State of Oregon
Department of Geology and Mineral Industries
Vicki S. McConnell, State Geologist

Open-File Report

OFR O-04-12

GEOLOGIC MAP OF THE ANTHONY BUTTE QUADRANGLE, UNION AND BAKER COUNTIES, OREGON

By

Ian P. Madin[1] and William H. Taubeneck[2]

2004

[1]Oregon Department of Geology and Mineral Industries
[2]Oregon State University

TABLE OF CONTENTS

1.0 INTRODUCTION 1
1.1 Previous Work and Methods 2
2.0 EXPLANATION OF MAP UNITS 5
2.1 Surficial Units 5
2.2 Columbia River Basalt Group 5
2.2.1 Grande Ronde Basalt 6
2.3 Tower Mountain Volcanic Field 7
2.4 Bald Mountain Batholith 8
2.4.1 Satellite Intrusions 9
2.5 Baker Terrane Paleozoic Igneous and Metamorphic Rocks 10
2.5.1 Hornfels Inclusions and Septa 10
3.0 STRUCTURE 11
3.1 Older Northwest Trending Faults 11
3.2 Shaw Mountain Fault Zone 11
3.3 Dutch Creek Fault Zone 11
4.0 GEOLOGIC HISTORY 12
5.0 RESOURCE AND HAZARDS 14
5.1 Mineral Resources 14
5.2 Water Resources 14
5.3 Geothermal Resources 14
5.4 Earthquake and Mass Wasting Hazards 14
6.0 ACKNOWLEDGMENTS 15
7.0 REFERENCES 16

TABLES

1.1 Analyses of Major Oxides and Trace Elements 4

FIGURES

1.1 Location Map 1
1.2 Shaded-Relief Map of the Anthony Butte Quadrangle 2
1.3 TAS Plot for Basaltic Rocks 3

NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this paper because the information furthers the mission of the Department. To facilitate timely distribution of the information, this report is published as received from the authors and has not been edited to our usual standards.

Oregon Department of Geology and Mineral Industries Open-File Report
Published in conformance with ORS 516.030

For copies of this publication or other information about Oregon's geology and natural resources, contact:
Nature of the Northwest Information Center
800 NE Oregon Street #5
Portland, Oregon 97232
(503) 872-2750
http://www.naturenw.org

1.0 INTRODUCTION

The Anthony Butte quadrangle lies at the northern end of the Elkhorn Mountains in northeast Oregon (Figure 1.1). Most of the quadrangle consists of mountainous terrain that is forested (Figure 1.2) and cut by the canyons of Wolf Creek, Beaver Creek, Anthony Creek and the east fork of the Grande Ronde River. Elevation ranges from about 1260 m (4140 ft) to 2160 m (7085 ft). The entire quadrangle is within the Wallowa-Whitman National Forest except a small inlier of private timberland in the northeast corner.

The map of the Anthony Butte quadrangle was produced as part of a cooperative program between the Oregon Department of Geology and Mineral Industries (DOGAMI) and U.S. Geological Survey. DOGAMI received partial funding for the mapping from the U.S. Geological Survey's National Cooperative Geologic Mapping Program under assistance award no. 1434-HQ-97-AG-01736.

Geologic mapping of the pre-Cenozoic intrusive and metamorphic rocks was done by Taubeneck during the period 1967 to 1997. Geologic mapping of the Cenozoic rocks of the quadrangle was carried out by Madin in 1997.

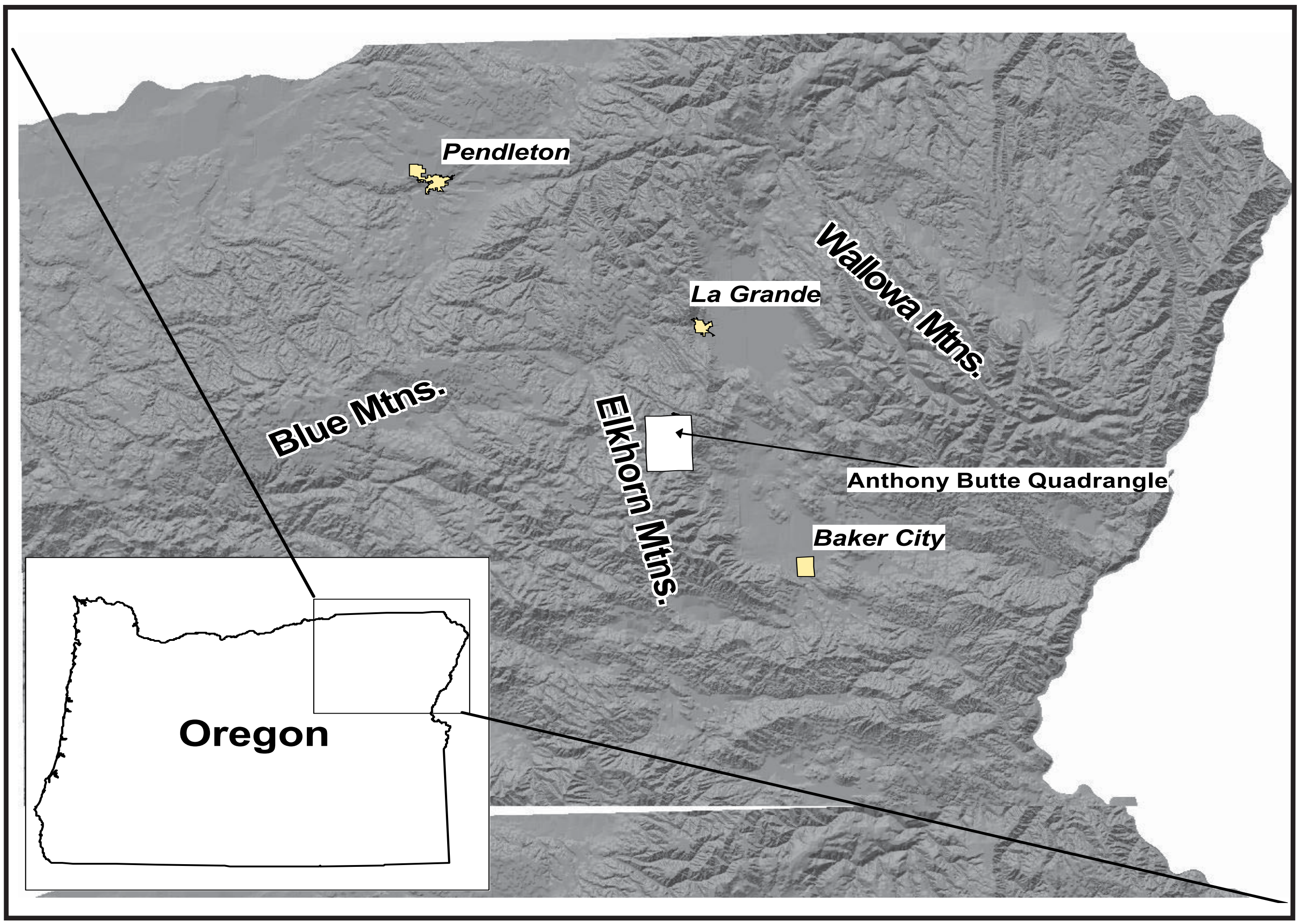

Figure 1.1. Location map, showing quadrangle location on shaded-relief map of northeast Oregon.

1.1 Previous Work and Methods

Published mapping for the area is low-resolution reconnaissance work (1:250,000; Walker, 1973, Swanson and others, 1981; 1:62,500; Hampton and Brown, 1964) and with the exception of Swanson and others (1981) does not differentiate the Cenozoic volcanic rocks of the area.

