may be viewed as *en echelon* segments of a single major syncline, mapped in various configurations by Hammond (1980; his Greenhorn Buttes syncline) and Walsh and others (1987). The two synclines represent a major low point in the regional structure. For example, dips in the Cowlitz Falls and Spirit Lake East quadrangles are typically eastward and east-northeastward, toward the synclinal troughs, with only local divergence caused by volcanic edifices (Evarts and Ashley, in press, a, b). In the Greenhorn Buttes and French Butte quadrangles, such edifices have little effect on the overall structural grain, as shown by the notable consistency in strike directions (Fig. 6).

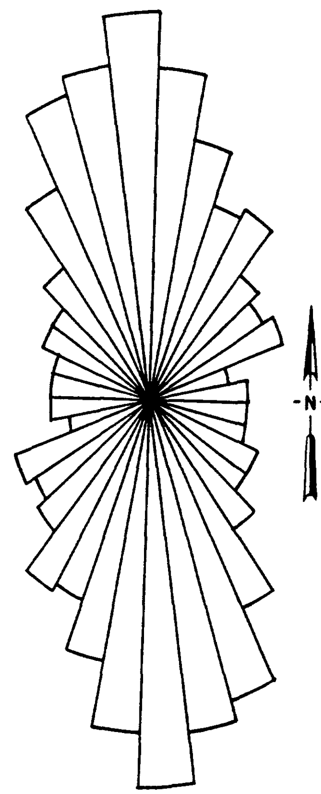



Figure 6. Equi-area rose diagram of 183 measured strikes of bedding and lava flows in French Butte and Greenhorn Buttes quadrangles, in 10° intervals. Mean azimuth, 357°; s.d., 35°.

An important caveat to my interpretation of two *en echelon* synclines plagues all interpretations of structures in the Cascades: the potential for confusion of significant primary dips in the volcanic units with younger tectonic dips. Steep primary dips, such as those at Pinto Rock, are easy to recognize, but the more common primary dips of 5-15° can readily be confused with later tilting. The attitudes in the French Butte and Greenhorn Buttes quadrangles clearly reflect a major synclinal structure, but I am less certain about my interpretation of two *en echelon* structures, owing to the possible mixing of primary and tectonic dips.

Probably the best test of the interpretation will come from further mapping south of the French Butte quadrangle and from a better understanding of the regional structural framework of the southern Washington.

## FAULTS AND SHEARS

No major faults were identified in the two quadrangles. However, small steeply dipping shears with subhorizontal slickensides are widespread. I could determine little if any offset along them. Typically they are oriented northwest to north-northwest and have polished surfaces that are stepped in a pattern suggestive of dextral slip; this pattern can be determined only by rubbing the polished surface with and against the "grain" of the slickensides. A few northeast-trending shears have stepping suggestive of sinistral movement. A particularly good example of a dextral shear is in a quarry 700 m due north of the mouth of Wakepish Creek in the Iron Creek drainage. Another dextral shear is clearly exposed in a quarry 1.3 km east of the mouth of Ames Creek in the northern part of the Greenhorn Buttes quadrangle. Both quarries are sometimes active, so the exposures are probably ephemeral.

These shear zones are probably part of a regional system of similar structures, chiefly north- to northwest-trending with dextral movement, recognized on the western Columbia Plateau in Washington and northern Oregon; in places they are simply shear zones with little displacement, and in other places they are faults with offsets of hundreds of meters or more (Bentley and Anderson, 1980; Anderson and others, 1987).

## DIKE ORIENTATIONS

Most dikes in the two quadrangles trend slightly north of due west (Fig. 7). All but two of the dikes are in the French Butte quadrangle, and most of those are in the southern half of the quadrangle, where they form a notable dike swarm of andesite and basaltic andesite. Dikes of hornblende dacite in the Pumice Creek area east of French Butte have a similar trend. Work in progress east of the mapped area shows a similar preferred orientation of dikes throughout a north-south extent of 25 km. Dikes west of the mapped area, however, have nearly random orientations (Evarts and Ashley, in press a, b).

Dikes propagate parallel to the direction of maximum principal stress and normal to the direction of least principal stress at the time of intrusion. The

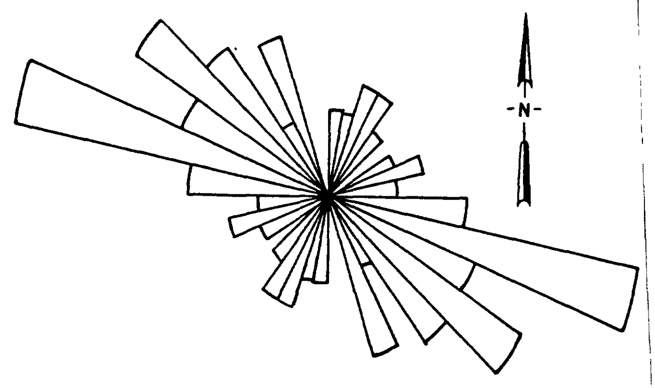



Figure 7. Equi-area rose diagram of measured trends of 60 dikes, 58 from French Butte quadrangle and 2 from Greenhorn Buttes quadrangle, in 10° intervals. Mean azimuth, 280°; s.d., 35°.

roughly east-west orientation within the mapped area suggests a roughly east-west maximum compressional stress and a north-south minimum principal stress. This stress orientation is consistent with that expected from the overall trend of the Cascade Range, according to Nakamura (1977; Nakamura and others, 1977). Significant variation from this orientation probably reflects local stress fields imposed on the regional one. For example, dikes of basalt and basaltic andesite on Huffaker Mountain trend north to north-northeast (Evarts and Ashley, in press b; this map) and may record stresses related to formation of the Huffaker edifice. The lack of consistent orientation in the Cowlitz Falls and Spirit Lake quadrangles to the west suggests complex interaction of regional and local stress systems, possibly caused by the intrusion of the Spirit Lake pluton and other bodies (Evarts and Ashley, in press a, b; Evarts and others, 1987).

The mean strike of the dikes, 280°, is about 10° greater than a normal to the approximately north-south trending Cascade Range. This difference could be accounted for by clockwise rotation of 10° since the dikes were emplaced. Clockwise rotation of Tertiary rocks in southern Washington has been documented by a number of workers on the basis of paleomagnetic data (Simpson and Cox, 1977; Beck and Burr, 1979; Bates and others, 1981; Wells and Coe, 1985). Whether the orientation of the dikes can be interpreted in terms of rotation is unclear but intriguing.

The relative consistency of dike orientations in the French Butte quadrangle and farther east suggests a kind of "norm" against which other orientations can be compared. In other words, dikes lacking such an orientation may be considered to reflect a local stress field and hence may help to guide more detailed field examination of the causes of that field.

