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DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

Geology and Mineral Resources Map of the Three Creek Butte Quadrangle, Deschutes County, Oregon

1995

GMS-87

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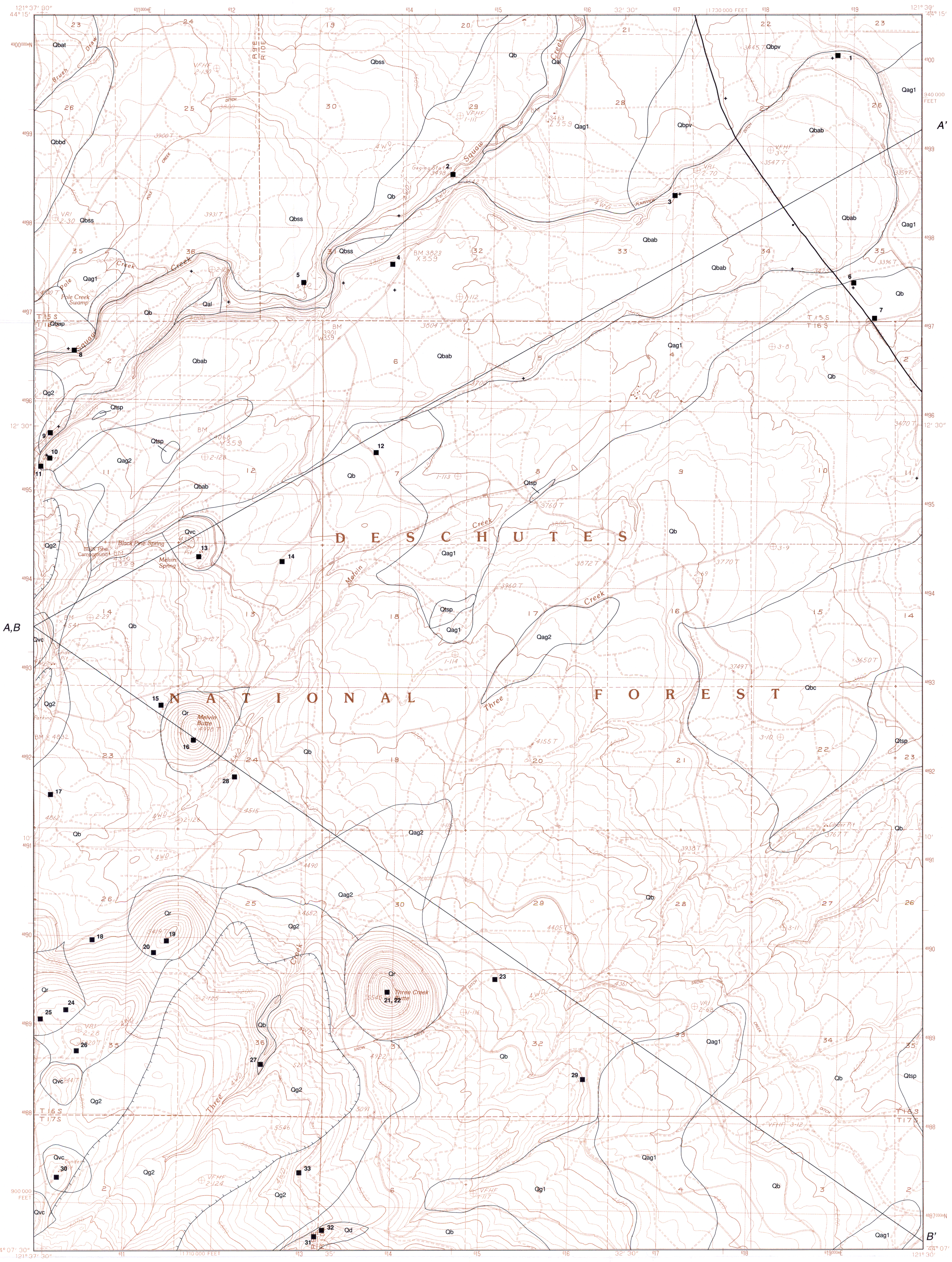
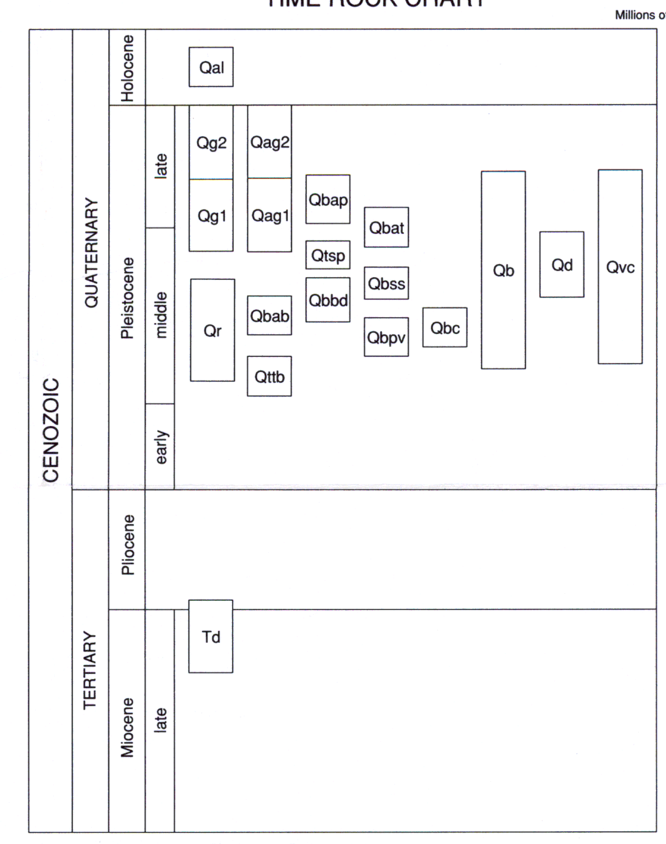
By E.M. Taylor and M.L. Ferns



