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GEOLOGIC MAP OF THE KLAMATH FALLS AREA, KLAMATH COUNTY, OREGON

By

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2008

NOTICE

This map cannot serve as a substitute for site-specific investigations by qualified practitioners. Site-specific data may give results that differ from those shown on the maps. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. government.

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1.0 INTRODUCTION

The area of the Klamath Falls geologic map lies east of the High Cascades at the south end of Upper Klamath Lake (Figure 1.1). The Klamath River (Figure 1.1) provides the main drainage from the area, flowing from Upper Klamath Lake to the Pacific Ocean. The map boundaries encompass the urban growth boundary for the City of Klamath Falls plus some fringing areas (Figure 1.2). The map covers all of the Klamath Falls and Altamont topographic quadrangles, ~20 percent of the Wocus quadrangle (Figure 1.2), and ~10 percent of the adjacent Whiteline Reservoir quadrangle to the northeast.

Situated in the extreme northwestern part of the Basin and Range province, the quadrangle is dominated by the horst and graben topography resulting from the extensional tectonics that characterize the Basin and Range of southeast Oregon (Figure 1.1). Elevation in the area ranges from 4,073 feet (1,240 m) at the Lost River to 6,200 feet (1,890 m) at the top of Hogback Mountain. The northwest-trending normal faults that bound Upper Klamath Lake and form the Klamath graben expose up to 480 m of volcanic and sedimentary rocks, ranging in age from late Miocene to Holocene. Upper Klamath Lake and surficial deposits of lake and river sediment cover approximately 25 percent of the map area. Link River flowing out of Upper Klamath Lake and the Klamath River flowing out of Lake Ewauna form the main perennial stream system in the area. The Lost River is a smaller river that flows on the southeastern side of the map area. Figures 1.1 and 1.2 show the location of the main physiographic and cultural features mentioned in the text.

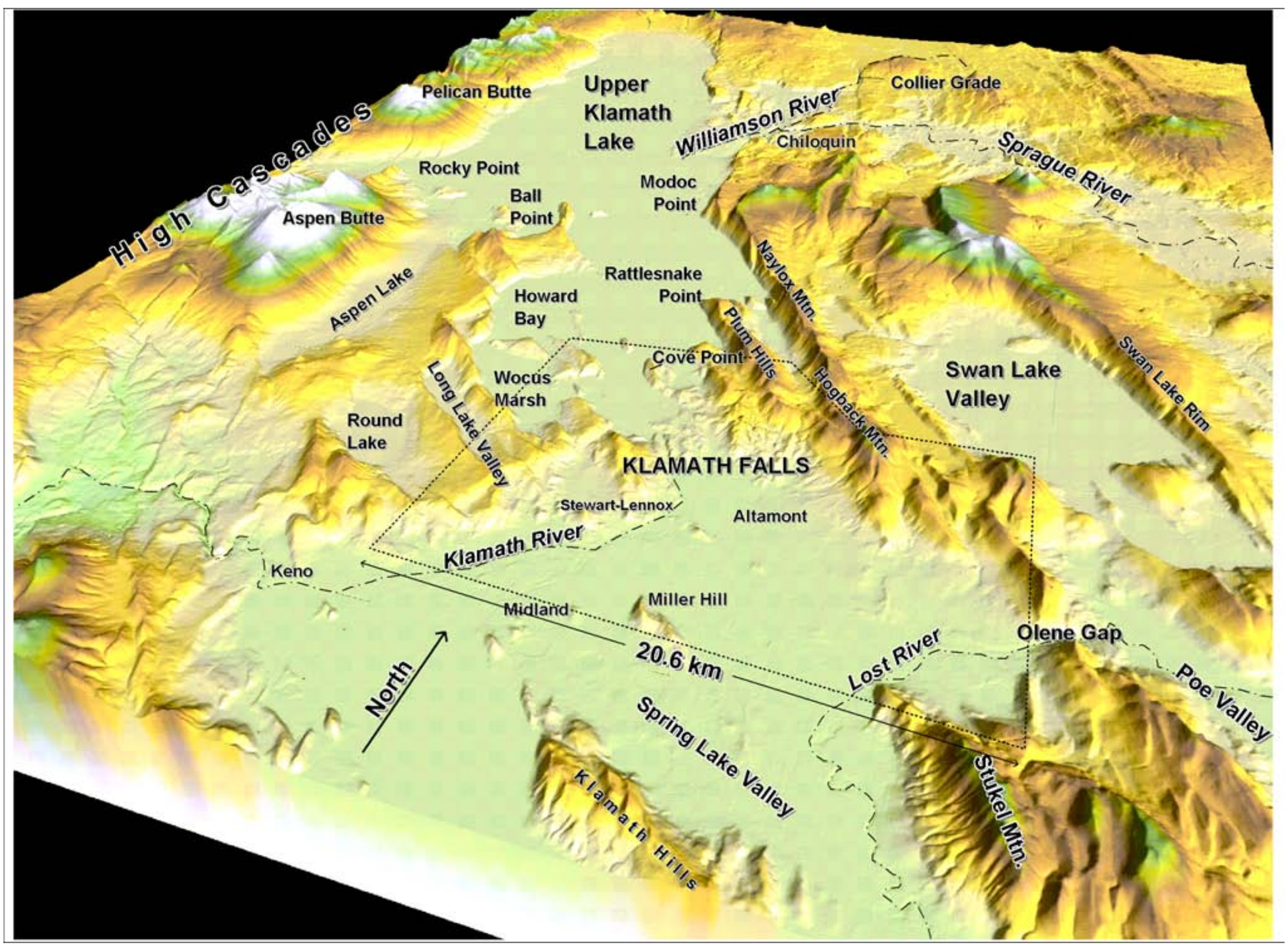

Figure 1.1. Location of mapped area (dotted line).

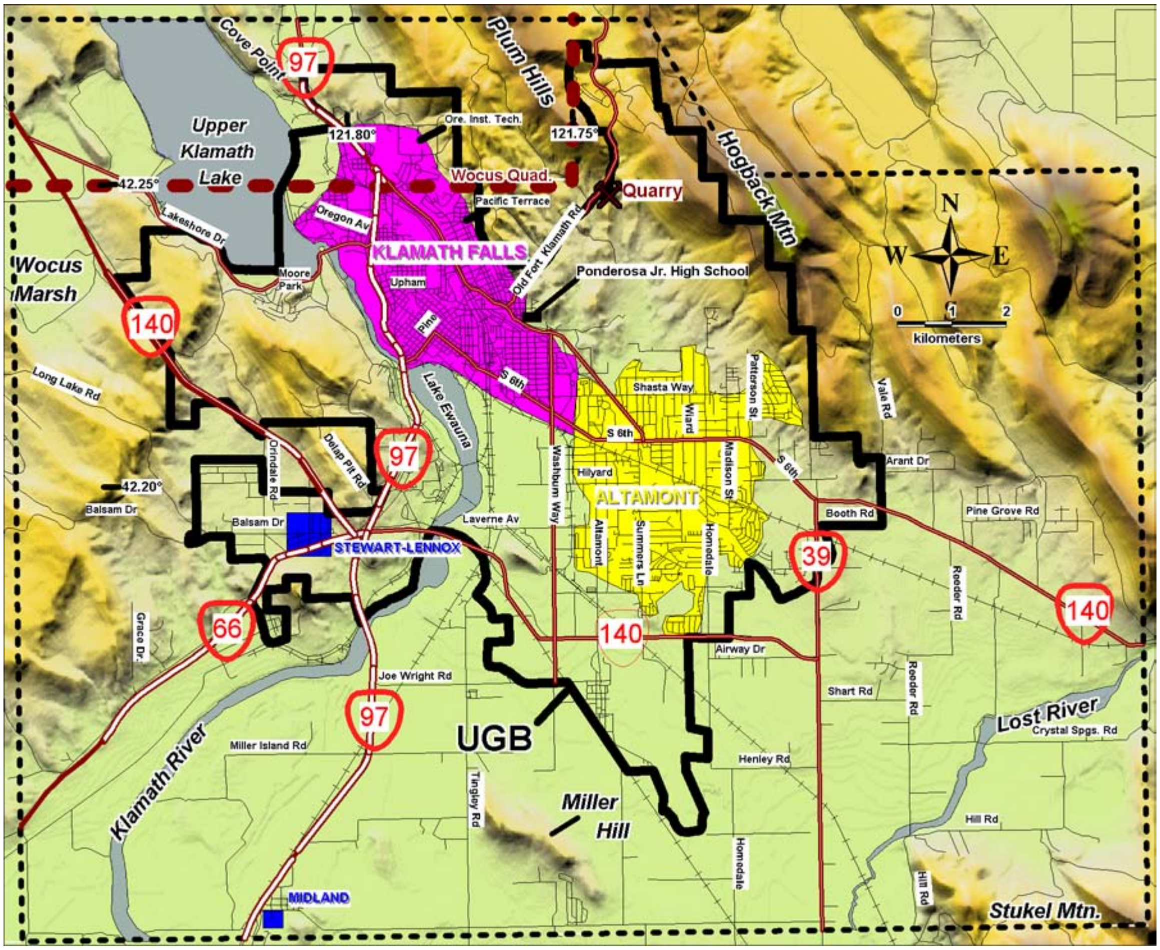

Figure 1.2. Location map of local geographic features. Dotted line is boundary of the geologic map. UGB is urban growth boundary; Ore. Inst. Tech. is Oregon Institute of Technology; Quad. is quadrangle.

Rock in the area is chiefly ~2-7 Ma dark gray lava (basalt and basaltic andesite) and contemporaneous to younger cream-colored diatomaceous mudstone. Local outcrops of sandstone and conglomerate cap a few low hills between Oregon Institute of Technology (OIT) and the Stewart Lennox area. Andesite crops out in a few areas near Link River, Stewart Lennox, and the southeastern tip of Hogback Mountain. Rocks in the area are the product of complex interaction between sedimentation and Cascade volcanism. Composition and extent of the volcanic rocks was modified after ~4 Ma by Basin and Range extension and the decreasing width of Cascade volcanic arc. By the time of the Pleistocene glaciations (by ~1.6 Ma) Cascade volcanic activity had mostly ceased in the area, as Cascade volcanism continued to narrow toward its present location in the High Cascades. Basin and Range extension continued to pull the area apart, dropping basins lower relative to ridges like Hogback Mountain, while sedimentation, helped along by periodic ash fall from the High Cascades, filled lake basins like Upper Klamath Lake and Round Lake.

The Klamath Falls geologic map covers areas mapped previously by Peterson and McIntyre (1970) and Sherrod and Pickthorn (1992). Geologic maps for adjacent quadrangles recently completed or in preparation include the Keno quadrangle (Hladky and Mertzman, 2000), and the Wocus quadrangle (Murray, in press). Overlapping portions of the Wocus quadrangle were taken directly from Murray (in press) with only minor alterations.

1.1 GEOLOGIC MAPPING TECHNIQUE

Geologic mapping was accomplished primarily to supply geologic data for the production of an earthquake hazard map of the Klamath Falls metropolitan area (Black and others, 2000); mapping detail and stratigraphic distinctions were influenced by this focus. In this regard, mapping is most detailed in the metropolitan area, and some surficial units are distinguished more for their engineering characteristics and importance to earthquake ground response than their geologic origins (e.g., see description of unit Qs versus unit Qal).

Fieldwork by Priest and Hladky was conducted during three months in 1997 and five days in 1998. The whole area was mapped in the field on stereo pairs of 1:62,500-scale aerial photos and on paper copies of 1:24,000-scale topographic quadrangles; hence most contacts are located no more accurately than ±12.2 m (40 ft) in the horizontal. In areas of soil cover, bedrock contacts are located less accurately than ±12.2 m. In many cases contacts observed in the field could be extended using photographic data. Subtle variations in relief are accentuated when viewed stereographically and often indicate changes in rock type beneath thinning soil cover. Field inspections on a case-by-case basis either confirmed or dispelled these indications. Poor exposure, due to colluvium and soil cover that are extensive on most slopes, made contact delineation in many areas difficult, even when the area was traversed on foot.

Detailed mapping by field traverse of critical areas was accomplished throughout the urban growth boundary; other areas were mapped in lesser detail using limited field traverses and interpretation of aerial photography. Mapping at Midland and the eastern part of Stukel Mountain is taken with only minor modification from Sherrod and Pickthorn (1992). In 1999 Robert Murray remapped the portion of the map overlapping the Wocus quadrangle (Figure 1.2) using digital orthophoto quadrangles with 1-m resolution, overlaid with digital line graphs of contour lines and hydrography, and printed out at 1:600 or 1:12,000 scale. These base maps allowed considerably improved location of contacts relative to previous mapping. As a result, Murray was able to map separately some units that were combined in other parts of the map area.

Faults are inferred from offset of rock units. Recognizing deformation required that units crop out and that the outcrops have distinct bedding in sedimentary units or distinct lithology in lavas. Outcrops are rare at Altamont and in the south central part of the map. Even where ditches or canals penetrated soil cover, the underlying sedimentary rocks generally lack distinct bedding or units that could be correlated. Absence of mapped faults in these areas does not mean that faults are not present, only that compelling evidence was not found. The density of mapped faults in areas of hard rock suggests that many faults are present in areas covered by surficial soil units or extensive outcrops of poorly bedded mudstone of unit Tm or Tms.

The classification of igneous rocks in this report follows the geochemical method of Le Bas and Streckeisen (1991) with one modification: lavas with <53 percent SiO_2 are classified as basalt, while lavas with SiO_2 between 53 and 58 percent are classified as basaltic andesite. Units for which no analytical data were available were assigned rock names based on the following criteria: the name "basalt" was used for rocks having abundant fresh or incipiently altered olivine phenocrysts, typically with granular to felty groundmass; the name "basaltic andesite" was used for rocks containing altered olivine ± orthopyroxene phenocrysts with intersertal to intergranular groundmass; the name "andesite" is used for rocks that contain clinopyroxene phenocrysts with orthopyroxene and perhaps a few thoroughly altered olivine phenocrysts in an intersertal intergranular, or devitrified, formerly hyalopilitic (glass plus crystals) groundmass.

1.2 RADIOMETRIC DATING

Duncan and others (1997) describe the $^{40}Ar/^{39}Ar$ methodology used for new isotopic age analyses cited in Table 1.1. Low potassium in the samples limited the accuracy of the ages, particularly for basalt samples less than 2 Ma in age (e.g., Table 1.1; samples K-362 and K-370).

1.3 GEOCHEMISTRY

Table 1.2 lists locations, paleomagnetic polarity, and lithology of all samples analyzed for chemical composition (Table 1.3) and includes all isotopic age samples of Table 1.1.

Major and trace element analyses are from the Washington State University geochemical laboratory. Samples were analyzed by Diane Johnson utilizing methods described by Hooper and others (1993). One analysis (Table 1.2; map no. 1, sample 980611-1) was analyzed by S. A. Mertzman of Franklin and Marshall College, Lancaster, Pennsylvania, using standard X-ray fluorescence techniques described by Mertzman (2000). Duplicate analyses on samples with map numbers of 13, 29, and 51 illustrate the precision (repeatability) of the data (Table 1.3).

1.4 DIATOM AND TEPHRA DATA

Diatom analyses are from Platt Bradbury of the U.S. Geological Survey (USGS) on samples collected by George Priest (Table 1.4). Andre M. Sarna-Wojcicki of USGS did a tephra analysis and correlation on one sample collected by George Priest from an outcrop on Highway 97 at Collier Grade (43 km north of the map area).

Table 1.1. $^{40}Ar/^{39}Ar$ Incremental Heating Ages for Rocks of the Klamath Falls Area

Map No.	Field No.	Unit	Material	Total Fusion Age (Ma)	Error	Plateau Age (Ma)	Error	^{39}Ar Percent of Total	Isochron Age (Ma)	Error	*N*	$^{40}Ar/^{39}Ar$ Intercept +1s	*J*
52	K-29	Tcba	whole rock	2.51	0.56	2.41	0.13	97	2.33	0.45	6	302.34 ± 101.99	0.001667
53	K-74	Thb	whole rock	2.83	0.70	2.67	0.21	88	3.5	1.25	6	270.01 ± 88.21	0.001666
14	K-90	Tba	whole rock	4.03	0.33	4.01	0.12	100	3.84	0.17	6	299.77 ± 5.86	0.00164
7	K-252	Tla	whole rock	3.60	0.20	3.43	0.06	98	3.48	0.21	6	253.94 ± 114.43	0.00159
—	K362	—	whole rock	1.14	0.10	—	—	—	—	—	1	—	—
3	K-370	QTwb	whole rock	0.94	0.64	—	—	—	—	—	1	—	—
3	K-370	QTwb	whole rock	0.97	0.64	0.97	0.64	100	0.68	0.68	6	313.41 ± 83.02	0.00144
—	980611-1	QTwb	—	—	—	1.80	0.39	—	—	—	–	—	—

Note: Analyses are by Robert A. Duncan, Oregon State University, Corvallis, Oregon. Table 1.2 lists locations. Sample K-362 is from unit Qsh1 of Wiley (2004), 43 km north of the map area. Sample 980611-1 is from Hladky and Mertzman (2000) in the adjacent Keno quadrangle.
Dash means no data or no map no. because sample is outside the map area; *N* is number of heating increments; *J* is neutron fluence factor; Ma is mega annums (million years ago).

Table 1.2. Locations, Paleomagnetic Polarity, and Lithology of All Samples Analyzed for Chemical Composition (see Table 1.3); Includes All Isotopic Age Samples of Table 1.1

Map No.	Sample No.	Formation	West Longitude	North Latitude	Polarity	Rock Type
0	K-362	—	121.85761	42.67179	n	Olivine basaltic andesite
1	980611-1	QTwb	121.84714	42.23032	-	Diktytaxitic olivine basalt
2	K-154	QTwb	121.84640	42.22175	-	Fresh diktytaxitic olivine basalt
3	K-370	QTwb	121.83814	42.23747	r	Diktytaxitic olivine basalt
4	K-367	QTwb?	121.83624	42.22379	n	Olivine basalt
5	K-247a	Ta	121.81175	42.24281	r	Two-pyroxene andesite
6	K-300	Ta	121.68700	42.20802	n	Olivine-two-pyroxene andesite
7	K-252	Tla	121.81540	42.23390	(r)	Two-pyroxene andesite
8	K-23	Tba	121.77737	42.26132	I	Olivine basaltic andesite
9	K-24	Tba	121.77692	42.26195	n	Olivine bearing two-pyroxene andesite
10	K-25	Tba	121.77710	42.26246	n	Olivine basaltic andesite
11	K-49	Tba	121.77796	42.25303	(r)	Glomerocrystic olivine basaltic andesite
12	K-88a	Tba	121.70999	42.23620	r	Sl. glomerocrystic olivine-augite basaltic andesite
13	K-89	Tba	121.71072	42.23584	(r)	Altered sl. glomerocrystic olivine-augite basaltic andesite
13	K-89R	Tba	121.71072	42.23584	(r)	Altered sl. glomerocrystic olivine-augite basaltic andesite
14	K-90	Tba	121.71111	42.23370	r	Sl. glomerocrystic olivine-augite basaltic andesite
15	K-91	Tba	121.71175	42.23517	(n)	Vesicular olivine basaltic andesite
16	K-91A	Tba	121.71213	42.23491	-	Altered sl. glomerocrystic olivine-augite basaltic andesite
17	K-92	Tba	121.71247	42.23437	(n)	Vesicular olivine augite basaltic andesite
18	K-157	Tba	121.79976	42.21785	(r)	Altered olivine basaltic andesite
19	K-159	Tba	121.81658	42.22360	r	Altered olivine basaltic andesite
20	K-160	Tba	121.81905	42.22593	(n)	Altered olivine basaltic andesite
21	K-161	Tba	121.81867	42.22586	(n)	Altered olivine basaltic andesite
22	K-162	Tba	121.81837	42.22600	-	Altered vesicular oxidized olivine basalt
23	K-163	(Tba)	121.81817	42.22729	r	Altered olivine basaltic andesite block probably from unit Tba upslope of the sample point
24	K-164	Tba	121.80250	42.20472	-	Fresh basaltic andesite ash and cinder deposit
25	K-166A	Tba	121.80630	42.20479	(r)	Altered olivine basaltic andesite
26	K-172	Tba	121.80282	42.20920	r	Altered olivine basaltic andesite
27	K-227	Tba	121.80184	42.23788	r	Altered olivine basaltic andesite
28	K-230	Tba	121.79652	42.23233	r	Altered olivine basaltic andesite
29	K-231	Tba	121.79626	42.23242	r	Altered olivine basaltic andesite
29	K-231R	Tba	121.79626	42.23242	r	Altered olivine basaltic andesite
30	K-236	Tba	121.80681	42.24056	r	Altered olivine basaltic andesite
31	K-238	Tba	121.80678	42.24139	r	Altered olivine basaltic andesite
32	K-248	Tba	121.80565	42.23766	r	Altered olivine basalt
33	K-259	Tba	121.78762	42.22749	n	Altered glomercrystic olivine basaltic andesite
34	K-313	Tba	121.75695	42.26311	n	Altered olivine-augite basaltic andesite
35	K-316	Tba	121.75794	42.26083	n	Altered olivine basaltic andesite
36	K-318	Tba	121.75656	42.25820	r	Olivine-augite basaltic andesite autobreccia
37	K-319	Tba	121.75542	42.25989	r	Olivine-augite basaltic andesite autobreccia
38	K-320c	Tba	121.75422	42.26131	-	Glomercrystic olivine-augite basaltic andesite
39	K-328	Tba	121.76900	42.26459	n	Olivine basalt
40	K-329	Tba	121.77203	42.26477	r	Fresh glomercrystic hyalopilitic olivine basaltic andesite
41	K-346	Tba	121.84400	42.17824	(n)	Olivine basalt
42	K-355	Tba	121.85551	42.18095	n	Olivine basalt
43	K-357m	Tba	121.77353	42.14950	n	Altered olvine basaltic andesite
44	K-359	Tba	121.73631	42.17783	n	Altered olvine basaltic andesite
45	K-381	Tba	121.78606	42.22515	r	Fresh olivine basaltic andesite
46	K-382	Tba	121.78826	42.22232	r	Altered glomercrystic olivine-augite basaltic andesite
47	K-383	Tba	121.78929	42.22298	r	Augite basaltic andesite
48	K-384	Tba	121.79009	42.22340	(r)	Fresh glomercrystic olivine-augite basaltic andesite
49	K-385	Tba	121.78469	42.22204	n	Augite basaltic andesite
50	K-386	Tba	121.78617	42.22068	r	Altered glomercrystic olivine-augite basaltic andesite
51	K-321	Tt	121.76083	42.25086	-	Fresh olivine-bearing sideromelane tuff
51	K-321R	Tt	121.76083	42.25086	-	Fresh olivine-bearing sideromelane tuff
52	K-29	Tcba	121.81164	42.26647	?	Glomerocrystic olivine-augite basaltic andesite
53	K-74	Thb	121.70767	42.24349	n	Glomerocrystic olivine basalt
54	K-76	Thb	121.70862	42.24363	n	Glomerocrystic olivine-augite basalt
55	K-80	Thb	121.70623	42.23984	n	Glomerocrystic olivine basalt
56	K-88	Thb	121.70944	42.23604	(n)	Glomerocrystic olivine basalt
57	K-96	Thb	121.71113	42.24111	n	Olivine augite basalt vitrophyre
57	K-96A	Thb	121.71113	42.24111	n	Olivine augite basalt vitrophyre
58	K-111	Thb	121.70719	42.23452	-	Very fresh olivine basalt
59	K-361	Tpt	121.75780	42.22807	-	Basaltic andesite vitrophyre

Note: I is indeterminate polarity; n is normal polarity; r is reversed polarity; () is weak polarity; dash symbol means no measurement; parentheses on formation label indicates that the sample is from a large block of rock that may not be in place.