## CHEMICAL CLASSIFICATION

All of the Tertiary rocks are to some extent altered and oxidized (Tables 1 and 2). Glass is hydrated or replaced by low-temperature clay and zeolite, and orthopyroxene and olivine are typically partly to wholly replaced by clay. Clinopyroxene and plagioclase are relatively fresh, although even these minerals are locally altered to clay and calcite. In addition, veinlets of clay and calcite are locally present. The alteration and oxidation reflect the regional burial and weak hydrothermal alteration that is prevalent in the middle Tertiary rocks of the Washington and Oregon Cascades. Interpretation of whole-rock chemical compositions must take into account the effects of such regional processes. Hence only analyses normalized to 100 percent on an $H_2O$- and $CO_2$-free basis, with all iron recalculated as $FeO_T$ are used in the following comparisons (Tables 1 and 2).

Overall the whole-rock compositions of the volcanic rocks in the two quadrangles are rather typical of those of orogenic arc volcanism, particularly that on a continental margin (Gill, 1981). The Tertiary rocks define a distinctly calcic suite, with an alkali-lime index of 62.6 (Fig. 8; Peacock, 1931). None of the rocks is alkalic (Fig. 2), and analyses of Tertiary basaltic andesite and andesite plot in the medium- and low-K andesite fields on a classification diagram slightly

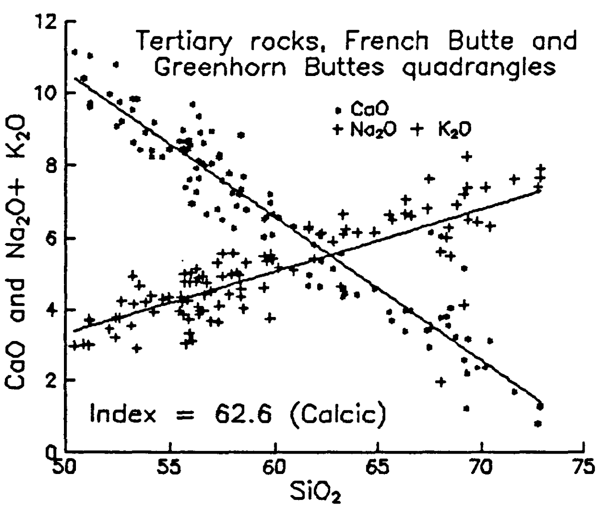



Figure 8. Plot of CaO and $Na_2O$ + $K_2O$ vs $SiO_2$ for Tertiary rocks in French Butte and Greenhorn Buttes quadrangles. Best-fit linear fits cross at $SiO_2$ = 62.6 percent, so that the suite can be classed as *calcic* in the terminology of Peacock (1931).

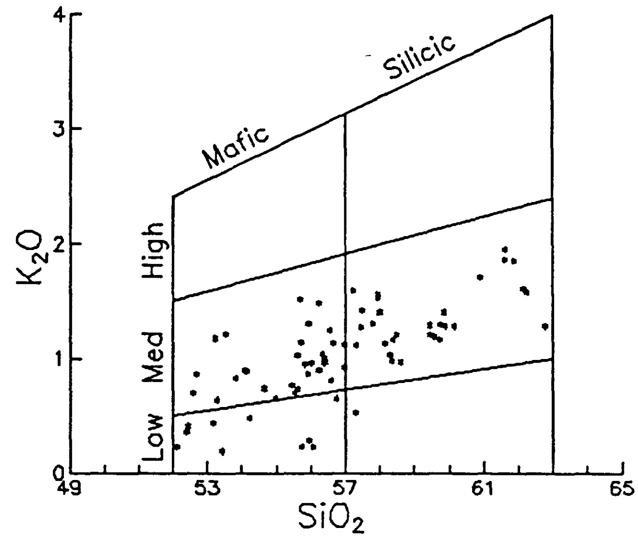



Figure 9. Plot of $K_2O$ vs $SiO_2$ for Tertiary basaltic andesite and andesite in French Butte and Greenhorn Buttes quadrangles. Fields modified from Gill (1981), so that mafic andesite (basaltic andesite in the IUGS terminology used in this paper) extends down to 52 percent. The rocks are dominantly medium-K mafic and silicic andesite (basaltic andesite and andesite in IUGS terminology), with a few (mostly basaltic andesite) in the low-K range.

modified after Gill (1981; Fig. 9). On an AFM diagram and a plot of $FeO_T/MgO$ vs $SiO_2$, the Tertiary rocks span the boundary between the tholeiite and calc-alkaline series in the classifications of Irvine and Baragar (1971; Fig. 10) and Miyashiro (1974; Fig. 11), respectively. Most analyses with less than 55 percent $SiO_2$ are tholeiitic in Miyashiro's (1974) classification. Overall the suite of analyses is skewed toward the tholeiite series of Miyashiro and toward the calc-alkaline series of Irvine and Baragar (1971).

At $SiO_2$=57.5, the Tertiary suite has an average $K_2O$ content ($K_{57.5}$) of 1.1 percent and an average $FeO_T/MgO$ ratio ($FeO_T/Mg_{57.5}$) of 2.8 percent, as determined from linear fits to the data. The $K_{57.5}$ value is well within the range of average values for volcanic arcs given by Gill (1981, Table 7.1), but the value of $FeO_T/Mg_{57.5}$ is high and most characteristic of volcanic fronts located on crust less than 25 km thick (Gill, 1981, p. 208-216). However, the spread in the data is great, so these comparisons are probably meaningless.

Within the Tertiary and Quaternary rocks, three distinct compositional groupings can be made and related to specific stratigraphic units. The Tertiary and Quaternary rocks are themselves readily distinguished chemically. At a given $SiO_2$ the Quaternary andesite and basaltic andesite are lower in $FeO_T$ than are the Tertiary rocks (Fig. 12), and they are also distinct on an AFM diagram (Fig. 10) and on a plot of $FeO_T/MgO$ vs $SiO_2$ (Fig. 11). Also, the Quaternary rocks tend to have higher $Al_2O_3$ contents than do most of the Tertiary rocks of similar $SiO_2$ content (Fig. 13).