TIME ROCK CHART



After Berggren and others, 1985; Richmond and Fullerton, 1986

EXPLANATION OF MAP UNITS

Surficial deposits

- Qal — Alluvium (Holocene)
- Qg2 — Glacial deposits (upper Pleistocene)
- Qag2 — Outwash and alluvial deposits (upper Pleistocene)
- Qg1 — Glacial deposits (upper and middle Pleistocene)
- Qag1 — Outwash and alluvial deposits (upper and middle Pleistocene)

High Cascade volcanic rocks

- Qb — Undivided mafic lava flows (upper and middle Pleistocene)
- Qbap — Basaltic andesite of Pole Creek cone (upper Pleistocene)
- Qbat — Basaltic andesite of Trout Creek Butte (upper or middle Pleistocene)
- Qbss — Basalt of Spruce Spring (middle Pleistocene)
- Qbab — Basaltic andesite of Black Pine Spring (middle Pleistocene)
- Qbbd — Basalt of Brush Draw (middle Pleistocene)
- Qbc — Basalt (middle Pleistocene)
- Qbpv — Basalt of Plainview (middle Pleistocene)
- Qd — Dacite flow (middle Pleistocene)
- Qr — Rhyolite domes (middle Pleistocene)

Pyroclastic deposits

- Qvc — Basalt and basaltic andesite cinder cones (upper and middle Pleistocene)
- Qtsp — Shevlin Park Tuff of Taylor (1981) (middle Pleistocene)
- Qttb — Tumalo Tuff and Bend Pumice of Taylor (1981) (middle Pleistocene) (shown only in cross section)

Deschutes Formation

- Td — Deschutes Formation (lower Pliocene and upper Miocene) (shown only in cross section)

MAP SYMBOLS

- Contact -- Approximately located
- Fault -- Bar and ball on downthrown side
- Approximate boundaries of Pleistocene glaciers; hachures towards ice
- \+ Sample with normal magnetic polarity
- ■ 21 Location of sample in Table 1 (see accompanying text)

Base map by U.S. Geological Survey
Control by USGS, NOS/NOAA
Projection: Lambert Conformal Conic
Grid: 1000-meter Universal Transverse Mercator, Zone 10
10,000-foot State Grid Ticks, Oregon, South Zone
UTM grid declination: 1 degree east
1980 magnetic north declination: 19 degrees east
Vertical datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum

N

QUADRANGLE LOCATION

SCALE 1:24 000

.5 0 1 2 KILOMETERS

1000 0 7000 FEET

.5 0 1 MILES

CONTOUR INTERVAL 40 FEET

Geology by Edward M. Taylor, Oregon State University, and Mark L. Ferns, Oregon Department of Geology and Mineral Industries

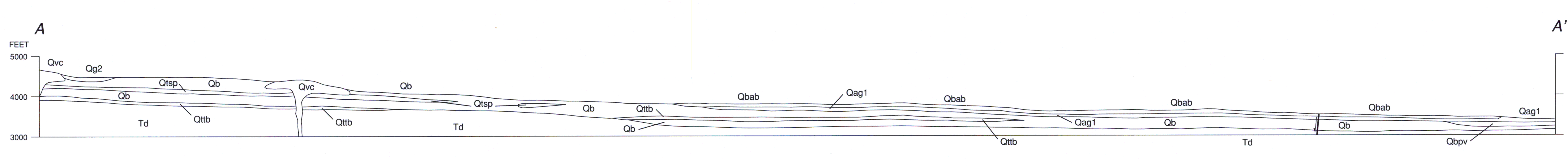
Field work conducted in 1978-1979 by Taylor and 1993 by Ferns

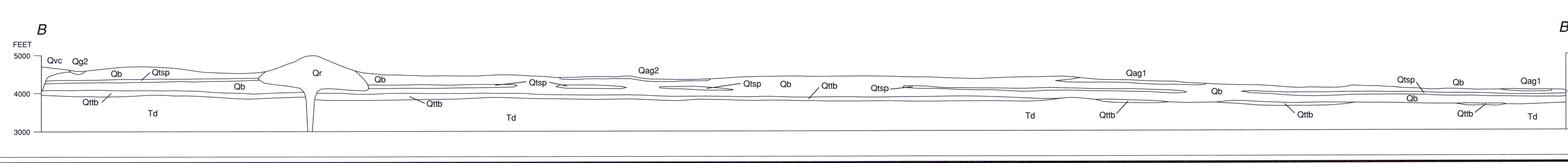
Reviewed by Dave Sherrod, USGS

Cartography by Mark E. Neuhaus

The geologic information on this map is available in digital formats

GEOLOGIC CROSS SECTIONS





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1995

By E.M. Taylor, Oregon State University,
and M.L. Ferns, Oregon Department of Geology and Mineral Industries

INTRODUCTION

The Three Creek Butte quadrangle encompasses part of the eastern margin of the High Cascades geologic province between the cities of Bend and Sisters. Geology of the quadrangle was mapped by E.M. Taylor during 1978 and 1979, with supplemental work by M.L. Ferns in 1993. The map is one product of a cooperative mapping effort by geologists from Oregon State University, the Oregon Department of Geology and Mineral Industries, and the U.S. Geological Survey (USGS). One project goal is to provide a detailed geologic framework for Oregon Department of Water Resources and USGS ground-water studies in the Deschutes River basin.

