ISSN 0270-952X

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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Geologic Map of the Steelhead Falls Quadrangle, Deschutes and Jefferson Counties, Oregon

1996

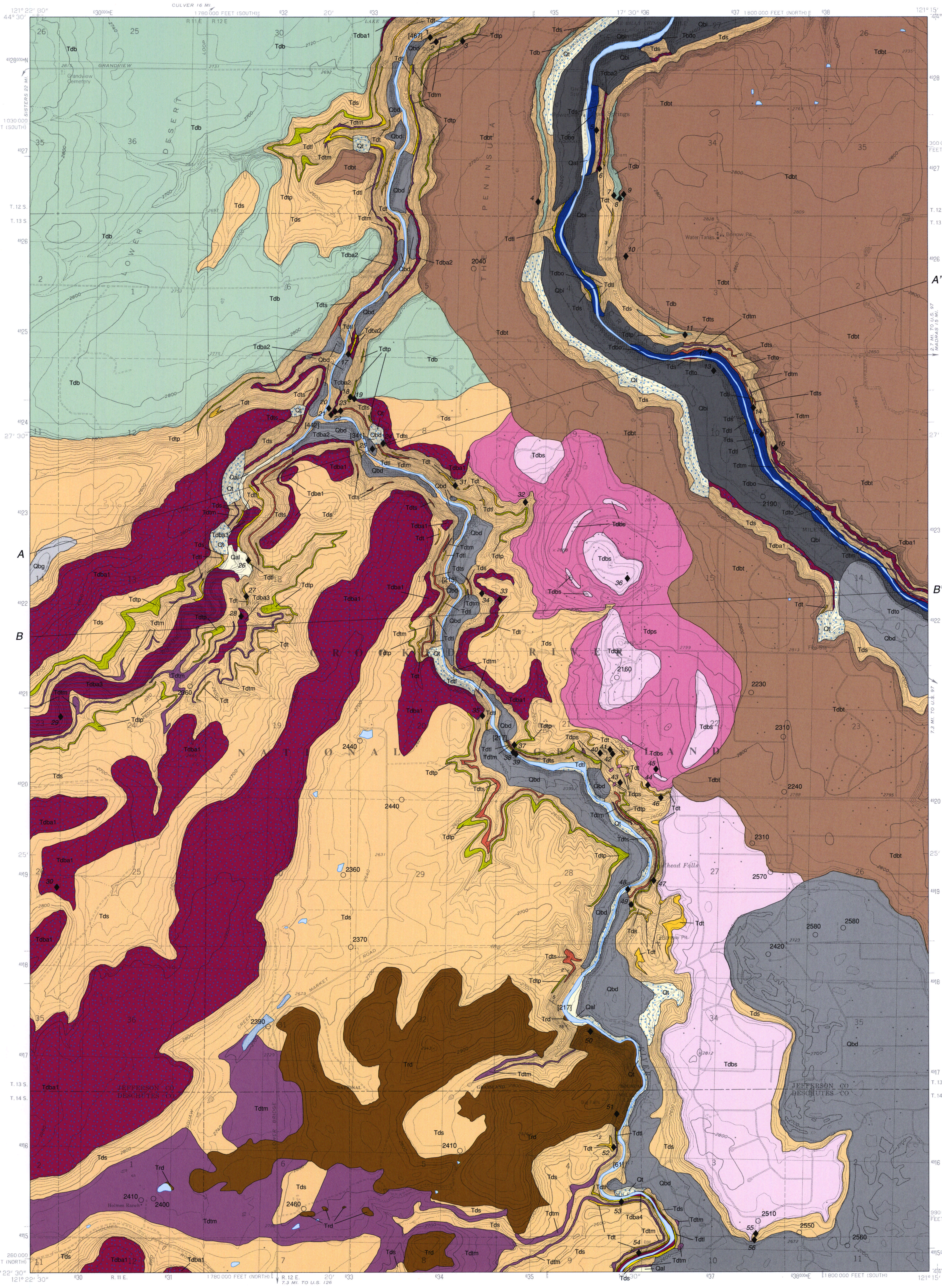
GMS-101

Geologic Map of the Steelhead Falls Quadrangle,
Deschutes and Jefferson Counties, Oregon

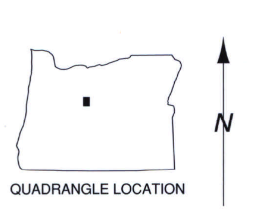
By M.L. Ferns, D.A. Stensland, and G.A. Smith

Funded in part by the National Geologic Mapping Program (STATEMAP)
administered by the U.S. Geological Survey

Published in cooperation with the Oregon Department of Water Resources and the U.S. Geological Survey



Base map by U.S. Geological Survey
Control by USGS and NOS/NOAA
Projection: Lambert Conformal Conic
Grid: 1000-meter Universal Transverse Mercator, Zone 10
10,000-foot State Grid Ticks, Oregon, South and North Zones
UTM grid declination: 1 degree, 11 minutes east
1985 magnetic north declination: 19 degrees east
Vertical datum: National Geodetic Vertical Datum of 1929
Horizontal Datum: 1927 North American Datum



QUADRANGLE LOCATION

SCALE 1:24 000

KILOMETERS (.5, 0, 1, 2)

FEET (1000, 0, 7000)

MILES (.5, 0, 1)

CONTOUR INTERVAL 20 FEET

Geology by Mark L. Ferns, Oregon Department of Geology and Mineral Industries; Donald A. Stensland, Southwest Oregon Community College; and Gary A. Smith, University of New Mexico

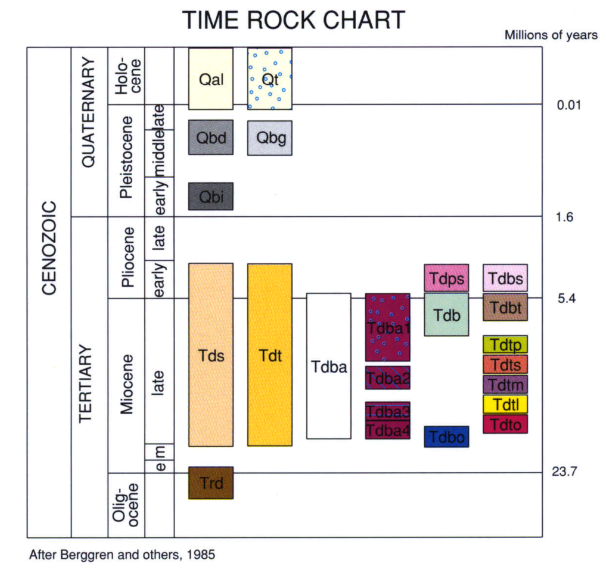
Field work by Ferns conducted in 1993

Reviewed by Dave Sherrod, U.S. Geological Survey

Cartography by Mark E. Neuhaus

The geologic information on this map is available in digital formats

TIME ROCK CHART



After Berggren and others, 1985

Explanation of Map Units

Qal	Alluvium (Holocene and upper Pleistocene)
Qt	Talus and landslide deposits (Holocene and upper Pleistocene)
	Intracanyon basalt (Pleistocene)
Qbg	Basalt of Garrison Butte (upper or middle Pleistocene)
Qbd	Basalt of the Deschutes River canyon (upper or middle Pleistocene)
Qbi	Basalt of The Island (lower Pleistocene)
	Deschutes Formation (lower Pliocene and upper Miocene)
Tds	Deschutes Formation, undivided (lower Pliocene and upper Miocene)
	Steamboat Rock member of Smith (1986b) (lower Pliocene)
Tdbs	Lava flows (lower Pliocene)
Tdps	Hydromagmatic deposits (lower Pliocene)
Tdt	Ash-flow tuff, undivided (lower Pliocene and upper Miocene)
Tdtp	Peninsula ignimbrite member of Smith (1986b, 1991) (upper Miocene)
Tdts	Steelhead Falls ignimbrite member of Smith (1986b, 1991) (upper Miocene)
Tdtm	McKenzie Canyon ignimbrite member of Smith (1986b) (upper Miocene)
Tdtl	Lower Bridge ignimbrite member of Smith (1986b) (upper Miocene)
Tdto	Osborne Canyon ignimbrite member (upper Miocene)
Tdbt	Tetherow Butte basalt flows (lower Pliocene or upper Miocene)
Tdb	Diktytaxitic olivine basalt flows (lower Pliocene and upper Miocene)
Tdba	Porphyritic basaltic andesite flows (lower Pliocene? and upper Miocene)
Tdba1	Rimrock-forming basaltic andesite flows (lower Pliocene? and upper Miocene)
Tdba2	Olivine-augite and hypersthene-bearing basaltic andesite lava flows (upper Miocene)
Tdba3	Augite basaltic andesite (upper Miocene)
Tdba4	Porphyritic olivine basalt (upper Miocene)
Tdbo	Opal Springs basalt member of Smith (1986b) (upper Miocene)
Trd	Rhyodacite (Miocene or Oligocene?)

