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Geologic Map of the Bryant Mountain and Langell Valley Quadrangles, Klamath County, Oregon

by

Margaret D. Jenks,
Oregon Department of Geology and Mineral Industries

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1.0 INTRODUCTION

The area covered by this map is located in south-central Oregon (Figure 1.1) in the central part of Klamath County. It is approximately 20 km east of the city of Klamath Falls, and the California/Oregon state border is the southern boundary of the map. The two principal geographic features in the area are Langell Valley, a broad, flat valley occupying the center of the map, and Bryant Mountain, a large, high-elevation area that occupies the western part of the map. The far southwest corner of the map includes a small portion of the larger Tule Lake Valley, which is located to the south and west of this mapped area. Langell Valley is drained by the Lost River, which runs down the center of the valley. Only two perennial streams drain the mapped area: Miller Creek, a major drainage on the east side of Langell Valley that connects the Gerber Reservoir with the Lost River, and Mills Creek, a small stream on the southwest side of Bryant Mountain, which ends when it reaches the valley floor. No towns are located within the mapped area, and the land is principally used for cattle ranching and hay production.

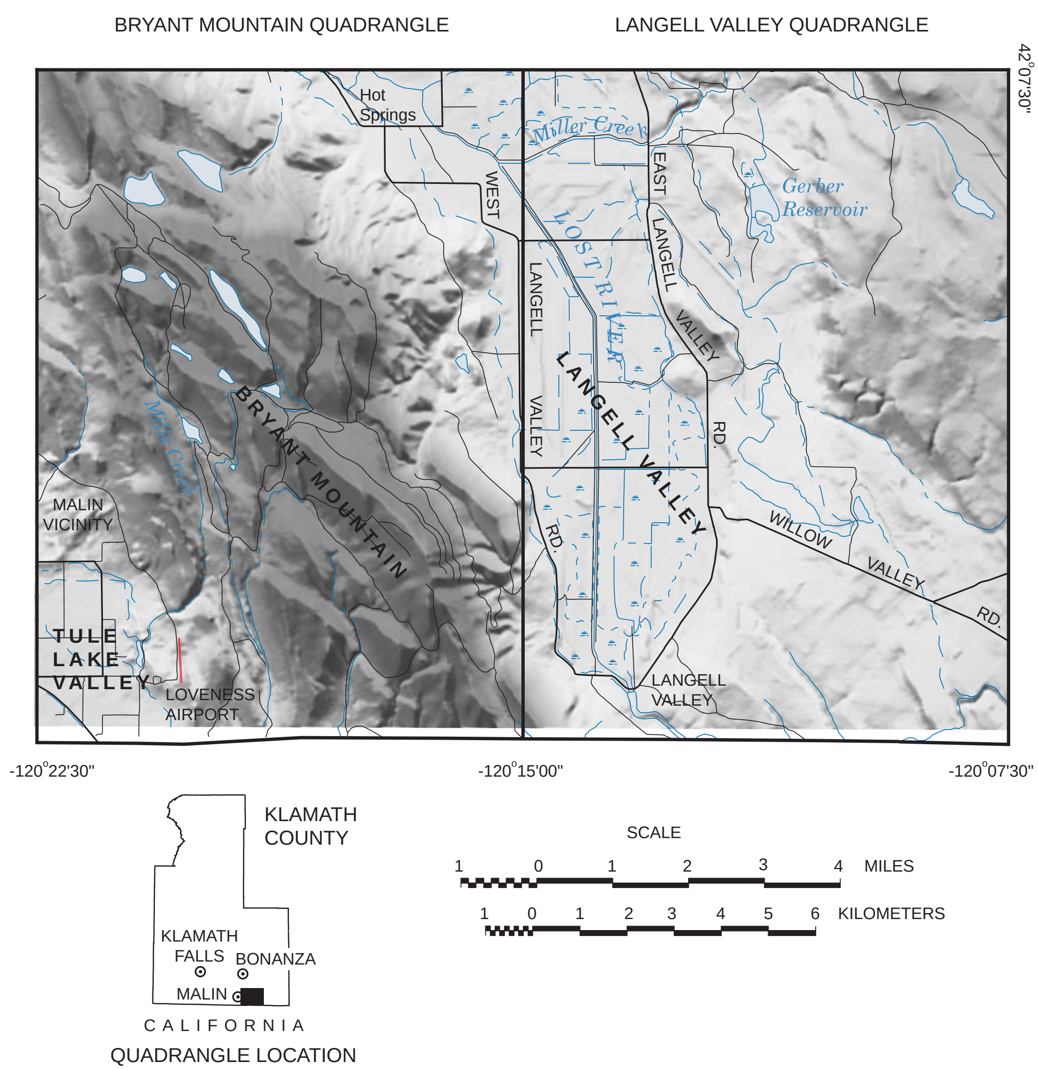

Figure 1.1. A shaded relief image of the Bryant Mountain and Langell Valley quadrangles, Klamath County, Oregon, showing locations of geographic features.