The volcanic rocks of the area are typically fine-grained, so they are assigned rock names on the basis of geochemistry. Nomenclature is based on total alkalis versus silica, following Le Bas and Streckeisen, 1991 (Figure 1.3). Plutonic rocks are named on the basis of mineral proportions determined by point counts, and follow the IUGS

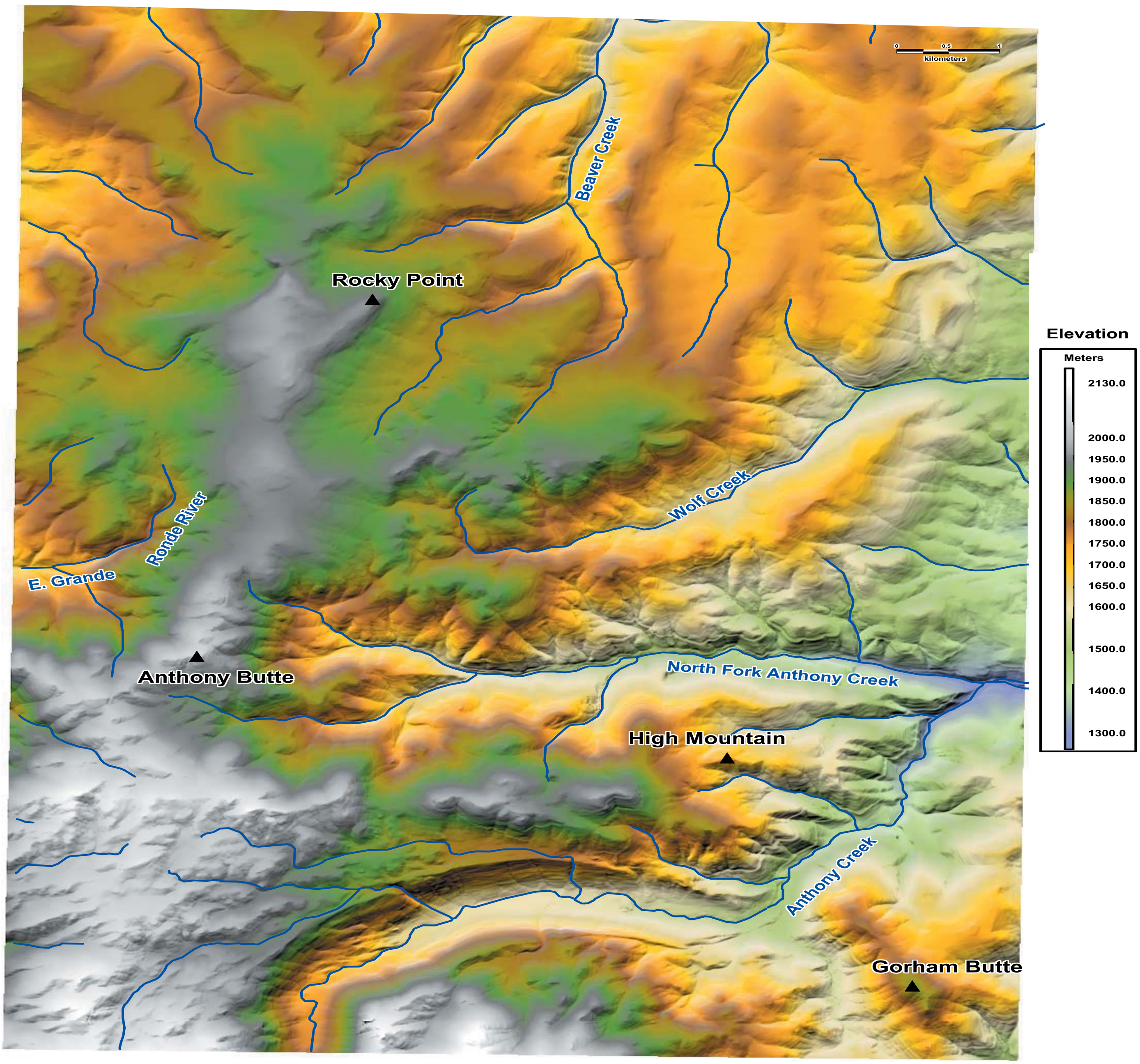

Figure 1.2. Shaded-relief map of the Anthony Butte Quadrangle showing major streams and high points. Note pronounced "U" shaped glaciated valley and well developed lateral moraines along upper Anthony Creek.

system (Streckeisen, 1973).

Volcanic rocks were analyzed for major and trace element geochemistry by X-Ray Fluorescence (XRF) at the Washington State University Geo-Analytical Laboratory at Pullman, Washington (WSU in Table 1.1) and XRAL, a commercial analytical laboratory (XRAL in Table 1.1). Analytical methods for WSU analyses are described in Hooper and others, 1993. Methods for XRAL analyses are described in Miller, 1997.

Paleomagnetic measurements re made on samples from lava flow outcrops to determine whether the remnant magnetization was in the same direction as the current field (normal) or opposite the current field (reversed). Magnetic polarity was measured with a portable fluxgate magnetometer. Polarity measurements were hampered by the relatively common occurrence of lightning-induced magnetism in natural outcrops in the map area. Fully a third of natural outcrops examined had areas sufficiently strongly magnetized by lightning to deflect a compass needle. A minimum of three widely spaced samples per outcrop were measured in order to minimize spurious results due to lightning strikes.