Geologic Map Symbols

Contact

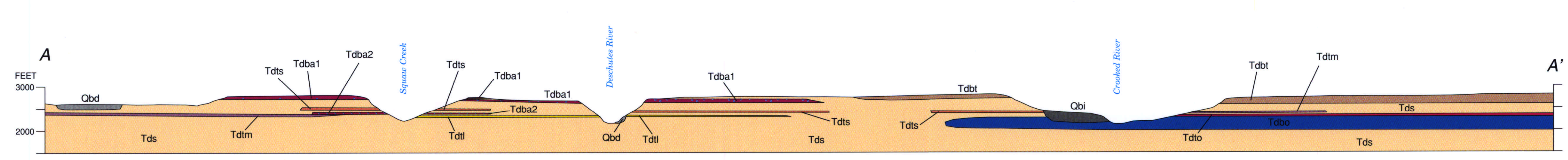
Strike and dip of beds

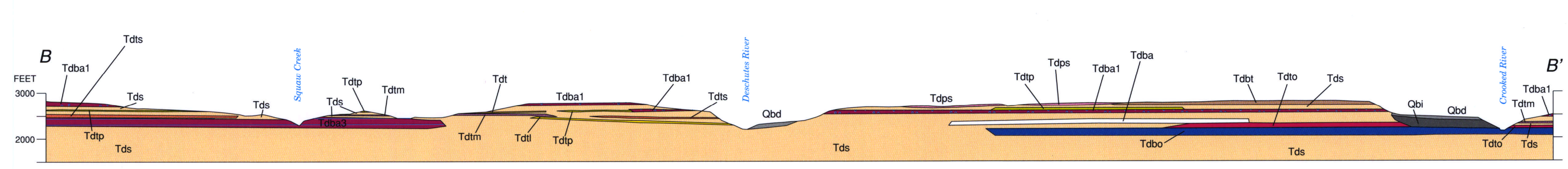
2560 Water well showing static water elevation in feet

[217] Measured streamflow in cfs (cubic feet/second)

55 Location of sample in Table 1 (see accompanying text)

GEOLOGIC CROSS SECTIONS





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By M.L. Ferns, D.A. Stensland, and G.A. Smith
Text

This map is dedicated to the memory of Donald E. Stensland, 1931–1995

Geology of the Steelhead Falls Quadrangle

by Mark L. Ferns, Oregon Department of Geology and Mineral Industries;
Donald E. Stensland, Southwest Oregon Community College; and Gary A. Smith, University of New Mexico

INTRODUCTION

The Steelhead Falls quadrangle covers the north-central part of the Deschutes basin between the city of Redmond and Lake Billy Chinook. This geologic map is one product of a STATEMAP project covering the Bend 30×60-minute quadrangle (Figure 1). Project goals include a 1:100,000-scale geologic map of the Bend quadrangle using new mapping by geologists from the U.S. Geological Survey, the Oregon Department of Geology and Mineral Industries, and Oregon State University. The new mapping is being used by the Oregon Department of Water Resources and the U.S. Geological Survey to develop a geologic model for groundwater in the Deschutes River basin.

The Steelhead Falls quadrangle encompasses part of the Deschutes basin, a broad, back-arc alluvial plain situated between the Quaternary volcanoes of the High Cascades to the west and older middle Tertiary volcanic rocks in the Ochoco Mountains to the east. Geologic units include the late Miocene to early Pliocene Deschutes Formation (5.06–5.77 million years old), composed of fluvial deposits, debris-flow deposits, silicic ash-flow and air-fall tuff, and basalt and basaltic andesite lava flows. Older volcanic rocks are exposed in a low hill in the southern part of the quadrangle. Younger Pleistocene (<1.5 million years old) diktytaxitic olivine basalt flows partially fill canyons carved into Deschutes Formation units.

Many volcanic rocks are too fine grained and glassy to be adequately characterized by mineralogical criteria. Instead, we classify volcanic rocks according to silica content, following the criteria used by Taylor (1978) and Taylor and Ferns (1995). These criteria are based on chemical analyses recalculated to a 100-percent total without volatiles and with all iron calculated as Fe^{+2}:

Silica < 53 weight percent = basalt
Silica ≥ 53 and < 58 percent = basaltic andesite
Silica ≥ 58 and < 63 percent = andesite
Silica ≥ 63 and < 68 percent = dacite
Silica ≥ 68 and < 73 percent = rhyodacite
Silica ≥ 73 percent = rhyolite

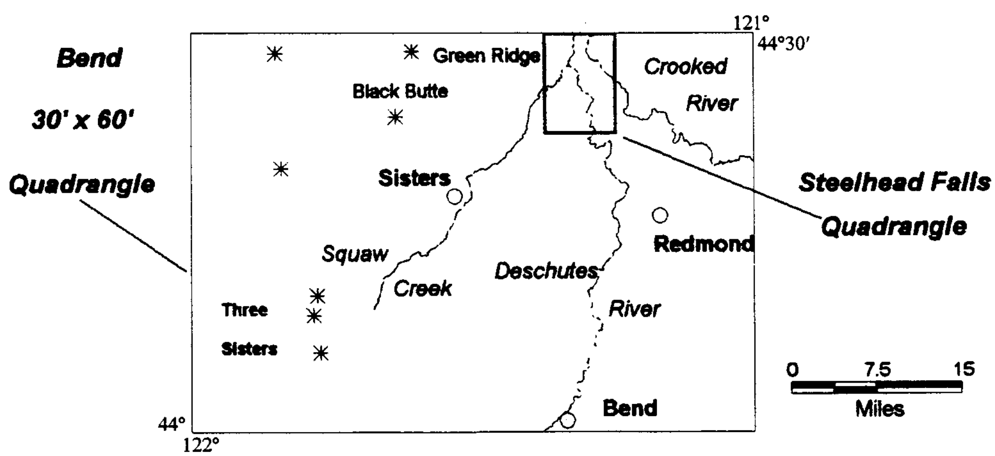

Figure 1. *Sketch map of Bend 30×60-minute quadrangle. Rectangle marks location of Steelhead Falls 7½-minute quadrangle.*

EXPLANATION OF MAP UNITS

Qal **Alluvium (Holocene and upper Pleistocene)**—Unconsolidated sand and gravel deposited along Squaw Creek and the Deschutes and Crooked Rivers. Unit includes thin fluviatile Pleistocene gravels deposited atop intracanyon lava flows where the flows entered the Deschutes River canyon in the southern part of the quadrangle. Unit also includes bench gravels above the modern Squaw Creek channel upstream from a thick talus wedge

Qt **Talus and landslide deposits (Holocene and upper Pleistocene)**—Unconsolidated deposits of angular basalt talus mantling steep slopes of Squaw Creek and the Deschutes and Crooked River canyons. Mapped only where talus boulders cover underlying strata. Includes thick talus wedges that apparently periodically blocked the Squaw Creek channel. Elsewhere, colluvium and soil largely obscure underlying strata on both sides of the Crooked River canyon

Intracanyon basalt (Pleistocene)—Gray, diktytaxitic, high-alumina olivine basalt lava flows exposed mainly along the Crooked and Deschutes River canyons. Divided into the following three units:

Qbg **Basalt of Garrison Butte (upper or middle Pleistocene)**—Gray to dark-gray, diktytaxitic olivine basalt lava flow erupted from group of cinder cones at Garrison Butte in the Little Squaw Back quadrangle to the west. Petrographically a holocrystalline olivine basalt flow with sparse olivine and plagioclase phenocrysts <2 mm in diameter. Chemically a high-alumina olivine basalt with <50 percent SiO_2 (Ferns and others, in preparation). Surface of flow is marked by tumuli and mantled by fluviatile gravel and sand. Middle or late Pleistocene age is based on intracanyon position, uneroded morphology of source cinder cones at Garrison Butte and normal-polarity natural remanent magnetization (NRM)