Table 1.3. Major Element Oxide Analyses and Trace Element Analyses

Map No.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Map Unit	*****	**QTwb**	**QTwb**	**QTwb**	**Tba**	**Ta**	**Ta**	**Tla**	**Tba**	**Tba**
Sample No.	**K-362**	**980611-1**	**K-154**	**K-370**	**K-367**	**K-247A**	**K-300**	**K-252**	**K-23**	**K-24**
Analytical Date	5-Jul-98	1998	3-Jul-98	5-Jul-98	5-Jul-98	4-Jul-98	4-Jul-98	4-Jul-98	2-Jul-98	2-Jul-98
West Longitude	121.85761	121.84714	121.84640	121.83814	121.83624	121.81175	121.68700	121.81540	121.77811	121.77738
North Latitude	42.67179	42.23032	42.22175	42.23747	42.22379	42.24281	42.20802	42.23390	42.26067	42.26142
Oxides, weight percent										
SiO_2	53.96	48.52	49.48	48.63	49.70	57.91	58.27	58.66	52.19	58.02
Al_2O_3	18.93	17.54	17.56	17.33	18.05	17.45	17.62	17.50	17.26	15.70
TiO_2	1.061	1.080	1.025	1.018	1.070	1.157	0.943	1.191	1.152	1.062
FeO*	7.51	9.76	8.23	8.51	8.00	6.72	6.24	5.25	7.98	6.46
MnO	0.128	0.17	0.157	0.161	0.136	0.127	0.130	0.108	0.165	0.137
CaO	7.98	7.19	11.03	11.06	11.59	6.54	6.48	6.38	8.59	6.45
MgO	4.97	11.14	8.99	8.96	7.35	3.26	2.37	3.09	6.48	4.71
K_2O	0.75	0.17	0.16	0.15	0.13	1.42	2.46	1.63	1.15	2.17
Na_2O	4.19	2.84	2.90	2.99	3.09	4.42	3.55	4.72	3.73	4.20
P_2O_5	0.209	0.12	0.104	0.104	0.112	0.343	0.488	0.360	0.424	0.413
Total	99.69	98.53	99.64	98.91	99.23	99.35	98.55	98.89	99.12	99.32
Trace Elements, parts per million										
Ni	76	123	160	155	156	22	14	27	95	59
Cr	74	229	243	249	251	33	23	36	139	152
Sc	21	30	40	35	37	18	19	22	27	20
V	182	242	219	222	227	190	176	202	216	191
Ba	320	144	79	78	162	517	1125	561	529	550
Rb	10	3	1	2	1	26	31	27	14	40
Sr	697	306	295	293	324	611	642	625	761	620
Zr	101	66	57	62	64	147	203	151	149	171
Y	17	25	21	24	24	25	29	26	19	21
Nb	3.7	2	2.6	3.1	2.1	5.4	9.0	6.4	7.0	7.2
Ga	21	16	17	16	18	17	18	20	19	18
Cu	67	91	85	83	116	64	61	79	78	76
Zn	77	71	66	65	77	85	80	100	88	82
Pb	3	3	4	3	0	8	11	6	3	8
La	7	3	3	5	14	5	27	16	43	38
Ce	30	14	22	16	25	42	58	54	47	57
Th	3	<0.5	0	1	1	2	1	2	2	3

Map No.	**10**	**11**	**12**	**13**	**13**	**14**	**15**	**15**	**17**	**18**
Map Unit	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**
Sample No.	**K-25**	**K-49**	**K-88A**	**K-89**	**K-89R**	**K-90**	**K-91**	**K-91A**	**K-92**	**K-157**
Analytical Date	2-Jul-98	2-Jul-98	2-Jul-98	2-Jul-98	6-Jul-98	2-Jul-98	3-Jul-98	3-Jul-98	3-Jul-98	3-Jul-98
West Longitude	121.77400	121.77796	121.70999	121.71072	121.71072	121.71111	121.71175	121.71213	121.71247	121.79976
North Latitude	42.26192	42.25303	42.23620	42.23584	42.23584	42.23370	42.23517	42.23491	42.23437	42.21785
Oxides, weight percent										
SiO_2	52.54	55.11	56.16	56.26	56.74	56.07	53.51	55.29	55.13	52.73
Al_2O_3	18.18	17.68	17.86	17.77	17.92	17.78	17.50	17.48	17.32	18.09
TiO_2	0.947	1.114	1.122	1.093	1.101	1.093	1.063	1.108	1.058	0.939
FeO	7.80	7.10	6.94	6.65	6.37	6.84	7.83	7.27	7.65	7.24
MnO	0.143	0.139	0.137	0.115	0.116	0.137	0.153	0.139	0.143	0.139
CaO	8.97	7.58	7.58	7.46	7.49	7.57	8.26	7.64	7.70	8.88
MgO	6.30	4.39	3.76	3.75	3.70	3.95	5.23	4.19	4.68	6.07
K_2O	0.55	1.42	1.60	1.55	1.55	1.50	1.25	1.55	1.48	0.69
Na_2O	3.57	4.14	4.05	4.20	4.19	4.29	3.53	3.68	3.55	3.60
P_2O_5	0.273	0.493	0.479	0.491	0.496	0.503	0.440	0.511	0.477	0.282
Total	99.27	99.17	99.69	99.34	99.67	99.73	98.77	98.86	99.19	98.66
Trace Elements, parts per million										
Ni	107	41	26	29	26	32	80	44	76	120
Cr	127	68	48	50	51	61	121	63	132	153
Sc	24	24	22	21	22	23	24	22	24	31
V	201	173	170	181	181	187	195	171	172	194
Ba	385	660	737	712	710	708	584	673	658	404
Rb	6	16	22	19	18	18	16	18	19	4
Sr	663	642	640	637	632	631	585	654	558	683
Zr	96	163	180	176	175	178	172	167	193	95
Y	17	23	25	25	25	24	25	24	24	17
Nb	4.8	8.8	10.6	9.6	9.5	8.6	9.7	9.5	11.4	4.8
Ga	16	21	23	18	21	21	17	20	19	20
Cu	70	65	71	50	50	65	60	68	22	78
Zn	78	85	85	83	83	84	85	87	97	75
Pb	7	5	7	9	8	9	8	8	7	4
La	16	22	33	6	21	30	26	27	18	25
Ce	31	60	61	55	60	47	65	59	60	34
Th	3	0	1	5	2	5	0	2	2	0

Note: File "K_Falls_Original_Chemistry.xls" in the accompanying digital database shows recalculated analyses used to assign rock names. FeO* means all iron oxide is shown as FeO. Map no. 1 is from Hladky and Mertzman (2000).
*- = outside mapped area.

Table 1.3. — continued

Map No.	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Map Unit	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba+**	**Tba**	**Tba**	**Tba**	**Tba**
Sample No.	**K-159**	**K-160**	**K-161**	**K-162**	**K-163**	**K-164**	**K-166A**	**K-172**	**K-227**	**K-230**
Analytical Date	3-Jul-98	3-Jul-98	3-Jul-98	3-Jul-98	3-Jul-98	3-Jul-98	3-Jul-98	4-Jul-98	4-Jul-98	4-Jul-98
West Longitude	121.81658	121.81905	121.81867	121.81837	121.81817	121.80250	121.80545	121.80282	121.80184	121.79652
North Latitude	42.22360	42.22593	42.22586	42.22600	42.22729	42.20472	42.04793	42.20920	42.23788	42.23233
Oxides, weight percent										
SiO_2	52.10	52.51	52.19	50.97	52.98	51.28	52.59	51.91	53.37	52.65
Al_2O_3	17.95	17.90	17.94	18.80	18.27	16.02	17.92	17.83	18.58	18.04
TiO_2	0.950	0.937	0.926	0.988	0.954	1.183	0.918	0.945	0.957	0.931
FeO*	7.36	7.37	7.42	7.93	7.35	8.29	7.52	7.73	7.24	7.06
MnO	0.147	0.147	0.124	0.192	0.155	0.183	0.138	0.141	0.123	0.137
CaO	9.06	8.89	8.95	8.98	8.93	8.30	9.04	8.96	8.88	8.74
MgO	6.47	7.01	6.47	6.69	5.79	8.41	6.53	6.64	4.58	6.67
K_2O	0.62	0.69	0.64	0.52	0.70	0.40	0.67	0.60	1.05	0.81
Na_2O	3.40	3.57	3.54	3.43	3.47	2.30	3.42	3.39	3.89	3.55
P_2O_5	0.288	0.290	0.270	0.301	0.277	0.198	0.279	0.287	0.274	0.272
Total	98.34	99.31	98.47	98.80	98.88	96.56	99.03	98.43	98.94	98.86
Trace Elements, parts per million										
Ni	115	123	107	130	99	155	116	112	36	99
Cr	154	165	153	161	129	306	151	158	74	142
Sc	22	25	29	25	21	23	25	29	27	25
V	201	198	197	151	196	194	192	204	207	207
Ba	440	410	377	423	381	159	348	342	406	372
Rb	7	3	4	5	11	5	9	8	15	10
Sr	712	689	693	692	688	331	699	713	706	682
Zr	102	100	93	101	100	89	93	101	105	90
Y	16	17	16	21	16	20	16	16	19	15
Nb	4.9	5.0	4.4	5.8	5.5	5.6	5.0	4.7	6.1	5.0
Ga	20	19	19	20	20	17	21	18	20	20
Cu	68	45	72	122	73	71	75	63	67	80
Zn	82	76	77	77	77	74	76	78	67	77
Pb	1	4	6	8	4	0	4	6	5	1
La	11	7	12	14	8	6	22	16	18	7
Ce	34	32	30	24	26	24	17	34	33	46
Th	3	2	1	0	2	1	1	0	2	2

Map No.	**29**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
Map Unit	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**
Sample No.	**K-231**	**K-231R**	**K-236**	**K-238**	**K-248**	**K-259**	**K-313**	**K-316**	**K-318**	**K-319**
Analytical Date	4-Jul-98	6-Jul-98	4-Jul-98	4-Jul-98	4-Jul-98	4-Jul-98	4-Jul-98	4-Jul-98	5-Jul-98	5-Jul-98
West Longitude	121.79626	121.79626	121.80681	121.80678	121.80400	121.78762	121.75695	121.75794	121.75656	121.75542
North Latitude	42.23242	42.23242	42.24056	42.24139	42.23680	42.22749	42.26311	42.26083	42.25820	42.25989
Oxides, weight percent										
SiO_2	52.20	52.31	53.79	54.02	52.32	55.54	55.59	51.89	52.22	52.00
Al_2O_3	18.09	18.08	17.73	17.93	17.74	17.86	16.77	17.70	17.80	18.06
TiO_2	0.937	0.944	0.954	0.932	0.939	1.146	0.938	1.313	1.069	1.373
FeO*	7.74	8.14	6.63	6.78	7.68	6.74	7.06	8.50	7.29	8.44
MnO	0.116	0.115	0.143	0.108	0.144	0.129	0.112	0.154	0.175	0.122
CaO	8.68	8.70	9.27	9.34	8.85	7.72	7.33	8.65	8.94	8.92
MgO	5.05	5.06	5.16	4.75	6.19	4.04	4.79	5.19	5.39	4.20
K_2O	0.75	0.75	0.73	0.48	0.72	1.29	1.52	1.17	0.58	0.69
Na_2O	3.51	3.51	3.48	3.51	3.67	4.11	3.67	3.30	3.13	3.59
P_2O_5	0.382	0.385	0.243	0.277	0.272	0.507	0.269	0.452	0.428	0.473
Total	97.45	97.99	98.13	98.13	98.53	99.08	98.05	98.32	97.02	97.87
Trace Elements, parts per million										
Ni	102	100	133	169	142	46	90	86	50	66
Cr	141	141	175	193	143	73	115	128	73	122
Sc	28	30	28	30	25	25	23	27	27	29
V	155	146	206	186	197	181	176	232	211	246
Ba	396	399	272	307	429	674	456	403	333	452
Rb	8	9	9	5	6	11	23	13	6	5
Sr	706	710	608	625	697	650	765	640	720	659
Zr	95	96	107	106	93	165	141	129	108	134
Y	18	16	20	20	19	25	24	23	18	30
Nb	3.2	3.3	4.6	5.3	4.2	9.3	5.5	8.1	6.1	8.6
Ga	23	21	20	21	18	21	20	19	18	20
Cu	69	73	77	76	86	68	88	74	70	73
Zn	78	82	68	74	94	87	75	83	80	88
Pb	5	5	3	3	4	6	7	6	2	5
La	26	0	14	1	1	15	8	23	31	0
Ce	37	38	22	21	28	33	40	46	55	35
Th	0	2	1	1	0	3	2	4	1	1

+ Single small basaltic ash and cinder layer within unit Tms but composed of rock unit Tba; too small to map separately from Tms diatomaceous mudstone and lithic sandstone.

Table 1.3. — continued

Map No.	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**
Map Unit	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**	**Tba**
Sample No.	**K-320C**	**K-328**	**K-329**	**K-346**	**K-355**	**K-357M**	**K-359**	**K-381**	**K-382**	**K-383**
Analytical Date	5-Jul-98	5-Jul-98	5-Jul-98	5-Jul-98	5-Jul-98	5-Jul-98	5-Jul-98	5-Jul-98	6-Jul-98	6-Jul-98
West Longitude	121.75422	121.76900	121.77203	121.84400	121.85551	121.77353	121.73631	121.78606	121.78826	121.78929
North Latitude	42.26131	42.26459	42.26477	42.17824	42.18095	42.14950	42.17783	42.22515	42.22232	42.22298
Oxides, weight percent										
SiO_2	55.95	48.46	53.22	52.57	53.50	52.89	54.04	55.77	55.62	55.88
Al_2O_3	17.80	17.58	17.76	17.51	18.37	19.00	18.41	19.12	18.11	18.57
TiO_2	0.977	1.043	1.121	0.769	1.093	1.068	1.058	1.209	1.098	1.131
FeO*	6.61	8.63	7.50	7.16	7.58	6.55	6.94	5.89	6.85	6.30
MnO	0.129	0.167	0.133	0.145	0.151	0.119	0.115	0.114	0.137	0.116
CaO	7.72	11.40	8.60	9.93	8.14	9.91	7.79	7.86	7.73	7.96
MgO	3.79	8.79	4.48	6.33	4.17	4.40	3.69	3.32	3.61	3.10
K_2O	1.61	0.14	1.23	0.61	1.09	0.67	1.60	1.01	1.39	1.19
Na_2O	3.86	2.78	3.65	3.14	3.99	3.56	4.20	4.00	3.99	3.94
P_2O_5	0.417	0.121	0.359	0.224	0.671	0.269	0.515	0.439	0.525	0.522
Total	98.86	99.11	98.05	98.39	98.75	98.44	98.36	98.73	99.06	98.71
Trace Elements, parts per million										
Ni	33	149	30	90	56	73	29	28	34	23
Cr	60	205	77	177	61	103	48	72	61	63
Sc	25	37	27	28	22	29	23	26	23	22
V	185	234	198	198	164	227	188	168	184	181
Ba	765	92	418	330	671	305	656	847	751	689
Rb	20	3	14	9	9	8	20	12	20	19
Sr	661	264	733	742	795	718	887	706	652	673
Zr	169	57	130	89	185	96	160	174	177	186
Y	22	23	21	13	25	16	22	31	24	27
Nb	7.7	2.3	6.6	3.0	10.0	5.3	8.6	9.7	8.8	10.9
Ga	21	16	19	21	20	21	21	20	22	22
Cu	78	99	68	71	38	83	65	46	54	62
Zn	81	64	76	71	97	77	84	78	94	88
Pb	9	3	6	2	4	3	9	9	9	9
La	23	0	7	2	29	22	31	27	41	38
Ce	54	14	46	31	57	24	51	50	52	57
Th	2	1	2	2	2	1	0	2	3	2

Map No.	**48**	**49**	**50**	**51**	**51**	**52**	**53**	**54**	**55**	**56**
Map Unit	**Tba**	**Tba**	**Tba**	**Tbtv**	**Tbtv**	**Tcb**	**Thb**	**Thb**	**Thb**	**Thb**
Sample No.	**K-384**	**K-385**	**K-386**	**K-321**	**K-321R**	**K-29**	**K-74**	**K-76**	**K-80**	**K-88**
Analytical Date	6-Jul-98	6-Jul-98	6-Jul-98	5-Jul-98	6-Jul-98	2-Jul-98	2-Jul-98	2-Jul-98	2-Jul-98	2-Jul-98
West Longitude	121.79009	121.78469	121.78617	121.76083	121.76083	121.81164	121.70767	121.70862	121.70623	121.70944
North Latitude	42.22340	42.22204	42.22068	42.25086	42.25086	42.26647	43.24349	42.24363	42.23984	42.23604
Oxides, weight percent										
SiO_2	55.73	55.88	55.37	45.54	45.53	53.94	51.62	51.53	51.27	50.51
Al_2O_3	17.87	18.55	18.00	15.21	15.22	18.31	17.81	17.32	16.95	16.66
TiO_2	1.104	1.141	1.107	1.184	1.187	0.973	1.503	1.591	1.551	1.597
FeO*	6.98	6.34	7.23	9.12	9.14	7.42	9.46	9.40	9.41	9.72
MnO	0.146	0.120	0.128	0.153	0.155	0.133	0.176	0.176	0.175	0.178
CaO	7.71	7.77	7.59	7.82	7.83	8.56	9.26	9.19	9.24	9.20
MgO	3.45	3.28	3.60	8.67	8.55	4.93	5.03	5.50	5.96	6.99
K_2O	1.36	1.24	1.30	0.47	0.47	0.92	0.80	0.74	0.76	0.71
Na_2O	4.05	4.10	3.96	0.63	0.66	3.85	3.60	3.44	3.53	3.36
P_2O_5	0.505	0.511	0.484	0.296	0.295	0.281	0.385	0.396	0.387	0.389
Total	98.91	98.93	98.77	89.09	89.04	99.32	99.64	99.28	99.23	99.31
Trace Elements, parts per million										
Ni	28	25	45	170	170	47	41	57	63	97
Cr	64	62	60	324	319	70	78	104	127	158
Sc	25	22	25	28	28	29	30	35	31	29
V	183	179	176	211	207	196	246	261	254	242
Ba	723	753	703	155	171	397	351	302	300	307
Rb	21	17	19	6	4	12	7	9	10	9
Sr	648	669	651	321	323	707	536	456	432	450
Zr	180	183	182	87	86	114	124	127	127	130
Y	24	26	25	24	26	18	29	29	28	28
Nb	11.0	10.6	10.5	6.9	6.0	4.8	6.3	7.7	7.5	8.5
Ga	22	19	22	16	19	21	19	20	19	21
Cu	50	50	59	78	73	74	56	64	46	61
Zn	84	87	82	80	83	78	91	88	88	93
Pb	3	9	8	2	0	5	3	3	2	2
La	27	22	15	9	15	26	15	16	12	4
Ce	58	61	64	19	40	24	27	29	41	33
Th	0	3	1	0	0	3	1	3	0	3

Table 1.3. — continued

Map No.	**57**	**57**	**58**	**59**
Map Unit	**Thb**	**Thb**	**Thb**	**Tpt**
Sample No.	**K-96**	**K-96A**	**K-111**	**K-361**
Analytical Date	3-Jul-98	3-Jul-98	3-Jul-98	5-Jul-98
West Longitude	121.71113	121.71113	121.70719	121.75780
North Latitude	42.24111	42.24111	42.23452	42.22807
Oxides, weight percent				
SiO_2	49.67	51.18	50.28	52.20
Al_2O_3	16.38	17.23	16.64	23.85
TiO_2	1.645	1.481	1.608	1.368
FeO*	9.76	9.44	9.91	3.78
MnO	0.179	0.166	0.177	0.039
CaO	9.25	9.50	9.17	12.05
MgO	7.82	5.84	6.92	1.22
K_2O	0.68	0.56	0.78	0.12
Na_2O	3.14	3.51	3.27	3.25
P_2O_5	0.422	0.363	0.385	0.443
Total	98.95	99.27	99.14	98.32
Trace Elements, parts per million				
Ni	128	72	92	43
Cr	192	133	156	218
Sc	32	33	26	42
V	269	254	255	206
Ba	336	295	312	162
Rb	8	3	9	4
Sr	468	446	453	379
Zr	135	124	134	72
Y	28	27	29	27
Nb	8.9	8.1	9.0	3.2
Ga	17	20	18	20
Cu	62	63	61	94
Zn	94	85	92	48
Pb	4	3	4	0
La	36	1	8	5
Ce	58	39	38	14
Th	3	1	1	0

Table 1.4. Diatom Analyses (by J. Platt Bradbury, U.S. Geological Survey)

Map No.	Sample No.	Unit	West Longitude	North Latitude	Geographic Location	Lithology	Estimated Age	Depositional Environment	Species
60	K-424	QTfs	121.85932	42.15817	Keno Hwy in unit QTfs	Cream colored tuffaceous diatomaceous mudstone almost barren of diatoms	indeterminate	indeterminate	A few corroded fragments of pennate species but are too small to identify.
61	K-429A	QTfs	121.72615	42.22455	Foothills Drive: NW end at first big cut at bottom of section of QTfs	Cream colored tuffaceous diatomaceous mudstone with poorly preserved, uncommon diatoms	Diatoms resemble modern forms	Slightly acidic plant-rich marsh of local extent	*Fragilaria virescens* is most common and chrysophyte cysts are abundant.
62	K-430C	QTfs	121.71723	42.22660	Foothills Drive: 0.5 km N. of Homedale Rd. at top of section of QTfs	Cream colored tuffaceous mudstone with rare diatoms, poorly preserved	< 1 Ma?	Shallow, alkaline slightly saline pond or marsh	*Fragilaria* species, *Anomoeoneis costata*, *Campylodiscus clypeus*, *Epithemia*. Nothing age diagnostic. In Tule Lake core this assemblage is sporadically present after 1 Ma, but that may not prove anything about sample age — the types live today.
-*	K-387	QTfs	121.86046	42.66692	Hwy 97 cut N. of Collier Park at 4415 ft elevation ~145 ft above base of section	White 1 cm air-fall ash layer correlative to several tephras at 48-m depth in Wocus Marsh		not given	*Stephanodiscus rhombus* suggests correlation to Tule Lake core ~1.8–2 Ma. This diatom is present in Lake Britton-Pit River deposits in N. Calif. but these are not dated. An ash in the Lake Britton seq. is close to Tule Lake ash at 226 m with tephra age of 2.3 Ma.
-*	K-387A	QTfs	121.86046	42.66692	Hwy 97 cut N. of Collier Park at 4415 ft elevation ~145 ft above base of section	White 1 cm air-fall ash layer correlative to several tephras at 48 m depth in Wocus Marsh		not given	*Stephanodiscus rhombus* suggests correlation to Tule Lake core ~1.8–2 Ma. This diatom is present in Lake Britton-Pit River deposits in N. Calif. but these are not dated. An ash in the Lake Britton sequence is close to Tule Lake ash at 226 m with tephra age of 2.3 Ma.
-*	K-432	QTfs	121.8705	42.66516	Hwy 97 cut N. of Collier Park at base of section	Lignite with a few diatoms	indeterminate	peaty marsh	A few scrappy diatoms.
63	K-399	Ths	121.73807	42.25850	NW scissor fault ridge: new house cut SE of K-398	Cream colored diatomaceous tuffaceous mudstone	indeterminate	not given	Large, wide-fascicled *Stephanodiscus* sp.— like *St. Carconensis*, but perhaps not the same thing; probably not the same assemblage as the Tule Lake core; similar to samples at North Ridge estates on Old Fort Rd. and the landfill.

Table 1.4. — continued

Map No.	Sample No.	Unit	West Longitude	North Latitude	Geographic Location	Lithology	Estimated Age	Depositional Environment	Species
64	K-411C	Ths	121.72581	42.26219	Hogback Rd: at 5330 ft on side road at sharp turn; N. of turn	Cream colored diatomaceous tuffaceous mudstone	indeterminate	not given	Large, wide-fascicled *Stephanodiscus* sp.-- like *St. Carconensis*, but perhaps not the same thing; probably not the same assemblage as the Tule Lake core; similar to samples at North Ridge estates on Old Fort Rd and Klamath Falls landfill.
65	K-336A	Tm	121.85095	42.19178	Balsam Rd.: SE quarry	Cream colored diatomaceous mudstone	> 2–3 Ma *Stephanodiscus* is not in the Tule Lake core (bottom at 3 Ma), this may argue for an age >3 Ma.	not given	Large, flat *Stephanodiscus* sp. similar to *S. subtransylvanicus*, *Cyclotella servant-vildary* (r), *Aulacoseira* spp. C. *servant-vildary* is rare & thus possibly reworked but suggesting >2 Ma (from Tule Lake strata where it is found in low numbers before 2 Ma).
66	K-395	Tm	121.75057	42.23548	Klamath Landfill at crop in middle	Cream colored diatomaceous tuffaceous mudstone	indeterminate	not given	Large, wide-fascicled *Stephanodiscus* sp.— like *St. Carconensis*, but perhaps not the same thing; probably not the same assemblage as the Tule Lake core; similar to samples at North Ridge estates on Old Fort Rd. and the landfill.
67	K-427A	Tm	121.84626	42.20629	Long Lake Rd. at gate to private property	Cream colored diatomaceous tuffaceous mudstone	> 2.8–3 Ma (could be Pliocene)	not given	*Cyclotella elgeri* dominates. It is common in Sheepy Ridge and Chalk Bank Landing in Lower Klamath Lake. Abundant near base of Tule Lake core and should be 2.8–3 Ma or older; also in Glenns Ferry Formation of Snake River Plain that is Pliocene in part.
68	K-428	Tm	121.74511	42.22256	Foothills Dr. at Detention Center below unit Tpt	Cream colored diatomaceous tuffaceous mudstone	> 3 Ma	not given	*Aulacoseira paucistriata* (d), *Stephanodiscus* sp. (kinked or sinuous costae) (c), *Cyclotella* sp. aff. C. *servant-vildary* (r). *Au. paucistriata* present in low numbers throughout; probably because it is easily reworked. Similar to samples from Poverty Flat, NE of Klamath Falls.
69	K-431	Tm	121.80499	42.26095	Hwy 97 cut S. of weigh station near Pelican City	White diatomite	indeterminate	not given	*Aulacoseira paucistriata* (d), *Stephanodiscus* sp. (kinked or sinuous costae) similar to assemblage of K-428.

2.0 EXPLANATION OF MAP UNITS

2.1 FILL

Mef **Engineered fill (Modern)**—Well graded (poorly sorted) stiff to very stiff mixed clay, sand, silt to small pebble size material; 2-3 m thick; has been mechanically compacted to form a semi-indurated deposit suitable for building foundations. Mapped in only one place in north Klamath Falls, but probably present in other areas beneath structures.

Mf **Fill (Modern)**—Mixed clay to gravel-sized material with unknown degree of compaction, but probably not highly compacted. Includes landfill on north side of Klamath Falls where it consists of refuse mixed with disaggregated tuffaceous mudstone. Generally well graded (poorly sorted) and 2–6 m thick. Mapped in extensive areas around the margins of Klamath Lake and a few areas adjacent to major roads. No attempt was made to map every fill area; only large areas of fill are shown.

2.2 SEDIMENTARY UNITS

Qc **Colluvium (Holocene)**—Poorly consolidated unit mantling bedrock slopes undergoing active mass movement by creep; includes talus deposits. Mostly cohesionless poorly sorted sandy, silty gravels. Generally 1–3 m thick.

Qac **Alluvium and colluvium undifferentiated (Holocene)**—Poorly consolidated unit mantling bedrock slopes undergoing active mass movement by creep or intermittent stream runoff. Poorly to moderately sorted cohesionless sands and gravels. Generally 1–3 m thick.

Qal **Coarse-grained alluvium (Quaternary)**—Poorly consolidated coarse- to medium-grained sand and gravel fringing and underlying rivers. Forms low slopes except where undercut by recent river erosion. Mostly cohesionless fluvial sands and gravels. Thickness generally 1–3 m but locally up to 30 m in the Link River area where boulder-size gravel is common; chiefly Holocene in age but lower part may be Pleistocene at Link River. Restricted to coarse-grained alluvium for the purposes of this map in order to distinguish unit Qal from fine-grained deposits of unit Qs that contain lacustrine and fluvial deposits of fine-grained sand and silt with coherent engineering properties, regardless of sedimentary facies. Probably underlies at shallow depth silt and sand of unit Qs in the Lake Ewauna-Klamath River area. Unit Qs there was probably deposited after installation of downstream dams near Keno.