Geologic units exposed in the Three Creek Butte quadrangle include middle to late Pleistocene (≤200,000-year-old) High Cascade basalt, basaltic andesite, and andesite lava flows and an andesitic ash-flow tuff that make up the mafic platform upon which the modern High Cascade peaks in the Three Sisters area were constructed (Taylor, 1978; Hughes and Taylor, 1986). Middle Pleistocene rhyolite domes that protrude through a cover of late Pleistocene lava flows and glacial deposits are the oldest rocks exposed in the quadrangle. They define the northern margin of the Tumalo volcanic center, the source for five pyroclastic units now exposed near Bend (Taylor, 1981, 1987). The youngest of these pyroclastic units, the Shevlin Park Tuff of Taylor (1981), is exposed within the quadrangle. Rocks in the northeast part of the quadrangle have been displaced by the Tumalo fault, which is part of the southeast-trending Sisters fault zone.

EXPLANATION OF MAP UNITS

SURFICIAL DEPOSITS

Qal **Alluvium (Holocene)**—Poorly sorted fluvial gravels and sands deposited in channel of Squaw Creek. Consists chiefly of reworked outwash deposits

Qg2 **Glacial deposits (upper Pleistocene)**—Chiefly unconsolidated, unsorted glacial drift and till exposed at and adjacent to terminal moraines. Moraines in the western part of the quadrangle near Black Pine Campground and Three Creek Butte were formed during the late Pleistocene (18,000–22,000 yr B.P.) Suttle Lake advance of the Cabot Creek glaciation of Scott (1977, 1990). The moraines are locally mantled by a rhyolite air-fall pumice (Table 1, map no. 33)

Qag2 **Outwash and alluvial deposits (upper Pleistocene)**—Poorly sorted, stratified deposits 2–15 m in thickness. Unit includes loess, local colluvium, and channel deposits of well-rounded fluviatile sand, gravel, and silt mantling surface lava flows along Three Creek. Absence of outwash deposits along Squaw Creek may be attributed to removal by catastrophic floods caused by overtopping of a moraine-dammed lake by avalanches (Laenen and others, 1987)

Qg1 **Glacial deposits (upper and middle Pleistocene)**—Chiefly unconsolidated, unsorted glacial drift and till. Older moraine surface characterized by more gentle sloping profile mantled by boulders with pitted, discolored, and weathered surfaces. Unit considered to be related to the 75,000 or 140,000 yr B.P. Jack Creek glaciation of Scott (1977, 1990)

Qag1 **Outwash and alluvial deposits (upper and middle Pleistocene)**—Poorly sorted, stratified deposits 2–15 m in thickness. Unit consists of loess, local colluvium, and channel deposits of well-rounded fluviatile sand, gravel, and silt. Unit includes fluviatile sand and gravel deposits that overlie the Shevlin Park Tuff of Taylor (1981) (unit Qtsp) and are overlain by basaltic andesite lava flows (unit Qb). Unit is considered to be correlative to deposits of the Jack Creek glaciation of Scott (1977, 1990)

HIGH CASCADE VOLCANIC ROCKS

Basalt, basaltic andesite, and dacite erupted from High Cascade vents, chiefly west and southwest of the quadrangle. Includes pyroclastic units and rhyolite domes associated with the Tumalo volcanic center. Many Cascade volcanic rocks are too glassy to be adequately characterized by mineralogical criteria. We follow the chemical criteria used by Taylor (1978) and Priest and others (1983), based on analyses recalculated to a 100-percent total without volatiles and with all iron as Fe^{+2}:

1. Silica <53 wt percent = basalt
2. Silica 53–58 wt percent = basaltic andesite
3. Silica 58–63 wt percent = andesite
4. Silica 63–68 wt percent = dacite
5. Silica 68–73 wt percent = rhyodacite
6. Silica >73 wt percent = rhyolite

Qb **Undivided mafic lava flows (upper and middle Pleistocene)**—Grayish-black to light-grayish-black, aphyric to sparsely porphyritic basalt and basaltic andesite lava flows with plagioclase and olivine phenocrysts set in a groundmass of plagioclase, clinopyroxene, magnetite, and glass. Some lavas contain large (4 mm) phenocrysts of zoned plagioclase, while others have pilotaxitic textures and sparse phenocrysts of plagioclase and clinopyroxene. Average weight percent SiO_2 in analyzed rocks of this group (Table 1) is 54.8. Some lava flows in the west part of the quadrangle (Table 1, map nos. 9 and 17) are of andesitic composition but are distinguished only by chemical analyses. All units that have been tested (see "+" symbols on map) display normal-polarity thermal remanent magnetization. Separately mapped units are as follows:

Qbap **Basaltic andesite of Pole Creek cone (upper Pleistocene)**—Black to gray platy lava flows (57.7 percent SiO_2) (PsBALa30 of Taylor [1987]) with sparse, 4-mm plagioclase phenocrysts. Unit consists of basaltic andesite flows with sparse olivine and clinopyroxene microphenocrysts that were erupted from a small eroded cinder cone in the Trout Creek Butte quadrangle. Upper Pleistocene age based on stratigraphic position above older glacial outwash deposits (unit Qagl) at Pole Creek Swamp

Qbat **Basaltic andesite of Trout Creek Butte (upper or middle Pleistocene)**—Gray to black, vesicular lava flows erupted from the well-preserved Trout Creek Butte shield volcano 3 km west of the quadrangle (PsBALa29 of Taylor [1987]). Plagioclase, olivine, and clinopyroxene occur as sparse phenocrysts and glomerophenocrysts in the flows. Pleistocene age based on stratigraphic position beneath older moraine deposits (unit Qgl) on the northwest flank of Trout Creek Butte (Taylor, 1987)