Qbd **Basalt of the Deschutes River canyon (upper or middle Pleistocene)**—Dark-gray diktytaxitic olivine basalt lava flow extending into the quadrangle from the south. Forms prominent benches along the Deschutes River about 60 m above modern river level. Petrographically a holocrystalline olivine basalt with sparse olivine phenocrysts <2mm in diameter. Chemically a high-alumina olivine basalt with <50 percent SiO_2 (Table 1, map no. 25). Bench surfaces decrease in elevation from 2,600 ft in the south to 2,260 ft in the north. Flows have normal-polarity natural remanent magnetization

Qbi **Basalt of The Island (lower Pleistocene)**—Gray, diktytaxitic olivine basalt lava flows extending into the quadrangle from the south. Forms prominent benches at elevation of 2,400 ft along the Crooked River. Unit is a 170-m-thick, flow-on-flow sequence with prominent columnar joints. Pillow basalt and hyaloclastite breccia are locally exposed along channel margins. In places, unit consists of a single cooling unit marked by a single thick columnar section capped by a thick entablature. Microporphyritic with ophitic clinopyroxene and sparse olivine microphenocrysts <1 mm in diameter. Chemically a high-alumina olivine basalt with <50 percent SiO_2 (Table 1, map no. 13). Early Pleistocene age based on $^{40}Ar/^{39}Ar$ age of 1.19±0.08 Ma (Table 2) and reversed-polarity natural remanent magnetization. Herein named for exposures on The Island, in the Round Butte Dam quadrangle at the confluence of the Crooked and Deschutes Rivers

Deschutes Formation (lower Pliocene and upper Miocene)—Diverse sequence of volcaniclastic rocks and lava flows. Unit consists of, in order of abundance, fluviatile volcanic conglomerate and sandstone; silicic- and intermediate-composition pyroclastic deposits, including ignimbrites (welded and nonwelded ash-flow tuff); air-fall lapilli tuff; basalt and basaltic andesite lava flows; matrix-supported mudflow breccia; and hydroclastic tuff. Age of unit in quadrangle is late Miocene to early Pliocene on basis of isotopic ages that range from 5.77 to 5.06 Ma for lava flows at stratigraphically lowest and highest exposures (Table 2). Elsewhere in basin, the Deschutes Formation is as old as about 7.5 Ma and as young as 4.0 Ma. Divided into the following units:

Tds **Deschutes Formation, undivided (lower Pliocene and upper Miocene)**—Mainly fluviatile volcanic sandstone and conglomerate with lava flows and ash-flow tuff. Includes lapilli tuff, matrix-supported mudflow breccia, and hyperconcentrated flood deposits produced during pyroclastic eruptions (Smith, 1986a). Volcaniclastic sedimentary rocks include massive, channel-filling, clast-supported conglomerate; pebbly, coarse-grained tuffaceous sandstone; and matrix-supported debris-flow deposits with angular clasts and matrix-poor, clast-supported boulder conglomerates. Sedimentary sections characterized by cut-and-fill channels with erosional surfaces that bound discrete depositional sequences (Smith, 1991). Late Miocene to early Pliocene age is based on isotopic ages from flows exposed at the top and base of the unit in the Steelhead Falls quadrangle

Steamboat Rock member of Smith (1986b) (lower Pliocene)—Lithologically diverse Deschutes Formation unit produced during fissure eruptions in the Deschutes basin. Possesses reversed-polarity natural remanent magnetization. Divided into:

Tdbs **Lava flows (lower Pliocene)**—Scoriaceous, black to reddish lava flows and agglutinate deposits. Includes agglutinate and spatter deposits along vent rims and crater-filling lava flows. Generally aphyric to sparsely porphyritic basaltic andesite with augite and plagioclase glomerocrysts and abundant iron-titanium oxides. Contains 54–56 percent SiO_2 and >2.00 percent TiO_2 (Smith, 1986b; Table 1, map nos. 42, 55, 56). Isotopic age of 5.06±0.03 Ma ($^{40}Ar/^{39}Ar$, whole-rock) from sample collected 2 km south of quadrangle (Table 2). Vent areas are exposed throughout the central part of the quadrangle

Tdps **Hydromagmatic deposits (lower Pliocene)**—Brown to grayish-yellow near-vent deposits as much as 100 m thick of sideromelane-rich lapilli-tuff and pyroclastic breccia. Basaltic tuffs at vents draped by cinder, scoria, and agglutinate. Juvenile clast compositions are similar to crater-filling lava flows of unit Tdbs (Smith, 1986b; Table 1, map nos. 40, 41). Unit is interpreted as proximal and medial facies of hydrovolcanic vent deposits. Relict morphology suggests that the deposits initially formed tuff rings. Includes small cylindrical breccias that form pinnacles surrounded by Deschutes Formation sediment and ash-flow tuff along the east side of the Deschutes River north of Steelhead Falls

Tdt **Ash-flow tuff, undivided (lower Pliocene and upper Miocene)**—Welded and nonwelded, pumiceous pyroclastic-flow deposits (ignimbrites of some workers) (Smith, 1986b, 1991). Each ash-flow tuff is a single cooling unit that may consist of multiple pyroclastic-flow and pumice-fall deposits. Irregularly distributed and highly variable in thickness, owing to channeling and erosion by succeeding ash flows, debris flows, and hyperconcentrated floods. Map unit delineates prominent exposures of unnamed or uncorrelated ash-flow tuffs exposed along canyon walls. Includes a channel-filling, welded vitric ash-flow tuff exposed at Alder Springs that lies between the Steelhead Falls (unit Tdts) and Peninsula (unit Tdtp) members. All sampled tuffs possess reversed-polarity natural remanent magnetization. Locally divided into the following informal members:

Tdtp **Peninsula ignimbrite member of Smith (1986b, 1991) (upper Miocene)**—Gray-brown to greenish-gray lithic ash-flow tuff characterized by large, black aphyric bombs as much as 15 cm in diameter and black vesicular lapilli. Unit typically contains sparsely phyric, gray (rhyolitic) and black (dacitic) pumice lapilli with plagioclase and clinopyroxene phenocrysts. Unit ranges from 1 to 12 m in thickness and thickens to the west. Nonwelded to partially welded with black lapilli of dacitic composition (65–66 percent SiO_2, 0.74–0.91 percent TiO_2). Black bombs are andesitic in composition (61 percent SiO_2) (Smith, 1986b; Table 1, map nos. 18, 33, 37, 49). Unit possesses reversed-polarity natural remanent magnetization. Equivalent to unit 6 of Stensland (1970). Late Miocene age based on stratigraphic position beneath the Tetherow Butte member

Tdts **Steelhead Falls ignimbrite member of Smith (1986b, 1991) (upper Miocene)**—Pinkish-gray, white, and tan vitric ash-flow tuff, nonwelded to partially welded. Unit is characterized by abundant rhyodacitic pumice lapilli (~70 percent SiO_2, 0.52 percent TiO_2) and commonly displays reverse grading (Smith, 1986b). Underlain by a cogenetic, white pumice lapillistone as much as 1.5 m thick. Unit ranges from 2 to 35 m in thickness and corresponds to unit 3 of Stensland (1970). Late Miocene age based on stratigraphic position

Tdtm **McKenzie Canyon ignimbrite member of Smith (1986b) (upper Miocene)**—Reddish-orange to orange lithic ash-flow tuff, typically white at the base. Characterized by diverse assemblage of pumice lapilli composed of white rhyodacite (70.5–72.2 percent SiO_2, 0.26–0.32 percent TiO_2), black andesite (59.8–61.2 percent SiO_2, 1.41–1.53 percent TiO_2), and striped pumice of mixed composition (64 percent SiO_2, 1.04 percent TiO_2) (Cannon, 1985; Smith, 1986b). Unit consists of a single cooling unit comprising one to five individual ash flows, each separated by white basal ashfall tuff. Individual ash flows are commonly welded and display reverse grading of pumice lapilli. Lower ash flows are white and rich in white rhyolite pumice, whereas the uppermost orange flow is welded and contains collapsed black and striped white-and-black pumice. Unit thickens to >10 m to the southwest, toward a buried vent presumably located southwest of Sisters (Cannon, 1985). Equivalent to the McKenzie Canyon tuff of Cannon (1985) and unit 2 of Stensland (1970). Late Miocene age based on stratigraphic position above the 5.77-Ma Opal Springs member (unit Tdbo) and below the Steamboat Rock member