Qs **Lacustrine and alluvial clay, silt, fine-grained sand, and peat (Quaternary)**—Unconsolidated unit that forms flat slopes except at recently eroded, steeply sloping river banks. Thickness probably more than 50 m at Lower Klamath Lake (Sherrod and Pickthorn, 1992), Wocus Marsh (Adam and others, 1994), and Round Lake (Adam and others, 1995), 6 m in the Klamath River area, and <3 m elsewhere. Varies from fine-grained sandy or silty units with low plasticity at the Klamath River and Altamont area to highly plastic organic clay at Upper Klamath Lake. Includes interbedded fine-grained fluvial sand and silt in and near the Klamath River. Fine-grained fluvial facies mapped separately from coarser sand and gravel of unit Qal in order to emphasize contrasting engineering properties. No data was available to constrain location of contact between fine-grained and gravelly facies at Link River where it runs into Lake Ewauna, so contact is inferred. Chiefly Holocene in age but lower part at deep sedimentary basins is Pleistocene; examples are Round Lake (Adam and others, 1995), Wocus Marsh (Adam and others, 1994), and probably Upper Klamath Lake and Lower Klamath Lake. A core at Wocus Marsh had sediment with ages of 31,720 ± 860 radiocarbon years at 11.21–11.25 m depth, 27,550 ± 780 radiocarbon years at 14.47–14.52 m depth, >48,000–49,000 radiocarbon years at 20.42–21.02 m depth, 400–470 ka at 26.58–28.11 m depth, and < 1.45 Ma at 49.38–49.42 m depth (Adam and others, 1994). At Round Lake a core had ages of 160–180 ka at 6.78–6.85 m depth, 1.36 Ma at 49.51–49.55 m, and <1.45 Ma at 49.94–49.95 m (Adam and others, 1995). Age <1.45 Ma to Holocene.

Qls **Landslide deposits (Quaternary)**—Unconsolidated to slightly consolidated landslide debris (poorly sorted mixtures of boulders, cobbles, sand, silt, and clay), and local blocks of bedrock. Forms low to moderate slopes. Highly variable thickness and engineering characteristics; chiefly Holocene in age.

Qoc **Older colluvium and alluvium (Pleistocene)**—Moderately indurated colluvium and alluvium. Forms low to moderate slopes with little evidence of extensive mass movements. Generally a stiff soil with fair to poor sorting. Sorting and induration distinguish the unit from unit QTfs, which is much better sorted and better indurated. Moderate induration distinguishes the unit from younger colluvium and alluvium. Generally 1–5 m thick. Age uncertain; inferred to be Pleistocene from degree of induration; could be similar in age to unit QTfs (i.e., a colluvial facies of unit QTfs), but lack of such a facies at a steep, well-exposed depositional contact of QTfs on the flank of Hogback Mountain casts doubt on the hypothesis.

QTfs **Sedimentary rocks of Foothills Drive (lower Quaternary or upper Pliocene)**—Upper part consists of poorly indurated pebble to cobble conglomerate underlain by and interbedded with poorly indurated, well-sorted sandstone; lower part consists of poorly indurated well-sorted, fine-grained sandstone interbedded and overlying lesser amounts of tuffaceous diatomaceous sandy and silty mudstone. In the Foothills Drive area the lower part is well exposed and consists mostly of very well sorted, poorly indurated sandstone interbedded with tuffaceous diatomaceous mudstone and minor silty sandstone; lower part may, in part, be lacustrine shallow lake and beach (strandline) deposits. Unit appears conformable on parts of unit Tm in the Altamont area, where unit Tm reaches a thickness of up to 400 m. Thickness is up to 150 m but generally no more than 50 m in most areas due to erosion. Lies in steep depositional contact with major fault blocks below 1,430 m (4,700 feet) elevation. At these steep contacts in the lower part of the unit fine-grained sandstone has only rare clasts larger than sand size, generally as a few subangular cobbles from underlying rocks; coarse-grained facies in upper part of unit have abundant lithic clasts, including many rounded cobbles, of underlying older rocks. Generally lacks significant chemical cement. Sandstone facies may be distinguished from unit Ts by much better sorting, rounding of clasts, poor induration and more mature composition (quartz clasts in some samples, dominance of hypersthene in mafic minerals in many samples, and less clay matrix). Sandstone closely resembles unit Ths but has more common occurrence of well-rounded amber volcanic glass clasts and lacks significant chemical cement. Unit Ths is locally uplifted on fault blocks to high elevations, whereas unit QTfs is not exposed above 1,430 m (4,700 feet) elevation; below that elevation unit QTfs lies unconformably on these same fault blocks. Tuffaceous mudstone is similar to unit Tm but is generally less well indurated, better bedded, and contains more silt and fine sand. Locally deformed by normal and oblique slip faulting and contains internal angular unconformities in upper part indicative of ongoing tectonic deformation during deposition. Younger than unit QTwb with radiometric age of 1.8 Ma (Hladky and Mertzman, 2000); older than unit Qs. Lower part of unit QTfs is lithologically similar and possibly correlative to sedimentary rocks exposed in outcrops along Highway 97 at Collier Grade ~43 km north of the map area (Figure 1.1), but has less olivine than those rocks. Preliminary correlation of a tephra layer in the uppermost part of the Collier grade sequence suggests an age >0.614 Ma and probably >1.45 Ma (unpublished interpretation and data of Andre M. Sarna-Wojcicki, 1998); diatoms at Collier grade suggest an age of 1.8–2 Ma. (Table 1.4; unpublished interpretation and data of J. Platt Bradbury). The Collier grade rocks are capped by basaltic andesite with a radiometric age of 1.14 ± 0.10 Ma (age reported here for unit Qsh1 of Wiley [2004]). Unit QTfs lies at base of fault blocks capped by unit QTwb with age of ~1.8 Ma, so younger than age inferred for Collier Grade tephra and diatoms, but these data are preliminary and not highly quantitative. If the 1.14 Ma age of the capping flow at Collier Grade is closer to the age of the underlying sequence, then the lower part of unit QTfs could be contemporaneous with Collier Grade sedimentary rocks. Late Pliocene fossils have been reported from the Wilson quarry at the north end of Stukel Mountain (Peterson and McIntyre, 1970), but this quarry contains both unit QTfs and Tm, so it is difficult to evaluate the significance of the information; nevertheless, locality and host rock descriptions by a local resident familiar with the fossil find match unit QTfs exposed at Stukel Mountain. Age is thus late Pliocene to Pleistocene, but less than ~1.8 Ma; lower part may be older than 1.14 Ma, if correlative to Collier Grade sedimentary rocks, but this is a highly speculative hypothesis.

2.3 VOLCANIC AND INTRUSIVE UNTS

QTwb **Basalt of Wocus Marsh (lower Quaternary or upper Pliocene)**—Olivine basalt with fresh appearance and slight development of diktytaxitic texture in most flows, although a few basal flows are compact. One flow has elevated (1.6 percent) TiO_2 similar to unit Thb; all others sampled have TiO_2 near 1 percent. Appears confined to the central west part of the area where it is 24–30 m thick. Unit pinches out to the southeast and northwest against highlands of the underlying Tertiary units. Extends southwestward out of the map area toward possible High Cascade source areas. Has irregular blocky fracture on a 1-2 m scale and forms cliffs. Age is uncertain. Radiometric age of 0.94 ± 0.64 Ma and 0.97 ± 0.64 Ma on uppermost flow in Lakeshore Drive area has potassium too low to yield an accurate age. Hladky and Mertzman (2000) obtained an age of 1.8 ± 0.39 Ma in the adjacent Keno quadrangle where they found the unit overlain by rocks with a 1.4 Ma age. Older than unit QTfs, which laps onto fault blocks capped by unit QTwb. Most probable age is ~1.8 Ma.

Tcba **Basaltic andesite of Cove Point (Pliocene)**—Glomerocrystic, slightly diktytaxitic olivine-augite basaltic andesite. Cliff forming unit with blocky fracture. About 90 m thick at Cove Point but complexly interbedded and invasive into unit Tm there. Minerologically, texturally, and chronologically similar to unit Thb but does not have the high TiO_2 and FeO* characteristic of unit Thb; chemical composition similar to unit Tba. Radiometric age of 2.41 ± 0.13 Ma.

Thb **Basalt of Hogback Mountain (Pliocene)**—Glomerocrystic high-titanium olivine basalt capping Hogback Mountain. High titanium tholeiitic composition with TiO_2 >1.4 pecent and FeO* >9.4 percent is distinctive; most lava flows have abundant glomerocryts of fresh olivine and plagioclase; basal lava flow locally has smaller glomerocrysts than overlying flows, has some clinopyroxene phenocrysts, and is vitrophyric where interbedded with sedimentary rock of unit Ths or hyaloclastic units. Approximately 330 m thick at Hogback Mountain, where unit unconformably overlies older Tertiary units; the contact at Hogback Mountain dips ~5°-6° NE, whereas underlying sedimentary units dip ~15°–22° NE. Generally overlies and is locally interbedded with palagonitic sandstone and unit Ths. Characterized by irregular blocky fracture on a scale of 1-2 m, which gives rise to distinctive talus forming narrow dark bands (basalt streamers). These basalt streamers are uncommon in older rocks in the area. Forms cliffs. Uppermost flow has a radiometric age of 2.67 ± 0.21 Ma. Roughly contemporaneous to basaltic rocks with similar texture dated at 2.80 ± 0.06 Ma at an outcrop on the north end of Naylox Mountain north of the map area (sample S5-1, Pickthorn and Sherrod, 1990). Overlies unit Tba with a radiometric age of 4.01 ± 0.22 Ma. Older than unit QTfs, which lies unconformably around the base of Hogback Mountain.

Tba2 **Basaltic andesite (Pleistocene and upper Pliocene)**—Relatively unaltered, glomerocrystic basaltic andesite with minor basalt and andesite. Locally includes minor thin or poorly exposed pyroclastic and sedimentary interbeds not mapped separately. Individual lava flows vary in thickness from approximately 1 to 20 m; total thickness is at least 240 m in the Plum Hills. Unit is cliff forming; blocky fracture is typical, platy fracture is well developed locally. Commonly crops out as rim-rock exposures; caps all major fault blocks, although is locally overlain by erosional remnants of pyroclastic or sedimentary rock on dip slopes. Typical lava is gray with conspicuous plagioclase and olivine phenocrysts; dark green clinopyroxene phenocrysts are smaller and less conspicuous. Phenocrysts commonly form glomerocrysts, some as large as 5 mm. Plagioclase is invariably subhedral and seriate; larger grains are zoned and commonly have abundant groundmass inclusions. Olivine is typically glassy green with tiny opaque inclusions but may be altered to glassy brown iddingsite. Some flows have small orthopyroxene phenocrysts. Flows are variably vesicular, locally grading to scoriaceous clinker, especially at flow margins; a few are slightly diktytaxitic. Most have a glassy groundmass with mixed intersertal/intergranular textures; trachytic and subophitic textures are rare. All samples of unit Tba2 analyzed from the map area can be classified as calc-alkaline using the criteria of Irvine and Baragar (1971). One sample, a basalt collected from the unit north of Whiteline Reservoir, fits the criteria of Hart and others (1984) for classification as a low potassium-low titanium tholeiite, although it plots as a calc-alkaline basalt otherwise. No sample from the unit can be classified as high alumina olivine tholeiite, which is common elsewhere in the northern Basin and Range (Malin and Hart, 1991). Differentiated from unit Tba by fresh appearance, especially of the olivine phenocrysts, common occurrence of conspicuous glomerocrysts, and the general lack of interbedded sedimentary rocks that are common in unit Tba. Age based on stratigraphic correlation with ~2.4 Ma basaltic andesite of Cove Point; offset by faults that pass through ~1.9 Ma and 0.86 Ma basaltic andesite vent deposits at Bald Hill and Algoma but offset more by these faults than are the ~1.9 to 0.86 Ma rocks.

Ths **Sedimentary rocks of Hogback Mountain (Pliocene)**—Poorly indurated tuffaceous mudstone and poorly sorted to well sorted volcanic lithic sandstone. May be, in part, lacustrine shallow water to beach (strandline) deposit. Sandstone is generally cemented by zeolitic? minerals or mineraloids but is still highly porous and permeable. Up to 24 m thick at northwest end of Hogback Mountain. May be distinguished from unit Ts by poorer induration and more mature composition (lack of olivine clasts, presence of quartz clasts in some samples, dominance of hypersthene in mafic minerals, less clay matrix, and better rounding of clasts). Difficult to distinguish from lower part of unit QTfs, which has similar fine-grained mudstone and sandstone. Distinguished from lower part of unit QTfs by rarity or absence of well-rounded, unaltered amber volcanic glass clasts, the presence of significant chemical cement in most samples, and the relationship as an interbed between units Tba and Thb, locally above 1,470 m (4,820 ft) elevation in the map area. Older than unit Thb with a radiometric age of 2.67 ± 0.21 Ma. Overlies unit Tba which has a radiometric age of 4.01 ± 0.22 Ma in lower part. Most probable age is close to 2.7 Ma; age is highly uncertain, so older age equivalent to unit Tm is possible.

Tpt **Tuff of Ponderosa Junior High School (upper Pliocene or upper Miocene)**—Very poorly sorted, nonwelded lapilli tuff with distinctive clasts of hydrated nearly aphyric basaltic andesite glass and prismatically jointed lapilli of fresh vitrophyric lithic fragments in a matrix of mostly cream colored diatomaceous mudstone with lesser amounts of Tertiary basaltic andesite clasts up to a decimeter across. Probably a subaqueous hyaloclastic flow deposit. Up to 50 m thick. Irregular dikes of the unit complexly intrude or are invasive into underlying Tertiary mudstone at the Ponderosa Junior High School, suggesting that unit Tm may not have been well consolidated at the time of eruption. Overlies unit Tm on a highly irregular surface of erosional unconformity possibly eroded in part by the flow emplacement process; upper contact is obscure owing to erosion and colluvial cover, so could be interbedded in unit Tm. Generally forms steep slopes with rare, small-scale landslides. Appears to be stratigraphically below unit QTfs, so pre-Pleistocene. Possibly similar in age to the thick sequence of unit Tm deposited in the Lake Ewauna-Altamont area, so possibly younger than unit Thb (see discussion of the age of the basin in the Altamont area below). Most probable age is upper Pliocene but less than ~2.7 Ma; age is highly uncertain so older age equivalent to unit Tm is possible.

Tt **Tuff, lapilli tuff, and tuffaceous breccia (Pliocene)**—Massive to well-bedded pyroclastic deposits. Predominantly well-indurated ash and lapilli tuff, with lesser amounts of volcanic breccia, formed where unit Tba was erupted through surface water or water saturated sediments. Includes minor lava, autobreccia, mudstone, and epiclastic tuffaceous sandstone and conglomerate (similar or equivalent to units Tm, Ts, and Tg, respectively) not mapped separately. Commonly exposed in fault escarpments throughout the area; excellent exposures crop out in the Highway 97 road cut south of Rattlesnake Point and east of Shady Pine. Coarser-grained lapilli tuff and brecciaare cliff-forming; ash and finer-grained lapilli tuff typically crop out in low relief or hollowed-out zones with little or no vegetation. Tuff and breccia are composed of black, scoriaceous clasts in a tan or yellow weathering palagonitic matrix. Bedding, defined by the ash-to-lapilli ratio, has normal and reverse grading and gradational contacts. Initial dips locally up to 30° suggest some deposits were emplaced as tuff cones. A sample collected from NE¼ sec. 21, T. 38 E., R. 9 S. is basalt with major oxides totaling 89 percent, indicating ~11 percent volatile components, probably from hydration (Table 1.3; Map no. 51, sample K-321). Unit Tt locally includes beds of well-sorted, poorly indurated, olive-gray or light-brown ash and black, scoriaceous lapilli. These beds are planar, 0.5–4 m thick, with wavy, locally cross-bedded internal stratification 2-3 cm thick that drapes underlying high spots. Distinguished from tuffaceous beds in underlying units Tms, Ts, and Tg by lack of multi-lithic clasts and fluvial structures. Thickness is about 110 m, increasing to 175 m five kilometers north in the Plum Hills, to greater than 245 m east of Shady Pine (3 km north of map); and to 425 m at Naylox Mountain (5 km north).

Tbv **Basalt or basaltic andesite vent complex (Pliocene and upper Miocene)**—Autobreccia, hyaloclastic breccia, palagonitic sandstone, cinders, and interbedded thin flows, generally with high initial dips. Occurs as highly dissected tuff cones and composite cones of unit Tba in the Stewart Lennox area, where it is up to 100 m thick at a possible vent area. Forms moderate to steep slopes with little tendency to form landslides. Probably similar in age to unit Tba.

Tbtv **Mafic diatreme vent complex (Pliocene and upper Miocene)**—Olivine-bearing (mafic) nonwelded lithic crystal, vitric lapilli tuff in diatreme dikes of tachylite sandstone cutting unit Tm at such close spacing (centimeters) that the dikes appear to be bedded. Probable hyaloclastic vent complex. Forms moderate to steep slopes with little tendency to form landslides. Unknown age but cuts uppermost unit Tm; is below an outcrop of unit tentatively correlated to unit QTfs; probably similar in age to adjacent unit Tpt, which was also locally vented and cuts uppermost unit Tm.

Ta **Andesite (Pliocene and upper Miocene)**—Highly phyric two-pyroxene andesite characterized by large (up to 1 cm) plagioclase phenocrysts and smaller orthopyroxene and clinopyroxene and, in a few cases, olivine reacting to other minerals; phenocrysts are set in a very fine-grained groundmass generally showing signs of devitrification. One thin flow of hornblende andesite occurs in the Plum Ridge area but is too small to depict at the map scale. Generally interbedded in lowermost part or at base of unit Tba and in unit Tm. Up to 115 m thick near Stewart Lennox, where distinctive flow can be correlated across some major faults. Thick platy to blocky joints are common. Forms cliffs. Similar in age to units Tba and Tla. May be roughly contemporaneous with the Klamath Gorge Two Pyroxene Andesite dated at 4.4 Ma (Hall, 1996) and the lower part of unit Tba with ages of 4–4.5 Ma.

Tla **Andesite of Link River (Pliocene or upper Miocene)**—Highly phyric two-pyroxene andesite characterized by 0.2–6 mm euhedral to subhedral sieved to clear plagioclase (8 percent) with 0.2–1 mm orthopyroxene (0.5 percent) and clinopyroxene (1 percent) set in a very fine grained, nearly opaque groundmass of the same minerals with iron-titanium oxides; contains very minor (0.1 percent) phenocrystic olivine altered to smectite. Occurs between olivine basaltic andesite of unit Tba and diatomaceous mudstone of Unit Tm in the Link River and Moore Park area, where it is 66–88 m thick. Unit is a blocky to platy jointed cliff former. Radiometric age is 3.43 ± 0.06 Ma but $^{40}Ar/^{39}Ar$ spectra on this whole rock sample are somewhat irregular, possibly indicating loss of radiogenic argon from alteration of the devitrified groundmass. Alteration of olivine to smectite suggests that unit has undergone significant alteration, which may have led to argon loss. Overlain by basaltic andesite with age of 4.47 ± 0.28 Ma (sample S5-12, Pickthorn and Sherrod, 1990), so probably somewhat older than about 4.5 Ma.

Tba **Tertiary basaltic andesite (Pliocene and upper Miocene)**—Compact olivine- and plagioclase-phyric basaltic andesite with minor andesite, olivine basalt, and locally thick interbeds of palagonitic sandstone and breccia. Holocrystalline units generally have seriate texture (complete gradation from phenocrystic to groundmass sizes); phenocrysts are generally plagioclase and olivine ± clinopyroxene. Most samples have some glomerocrysts. Olivine is generally altered to iddingsite or green minerals. Spherical blue-green amygdules of smectite occur in many outcrops. Commonly interbedded with units Ta, Tm, Tms, Ts, and Tg; 117 m thick south of Moore Park; 213 m thick at Hogback Mountain; up to 67 m thick in and around the Plum Hills; 450 m of dark lava intercepted in geothermal wells near OIT may be unit Tba, but there are no samples to prove this. Platy fracture in basaltic andesite units is a distinguishing characteristic from younger basaltic units in the area; basalt in the unit has blocky to columnar fracture. Forms cliffs. Radiometric age of 4.47 ± 0.28 Ma from a flow interbedded in unit Ts at prominent outcrop on Highway 97 near Lake Ewauna (sample S5-12, Pickthorn and Sherrod, 1990); age of 4.01 ± 0.22 Ma from a flow near the base of a thick section at Hogback Mountain, where it overlies units Ts and Tm; age of 4.08 ± 0.12 Ma from a flow near the top of the section at Indian Springs Ridge, 5.8 km east of Klamath Falls quadrangle (Hladky and Mertzman, 2000). The sequence containing the flow dated at 4.47 Ma appears to overlie unit Tla with an age of 3.43 ± 0.06 Ma, so accuracy of unit Tla age is doubtful. Unit Tba underlying thick sections of unit Tm at Lake Ewauna-

Altamont is not dated. Regionally the oldest age from the unit is 6.88 Ma (Sherrod and Pickthorn, 1992). Overlain by unit Thb with a radiometric age of about 2.7–2.8 Ma. Most of the unit is 4–7 Ma in age.

Tbas **Mixed volcanic and sedimentary rocks (Pliocene or upper Miocene)**—Subequal abundance of volcanic flows (unit Tba) and lacustrine and fluvial sedimentary rocks (lower unit Tms) interbedded at a scale too small to map separately. Crops out in the fault scarp east of the OIT campus and Wocus. Lava flows are typically water affected, with the groundmass variably altered to palagonite, locally to the point of disintegration. A red "baked" zone commonly marks contacts between lava and the underlying sediments. Outcrop patterns, palagonitic alteration, and abundance of interbedded conglomerate suggest that the lava flows were deposited within existing stream channels. Base not exposed; top mapped at the base of the first overlying lava flow or sedimentary bed thick enough to map as a distinct unit. Up to 270 m thick near OIT. Age equivalent to oldest part of unit Tm in quadrangle.

Tm **Lacustrine mudstone (Pliocene and upper Miocene)**—Tuffaceous diatomaceous mudstone with cream color and fair induration except in upper part of section in basins. In basin areas, the unit may be only weakly indurated, locally forming a plastic silty clay with loose silty or fine sand interbeds that may be difficult to distinguish from Holocene sediments of similar composition. However, if sandstone interbeds can be found, they are generally well indurated, unlike sand layers in younger units. Nearly always massive and poorly bedded unless interbedded with coarser-grained sedimentary rocks. Generally highly fractured weak material that forms low slopes and valley floors throughout the area. Locally fails in small landslides and slumps. About 260 m of unit is overlain by unit Tba dated at about 4 Ma at Hogback Mountain; overlain by unit Tba dated at 4.47 Ma by Pickthorn and Sherrod (1990) on the west side of Lake Ewauna. Diatoms from samples in fault blocks indicate an age >2.8–3 Ma (unpublished data of Platt Bradbury, 1998, Table 5). Water well logs (Table A1) indicate that unit Tm is 400 m thick in the Lake Ewauna-Altamont basin area, where the unit overlies lava flows of unknown age; underlies unit QTfs. Lava flows of the basaltic andesite of Cove Point with an age of 2.4 Ma are invasive into unit Tm and thus contemporaneous with part of it. In local subsiding basins like Round Lake and probably Wocus Marsh and Upper Klamath Lake, where continuous deposition of lake mud has occurred, uppermost unit Tm is probably indistinguishable from lowermost unit Qs at a gradational boundary. A similar gradational contact separates unit Tm in the Altamont area from unit QTfs, so there may not be significant age separation at the contact; upward change from essentially sand-free mudstone to sandy mudstone and well-sorted sandstone of unit QTfs may reflect a change from deeper to shallower water (strandline or deltaic) conditions of lowermost unit QTfs. Outside the map area the unit is underlain by volcanic rocks ranging in age from 5.52 to 6.88 Ma and overlain by a flow dated at 3.68 Ma (Sherrod and Pickthorn, 1992). Middle to late Pliocene vertebrate fossils were reported from various localities (Peterson and McIntyre, 1970). It is possible that some of these localities were actually in unit QTfs, as explained above (description of unit QTfs). Unit is between ~2.4 and ~5.5 Ma but is probably younger in the Altamont area and in other subsiding basins.

Tms **Mudstone and sandstone (Pliocene and upper Miocene)**—Diatomaceous mudstone of unit Tm but with lesser amounts of fine-grained sandstone, siltstone, and very minor conglomerate interbedded at a scale too small to map; as the unit is essentially a facies change and laterally contemporaneous with unit Tm, contacts are laterally gradational. Forms moderate- to low-angle slopes with only minor mass movement. Same age and general thickness as unit Tm.

Tg **Conglomerate (Pliocene and upper Miocene)**—Moderately indurated volcaniclastic conglomerate with well rounded pebble- to cobble-size clasts in a moderately sorted sandstone matrix. Forms low, rolling hills and moderate slopes in the northwest and northeast part of the area; locally mined for gravel aggregate. Up to 85 m thick near Stewart Lennox. Locally interbedded with unit Tba. Most probable age is between 2.4 and 4.5 Ma.

Ts **Sandstone (Pliocene and upper Miocene)**—Well-indurated, moderately sorted to very poorly sorted volcaniclastic sandstone. Generally medium-grained angular to subangular sand of olivine, clinopyroxene, hypersthene and >85 percent volcanic lithic clasts; contains local pebbly layers and minor hyperconcentrated flood flow deposits. Up to 60 m thick near Stewart Lennox but mostly 10–20 m thick and enclosed in unit Tm. Extensive smectite and zeolite cement causes the unit to be resistant to weathering and slope instability; forms very steep slopes and ridge crests. Interbedded with unit Tba and unit Tm. Most probable age is between 2.4 and 4.5 Ma.