Qbss **Basalt of Spruce Spring (middle Pleistocene)**—Highly vesicular, black diktytaxitic lava flows (51–52 wt percent SiO_2) equivalent to the basalt of Spruce Spring (PsBsLa4 of Taylor [1987]). Flows contain less than 3 percent phenocrysts of olivine and plagioclase suspended in a coarse groundmass of stubby plagioclase prisms, intergranular clinopyroxene, magnetite, olivine, and interstitial glass. Unit is overlain by basaltic andesite flows from Trout Creek Butte (unit Qbat) and underlain by the basalt of Brush Draw (unit Qbbd)

Qbab **Basaltic andesite of Black Pine Spring (middle Pleistocene)**—Dark-gray, sparsely porphyritic lava flows (54–55.5 percent SiO_2) (PsBALa35 of Taylor [1987]) erupted from a large cinder cone in the west center of the quadrangle. Flows contain less than 1 percent plagioclase phenocrysts and clinopyroxene and olivine microphenocrysts set in a fine-grained pilotaxitic groundmass. Middle Pleistocene age based on stratigraphic position beneath the Shevlin Park Tuff (unit Qtsp) and air-fall pumice deposits probably equivalent to the pumice that underlies the Shevlin Park Tuff at Columbia Southern Canal (Hill and Taylor, 1990). The Black Pine Spring lava flow is offset approximately 10 m by a western segment of the Tumalo fault

Qbbd **Basalt of Brush Draw (middle Pleistocene)**—Black, olivine- and clinopyroxene-bearing, blocky lava flows (52–53 percent SiO_2) (PsBsLa 5 of Taylor [1987]) with 15 percent plagioclase, 2 percent clinopyroxene (up to 4 mm), and 2 percent olivine phenocrysts. Unusually high CaO content of 10.6 wt percent reported by Taylor (1987). Middle Pleistocene age based on stratigraphic position beneath the basalt of Spruce Spring (unit Qbss)

Qbc **Basalt (middle Pleistocene)**—Olivine-bearing diktytaxitic lava flows. Highly vesicular, black, coarsely porphyritic lava flows with olivine phenocrysts and 10–15 percent plagioclase phenocrysts. Middle Pleistocene age based on stratigraphic position beneath the Shevlin Park Tuff (unit Qtsp)

Qbpv **Basalt of Plainview (middle Pleistocene)**—Olivine-bearing lavas with up to 20 percent plagioclase phenocrysts. Unit is a widespread early High Cascade lava flow that extends 12 km to the northeast, entering into Deep Canyon in the Henkle Butte quadrangle (Taylor and Priest, in preparation, a). Middle Pleistocene age based on stratigraphic position beneath outwash deposits of unit Qagl and the basalt of Brush Draw (unit Qbbd)

Qd **Dacite flow (middle Pleistocene)**—Platy-jointed, porphyritic, two-pyroxene dacite flow (63 percent SiO_2) exposed in a stream channel in the southwest quarter of the quadrangle. Overlain by mafic lava flows of unit Qb

Qr **Rhyolite domes (middle Pleistocene)**—Light-gray to yellow, aphyric flow-banded rhyolite (73–74 percent SiO_2) (PsRdLa 15 of Taylor [1987]). Unit consists of rhyolite domes at Three Creek Butte, Melvin Butte, and in the southwest corner of the quadrangle. The rhyolites are typically aphyric with rare plagioclase phenocrysts and granular magnetite. Hill (1985, 1991) suggested that strong similarities in major and minor element abundances between the rhyolite domes and the Bend Pumice (unit Qttb) (see Table 1) indicate a genetic relationship between the dome-forming eruptions and the pyroclastic eruption that formed the Bend Pumice. The Three Creek Butte dome marks the north margin of the Tumalo volcanic center (Hill, 1988b). Although isotopic ages of 0.4±0.4 (Melvin Butte) and 0.2±0.9 Ma (Three Creek Butte) have been reported (Armstrong and others, 1975), the standard errors are unacceptably large. Potassium-argon ages of 0.34±0.2 Ma and 0.63±0.09 Ma are reported by Hill (1991) for andesite and basaltic andesite vents associated with the Tumalo volcanic center to the south

Pyroclastic deposits

Qvc **Basalt and basaltic andesite cinder cones (upper and middle Pleistocene)**—Black, red, and yellow mantle-bedded cones in three locations: (1) a group of three buttes with glaciated lavas in the southwest corner of the quadrangle, (2) the source cone for the Black Pine Spring flow, and (3) a small cone 2 km north of Melvin Butte. All of the cones have been quarried for aggregate

Qtsp **Shevlin Park Tuff of Taylor (1981). (middle Pleistocene)**—Black, andesitic, vitric, welded to nonwelded pyroclastic-flow deposit containing black pumiceous bombs, andesite scoria, and white rhyolite fragments in an unsorted matrix of black and gray ash (Taylor, 1981). Pumice contains phenocrysts of plagioclase (An_{36}), olivine (Fo_{71}), hypersthene ($Wo_3En_{65}Fs_{32}$), and augite ($Wo_{42}En_{43}Fs_{15}$) (Hill and Taylor, 1990). Middle Pleistocene age is based on stratigraphic position above the Tumalo Tuff of Taylor (1981), which has been given an age of 0.29±0.12 Ma (Sarna-Wojcicki and others, 1989). Although distal fallout tephra at Summer Lake (Gardner and others, 1992) and age of underlying tephra there (Herrero-Bervera and others, 1994) indicate that the Shevlin Park Tuff is younger than 0.17 Ma, an isotopic age of 0.34±0.02 Ma for the Triangle Hill andesite cone, which erupted after the Shevlin Park Tuff, may indicate an older age (Hill, 1991). Increases in thickness, degree of welding, and average pumice size (Hill, 1991) toward a 10-mgal gravity anomaly (Pitts and Couch, 1978) centered on Triangle Hill, 2 km south of the quadrangle, indicate that the Shevlin Park eruption predated construction of the Triangle Hill cinder cone