Tdtl **Lower Bridge ignimbrite member of Smith (1986b) (upper Miocene)**—Pinkish-gray to pinkish-white, nonwelded, pumiceous vitric ash-flow tuff with white and gray pumice lapilli. White lapilli are rhyodacite (70.1–71.5 percent SiO_2, 0.4–0.64 percent TiO_2), and gray lapilli are dacite (66–68.7 percent SiO_2, 0.54–0.85 percent TiO_2) in composition (Table 1, map nos. 26, 38). Unit consists of two ash flows that form a single cooling unit. Basal part of unit includes a distinctive accretionary-lapilli fallout deposit (Cannon, 1985). Unit thickens to >15 m southwestward, toward a buried vent area presumably located southwest of Sisters (Cannon, 1985). Equivalent to the Lower Bridge tuff of Cannon (1985) and unit 1 of Stensland (1970). Late Miocene age is based on stratigraphic position above the 5.77-Ma Opal Springs member and below the Steamboat Rock member

Tdto **Osborne Canyon ignimbrite member (upper Miocene)**—Orange and pinkish-gray to pinkish-white, non-welded vitric ash-flow tuff. Forms single cooling unit comprising two emplacement units. Unit is typified by fumarolically altered orange pumice lapilli and bombs and reverse grading of pumice lapilli. Pumice lapilli include white rhyolite pumice (72.5–74.9 percent SiO_2, 0.26–0.27 percent TiO_2) and black andesite pumice (62.8 percent SiO_2, 1.18 percent TiO_2) (Table 1, map nos. 12, 14). Unit is from 9 to 40 m thick, fills channels, and weathers to form a distinctive hoodoo topography in the Crooked River canyon. Equivalent to the Hollywood ignimbrite member of Smith (1986b) and unit O of Cannon (1985) and herein named for exposures in the Opal City quadrangle, on the Crooked River at the mouth of Osborne Canyon. Late Miocene age is based on stratigraphic position immediately above the 5.77-Ma Opal Springs member

Tdbt **Tetherow Butte basalt flows (lower Pliocene or upper Miocene)**—Black, aphyric basalt flows forming rimrock on both sides of the Crooked River. Characterized by glomerocrysts of plagioclase and zoned green clinopyroxene. Chemical analyses show low silica contents (51–52 percent SiO_2) and high titania contents (>2.4 percent TiO_2) (Smith, 1986b; Table 1, map nos. 4, 10). Includes the Agency Plains and Crooked River basalt flows of Smith (1986b) and is correlative to the Crooked River flow of Robinson and Stensland (1979). Flows display normal-polarity natural remanent magnetization. Isotopic age from Agency Plains basalt flow is 5.31±0.05 Ma ($^{40}Ar/^{39}Ar$, whole-rock) (Smith, 1986c)

Tdb **Diktytaxitic olivine basalt flows (lower Pliocene and upper Miocene)**—Gray, diktytaxitic olivine basalt lava flows exposed in the upper part of the Deschutes Formation. Includes rimrock flows on northwest flank of the Deschutes River canyon (Canadian Bench and Fly Lake basalt flows of Dill, 1992). Also includes lava flows exposed beneath the Tetherow Butte member (unit Tbdt) on the east side of the Crooked River canyon. Typically gray, holocrystalline olivine basalts contain plagioclase laths and ophitic or intragranular clinopyroxene and are high-alumina olivine tholeiites (Conrey, 1985) with 50–53 percent SiO_2, <1.0 percent TiO_2, and >17 percent Al_2O_3 (Table 1, map nos. 8, 11, 19). Isotopic age of 5.43±0.05 Ma ($^{40}Ar/^{39}Ar$, whole-rock) obtained from the Canadian Bench flow (Smith, 1986c). Vent area for the Fly Lake basalt lies west of Green Ridge (Conrey, 1985; Smith, 1986b, 1991)

Tdba (Shown only in cross section) **Porphyritic basaltic andesite flows (lower Pliocene? and upper Miocene)**—Grayish-black, porphyritic basaltic andesite flows exposed at different stratigraphic levels in the Deschutes Formation. On map, divided on the basis of stratigraphic position into the following units:

$Tdba_1$ **Rimrock-forming basaltic andesite flows (lower Pliocene? and upper Miocene)**—Includes lava flows overlying the tuff of the Peninsula ignimbrite member (unit Tdtp) and flows between the Peninsula and the Steelhead Falls (unit Tdts) ignimbrite members. Generally grayish-black, glassy, glomeroporphyritic olivine basaltic andesites with sparse augite and olivine phenocrysts. Unit includes both low- and high-titania basaltic andesites (1.4–1.7 percent TiO_2 and > 2.0 percent TiO_2 at 53–54 percent SiO_2) (Smith, 1986b; Table 1, map nos. 7, 16, 24, 29, 34, 35). Unit interfingers with diktytaxitic olivine basalt flows (unit Tdb) to the west in the Squawback Ridge quadrangle. Late Miocene age based on stratigraphic position

$Tdba_2$ **Olivine-augite and hypersthene-bearing basaltic andesite lava flows (upper Miocene)**—Unit is comprised of lava flows exposed beneath the Steelhead Falls ignimbrite member (unit Tdts) and above the Lower Bridge ignimbrite member (unit Tdtl). Includes flows exposed near the confluence of Squaw Creek and the Deschutes River between 2,300 and 2,420 ft elevation (Table 1, map nos. 21, 22, 23) and on the Crooked River near Opal Springs at 2,360 ft elevation (Table 1, map no. 6). Chemically basaltic andesite with 53.7–55 percent SiO_2 and 18–18.5 percent Al_2O_3. Measured flows have reversed-polarity natural remanent magnetization. Late Miocene age based on stratigraphic position

$Tbda_3$ **Augite basaltic andesite (upper Miocene)**—Unit consists of a 70-m-thick basaltic andesite flow exposed in the canyon of Squaw Creek between 2,300 and 2,400 ft elevation (Table 1, map nos. 27, 31). Unit underlies the Lower Bridge ignimbrite member (unit Tdtl). Compositionally a basaltic andesite with 53.9–54 percent SiO_2, 16.9–17.8 percent Al_2O_3, and 1.4 percent TiO_2. Late Miocene age based on stratigraphic position

$Tdba_4$ **Porphyritic olivine basalt (upper Miocene)**—Unit consists of a 15-m-thick olivine basalt flow exposed below the Lower Bridge ignimbrite member (unit Tdtl) near the southern quadrangle boundary. Analyses from exposures in the Cline Falls quadrangle to the south are of a high-alumina basalt with 53 percent SiO_2 and 19–20 percent Al_2O_3 (Smith, 1986b). Equivalent to flow 3 of Stensland (1970). Small outcrop of chemically similar basalt is located at the confluence of Squaw Creek and the Deschutes River at 2,100 ft elevation (Table 1, map no. 20)

Tdbo **Opal Springs basalt member of Smith (1986b) (upper Miocene)**—Gray, diktytaxitic olivine basalt lava flows exposed along the floor of the Crooked River canyon. Unit consists of several lava flows separated by paleosols and ash-flow tuff. Underlies the Osborne Canyon ignimbrite member (unit Tdto) and has normal-polarity natural remanent magnetization. Chemical compositions range from 49.5 to 50 percent SiO_2, 16.6 to 17 percent Al_2O_3, and 1 to 1.1 percent TiO_2 (Table 1, map nos. 5, 15). Equivalent to basalt flow 1 of Stensland (1970). Isotopic age of 5.77±0.07 Ma ($^{40}Ar/^{39}Ar$, whole-rock) is reported by Smith (1986c)

Trd **Rhyodacite (Miocene or Oligocene?)**—Gray to pinkish-gray, flow-banded porphyritic rhyodacite dome. Northern exposures include devitrified carapace breccia with blebs of grayish-black perlite. The rhyodacite contains 10–15 percent plagioclase phenocrysts and <1 percent black orthopyroxene and clinopyroxene phenocrysts set in a pilotaxitic groundmass of fine plagioclase laths, iron oxides, and interstitial cryptocrystalline silica, feldspar, and glass. Chemically a calc-alkaline rhyodacite with 68–69 percent SiO_2 and 0.53–0.69 percent TiO_2 (Table 1, map nos. 50, 51). Miocene or Oligocene age based on stratigraphic position beneath the Lower Bridge ignimbrite member and presumed correlation with units in the upper part of the John Day Formation. Even so, the unit contains fresh glass, and its composition is more like that of silicic tuffs in the Deschutes Formation than of tuffs in the John Day Formation

GEOLOGIC HISTORY

The rhyodacite dome (unit Trd) exposed as an inlier along the Crooked River is the oldest unit exposed in the Steelhead Falls quadrangle. Although its exact age is unknown, this dome marks one of several silicic vents that protrude through the Deschutes Formation along the east flank of the Deschutes basin. The vents formed topographic prominences that rise above older, extensive rhyolite ash-flow members of the John Day Formation to the east.