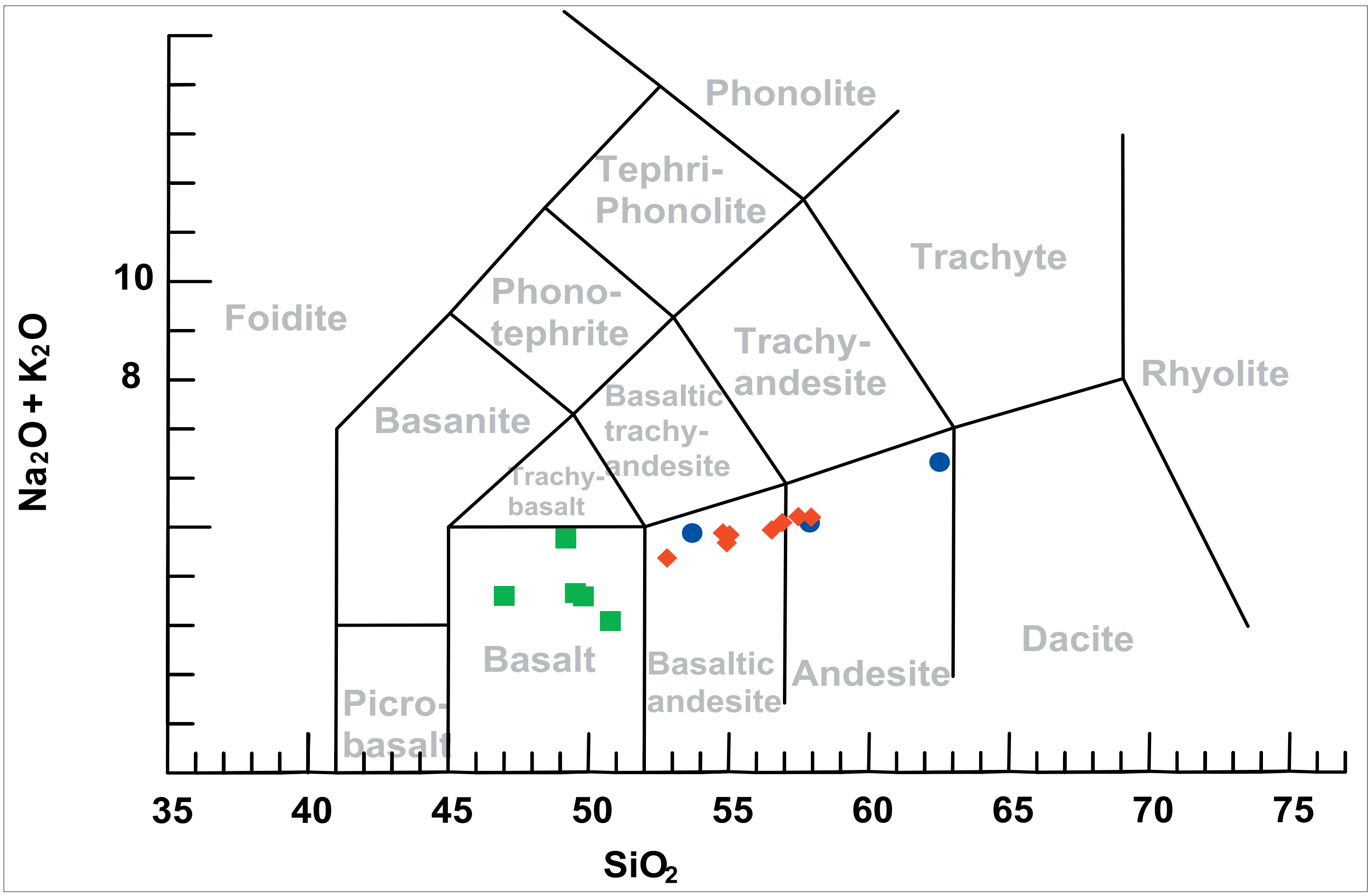

Figure 1.3. Total Alkali versus Silica plot for analyzed volcanic rocks in the study. Digram form Le Bas and Streckeisen, 1991. Green squares are Oligocene basalts, blue circles Oligocene basaltic andesites and andesites, red diamonds are Grande Ronde “basalts”.

TABLE 1.1. ANALYSIS OF MAJOR OXIDE AND TRACE ELEMENTS

NUMBER	YEAR	FIELD ID	UTM E	UTM N	ELEV	UNIT	LITHOLOGY	SOURCE	LAB	SiO2	Al2O3	TiO2	FeO	MnO	CaO	MgO	K2O	Na2O	P2O5	TOTAL	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y
1	1996	TF15	411321	4992304	4220	Tgr1	basaltic andesite	Madin	WSU	52.80	15.17	1.83	10.46	0.180	9.31	5.59	1.10	3.28	0.28	0.00	45	98	26	327	451	21	383	134	30
2	1997	Ar133	406560	4994520	5600	Tgr1	basaltic andesite	Madin	WSU	56.53	13.85	1.97	11.41	0.190	7.23	3.55	1.75	3.20	0.33	99.21	0	21	30	338	712	47	313	166	33
3	1997	Ar135	407200	4994625	5590	Tgr1	basaltic andesite	Madin	WSU	56.91	15.03	2.46	8.57	0.180	7.50	3.86	1.59	3.51	0.39	99.64	6	17	31	398	1169	35	376	205	46
4	1997	Ar33	405870	4994330	5960	Tgr1	basaltic andesite	Madin	WSU	54.93	14.06	2.05	11.54	0.190	8.15	4.03	1.56	3.13	0.35	99.61	10	47	30	368	610	37	318	163	36
5	1997	Ar55	407490	4994790	5970	Tgr1	basaltic andesite	Madin	WSU	57.94	14.19	2.02	9.54	0.170	7.28	3.31	2.05	3.16	0.34	99.03	5	23	31	350	913	53	339	171	36
6	1996	TF183	411362	4996599	5410	Tgr1	basaltic andesite	Madin	XRAL	54.79	13.44	2.22	13.95	0.170	6.74	3.40	1.65	3.24	0.39	98.93	nr	nr	nr	nr	678	57	336	189	40
7	1996	TF184	411066	4997035	5540	Tgr1	basaltic andesite	Madin	XRAL	55.03	13.94	2.32	12.61	0.180	7.05	3.65	1.44	3.41	0.37	98.31	nr	nr	nr	nr	619	25	348	204	39
8	1997	Ar125	406845	4991220	6420	Tgr1	basaltic andesite	Madin	WSU	57.48	14.44	2.37	9.15	0.180	7.46	3.32	1.93	3.29	0.39	98.59	0	11	32	369	965	42	362	199	43
9	1998	Ar130	405080	4994260	6210	Tap	andesite porphyry	Madin	WSU	62.51	16.84	1.164	5.98	0.073	5.05	1.74	1.95	4.38	0.310	98.56	12	12	14	110	766	47	519	185	22
10	1997	AR156	403040	4995365	6120	Tap2	andesite porphyry	Madin	XRAL	53.69	16.88	1.50	9.13	0.120	8.37	5.38	1.42	3.47	0.33	98.90	nr	nr	nr	nr	404	28	423	179	21
11	1997	Ar107	404785	4992990	6420	Ta	andesite	Madin	WSU	57.88	16.42	1.34	6.95	0.120	7.27	4.64	1.89	3.21	0.28	99.29	63	124	20	152	560	37	387	162	24
12	1997	AR155	403685	4994275	6130	Tb	olivine basalt	Madin	XRAL	47.00	16.52	2.28	12.21	0.170	10.36	7.28	1.21	2.40	0.29	97.45	nr	nr	nr	nr	205	21	940	172	16
13	1997	Ar27	404770	4991045	6400	Tb	olivine basalt	Madin	WSU	49.19	15.59	3.67	12.56	0.180	8.50	5.07	1.46	3.32	0.47	98.23	14	46	25	388	704	45	430	181	27
14	1998	Ar29	402830	4991680	6220	Tb	olivine basalt	Madin	WSU	50.78	16.07	1.475	8.78	0.151	10.98	8.40	0.42	2.68	0.254	98.92	120	298	30	229	240	6	436	108	20
15	1997	Ar32	405980	4993290	5990	Tb	olivine basalt	Madin	WSU	49.53	17.06	1.68	9.50	0.170	10.50	7.60	0.75	2.92	0.29	98.98	84	164	31	234	260	10	433	119	22
16	1998	Ar106	405105	4993455	6460	Tb	olivine basalt	Madin	WSU	49.82	17.18	1.669	9.09	0.169	10.55	7.63	0.84	2.76	0.288	98.43	85	171	37	232	317	11	613	117	21
17		R118				Jbv	granodiorite	Taubeneck (1995)	TU	74.51	12.71	0.24	2.39	0.07	1.84	0.49	3.77	3.01	0.06	99.76	nr	nr	nr	nr	nr	nr	nr	nr	nr
18		R121				Jab	granite	Taubeneck (1995)	TU	73.06	13.44	0.27	2.54	0.06	2.04	0.67	3.76	3.22	0.07	99.86	nr	nr	nr	nr	nr	nr	nr	nr	nr
19		R123				Jab	granite	Taubeneck (1995)	TU	72.95	13.76	0.27	2.45	0.06	1.62	0.43	3.69	3.74	0.04	99.60	nr	nr	nr	nr	nr	nr	nr	nr	nr
20		R128				Jab	granite	Taubeneck (1995)	TU	74.39	12.81	0.23	2.08	0.09	1.14	0.39	4.12	3.67	0.05	99.64	nr	nr	nr	nr	nr	nr	nr	nr	nr
21		R125				Jwc	quartz diorite	Taubeneck (1995)	USGS	62.00	16.30	0.63	5.07	0.09	6.53	3.10	1.72	3.34	0.20	99.49	nr	nr	nr	nr	nr	nr	nr	nr	nr
22		B6				Jbm	tonalite	Taubeneck (1995)	Penn	60.70	17.83	0.75	5.42	0.09	6.58	2.98	0.53	4.01	0.15	99.71	nr	nr	nr	nr	nr	nr	nr	nr	nr
23		R22				Jdc	leucogranite	Taubeneck (1995)	USGS	77.00	12.40	0.07	0.57	<.02	0.78	0.15	4.95	2.90	<.05	99.33	nr	nr	nr	nr	nr	nr	nr	nr	nr

Note: Labels on chemistry data points on map correspond to entries in the NUMBER column of this table. Samples 17-23 not shown on map.
All major oxides reported as normalized values, trace elements in PPM, nr=not reported. All analyses by XRF except Penn and TU, which are wet chemistry.
Analytical methods for WSU analyses described in Hooper and others, 1993. Methods for XRAL analyses described in Miller, 1997.