Qttb **Tumalo Tuff and Bend Pumice of Taylor (1981) (middle Pleistocene)** (shown only in cross section)—Welded ash-flow tuff (Tumalo Tuff) and underlying air-fall pumice deposits (Bend Pumice) of equivalent age and composition. The Tumalo Tuff is a 10- to 22-m-thick pyroclastic flow deposit composed of unsorted pumice, rock fragments, and ash. The underlying Bend Pumice is a 3- to 16-m-thick air-fall deposit composed of well-sorted pumice lapilli and minor rock fragments. Middle Pleistocene age based on radiometric age of 0.29±0.12 Ma (Sarna-Wojcicki and others, 1989). Although neither unit is exposed at the surface in the quadrangle, water and geothermal well logs indicate their presence in the subsurface

DESCHUTES FORMATION

Td **Deschutes Formation (lower Pliocene and upper Miocene)** (shown only in cross section)—Heterogeneous sequence of upper Miocene and lower Pliocene lava flows, pyroclastic deposits, and volcaniclastic sediment exposed in adjacent quadrangles to the north, east, and south. In the quadrangle, unit Td underlies Pleistocene lava flows, perhaps at shallow depths. Lavas of the Deschutes Formation, the nearest exposures of which are 3 km to the east in the Tumalo Dam quadrangle, typically consist of dark-gray, aphryic basalt, basaltic andesite, and andesite lava flows that are enriched in Fe and Ti when compared with High Cascade lavas. The well log for the 860-ft-deep geothermal gradient hole (Brooks-Scanlon # 9) drilled by UNOCAL Geothermal in 1979 in NE¼ sec. 27, T. 16 S., R. 10 E., at 3,830 ft elevation (Oregon Department of Geology and Mineral Industry unpublished geothermal files) records a black tuff (Shevlin Park Tuff) at 3,780 ft elevation, dense aphanitic lavas at 3,700 ft elevation, a sequence of interbedded lavas and red ash-flow tuffs from 3,640 to 3,540 ft elevation and volcaniclastic sandstone and conglomerate from 3,540 to

3,240 ft elevation. While the volcaniclastic sandstone is considered herein to be correlative with Deschutes Formation sediments, Hill (1991) suggests an alternative correlation with younger Pliocene units such as the Parkette Creek unit (Black and others, 1987) and Camp Sherman beds (Smith, 1986) exposed elsewhere within the High Cascade graben

STRUCTURE

The fault that cuts the northeast corner of the quadrangle is the westernmost segment of a series of generally short, northwest-striking faults that lie between the Brothers fault zone (Lawrence, 1976) to the southeast and the north-striking Green Ridge fault to the north. The northwest-trending fault zone has been variously referred to as the Sisters fault zone (Lawrence, 1976), the Brothers-Sisters fault zone (Taylor, 1981), and the Tumalo fault zone (Smith, 1986; Smith and others, 1987). The fault in the quadrangle is a splay of the Tumalo fault, the largest (about 35 km in strike length) and apparently one of the most recently active faults in the zone (Pezzopane, 1993; Geomatrix Consultants, 1995). The fault displaced the distal edge of the basaltic andesite of Black Pine Spring down to the west. The main segment of the Tumalo fault to the east is a down-to-the-west fault that displays possible lateral separation (Taylor and Ferns, 1994).

Although attention has been focused recently on seismic hazards in the Bend area, no unambiguous Holocene (<10,000 yr B.P.) surface ruptures have been identified. Displaced lava-flow surfaces and offset sedimentary deposits in the Tumalo Dam quadrangle (Taylor and Ferns, 1994) constrain maximum possible vertical movement along that segment of the Tumalo fault to less than 7 m over the past 75,000 to 140,000 years. The amount of displacement along the fault segment in the northeast corner of the quadrangle is less than 10 m.

Absence of surface ruptures in Holocene units and relatively minor displacement of Pleistocene units makes seismic risk assessment of the Tumalo fault difficult. Recent magnitude-5+ earthquakes at Klamath Falls and Scotts Mills demonstrate that not all potentially damaging earthquakes involve long strike-length faults with observable surface ruptures. The Sisters fault zone can be viewed as a potentially active fault capable of generating earthquakes of magnitude 5.5–7.0.

GEOLOGIC HISTORY

The Three Creek Butte quadrangle lies on the east flank of the central High Cascade Range, an active volcanic province. Although the generalized model of the quadrangle presented here incorporates three stages—(1) late Miocene to early Pliocene volcanism, (2) Pliocene-Pleistocene subsidence, and (3) middle to late Pleistocene volcanism and glaciation—the only rocks now exposed in the quadrangle are Quaternary volcanic and glacial deposits formed during the middle to late Pleistocene stage.

Evidence for Tertiary tectonism and volcanism between 5.5 and 7 Ma (stage 1) is based on exposures of older rocks in adjoining quadrangles. Distal upper Miocene and lower Pliocene volcanic and volcaniclastic deposits exposed in mountains west of the High Cascade Range (Priest and others, 1983) and Deschutes Formation lava and pyroclastic flows in the Deschutes basin to the east (Smith and others, 1987) provide indirect evidence of pre-Quaternary High Cascade volcanism. Cannon (1985) demonstrated that two Deschutes Formation pyroclastic flows (Lower Bridge and McKenzie Canyon members) thicken southwestward from the Deschutes River canyon toward a buried vent somewhere south or southwest of Sisters, very likely within or near the Three Creek Butte quadrangle. Other nearby Deschutes Formation vents include the 4.7±0.1 Ma proximal-vent-facies andesitic and silicic lavas exposed at Bull Spring in the Shevlin Park quadrangle to the southwest (Hill, 1991), mafic Deschutes Formation vents exposed 7 km to the east in the Tumalo Dam quadrangle (Taylor and Ferns, 1994), and mafic to silicic vents in the Sisters quadrangle to the north (Taylor and Priest, in preparation, b).