Deschutes Formation exposures along the Deschutes and Crooked Rivers record cycles of volcanism-related aggradation and erosional degradation in a broad, low-relief, back-arc alluvial plain during the late Miocene and early Pliocene (Smith, 1991). Ancestral drainages were choked by lava, pyroclastic flows, and debris flows during volcanic eruptions, when influx of volcanic material into the Deschutes basin exceeded erosion. Quiescent periods, marked by downcutting, were followed by periods of renewed volcanic activity that again choked the drainages with volcanic and volcaniclastic debris. Aggradation began between 7 and 7.5 Ma, when basalt and basaltic andesite lava flows and andesitic, dacitic, rhyodacitic, and rhyolitic pyroclastic flows were erupted from vents within the central Oregon High Cascades (Priest and others, 1983; Smith and others, 1987). Collapse of the central Oregon High Cascade volcanic axis into an intra-arc extensional graben (Taylor, 1981; Smith and Taylor, 1983; Smith and others, 1987) at about 5.4 Ma resulted in formation of a topographic barrier along the Green Ridge fault that effectively shielded the basin from most subsequent High Cascade eruptive products (Smith and others, 1987; Smith, 1991).

Only a part (5.06–5.77 Ma) of the Deschutes Formation (3.97–7.42 Ma) is exposed in the Steelhead Falls quadrangle. Older units exposed to the north are mainly fluvial sediments, debris flows, and basalt flows that record early and predominantly mafic volcanism. The oldest Deschutes Formation unit exposed in the quadrangle is the 5.77-Ma Opal Springs basalt member. Exposures of the Opal Springs member are confined to the Crooked River and may indicate a source to the south or east.

The basaltic andesite flow exposed on Squaw Creek (unit $Tdba_3$) is the oldest clearly Cascade-derived lava flow exposed in the quadrangle. Early mafic lava-flow eruptions were followed by numerous pyroclastic eruptions that produced ash-flow, debris-flow, hyperconcentrated-flood, and flood-gravel deposits. The pyroclastic flows were deposited in a dynamic aggrading environment, where successive depositional units scoured, filled, and then overtopped shallow channels cut into previously emplaced units. The Osborne Canyon, Lower Bridge, and McKenzie Bridge ignimbrite members were erupted over a short time interval; forming a distinct stratigraphic succession about 70 m thick. Source of the Osborne Canyon ignimbrite member, confined to channels above the Opal Springs basalt, is unknown. Overlying Lower Bridge and McKenzie Canyon ignimbrite members originated from vent areas to the southwest, possibly near Sisters (Cannon, 1985). Ash flows from both members overtopped shallow channels and extended laterally across considerable distances.

A second basaltic andesite flow (unit $Tdba_2$), entered the southern part of the quadrangle along a broad channel cut through the McKenzie Canyon ignimbrite member. Later, the Steelhead Falls ignimbrite member was erupted onto a surface marked by small channels incised into the underlying ash-flow tuff. Source of the Steelhead Falls ignimbrite is unknown, as the unit is not exposed beyond the Steelhead Falls quadrangle.

Channels were cut into underlying units following eruption of the Steelhead Falls ignimbrite member, as the relative volume of pyroclastic and lava flows erupted into the basin decreased. The upper, largely fluviatile part of the Deschutes Formation records a period of stream degradation characterized by incision and regrading of stream profiles. Later pyroclastic, lava, and debris flows filled large channels, such as the one at Alder Springs, that were incised through as much as 100 m of underlying strata. Channels cut into the upper part of the Deschutes Formation follow down a paleoslope from southwest to northeast (Smith, 1986b, 1991). The deepest channel at Alder Springs is coincident with a northeast-trending fault that cuts the McKenzie Canyon ignimbrite member.

Deeper channels had largely filled with debris flows and fluviatile deposits by the time the Peninsula ignimbrite member was emplaced. Exposure patterns indicate that the Peninsula ignimbrite member was deposited in broad, northeast-trending channels. Source of the Peninsula ignimbrite member, which thickens to the west, was apparently north of the presumed vent area for the Lower Bridge ignimbrite and McKenzie Canyon ignimbrite members.

Youngest Deschutes Formation units are the basalt (unit Tdb) and basaltic andesite (unit $Tdba_1$) lava flows that were erupted from vents near the Green Ridge fault zone. Distinctive high-titania lava flows were erupted from the east flank of the Deschutes basin between 5.31 and 3.97 Ma. Small vents at Tetherow Buttes fed 5.31-Ma lava flows that entered the Steelhead Falls quadrangle from the south (Smith, 1986b, 1991). Hydrovolcanic vent complexes within the quadrangle mark the source of the 5.07-Ma Steamboat Rock flows of Smith (1986b).

Lavas and sediments deposited in drainages incised into the Tetherow Butte and Steamboat Rock units are excluded from the Deschutes Formation by Smith (1986b). Oldest post-Deschutes Formation units are 3.36-Ma diktytaxitic olivine basalts that were erupted from south of Terrebonne (Smith, 1986b) and flowed northward past Redmond to just south of the quadrangle boundary. By early Pleistocene time, the ancestral Crooked and Deschutes Rivers had cut as deep as the modern canyons. The oldest of the Quaternary intracanyon basalt (unit Qbi) flowed into the Crooked River canyon from the south at about 1.2 Ma, clogging the canyon with over 100 m of lava. A younger Quaternary intracanyon basalt (unit Qbd) originated from Newberry volcano to the south and flowed into both the Crooked and Deschutes River canyons some time after 780,000 yr B.P.

The Deschutes basin has been largely isolated from Cascade Range volcanism since the late Miocene. Large Pliocene shield volcanoes built up at Squaw Back Ridge at 2.9 Ma (Armstrong and others, 1975; recalculated by Fiebelkorn and others, 1983) and Little Squaw Back, approximately 4 mi west of the quadrangle boundary. Although these volcanoes lie east of the Green Ridge fault, the viscous basaltic andesite lavas did not reach the ancestral Deschutes River. A younger High Cascade olivine basalt (unit Qbg) from the Garrison Buttes cluster of cinder cones flowed into the quadrangle along a tributary drainage north of Squaw Creek.

WATER RESOURCES

The Oregon Water Resources Department (OWRD) and the U.S. Geological Survey are now finishing a detailed study of surface and subsurface water resources in the middle Deschutes basin. The geology of the Steelhead Falls quadrangle was mapped in support of that study, as the Crooked and Deschutes Rivers have carved canyons deep enough to intersect the deep water table. Measured groundwater elevations in nearby water wells show decrease in the regional water table elevation that roughly coincides with the elevation of the Deschutes River. Groundwater elevations in water wells located 1mi east of the Deschutes River drop from 2,510 ft in a well in the south to 2,040 ft in a well to the north. River-bed elevations due west of these wells drop from 2,460 ft to 2,050 ft.