Ti **Intrusion (Pliocene)**—Fine- to medium-grained, green-black, amygdaloidal diorite. Crops out in the southeast part of the quadrangle as a thick sill but also crosscuts the enclosing sedimentary rocks of units Tba, Tbas, and lower part of unit Tms; small outliers crop out in T. 38 S. R. 9 E., sec. 21. Plagioclase is subhedral, seriate up to 1 mm (rarely 2 mm). Olivine is anhedral or subhedral, less than 0.5 mm, variably altered to iddingsite or bowlingite. Clinopyroxene up to 4 mm ophitically or subophitically encloses plagioclase. Amygdules filled by radiating needles of white zeolite (probably natrolite) and milky, blue-white chert. Interstitial glass nearly completely altered to brown or green fine-grained, fibrous minerals. Slightly younger than unit Tba and lower unit Tms; uplifted on range front faults, so older than basin filling units like uppermost unit Tm and unit QTfs.

Hydrothermal alteration (Holocene? to Pliocene)—Areas of silicification and argillization affecting rock units. Varies from hydrothermally bleached and slightly argillized sedimentary rock to complete replacement of host rock by masses of chalcedonic quartz. Highly variable on a meter scale from soft, poorly indurated argillized rock to highly resistant silicified units. Forms moderate to steep slopes with little evidence of extensive mass movements. Alteration is of unknown age; hydrothermal systems are still active below the water table, where alteration is most intense.

3.0 STRUCTURAL GEOLOGY

3.1 INTRODUCTION

The following text is included with the geologic map to provide an overview of the geologic hazards, resources, and geologic history of the area. The importance of geologic structure (faults and folds) to understanding resources, hazards, and geologic processes is such that this discussion is best begun with an overview of the structural geology. An attempt is made to make the information understandable to a lay audience, while still being useful to a geoscientist. This attempt was more successful in the geologic history, resources, and hazards sections; less so in the geologic structure section, which is necessarily a more technical discussion.

3.2 GEOLOGIC STRUCTURE

3.2.1 Northwest-Striking Normal Faults

The dominant structures in the quadrangle are N30-40°W-striking normal faults (Figures 3.1, 3.2, and 3.3) that rotate fault blocks northeastward on the northeast side of the area and southwestward on the southwest side (see cross section A-A' on the geologic map). These faults are the result of N. 50°–60° E. extension in response to a minimum stress axis in this direction with maximum principle compressive stress probably N. 0°–10° W. to vertical (i.e., gravity).

One of the ways of achieving the fault block rotation is by development of a series of half graben detached at depth from deeper basement rocks by a décollement (Figure 3.1). Another way is by listric faulting (Figure 3.2). A key difference between the two rotations is the planar faults bounding the half graben versus the curving listric faults. Exposures and subsurface data were inadequate to distinguish which of these rotation models applies to the Klamath Falls area. Slightly curved fault planes are inferred on cross sections (see geologic map).

Areas of northeast- and southwest-tilted fault blocks are separated from one another by either the Klamath Graben (Figure 3.3), or by single faults within complex zones of normal and high angle reverse faulting, as in the ridges west of Link River (see geologic map and Figures 3.4 and 3.5). The Klamath Graben is bounded by the West Klamath Lake fault zone (Hawkins and others, 1989) and the East Klamath Lake fault zone (Figure 3.3; Bacon and others, 1999). The East Klamath Lake fault zone enters the map area as the normal faults at OIT, the Plum Hills, and Hogback Mountain (Figure 3.4). Structural relief on the Klamath graben is inferred to be about 450 m in the vicinity of Klamath Falls (Sherrod and Pickthorn, 1992) but probably increases

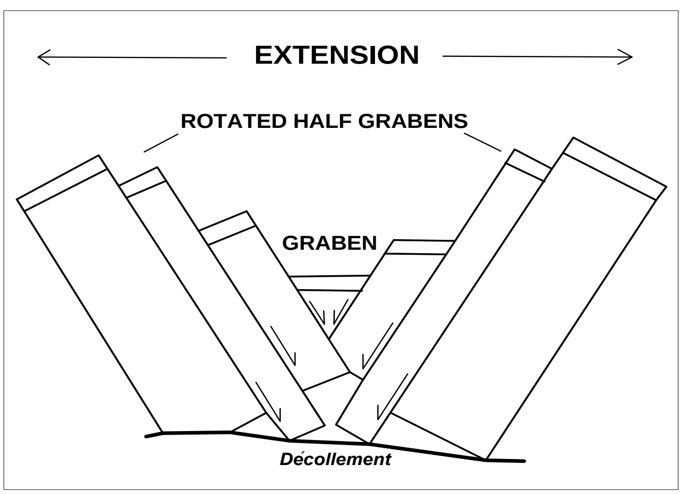

Figure 3.1. Illustration of how block rotation occurs during the development of half graben (modified from an illustration on the cover of the Ninth Keck Research Symposium in Geology [1996]).

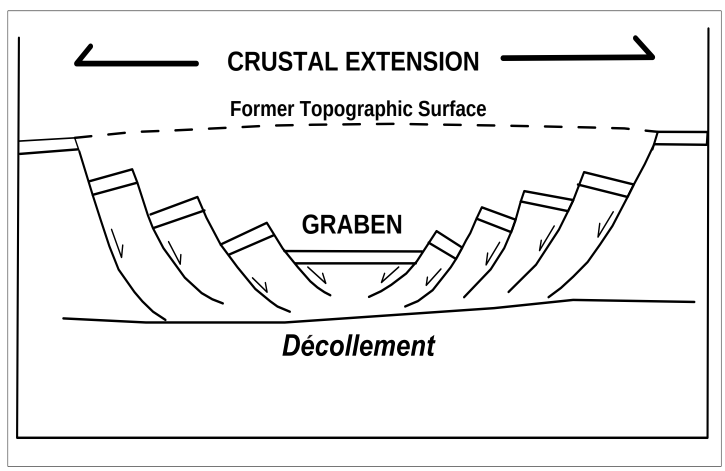

Figure 3.2. Illustration of how listric normal faulting can rotate fault blocks.

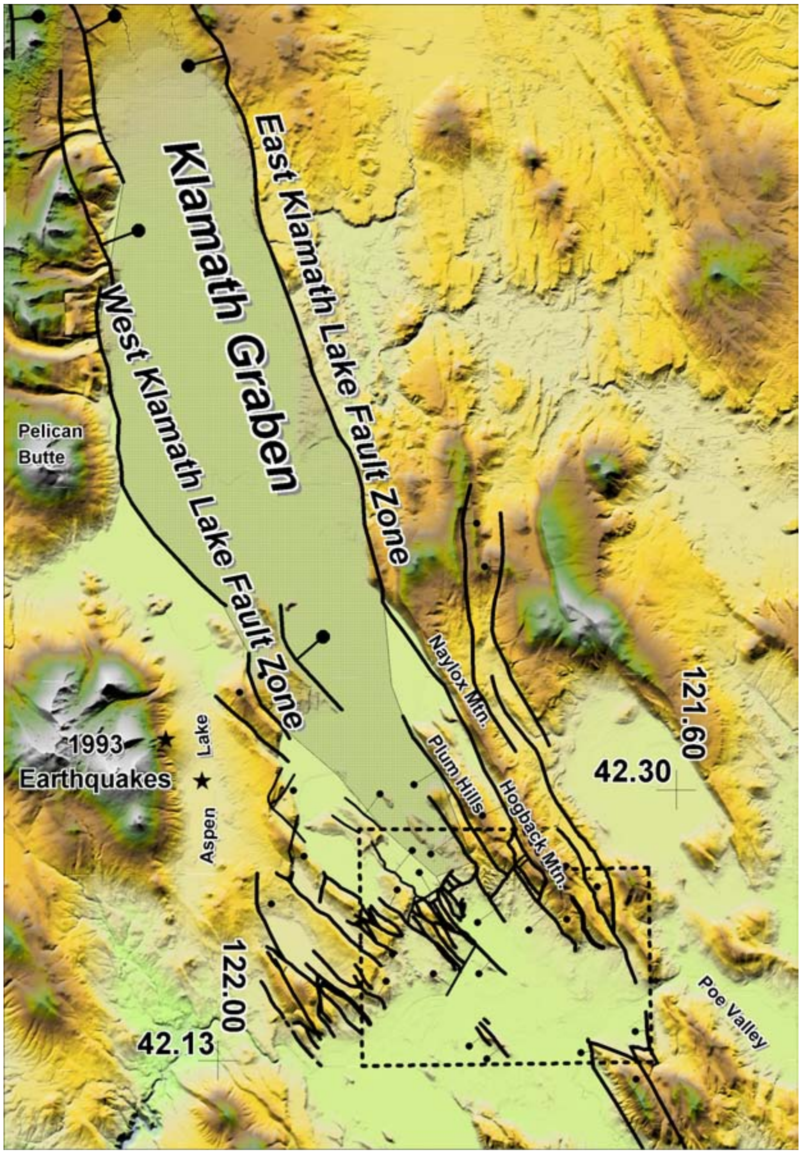

Figure 3.3. Location of the Klamath Falls geologic map (dotted line) with respect to regional faults and the 1993 Klamath Falls earthquakes. The Klamath Graben and East and West Klamath Lake fault zones are taken from Bacon and others (1999) supplemented by the map of Sherrod and Pickthorn (1992) and Smith and others (1982). Only faults adjacent to the graben and in the map area are shown. Downthrown side of each fault is marked by a bar and ball. Thinner lines are faults with somewhat less offset. See Figure 1.1 for a three-dimensional view of the topographic base map.

in structural relief to the north where large negative gravity anomalies are consistent with up to 1.2 km of basin fill (Couch and others, 1982a and 1982b). Structural relief on the Hogback Mountain fault could be as much as 1.4 km, if dark lava found in water wells under 400 m of mudstone in the Altamont area is the downdropped basalt of Hogback Mountain. Evidence for a subsiding basin at Altamont is discussed later in the text.

The dominant northwest-striking faults generally terminate along strike at zones of decreasing displacement or at northeast-striking faults. The ends of tilted fault blocks at Moore Park (Figures 3.4 and 3.5) and the southeast end of Hogback Mountain (geologic map) are marked by 600- to 700-m-long blocks of rock rotated at high angles to the direction of rotation of the main block. The one at Hogback Mountain is rotated in the opposite direction from the main block and exposes a capping andesite unit not seen in the main block. Because andesite in other areas, like Link River, tends to underlie unit Tba, this rotated block probably has a large amount of displacement, enough to bring up a unit older than the rest of the exposed stratigraphic section.

Large slump blocks along range front faults can in some cases resemble normal faults. One northwest-striking normal fault 1 km northwest of Moore Park on Lakeshore Drive may be such a block. The short length (0.8 km) and arcuate shape argue for a large slide block, but the northeast dip of underlying diatomaceous mudstone in the block argues against any large amount of backward rotation that would normally be associated with a slump. Offset on this structure is ~50 m down toward Upper Klamath Lake.

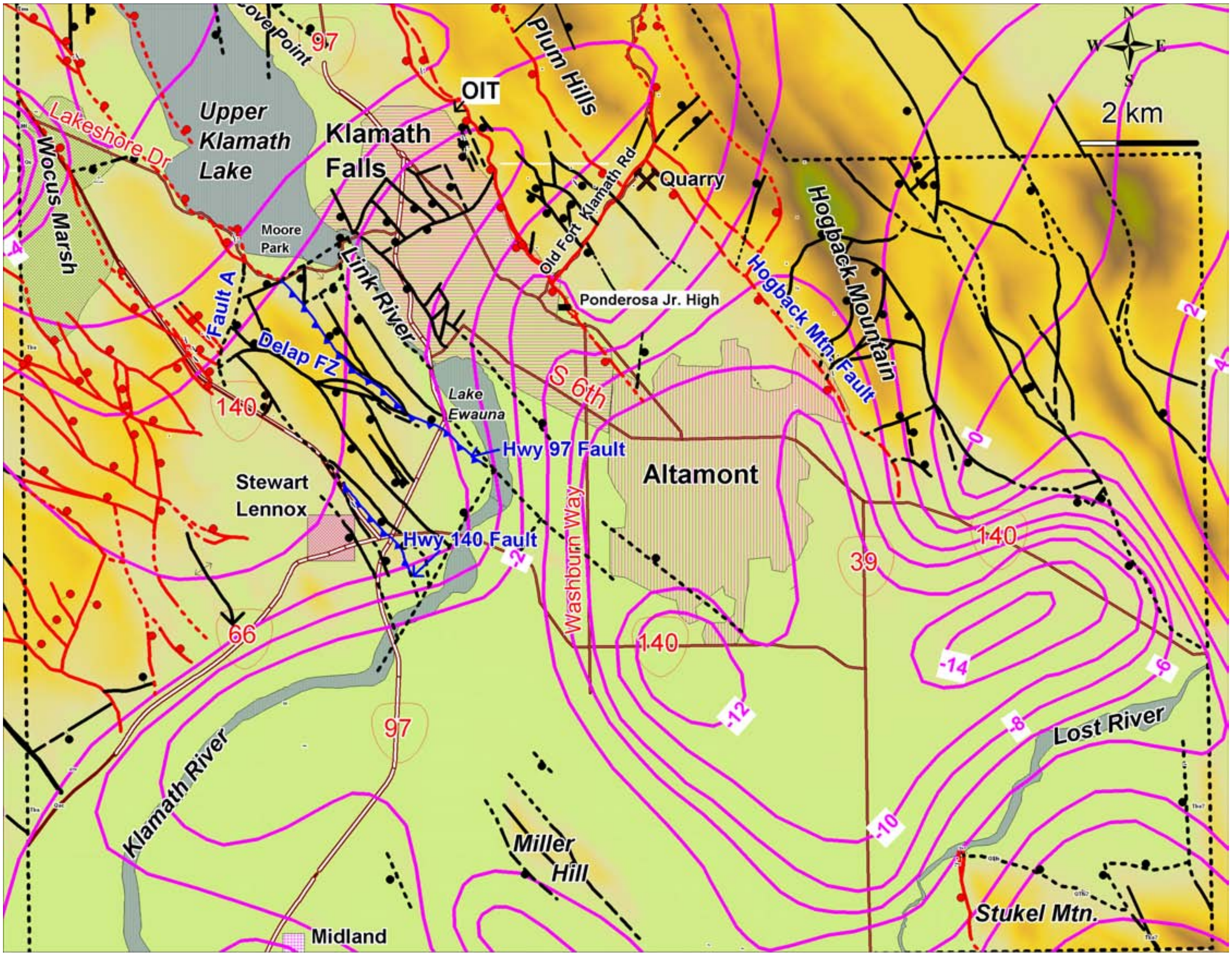

Figure 3.4. Faults and folds in the area of the Klamath Falls geologic map. Dotted line is geologic map boundary. Faults outside the map boundary are from Sherrod and Pickthorn (1992), Murray (in press), and Hladky and Mertzman (2000). Dots are on the downward displaced side of each fault. Lines with triangular teeth are high angle reverse faults with teeth toward upthrust side; others are normal faults. Red faults have evidence of more recent activity (post-1.8 Ma). Black and blue faults cut rocks older than 1.8 Ma. Dotted lines indicate cover by surficial deposits. Arrows on fold lines point in direction of plunge; opposed arrows pointing away from the fold axis indicate an anticline (upwarped rocks). Purple lines are residual gravity contours of Couch and others (1982b) in milligals. FZ is fault zone; OIT is Oregon Institute of Technology.

3.2.2 Northwest-Striking Lateral Faults, Reverse Faults, and Folds

The northeast- and southwest-tilted blocks west of Link River generally come together at zones of complex reverse and possible northwest-striking, oblique-slip faulting. A northwest-striking reverse fault with a dip of 57° SW is exposed along Highway 97 southeast of Link River (Highway 97 Fault, Figure 3.5). This fault extends to the northwest where it separates northeast- and southwest-rotated fault blocks (Figure 3.5). On the northwest end of what appears to be the extension of this fault the distinctive andesite of Link River (unit Tla) is offset about 240 m, with the southwest side (hanging wall) up (cross section A-A'). An interpretation of reverse movement is based on the assumption that unit Tms exposed on the hanging wall at Highway 97 is older than unit Tba on the footwall and that the southwest fault dip persists to the northwest. Similarity of diatomaceous, tuffaceous mudstone of unit Tms in the hanging wall to unit Tms and contemporaneous unit Tm underly-

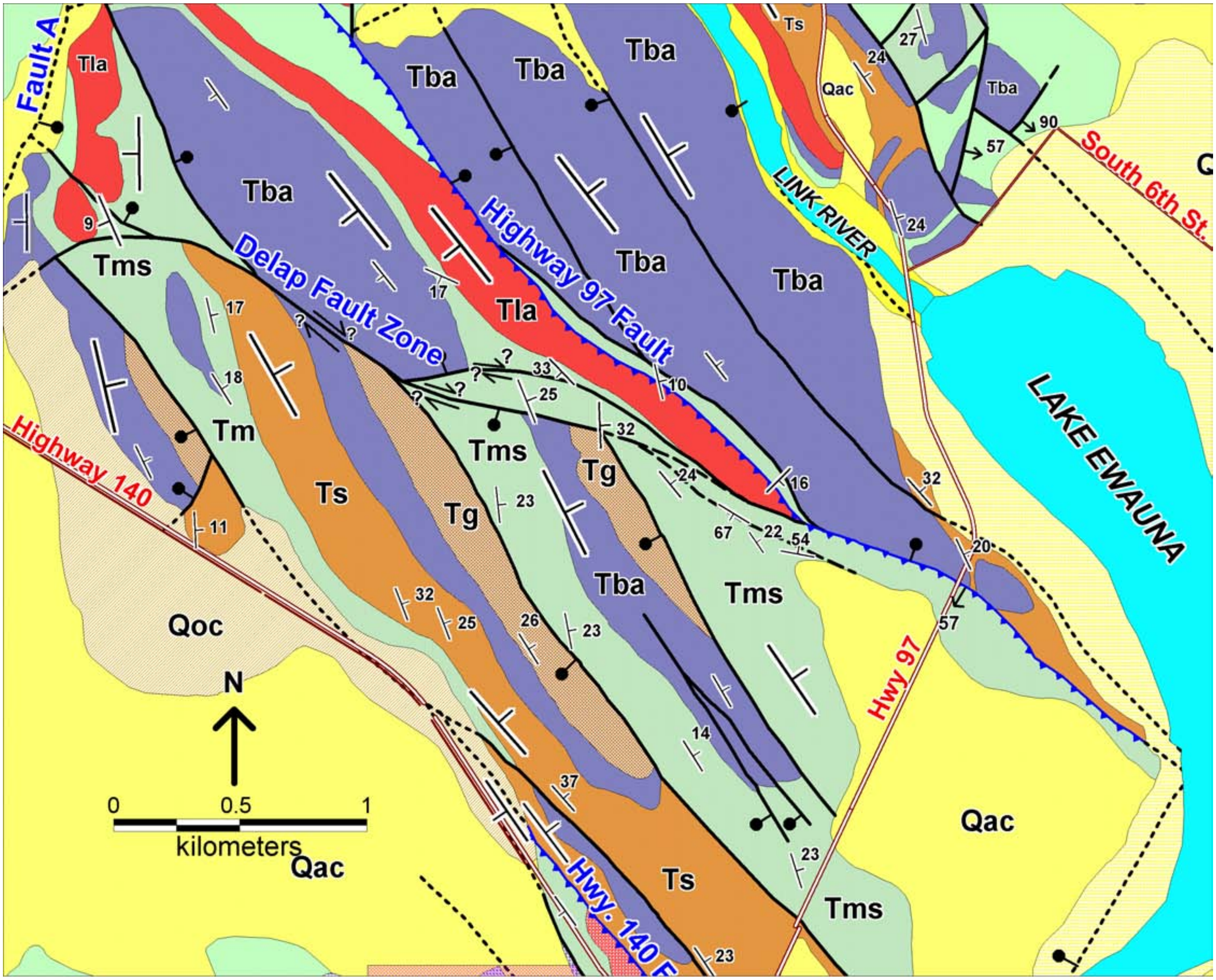

Figure 3.5. Map of complex faulting near Link River. Faults with triangular teeth are high-angle reverse faults with teeth in direction of the upthrust side. The Highway 97 Fault is exposed in a prominent road cut on Highway 97 (see 57° dip). Note how fault blocks tilt away from the Highway 140 Fault and the Highway 97 Fault (see also cross sections A-A′ and C-C′ on the geologic map). Note how fault blocks tilt toward the Delap Fault Zone on its northwest end; this fault is inferred to have a component of right-lateral offset. Symbols are defined in geologic map explanation. Pink square at the bottom marks the Stewart Lennox area shown in Figure 3.4.

ing both unit Tba and unit Tla at the base of adjacent fault blocks support this interpretation. Note that the northwest end of the Highway 97 Fault separates fault blocks that dip away from the fault, effectively forming a broken anticline. This is further evidence that it is probably a compressional structure.

The Delap Fault Zone separates southwest-tilted from northeast-tilted groups of fault blocks (Figure 3.5). This fault zone extends west-northwest from the Highway 97 Fault and separates somewhat different stratigraphic sequences. The sequence on the north side of the Delap Fault Zone is unit Tba underlain by a thin layer of unit Tms, then unit Tla, and a thick section of unit Tms. The sequence on south side is unit Tg, underlain by unit Tba, which is underlain by a thick section of unit Tms in the eastern tilted block and unit Ts in the western blocks. Lava flows in unit Tba on both sides of the fault zone are mineralogically and chemically similar (see Table 1.2; samples 19 and 20 compared to 25 and 26), so the difference in sequence could be from juxtaposition of laterally distant parts of correlative lava in unit

Tba by lateral faulting. This fault zone could also be a zone of accommodation between these two areas of tilted blocks with no significant lateral movement. Another possibility is some kind of oblique-slip movement. Lateral motion is consistent with the mismatch of the stratigraphic sequence across the fault. Right lateral motion is compatible with the clockwise rotation of the strike of unit Tms (from northwest to north-south) in the small elliptical fault block that occurs in the central part of the fault zone; queried arrows there show the possible direction of lateral motion (Figure 3.5). Right lateral motion in the general region of Klamath Falls is also consistent with interpretations of regional gravity data by Blakely and others (1997). It is possible that some portion of the west-northwest trending right-lateral faulting inferred by Lawrence (1976) occurs in this area. More detailed mapping, chemical analysis, and paleomagnetic measurement may resolve this problem.

The Highway 140 Fault is 1.6 km south of the Delap Fault Zone (Figure 3.5). Northeast- and southwest-rotated blocks come together at a shear zone tens of meters wide in this area. The exposed fractured, sheared, and weathered rocks in this zone reveal no well-defined fault plane dip. Because the fault blocks rotate away from the shear zone, a broken anticlinal structure is inferred, as at the Highway 97 Fault. This would make the fault a high-angle reverse fault. No rock units correlate across this shear zone, so it may have large reverse offset. Without a dip on the fault plane, it is not possible to infer which side is up. It is possible that the same forces that caused the Highway 97 Fault caused the Highway 140 Fault; hence it may have a similar dip and sense of movement (southwest dip and southwest side up). That is what is shown on cross section C-C'. Once again, this inferential evidence does not prove that this is a reverse fault.

Two kilometers west of Stewart Lennox, a reversal in dip occurs across a gentle, northwest trending anticline with only minor faulting (less than 2 m offset) along the anticlinal axis (Figure 3.5; cross section C-C'.). This anticline is consistent with a component of northeast compression in the Stewart Lennox area. This inferred northeast-southwest compression is in the correct direction to cause the inferred reverse movement on the Highway 97 and 140 faults, although one might wonder why this compression is manifested here as such a gentle fold rather than a more heavily deformed broken anticline. If all these structures are caused by the same general stress regime, then, for some reason, the resulting deformation (strain) varies over relatively small (3 km) distances.

Regional northeast-southwest compression is not compatible with the overall northeast-southwest extension that causes tilting of fault blocks bounded by northwest-trending faults throughout the area unless (1) the reverse faulting is of a different age or (2) there is some local stress regime at work. A component of lateral motion can produce local areas of compression, especially where the trend of the lateral fault takes a sharp bend. Judging from the evidence at the Delap Fault Zone, faulting with a right-lateral component of motion could be present in the area, so local regions of compression are possible. A similar, but highly speculative right-lateral or right-lateral oblique-slip fault appears to be present on the northeast side of the gentle anticline west of Stewart Lennox (geologic map). Both this inferred lateral fault and the Delap Fault Zone appear to have undulating trends compatible with development of local regions of compression.

If the N. 55°–75° W. strike (averaging ~N. 65° W.) of the possible right-lateral or right-lateral oblique-slip faults is at 30° to the principal compressive stress, as is usually the case, then one might infer a principal compressive stress axis oriented ~N. 35° W., virtually parallel to the overall strike of normal faults in the area. Clearly this is not consistent with overall north-south to vertical orientation of the principal compressive stress inferred from the north northwest trending normal faults that dominate the area. Another possibility is that the possible lateral faults are actually related to parallel west-northwest-trending transform faults that bound varying amounts of extension in the Basin and Range (Lawrence, 1976; Davis, 1980). Lawrence (1976) summarizes evidence for a number of major west-northwest-trending right-lateral transform fault zones that appear to take up the decrease in extension of the Basin and Range Province from southeastern Oregon to the Blue Mountains. The closest right-lateral fault zone identified by Lawrence is his McLoughlin zone, which on his maps has a measured trend of N. 58° W. and causes an apparent 15–20 km of right-lateral offset of "the High Cascade trend" (term from Lawrence, 1976). The possible right-lateral or right-lateral oblique-slip faults mapped here are subparallel to this trend and could be related. All this is speculative, as the potential lateral and reverse faults could just as easily be local zones of accommodation between groups of tilted fault blocks with differing directions of tilting.

Because the hypothesis of reverse faulting at the Highway 97 Fault hinges in part on the assumption that outcrops of unit Tms in the hanging wall are older than unit Tba in the footwall, it is important to understand that, although this is the simplest interpretation, it is not proven. The uppermost parts of units Tm and Tms in the adjacent Lake Ewauna and Altamont areas are lithologically similar to the mudstone in the hanging wall of the Highway 97 Fault but probably younger than unit Tba. If this younger part of unit Tms is what is in the hanging wall, then the fault is a normal fault. The younger part of units Tm and Tms in Altamont-Lake Ewauna area is worth farther exploration.