1.1 PREVIOUS WORK

The area was previously included in two geologic maps, both 1:250,000 scale (Peterson and McIntrye, 1970; Sherrod and Pickthorn, 1992). This map is the first 1:24,000 scale map of the area. The field work was completed during the summer and fall, 1999. Figure 1.2 shows the locations of stations where information was gathered in red and the traverses around each station location in blue. These traverses are superimposed on the geologic map.

1.2 ANALYTICAL METHODS

1.2.1 Geochemistry

The forty-one geochemical samples listed in Table 1.1 were analyzed by Dr. Stanley A. Mertzman, Franklin and Marshall College, Lancaster, Pennsylvania. The samples were collected from the massive interior portions of the lava flows, with care being taken to avoid areas of alteration or significant post-eruption deposits in the flow's vesicles. The whole-rock analyses for major and trace elements

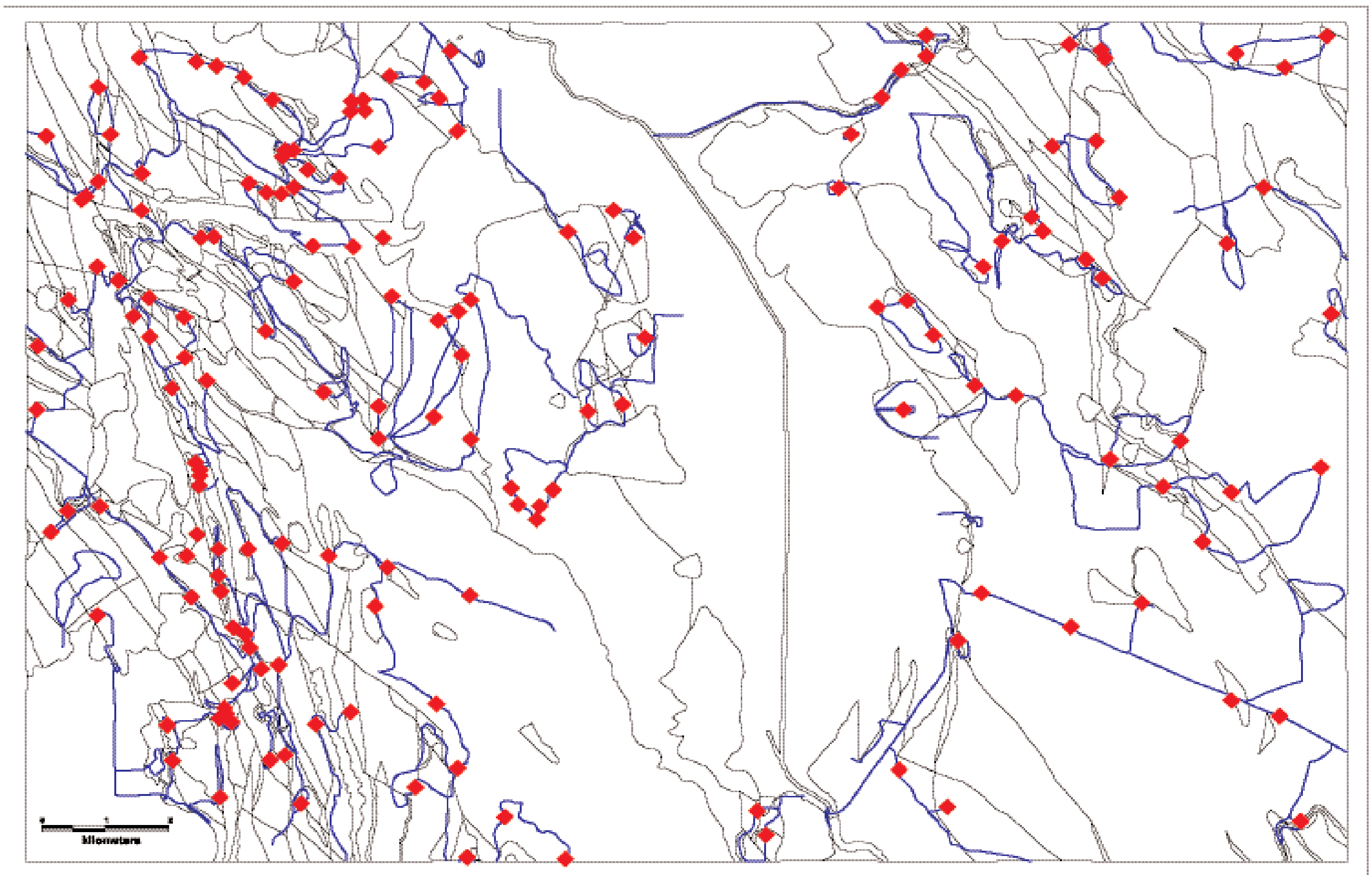

Figure 1.2. Traverse map showing the locations of stations (field locations) where information was gathered (red diamonds) and the traverse routes around each station location (blue lines). These traverses are superimposed on the geologic map of the quadrangles (see GMS117map.pdf for geologic map explanation).

were performed using a Phillips 2404 X-ray fluorescence vacuum spectrometer equipped with a 102 position sample changer. The Loss on Ignition (LOI) was determined by heating accurately pre-weighed amounts of sample rock powder to 950° C for one hour, and then reweighing the sample to determine the relative percentage of weight gain and loss. The amount of ferrous Fe was titrated using a modified Reichen and Fahey (1962) method. Also listed in Table 1.1 are the analyses on the dated samples from Mallin and Hart's (1991) age determination paper.

1.2.2 Age Determination

Mallin and Hart (1991) published four whole-rock K/Ar age determinations (Table 1.2), from samples located within the mapped area, from master's research by Mallin at Miami of Ohio University (1989). In addition, Dr. Robert Duncan of Oregon State University provided three new whole-rock Ar^{40}/Ar^{39} age determinations (Table 1.2) on samples from units located within or near the boundaries of this present mapping. (Note: the location of sample KM86-56 (Mallin, 1989) is not sufficient to place this sample with certainty within the Bryant Mountain quadrangle, and thus the age on this