In-stream flows in the Steelhead Falls quadrangle increase dramatically from south to north along the Deschutes and Crooked Rivers. Large increases of in-stream flow result from spring discharge where the rivers cut highly permeable units below the regional water table. OWRD measurements along the Deschutes River in May 1992 and 1994 recorded in-stream flows between 61 and 68 cfs (cubic ft/second) at river mile 130.5, south of the rhyodacite dome. Immediately north of the dome, at river mile 128.7, in-stream flow increased dramatically to 216–217 cfs, an increase of about 150 cfs over a 1.8-mi-long segment of river (Ferns and others, 1996). The flow increase comes from springs issuing from open cavities in dome carapace and talus breccias along the dome margin. Similar increases of in-stream flow (from 213–226 cfs at river mile 124.9 to 341–365 cfs at river mile 123.3) are observed where the Deschutes River cuts through clast-supported conglomerates and sandstones upstream from the mouth of Squaw Creek. Elsewhere in the quadrangle, springs flow from marginal talus breccias and basal flow breccias in basalt members. Springs along the Crooked River issue from basal flow breccias in the Opal Springs basalt and discharge an average of 620 million gallons of water per day (~850 cfs) (Stearns, 1931). Large volumes of water also discharge into Squaw Creek from talus breccias on the flank of a basaltic andesite flow at Alder Springs.

MINERAL RESOURCES

The potential for future development of mineral resources in the quadrangle is limited. Aggregate in the form of cinders and scoria has been mined from spatter cones east of the Crooked River in sections 3 and 4, T. 13 S., R. 12 E. Nearly all of these sites have been mined out.

Sand and gravel resources are also limited. Fluviatile units below the Steamboat Rock member include weakly cemented, clast-supported conglomerate and sandstone used in the past as aggregate. The conglomerates contain interbedded air-fall tuff and reworked pumice layers. Although thick sections of gravel remain in the SW¼ sec. 27, T. 13 S., R. 12 E., encroachment by residential housing tracts limits the likelihood that significant amounts of gravel will be mined in the future. The fact that gravel units in the lower part of the Deschutes Formation are located within the highly scenic Deschutes and Crooked River canyons precludes development. The gravels are exposed only along steep canyon walls in a road-free, high-use recreation area, where they are overlain by as much as 50 m of lava flows and pyroclastic deposits.

Despite lack of evidence for precious-metal mineralization in the quadrangle, an attempt was made in 1940 to mine placer gold reputed to occur within Deschutes Formation conglomerates. A dilapidated wooden building on the west bank of the Deschutes River in section 33, T. 13 S., R. 12 E., is all that remains of an attempt to extract gold from the conglomerates by cyanidization and electrolysis (Allen, 1941).

Some welded parts of ash-flow tuffs in the McKenzie Canyon ignimbrite member have potential use as building stone. Blocky jointed welded zones are reddish orange in overall color with contrasting black and white pumice.

Thicker intervals are exposed in the southwest corner of the quadrangle, west of the scenic canyons. Similar-looking ash-flow tuff has been mined in the Bend area for use as building stone throughout the Northwest (Peterson and others, 1976).

ANALYTICAL METHODS

Most chemical analyses were determined by X-ray fluorescence (XRF) and atomic absorption spectrophotometry at Oregon State University by G.A. Smith (1986b) and D.M. Cannon (1985). See these references for analytical methods. Analyses marked by an asterisk (*) were determined by XRF at Washington State University GeoAnalytical Laboratory with procedures described by Hooper and others (1993). All results have been normalized on a volatile-free basis with total iron expressed as FeO.

ACKNOWLEDGMENTS

Information on water resources including water-well logs and in-stream flow measurements as well as insightful observations on how the rhyodacite dome influences groundwater flow, was kindly provided by Ken Lite, Oregon Water Resources Department. Dave Sherrod, U.S. Geological Survey, Vancouver, Wash., deserves special thanks, both for his thoughtful review and for observations made during field trips through the map area. We also thank Marshall Gannett, U.S. Geological Survey, Portland; Larry Chitwood, USDA Forest Service, Bend; and Carrie Gordon, USDA Forest Service, Prineville, for their support. Special thanks to Edward M. Taylor, who introduced most of us to the area and should be recognized for preparing the geologic framework upon which this map is based.

REFERENCES

Allen, J.E., 1941, Deschutes black sand and pumice: Unpublished report on file in Oregon Department of Geology and Mineral Industries Mine-File Collection, Deschutes County, 2 p.

Armstrong, R.L., Taylor, E.M., Hales, P.O., and Parker, D.J., 1975, K-Ar dates for volcanic rocks, central Cascade Range of Oregon: Isochron/West 13, p. 5–10.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, no. 11, p. 1407–1418.

Cannon, D.M., 1985, The stratigraphy, geochemistry, and mineralogy of two ash-flow tuffs in the Deschutes Formation, central Oregon: Corvallis, Oreg., Oregon State University master's thesis, 142 p.

Conrey, R.M., 1985, Volcanic stratigraphy of the Deschutes Formation, Green Ridge to Fly Creek, north-central Oregon: Corvallis, Oreg., Oregon State University master's thesis, 349 p.

Dill, T.E., 1992, Stratigraphy of the Neogene volcanic rocks along the lower Metolius River, Jefferson County, central Oregon: Corvallis, Oreg., Oregon State University master's thesis, 343 p.

Ferns, M.L., Lite, K.E., Jr., and Clark, M.D., 1996, Lithologic controls on groundwater discharge to the Deschutes River between Lower Bridge and Lake Billy Chinook, central Oregon [abs.]: Geological Society of America Abstracts with Programs, v. 28, no. 5, p. 65.

Ferns, M.L., Stensland, D.E., and Smith, G.A., in preparation, Geologic map of the Squaw Back Ridge quadrangle, Deschutes and Jefferson Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–102, scale 1:24,000.

Fiebelkorn, R.B., Walker, G.W., MacLeod, N.S., McKee, E.H., and Smith, J.G., 1983, Index to K-Ar age determinations for the State of Oregon: Isochron/West 37, p. 3–60.

Hooper, P.R., Johnson, D.M., and Conrey, R.M., 1993, Major and trace element analyses of rocks and minerals by automated X-ray spectrometry: Pullman, Wash., Washington State University, Department of Geology, Open-File Report, 36 p.

Peterson, N.V., Groh, E.A., Taylor, E.M., and Stensland, D.E., 1976, Geology and mineral resources of Deschutes County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 89, 66 p., 3 maps.

Priest, G.R., Woller, N.M., Black, G.L., and Evans, S.H., 1983, Overview of the geology of the central Oregon Cascade Range, *in* Priest, G.R., and Vogt, B.F., eds., Geology and geothermal resources of the central Oregon Cascade Range: Oregon Department of Geology and Mineral Industries Special Paper 15, p. 3–28.

Robinson, P.T., and Stensland, D.E., 1979, Geologic map of the Smith Rock area, Jefferson, Deschutes, and Crook Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I–1142, scale 1:48,000.

Smith, G.A., 1986a, Coarse-grained nonmarine volcaniclastic sediment: Terminology and depositional process: Geological Society of America Bulletin, v. 97, no. 1, p. 1–10.

———1986b, Stratigraphy, sedimentology, and petrology of Neogene rocks in the Deschutes basin, central Oregon: A record of continental-margin volcanism and its influence on fluvial sedimentation in an arc-adjacent basin: Corvallis, Oreg., Oregon State University doctoral dissertation, 467 p.

———1986c, Stratigraphy, sedimentology, and petrology of Neogene rocks in the Deschutes basin, central Oregon: A record of continental-margin volcanism and its influence on fluvial sedimentation in an arc-adjacent basin: Richland, Wash., Rockwell Hanford Operations, Basalt Waste Isolation Project, Report RHO-BW-SA-555 P, var. pag., Appendix I.

———1991, A field guide to depositional processes and facies geometry of Neogene continental volcaniclastic rocks, Deschutes basin, central Oregon: Oregon Geology, v. 53, no. 1, p. 3–20.

Smith, G.A., Snee, L.W., and Taylor, E.M., 1987, Stratigraphic, sedimentologic, and petrologic record of late Miocene subsidence of the central Oregon High Cascades: Geology, v. 15, p. 389–392.

Smith, G.A., and Taylor, E.M., 1983, The central Oregon High Cascade graben: What? Where? When?: Geothermal Resources Council Transactions, v. 7, p. 275–279.

Stearns, H.T., 1931, Geology and water resources of the middle Deschutes River basin, Oregon, *in* Grover, N.C., ed., Contributions to the hydrology of the United States, 1930: U.S. Geological Survey Water-Supply Paper 637, p. 125-212.