3.2.3 Altamont-Lake Ewauna Area and Displacement on the Hogback Mountain Fault

The Altamont-Lake Ewauna area is mostly covered by surficial units, so the geologic structure shown on cross sections is based on water well data (Table A1) and observations in a few exposures. At Altamont this relatively flat basin is bounded on the east by Hogback Mountain which rises 640 m above the valley floor. As much as 400 m of moderately to well consolidated tuffaceous and diatomaceous mudstone of unit Tm overlies what is described in water well logs as hard, dark-colored rock that could be any dark-colored hard rock unit in the area (units Tba, Ta, Thb, etc.). Couch and others (1982b) show a negative (–6 to –14 milligal) residual gravity anomaly in the Altamont area that roughly defines the basin area (Figure 3.4). Couch and others (1982a) infer about 1.2 km of sediment fill in the northernmost part of the Klamath Graben based on modeling of a –20-22 milligal residual anomaly there; because the negative anomaly at Altamont is 30–60 percent of the one at Upper Klamath Lake, one might expect about 360–760 m of fill. Considering the errors inherent in geophysical modeling (see Veen, 1982, for discussion of the gravity data), this is reasonably close to the ~300–400 m of low density mudstone intercepted in several deep drill holes in and near Altamont (see well data, Table A1).

Without chemical, mineralogical, and age data from rocks in the wells there is no way to tell which hard rock unit or units underlie the thick section of mudstone. Likewise, the age of the mudstone in the Altamont-Lake Ewauna area is unknown. If the mudstone is relatively young, there could be very large displacement on the Hogback Mountain fault (i.e. the basalt of Hogback Mountain, unit Thb, would be displaced beneath the mudstone). If unit Tm is relatively old, say, older than the rock capping Hogback Mountain, then the displacement on the Hogback Mountain fault could be much less.

Some insight into the possible age of unit Tm can be gleaned from observations of lava flows that are interbedded in it. At Cove Point the basaltic andesite of Cove Point (unit Tcba), age ~2.4 Ma, is invasive into the upper part of unit Tm and has a lower contact at about the same elevation as the surface of Upper Klamath Lake (1280 m). About 100 m of mixed unit Tcba and unit Tm crop out there, indicating eruption of the basaltic andesite into a persistent lake. The age of the upper part of unit Tm is therefore roughly 2.4 Ma at Cove Point.

Basalt of unit Thb, with an age of ~2.7 Ma caps Hogback Mountain. At its lower contact (1615 m elevation), unit Thb is interbedded with a minor amount of mudstone and fine-grained, well-sorted sandstone and has hyaloclastic texture and mineralogy indicative of eruption into water. Below that is a thick sequence of basaltic andesite of unit Tba. The lower contact of unit Thb is therefore 335 m above the lower contact of unit Tcba and both were interacting with water at the time of initial eruption. The upper part of unit Thb, however, is subaerial, whereas the upper part of unit Tcba is still interbedded with unit Tm. There is clearly not much geologic time between emplacement of units Thb and Tcba; in fact the ages are the same within 1-2 standard deviations of the error (Table 1.1; 0.13–0.21 Ma). The two units, while differing in chemical composition, share enough mineralogical and textural similarities that they are difficult to tell apart in outcrop. One might conclude that at 2.4–2.7 Ma unit Thb filled a valley that was a shallow arm of the lake where unit Tcba was erupting. If so, then there was probably not much elevation difference between them at this time. The current 335 m of elevation difference is probably caused by faulting after 2.4 Ma.

This reasoning is fine for Cove Point, but what about Altamont? Because there is no basaltic andesite of Cove Point or basalt of Hogback Mountain at Altamont, just tuffaceous mudstone and some sandstone, these basalt and basaltic andesites were either eroded away, making the mudstone older, or they lie beneath the mudstone. If the basalt of Hogback Mountain or contemporaneous lava was eroded away, then this occurred sometime after 2.7 Ma (age of Thb) but before the start of deposition of unit QTfs (i.e., sometime after ~1.8 but before ~1.1 Ma?). There is no evidence of a major erosional episode in this interval. All evidence seems to point to gradually decreasing eruption of lava flows with time at Altamont, and progressively more opportunity for uninterrupted deposition of thick lacustrine mudstone of unit Tm. The weight of the evidence is therefore on the side of a youthful (<2.7 Ma) age for the Altamont mudstone that accumulated atop downward offset unit Thb. The down-to-the-west offset on the Hogback Mountain Fault would then have to be on the order of 1.4 km (cross section D-D').

One problem with the above hypothesis is that one would expect to see some exposures of units Thb, Tba2 or Tcba in tilted fault blocks that emerge from this cover of lacustrine mudstone in downtown Klamath Falls. Instead, lava of unit Tba chemically and mineralogically identical to basaltic andesite underlying units Thb and Tba2 caps many of these fault blocks. Other fault blocks in the downtown area are capped by unit Ts lithologically similar to sandstone underlying unit Tba at Hogback Mountain. Did units Thb, Tba2, or Tcba never reach this area? Were they eroded off during progressive uplift and fault block rotation? Did the tilted fault blocks in downtown Klamath Falls form after eruption of unit Tba but before unit Thb and contemporaneous lavas? If bedrock exposed in downtown Klamath Falls is representative of the basement of older rock beneath the Altamont and Lake Ewauna area, then there may not be much or any basalt of Hogback Mountain there. The lateral extent of unit Thb shown in cross section D-D' is thus highly speculative. Units Tba and Thb are shown queried in cross sections B-B', C-C', and D-D' and in data fields of the water well table (Table A1) to emphasize the uncertainty of the stratigraphic interpretations.

It is also not known whether the older basaltic andesite flows of unit Tba in the downtown area pinch out to the southeast into the Lake Ewauna area, interfingering with the thick mudstone sequence under the basin. If so, then at least part of the mudstone sequence at Altamont could be older than unit Thb.

The structure under Altamont and Lake Ewauna is probably just as complex as that exposed in downtown Klamath Falls. Without extensive geophysical and drilling data it is not possible to accurately represent this complex structure in the cross sections. The cross sections are thus highly simplified compared to the real situation.

3.2.4 Northeast-Striking Faults

Northeast-striking faults are not as common as northwest-striking faults, but a number are interpreted mainly from abrupt termination along northeast trends of groups of northeast- or southwest-tilted fault blocks. A northeast-striking fault at the Klamath River south of Stewart Lennox appears to offset a sequence of andesite and interbedded sedimentary rock downward to the northwest by about 440 m (Figure 3.4; cross section C-C'). The northeast strike is inferred from the trend of the river and the residual gravity anomaly in this locality (Figure 3.4). Another northeast-striking fault occurs southwest of Moore Park, separating a series of southwest-tilted fault blocks to the northwest from an east-rotated fault block (fault A on Figure 3.4; see strike and dips on the geologic map). Northeast tilted fault blocks north of Link River are inferred to terminate against inferred northeast-striking faults that also appear to show up in the residual gravity data (Figure 3.4; geologic map). A major northeast-striking fault approximately follows Old Fort Klamath Road (Figure 3.4). As discussed below, this fault at Old Fort Klamath Road has some of the best evidence in the area for geologically recent activity.

3.2.5 Age of Faulting

The age of deformation in the Klamath Falls area appears to be chiefly less than 4 million years. Petrographic and chemical correlation of the rocks from single lava flows of unit Tba from the Link River area to the Plum Hills and Hogback Mountain demonstrate that some basaltic lava flows spread at least several kilometers east-west across areas now occupied by prominent northwest-trending, fault-bounded ridges. The age on these flows is approximately 4 to 4.5 Ma (Table 1.1; sample K-90, 4.47 Ma date by Sherrod and Pickthorn, 1992). Progressive tilting and deposition has occurred since that time. For example, at Hogback Mountain an age of 4.01 ± 0.12 Ma (Table 1.1; sample K-90) was obtained near the base of basaltic andesite unit Tba. There the underlying sandstone dips 20° to 30° NE. Flows near the top of the basaltic andesite dip about 11° NE, and the capping basalt of Hogback Mountain (unit Thb, age about 2.7 Ma) lies on a surface dipping 5°-6° NE. Thus approximately 16° of tilting apparently occurred between about 4 and 2.7 Ma. Many of the tilted fault blocks capped by units Tba and Ts northwest of Old Fort Klamath Road and in downtown Klamath Falls may have formed in this interval. This might explain why they lack capping lava flows of unit Tba2 or Thb. One caveat about this observation is that the dips in the older rocks at Hogback Mountain are taken from exposures of sedimentary rock near the Hogback Mountain Fault (Figure 3.4); it is quite possible that those dips are created by highly localized deformation rather than tilting of large parts of the fault block.

On the basis of the dip of its lower contact, the basalt of Wocus Marsh appears to be tilted 4-5° southwest in the fault blocks surrounding Wocus Marsh, but underlying rocks of unit Tm have southwest dips up to 18°. Diatoms indicate an age >2.8–3 Ma for unit Tm (Table 1.4; unpublished data of J. Platt Bradbury). The age of the basalt of Wocus Marsh is probably about 1.8 Ma. Thus tilting of as much as 14° could have occurred between 1.8 Ma and sometime before ~3 Ma, but the same caveat applies. Local faulting can cause dip measurements unrepresentative of overall structure in a sedimentary sequence, whereas the dip of a formation contact can give a much more accurate picture of fault block tilt.

Possible right-lateral faults and reverse faults north and northwest of Stewart Lennox cannot be traced northwest into the faulted basalt of Wocus Marsh. Faults cutting the basalt of Wocus Marsh northwest of Stewart Lennox appear to be northwest-striking normal faults with no evidence of reverse or lateral faulting. Sherrod and Pickthorn (1992) note that most slickensides and mullions in the west half of the Klamath Falls 1° by 2° quadrangle plunge directly down dip, consistent with normal slip. Some of the best-exposed slickensides of this type are on the northwest-striking Holocene faults cutting colluvial deposits in the East Klamath Lake fault zone (Figure 3.3). The only place where there may be some small lateral offset on basalt of Wocus Marsh is 3.3 km west of Stewart Lennox at the extension of a small fault with highly speculative inferred right-lateral oblique-slip (see geologic map). Even there, the major offset on the basalt is obviously normal, and no lateral offset is needed to explain the outcrop pattern. The stress regime that gave rise the possible reverse and lateral faults either changes to the north and northwest of Stewart Lennox (the stress regimes are highly localized) or ceased after 1.8 Ma (age of unit QTwb)—or the reverse and lateral faults are really normal faults that have been misinterpreted. Rocks involved in the possible reverse and lateral faults north and northwest of Stewart Lennox are some of the oldest units in the area; the youngest is unit Tba with an age of about 4-4.5 Ma in this area; hence it is possible that these complex faults represent an older episode of deformation characterized by west-northwest right-lateral transform faulting that has either ceased or slowed since 1.8 Ma.

Where faults cut the youngest rock units, one can infer that those faults are potentially active. The late Pliocene (?) and early Pleistocene sedimentary rocks of Foothills Drive (unit QTfs) are locally highly deformed; examples are the gravel quarry on Old Fort Klamath Road and the quarry at the northwest tip of Stukel Mountain (Figure 1.1; geologic map). The gravel quarry at Old Fort Klamath Road is noteworthy because a northeast-striking fault passes through the west side of the quarry, tilting poorly consolidated sedimentary rocks of unit QTfs to near-vertical dip. Exposures ~100–200 feet east of the fault show decreasing dip upward and eastward in section, suggesting ongoing deformation during deposition of unit QTfs. In other areas, measured dips in unit QTfs are on the order of 10°–12° E. to NE. Some of this dip may be original depositional dip in the coarser grained sedimentary beds, but the dip persists in tuffaceous mudstone beds, so some tilting has occurred even in areas relatively far removed from mapped faults. This tilt suggests the presence of unmapped normal faults in the Altamont area.

North of the map area at Upper Klamath Lake there is abundant evidence of Holocene and Pleistocene faulting. Volcanic rock with an age of 1.9 ± 0.5 Ma is cut by graben bounding faults on the east side of Upper Klamath Lake at Rattlesnake Point (Sherrod and Pickthorn, 1992; M. O'Brien and S. Benson, in Fiebelkorn and others, 1983). The structural relief on the Klamath Graben has therefore developed chiefly after 1.9 Ma (Sherrod and Pickthorn, 1992) and created topographic escarpments rising up to 1.3 km above Upper Klamath Lake (e.g. southeast of Rattlesnake Point). Veen (1982) infers from gravity data 0.4–1.2 km of sediment fill in the Klamath Graben at Upper Klamath Lake. Couch and others (1982a) infer sediment fill of 1.2 km, based on modeling residual gravity anomalies. In the map area at least 110 m of structural relief was developed on the west side of Upper Klamath Lake where northwest-striking faults cut the basalt of Wocus Marsh (age ~1.8 Ma). Geophysical surveys of Upper Klamath Lake revealed that numerous northwest-striking faults offset the Mazama ash bed by 1-2 m (Colman and others, 2000). One fault cutting Upper Klamath Lake sediment has had at least three episodes of movement since deposition of the Mazama ash 7,540 calendar years ago (Colman and others, 2000).

Bacon and others (1999) have demonstrated similar youthful faulting and potential for future fault movement on the West Klamath Lake fault zone. The September 20, 1993, Richter magnitude 5.9 and 6.0 earthquakes (Wiley and others, 1993) occurred at the southernmost end of the West Klamath Lake fault zone (Figure 3.2). Although the number of aftershocks related to the 1993 earthquakes has decreased every year since 1993, future earthquakes with magnitudes as high as Mw 7.25 are possible on the West Klamath Lake fault zone (Bacon and others, 1999). The faults on the east side of the Klamath graben at Upper Klamath Lake probably have similar potential for large earthquakes. The West and East Klamath Lake fault zones extend into the Klamath Falls urban area but have less obvious youthful displacement than outside the urban area. However, preservation of youthful fault scarps in the urban area is difficult owing to the dominance in many areas of easily eroded tuffaceous mudstone and diatomite.

The Hogback Mountain and Plum Hills faults are part of the East Klamath Lake fault zone that extends into the map area (Figures 3.3 and 3.4). Deformation rates on these fault zones at Upper Klamath Lake are so high that range front faults appear as sheared colluvium-bedrock contacts that are preserved high on the slopes (Sherrod and Pickthorn, 1992). Similar sheared colluvial-bedrock contacts have not been found on the southeast extension of these faults into the map area, but this may be due in part to poorer exposures and to the less competent nature of the sedimentary rocks forming the base of the Plum Hills and

Hogback Mountain. Escarpments bounding the Klamath Graben in Upper Klamath Lake are composed chiefly of basaltic lava that is much more likely to preserve fault scarps for long periods of time. Nevertheless, there are no areas in the Klamath urban area where Holocene alluvial fans are clearly cut by fault scarps, so it is possible that overall deformation rate is less than to the north. The only alluvial fan that appears to be cut by a major northwest-striking range front fault is probably Pleistocene in age (uppermost unit QTfs) on the southeast side of Old Fort Klamath Road (Figure 3.4; geologic map).

3.2.6 Recent Faulting at Ponderosa Junior High School

Over the last few decades cracks and small graben have formed along a northwest-trending zone up to 70 m wide at Ponderosa Junior High School and surrounding school grounds (Figure 3.6). Subsidence in this zone is as much as 45 cm in the asphalt track around the playing field southeast of the school; numerous small vertical offsets of the school parking lot are on the order of 3–10 cm (Figure 3.7). The scarp cutting the running track on its southeast margin trends N. 15° W. with ~36 cm of pure dip-slip motion down to the west (Figure 3.6). This scarp trends N. 17° W. at the playing field but turns to a trend of N. 8° W. where it passes through the bus shelter and the chain link fence to the southeast (Figure 3.8). The scarp could not be followed northwest of the playing field owing either to a lack of deformation or lack of easily recognized features that could be offset. A historical photo taken during construction of the canal to the southeast shows a hot spring at the projected extension of this feature (Figure 3.9).

A small shear cuts through a slightly uplifted part of the running track at its north end. The shear has ~6 cm of left-lateral offset across a cement curb on the inside of the track (Figure 3.10). It strikes N. 17° W. toward a similar but much smaller left-lateral offset of a curb on the southeast side of the school parking lot (Figure 3.11). Overall, deformation in this area and at the school parking lot is, however, a series of small irregular, generally northwest trending graben (Figure 3.12). Most of these features either have pure dip-slip or small (~1 cm) component of right-lateral oblique offset.

Deformation of the school building (Figure 3.13) is being quantitatively monitored, so data exist on how deformation has varied with time (data and interpretations from Mark Dew, Dew Engineering, 1998, oral comm.). The conclusion from this monitoring is that recent deformation was caused by ground-water withdrawal from the active geothermal system. This interpretation is supported by observed dramatic decrease of deformation of the school building after geothermal wells in the area began to reinject water. Furthermore, minor, ongoing deformation of the school building appears to correlate with seasonal changes in the ground-water table. Similarly deformed areas of the school grounds to the southeast of the parking lot were reportedly sites of active hot springs prior to development.

Ponderosa Junior High School lies at the southwest end of a large zone of active geothermal circulation tapped by numerous wells at Pacific Terrace and OIT. Because hydrothermal minerals commonly seal up such systems unless fractured by episodic deformation, this system is probably cut by active faults. A number of major northwest-striking faults are mapped in the same area, one inferred through the Ponderosa Junior High School site (Figure 3.4; geologic map). It is recommended that detailed analysis of the deformation and seismicity near and at Ponderosa Junior High School be conducted to determine if some movement could be from active fault creep.

3.2.7 Summary

To summarize, northeast-southwest extension that has caused northeast and southwest tilting of fault blocks over the last 4 million years probably continues today. Structural relief on the northwest-trending fault bounding the northeast-tilted block at Hogback Mountain could be up to 1.4 km. All of this structural relief developed after ~2.7 Ma, the age of lava capping Hogback Mountain. A west-northwest fault zone at the Delap Pit Road area near Stewart Lennox could be part of a right-lateral transform fault zone or simply a zone of accommodation between groups of tilted fault blocks with differing tilt.

Probable high-angle reverse motion on the Highway 140 and Highway 97 Faults may be related to local northeast-southwest-directed transpressive forces on a regional right-lateral transform fault or similar forces accommodating the reversal in tilt of fault blocks. The evidence for the reverse and lateral faulting is highly speculative and needs to be confirmed by more detailed investigations.

Faults bounding the Klamath graben extend into the map area and are probably still active and capable of producing local large (~magnitude 7) earthquakes. Faults that are considered most likely to experience further movement are colored red on the geologic map. These faults are either extensions of fault zones known to have Holocene movement northwest of the map area, or they are closely related to faults that cut rocks less than 1.8 Ma in age (age of unit QTwb). These youthful faults, where the fault planes are well exposed north of the map area, appear to be normal faults with pure dip slip.

Figure 3.6. Structural geologic map of the area around the Ponderosa Junior High School. Hachures are on the down thrown side of scarps. Areas depicted as brown grass were taken (by inspection) from unpublished, undated engineering geology map of CH2M Hill and provided by Oregon Institute of Technology. The circled area refers to Figure 3.9.

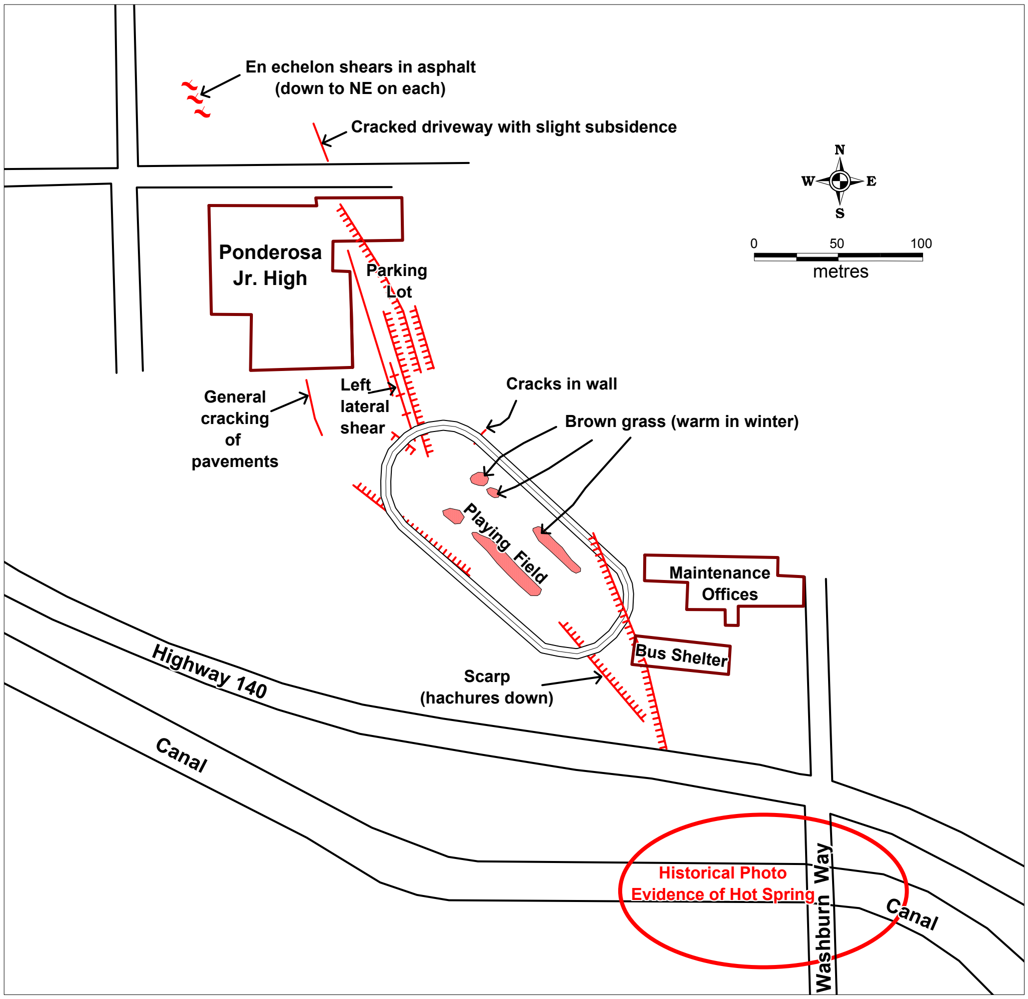

Figure 3.7. Looking northwest at down-to-the-west offset of school parking lot.

Figure 3.8. Northwest-trending scarp offsets the bus shelter.

Figure 3.9. Historical photo of hot spring in canal when the canal was constructed. See Figure 3.6 for approximate location. Photograph is courtesy of James K. Bryant, Chief of the Water and Lands Division of the U.S. Bureau of Reclamation in Klamath Falls.

Figure 3.10. Left-lateral shear at north end of running track.

Figure 3.11. Left-lateral offset in curb at parking lot northwest of shear in Figure 3.10. The two shears are connected by a small, northwest-trending notch cut by erosion of apparently sheared soil.

Figure 3.12. Approximately 7-m-wide graben in school parking lot. Backpack is shown for scale.

Figure 3.13. Slightly deformed roof line on Ponderosa Junior High School where down-to-the-west (left) ground deformation crosses the building.

4.0 GEOLOGIC HISTORY

6–4 Ma. Between 6 and 4 million years ago the Klamath falls area looked very different from today. It was much more volcanically active and probably had much lower topographic relief. Volcanoes periodically erupted basaltic andesite and andesite lava with calc-alkaline chemical composition similar to lavas from subduction zone volcanoes worldwide. As basaltic andesite magma rose through the Earth's crust, it cooled faster and faster, culminating in very rapid crystallization during eruption at the surface. This process gave nearly all of these flows a distinctive seriate texture characterized by all sizes of crystals from a millimeter or two down to microscopic sizes. Many of the magmas intruded into the lake sediment and flashed the ground water and lake water to steam. The resulting violent steam explosions blasted out fragments of the lava and underlying country rock. Slurries of steam-blasted ash built up palagonite tuff cones. An example is the hill of unit Tbv immediately south of Stewart Lennox. Erupting lavas flowed into the extensive lakes, intruding upward from below at vents and invading downward from above into the soft lake mud as they flowed out and sank into it.

Local streams were flooded with sand and gravel from the abundant volcanic activity, so the deposits were rapidly accumulated with little time for rounding or sorting of clasts. Many of these same streams funneled lava flows, so there is often a close association between lava outcrops of unit Tba and outcrops of sandstone (unit Ts) and conglomerate (unit Tg) in the area (e.g. hills north of Stewart Lennox).

Volcanic ash carried by westerly winds from Cascade volcanoes rained down on the lakes. Silica from weathering of these ash fall deposits and local volcanic rocks nourished blooms of microscopic plants called diatoms. The result was extensive deposits of cream-colored diatomaceous, ash-rich mud similar to modern lake mud of Upper Klamath Lake.

4–2.7 Ma. After ~4 Ma, andesite eruptions ceased, and volcanic activity consisted mainly of basaltic andesite eruptions. Between 4 and 2.7 Ma earthquake activity probably increased as the area began to be slowly pulled apart (extended) in a northeast-southwest direction. This crustal extension caused normal faulting and tilting of rocks and lake sediments toward the southwest and northeast away from Upper Klamath Lake and Altamont-Lake Ewauna. Figures 3.1 and 3.2 show ways in which this may have occurred. Keystone-like blocks (graben) started to drop, forming depressions similar to the current basin at Upper Klamath Lake. Additional blocks formed on each side of these basins, rotating backward toward the northeast on the northeast side and southwest on the southwest side. A west northwest trending fault located where the Delap Pit Road is now began taking up the offset between groups of these southwest- and northeast-tilted blocks.