2.0 EXPLANATION OF MAP UNITS

2.1 Surficial Units

Qp **Paludal deposits (Holocene)**—Sand and silt deposited in closed depressions formed on the surface of major landslides.

Qal **Alluvium (Holocene)**—Sand, silt and pebble to boulder gravel deposited by Beaver Creek, Anthony Creek, Wolf Creek and the east fork of the Grande Ronde river and their tributaries.

Qls **Landslides (Quaternary)**—Broken and jumbled masses of rock and soil, typically with hummocky or irregular surface. Many slides are large (more than 1 km^2), deep-seated and involve thicknesses of tens of meters of bedrock. Most slides are located where lava flows overlie sedimentary rocks (Tg). Several large slides also occur in the Triassic-Permian metamorphic rocks.

Qt **Terrace deposits (Pleistocene)**—Cobbles, boulders, pebbles and sand deposited behind a landslide dam in the headwaters of Beaver Creek.

Glacial deposits (Pleistocene)—Glacial till deposited by a major valley glacier along the canyon of Anthony Creek and by a small glacier or rock glacier at the south end of Beaver Meadow. Includes both Pinedale age (10,000 to 30,000 years B.P.) and Bull Lake age deposits (150,000-200,000 years B.P.). Differentiation of Pine Lake and Bull Runs deposits by Bilderback (1999), Geraghty (1999) and Robert J. Carson (personal Communication, 2000)

Qgp **Undifferentiated Pinedale age till (Pleistocene)**—Sand silt and gravel. The deposits in the well-developed glacial valley of Anthony Creek include sand and gravel reworked from the original glacial till by Anthony Creek. Assigned Pinedale age by Bilderback (1999).

Qgl **Pinedale age lateral moraines (Pleistocene)**—Sand, silt and gravel in well preserved lateral moraines along the sides of the well-developed glacial valley along Anthony Creek.

Qgb **Undifferentiated Bull Lake age till (Pleistocene)**—Sand, silt and gravel in remnants of terminal and lateral moraines. Boulders in Bull Lake age till are noticeably weathered to grus and deposits are stained orange.

Qgi **Bull Lake age glacial Lake Indian (Pleistocene)**—A small lake formed when the Bull Lake age Anthony Creek glacier dammed a minor tributary, Indian Creek. Carson (personal Communication, 2000) reports finding remnants of fine grained lake deposits within the estimated extents of the lake.

2.2 Columbia River Basalt Group

Numerous, voluminous flows of iron-rich basalt and basaltic andesite that originated from fissure vents in eastern Oregon, southeast Washington and western Idaho during the middle Miocene. The Columbia River Basalt Group covers 163,700 km^2 in Oregon, Washington and Idaho. Individual flows have volumes as high as 1900 km^3 (Tolan and others, 1989).

2.2.1 Grande Ronde Basalt

In the Anthony Butte quadrangle, the Columbia River Basalt Group is represented by flows of the Grande Ronde Basalt (Swanson and others, 1981, Reidel and others, 1989). The Grande Ronde Basalt has been divided into four magnetostratigraphic units based on the direction (normal or reversed) of remnant paleomagnetism (units Tgn1, Tgr1, Tgn2, Tgr2; Swanson and others, 1979; Reidel, 1983; Reidel and others, 1989; Baksi, 1989). The magnetostratigraphic units have also been divided into numerous flow groups based on geochemistry. However, the chemistry of almost all the flow groups is quite similar, and many groups have overlapping chemistry. Chemical correlations are possible for some of the more distinctive flows, or in areas where there is a thick section of flows from which a pattern of chemical change can be discerned. No rock specimens in this study could be assigned to a particular flow group based on chemistry (Dr. Stephen Reidel, Personal Communication, 1998): the chemistry was either not unique enough to make a positive correlation, or was substantially different from the well-established Grande Ronde units. Accordingly, flows were assigned to magnetostratigraphic units using multiple measurements of magnetic polarity in the field with a hand-held fluxgate magnetometer, field stratigraphic relations and some chemistry.

Flows of the Grand Ronde Basalt tend to be poorly exposed. Natural outcrops are rare and generally consist of rubbly flow-top breccia. Systematic observation of jointing patterns in the flows was not possible, nor was it possible to knowingly sample for geochemical analysis or magnetic polarity from a particular horizon within individual flows.

Previous reconnaissance mapping (Swanson and others, 1981) correlated the Grande Ronde flows in the map area exclusively with the R2 and N2 magnetostratigraphic units. In this study, the R1 and N1 units are mapped. Although there is no definitive evidence to distinguish R2/N2 from R1/N1 in the Anthony Butte quadrangle, there is abundant evidence in the adjacent La Grande Reservoir (Madin, in prep) and Tucker Flat (Madin, 1998). The two respective quadrangles were mapped by Madin in 1996 and 1997. Chemically and lithologically distinctive flows of the R1 magnetostratigraphic unit (Buckhorn Springs, Rogersburg and Teepee Butte flows) are extensively exposed in both quadrangles and confirmed R1 outcrops are located within 400 m of the northeast corner of the map area, providing a stratigraphic reference point.

Chemically, these rocks plot (Figure 1.3) in the basaltic andesite or even andesite fields of LeBas and Streckeisen (1991) but by long tradition, flows of the Grande Ronde Basalt are referred to as “basalt”.

Tgn1 **N1 magnetostratigraphic unit undifferentiated (middle Miocene)**—Numerous flows of gray to black, glassy to holocrystalline basaltic andesite typically with plagioclase phenocrysts up to 1 mm in length and rare plagioclase-pyroxene glomerophenocrysts up to 2 mm in length. Magnetic polarity was normal in almost all exposures where measurements were taken. The N1 unit is up to 40 m thick, and its age is between 16.1 and 15.9 Ma (Baksi, 1989)

Tgr1 **R1 magnetostratigraphic unit undifferentiated (middle Miocene)**—Numerous flows of gray to black, glassy to holocrystalline basaltic andesite with plagioclase phenocrysts up to 1mm in length and rare plagioclase-pyroxene glomerophenocrysts up to 2 mm in length. Almost all exposures had reversed magnetic polarity where measured. Chemical analyses of these flows are given in Table 1.1 (sample nos. 1-8). The unit is up to 150 m thick, and its age is between 17.0 and 16.1 Ma (Baksi, 1989).