sample is not included in the following discussion.) The published whole rock K/Ar age, 7.32 ± 0.24 Ma, for the undivided basaltic andesite (unit Tba) is relatively equivalent to the new whole rock Ar^{40}/Ar^{39} age determination of 8.18± 0.12 Ma for the similar trachyandesite of Gift Butte (Tgb). These dates place the age of the basaltic andesite volcanism within the middle Miocene era. In addition, the new whole rock Ar^{40}/Ar^{39} 5.25±0.58 Ma age of the Brady Butte basalt flows brackets all of the basaltic flows on the east side of Langell Valley as late Miocene to early Pliocene. The flows from Brady Butte are located just east of the Langell Valley quadrangle and are the top of the volcanic stratigraphic section within the east Langell Valley area. This date also is in the range of dates published by Sherrod and Pickthorn (1992) from samples on the Goodlow Mountain Rim and Horsefly Mountain, both within the Langell Valley area.

The new and previously published age determinations on the basalt units on top of Bryant Mountain create some confusion as to the period during which those flows erupted. Mallin and Hart's (1991) published whole rock K/Ar ages for two samples from the basalt section on the top of Bryant Mountain, 5.67 ± 0.17 Ma and 4.98 ± 0.22 Ma, are in variance with the new 7.33 ± 0.77 Ma whole rock Ar^{40}/Ar^{39} date published here. The sample for this new date comes from the uppermost flow of the basalt of Captain Jack Lake (unit Tcj), the uppermost unit throughout the north side of Bryant Mountain. The small amount of interstitial glass in this seriate texture, coarsely diktytaxitic basalt and the resulting low K_20 content of this sample, 0.35%, gives a small yield of radiogenic Ar^{40} (Table 1.2). This accounts for the relatively large age date uncertainty associated with this sample (R.A. Duncan, 2000, personal communication), and possibly for the older age date. Mallin (1989) gives K_2O percentages of 0.38 and 0.23, respectively, for his two age determinations, which also may have skewed those K/Ar ages. In general, Mallin's K/Ar ages on the subaerial basalt flows of Bryant Mountain are more similar to ages on possibly equivalent subaerial flows around the region, than the new Ar^{40}/Ar^{39} age from this present mapping.

Table 1.1. Major Oxide and trace element composition, Bryant Mountain, Langell Valley, and adjoining quadrangles, Klamath County, Oregon.