2.7–2.4 Ma. About 2.7-2.4 million years ago the basalt of Hogback Mountain (unit Thb) and basaltic andesite of Cove Point (unit Tcba) poured out across a landscape that was probably similar to the present topography but with much less relief. The extensional faulting allowed magma from deep in the Earth's mantle to rise more quickly toward the surface than in earlier times, so there was not as much time for magma to exsolve volatiles or mix with melted crustal rocks. Many of these lava flows have small angular vesicles indicative of exsolution of volatiles after the flows reached the surface and began to crystallize. The basalt of Hogback Mountain also has a high titanium (TiO2) content similar to other basalt erupted during crustal extension in the Basin and Range province (e.g. Hart and others, 1984) and Cascades (Priest and others, 1983; Priest, 1989). When these flows spread out on the surface, the ones around Cove Point sank into the soft unconsolidated sediment of a lake, while flows at Hogback Mountain mainly flowed onto stream or deltaic sediments and quickly built up a shield volcano of subaerial flows. Magmatic processes that led to eruption of these two units and contemporaneous unit Tba2 favored entrainment of clumps of partially crystallized magma (olivine and plagioclase feldspar), giving most of the flows a distinctive glomeroporphyritic texture. Magma probably paused within the Earth's crust long enough to form mats of crystals that were continually disrupted by fresh intrusions of magma.

2.4–1.8 Ma. Between 2.4 and 1.8 million years ago, the faulted topography began to look more like the current landscape as volcanic activity decreased, forming by 1.8 Ma a belt of basalt vents located immediately west of the area and in the High Cascades. Overall extension of the Earth's crust at this time allowed erupting magma to rise through the crust even faster than before. Transit time was so fast that very little dissolved water was able to exsolve out of the basalt flows, so when they erupted, they were highly fluid, rapidly spreading out in thin layers that puffed up when the dissolved water was finally driven out of solution by cooling and crystallization. This process causes the numerous angular vesicles and large crystals termed diktytaxitic texture characteristic of the basalt of Wocus Marsh. The flows covered a surface of consolidated mudstone on the southwest side of the area, flowing over a surface that was mainly free of lakes, the area having already undergone normal faulting, uplift, and erosion. The basalt of Wocus Marsh appears to thin out toward the east along a north-northeast trending line that was probably an old valley wall; the wall was controlled in part by a north-northeast-striking fault (fault A, Figure 3.4).

Basins subsided at Upper Klamath Lake and probably in the Altamont area, allowing persistent lakes to collect hundreds of meters of tuffaceous, diatomaceous mud. The lower part of this stack of mud compacted and lost water, converting the material to mudstone.

A unique volcanic eruption at the area now occupied by the Ponderosa Junior High School formed a 50-m-thick mound of broken rock and still-hot lava fragments that spread out over the lake bottom; the resulting deposit is the tuff of Ponderosa Junior High School. The soft cream-colored mud of the lake allowed the hot, steaming mound of broken material to sink into the lake bottom. The age of this eruption is not known. It could have been as early as 4-6 Ma, but the association with thick sections of diatomaceous mudstone in the Altamont area is consistent with a eruption in the 2.4–1.8 Ma time interval, while a fairly deep lake still persisted in the sedimentary basin at Altamont.

The eruption near the Ponderosa Junior High School was roughly contemporaneous with violent venting of steam and basaltic glass shards (ash-size tachylite glass) from N. 20° W.-trending fissures 1 km east of the present site of the school.

Both the tuff of Ponderosa Junior High School and the diatreme dikes left behind by the fissure eruptions are evidence of basaltic magma intruding into the lake sediments, flashing ground water to steam, and blasting out mixtures of country rock, lake sediment, and quenched, broken fragments of the magma itself. The phreatic (steam) eruptions were probably the last gasp of volcanic activity within the map area.

1.8–1.1 Ma. Between 1.1 and 1.8 Ma volcanic activity ceased in the map area but continued in adjacent areas to the north and west. The Upper Klamath Lake and Altamont basins continued to subside even as sediment from lakes and streams filled the basins. The lower parts of these deposits are chiefly lake and deltaic sediments that accumulated in the latest Pliocene, whereas the upper part is characterized in some areas by alluvial fan gravels that spread out at the base of the largest ridges like Hogback Mountain. These sediments are the sedimentary rocks of Foothills Drive (unit QTfs). Owing to the cessation of local volcanic activity, sediment accumulated much less rapidly, and the resulting sandstone in the lower part of unit QTfs is much better sorted, rounded, and generally finer-grained than sandstone deposited earlier (unit Ts). Minerals (for example, orthopyroxene and phenocrystic quartz) in these fine-grained sandstone beds are not common in volcanic rocks of the local area, suggesting sources outside the map area brought in by either streams or air fall ash. Gravels in the uppermost part of unit QTfs appear to be derived from erosion of local volcanic rocks. The upward change from fine-grained sediment to locally derived gravels and sands may have been caused by a change in climate from the Pliocene to the colder, wetter glacial climates of the Pleistocene. Increased rainfall probably led to greater discharge from streams during glacial times, so coarser sediment could be mobilized from local highlands.

At Hogback Mountain the top of sedimentary rocks of Foothills Drive is at elevations as high as 1,420 m (4,700 feet), while the base is at ~1,270 m (4,180 feet), suggesting that 150 m of the unit accumulated on top of the ~400 m of lake deposits (diatomaceous mudstone) of unit Tm in the Altamont basin. This 150 m is a maximum thickness, since these rocks have been cut and uplifted an unknown amount on the Hogback Mountain Fault (Figure 3.4). Nevertheless, it is clear that the sedimentary basin at Altamont was at one time filled to higher elevations than at present and that this fill helped consolidate unit Tpt and the underlying ~400 m of mudstone in unit Tm.

After 1.1 Ma. Sometime after 1.1 Ma, a radical change occurred; instead of the basin at Altamont filling with sediment, sediment was flushed out of the area, probably down some newly opened river outlet. How and where this occurred is not clear. One possibility is that an ancestral Klamath River eroded its headwall back through the High Cascades and into the Klamath Basin at this time, so sediment could for the first time escape to the sea. Indeed, a lava flow at the top of the Klamath River gorge in the Topsy Grade area of the High Cascades has an age of 1.1 Ma, suggesting that headward erosion of the river crossed the High Cascades sometime after 1.1 Ma (Gravley, 1996). In areas of uplift or with low rates of subsidence, like the Altamont area, the sedimentary rocks of Foothills Drive were exposed to erosion. Increased river discharge possibly caused by climate changes, episodically bursting ice dams in the High Cascades, and glacial melting at the end of each ice age stripped away from the map area most of the sedimentary rocks of Foothills Drive. Boulder deposits up to 30 m thick beneath Link River could be deposits left behind by these Pleistocene rivers.

Basins like the Klamath graben in Upper Klamath Lake, Wocus Marsh, and Round Lake probably subsided and trapped sediment even as sediment was being stripped out of other areas after 1.1 Ma. For example, at Round Lake and Wocus Marsh, the upper 50 m of sediment was deposited in the last 1.4 million years (Adam and others, 1994, 1995). From gravity data, Veen (1982) infers that 0.4–1.2 km of sedimentary deposits probably fill the Klamath Graben north of Modoc Point in Upper Klamath Lake.

About 0.9 Ma, renewed volcanic activity occurred immediately north of the map area at Bald Hill. This volcano appears to be on the extension of the northwest-trending normal fault that passes through the OIT and the Ponderosa Junior High School. This fault is probably still active, as it cuts the Bald Hill rocks and appears to conduct upwelling geothermal water through its fracture systems (see discussion of geothermal resources below).

As explained above, crustal deformation is ongoing, so Klamath Falls is still affected by the same forces that started 3-4 million years ago. The 1993 earthquakes are a harbinger of possibly larger earthquakes that may occur in the future on faults within the city (see Wiley and others [1993] and Bacon and others [1999] for more information).

Extensive glaciers of the last Pleistocene ice age are now gone from the High Cascades, so rivers have only modest flow—much less than during melting of the last glaciers. The low flow of the streams coupled with the dry climate and growing needs of the local population has led to water quality and quantity problems.

5.0 GEOLOGIC HAZARDS

5.1 MINERAL RESOURCES

Aggregate. All of the lava flow units in the area (units Tba, Ta, Tla, Thb, and Thb) can be or have been used as sources for crushed aggregate. The conglomerate of unit Tg has also been excavated for aggregate, as have similar rocks within the uppermost part of unit QTfs in the Old Fort Klamath Road area. Units Qal, Qac, and Qc have been used locally as fill. Gravel within unit Qal can be used for aggregate.

Diatomite. Diatomite deposits occur throughout unit Tm and locally in unit Qs and QTfs, but none have been exploited for commercial production. Peterson and McIntyre (1970) identified four surface exposures that may have commercial potential (see geologic map).

Mercury. Ancient hot springs deposits surround OIT and are mapped as hydrothermal alteration (see geologic map). Mercury in the form of the red mineral cinnabar is commonly deposited in such rocks by hot springs. Peterson and McIntyre (1970) show one such occurrence in the OIT area (see geologic map).

5.2 WATER RESOURCES

5.2.1 Overview of Geologic and Hydrologic Resources

For a more detailed discussion of geologic and hydrologic resources, see Peterson and McIntyre (1970). An in-depth analysis of the hydrologic and hydrothermal systems is given by Sammel (1980); the following is a brief summary.

Groundwater. The water table (top of the zone of ground-water saturation) may be pictured as forming a gently undulating surface that looks like the local topography but with lower relief. The surface of the Earth intersects the water table at lakes and perennial streams. Excessive withdrawal of ground water can lower the water table over large areas, causing shallow water wells to dry up. In some cases a lowered water table can cause perennial streams to lose rather than gain water from stretches of a stream where the water table has been lowered. A high water table does just the opposite, adding water to the stream channel.

Finding the water table in a well does not mean that the well produces adequate water. A permeable zone of water-saturated rock or soil (an aquifer) must be present as well. Local aquifers are mainly in stream sand and gravel, the equivalent rocks (sandstone and conglomerate), or in lava flows. Highly fractured zones at the base or top of lava flows generally produce large amounts of water. Mudstone of unit Tm is nearly impermeable to water and confines aquifers contained within it. In some cases these confined aquifers have water pressure high enough to produce artesian wells. Much of the Altamont area is underlain by a thick section of mudstone, which makes it necessary to drill over 400 m to reach confined lava flow aquifers adequate for large-scale municipal or commercial uses. Total depths of wells listed in Table A1 and on the geologic map give a good indication of how deep to drill for productive aquifers in a given area. Table A1 also lists rock types intercepted at various depths. These rock types are interpreted from well logs filed with the Oregon Water Resources Department (OWRD) by water well drillers who are not generally trained in geology, so there is considerable uncertainty about the actual rocks penetrated; nevertheless, it may be inferred that parts of wells interpreted to intercept units Qal, QTfs, QTwb, Tcba, Thb, Tba2, Ths, Tbv, Tla, Ta, Tba, Tbas, Tg, and Ts may contain adequate flows of ground water, if located below the water table. Fracturing of rock can greatly increase its permeability, hence fault zones are often desirable targets for water wells. Wells should be sited to penetrate fault zones in one or more of the above units below the water table, taking into account the possible inclination (dip) of the fault zone. The cross sections on the geologic map give an approximation of what inclination faults typically have, but detailed, site-specific geologic and geophysical investigations can give a much better estimate. Keep in mind that the geologic map shows only the fault zones that could be easily recognized from mapping outcrops or interpreting water well data. There are many more faults that remain undiscovered. These faults may be found with appropriate geological and geophysical investigations of individual sites.

5.2.2 Water and Geothermal Well Data

Water Well Database. Depths, temperatures, and hydrologic information for water wells are taken from files of the OWRD. No well location was plotted unless there was some corroborating evidence that the listed location was at least approximately correct (e.g., listed address matching the plotted location, similarity of data to adjacent wells, etc.). Wells are plotted with different symbols depending on accuracy of the location. In some instances the locations are from field surveys; in others, the location is from the information supplied in the water well registration information, which locates the well to the quarter-quarter section level. In a few cases, even though the location is given at the quarter-quarter section level, other information on the registration form (e.g., address) allowed a better approximation (generally within about 50 m) of the actual well location. As OWRD field-locates wells, the locations are modified in their database. New wells are also regularly added to the database at OWRD. Check their web site at http://egov.oregon.gov/OWRD/ for the most recent information on water wells. Water well logs can be directly downloaded from submenus within this web site. The well number field in Table A1 corresponds to the OWRD log identification number. All well logs in Table A1 are in Klamath County.

Geologic unit assignments in Table A1 are derived from interpretations of lithologic descriptions in OWRD records. These descriptions are often ambiguous with respect to actual lithology, because water well drillers are not trained geologists. Unit assignments and parts of the cross sections based on well data must therefore be considered speculative. Wells shown in cross sections are projected along the inferred northwest strike of the rocks to the section; only surveyed, field-located wells are shown in cross sections.

5.3 GEOTHERMAL RESOURCES

Geothermal Well Spreadsheet. A geothermal well database consisting of two data sets, one for the City of Klamath Falls and one for Klamath County, were provided by OIT. These data were used for the data points in Figure 5.1. No attempt was made to merge or correlate this data set with Table A1 OWRD data. Accuracy and precision of these well locations and listed temperatures is not known. The raw data sets are included on the CD-ROM as spreadsheet and GIS files.

Geothermal systems are still active in an elongate area parallel to the northwest striking fault from OIT to Ponderosa Junior High School (Figure 5.1). Warm (63–71°C) aquifers have been intersected at Miller Hill and Stukel Mountain (Figure 5.1). Many wells in and near OIT, Pacific Terrace, and Ponderosa Junior High School have water at or near boiling temperatures and are used for direct heat applications, including a municipal district heating system. Homeowners generally extract heat from wells by use of heat exchangers, whereas the municipal system pumps and reinjects hot water. Wells deep enough to test for electric generation potential (150–200°C) have not been drilled, but fluids of this temperature could be present (Peterson and McIntyre, 1970; Mariner and others, 1980). For example, one of the OIT geothermal wells (well 6) has a reservoir temperature of 185°C estimated by the sulfate-water method (Mariner and others, 1980).

Figure 5.2 illustrates how rapidly temperature increases with depth in the map area. Figure 5.2 is based on the assumption that all temperatures in the two well spreadsheets represent approximate bottom-hole temperatures and that the ambient ground temperature is about 10°C (Gerald Black, personal communication, 2002), so gradients are calculated by dividing temperature minus 10°C by total depth. Obviously, temperatures are actually measured water temperatures, which represent a mixture of all water flows encountered, so this is not a true representation of the actual gradient. Nevertheless, this calculation gives some crude indication of temperature gradient, as most wells stop drilling shortly after they penetrate into a significant aquifer that contributes much of the water to the well.

The natural background temperature gradient is approximately 30–60°C/km in this area, on the basis of some of the deeper water wells. Areas of background gradient are shown approximately by the blue colors in Figure 5.2. In these areas one would need to drill to depths of 2-3 km to get temperatures high enough to be of interest for direct use heating. Anomalously high gradients occur in much of downtown Klamath Falls to Link River, from OIT to Ponderosa Junior High School, several areas of Altamont, at Miller Hill, and at Stukel Mountain. Many of these high gradients are based on temperatures measured in shallow wells, so they may not persist at depth. High gradients from shallow wells in mudstone of units Tm or Tms are particularly hard to project to greater depth, because these rocks have low thermal conductivity (they are insulators that store heat) relative to hard rocks like lavas, sandstone, conglomerate, or altered, vein-quartz flooded rocks that may lie at depth. If these more thermally conductive rocks lie below, then temperature gradient will be lower than in the overlying mudstone. Nevertheless, it is possible that deeper drilling in areas with high gradients may yield significant hot water at relatively shallow depths.

Targeting areas at depth that have potentially high fracture permeability is the best way to improve the chances of getting geothermal resources. Good targets include fault zones and lava flows. Parts of fault zones cutting brittle rocks like sandstone, conglomerate, lava flows, or silicified rock units are particularly likely to be permeable. Areas of combined high gradient and faulting are apparent on Figure 5.3. Predicting where these fault zones cut brittle rocks deep enough to be hot requires detailed geological exploration and analysis.

5.4 EARTHQUAKE AND MASS WASTING HAZARDS

Earthquakes. The main geologic hazard is earthquake shaking and associated slope instabilities. A map showing areas most vulnerable to earthquake shaking was produced by Black and others (2000) and is available from the Oregon Department of Geology and Mineral Industries (web site: http://www.oregongeology.com). Youthful faulting on long (~ 70 km) fault zones and the two ~Mw 6.0 earthquakes on September 21, 1993, (Figure 3.3) clearly argue for the possibility of large (~magnitude 7) earthquakes in the future (e.g., Bacon and others, 1999). Any area with soft soil will tend to amplify ground shaking, particularly if the soft soil is underlain by hard rock. Areas with loose silty or sandy soil and high ground-water table, as around Upper Klamath Lake, Lake Ewauna, and the Klamath River, could experience liquefaction during an earthquake. Soil turns to the consistency of quicksand when liquefied by ground shak-

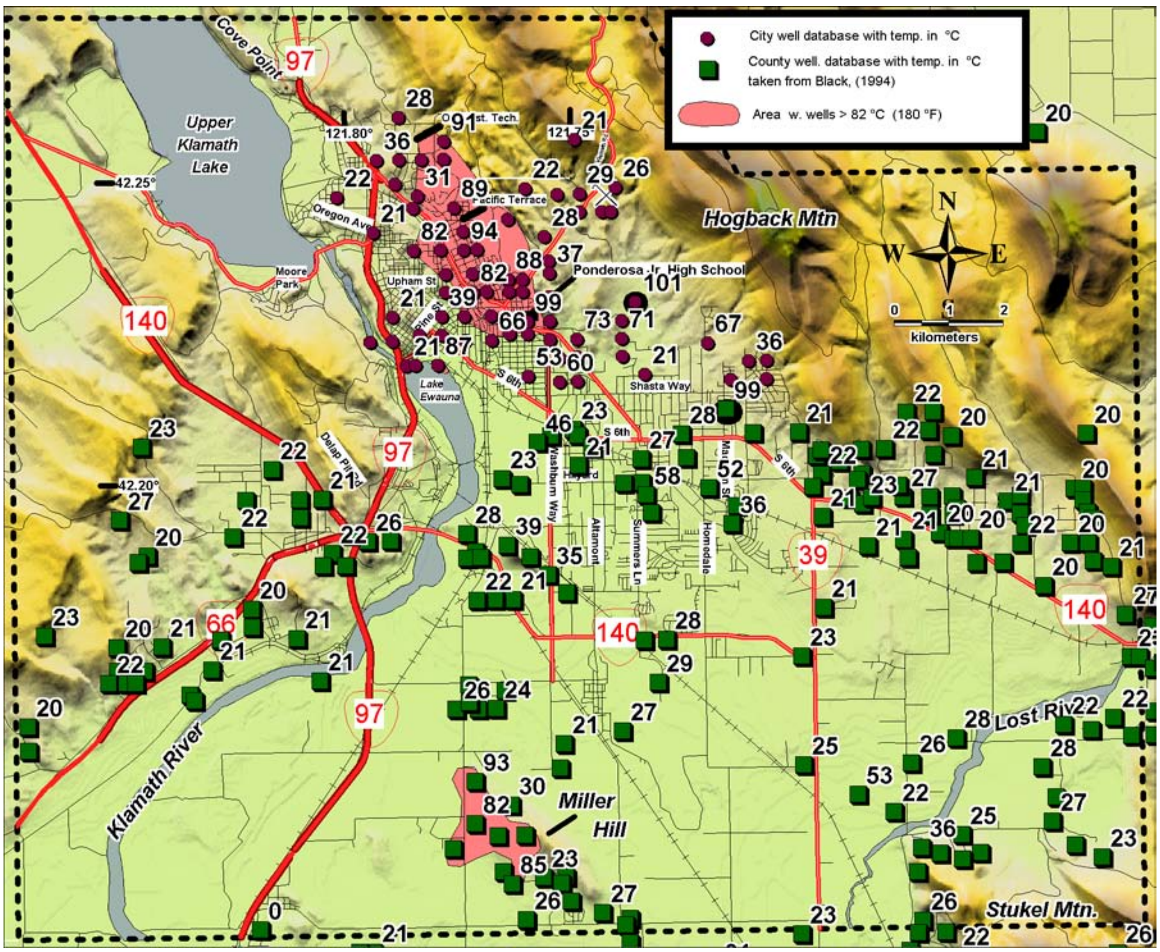

Figure 5.1. Well temperatures for the mapped area (in degrees Centigrade); red areas indicate where wells have intercepted rock at temperatures greater than 82°C (180°F), a temperature useful for direct-use geothermal heating applications. The fact that a well has a relatively low temperature does not mean that the area lacks higher temperatures. The well may be a shallow well that never reached deep enough to be hot. Consult the digital spreadsheet Geoth_KlamCounty_FINAL2.xls and OITcitywells_FINAL.xls files directly and see Figure 5.2 for a map of how quickly temperature increases with depth in the area. Some of the data points have more than one well in a small area, but a temperature label for only one of the wells will show in this map view of the data; that temperature may or may not be the highest one in that area. The areas highlighted in red take into account the highest temperature wells for each such area of closely spaced wells. Warmer colors on the base map indicate higher elevations; Ore. Inst. Tech. is Oregon Institute of Technology.

ing. In liquefied material dense, heavy things like buildings sink; buoyant, light things like buried fuel tanks rise; and very gentle slopes can slide, particularly if there is a cut like a riverbank at the end of the slope. This sliding of liquefied material is called lateral spreading and can tear buildings, roads, and bridges apart.

The other major slope stability hazard is from rock falls on steep slopes. Rock falls can be a problem wherever rock units composed of lava form a substantial part of a steep slope. Road cuts create particularly steep slopes, so vehicle traffic is inevitably located next to some of the most dangerous rock fall hazards. Rock falls could be severe during an earthquake. The only fatality from the 1993 earthquakes resulted from a rock fall striking a moving vehicle.

Active Fault Displacement. If fault rupture during an earthquake is large enough, it can propagate to the surface, displacing roads and buildings. Any mapped fault in the area might produce such displacement, as fault activity was

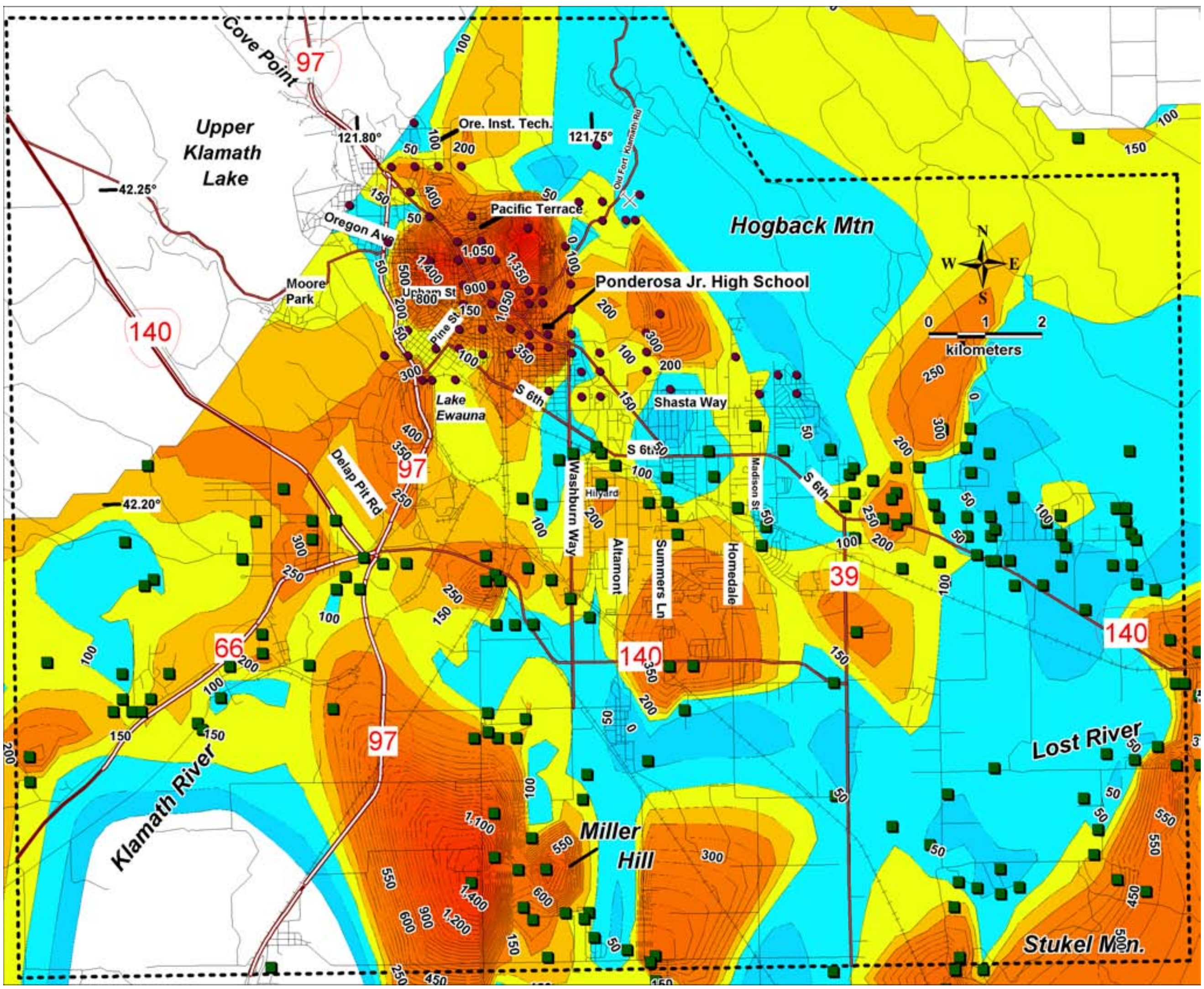

Figure 5.2. Contour map of geothermal gradients in the map area at intervals of 50°C/km. Areas with widely spaced well data do not have accurate contours and should be disregarded. Examples are the areas east and west of Miller Hill, the Delap Pit Road-Moore Park area, and Hogback Mountain. White areas have data spaced at such wide intervals that the contouring program did not produce contours. Gradients shown are crude estimates at best; they are calculated by subtracting the regional ambient surface temperature of 10°C (Gerald Black, personal communication, 2002) from the well temperature and dividing by the total depth of the well. Accurate temperature gradients can only be calculated by measuring temperatures at intervals throughout the length of a well.