Stage 2, which began about 5.4 Ma, was marked by subsidence as the Green Ridge and other north-striking faults became active, trapping volcanic and pyroclastic debris within the High Cascade graben (Taylor, 1990). Geographic distribution of units in the upper part of the Deschutes Formation in the Deschutes basin indicates that the eruptive axis of the ancestral Cascade Range began subsiding into the High Cascade graben about 5.4 million years ago (Smith and others, 1987), when lava and pyroclastic flows erupted during subsidence (<5.4 Ma) were topographically confined by graben-bounding faults and blocked by topographic highs along the faults from flowing eastward into the Deschutes basin. The eastern margin of the High Cascade graben is marked by large down-to-the-west faults, the most obvious of which is the 750-m-high, south-trending Green Ridge escarpment, located about 40 km north of the Three Creek Butte quadrangle. It is unclear as to whether north-trending graben boundary faults extend due south from Green Ridge into the Three Creek Butte quadrangle, forming a graben whose east margin has been buried by Quaternary lavas (Taylor, 1978, 1990; Conrey, 1985; Hill, 1991) or whether the graben boundary broadens to the east as the north-trending Green Ridge fault merges with the wider, southeast-trending Sisters fault zone (Lawrence, 1976; Peterson and others, 1976; Smith, 1986; Smith and others, 1987; MacLeod and Sherrod, 1988). An inlier of upper Pliocene volcanic rocks occurs west of Bull Spring in the Shevlin Park quadrangle (Hill, 1988a, 1991), in the east foothills of the High Cascades, well west of the Sisters fault zone. Hill (1988a, 1991) argues that the rocks of the Bull Spring inlier represent the crest of a pre-Quaternary fault block bounded by a western fault downdropped on the west side.

Stage 3 began in the Pleistocene, about 600,000 yr B.P., with eruption of ash-flow and air-fall tuffs (the Desert Spring Tuff, Bend Pumice, and Tumalo Tuff of Taylor [1981]) from the Tumalo volcanic center (Hill and Taylor, 1990). Rhyolite domes (unit Qr) emplaced along the margin of the Tumalo volcanic center define a crudely arcuate, 25-km-long structure. A closed Bouguer gravity low centered on Triangle Hill (Couch and others, 1982) indicates that low-density material underlies Triangle Hill.

Later mafic eruptions of stage 3 produced basalt and basaltic andesite lava flows such as the basaltic andesite of Black Pine Spring (unit Qbab) and an andesitic pyroclastic flow, the Shevlin Park Tuff. The Shevlin Park Tuff was erupted less than 170,000 yr B.P. from a vent centered near Triangle Hill.

Last eruptions within the quadrangle occurred less than 140,000 yr B.P., following the Jack Creek glaciation, when basaltic andesite flows of unit Qb were erupted from pyroclastic vents along the west edge of the quadrangle and buried glacial outwash deposits of unit Qgl. Slightly younger basaltic andesites of Pole Creek cone flowed into the quadrangle from a vent to the west (Taylor, 1987) following the Jack Creek glaciation. Late Pleistocene glaciers from the Suttle Lake advance entered into the western margin of the quadrangle, forming lateral and terminal moraines on Squaw Creek and Three Creek.

MINERAL, GEOTHERMAL, AND GROUND-WATER RESOURCES

Aggregate used in road construction is the main mineral resource produced in the quadrangle. Main quarries are USDA Forest Service rock pits in cinder cones (unit Qvc), which have produced volcanic cinders and scoria for road metal. Large volcanic bombs from similar cinder cones are commonly used in the Bend area for landscaping purposes. Small quantities of gravel occur in outwash sediment (unit Qagl) on Melvin Creek and in reworked fluvial deposits (unit Qal) on parts of Squaw Creek. The Shevlin Park Tuff is an aggregate and building stone resource. An attractive, dark-colored building stone has been produced from Shevlin Park Tuff quarries to the south (Peterson and others, 1976; Taylor and Ferns, 1994).

Although the relatively young age of rhyolites in the Tumalo volcanic center suggests a geothermal resource potential, limited exploration to date has been largely disappointing and has failed to identify a resource. Geothermal gradient holes were drilled in 1979 by UNOCAL along the flanks of the Tumalo volcanic center. A deep exploration well was completed in 1993 by California Energy Company in the Tumalo volcanic center in the Tumalo Falls quadrangle to the south. Under Oregon law, geologic information on stratigraphy and temperatures encountered is unavailable to the public until four years after completion of a geothermal exploration hole.

Information on ground-water resources in the quadrangle is limited. Drill logs on file with the Oregon Department of Water Resources indicate a water table elevation of about 3,100–3,150 ft, between 300 and 400 ft below the land surface in the extreme northeast corner of the quadrangle. Water wells have not been drilled in the part of the Deschutes National Forest that encompasses most of the remainder of the quadrangle. The rate of surface runoff is low; most streams are dry through much of the year.