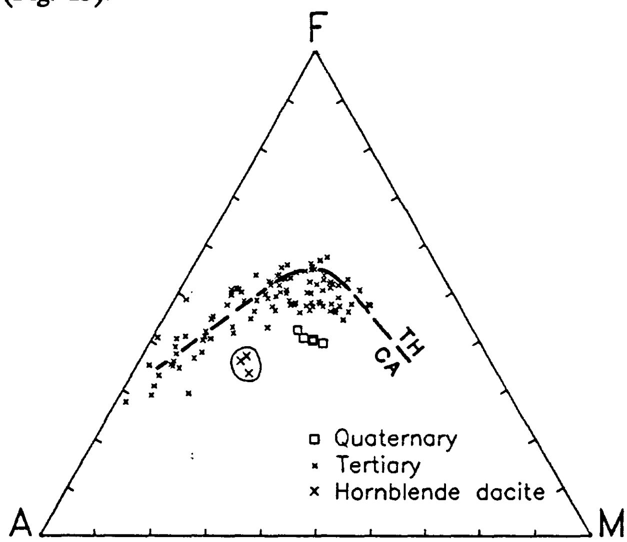



Figure 10. AFM diagram for Tertiary and Quaternary rocks in French Butte and Greenhorn Buttes quadrangles. A, $Na_2O + K_2O$; F, $FeO_T$; M, MgO. Heavy dashed line separates fields of tholeiitic (TH) and calc-alkaline (CA) compositions according to Irvine and Baragar (1971). Note that both tholeiitic and calc-alkaline compositions occur in the quadrangles, and that the Tertiary hornblende dacite (unit Thd, exclusive of analysis no. 61) and Quaternary andesite and basaltic andesite each plot in distinct fields.

The "Kidd-Creek type" hornblende dacite intrusions (unit Thd, exclusive of analysis no. 61, which is from a body tentatively mapped in unit Thd but which is chemically quite distinct from rest of unit) are lower in $FeO_T$ (Fig. 12), $TiO_2$ (Fig. 14), and MnO (Table 1) and higher in $Al_2O_3$ (Fig. 13) than are the other Tertiary rocks at a given $SiO_2$ content. They also are decidedly calc-alkaline and form a distinct cluster on an AFM diagram and a plot of $FeO_T/MgO$ vs $SiO_2$ (Figs. 10 and 11). These differences are not particularly convincing from the few analyses in Tables 1 and 2, but numerous other analyses from "Kidd-Creek" intrusions east of the mapped quadrangles confirm these generalizations (unpublished data; J. N. Marso, oral commun., 1988).

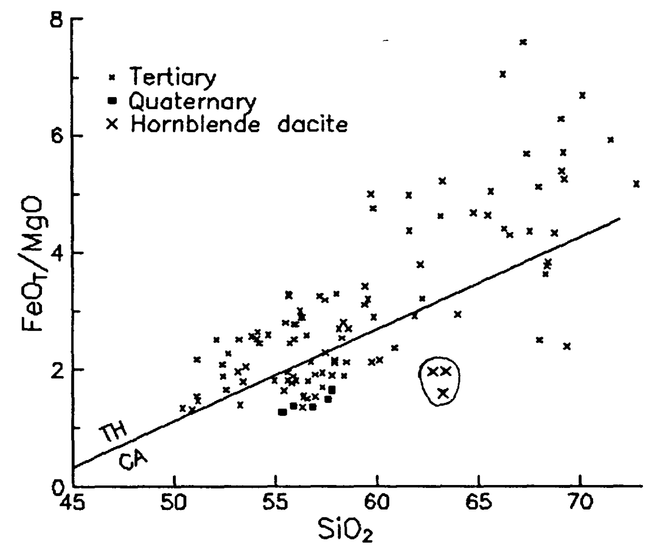



Figure 11. Plot of $FeO_T/MgO$ vs $SiO_2$ for Tertiary and Quaternary rocks in French Butte and Greenhorn Buttes quadrangles. Boundary between tholeiite (TH) and calc-alkaline (CA) suites after Miyashiro (1974). Note that the Tertiary analyses straddle the boundary but that Quaternary rocks are all calc-alkaline by this definition, and that analyses of hornblende dacite (exclusive of analysis 61) plot in a tight cluster in the calc-alkaline field.

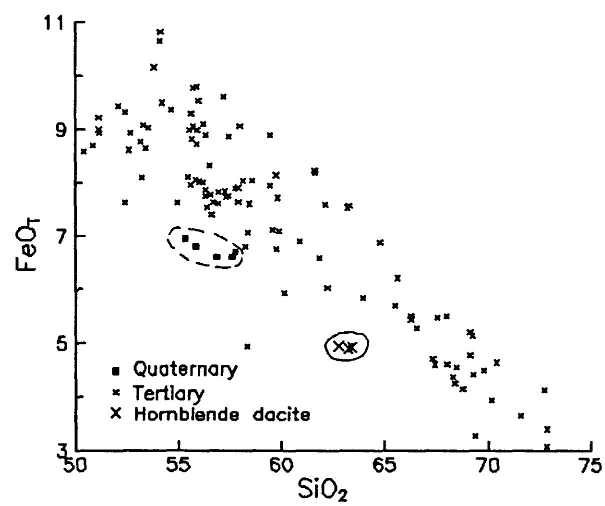



Figure 12. Plot of $FeO_T$ vs $SiO_2$ for Tertiary and Quaternary rocks in French Butte and Greenhorn Buttes quadrangles. Quaternary basaltic andesite and andesite (within dashed circle) have low total iron relative to that of Tertiary rocks, and Tertiary hornblende dacite (excluding analysis 61) is also relatively low in iron.

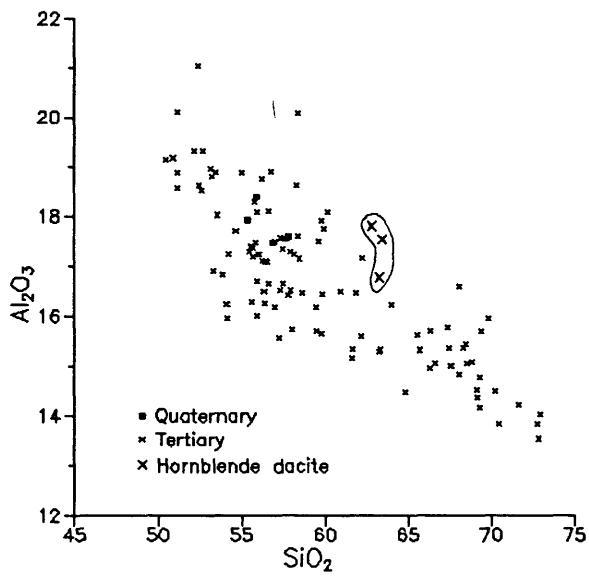



Figure 13. Plot of $Al_2O_3$ vs $SiO_2$ for Tertiary and Quaternary rocks in French Butte and Greenhorn Buttes quadrangles. Quaternary basaltic andesite and andesite, and Tertiary hornblende dacite, tend to have higher $Al_2O_3$ at a given $SiO_2$ content than do most Tertiary rocks.