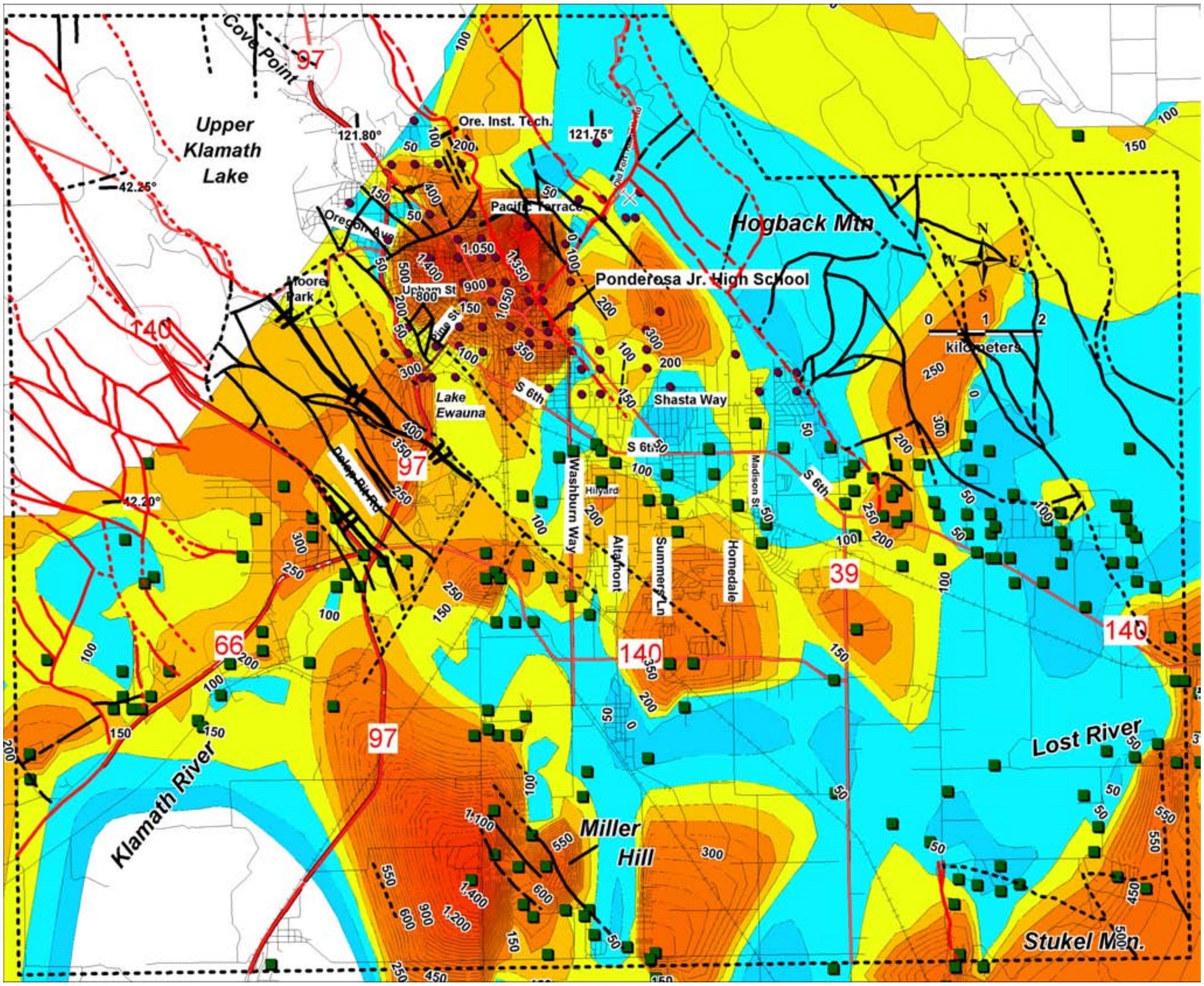

Figure 5.3. Geothermal gradients and faults in the map area. Gradients are contoured at intervals of 50°C/km. Faults may be areas of higher fracturing of rock units, leading to higher permeability and more likelihood of good flow of geothermal fluid. Brittle rock units like lava flows, sandstone, conglomerate, and silicified (quartz-flooded) rocks are more likely to have open fractures that carry water. Hot water is more likely to be found at shallow depth in areas where temperature gradients are high. Good geologic reasoning based on detailed, site-specific geological and geophysical data should be used to infer where and at what depth faults intercept brittle rocks.

hard to determine in most cases. The faults marked in red on the map probably have somewhat higher potential for damaging offsets. In some cases, active faults can displace the surface gradually with little or no earthquake shaking; this process is called fault creep. It is possible that some portion of the ground deformation at Ponderosa Junior High School could be from active fault creep. A review of existing seismic data for microseismicity on the fault projected through the school would be a low-cost first step in evaluating whether fault creep is occurring. A detailed tectonic analysis of the pattern of ground displacement would also be very useful and relatively inexpensive. If resources are available, active monitoring of seismicity with a local seismograph array could yield valuable information. Monitoring of displacement of the ground (strain measurements) would be a useful addition to monitoring of displacements of the school buildings currently being done by the school district.

Landslides. Relatively few landslides were mapped, so landslides are not a major hazard. The few that were mapped are in weathered sedimentary beds of units Tm and Tpt. The small number of landslides is probably a function of the dry climate, but should an earthquake occur during an unusually wet winter when ground water tables are high, landslides could pose a threat. Indeed, there are a few large landslides immediately outside the map area (see Sherrod and Pickthorn, 1992). The small number of landslides in the study area probably indicates that the coincidence of an earthquake with an extremely high water table is a rare event.

Expansive Soils. Clay-rich soil derived mainly from sedimentary units Tm, Tms, or Tpt is composed of minerals that swell when wet but shrink when dried. These soils, unless removed or stabilized by engineering techniques, can crack pavement and foundations. Some of the cracking of pavement in the parking lot of the Ponderosa Junior High School could be from expansive soils.

Subsidence. Damage can occur when ground water is withdrawn on a large enough scale to cause subsidence. Previously discussed correlation of ground-water changes with deformation of buildings at Ponderosa Junior High School is an example. Reinjection of water such as the hot water used for geothermal heating can reduce or eliminate subsidence.

5.5 VOLCANIC HAZARDS

Volcanic activity is concentrated tens of kilometers to the west and northwest in the High Cascades. It is possible that some ash could fall on the area from High Cascades eruptions, but this would likely not be a devastating hazard unless coming from the large volcanic centers at Crater Lake or, possibly, Mount Shasta. Eruption from Crater Lake could cause the caldera lake to be ejected. Should this occur, hot volcanic mudflows of large volume would flow down the sides of the volcano, probably reaching Upper Klamath Lake. Influx of these flows and associated hot air fall ash could degrade the quality of lake and stream water. The shallow depth of the lake would probably render insignificant any tsunami hazard to Klamath Falls from large-scale influx of volcanic mudflows, although temporary flooding of low-lying areas might occur due to displacement of lake water.

6.0 ACKNOWLEDGEMENTS

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8.0 APPENDIX A: WATER WELL DATA

Table A1. Water Well Data*

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
1	2214	965	4	130	88	Qs, 0-12, Tm, 12-951, Tba? or Th	121.760214	42.200148
2	2491	415	319	50	72	Qc, 0-3, Tm?, 3-11, Tcba, 11-141, Tm +Tcba, 141-283, Tm, 283-327, Tba?, 327-415	121.821261	42.269887
3	2502	154	40	60	49	Tm, 0-17, Tba, 17-19, Tm, 19-54, Ts, 54-130, Tm, 130-153, Tba, 153-154	121.843174	42.244447
4	2505	240	8	30	54	Qs? w. sand + Qc boulders, 0-80, Tm? brown clay, 80-240	121.833646	42.240084
5	2506	214	12	30	53	Qs organic silt, 0-9, Tm? clay, 9-198, Ts? cem. gravel, 198-214	121.819563	42.233082
6	2508	235	7	30	60	Qs clay + gravel, 0-3, Tm, 3-200, Tba, 200-235	121.837086	42.241098
7	10014	62	12	10	54	QTfs?, 0-33, Tms, 33-62	121.695993	42.186007
8	10019	166	19	30	59	QTfs, 0-11, Ts, 11-51, Tms, 51-73, Ts, 73-114, Tm, 114-148	121.688137	42.188635
9	10139	360	65	800	80	QTfs, 0-29, Tms, 29-290, Tba, 290-360	121.67398	42.196415
10	10179	219	2	1700	68	Qal, 0-23, Tm, 23-59, Tba, 59--219	121.7918	42.221796
11	10187	501	315	30	89	Tm, 0-304, Tba, 304-501	121.753877	42.242802
12	10200	684	8	25	80	Qs, 0-2, Tms, 2-13, Tm, 13-118, Tms, 118-147, Tm, 147-550, Tm?, 550-684	121.750174	42.200381
13	10232	500	144	14	65	Tms, 0-208, Tba, 208-249, Tm, 249-500	121.749925	42.24795
14	10264	309	125	200	70	Tm, 0-278, Tba, 278-309	121.809237	42.200126
15	10274	59	4	12	56	Qs, 0-12, Ts, 12-59	121.735395	42.134791
16	10302	286	118	30	54	Tba?, 0-46, Tm, 46-92, Tba?, 92-103, Tms, 103-206, Tba, 206-225, Tm, 225-243, Tba, 243-286	121.862835	42.163758
17	10350	545	25	25	151	Qs, 0-.5, Tba? or Thb?, .5-15, Tms, 15-67, Tm, 67-511, Tms, 511-545	121.76664	42.222906
18	10367	196	13	18	78	Qs, 0-3, Tms, 3-118, Ts, 118-124, Tm, 124-168, Ts, 168-181, Tms, 181-196	121.779414	42.16366
19	10380	430	341	0	0	Tms, 0-331, Tba?, 331-341	121.754861	42.244416
20	10390	1675	173	1000	109	Tms, 0-210, Hard silicified? Tms?, 210 -518, Tba?, 518-995, Tms?, 995-1078, Tba?, 1078-1675	121.789173	42.254971
21	10419	832	28	2	66	Qs, 0-3, Tm, 3-568, Ts, 568-576, Tm, 576-832	121.706061	42.152514
22	10476	335	296	30	63	Tm, 0-77, Tba, 77-182, Ts, 182-296, Tba, 296-308, Tm, 308-335	121.842946	42.196442
23	10581	250	54	1500	64	Tm, 0-97, Tba, 97-250	121.833205	42.211261
24	10600	225	94	60	64	Tm, 0-87, Tba?, 87-225	121.823537	42.207618
25	10718	862	25	15	60	QTfs, 0-11, Tms, 11-862	121.686056	42.17848
26	10719	90	5	40	55	Qs, 0-3, Tm, 3-8, Ts, 8-42, Tm, 42, 78, Ts, 78-90	121.681593	42.15649
27	10747	781	7	900	92	Qs, 0-12, Tm, 12-530, Tba? or Thb?, 530-781	121.774589	42.215936
28	10750	233	13	400	62	Tm, 0-63, Ts, 63-90, Tba, 63-233	121.779663	42.20016
29	10766	103	25	25	58	Tm, 0-24, Ts, 24-90, Tm, 90-103	121.681523	42.16723
30	10768	850	50	220	80	QTfs, 0-24, Tms, 24-730, Tba, 730-850	121.666874	42.189156

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
31	10770	402	36	25	64	QTfs, 0-23; Tm, 23-370, Tg, 370-402	121.686131	42.193094
32	10782	685	446	20	82	QTfs, 0-49, Tba?, 49-79, Tm?, 79-89, Ts?, 89-96, Tm?, 96-112, Ts?, 117-129, Tba, 129-190, Tm?, 190-222, Ts?, 222-234, Tm, 234-264, Tba, 264-271, Tm?, 271-322, Ts?, 322-363, Ts?, 363-373, Tm, 373-439, Ts?, 438-462, Tm, 462-572, Tba, 572-633, Tms, 633-685	121.721097	42.231903
33	10802	319	89	20	66	Tm, 0-74, Tms?, 74-319	121.813807	42.193141
34	10809	104	15	40	62	Qs, 0-3, Tm, 3-69, Ts, 69-83, Tba, 83-104	121.814607	42.133564
35	10822	488	80	700	79	Tm, 0-271, Ts, 271-303, Tba, 303-488	121.837485	42.205592
36	10921	575	92	750	70	Tms, 0-374, Tba, 374-575	121.677549	42.200408
37	10961	449	30	450	68	Mf, 0-5, Tm, 5-193, Ts or Tba?, 193-449	121.798473	42.183832
38	10966	134	13	10	50	Qs, 0-4, Tms, 4-134	121.784244	42.174901
39	11001	455	335	24	77	Tg, 0-3, Tba, 3-455	121.845453	42.191015
40	11135	555	14	20	87	Soil of Ts varying hardness with depth 0-3, Ts, 3-18, Tm, 18-152, Tms, 152-540	121.686424	42.141949
41	11159	454	138	250	65	Ts, 0-6, Tba?, 6-8, Ts?, 8-10, Tba?, 10-12, Tms, 12-454	121.785486	42.206084
42	11223	200	79	29	52	Tm?, 0-24, Tba,24-118, Tm, 118-194, Ts, 194-200	121.847648	42.248036
43	11251	150	11	300	56	Qc + Qs, 0-8, Tba, 8-150	121.84368	42.254327
44	11258	743	390	20	74	QTfs, 0-57, Tm?, 57-79, Ts?, 79-86, Tm?, 86-95, Ts?, 95-147, Tm, 147-166, Ts?, 166-171, Tm, 171-312, Tba, 312-743	121.748655	42.251627
45	11260	70	14	20	57	Qac, 0-56, Tm, 56-59, Ts, 59-70	121.688911	42.169118
46	11266	411	189	25	69	QTfs, 0-57, Tm, 57-203, Ts, 203-205, Tm, 205-384, Tms, 384-409, Tm, 409-411	121.745081	42.247918
47	11474	964	18	30	79	Qs, 0-4, Ts, 4-17, Tm (clay), 17-125, Ts, 125-126, Tm (clay), 126-934, Ts, 934-944, Tm (shale), 944-964	121.696076	42.163852
48	11544	309	33	1300	59	Qs, 0-27; QTwb, 27-309	121.857944	42.239218
49	11630	120	14	20	52	Qs, 0-6, Tm?, 6-82, Tm? + Tg?, 82-94, Tba?, 94-120	121.809015	42.273345
50	11631	88	12	25	55	Qac, 0-3, Tm? + Tg?, 3-50, Tba?, 50-88	121.801766	42.275056
51	11643	610	106	1000	58	Tm, 0-12, Tba, 12-610	121.7745	42.273566
52	11655	816	105	25	0	Tms, 0-454, Tba?, 454-816	121.789471	42.258926
53	11657	246	37	100	62	Qs, 0-20, Tba, 20-169, Tm, 169-234, Tba, 234-246	121.811313	42.26055
54	11658	210	143	45	56	Tm + Tg, 0-35, Tm, 35-58, Tba?, 58-68, Tm, 68-85, Tba, 85-210	121.803902	42.269521
55	11659	280	97	150	64	Tm, 0-1, Tba, 1-20, Tm, 20-37, Tba, 37-84, Tm, 84-236, Tba, 236-241, Tm, 241-249, Tba, 249-265, Tm, 265-267, Tba, 267-280	121.809032	42.263357
56	11669	170	28	15	0	Qac, 0-16, Tm, 16-56, Tba, 56-170	121.808739	42.269531
57	11671	267	7	40	60	Mf?, 0-20, Tm, 20-55, Ts, 55-58, Tm, 58-92, Tms, 92-100, Tm, 100-161, Tms, 161-165, Tm, 165-258, Tms, 258-267	121.812456	42.254871
58	11672	349	8	20	60	Mf?, 0-15, Tm?, 15-112, Ts, 112-115, Tm, 115-160, Tms, 160-180, Tm, 180-275, Ts, 275-276, Tm, 276-336, Ts + Tg, 336-349	121.813831	42.251237

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
59	11674	1021	9	1700	62	Qs, 0-5, Tm, 5-9, Ts, 9-15, Tm, 15-223, Tba, 223-365, Ts, 365-376, Tm, 376-565, Tba, 565-785, Tm, 785-962, Tba, 962-1021	121.804715	42.250126
60	11676	120	27	20	0	Tm, 0-95, Ts, 95-120	121.808583	42.245209
61	11679	188	132	2	81	Mf, 0-3, Tm, 3-66; Tms?, 66-188	121.750206	42.233203
62	11821	530	462	90	0	Ts, 0-6, Tm, 6-411, Tba, 411-530	121.790343	42.24426
63	11824	929	299	30	170	Qac, 0-12, Tm, 12-260, Tba?, 260-312, Tm?, 312-409, Tg?, 409-511, Ts?, 511-549, Tg?, 549-639, Tm?, 639-654, Tg?, 654-663, Ts?, 663-692, Tba?, 692-818, Tg?, 818-929	121.778026	42.243383
64	11825	1205	449	500	92	Tba, 0-43, Tg, 56-58, Tm, 58-68, Tba, 68-1205	121.779343	42.257143
65	11826	1288	333	105	182	Tms, 0-135, Tba?, 135-191, Tm?, 191-197, Tba?, 197-208, Tm?, 208-238, Tba?, 238-1288	121.781216	42.253812
66	11828	1224	315	330	87	Tms, 0-50, Tba?, 50-86, Tms?, 86-157, Tba?, 157-163, Tms?, 163-240, Tba?, 240-1224	121.780594	42.25572
67	11829	1805	359	250	146	Tms, 0-278, Tba, 278-305, Tms?, 305-315, Tba?, 315-380, Tms?, 380-472, Tba?, 472-1805	121.781716	42.252374
68	11829	1805	146	181	0	Tm, 0-278, Tba, 278-1805	121.784548	42.244146
69	11830	1716	358	470	194	Tms, 0-106, Tba?, 106-1700, Ts?, 1700-1716	121.780171	42.252546
70	11833	1584	323	400	196	Tms, 0-841, Tba?, 841-1584	121.783155	42.253619
71	11836	314	86	250	74	Tms, 0-314	121.784762	42.251068
72	11837	371	234	125	97	Tms, 0-332, Tba?, 332-371	121.785381	42.251178
73	11844	500	34	35	71	Tm, 0-226, Ts?, 226-500	121.759533	42.248352
74	11848	0	0	0	0	QTfs (gravel facies), 0-58, QTfs (mudstone +sand), 58-96	121.740124	42.251533
75	11855	696	385	60	79	QTfs, 0-130, Tms, 130-394, Ts?, 394-393, Tm?, 398-583, Tba? or Thb?, 583-696	121.74021	42.247865
76	11863	374	196	30	91	Tm, 0-108, Tba? or Thb?, 108-374	121.754992	42.236851
77	11868	243	149	0	196	Qc, 0-5; Tba, 5-8, Tms, 8-145, Tba, 145-243	121.774617	42.240295
78	12019	400	0	50	0	no record, 0-150, Tms?, 150-378, no record, 378-400	121.768547	42.228907
79	12021	300	0	300	198	Qac, 0-14, Tm, 14-40, Tg, 40-43, Tm, 43-137, Tms?, 137-245, Tba?, 245-250, Tm, 250-300	121.77023	42.228975
80	12042	250	15	0	198	Qc, 0-2; Tm, 2-34, Tba, 34-250	121.76729	42.234916
81	12046	240	-1	350	0	0-223, no data, Tba (hot aquifer), 223-228, no data, 228-240	121.778864	42.229771
82	12047	455	0	0	217	Qc, 0-10, Tba, 10-255, Tm, 255-385, Tba:385-456	121.772026	42.238505
83	12050	900	60	0	0	Tm, 0-108, Tba, 108-138, Tm, 138-226, Tba, 226-360, Tm, 360-465, Tba, 465-565, Tg?, 565-640, Tba, 640-900	121.765007	42.230245
84	12051	364	60	280	0	Tm, 0-325, Tba, 325-364	121.769875	42.22952
85	12062	193	85	0	220	Tm, 0-136, Tba, 136-193	121.765972	42.23135
86	12066	448	65	0	180	Tm, 0-92, Tba, 92-448	121.774612	42.236772
87	12073	600	140	60	208	Qc, 0-5, Tm, 5-68, Tba, 68-600	121.778075	42.237892
88	12076	840	8	0	130	Qac, 0-5, Tm, 5-77, Tba, 77-145, Tm, 145-160, Tba, 160-215, Tm, 215-314, Tba, 314-336, Tm, 336-384, Tba, 384-429, Tm, 429-814, Tba, 814-840	121.779965	42.229261

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
89	12082	170	0	0	208	Qc, 0-9, Tm, 9-117, Tba, 117-170	121.777125	42.239757
90	12084	272	0	0	0	Mf + Qac +Tm, 0-30, Tba, 30-80, Tm, 80-215, Tba, 215-272	121.778604	42.233156
91	12085	625	80	0	0	Qc boulders, 0-20, Tm?, 20-170, Tba, 170-625	121.789478	42.240159
92	12086	330	0	0	202	no data, 0-242, Tba, 242-330	121.779229	42.234341
93	12098	187	160	75	0	Qal boulders, 0-15, Tba, 15-40, Tm, 40-170, Tba, 170-187	121.793623	42.223308
94	12101	263	0	65	72	Qs, 0-4, Tm,4-79, Tba, 79-263	121.782099	42.223523
95	12102	627	-1	4200	70	Qal, 0-56, Tba, 56-278, Tm?, 278-417, Tba, 417-452, Tm, 452-520, Tba, 520-553, Tm, 553-556, Tba, 556-627	121.791353	42.221589
96	12111	35	4	10	58	Qal, 0-14, Tm, 14-26, Ts, 26-35	121.79116	42.219214
97	12115	125	5	210	71	Qal boulders, 0-10, Tba, 28-125	121.792221	42.222337
98	12116	155	16	15	64	Qs, 0-3, Tm, 3-40, Tba, 40-155	121.784727	42.22353
99	12117	500	156	30	68	Tba, 0-500	121.789476	42.221954
100	12118	1069	8	275	74	Tm, 0-310, Tba, 310-425, Tm, 425-551, Tba?, 551-692, Tm, 692-874, Tba?, 874-914, Tm, 914-941, Tba?, 941-949, Tm, 949-1053, Tba?, 1053-1069	121.778293	42.21773
101	12121	435	0	4600	68	Qal boulders, 0-100, Tba, 100-227, Tm, 227-331, Tba, 331-435	121.791949	42.222114
102	12129	406	25	0	230	Tm, 0-269, Tba? or Thb?, 269-406.5	121.760131	42.225703
103	12131	679	0	50	176	Qs, 0-5, Tm, 5-15, Tba? or Thb?, 12-20, Tms, 20-70, Tba? or Thb?, 70-85	121.764977	42.223939
104	12137	710	35	50	200	Qac, 0-5, Tm, 5-174, Tba, 174-180, Tm?, 180-302, Tba, 302-307, Tm, 307-312, Tba, 312-314, Tm, 314-337, Tba?, 337-340, Tm, 340-412, Tba, 412-511, Tm, 511-554, Tba, 554-555, Tm, 555-640, Tba, 640-643, Tm, 643-661, Tba, 661-663, Tm, 663-672, Tba, 672-675	121.768783	42.228094
105	12138	367	30	80	200	Tm, 0-140, Tms, 140-155, Tm, 155-246, Tba? or Thb?, 246-275, Tm?, 275-305, Tba? or Thb?, 305-318, Tm?, 318-331, Tba? or Thb?, 331-349, Tm, 349-367	121.762256	42.226379
106	12141	545	8	10	0	no record, 0-480, Tba? or Thb?, 480-545	121.768077	42.226621
107	12143	800	0	250	192	Tm, 0-142, Ts, 142-147, Tm, 147-437, Tg, 437-438, Tm?, 438-458, Tba, 458-505, Tm, 505-545, Tba, 545-553, Tm, 553-654, Tba, 654-668, Tg, 668-670, Tm, 670-684, Tba? or Thb?, 684-699, Tm, 699-712, Tba? or Thb?, 712-800, D/T,425/140,500/154,550/165,575/155,	121.766391	42.224387
108	12147	545	40	10	152	Tm?, 0-425, Tba? or Thb?, 425-545	121.757547	42.223092
109	12149	1220	7	75	130	Tm, 0-858, Tba? or Thb?, 858-874, Tm, 874-909, Tba? or Thb?, 909-935, Tm, 935-961, Tba? or Thb?, 961-1035, Tm, 1035-1051, Tba? or Thb?, 1051-1128, Tm, 1128-1169, Tba?, 1169-1173, Tm, 1173-1187, Tms, 1187-1220	121.754859	42.225788
110	12155	1400	8	175	127	Qs, 0-4, Tms, 4-1173, Tba? or Thb?, 1173-1400	121.757525	42.214638
111	12162	1401	366	760	151	Tm, 0-850, Tba? or Thb?, 850-1401	121.747765	42.223427