ANALYTICAL METHODS

Most chemical analyses were determined by X-ray fluorescence (XRF) and atomic absorption spectrophotometry at Oregon State University; the methods used are described by Taylor (1987). Analysts were E.M. Taylor and R. Lightfoot. One analysis (map no. 7) was determined by X-ray fluorescence (XRF) at the Washington State University GeoAnalytical Laboratory; the procedures used are described by Hooper and others (1993). Methods for analyses from Hughes (1983) or Hill (1991) are explained by those authors in their papers. All results have been normalized on a volatile-free basis with total iron expressed as FeO*.

ACKNOWLEDGEMENTS

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Table 1. Geochemical analyses, Three Creek Butte quadrangle[1]

Map no.	Field no.	1/4	1/4	Sec.	T. (S.)	R. (E.)	UTM coordinates	Elev. (ft)	Lithology	Map unit	Oxides (weight percent) SiO_2	Al_2O_3	TiO_2	FeO*	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	Total
1	BT-82	NW	NW	26	15	10	4900060N 618840E	3360	Basaltic andesite	Qbab	55.32	17.17	1.10	8.39	na	8.89	4.79	0.75	3.59	na	100.00
2	BT-52	SE	SW	29	15	10	4898620N 614530E	3500	Basaltic andesite	Qb	54.53	17.71	1.46	8.71	na	8.51	4.30	0.76	4.02	na	100.00
3	BT-51	NE	NE	33	15	10	4898460N 617020E	3560	Basaltic andesite	Qbab	55.36	18.22	1.01	7.55	na	8.45	5.23	0.55	3.62	na	100.00
4	BT-73	NE	SE	31	15	10	4897630N 613880E	3840	Basaltic andesite	Qbab	54.72	18.48	1.01	8.08	na	9.09	4.75	0.45	3.43	na	100.00
5	BT-59	NE	SW	31	15	10	4897380N 612880E	3810	Basalt	Qbss	52.08	16.86	1.66	9.83	na	9.23	6.82	0.40	3.11	na	100.00
6	BT-53	NW	SW	35	15	10	4897480N 619080E	3420	Basaltic andesite	Qb	53.43	17.37	1.41	8.69	na	8.69	5.86	0.96	3.60	na	100.00
7	93-Be-25	SE	SW	35	15	10	4897080N 619620E	3300	Basaltic andesite	Qb	54.91	17.41	1.47	8.75	0.15	8.08	3.67	0.98	4.31	0.27	100.00
8	BT-66	NE	NW	2	16	9	4896580N 610300E	4120	Basaltic andesite	Qbap	57.74	16.94	1.65	9.02	na	6.72	3.01	0.70	4.21	na	100.00
9	BT-76	NW	NW	11	16	9	4895640N 610030E	4200	Andesite	Qba	59.13	15.81	1.76	8.60	na	6.30	2.80	1.34	4.25	na	100.00
10	BT-70	SW	NW	11	16	9	4895400N 610040E	4360	Basaltic andesite	Qbab	54.50	18.00	1.01	8.04	na	8.65	5.03	0.65	4.12	na	100.00
11	BT-384	SW	NW	11	16	9	4895260N 609920E	4320	Basaltic andesite	Qbab	54.34	18.45	1.05	7.62	na	8.22	5.71	0.80	3.81	na	100.00
12	BT-237	SE	NW	7	16	10	4895540N 613640E	3880	Basalt	Qb	51.74	18.35	1.40	9.33	na	8.62	6.62	0.31	3.63	na	100.00
13	BT-32	NW	NW	13	16	9	4894300N 611680E	4280	Basaltic andesite	Qvc	54.02	17.94	1.44	8.37	na	8.97	4.74	0.86	3.67	na	100.00
14	BT-233	NW	NE	13	16	9	4894260N 612700E	4120	Basalt	Qb	51.97	17.39	1.66	9.65	na	7.74	7.04	0.52	4.03	na	100.00
15	BT-235	NE	NE	23	16	9	4892660N 611340E	4520	Basaltic andesite	Qb	55.35	18.32	1.16	7.69	na	7.89	4.05	0.86	4.68	na	100.00
16	3S034	SW	NW	24	16	9	4892260N 611720E	4990	Rhyolite	Qr	74.95	13.75	0.16	1.58	0.06	0.72	0.02	3.47	5.27	0.02	100.00
17	BT-236	SW	SW	23	16	9	4891580N 610080E	4900	Basaltic andesite	Qb	56.93	16.97	1.26	8.33	na	7.03	3.92	0.98	4.58	na	100.00
18	BT-241	SE	SW	26	16	9	4889960N 610580E	4960	Basaltic andesite	Qb	54.50	16.43	1.55	8.62	na	8.01	5.61	0.90	4.38	na	100.00
19	BT-242	SE	SE	26	16	9	4890000N 611480E	5400	Rhyolite	Qr	74.25	14.05	0.16	1.61	na	0.80	0.20	3.27	5.66	na	100.00
20	3S035	NE	SE	26	16	9	4889820N 611320E	5300	Rhyolite	Qr	74.97	13.85	0.15	1.58	0.06	0.70	0.00	3.53	5.14	0.02	100.00
21	3S032	NE	NW	31	16	10	4889440N 613960E	5540	Rhyolite	Qr	74.81	13.76	0.15	1.71	0.06	0.71	0.00	3.49	5.28	0.02	100.00
22	BT-385	NE	NW	31	16	10	4889440N 613960E	5540	Rhyolite	Qr	75.00	13.40	0.15	1.80	na	0.70	0.20	3.55	5.20	na	100.00
23	BT-244	NW	NW	32	16	10	4889600N 615180E	4520	Basaltic andesite	Qb	53.20	17.63	2.15	10.62	na	7.51	4.01	0.33	4.55	na	100.00
24	BT-91	NW	NW	35	16	9	4889200N 610320E	5720	Rhyolite	Qr	73.84	14.89	0.15	1.90	na	0.60	0.10	3.10	5.43	na	100.00
25	3S042	NW	NW	35	16	9	4889060N 610050E	5700	Rhyolite	Qr	74.77	13.95	0.15	1.65	0.06	0.67	0.03	3.50	5.20	0.02	100.00
26	BT-238	NE	SW	35	16	9	4888720N 610480E	5810	Basaltic andesite	Qb	55.53	17.97	1.01	7.87	na	7.87	5.15	0.66	3.94	na	100.00
27	BT-243	NW	SE	36	16	9	4888600N 612520E	5240	Basaltic andesite	Qb	55.07	18.83	0.97	7.05	na	7.95	5.44	0.64	4.05	na	100.00
28	3S033	NE	SW	24	16	9	4891620N 612180E	4550	Basaltic andesite	Qb	56.43	17.43	1.30	8.32	0.15	7.55	3.83	1.03	3.64	0.31	100.00
29	BT-245	NE	SE	32	16	10	4888460N 616180E	4600	Basaltic andesite	Qb	53.92	18.92	1.52	8.30	na	8.70	4.25	0.56	3.84	na	100.00
30	BT-248	SW	NW	2	17	9	4887320N 610240E	6040	Basaltic andesite	Qvc	55.42	17.93	1.11	7.50	na	7.80	5.27	0.61	4.36	na	100.00
31	BT-247	SE	SE	1	17	9	4886680N 613180E	5440	Dacite	Qd	63.10	15.73	1.01	7.51	na	3.71	1.50	2.00	5.44	na	100.00
32	3S085	SW	SW	6	17	10	4886700N 613260E	5360	Dacite	Qd	63.41	16.10	1.13	5.70	0.12	3.90	1.70	2.11	5.44	0.38	100.00
33	3S086	SE	NW	1	17	9	4887380N 612990E	5360	Rhyolite pumice	Qg2	75.81	14.24	0.13	1.07	0.04	0.93	0.09	3.41	4.23	0.04	100.00
—[3]	3SXBP	—	—	—	—	—	—	—	Bend Pumice	Qtbb	74.71	14.30	0.16	1.83	0.07	0.82	0.08	3.49	4.51	0.03	100.00