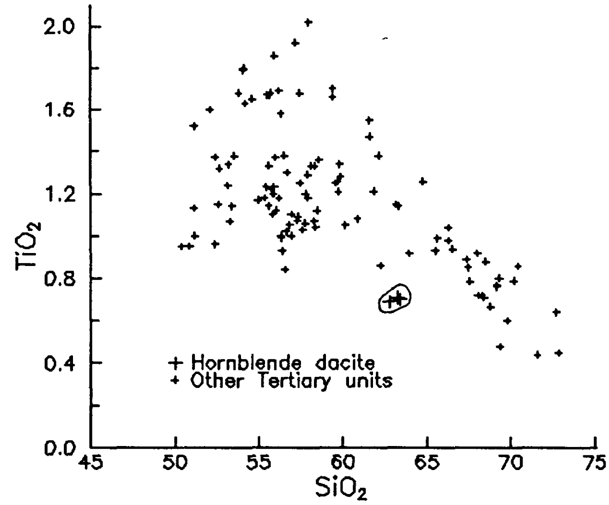



Figure 14. Plot of $TiO_2$ vs $SiO_2$ for Tertiary rocks in French Butte and Greenhorn Buttes quadrangles. Dikes of hornblende dacite have lower content of $TiO_2$ at a given $SiO_2$ content than do the other rocks. See text.

## DESCRIPTION OF MAP UNITS

### SURFICIAL DEPOSITS

Qal **Alluvium (Holocene and late Pleistocene)**–Unconsolidated, moderately to well-sorted deposits of silt, sand, and gravel along major modern streams. Includes fine-grained deposits in swamps. Locally includes colluvium and drift

Qc **Colluvium (Holocene and late Pleistocene)**–Unsorted, unconsolidated deposits of slope wash and local open-work talus on lower slopes of major stream valleys. Mapped only locally, chiefly along Cispus River.

Qls **Landslide deposits (Holocene and late Pleistocene)**– Diamicts produced by mass down-slope movement. Includes both active and inactive slides. Generally involves movement of relatively dense and competent andesite and basalt lava flows over clay-rich volcaniclastic rocks. Particularly extensive, locally active landslide deposits occur on dip slope on west side of Iron Creek valley, on dip slope on east side of Greenhorn Creek, and below Huffaker Mountain in northwest corner of Greenhorn Buttes quadrangle. The Huffaker Mountain deposits are locally overlain by glacial outwash of Evans Creek age and hence are late Pleistocene or older (Evarts and Ashley, in press b)

**Evans Creek Drift (late Pleistocene)**–Divided into:

Qet **Till deposits**–Diamict between about 1,200 and 1,800 ft (365-550 m) elevation in northern part of Greenhorn Buttes quadrangle, deposited by Cowlitz River glacier as it spilled southward out of Cowlitz valley (Crandell and Miller, 1974). Contains diverse rock types foreign to the mapped area, including large stones from Tatoosh Pluton in Mount Rainier National Park. Unweathered; most clasts lack significant weathering rinds. Locally includes post-glacial alluvium and colluvium. Probable age approximately 17-25 ka (Barnosky, 1984; Crandell, 1987)

Qem **Moraine deposits**–Lithologically resembles till (unit Qet) but forms morphologically distinct low hills and ridges. Best exposed low on east flank of Huffaker Mountain in northwest corner of Greenhorn Buttes quadrangle. Elsewhere heavily vegetated and identification somewhat problematic. Tends to occur between unit Qet and Evans Creek-age outwash deposits (unit Qeo)

Qeo **Outwash deposits**–Unconsolidated, bedded, moderately- to well-sorted gravel, sand, and silt forming valley fill and terraces in Cispus and Cowlitz valleys. Also occurs along Woods and Stump Creeks, where meltwater streams carried outwash into Cispus River from margin of Cowlitz River glacier. Includes modern alluvium along channel of Cispus River

**Hayden Creek Drift (middle Pleistocene)**–Divided into:

Qht **Till deposits**–Diamict distributed throughout both French Butte and Greenhorn Buttes quadrangles at elevations from 1,100 to 4,200 ft (335-1,280 m). Contains numerous clasts with weathering rinds 1-2 mm thick; upper 0.5-1 m are deeply weathered. These features suggest correlation with Hayden Creek Drift (Crandell and Miller, 1974; Colman and Pierce, 1981). Till in French Butte and southern part of Greenhorn Buttes quadrangles probably deposited by alpine glaciers flowing from cirques in headwaters of Greenhorn, Soldier, 1918, Iron, Pinto, Clearwater, and Elk Creeks. Till in central and northern part of Greenhorn Buttes quadrangle probably deposited by Cispus and(or) Cowlitz River glaciers. Locally includes modern alluvium, colluvium, and, along Iron Creek, landslide deposits. Contacts with Evans

Creek Drift north of Cispus River poorly constrained. Age of Hayden Creek Drift 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

**Qhm** **Moraine deposits**—Lithologically resembles till of unit Qht. Area of subdued (degraded?) morphology near junction of Soldier and Greenhorn Creeks in southernmost part of Greenhorn Buttes quadrangle may be terminal moraine of glaciers flowing from cirques at north foot of French Butte

**Qao** **Older alluvium (middle Pleistocene?)**--Moderately sorted, coarse gravel and sand 100-175 m above present floor of Iron Creek. Mapped at only one location 2 km upstream from mouth of Iron Creek, but smaller patches occur elsewhere above the creek. Possibly deposited by ice-marginal steam during Hayden Creek glaciation

## BEDROCK

### Volcanic and volcaniclastic rocks

**Qbbr** **Olivine-bearing basaltic andesite of Badger Ridge (middle Pleistocene)**—At least three flows of aphyric to very sparsely phyric basaltic andesite and andesite erupted from eroded vent on Badger Ridge, 1 km north of Badger Peak in the French Butte quadrangle. Olivine and brown clinopyroxene phenocrysts generally less than 1 mm in diameter comprise less than 1 percent of rock. No plagioclase phenocrysts, except for rare highly zoned "megacrysts" 1-2 mm across. Light gray, sparkly appearance in field. Intergranular to intersertal texture, commonly with flow-aligned microlites. Highly platy in places where flow-alignment is well developed. Three chemical analyses available; two are basaltic andesite and one is andesite (Table 1, no. 12, 17, and 32). Normal magnetic polarity, consistent with whole-rock K-Ar age of about 0.65 Ma (Table 3, no. 5A). Lava flows moved into and down ancestral Pinto Creek to its junction with Yellowjacket Creek about 3 km northeast of northernmost extent of unit in mapped area. Flow was glaciated and most vent material removed. However, several small outcrops of welded spatter occur within 200 m south of end of road at south end of Badger Ridge. Massive nature of unit just south of there suggests plug for vent that fed unit (star on map)