2.3 Tower Mountain Volcanic Field

Andesite, dacite and basalt flows and associated volcaniclastic sediments. Ferns and others (2001) proposed the name Tower Mountain Volcanic Field for a suite of Oligocene age tuffs, flows and intrusions associated with the Tower Mountain Caldera, located some 10 km to the northwest of the map area.

Ta **Andesite (Oligocene)**—A single flow of grey fine grained lava with rare plagioclase phenocrysts to 3 mm. Caps the ridge south of Marion Point and Rocky Point. In thin section the rock is holocrystalline, and composed predominantly of fine trachytic plagioclase laths with stubby subhedral pyroxene prisms and abundant very fine euhedral magnetitie. In the field this rock resembles flows of the Grande Ronde Basalt, but the trachytic texture and geochemistry (high Al, low Fe; Table 1.1, sample no. 11) clearly make it part of the Tower Mountain lavas.

Tap **Andesite porphyry (Oligocene)**—Flow or flows of gray porphyritic andesite. The unit is poorly exposed. Petrographically, the rocks have a groundmass composed of fine plagioclase laths and irregular fine pyroxene grains. Phenocrysts are common, up to 4 mm long and consist of euhedral to subhedral twinned plagioclase and irregular anhedral clinopyroxene. Chemistry of the unit is given in Table 1 (sample no. 9). The thickness of the unit is unknown. The unit is correlated to unit Tpa on the adjacent (to the west) Limber Jim Creek and Fly Valley quadrangles (Ferns and Taubeneck, 1994; Ferns, 1998), and to unit Tap on the adjacent (to the north) La Grande Reservoir quadrangle (Madin, in review). In the Fly Valley quadrangle, the unit Tpa is overlain by andesite flows dated at 22.4 ± 0.16 Ma by stepwise Ar^{39}/Ar^{40} dating. Unit Tap on this map overlies unit Tb, and so is younger than 29.8 ± 0.39 Ma.

Tap2 **Basaltic andesite porphyry (Oligocene)**—Flow or flows of black, gray, pinkish or greenish gray porphyritic andesite. Petrographically composed of a groundmass of fine plagioclase laths and interstitial pyroxene. The phenocrysts include subhedral to rounded plagioclase and clinopyroxene up to 5 mm in length, olivine up to 1 mm and rounded biotite up to 1 mm. Thickness is at least 60 m. Unit Tap2 in the Anthony Butte quadrangle overlies unit Tb, and so is younger than 29.8 ± 0.39 Ma. Chemistry is given in Table 1.1 (sample no. 10).

Tb **Basalt of Rocky Point (Oligocene)**—Olivine basalt flows. Pilotaxitic, fine grained with olivine and plagioclase phenocrysts to 0.5 mm. Groundmass typically plagioclase laths with interstitial or ophitic clinopyroxene. Flows generally massive, locally with well-developed columnar jointing, typically weather to large (up to 1 m) light-colored blocks. Chemistry for these flows is shown in Table 1.1 (sample nos. 12-16). This unit correlates with unit Tb (olivine basalt) on the adjacent (to the west) Limber Jim quadrangle (Ferns and Taubeneck, 1994). The basalt of Rocky Point has a radiometric age of 29.8 ± 0.39 Ma based on stepwise Ar^{39}/Ar^{40} dating (Personal Communication, Dr. Robert Duncan, 1988).

Tg **Older conglomerate (Oligocene)**—Boulder and cobble conglomerate, sandstone, siltstone and lahar deposits. Some boulder conglomerates are composed largely of metamorphic and intrusive rocks with distinctive tan, yellow, black and pinkish massive to laminated metamorphic quartzite boulders. Most of the remaining rocks are volcaniclastic; the lahars contain abundant clasts of porphyritic andesite and dacite. Correlates with the units Tg (conglomerate, sandstone and siltstone) and Tvs (lahars) of Ferns and Taubeneck (1994) on the adjacent (to the west) Limber Jim Creek quadrangle. Age is undetermined; unit is overlain by Oligocene volcaniclastic and volcanic units. Possible Eocene/Paleocene age is based on interpretation that the unit could be a high-energy river channel deposit associated with the deltaic sandstones of the Herren Formation (unit Tes) located tens of km to the west (Ferns and others, 2001).

2.4 Bald Mountain Batholith

The Bald Mountain Batholith is an extensive body of granodiorite and tonalite with minor associated intrusions of norite, granodiorite, granite, quartz diorite and quartz gabbro (Taubeneck, 1957, 1995). The northeastern margin of the batholith is exposed in the Anthony Butte quadrangle and the descriptions of the facies of the batholith and chemical analyses are taken from Taubeneck (1957, 1995). For more detailed petrographic descriptions of the units below see Taubeneck (1957, 1995). The age of the batholith is late Jurassic to early Cretaceous. Armstrong and others (1977) report mineral separate and whole-rock K/Ar ages ranging from 131 ± 4 Ma (biotite) to 158 ± Ma (aplite). Armstrong and others also report a whole-rock Rb/Sr isochron of 147 ± 17 Ma, and Walker (1989) reports a 143 Ma U-Pb zircon age for an early phase of the batholith.

KJdc **Leucogranite of Dutch Creek (late Jurassic-early Cretaceous)**—Fine- to medium-grained faintly- to moderately foliated leucogranite. The leucogranite is typically gray where fresh, yellow or yellow orange where weathered, and typically weathers to grus. Minor deformation is evident in recrystallized quartz. Chemical analysis of the leucogranite is reported in Table 1.1. The leucogranite intrudes the adjacent boundary quartz diorite unit. Chemistry for this unit is presented in Table 1.1 (sample no. 23).

KJab **Granite of Anthony Butte (late Jurassic-early Cretaceous)**—Medium grained pinkish to yellowish gray biotite bearing granite. The granite is commonly foliated, and locally contains potassium feldspar megacrysts up to 3.5 cm long. Recrystallization and fracturing of plagioclase, strained and recrystallized quartz, and bent biotite flakes indicate significant deformation. Locally contains garnet, orthopyroxene and cummingtonite. Typically weathers to grus, and is poorly exposed except for isolated outcrops. Chemistry for this unit is given in Table 1.1 (sample nos. 18-20).

KJbv **Granodiorite of Beaver Meadow (late Jurassic-early Cretaceous)**—Medium grained, foliated biotite granodiorite. Light gray where fresh, yellow-brown where weathered. Contains less than 2 percent potassium feldspar megacrysts up to 2.5 cm in length and minor hornblende, orthopyroxene and cummingtonite. Fractured and recrystallized plagioclase, strained and recrystallized quartz and bent biotite all indicate significant deformation. Chemistry for this unit is given in Table 1.1 (sample no. 17).

KJim **Granodiorite of Indiana Mine road (late Jurassic-early Cretaceous)**—Light gray medium-grained biotite hornblende granodiorite. Strongly foliated, bent plagioclase twins and recrystallized quartz indicate significant deformation. Typically weathers to yellowish grus.

KJbm **Tonalite of Bald Mountain (late Jurassic-early Cretaceous)**—Medium-grained pale gray biotite hornblende tonalite and granodiorite. This unit comprises the bulk of the Bald Mountain Batholith and is described in detail by Taubeneck (1995, 1957). Commonly weathers to grus, with scattered corestone outcrops. Chemistry for this unit is presented in Table 1.1 (sample no. 22).

KJqd **Quartz diorite inclusions in granite of Anthony Butte (late Jurassic-early Cretaceous)**—Medium-grained, moderately foliated hornblende-biotite quartz diorite, color index generally 25-35.