Stensland, D.E., 1970, Geology of part of the northern half of the Bend quadrangle, Jefferson and Deschutes Counties, Oregon: Corvallis, Oregon, Oregon State University master's thesis, 118 p.

Taylor, E.M., 1978, Field geology of S.W. Broken Top quadrangle, Oregon: Oregon Department of Geology and Mineral Industries Special Paper 2, 50 p.

———1981, Central High Cascade roadside geology, Bend, Sisters, McKenzie Pass, and Santiam Pass, Oregon, *in* Johnston, D.A., and Donnelly-Nolan, J., eds., Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U.S. Geological Survey Circular 838, p. 55–83.

Taylor, E.M., and Ferns, M.L., 1995, Geologic map of the Three Creek Butte quadrangle, Deschutes County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–87, scale 1:24,000, 8 p. text.

Table 1. *Geochemical analyses, Steelhead Falls quadrangle*

Map no.	Field no.	¼	¼	Sec.	T. (S.)	R. (E.)	UTM	Elev. (ft)	Lithology	Map unit	SiO_2	Al_2O_3	TiO_2	FeO_T	MnO	CaO	MgO	K_2O
1	SF-91	SW	SE	29	12	12	4928343N633628E	2,180	White pumice	Tdt	71.65	15.39	0.33	2.46	-	1.24	0.61	5.27
2	SF-84	SW	SE	29	12	12	4928296N633695E	2,290	Gray pumice	Tdt	70.79	16.26	0.40	2.82	-	1.49	1.51	3.69
3	SF-92	SW	SE	29	12	12	4928310N633989E	2,650	Basalt	Tdbt	52.06	14.46	2.52	13.32	-	8.74	4.85	0.61
4	SF-144	SE	SW	33	12	12	4926548N634861E	2,760	Basalt	Tdbt	51.07	13.44	2.91	14.37	-	8.07	5.97	0.59
5	SF-139	SW	NE	33	12	12	4927353N635489E	2,200	Diktytaxitic basalt	Tdbo	50.04	16.99	1.04	8.78	0.17	11.36	9.17	0.00
6	SF-140	SE	NW	33	12	12	4926930N635524E	2,360	Basaltic andesite	Tdba$_2$	54.22	18.54	1.30	8.01	-	8.52	4.61	0.79
7	SF-141	SE	SE	33	12	12	4926635N635696E	2,600	Basaltic andesite	Tdba$_1$	52.89	17.80	1.72	9.71	-	8.94	4.73	0.80
8	SF-142	SE	SE	33	12	12	4926602N635761E	2,650	Diktytaxitic basalt	Tdb	50.60	17.10	0.97	8.37	0.17	10.90	9.26	0.18
9	SF-143a	SE	SE	33	12	12	4926650N635804E	2,760	Basalt	Tdbt	52.25	14.85	2.68	13.25	-	8.67	4.66	0.55
9	SF-143b	SE	SE	33	12	12	4926650N635804E	2,760	Basalt	Tdbt	52.06	13.66	2.67	13.92	0.24	7.51	5.09	0.62
10	SF-129a	NE	NE	4	13	12	4925967N635842E	2,790	Basalt	Tdbt	52.30	14.02	2.44	13.01	-	8.24	5.87	0.45
11	SF-134	SE	SW	3	13	12	4925109N636514E	2,620	Diktytaxitic basalt	Tdb	50.52	16.95	0.95	8.46	0.17	11.00	9.22	0.22
12	SF-132b	SE	SW	3	13	12	4924936N636794E	2,260	Black pumice	Tdto	62.81	16.58	1.12	5.93	-	4.50	2.80	1.88
12	SF-132w	SE	SW	3	13	12	4924936N636794E	2,260	White pumice	Tdto	72.48	14.88	0.27	2.13	-	1.10	0.50	5.32
13	BBB-1	NW	NE	10	13	12	4924720N636840E	2,380	Basalt	Qbi	49.59	17.04	1.51	9.32	0.16	9.64	8.69	0.39
14	DC-170	NW	NE	10	13	12	4924321N637286E	2,160	Mixed pumice	Tdto	70.41	13.61	0.90	5.06	-	3.17	0.92	3.19
14	DC-170	NW	NE	10	13	12	4924321N637286E	2,160	White pumice	Tdto	74.93	13.41	0.26	2.25	-	1.09	0.16	5.87
15	SF-130	NE	SE	10	13	12	4924026N637385E	2,170	Diktytaxitic basalt	Tdbo	49.45	16.62	1.11	9.80	0.19	10.92	9.31	0.05
16	SF-135	NE	SE	10	13	12	4923872N637544E	2,520	Basaltic andesite	Tdba$_1$	53.40	18.59	1.62	8.57	-	8.44	4.47	0.92
17	SF-54	SE	SE	6	13	12	4924818N632796E	2,220	Dark gray pumice	Tdt	61.79	16.23	1.29	6.61	-	4.69	3.02	1.82
18	SF-97d	SE	NE	7	13	12	4924351N632824E	2,580	Dark gray pumice	Tdtp	65.07	16.92	0.88	4.51	-	2.70	1.40	2.60
18	SF-99d	SE	NE	7	13	12	4924351N632824E	2,580	Dark gray pumice	Tdtp	65.83	16.43	0.74	4.52	-	4.16	1.90	2.61
19	SF-69	SW	NW	8	13	12	4924335N632866E	2,710	Olivine basalt	Tdb	49.94	16.55	1.12	9.45	-	10.72	9.28	0.11
20	SF-124	SW	NE	7	13	12	4924220N632587E	2,100	Basaltic andesite	Tdba$_4$	52.31	21.38	1.01	7.17	-	9.95	4.57	0.42
21	SF-59	SE	NE	7	13	12	4924150N632614E	2,300	Basaltic andesite	Tdba$_2$	53.97	18.70	1.58	8.54	-	7.99	4.27	1.19
22	BBB-9	SE	NE	7	13	12	4924194N632719E	2,420	Basaltic andesite	Tdba$_2$	55.13	17.35	1.38	7.90	0.15	8.57	4.02	0.92
23	SF-64	SE	NE	7	13	12	4924187N632657E	2,370	Basaltic andesite	Tdba$_2$	53.77	18.06	1.37	8.71	-	8.43	4.89	0.69
24	SF-47	NE	SW	8	13	12	4923844N633197E	2,540	Basaltic andesite	Tdba$_1$	54.17	16.25	2.22	10.39	-	7.82	4.71	1.02
25	BBB-3	NW	SW	8	13	12	4923780N633080E	2,440	Basalt	Qbd	49.72	17.43	1.55	8.80	0.16	9.71	8.62	0.49
26	DC-151	SW	NE	18	13	12	4922520N631730E	2,330	White pumice	Tdtl	71.71	15.62	0.54	3.16	-	1.86	0.79	3.45
27	SF-145	NE	SW	18	13	12	4922124N631714E	2,330	Black pumice	Tdt	65.56	16.54	0.79	3.81	-	3.22	2.51	2.16
28	SF-146	NE	SW	18	13	12	4921902N631661E	2,410	Basaltic andesite	Tdba$_3$	53.96	16.89	1.39	9.46	-	9.02	4.90	0.78
29	SF-147	SW	NW	24	13	12	4920750N629682E	2,400	Basaltic andesite	Tdba$_3$	53.47	17.76	1.40	9.05	-	8.48	5.82	0.92
30	SR-6	NE	SW	26	13	11	4918863N629676E	2,750	Basaltic andesite	Tdba$_1$	54.83	16.26	2.13	10.62	0.00	7.19	3.84	0.79
31	SF-148b	SW	SW	16	13	12	4923393N634006E	2,670	Basalt block	Tdps	50.28	17.16	0.86	8.49	-	12.05	8.91	0.00
32	Bk	NW	NW	16	13	12	4923226N634786E	2,680	Basalt bomb	Tdbs	54.62	16.40	2.12	10.24	-	7.83	4.29	1.03
33	SF-78d	NE	SE	17	13	12	4922144N634524E	2,540	Dark gray pumice	Tdtp	65.79	16.63	0.85	4.61	-	2.76	1.43	2.02
33	SF-78d	NE	SE	17	13	12	4922144N634524E	2,540	Dark gray pumice	Tdtp	66.01	16.20	0.84	4.52	-	2.75	1.42	1.99
34	SF-43	NE	SE	17	13	12	4922207N634324E	2,540	Basaltic andesite	Tdba$_1$	53.18	17.05	2.14	10.82	-	7.69	4.04	0.75
35	SF-70	SE	NE	20	13	12	4920852N634358E	2,500	Basaltic andesite	Tdba$_1$	54.60	17.42	1.72	8.90	-	8.09	4.07	1.01
36	WTHa	NE	SE	16	13	12	4922404N635930E	2,850	Agglutinate	Tdbs	55.49	15.64	2.10	10.05	-	7.81	4.34	1.24
36	WTHb	NE	SE	16	13	12	4922404N635930E	2,850	Agglutinate	Tdbs	55.38	15.46	2.19	10.09	0.19	7.73	4.29	1.17
37	SF-37d	NW	SW	21	13	12	4920524N634719E	2,440	Dark gray pumice	Tdtp	65.32	17.56	0.90	4.75	-	2.97	1.51	1.78
37	SF-37d	NW	SW	21	13	12	4920524N634719E	2,440	Dark gray pumice	Tdtp	65.83	17.08	0.92	4.69	-	2.92	1.60	1.87
38	DC-238	NW	SW	21	13	12	4920460N634700E	2,300	White pumice	Tdtl	68.72	16.16	0.54	2.97	-	2.02	2.90	3.22
38	DC-239	NW	SW	21	13	12	4920460N634700E	2,300	Gray pumice	Tdtl	70.11	16.14	0.40	2.61	-	1.61	1.35	4.17
39	SF-128b	NW	SW	21	13	12	4920440N634720E	2,280	Black pumice	Tdt	60.55	16.27	1.28	6.68	-	5.10	2.81	1.79
39	SF-128w	NW	SW	21	13	12	4920440N634720E	2,280	White pumice	Tdt	68.74	15.61	0.76	3.74	-	2.98	2.87	1.95
40	SF-109	NW	SW	21	13	12	4920464N635666E	2,650	Block	Tdps	52.18	19.68	1.50	8.94	-	9.07	4.31	0.90
41	SF-113	NW	SW	21	13	12	4920507N635776E	2,670	Cinder	Tdps	54.58	16.89	2.02	9.85	-	8.10	4.32	0.91
42	SF-112	NW	SW	21	13	12	4920458N635805E	2,680	Basalt	Tdbs	55.42	15.49	2.15	10.09	-	8.01	4.43	1.10
43	SF-32b	SW	SW	22	13	12	4920143N635914E	2,640	Black pumice	Tdt	64.17	16.67	1.00	5.38	-	3.44	2.02	1.87
43	SF-32b	SW	SW	22	13	12	4920143N635914E	2,640	Black pumice	Tdt	65.66	16.36	0.93	4.85	-	2.99	2.05	2.06
44	SF-39	SW	SW	22	13	12	4920121N636202E	2,730	Cinder	Tdps	54.70	16.85	2.06	9.86	-	7.85	4.26	1.07
45	SF-38	SW	SW	22	13	12	4920300N636288E	2,785	Agglutinate	Tdps	55.34	15.93	2.10	10.04	-	7.72	4.44	1.22
46	SF-104	SW	SW	22	13	12	4920004N636356E	2,650	Block	Tdps	49.97	17.19	0.71	8.52	-	12.40	9.09	0.02
46	SF-105	SW	SW	22	13	12	4920004N636356E	2,650	Block	Tdps	55.04	15.94	2.13	10.06	-	8.15	4.06	1.26
47	SF-76	NW	SW	27	13	12	4919064N636288E	2,540	Black pumice	Tdt	60.86	17.05	1.26	7.12	-	4.74	2.21	1.44
48	SF-25	SE	NE	28	13	12	4918962N636003E	2,310	Basaltic andesite	Tds	54.41	19.28	1.38	8.05	-	8.26	3.74	1.25
49	SF-26d	NE	SE	28	13	12	4918880N636064E	2,420	Dark gray pumice	Tdtp	65.01	17.72	0.85	4.51	-	2.96	1.69	1.89
49	SF-26d	NE	SE	28	13	12	4918880N636064E	2,420	Dark gray pumice	Tdtp	66.38	17.02	0.83	4.56	-	2.96	1.71	2.00
49	SF-26l	NE	SE	28	13	12	4918880N636064E	2,420	Light gray pumice	Tdtp	67.04	16.69	0.77	4.25	-	2.68	1.49	2.01
49	SF-26l	NE	SE	28	13	12	4918880N636064E	2,420	Light gray pumice	Tdtp	68.47	16.99	0.69	4.05	-	2.51	2.31	1.85
49	SF-26w	NE	SE	28	13	12	4918880N636064E	2,420	White pumice	Tdtp	72.41	15.75	0.26	2.09	-	0.96	0.40	4.12
50	BBB-8	NW	SE	33	13	12	4917380N635620E	2,500	Rhyodacite	Trd	69.21	15.37	0.53	3.24	0.08	2.51	0.72	3.18
51	SF-14	NE	NE	4	14	12	4916473N635929E	2,650	Rhyodacite	Trd	68.28	16.43	0.69	3.65	-	2.42	0.41	2.60
52	SF-12	SE	NE	4	14	12	4916104N635903E	2,600	White pumice	Tdt	69.42	16.88	0.43	3.03	-	2.49	1.82	3.24
53	SF-8	NE	NE	9	14	12	4915502N635999E	2,620	White pumice	Tdt	66.37	17.12	1.00	5.14	-	3.89	1.22	2.47
54	SF-4	NE	NE	9	14	12	4914940N636203E	2,620	White pumice	Tdt	67.74	18.03	0.90	4.61	-	2.56	1.53	2.23
55	SF-116	NE	NE	10	14	12	4915177N637494E	2,730	Basalt	Tdbs	55.10	15.80	2.10	10.11	-	7.90	4.40	1.09
56	SF-117	NE	NE	10	14	12	4915109N637479E	2,680	Basaltic andesite	Tdbs	55.04	15.97	2.10	10.21	-	7.85	4.32	1.20