**Qbl** **Olivine andesite of The Loaf (Pleistocene)**—Sparsely olivine-phyric basaltic andesite and andesite flow or flows in southeast part of French Butte quadrangle. Olivine phenocrysts generally less than 1 mm across form less than 3 percent of rock; rare small brown clinopyroxene phenocrysts. Groundmass is intergranular and strongly flow-aligned. Resembles olivine-bearing basaltic andesite of Badger Ridge but more phyric and contains less brown pyroxene. Forms mesa-like hill called The Loaf, where flow is locally more than 60 m thick and may partly fill an ancient canyon. Outcrop at south edge of quadrangle extends only 100 m farther south; it forms dike-like rib (which could be either a dike or a narrow gorge-fill), with steeply dipping platy joints parallel to its trend, and merges northward into or feeds a subhorizontal 9-10-m-thick lava flow. This flow overlies thinly bedded olivine-bearing mafic spatter (presumably of same unit and indicating proximity to vent) and underlies thin deposit of till(?). Chemical analyses indicate unit straddles basaltic andesite-andesite boundary (Table 1, no. 26 and 31). Normal magnetic polarity, so probably younger than about 0.73 Ma

**Tdbm** **Dacite of Bluff Mountain (Miocene)**—Vitrophyric lava flow capping Bluff Mountain in east-central part of Greenhorn Buttes quadrangle and forming narrow, northeast-trending outcrop belt across Cispus River southwest of Bluff Mountain. Strikingly columnar in most outcrops, with columns generally less than 20 cm in diameter, as best seen in quarry 800 m north of Monroe Creek. Base of flow is rubble zone as much as 15 m thick underlying colonnade with columns 50-100 cm in diameter. Upper part of Bluff Mountain dominated by steeply-dipping platy zone near top of flow, probably one or more ramp structures. Phenocrysts are plagioclase, hypersthene, and clinopyroxene in order of abundance; total phenocryst content about 10 percent. Very fine-grained to glassy groundmass, except for more coarsely crystalline snowflake-textured platy zone on Bluff Mountain. Glass is fresh although probably hydrated. Chemically unit is dacite (Table 2, no. 95 and 96) to rhyodacite (Table 2, no. 114; Koresec, 1987). Fills northeast-trending paleocanyon eroded in unit Ttv, as seen by contact relations and joint orientation on south side of Bluff Mountain and at northeast end of outcrop belt south of Cispus River. Whole-rock K-Ar age of 15.7±0.2 Ma (Table 3, no. 4A; Phillips and others, 1986; Korosec, 1987) consistent with erosional relation to underlying rocks. Relation to unit Td at Iron Creek Butte not clear; thick vegetation obscures contact. However, unit fills canyon eroded into rocks that appear to overlie unit Td northwest of Iron Creek Butte; on that basis, unit is considered younger than rocks on Iron Creek Butte

French Butte area

**Tbfb** **Basaltic andesite of Point 5144 (Miocene)**—Fresh, sparsely plagioclase-phyric basaltic andesite forming low hill at Point 5144 1.5 km northwest of French Butte. Columnar jointed, with basal colonnade and overlying entablature. Colonnade-entablature contact dips about 20° NE. Intersertal to locally intergranular. Chemical analysis indicates basaltic-andesite composition (Table 1, no. 23). Presence of entablature suggests rapid cooling in water-rich environment, as in intracanyon flows or hydrothermally-quenched shallow intrusions. Probably in erosional contact with, and perhaps substantially younger than, underlying andesite of French Butte. Contacts not exposed, and unit could be intrusion rather than lava flow

**Ttpp** **Ash-flow tuff of Pole Patch (Miocene)**—Poorly exposed, buff to tan, weakly welded to non-welded crystal-lithic pumice-lapilli tuff probably of ash-flow origin in northeast corner of French Butte quadrangle. Many plagioclase and clinopyroxene phenocrysts and small lithic clasts, mostly of dacite. Includes similar tuff capping ridge 0.5 km northeast of French Butte

**Ttfb** **Pumiceous tuff of French Butte (Miocene)**—Poorly exposed white pumice-lapilli tuff 2 km northwest of French Butte. Clay-rich. Includes minor lithic-lapilli tuff. Possibly correlative with ash-flow tuff of Pole Patch

**Tafb** **Andesite of French Butte (Miocene)**—Flows of basaltic andesite and andesite, typically platy and plagioclase-pyroxene (both clinopyroxene and hypersthene)-phyric, capping ridge in French Butte area. Phenocrysts generally comprise 10-20 percent of rock. Flows typically 5-10 m thick, with rubbly upper and lower zones. Typically intersertal to locally intergranular, with relatively fresh glass in some flows. Flow-aligned microlites in some platy flows. The one chemical analysis is basaltic andesite (Table 1, no. 21).

**Tdpp** **Dacite domes(?) of Pole Patch (Miocene)**—Complex of three contiguous domes(?) or shallow intrusions on north side of Pole Patch in northeast corner of French Butte quadrangle, separated by ---- symbol on map. Westernmost, largest body is fine-grained, holocrystalline, has scattered phenocrysts of plagioclase and two pyroxenes, and is a mafic dacite chemically (Table 1, no. 44). Eastern two bodies are fine-grained, pilotaxitic, and have scattered phenocrysts of plagioclase, two pyroxenes, and oxidized hornblende. All bodies have internal coarse jointing, whose attitude varies greatly but commonly dips 30-40° south. No contact exposed, and relation to other units obscure

**Tbpr** **Bedded breccia of Pinto Rock (Miocene)**—Lithic breccia, lapilli tuff, and tuff related to vent complex between Pinto Rock (2.5 km south of French Butte) and Greenhorn Buttes. Sorting, clast angularity, bed thickness, and other physical characteristics highly variable. Probably chiefly near-vent products of explosions. Beds generally strike northward and dip steeply (much more so than underlying units) and in variable directions, in general defining linear north-south-trending ridge along vent complex. Particularly good exposures of steeply dipping unit are 1 km north of Pinto Rock and 1.5 km NNE of French Butte. Locally, as near Pinto Rock, dips are quaquaversal and probably define loci of explosions. Vesicular dikes of unit Tai near Pinto Rock probably related to this unit. Locally includes thin lava flows. Lava flows and clasts in bedded deposits are basaltic andesite (some almost as mafic as basalt) and andesite (Table 1, no. 5 and 40), generally plagioclase-two pyroxene phyric. Commonly oxidized and riddled with veins of green clay minerals, zeolites, calcite, amorphous $SiO_2$ and quartz, probably formed by alteration in shallow, near-vent hydrothermal setting

Ttv **Volcaniclastic rocks, undivided (Miocene)**—Pumice- and lithic-lapilli tuff, fine-grained tuff, bedded volcaniclastic conglomerate, sandstone, and 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. Correlates with *volcaniclastic sedimentary rocks* and *tuff* in adjacent Cowlitz Falls and Spirit Lake East quadrangles (Evarts and Ashley, in press a, b).