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
112	12164	1529	42	430	160	Tm, 0-1254, Tba? Thb? Ts?, 1254-1303, Tba? or Thb?, 1303-1409, Tm, 1408-1421, Tba? or Thb?, 1421-1439, Tm, 1439-1479, Tba? or Thb?, 1479-1490, Tm, 1490-1494, Tba?-1494-1529	121.739292	42.217966
113	12167	530	135	750	0	QTfs, 0-28, Tms, 28-530	121.723098	42.215882
114	12182	970	0	225	75	Qc, 0-8, Ts, 8-150, Tba, 150-246, Tm, 246-276, Tba?, 276-389, Tm, 389-627, Tba, 627-710, Tm, 710-813, Tba, 813-970	121.705265	42.217032
115	12183	1100	354	100	80	Qc, 0-23, Ts (weathered), 23-100, Ts (hard), 100-108, Tba, 108-168, Ts?, 168-204, Tba, 204-244, Tm?,244-740, Tms?, 740-905, Tba?, 905-945, Tm, 935-980, Tba, 980-1040, Tba, 1070-1100	121.705253	42.216785
116	12185	580	150	225	58	Qac, 0-21, QTfs, 21-81, Tba?, 81-85, Ts?, 85-145, Tba?, 145-151, Ts?, 151-220, Tm, 220-330, Tg, 330-331, Tms, 331-388, Tba? or Thb?, 388-406, Tm, 406-503, Tg, 503-506, Tms, 503-580	121.710252	42.217563
117	12487	1000	230	710	69	QTfs, 0-28, Tm, 28-76, Ts, 76-92, Tm, 92-230, Tg, 239-276, Ts, 276-390, Tm, 390-980, Tba? or Thb?, 980-1000	121.705145	42.207744
118	12495	1562	0	450	0	QTfs, 0-20, Ts?, 20-145, Tm, 145-200, Tg +Tm?, 200-305, Tba? or Thb?, 305-310, Tm, 310-500, Ts, 500-520, Tm, 520-1190, Tba? or Thb?, 1190-1562	121.707689	42.20987
119	12518	300	10	5	56	Qac, 0-4, Tms, 6-300	121.738175	42.200511
120	12520	1520	-1	320	114	Qs, 0-8, Tms, 8-1040, Tba? or Thb?, 1040-1158, Tm, 1158-1520	121.759237	42.208775
121	12537	438	113	350	72	Tbv, 0-85, Tba, 85-126, Tms, 126-171, Ts?, 171-407, Tba?, 407-438	121.807965	42.191755
122	12548	131	100	18	0	Tms, 0-101, Tba, 101-131	121.803969	42.193043
123	12563	265	84	663	75	Ta?, 0-16, Ts, 16-68, Tba, 68-113, Ts?, 113-124, Tba, 124-265	121.793044	42.190282
124	12578	200	5	15	56	Qs, 0-1.3, Tm, 1.3-200	121.749741	42.195103
125	12579	667	5	10	66	Qs, 0-2, Tm, 2-380, Tms, 380-390, Tm, 390-667	121.749709	42.199223
126	12580	1210	16	450	136	Mf, 0-6, Tm, 6-780, Tg?, 780-782, Tm, 782-1098, Tba? or Thb?, 1098-1210	121.732954	42.197921
127	12588	110	25	35	52	QTfs?, 0-13, Tms, 13-110	121.702823	42.187748
128	12595	138	5	20	53	QTfs?, 0-3, Tms, 3-31, Tm, 31-125, Tms, 125-138	121.699363	42.191324
129	12601	95	13	8	50	Qs. 0-3. Tm, 3-95	121.708136	42.176465
130	12602	260	18	0	0	QTfs, 0-14, Ts, 14-20, Tm, 20-32, Ts, 32-40, Tm, 40-43, Ts, 43-65, Tg?, 65-87, Ts, 87-188, Tms, 188-205, Tg?, 205-210, Ts?, 210-252, Tm?, 252-260	121.699028	42.183757
131	12605	817	0	100	0	Tm, 0-75, Tba?, 75-817	121.818504	42.174128
132	12607	434	4	9	60	Qs, 0-4, Tms, 4-423	121.700974	42.171094
133	12609	155	42	60	82	Qs, 0-4, Tm, 4-9, Tba, 9-155	121.725588	42.175549
134	12616	122	4	3	0	Qs, 0-4, Tm, 4-122	121.725102	42.182053
135	12617	150	24	8	58	Tm, 0-150	121.73001	42.182161
136	12618	300	5	10	54	Qs, 0-3, Tm, 3-300	121.734781	42.182002

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
137	12619	640	0	50	0	Qs, 0-4, Tm, 4-640	121.723608	42.178491
138	12620	78	11	30	72	Tms, 3-31, Tba, 31-78	121.734921	42.174964
139	12622	215	5	8	0	Qs, 0-4, Tm, 4-215	121.72048	42.171258
140	12632	435	4	75	70	Qs, 0-15, Tm, 15-435	121.764523	42.178542
141	12633	200	10	8	58	No record, 0-23, Tm, 23-200	121.771704	42.180395
142	12635	40	8	50	60	Qs, 0-7, Tm, 7-40	121.774065	42.182258
143	12636	615	8	0	0	Qs, 0-6, Tm, 6-611, Tba, 611-615	121.77421	42.178639
144	12639	80	20	20	58	Qs, 0-16, Tm, 16-80	121.786973	42.176796
145	12640	190	18	40	86	Qs, 0-14, Tm, 14-196	121.794067	42.171506
146	12642	332	15	5	0	no record	121.794003	42.17492
147	12645	125	43	40	0	Tm, 0-58, Tba, 58-125	121.799007	42.181881
148	12653	545	94	1225	0	Tms, 0-65, Tba, 65-524	121.813673	42.174881
149	12657	92	13	10	61	Qs, 0-6, Tms, 6-92	121.789063	42.156453
150	12661	335	17	60	66	Qs, 0-12, Tm, 12-335	121.779552	42.156507
151	12667	105	4	15	67	Qs, 0-15, Tms, 15-105	121.769343	42.1822
152	12668	146	39	20	49	Qs, 0-1, Tm, 1-131, Ts, 131-139, Tm, 139-146	121.784358	42.156558
153	12670	329	12	20	0	QTfs, 0-3, Tm, 3-329	121.774739	42.156767
154	12678	200	7	20	60	No record, 0-55, Tm, 55-200	121.767321	42.162053
155	12683	300	12	10	0	Tm, 0-300	121.774344	42.167453
156	12690	554	16	40	0	Qs, 0-4, Tm, 4-520, Tba?, 520-554	121.774601	42.16392
157	12705	1388	6	0	85	Qs, 0-3, Tms, 3-1368; Tba, 1368-1388	121.732614	42.165782
158	12710	500	9	3	54	Qs, 0-10, Tm, 10-500	121.725624	42.156621
159	12719	425	10	5	60	Qs, 0-3, Tm, 3-425	121.712923	42.168474
160	12724	45	4	50	53	Qs, 0-3, Ts+Tg, 3-12, Tm, 12-17, Ts, 17-18, Tm, 18-35, Ts+Tg, 35-45	121.70122	42.149038
161	12727	102	15	30	53	Qs, 0-1, Tm, 1-8, Tms, 8-15, Tm, 15-19, Ts, 19-74, Tm, 74-81, Ts, 81-95, Tg?, 95-101, Tms, 101-102	121.698829	42.142252
162	12730	52	6	25	58	Qs, 0-2, Tms, 2-52	121.710867	42.152568
163	12737	135	18	1	0	Ts, 2-6, Tm, 6-21, Tg, 21-22, Tm, 22-135	121.708362	42.147253
164	12739	127	10	30	56	Qs, 0-10, Tm, 10-120, Ts, 120-127	121.752277	42.151082
165	12747	500	133	295	86	Tm, 0-52, Tba, 52-500	121.767294	42.147279
166	12748	298	165	0	216	Ts, 108-161, Tba, 161-298	121.768584	42.233235
167	12757	62	6	10	0	Ts, 3-17, Tm, 17-45, Ts?Tba?, 45-62	121.708153	42.161951
168	12758	65	4	15	0	Qs, 0-3, Ts, 3-15, Tm, 15-41, Ts, 41-61, Tm, 61-65	121.786627	42.147174
169	12759	173	60	35	58	Qs, 0-2, Tm, 2-24, Ts, 24-40, Tm, 40-50, Ts, 60-79, Tm, 79-160, Ts, 160-173	121.784502	42.149017
170	12768	340	25	90	62	Qal, 0-6, Tm, 6-340	121.808534	42.149043
171	12772	375	3	25	0	Tm, 0-355, Tba, 355-365, Tm, 365-375	121.813808	42.141924
172	12773	80	32	25	55	Tm, 0-34, Tba, 34-80	121.813917	42.127331
173	12781	80	20	15	56	Qs, 0-4, Tm, 4-73, Tms, 73-80	121.808821	42.130832
174	12784	177	12	20	0	Qs, 0-10, Tm, 10-162, Tba, 162-177	121.813423	42.130943

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
175	12785	93	1	20	55	Qs, 0-2, Tg, 2-6, Ts, 6-16, Tms, 16-93	121.794316	42.127426
176	12793	110	5	20	58	Tms, 0-110	121.774747	42.134684
177	12795	61	15	35	62	QTfs?, 0-3, Tm, 3-50, Tba, 50-61	121.745255	42.130944
178	12805	105	18	40	0	Qs, 0-4, Tms, 4-105	121.755244	42.127631
179	12813	500	135	240	88	Tm, 0-52, Tba, 52-500	121.754896	42.134781
180	12816	161	7	20	54	Qs, 0-13, Tm, 13-60, Ts (loose), 60-161	121.730673	42.131246
181	12817	57	4	30	0	Qs, 0-3, Ts, 3-10, Tm, 10-16, Tms, 10-38, Ts + Tg, 38-52, Tm, 52-57	121.728192	42.132965
182	12821	1050	29	85	98	Qs, 0-2.6, Ts (hardened), 2.6-7, Tm, 7-86, Tms, 86-305, Ts (loose, fine), 305-380, Tm (hardened), 380-1015, Tba, 1015-127, Tm, 1027-1035, Ts+Tg, 1035-1050	121.750233	42.127499
183	12825	49	6	15	0	Qs, 0-2, Tm, 2-49	121.715556	42.127349
184	12827	64	6	30	54	Qs, 0-5, Ts (loose), 5-30, Tm, 30-40, Ts (loose), 40-64	121.703606	42.129122
185	12843	227	56	60	74	Tms, 0-202; Tba, 202-227	121.678386	42.199786
186	12856	460	230	350	72	QTfs, 0-36, Tba, 36-42, Tm, 42-58, Tba, 58-61, Tm, 61-90, Tba, 90-93, Tm, 93-138, Ts, 138-156, Tm, 156-341, Tba, 341-349, Tm, 349-369, Tba, 369-460	121.698015	42.206521
187	12860	333	150	0	63	no data	121.691262	42.201538
188	12861	312	55	20	0	QTfs, 0-14, Tm, 14-275, Tba, 275-312	121.693479	42.187821
189	12864	338	20	10	69	Qac, 0-3,Tms, 3-338	121.686149	42.189503
190	12872	123	20	18	55	QTfs, 0-48, Tms, 48-123	121.688526	42.191326
191	12879	287	30	20	64	QTfs, 0-14, Tm, 14-185, Ts, 185-186, Tm, 186-244, Ts (hard), 244-276, Tba, 276-287	121.691039	42.185997
192	12886	720	87	42	82	QTfs, 0-15, Tms, 15-692, Tba, 692-720	121.67072	42.19912
193	12892	1080	62	75	86	no data, 0-590, Tm, 590-1036, Ts, 1036-1038, Tm, 1038-1046, Tba, 1046-1080	121.664356	42.188706
194	12893	285	40	75	0	no data	121.661021	42.190162
195	12944	406	43	420	72	Qc, 0-3, QTfs, 3-38, Tm, 38-353, Tms, 353-378, Tba, 378-406	121.679633	42.199057
196	12944	406	43	420	72	Qc, 0-3, QTfs, 3-38, Tm, 38-353, Tms, 353-378, Tba, 378-406	121.676342	42.196697
197	12997	503	115	35	56	QTfs, 0-7, Tm, 7-480, Tms, 480-503	121.649757	42.191219
198	12998	1090	91	75	69	QTfs, 0-6, Tm, 6-299, Tms, 299-307, Tm, 307-847, Ts, 857-860, Tm, 860-931, Tms, 931-938, Tm, 938-1050, Ts? Tba?, 1050-1090	121.656914	42.185859
199	13033	978	128	14	54	QTfs?, 0-39, Tm, 39-875, Tms, 875-978	121.653484	42.19588
200	13035	237	150	40	57	QTfs?, 0-36, Tm?, 36-105, Tms?, 105-127, Tm, 127-135, Tm?, 135-144, Tm, 144-158, Tba, 158-237	121.644735	42.194745
201	13062	451	128	16	56	Qc, 0-2, Tm, 2-330, Tms, 330-416, Tba, 416-451	121.648069	42.196537
202	13076	53	21	7	54	QTfs, 0-53	121.644925	42.18751
203	13085	850	281	30	69	Qc, 0-18, Tba, 18-28m Tm, 28-34, Tba, 34-92, Ts?, 92-150, Tms?, 150-166, Tba, 166-188, Tms?, 188-198, Tba, 198-210, Tms, 210-275, Tm, 275-850	121.63478	42.185675
204	13122	200	6	50	56	Qac, 0-13, Tm, 13-18, Ts, 18-200	121.671647	42.174832

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
205	13129	198	7	35	62	Qac, 0-15, Ts?, 15-130, Tm, 130-180, Tms, 180-195, Ts, 195-198	121.664367	42.172921
206	13136	453	43	15	64	QTfs, 0-17, Tms, 17-453	121.68129	42.178379
207	13139	319	10	4	54	QTfs, 0-4, Tm, 4-35, Ts, 35-52, Tms, 52-73, Tm, 73-319	121.691008	42.17849
208	13143	142	38	45	55	Mf, 0-2, Ts, 2-142	121.690871	42.182173
209	13148	300	0	0	0	Qac, 0-4, Tms, 4-21, Tm, 21-300 (dry hole so no water data)	121.686192	42.174889
210	13149	167	55	12	0	QTfs, 0-36, Tm, 36-50, Ts, 50-120, Tm, 120-150, Ts, 150-167	121.681211	42.1822
211	13153	102	23	300	0	QTfs, 0-27, Tg, 27-79, Tg + Ts, 79-102	121.696754	42.182414
212	13155	170	35	1000	56	QTfs, 0-23, Tms, 23-92, Tg, 92-97, Ts, 97-102, Ts + Tg, 97-170	121.696046	42.183312
213	13161	71	3	20	54	Qs, 0-2, Tm, 2-7, Ts, 7-12, Tm, 12-18, Ts, 18-44, Tm, 44-60, Ts, 60-71	121.68393	42.15825
214	13173	505	18	10	61	Qs, 0-2, Tms, 2-505	121.69593	42.167444
215	13224	114	6	20	54	Qs, 0-3, Tm, 3-7, Ts, 7-45, Tm, 45-55, Ts, 55-65, Tm, 65-114	121.693714	42.158362
216	13225	175	35	3	0	Ts, 3-8, Tm, 8-175	121.69618	42.160411
217	13232	63	18	25	53	Tm, 0-11, Ts, 11-63	121.67717	42.167659
218	13245	305	12	25	63	Qs, 0-2, Tm, 2-220, Tms, 220-225, Tm, 225-290, Ts?, 290-305	121.64967	42.162066
219	13246	87	10	40	52	Qs-0-4, Tms, 4-65, Ts, 65-70, Tm, 70-78, Tg, 78-80, Tm, 80-87	121.656796	42.156593
220	13248	344	9	188	66	Qs, 0-2, Tm, 2-315. Ts?, 315-344	121.644808	42.158333
221	13270	206	16	75	60	Qs, 0-2, Tms, 2-32, Tm, 32-37, Tms, 37-90, Tm, 90-206	121.632213	42.152771
222	13272	206	17	35	59	Qs, 0-2, Tm, 2-23, Ts, 23-31, Tms, 31-39, Tm, 39-50, Tms, 50-65, Tm, 65-206	121.642239	42.149085
223	13283	350	-1	25	0	Tm, 0-348, Tba, 348-350	121.643785	42.144028
224	13290	1210	-1	45	84	Qac, 0-5, Tm, 5-1135, Tba, 1135-1210	121.665984	42.141032
225	13293	88	5	20	52	Qs, 0-1, Tm, 1-8, Tg, 8-12, Tms, 12-18, Tg, 18-43, Tm, 43-58, Ts, 58-62, Tm, 62, 70, Tms, 70-78, Ts, 78-88	121.661665	42.149125
226	13295	112	16	100	61	Qs, 0-2, Tms, 2-112	121.695827	42.141979
227	13296	1506	2	1000	128	Qs, 0-4.5, Tm, 4.5-392, Ts, 392-432, Tm, 432-479, Ts, 479-491, Tm, 491-1116, Tba, 1116-1207, Tm, 1207-1220, Tba, 1220-1506	121.691304	42.151048
228	13298	845	31	100	72	Qs, 0-1, Ts, 1-9, Tm, 9-385, Ts, 385-388, Tm, 388-840, Ts, 840-845	121.681388	42.14909
229	13315	916	58	875	81	QTfs?, 0-24, Tm, 24-841, Tba, 841-916	121.665972	42.138345
230	13317	1185	-1	60	96	no data, 0-720, Tm, 720-1070, Ts, 1060-1062, Tm, 1062-1090, Ts, 1090-1092, Tm?, 1092-1114, Tba, 1114-1185	121.674161	42.140211
231	14060	540	81	1800	0	Qac, 0-2, Tba, 2-14, Tms?, 14-149, Tba, 149-286, Tm?, 286-428, Tba, 428-540	121.830589	42.206573
232	14086	242	44	40	66	Tm, 0-208, Tba, 208-242	121.833404	42.204026
233	14093	225	38	40	63	Tm, 0-155, Tba, 155-225	121.818839	42.203828

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
234	14103	150	43	10	66	Tm, 0-102, Tba, 102-150	121.818972	42.200235
235	14138	360	260	40	72	Tg, 0-10, Tba?, 10-20, Ts?, 20-46, Tba?, 46-69, Tm?, 46-127, Tms?, 127-211, Tba?, 211-360	121.847971	42.189381
236	14139	765	343	500	80	Tba, 0-765	121.850863	42.195213
237	14141	380	53	730	74	Qac, 0-5, Tba, 5-61, Tms, 61-248, Tba, 248-380	121.818602	42.198537
238	14148	145	23	38	66	Tm, 0-74, Tba, 74-145	121.83321	42.196589
239	14161	155	50	20	57	Tms, 0-155	121.819606	42.190792
240	14168	286	37	200	72	Tm, 0-23, Ts, 23-101, Tms, 101-186, Tba, 186-286	121.828311	42.192945
241	14182	133	16	18	59	Tm, 0-30, Tba, 30-76, Tms, 76-110, Tba, 110-133	121.832946	42.182049
242	14183	203	88	30	70	Qac, 0-3, Tba, 3-203	121.823446	42.178362
243	14184	366	2	700	68	Qs, 0-35, Ts, 35-95, Tm?, 95-224, Tba, 224-395	121.83423	42.172187
244	14186	165	48	24	60	Qc, 0-8, Tm, 8-135, Ts, 135-160, Tm, 160-168	121.816755	42.177762
245	14187	110	90	100	0	Qc, 0-14, Tm, 14-27, Tms, 14-52, Tbv, 52-103, Tba, 103-110	121.820897	42.180157
246	14188	817	28	100	0	Tm, 0-140, Tba, 140-817	121.818924	42.17461
247	14197	400	250	35	68	Qc, 0-5, Tm?, 5-36, Tba?, 36-400	121.852879	42.174693
248	14202	229	24	150	63	Tm, 0-143, Ts, 143-165, Tg, 165-171, Ts?, 171-212, Tm, 212-218, Ts, 218-222, Tm, 222-229	121.840515	42.171216
249	14211	135	52	20	64	Tm, 0-25, Tg, 25-45, Tm, 45-63, Tg, 63-88, Tm, 88-118, Tg, 118-125, Tba?, 125-135	121.844168	42.177313
250	14236	126	45	19	0	Ts, 0-6, Tm, 6-85, Tg, 85-105, Tm, 105-126	121.845343	42.176204
251	14239	220	137	35	70	Tm, 0-114, Tba?, 114-182	121.848081	42.171091
252	14241	175	146	30	47	Tg?Tba?, 0-111, Tm?, 111-160, Tba?, 160-195	121.843154	42.174595
253	14243	363	204	30	73	Qc, 0-34, Tba, 34-363	121.867557	42.174585
254	14254	415	57	1000	68	Qac, 0-6, Tm, 6-130, Tba, 130-415	121.833731	42.192134
255	14260	80	48	30	58	Tm, 0-10, Ts, 10-45, Tm, 45-61, Ts, 61-80	121.868461	42.158189
256	14264	177	120	30	60	Ts, 0-80, Tba, 80-177	121.865263	42.161796
257	14269	156	50	40	56	Tm, 0-74, Ts, 74-112, Tm, 112-156	121.857922	42.160019
258	14271	155	57	30	54	Tm, 0-143, Tba, 143-156	121.858002	42.163627
259	14275	170	38	75	54	Tm, 0-47, Ts, 47-56, Tm, 56-132, Ts, 132-170	121.85267	42.163521
260	14277	170	24	82	57	Qac, 0-3, Ts, 3-18, Tm, 18-60, Tba, 60-185	121.843121	42.167042
261	14295	175	64	15	0	Tms, 0-175	121.840539	42.165199
262	14299	110	27	22	54	Tm, 0-55, Tms, 55-110	121.847814	42.167026
263	14449	83	14	15	53	Tm, 0-75, Ts, 75-83	121.818543	42.130742
264	14451	155	28	55	62	Qs, 0-3, Tm, 3-133, Ts?, 133-155	121.823286	42.127201
265	14458	112	18	20	53	Qs, 0-4, Tm, 4-60, Tba, 60-62, Tms, 62-112	121.825581	42.132429
266	14468	145	14	30	66	Qs, 0-7, Tm + minor sands (soft), 7-47, Tms (hard), 47-95, Tg, 95-145	121.821048	42.128991
267	14478	140	12	500	58	Qs, 0-11, Tm, 0-144	121.823482	42.130798
268	14521	930	7	150	70	Qs, 0-4, Tm, 4-80, Ts, 80-86, Tms, 86-490, Tba, 490-510, Tm, 510-590, Tba, 590-593, Tm, 593-800, Tba, 800-815, Tm, 815-840, Tba, 840-858, Tm, 858-870, Tba, 870-879, Tm, 879-885, Tba, 885-930	121.801053	42.125824

Table A1. — continued

Map No.	Well No.	Total Depth, ft	Static Water Depth, ft	Flow, gpm	Temp, deg F	Stratigraphy (depth intervals in feet following unit names)	West Longitude	North Latitude
269	50045	12	6	5	0	Mf, 0-2, Tms, 2-12	121.804144	42.25117
270	50152	1111	135	75	67	QTfs, 0-35, Tm, 35-59, Tms, 59-96, Tm, 96-587, Tms, 587-601, Tm, 601-998, Tms, 998-1111	121.647298	42.189298
271	50173	84	58	18	54	QTfs, 0-5, Ts, 5-24, Tms, 24-56, Ts, 56-84	121.68151	42.171196
272	50197	125	8	12	56	QTfs, 0-47, Tms, 47-109, Tm, 109-125	121.695836	42.178591
273	50222	391	98	20	0	Ts, 0-198, Tm, 198-318, Ts, 318-391	121.789207	42.24077
274	50233	261	126	80	66	Tm, 0-11, Tba?, 11-261	121.84733	42.175707
275	50266	306	6	7	70	Qs, 0-14, Tm, 14-306	121.701147	42.152614
276	50269	98	5	15	50	Qs, 0-2, Tms, 2-98	121.719693	42.144969
277	50293	50	0	0	0	Tba 0-50'	121.805116	42.236243
278	50315	70	19	1000	0	Qs peat, 0-10', Qal boulders, 10-33; Tba 33-70'	121.804056	42.23896
279	50328	971	153	330	60	Qc, 0-27, Tm, 27-123, Ts, 123-128, Tm, 128-136, Ts, 136-139, Tm, 139-866, Tba, 866-971	121.644394	42.192742
280	50344	425	1	100	58	Qs, 0-5, Tm, 5-7, Ts, 7-40, Tm, 40-75, Tms, 75-395, Tm, 395-425	121.686302	42.163783
281	50365	613	10	300	62	Qs, 0-6, Ts, 6-9, Tba, 9-123, Tms, 123-261, Tba, 261-275, Tms, 261-522, Tba, 522-613	121.789385	42.189108
282	50379	338	49	640	72	Tm, 0-160, Tba, 160-338	121.83347	42.200432
283	50417	768	38	5	64	Qac, 0-5, Tba, 5-25, Tm, 25-40, Tms, 40-48, Tm, 48-117, Tms, 117-163, Tm, 163-197, Tms, 197-206, Tm, 206-230, Tms, 230-236, Tm, 236-458, Tms + Tg, 458-485, Tm, 485-768	121.642324	42.174798
284	50429	334	49	30	64	QTfs, 0-36, Tm, 36-297, Tba, 297-334	121.691073	42.193067
285	50447	875	200	2000	0	no data, 0-605, Tba? or Thb?, 605-711, Tm?, 711-875	121.747432	42.224554
286	50449	248	6	5	65	Qs, 0-5, Tms, 5-248	121.715291	42.167495
287	50468	398	328	22	58	Tcba, 0-335, Tm, 335-366, Tba?, 366-398	121.822767	42.27146
288	50598	130	72	28	60	Qac, 0-6, Tba? or Tg + Tm?, 6-11, Tms, 11-130	121.79904	42.26939
289	50600	300	18	150	120	no data; nearby well has Tba @ 595'	121.775217	42.225698
290	50616	15	7	0	0	Qs, 0-15	121.789547	42.236546
291	50617	15	7	0	0	Qs, 0-15	121.794374	42.236597
292	50643	22	0	0	0	Mf, 0-9, Qs, 9-22	121.804262	42.247537
293	50667	269	51	15	62	Tms, 0-269	121.823568	42.18937
294	50779	74	10	10	54	QTfs, 0-27, Tms, 27-62, Ts, 62-74	121.695787	42.193204

*Location and data for water wells from Oregon Department of Water Resources (ODWR) database; lithologic unit assignments are based on interpretations of the ODWR data.
Map no.: Integer identification number.
Well no.: Integer identification number from Oregon Department of Water Resources, accessible on the web at http://apps2.wrd.state.or.us/apps/gw/well_log/Default.aspx.
Total depth: Total depth in feet.
Static water depth: Depth in feet to standing water in the hole; 0 value generally indicates artesian flow.
Flow: Yield of pumped well in gallons per minute
Temp, degrees F: Temperature in degrees Fahrenheit of water; 0 indicates no temperature data.
Stratigraphy: Interpreted geologic units penetrated by well with depth intervals in feet following unit name; based on descriptions by water well drillers; queried where unit assignment is highly uncertain.