Table 1. *Geochemical analyses, Steelhead Falls quadrangle (continued)*

Map no.	Na_2O	P_2O_5	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Ni	Nb	Ga	Cu	Zn	Pb	La	Ce	Th
1	3.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	3.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	3.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	3.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	2.29	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	4.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	3.42	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	2.28	0.17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	3.69	0.53	-	41	444	483	22	386	155	38	38	-	-	-	-	-	-	-	-
10	3.68	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	2.35	0.16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	4.39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	3.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	3.35	0.31	306	27	210	232	3	358	132	28	-	9	19	50	75	1	0	27	0
14	2.74	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	2.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	2.34	0.21	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	3.98	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	4.54	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	5.91	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	3.81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	2.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	3.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	3.76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
22	4.27	0.31	66	26	239	327	12	561	125	24	-	8	20	71	80	0	24	44	0
23	4.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
24	3.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
25	3.22	0.30	246	31	204	180	7	384	134	25	-	12	16	59	68	0	15	32	0
26	2.87	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27	5.41	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
28	3.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	3.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	4.34	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
31	2.24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
32	3.49	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	5.92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
33	6.28	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
34	4.34	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
35	4.18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	3.33	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
36	2.82	0.68	-	36	205	556	24	362	153	34	42	-	-	-	-	-	-	-	-
37	5.22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
37	5.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	3.48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
38	3.60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	5.52	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
39	3.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	3.43	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
41	3.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
42	3.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	5.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
43	5.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
44	3.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
45	3.23	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	2.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
46	3.35	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	5.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
48	3.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	5.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	4.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	5.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	3.12	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
49	4.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	5.03	0.13	3	11	19	759	62	266	257	31	-	16	19	14	58	9	27	69	4
51	5.51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
52	2.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
53	2.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
54	2.39	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
55	3.50	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
56	3.31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. *Whole-rock isotopic ages ($^{40}Ar/^{39}Ar$) from the Steelhead Falls quadrangle and vicinity. From Smith (1986c)*

Laboratory no. of Smith (1986c)	Map unit	Quadrangle	Age (million years)
D4	Qbi	Steelhead Falls	1.19±0.08
D1a	Tdbs	Cline Falls	5.06±0.03
D7	Tdbt	Round Butte Dam	5.31±0.05
D9	Tdb	Round Butte Dam	5.43±0.05
D5	Tdbo	Opal City	5.77±0.07