Most pumice-lapilli tuff probably is of ash-flow origin. Welding ubiquitous in vitrophyric zones and commonly evident in non-vitrophyric parts of lapilli tuff; however, much pumice-lapilli tuff and most lithic- and lithic-pumice-lapilli tuff is nonwelded. Several prominent, densely welded, vitrophyric zones can be traced for considerable distances (indicated by –x–x–x–x– symbol on maps). Thickness ranges from several meters to more than 50 m. Typically plagioclase-phyric, with minor clinopyroxene; no quartz or hornblende. Lithic clasts, generally andesite or dacite, sparse to abundant. Pumice-lapilli tuff is particularly common in northern half of French Butte quadrangle and southern half of Greenhorn Buttes quadrangle. Typically of rhyodacite (Table 1, no. 53-60, 63; Table 2, no. 98) or silicic dacite (Table 1, no. 51-52) chemical composition. Most vitrophyre strongly hydrated (Table 1, no. 52-57; Table 2, no. 98) but otherwise chemically similar to other samples (Table 1, no. 58-60, 63). Radiometric ages determined on plagioclase from ash-flow tuff are 23.3±1.8 Ma near mouth of Wakepish Creek in French Butte quadrangle (Table 3, no. 1A; Evarts and Ashley, in press a) and 18.4±0.3 and 18.9±0.3 Ma in Soldier Creek drainage near axis of Pole Patch syncline along southern edge of Greenhorn Buttes quadrangle (Table 3, no. 3A; Hammond, 1980). These ages are consistent with structure of area; oldest is on flank and youngest near trough of syncline.

Vitric airfall tuff is typically fine-grained and occurs in beds several centimeters or less thick. Commonly white, bentonitic, and zeolitic.

Bedded volcaniclastic rocks aside from airfall tuff range in grain size from silt to gravel, in sorting and rounding from poor to good, and in bed thickness from <1 c m to more than 50 cm. Sedimentary structures, such as cross bedding, channeling, and both normal and inverse size grading common. Clasts entirely of volcanic derivation, chiefly basaltic andesite and andesite but including dacite. Wood plentiful locally, with limbs as long as 2 m and stumps as wide as 1 m. Detritus probably derived from reworking of freshly erupted debris or erosion of slightly older volcanic rocks and deposited in fluvial environment.

Lithic diamictite typically poorly sorted, with clasts ranging from sand to boulder in size. Wide range in degree of rounding, with angular boulders commonly mixed with rounded gravel and cobble. Thickness of single units typically several meters but ranges from 1 m to more than 15 m. Some units have pumiceous component, and some carry wood fragments. Commonly interbedded with volcaniclastic sandstone. Probably most are laharic deposits, but locally units could have debris-avalanche, explosion-breccia, or landslide origin

Mafic lava flows

**Ta** **Andesite and basaltic andesite flows, undivided (Miocene)**– Highly (>20 percent) phyric to slightly (<5 percent) phyric, darkly hued, fine- to medium-grained flows and associated basal- and flow-top breccia of andesite and basaltic andesite not assigned to other units. Flows typically 5-20 m thick, commonly platy and-or columnar, with vesicular or amygdaloidal zones in many places. Striking colonnades in some flows, as on east side of Iron Creek upstream from mouth of Fourmile Creek in Greenhorn Buttes and French Butte quadrangle, probably record ponding in topographic lows or paleocanyons. Phenocrysts dominantly plagioclase, with lesser clinopyroxene and hypersthene; most common phenocryst assemblage (minerals listed in decreasing order of abundance) is plagioclase-clinopyroxene, followed by plagioclase-clinopyroxene-hypersthene and plagioclase-hypersthene-clinopyroxene. Rare phenocrysts of olivine (typically altered to clay) and hornblende. Groundmass texture chiefly fine-grained intersertal or intergranular, with flow-aligned microlites common; very fine-grained pilotaxitic texture common in more silicic rocks. Fresh glass uncommon; glass generally altered to clay minerals. Chemical analyses (Tables 1 and 2) indicate mostly basaltic andesite and andesite compositions. In general basaltic andesite is more highly phyric than andesite, with many exceptions. Andesite and basaltic andesite are interbedded (for example, along creek draining southeast side of Pinto Rock) and cannot be mapped separately short of analyzing each flow. Minor dacite (generally very fine-grained or glassy, with platy or entablature-like jointing but lacking prominent flow layering) included in unit (Table 1, no. 43, 46, and 50; Table 2, no. 91). Dikes and other intrusions of unit Tai probably fed some flows in unit. Section of thin flows 2.5 km south-southwest of Elk Pass dips about 18° NE and probably represents part of cone. Unit Tav 1 km south of Pinto Rock probably fed part of unit. Includes thin beds of volcaniclastic rocks too small to show on map. Interbedded extensively with dacite (unit Td) and volcaniclastic rocks (unit Ttv)

**Tav** **Andesite vent deposits (Miocene)**–Red, oxidized spatter and cinders capped by thin, sparsely plagioclase-phyric lava flow 1 km south of Pinto Rock in French Butte quadrangle. Probably remnant of cone within unit Ta

**Tagc** **Basaltic andesite of Greenhorn Creek (Miocene)**–Highly plagioclase-phyric lava flows in southeast part of Greenhorn Buttes quadrangle. Most plagioclase-phyric unit in mapped area. Plagioclase phenocrysts generally large (several millimeters long) and abundant (10-30 percent of rock). Phenocrysts of clinopyroxene and hypersthene considerably less abundant and smaller than those of plagioclase. Typically fine-to medium-grained, intergranular to intersertal groundmass. Underlies steep dip slope on east limb of Pole Patch syncline but does not reappear in west, gentler limb along Iron Creek. Forms bed of Greenhorn Creek near trough of syncline. Interbedded with volcaniclastic rocks of unit Ttv. Chemically basaltic andesite (Table 2, no. 73 and 75). Clay-rich in many places