KJb **Boundary quartz diorite (late Jurassic-early Cretaceous)**—Medium-grained massive to slightly foliated hornblende biotite quartz diorite. Gray where fresh, typically weathers to grus. Minor recrystallization of plagioclase margins and quartz grains and undulatory extinction in quartz indicates minor deformation. Chemistry for this unit is presented in Table 1.1 (sample no. 23).

KJwc **Quartz diorite of Wolf Creek (late Jurassic-early Cretaceous)**—Gray, medium grained hornblende biotite augite quartz diorite. Strong foliation is defined by aligned biotite and tabular plagioclase and trends E-W to W-NW and dips steeply N. Bent lamellae, recrystallization and fractures in plagioclase, strained and recrystallized quartz indicate significant deformation. Chemistry for this unit is presented in Table 1.1 (sample no. 21).

2.4.1 Satellite Intrusions

Minor bodies of intrusive rocks associated with the batholith, but outside the mapped margin of the batholith.

KJis **Granite of Isham Spring (late Jurassic-early Cretaceous)**—Medium-grained light gray biotite-bearing granite that is weakly foliated. Restricted to a small tabular body emplaced concordantly between schistose sedimentary rocks that strike W and dip 35°-50° N. Recrystallized quartz and fractured plagioclase indicate some post-emplacement deformation. Also contains red-brown biotite and unusual clusters of monazite and zircon crystals.

KJnf **Tonalite of North Fork (late Jurassic-early Cretaceous)**—Medium grained biotite-hornblende tonalite. Biotite defines a distinct foliation that strikes from due W to N. 60° W., and dips of

35°-60° N. Deformed plagioclase, strained and recrystallized quartz and bent biotite all indicate significant deformation.

2.5 Baker Terrane Paleozoic Igneous And Metamorphic Rocks

The Baker Terrane is one of several exotic blocks of older rock accreted to the western edge of the North American Continent in the Mesozoic (Vallier, 1995; Ave L'Allemant, 1995). These metamorphosed mafic igneous and sedimentary rocks occur in the study area as a large block of mixed lithologies in the SE corner of the map, and as small hornfelsed pods that form discontinous septa and inclusions within the Bald Mountain Batholith. The large block was not differentiated, and is mapped as unit TrPm. The septa remnants are described separately.

TrPm **Mixed mafic intrusive and metamorphic rocks (Permian-Triassic?)**—Poorly exposed and complexly intermixed metamorphic rocks derived from both igneous and sedimentary protoliths. Includes meta-gabbro, amphibolite, meta-diorite, meta-ribbon chert, argillite, quartz-mica schist, and minor serpentinite, metaperidotite, talc schist, pyroxenite, and massive recrystallized chert. Most of the gabbro and diorite are weakly to strongly foliated. Near the Bald Mountain batholith, the rocks are contact metamorphosed to hornblende and pyroxene hornfelses. No direct age dating is available for the unit, but it is cut by the Jurassic Bald Mountain batholith, providing an upper limit. The unit is descriptively similar to the mafic intrusive facies of the informal Goodrich Creek unit mapped to the south and west (Ferns and others 1987, Ferns and Brooks, 1995) which is correlated to rocks still further west with a U/Pb date of 243 Ma (Brooks and others 1982).

2.5.1 Hornfels inclusions and septa

TrPs **Metasediments (Permian-Triassic?)**—Inclusions of meta-ribbon chert are important relict components of the Elkhorn Ridge argillite (Gilluly, 1937). This formation underlies large areas to the south and southwest, where fossil radiolarians of Permian and Triassic age occur (Ferns and others, 1987). Intensely recrystallized quartz is glassy, with crystals commonly 2-3 mm across. The narrow argillaceous partings between the ribbons are recrystallized to quartz, biotite feldspar and rare garnet and cordierite.

TrPg **Metagabbro (Permian-Triassic?)**—Dark green to black fine to medium grained, commonly a strongly foliated amphibolite that may retain only traces of the original gabbroic texture. Some intensely deformed schistose amphibolites contain leucocratic veins and lenses with a central concentration of garnet (Taubeneck,1995) that provides the only conclusive evidence of the metagabbroic origin of the rocks.

TrPu **Metamorphosed ultramafic rocks (Permian-Triassic?)**—Dark green to black medium-grained metaperidotite, serpentinite and minor coarse grained pyroxenite. Common minerals in the metaperidotite hornfelses are olivine, clinopyroxene, enstatite, and green spinel.

3.0 STRUCTURE

The dominant structure in the quadrangle is a gentle north dip, superimposed on paleotopography that also sloped to the north. These features cause successively older rock to be exposed from north to south across the quadrangle. This gross structure is cut by three sets of faults; older northwest-trending faults, a younger northwest-trending fault of the Shaw Mountain fault zone, and the north-trending Dutch Creek fault zone.

3.1 Older Northwest Trending Faults

Northwest-trending faults occur in the west-central portion of the map. The southernmost, which runs through High Summit Spring, is a scissors fault. It offsets the Oligocene volcanic rocks down to the north at least 50 m along it's northwest end, and offsets the same rocks about 30 m down to the southwest south and east of High Summit Spring. It is not possible to trace the southeast extension of this fault into the Bald Mountain Batholith. The northernmost fault offsets the Oligocene volcanic rocks at least 70 m down to the northwest, and strongly tilts the contact between the Bald Mountain Batholith and unit Tg in sec. 33, T. 5 S., R. 37 E. This fault also appears to offset the contact between the Bald Mountain Batholith and the Grande Ronde Basalt at it southeastern end, but is buried by the Grande Ronde Basalt at its northwestern end. This observation suggests that the fault ceased to move some time in the middle Miocene.

3.2 Shaw Mountain Fault Zone

The Shaw Mountain fault zone is a set of northwest-trending faults mapped on the adjacent La Grande Reservoir (to the north) and Tucker Flat (to the east) quadrangles by Madin (1998). Only one strand is exposed on the Anthony Butte quadrangle, and it has about 70 m of vertical offset, down to the north. On the adjacent quadrangles, the Shaw Mountain fault zone has both down to the north and down to the south offsets. The Shaw Mountain fault zone cuts the Grande Ronde Basalt, but does not cut Quaternary deposits. On the adjacent quadrangles, the fault zone was clearly active during the eruption of the Grande Ronde Basalt and acted as a barrier for some flows (Madin, 1998).

3.3 Dutch Creek Fault Zone

The Dutch Creek Fault zone occurs in the northeast corner of the map area, and consists of two north-trending faults. The easternmost fault is east-side-down, and the westernmost is west-side-down, defining a small horst in the Grande Ronde Basalt (see OFR O-04-12map, cross section A-A'). The offsets on these faults are a few tens of meters, and there is no direct evidence for strike slip motion, or for the dip of the structures. These faults are part of the Dutch Creek fault zone mapped by Madin (1998) on the adjacent (to the east) Tucker Flat quadrangle, and together comprise a zone about 4 km wide. The Dutch Creek fault zone cuts the Miocene Grande Ronde Basalt, but does not cross any significant Quaternary deposits and so the minimum age is unknown.

4.0 GEOLOGIC HISTORY

The geology mapped on the Anthony Butte quadrangle records some 250 million years of complex and tectonically active geologic history. Six important events that shaped the region are recognized:

- deep ocean subduction and island arc volcanism in exotic locations during the Permian and Triassic;

- plutonism, deformation and metamorphism associated with the docking of the exotic terranes with North America;

- uplift and erosion during the late Mesozoic and early Tertiary;

- Oligocene continental volcanism;

- widespread tholeiitic flood basalt eruptions during the Miocene;

- and, Neogene uplift and erosion, accompanied by montane glaciation.