continued next page

Table 1. (continued)

Map no.	Field no.	Trace elements (ppm)																												Reference/Analyst[2]
		Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Co	Zn	Cu	Pb	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Cs	Hf	Ga	Y	Nb	Ta	Th	U	
1	BT-82	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
2	BT-52	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
3	BT-51	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
4	BT-73	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
5	BT-59	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
6	BT-53	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
7	93-Be-25	6	32	30	262	305	19	523	140	nd	85	57	6	13	39	na	na	na	na	na	na	na	na	19	27	7.2	nd	3	nd	Washington State
8	BT-66	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
9	BT-76	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
10	BT-70	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
11	BT-384	70	84	23	na	200	12	570	60	31	na	na	na	6.6	18.3	11	2.82	1.13	0.49	1.47	0.32	na	2.46	na	na	na	0.29	0.82	0.4	Hughes, 1983
12	BT-237	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
13	BT-32	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
14	BT-233	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
15	BT-235	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
16	3S034	10	nd	4.3	2	818	82	50	219	0.5	64	na	na	24.2	53.0	21.8	4.71	0.63	0.78	3.5	0.54	1.6	6.5	18	32	18.0	1	7.8	2.5	Hill, 1992
17	BT-236	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
18	BT-241	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
19	BT-242	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
20	3S035	12	nd	4.0	1	802	83	49	219	0.5	73	na	na	23.0	51.2	21.5	4.83	0.60	0.72	3.3	0.51	1.1	6.1	19	30	17.8	1	7.7	2 3	Hill, 1992
21	3S032	10	nd	4.3	0	796	86	52	222	0.5	84	na	na	25.3	52.6	20.4	4.77	0.64	0.78	3.7	0.53	1.5	6.5	20	31	17.8	1	7 9	2.7	Hill, 1992
22	BT-385	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Hughes, 1983
23	BT-244	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
24	BT-91	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
25	3S042	12	1	4.6	8	788	83	49	217	0.9	68	na	na	19.4	44.0	17.6	3.66	0.60	0.59	3.0	0.46	1.5	6.6	18	24	16.3	1	8.2	2.6	Taylor
26	BT-238	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
27	BT-243	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
28	3S033	5	23	22.7	203	383	16	611	142	20.0	67	na	na	14.2	29.6	17.0	4.15	1.30	0.56	2.0	0.28	0.6	2.9	20	24	8.3	0	1 5	0.8	Hill, 1992
29	BT-245	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
30	BT-248	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor, 1987
31	BT-247	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	na	Taylor
32	3S085	5	7	16.6	93	634	41	393	239	10.5	nd	na	na	24.7	58.7	31.6	6.96	1.82	1.18	3.7	0.58	1.1	6.7	19	35	13.3	1	4.2	1.8	Hill, 1992
33	3S086	11	4	2.0	0	861	74	115	97	0.9	58	na	na	20.0	43.5	16.3	2.77	0.44	0.41	1.5	0.26	1.8	3.3	17	16	10.9	1	7.3	4 5	Hill, 1992
—[3]	3SXBP	11	1	4.29	0	794	84	65	231	0.5	105	—	—	28.7	59.7	26.5	5.95	0.83	0.94	4.2	0.58	3.1	6.7	20	36	16.9	1.2	8.1	2.7	Hill, 1992

[1] See text for explanation of analytical procedures. na = not available nd = not detected

[2] Undated when analyst's data are unpublished. See text section on analytical methods.

[3] Included for comparative purposes only.