**Tabc** **Andesite of Benham Creek (Miocene)**– Two or more very sparsely and finely plagioclase-clinopyroxene-phyric, platy, fine-grained lava flows along Benham Creek near southwest corner of Greenhorn Buttes quadrangle. Groundmass is very fine-grained and commonly pilotaxitic. Chemically ranges from basaltic andesite to andesite (Table 2, no. 74 and 87). Contiguous with unit of same name in adjacent Cowlitz Falls quadrangle (Evarts and Ashley, in press b). Includes thin flow at west edge of quadrangle 2.5 km north of Benham Creek, which resembles flows at Benham

Creek and is continuous with unit mapped by Evarts and Ashley in Cowlitz Falls quadrangle. Possibly erupted from plug on summit of Strawberry Mountain about 2 km west of mapped area and 5 km south of the Cispus River (Evarts and Ashley, in press b)

Tbhm **Basalt and basaltic andesite of Huffaker Mountain (Miocene)**—Nearly 500 m of thin flows and associated flow rubble of plagioclase-clinopyroxene-olivine (generally altered)-phyric basalt and plagioclase-two pyroxene-phyric basaltic andesite forming Huffaker Mountain in northwest part of Greenhorn Buttes quadrangle. Some flows are clinopyroxene-plagioclase-phyric, characterized by single crystals of clinopyroxene 5-8 mm in diameter. Some flows have ropy surfaces resembling those of some pahoehoe. Groundmass typically intergranular, with minor residual glass now altered to clay and zeolite. Unit ranges chemically from basalt (Table 2, no. 108 and 102) with $SiO_2$ of 51.2 percent to basaltic andesite (Table 2, no. 103, 68, 72, and 104) with $SiO_2$ as high as 56.6 percent. Relative thinness of flows suggests proximity to vent. Contiguous with basalt of Huffaker Mountain in Cowlitz Falls quadrangle (Evarts and Ashley, in press b). Plagioclase from two flows in unit yielded K-Ar ages of 23.3 Ma (Evarts and others, 1987); one dated sample is from site along western boundary of Greenhorn Buttes quadrangle (Table 3, no. 2A)

Silicic lava flows and domes

Td **Dacite, rhyodacite, and rhyolite flows, undivided (Miocene)**—Flow-layered, generally pink to gray, aphyric to moderately plagioclase-phyric, silicic flows not assigned to another unit. Widespread in both quadrangles but not abundant. Two especially prominent and easily accessible exposures, both in Greenhorn Buttes quadrangle, are: silicic rhyodacite or low-$SiO_2$ rhyolite (Table 2, no. 100) along Road 7708 2 km south of Iron Creek Butte; and cliff of dacite (Table 2, no. 97) at top of clearcut 1.5 km northeast of Bluff Mountain. Groundmass typically cryptocrystalline and devitrified to snowflake texture. Typically shows evidence of low-grade alteration and commonly bears fresh or oxidized pyrite. Includes some flows that lack prominent flow layering but have snowflake texture and silicic composition; examples are rhyodacite flows 500 m northwest of The Loaf (Table 1, no. 62; French Butte quadrangle) and 1 km northeast of Iron Creek Butte (Table 2, no. 99; Greenhorn Buttes quadrangle). Limited extent, befitting their probably low fluidity

Trds **Rhyodacite of Strawberry Mountain (Miocene)**—Sparsely phyric, pink to light-gray, flow-layered flows of dacite and rhyodacite along west edge of French Butte quadrangle. Contiguous with dacite of Strawberry Mountain in adjacent Spirit Lake East quadrangle (Evarts and Ashley, in press a). Small phenocrysts of plagioclase, clinopyroxene, and iron oxide typically less than 10 percent of rock. Lacks quartz phenocrysts. Groundmass cryptocrystalline, typically flow-layered, and devitrified to snowflake texture. Locally spherulitic; brecciated in many places. Generally contains low-temperature alteration products including albite, illite, montmorillonite, adularia, and hematite (Evarts and Ashley, in press a). Chemically rhyodacite (Table 1, no. 64-66). Conformably overlies section of unit Ttv containing ash-flow tuff dated as 23.3±1.8 Ma (Table 3, no. 1A; Evarts and Ashley, in press a)

Tdq **Quartz-phyric dacite (Miocene)**—Single flow-layered body 2 km west of Elk Pass in southwest part of French Butte quadrangle. Sparsely phyric with scattered, small quartz phenocrysts; no other phenocryst phase. Snowflake groundmass texture. Forms low hill against which andesite flows of unit Ta appear to abut. Occurs at same elevation as, and in contact with, rhyodacite of Strawberry Mountain (Trds), which lacks quartz phenocrysts (R. C. Evarts, oral commun., Feb. 1989). Could be a dome, possibly correlative to dacite of Clearwater

Creek (Tdc) or unusual variant of Strawberry Mountain unit. No chemical analysis available

**Tdc** **Dacite of Clearwater Creek (Miocene)**—Several pink to gray flows of aphyric to plagioclase-clinopyroxene-phyric, flow-layered dacite or rhyodacite in southwest corner of French Butte quadrangle. Contiguous with unit of same name in adjacent Spirit Lake East quadrangle (Evarts and Ashley, in press a), but includes less plagioclase-phyric dacite than in unit mapped by Evarts and Ashley. At least one flow has quartz phenocrysts; this and unit Tdq (a possible correlative) are the only quartz-phyric rocks in mapped area. Groundmass is cryptocrystalline with snowflake texture and commonly flow layered. Unit is nearly 300 m thick on northeast side of Clearwater Creek valley but thins eastward and pinches out along Elk Creek, where two flows are interbedded with andesite flows of unit Ta and volcaniclastic rocks of unit Ttv. No chemical analysis available. Alteration similar to that of rhyodacite of Strawberry Mountain

**Tbt** **Basalt of Twelvemile Creek (late Oligocene or early Miocene)**—Thin olivine-bearing flows and associated rubble in Twelvemile Creek drainage and adjacent area, west-central part of French Butte quadrangle. Typically sparsely phyric or seriate, with phenocrysts of plagioclase, clinopyroxene, and olivine. Groundmass generally intergranular to subophitic, and may contain olivine. Most olivine altered to clay minerals, but relict cores of olivine in phenocrysts common. Numerous vesicular zones, mostly amygdaloidal. Thinness of flows (commonly 2-5 m), and related dike (unit Tbi), suggest basaltic vent area, possibly a shield. Field relations suggest that unit predates other rocks in mapped area and formed topographic high with at least 300 m of relief, against which younger units Ttv and Ta were deposited before finally covering it (cross section B-B'). However, these relations are not definitive, and unit could be underlain by unit Ttv. Generally more altered than younger units; rich in clay minerals, zeolites, and calcite. Weathers to grus in places. Two relatively fresh samples (Table 1, no. 1 and 2) are basalt with less than 51 percent $SiO_2$, the most mafic unit in mapped area