The oldest rocks in the area are the mixed metamorphic rocks of the Baker Terrane, which are believed to have originated as a deep water accretionary complex (Bourne subterrane, Ferns and Brooks, 1995) and a forearc melange complex (Greenhorn subterrane, Ferns and Brooks, 1995). The origins of these rocks in a subduction environment, coupled with later deformation and metamorphism makes it difficult to extract much information about their origin and early history from the remanants exposed in the Anthony Butte quadrangle.

During the late Juraissic and early Cretaceous the exotic Baker Terrane was accreted to the North American continent and intruded by the Bald Mountain Bathlolith (Vallier, 1995). This composite intrusion ranges from gabbro and diorite to leucogranite in composition, with the bulk of the rock in the quartz diorite to granodiorite range. Within the Anthony Butte quadrangle, there is a clear trend of composition with age, with earlier units more mafic and less potassic quartz diorite and tonalite, and later units more felsic and potassic granites. During the intrusions the Baker terrane country rock was contact metamorphosed to hornblende and pyroxene hornfels facies.

During much of the Cretaceous and early Tertiary, the region underwent uplift and erosion, exposing the plutons and their country rock at the surface. During this time, rivers transported sediment across the region including exotic metamorphic rocks from sources presumably to the north and east. The same rivers that deposited the quartzite boulder gravels in the Anthony Butte quadrangle may have deposited the Paleocene-Eocene Herren Formation sandstones further to the west (Ferns and others, 2001).

During the Oligocene volcanic activity began west of the area, centered around the Tower Mountain Caldera (Ferns and others, 2001) producing both lava flows and volcaniclastic rocks (lahars and tuffs). In the Anthony Butte quadrangle this eruptive activity is largely represented by early basalt flows and later basaltic andesite to dacite flows.

In the middle Miocene, fissure eruptions of Grande Ronde Basalt flowed into the area from the north and east. They encountered a landscape of considerable relief, and were blocked from further southward progress by a topographic high of Oligocene and Jurassic rocks extending across the southern third of the quadrangle. Continued uplift of the area during the eruptions of the Grande Ronde Basalt resulted in an offlap relation, in which successively younger flows are found further north of older high.

The eruption of the Grande Ronde Basalt was followed by a long period of continued uplift which led to dissection of the area by the various streams. During the Pleistocene, a valley glacier at least 200 m thick and originating in the higher Elkhorn Mountains south of the quadrangle extended down the valley of Anthony Creek at least twice, carving out a classic “U” shaped glacial valley and leaving behind deposits of glacial till. The downstream terminus of the most extensive glacial advance appears to have been at the confluence of Anthony Creek and Indian Creek, as there is little till downstream of this point. This raises the possibility that a glacially dammed lake may have formed on Indian Creek upstream of the confluence. It is interesting to note that terrace surfaces downstream on Anthony Creek on the adjacent Tucker Flat (to the east) quadrangle are strewn with boulders up to 1 m in diameter, possibly from catastrophic emptying of such a lake. During this time, a small glacier or rock glacier developed in the headwaters of Beaver Creek, leaving a small deposit of till.

Also during the Pleistocene, erosion along the major streams in the area locally exposed the Oligocene volcanic sediments, and major landslides began to move where Grande Ronde Basalt or unit Tb overlay the sediments. These slides probably have long histories of movement, and some possibly continue to move in times of unusually high precipitation or during seismic shaking.

In the Holocene, paludal deposits filled some of the closed depressions on the surfaces of the landslides, and small amounts of alluvium were deposited in the channels of the streams. In one instance on Beaver Creek, a landslide dammed the stream, causing deposition of an alluvial terrace upstream of the slide.

5.0 GEOLOGIC RESOURCES AND HAZARDS

5.1 Mineral Resources

The Anthony Butte quadrangle has a modest potential for mineral resources. Known quarries and prospects are shown on the geologic map (OFR O-04-12map.pdf), although locations for prospects are generally approximate. The quarries supply road metal for local paving and construction needs, generally from basalt or andesite flows. There are several placer gold prospects hosted in the quartzite boulder conglomerate facies of unit Tg, which also hosts a placer mine on the adjacent (to the west) Limber Jim Creek quadrangle (Ferns and Taubeneck, 1994). Wagner (1944) reports that there was one small antimony mine (named the Stibnite or Parker Mine) located in the E½ sec. 5, T. 6 S., R. 37 E. The mine was originally opened as a gold mine, but produced three cars of ore during World War 1 from a quartz vein containing bunches of stibnite crystals.

Some of the intrusions in the Bald Mountain Batholith may hold some promise for decorative building stone. The pinkish-orange weathering granite of Anthony Buttes, which bears potassium feldspar megacrysts may have some potential.

5.2 Water Resources

The geology of the area is not conducive to developing significant groundwater resources. The older metamorphic, volcanic and intrusive rocks have low permeability and although the north dipping Grande Ronde Basalt may have good aquifers in interflow zones; it is deeply incised by many streams which probably largely drain the aquifers. The Oregon Water Resources Department database of water well logs shows a single well on the extreme east edge of the quadrangle, which was drilled to 43 feet in unit Tg or Qls, and abandoned without further development.

5.3 Geothermal Resources

Geothermal energy resources in the quadrangle are probably nil.

5.4 Earthquake and Mass Wasting Hazards

Plausible geologic hazards in the area include landslides, earthquakes, and catastrophic failure of landslide-dammed lakes. Periodic flooding along the east Fork of the Grande Ronde River, Anthony Creek, Wolf Creek and Beaver Creek, and their tributaries is probable. These drainages carry considerable snowpack in winter and are susceptible to high flows during periods of rapid meltoff.

Landslides are numerous in the area and are typically large relatively deep-seated block slides with failure planes in the Oligocene volcaniclastic sediments. Existing slides and areas where the Oligocene sediments are at or near the surface should be considered especially hazardous. An added hazard is that many of the existing slides appear to have dammed streams in the steep, narrow valleys, which probably resulted in subsequent outburst flooding as the streams breached the slide dams. Such outburst floods could pose a serious risk to areas a considerable distance downstream of the initial slide.

The degree of seismic hazard in the area is unknown. Although there are several faults, there is no evidence of Holocene activity on any of them. Recorded seismicity is absent, but the threshold of detection for seismograph recordings in the area is high, about M 3-3.5. Seismic shaking from earthquakes originating in the nearby Baker and La Grande valleys could be considerable, and the 1000-year probabilistic peak acceleration for the area is 0.16 G (Madin and Mabey, 1996). It is likely that significant ground shaking in the area would trigger more landslides.

6.0 ACKNOWLEGEMENTS

Thanks are due to Allan Madin, Alida Purves, and Dan Wermiel for help in the field. Thorough and constructive reviews of the map and text were provided by Dr. Tracy Vallier and Dr. Stephen Reidel and Mark Ferns.

7.0 REFERENCES

Armstrong, R.L., Taubeneck, W.H., and Hales, P.O., 1977, Rb-Sr Sr isotopic composition, Oregon, Washington, and Idaho; Geological Society of America Bulletin, v. 88, p. 397-411.

Avé Lallemant, H.G., 1995, Pre-Cretaceous Tectonic Evolution of the Blue Mountains Province, Northeastern Oregon: in Vallier, T.L., and Brooks, H. C., eds., Geology of the Blue Mountains Region of Oregon, Idaho and Washington: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1438, p. 271-304.

Baksi, A.K., 1989, Reevaluation of the timing and duration of extrusion of the Imnaha, Picture Gorge, and Grande Ronde Basalts: in Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 105-112

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. 1,407-1,418

Bilderback, E., 1999, Late Quaternary glacial geology and paleoclimate interpretations of the Anthony Lakes drainages, Elkhorn Mountains, Oregon: In Mendelson, C.V., and Mankiewicz, C., compilers, Twelfth Keck Research Symposium in Geology Proceedings, p. 275-278

Brooks, H.C., Ferns, M.L., Coward, R.L., Paul, E.K., and Nunlist, M., 1982, Geology and gold deposits of the Bourne quadrangle, Baker and Grant Counties, Oregon: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-19, scale 1:24,000.

Compton, R.R., 1985, Geology in the Field; John Wiley and sons, New York, 398 pp.

Ferns, M.L. and Brooks, H.C., 1995, The Bourne and Greenhorn Subterranes of the Baker Terrane, Northeastern Oregon: Implications for the Evolution of the Blue Mountains Island-Arc System: in Vallier, T.L., and Brooks, H. C., eds., Geology of the Blue Mountains Region of Oregon, Idaho and Washington: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1438, p. 331-358.

Ferns, M.L., Madin, I.P., and Taubeneck, W. H., 2001, Geology of the La Grande 30' x 60' Quadrangle, Baker, Grant, Umatilla, and Union Counties, Oregon: Oregon Department of Geology and Mineral Industries RMS-1, Scale 1:100,000

Ferns, M.L., 1998, Geology and Mineral Resources Map of the Fly Valley Quadrangle, Union County, Oregon; Oregon Department of Geology and Mineral Industries GMS-113, scale 1:24,000

Ferns, M.L., and Madin, I.P., 1999, Geologic Map of the Summerville Quadrangle, Union County, Oregon. Oregon Department of Geology and Mineral Industries (DOGAMI) GMS-111. scale 1:24,000

Ferns, M.L., and Taubeneck, W.A., 1994, Geology and Mineral Resources Map of the Limber Jim Creek Quadrangle, Union County, Oregon: Oregon Department of Geology and Mineral Industries GMS 82, scale 1:24,000

Ferns, M.L., Brooks, H.C., Avery, D.G., and Blome, C.D., 1987, Geology and mineral resources map of the Elkhorn Peak quadrangle, Baker County, Oregon: Oregon Department of Geology and Mineral Industries Geologic Map Series GMS-41, scale 1:24,000.

Geraghty, E., 1999, Glaciation of the Elkhorn Mountains, northeastern Oregon: In Mendelson, C.V., and Mankiewicz, C., compilers, Twelfth Keck Research Symposium in Geology Proceedings, p.

Gilluly, J., 1937, Geology and Mineral Resources of the Baker Quadrangle, Oregon: U.S. Geological Survey Bulletin 879, 119 p.

Hampton, E.R., and Brown, S.G., 1964, Geology and Ground-Water Resources of the Upper Grande Ronde River Basin, Union County, Oregon: U.S. Geological Survey Water-Supply Paper 1597

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: Washington State University Geology Department Open-File Report, 36 p.

Kent, D.V., and Gradstein, F.M., 1985, A Cretaceous and Jurassic geochronology: Geological Society of America Bulletin, v. 96, p. 1419-1427.

Le Bas, M.J., and Streckeisen, A.L., 1991, The IUGS Systematics of Igneous Rocks: Journal of the Geological Society, London, v. 148, pp 825-833.

Madin, I.P., 1998, Geologic Map of the Tucker Flat Quadrangle, Baker and Union Counties, Oregon: Oregon Department of Geology and Mineral Industries GMS-110, scale 1:24,000

Madin, I.P., and Mabey, M.A., eds, 1996, Earthquake Hazard Maps for Oregon: Oregon Department of Geology and Mineral Industries (DOGAMI) GMS 100 scale 1:200,000,000

Madin, I.P., in review, Geologic Map of the La Grande Reservoir Quadrangle, Union County, Oregon; Oregon Department of Geology and Mineral Industries GMS 1xx

Miller, Marjorie, 1997 X-Ray Fluorescence Spectrometry Methods for Method Codes XRF-7 and XRF-102. Information sheet from XRAL Laboratories, Dons Mills, Ontario, Canada.

Robinson, P.T., Walker, G.W., and McKee, E.H., 1990, Eocene(?), Oligocene, and lower Miocene rocks of the Blue Mountains region: in Walker, G.W., ed., Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Cenozoic Geology: U.S. Geological Survey Professional Paper 1437, p. 29-62.

Reidel, S.P., 1983, Stratigraphy and petrogenesis of the Grande Ronde Basalt from the deep canyon country of Washington, Oregon and Idaho: Geological Society of America Bulletin, v. 94p. 519-542

Reidel, S.P., Tolan, T.L., Hooper, P.R., Beeson, M.H., Fecht, K.R., Bentley, R.D., and Anderson, J.L., 1989, The Grand Ronde Basalt, Columbia River Basalt Group - stratigraphic descriptions and correlation's in Washington, Oregon, and Idaho, in Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 21-54

Streckeisen, A.L., 1973, Plutonic rocks—Classification and nomenclature recommended by the IUGS subcommission on the systematics of igneous rocks: Geotimes, v. 18, p. 26-30

Swanson, D.A., Anderson, J.L., Camp, V.E., Hooper, P.R., Taubeneck, W.H., and Wright, T.L., 1981, Reconnaissance Geologic Map of the Columbia River Basalt Group, Northern Oregon and Western Idaho; U.S. Geological Survey Open-File Report 81-797

Swanson, D.A., Wright, T.L., Hooper, P.R., and Bentley, R.D., 1979, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Taubeneck, W.H., 1957, Geology of the Elkhorn Mountains, northeastern Oregon—Bald Mountain Batholith: Geological Society of America Bulletin, v. 68, p. 181-238

Taubeneck, W.H., 1995, A closer look at the Bald Mountain Batholith, Elkhorn Mountains, and some comparisons with the Wallowa Batholith, Wallowa Mountains, northeastern Oregon: in Vallier, T.L., and Brooks, H. C., eds., Geology of the Blue Mountains Region of Oregon, Idaho and Washington: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1438, p. 45-124

Tolan, T.L., Reidel, S.P., Beeson, M.H., Anderson, J.L., Fecht, K.R., and Swanson, D.A., 1989, Revisions to the areal extent and volume of the Columbia River Basalt Group, in Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt Province: Geological Society of America Special Paper 239, p.1-20

USGS, 1990, Side-Looking Airborne Radar Mosaic of the Pendleton 1o x 2o Quadrangle, Oregon and Washington, U.S. Geological Survey CD-ROM Digital Data

Vallier, T.L., 1995, Petrology of pre-Tertiary igneous rocks in the Blue Mountains region of Oregon, Idaho and Washington: Implications for the geologic evolution of a complex island arc: in Vallier, T.L., and Brooks, H. C., eds., Geology of the Blue Mountains Region of Oregon, Idaho and Washington: Petrology and Tectonic Evolution of Pre-Tertiary Rocks of the Blue Mountains Region: U.S. Geological Survey Professional Paper 1438, p. 125-210

Wagner, N. S., 1944, Antimony in Oregon: Oregon Department of Geology and Mineral Industries GMI Short Paper 13, 20 pp.

Walker, G.W., 1973, Reconnaissance Geologic Map of the Pendleton Quadrangle, Oregon and Washington: U.S. geological Survey Miscellaneous Geologic Investigation Map I-727, scale 1:250,000

Walker, N.W., 1989, Early Cretaceous initiation of post-tectonic plutonism and the age of the Connor Creek fault, northeastern Oregon: Geological Society of America Abstracts