## Intrusive rocks

**Thd** **Hornblende dacite intrusions (Miocene)**—Hornblende-clinopyroxene-plagioclase-phyric dacite and microdiorite dikes and irregular bodies in French Butte quadrangle. East-trending dikes of dacite occur chiefly 1 km south and southeast of Pole Patch; irregular body of microdiorite is poorly exposed 1 km east of mouth of Wakepish Creek. Dikes have fine-grained to glassy groundmass; microdiorite is holocrystalline and fine- to medium-grained. Hornblende occurs in groundmass but chiefly as phenocrysts as long as 4 mm, with scattered megacrysts and clots to more than 1 cm in diameter. Hornblende phenocrysts comprise 2-4 percent of rock, clinopyroxene phenocrysts about the same, and plagioclase phenocrysts, about 5-15 percent. Chemically the dikes (Table 1, no. 45, 47, 48) and microdiorite (J. N. Marso, per. commun., 1988) are very similar mafic dacite and silicic andesite, with distinctively low $TiO_2$, $FeO_T$, and MnO. Forms western end of regional swarm of dikes and sills of similar chemical composition and appearance, informally termed "Kidd Creek type" by current workers from exposures along Kidd Creek in Tower Rock quadrangle about 7 km east-northeast of Pole Patch. Unit extends at least 20 km east of Pole Patch. Apparently younger than age of low-grade metamorphism that affects most rocks in area, and probably younger than most folding. Unit includes hornblende-plagioclase-phyric microdiorite in tiny outcrop 2-5 m in diameter along Little Creek 1 km west of Iron Creek; this body is more silicic and otherwise differs chemically from rocks of "Kidd Creek type" (Table 1, no. 61)

**Tai** **Andesite and basaltic andesite intrusions (Miocene)**—Dikes and small subequant hypabyssal intrusions that, except for andesite intrusion (plug?) at Greenhorn Buttes, are confined to French Butte quadrangle. Larger intrusions generally slightly to moderately plagioclase-pyroxene (one or both clinopyroxene and hypersthene)-phyric or seriate, with coarse intergranular to hypidiomorphic groundmass commonly containing interstitial quartz. Interstitial glass in some coarse-grained bodies, such as that just north of Wakepish Creek near west edge of French Butte quadrangle. Locally, quenched margins in contact with country rock crop out, as on the east side of body 2 km northeast of Pinto Rock, and make intrusive origin of body evident. However, origin generally must be *interpreted*, on basis of coarser grain size, outcrop pattern, and relatively more massive—though jointed—appearance, to be intrusive rather than extrusive. Body mapped as intrusion 1 km north of French Butte has finely-columnar, entablature-like jointing habit and locally intersertal groundmass and could be lava flow. Larger intrusions range chemically from mafic basaltic andesite 2 km northeast of Pinto Rock (Table 1, no. 6) to mafic andesite at Greenhorn Buttes (Table 2, no. 85). No large intrusion is associated with dike swarm, either radial or linear. Relatively small intrusions near Badger Peak in southeast part of French Butte quadrangle are elongate parallel to regional east-west trend of dikes.

Dikes are fine-grained and texturally resemble lava flows. Characterized by horizontal columnar jointing, quenched margins, and nearly vertical attitudes. Typically 1-5 m wide. Locally vesicular, but generally nonvesicular. Only two chemical analyses available (Table 1, nos. 37 and 39), both of which are andesite from dikes radial to Pinto Rock. Most dikes of unit occur in southern third of French Butte quadrangle in swarm about 4 km wide and more than 7 km long, with its eastern extent unmapped. Swarm notable for consistent 280° trend of dikes. About 35 dikes mapped in swarm; probably several times that number are not exposed. Length of single dikes shown schematically, except for *en echelon* segments along upper Elk Creek 1 km east-northeast of The Loaf, which crop out for most of mapped 1-km length along creek

Tg **Gabbro (Miocene)**—Coarse-grained, seriate to hypidiomorphic granular gabbro in headwaters of Badger Creek 1.3 km east of Badger Peak in southeast part of French Butte quadrangle. Eastern extent of unit in adjacent McCoy Peak quadrangle is unmapped. Groundmass contains interstitial quartz. Chemical analysis from location just outside quadrangle is that of basalt (Table 1, no. 3)

Tdi **Dacite intrusion or dome complex (Miocene)**—Plagioclase-clinopyroxene-phyric microdiorite or coarse dacite in small body just north of south edge of French Butte quadrangle. Coarsely platy. Holocrystalline groundmass, rich in apatite. Could be one or two intrusions or domes. Along trend with quartz-phyric dacite flow of unit Tdc. Chemically unit is mafic dacite (Table 1, no. 49), probably less silicic than flows of unit Tdc judging from petrography and field appearance of unit Tdc. Lacks quartz either as phenocrysts or in groundmass

Thmi **Basalt dikes on Huffaker Mountain (Miocene)**—Two dikes, or one dike with two *en echelon* segments, cutting unit Tbhm. Plagioclase-clinopyroxene-olivine (altered)-phyric; intergranular groundmass. About 2 m wide. Trends 20°, parallel to nearby dike mapped by Evarts and Ashley (in press b) in adjacent Cowlitz Falls quadrangle. May be feeder(s) for flows in unit Tbhm

Tbi **Basalt dike (late Oligocene or early Miocene)**—One 1.5-m-wide dike of aphyric, intergranular basalt with flow-aligned plagioclase microlites and groundmass olivine, cutting basalt of Twelvemile Creek 0.5 km south of junction of Iron and Twelvemile Creeks. Presumably related to volcanism that erupted flows in wallrock, judging from petrography and similar degree of alteration

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## EXPLANATION

| | |
|---|---|
| ?— | Contact, dashed where approximate, queried where uncertain |
| | Approximate contact between domes(?) within unit Tdpp |
| 5 | Strike and dip of bedding and flow contacts |
| ⊕ | Horizontal beds or flows |
| 5 | Fault or shear zone, with dip of major slip plane if known |
| | Dextral shear zone |
| | Sinistral shear zone |
| | Troughline of syncline, dotted where beneath Quaternary deposits |
| | Dike |
| x—x—x—x | Prominent basal vitrophyre of welded ash-flow tuff |
| | Site of chemically analyzed sample, with map number |
| ▼ 1 | Basalt |
| 20 ▲ | Basaltic andesite |
| △ 41 | Andesite |
| 50 ○ | Dacite |
| ● 64 | Rhyodacite and rhyolite |
| 3A ◆ | Site of radiometric age, with map number |
| ★ | Vent area for basaltic andesite of Badger Ridge |

# CORRELATION OF MAP UNITS