Map number	Station number	Sample number	Location: 1/4	1/4	Sec.	T. (S.)	R. (E.)	UTM Coordinates[1] (N)	UTM Coordinates[1] (E)	Quadrangle	Unit	Lithology	Basaltic province affinity	Major Oxides[2]: SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	**Total**
A	BRY991116-4	BRY991116-4	NW	NE	10	41	13	642,780.26	4,654,815.38	Bryant Mtn.	Tba	Basaltic andesite		55.04	0.98	17.31	2.67	5.03	0.15	4.15	6.91	3.86	2.18	0.58	0.99	**99.85**
B	MJ99-094	JN-03	SW	SW	19	40	13	636,960.40	4,659,759.49	Bryant Mtn.	Tlp	Basalt	Snake River Plain	48.56	1.31	16.86	3.68	6.95	0.18	7.51	9.75	2.98	0.50	0.29	0.94	**99.51**
C	JN-21	JN-20	NW	SE	34	40	13	638,323.05	4,663,471.64	Bryant Mtn.	Tcj	Basalt	Snake River Plain	48.17	1.04	17.98	4.34	5.70	0.18	7.32	9.89	3.04	0.44	0.28	1.26	**99.64**
D	JN-9	JN-25	NW	NW	17	40	13	642,652.82	4,657,004.77	Bryant Mtn.	Tba	Basaltic andesite		52.33	1.21	17.37	2.89	6.19	0.18	4.63	6.89	4.06	1.69	0.78	1.72	**99.94**
E	MJ99-004	MJ99-002	NW	NE	29	40	14	648,751.67	4,659,583.73	Langell Valley	Tgb	Basaltic andesite		57.19	0.91	17.17	2.27	4.70	0.14	3.63	6.25	3.73	2.47	0.52	1.13	**100.11**
F	MJ99-007	MJ99-005	NW	SE	5	41	14	649,165.09	4,655,638.00	Langell Valley	Twv	Basalt	Transitional	48.09	0.94	17.31	2.71	7.08	0.17	8.84	10.90	2.63	0.21	0.11	1.04	**100.03**
G	MJ99-012	MJ99-009	SE	SE	32	40	14	649,324.60	4,656,790.52	Langell Valley	Ttr	Basalt	Transitional	47.63	0.89	17.96	6.76	3.79	0.18	7.95	11.41	2.55	0.16	0.10	1.11	**100.49**
H	MJ99-012	MJ99-010	SE	SE	32	40	14	649,324.60	4,656,790.52	Langell Valley	Twv	Basalt	Transitional	47.35	0.86	17.37	1.86	7.82	0.19	9.43	11.02	2.41	0.32	0.10	1.53	**100.26**
I	MJ99-012	MJ99-011	SE	SE	32	40	14	649,324.60	4,656,790.52	Langell Valley	Twv	Basalt	Transitional	48.00	0.84	17.90	3.26	6.26	0.20	8.44	11.20	2.57	0.19	0.14	1.25	**100.25**
J	MJ99-021	MJ99-020	NE	SE	12	40	13	645,763.87	4,663,587.39	Langell Valley	Twv	Water affected basalt		46.03	0.84	17.19	2.98	6.57	0.18	10.17	9.66	2.13	0.19	0.10	4.36	**100.40**
K	MJ99-031	MJ99-030	SW	SE	31	40	14.5	656,782.05	4,657,276.21	Brady Butte	Tbb	Basalt	Transitional	47.85	1.04	17.38	3.02	6.96	0.17	8.81	10.69	2.56	0.21	0.13	1.46	**100.28**
L	MJ99-031	MJ99-031	SW	SE	31	40	14.5	656,782.05	4,657,276.21	Brady Butte	Twv	Basalt	Transitional	48.25	1.12	17.49	3.64	6.78	0.18	7.84	10.80	2.79	0.31	0.17	0.87	**100.24**
M	MJ99-033	MJ99-033	NW	NW	14	41	14.5	662,753.64	4,653,211.92	Brady Butte	Tbb	Basalt	Transitional	47.95	1.08	17.16	2.88	7.41	0.18	8.24	11.24	2.69	0.21	0.13	0.92	**100.09**
N	MJ99-034	MJ99-034	NE	NW	23	41	14.5	663,426.79	4,651,614.27	Brady Butte	Tbb	Basalt	Transitional	47.96	1.13	17.23	0.64	9.58	0.18	8.48	10.90	2.73	0.26	0.15	0.96	**100.20**
O	MJ99-038	MJ99-037		SE	30	40	14.5	653,415.81	4,660,694.67	Langell Valley	Tcr	Basalt	Transitional	47.96	1.02	18.04	3.94	6.26	0.17	7.84	10.84	2.88	0.31	0.17	0.83	**100.26**
P	MJ99-042	MJ99-040	SW	SW	27	40	14	651,499.21	4,658,543.17	Langell Valley	Tgb	Basaltic andesite		57.06	0.90	17.20	2.52	4.62	0.14	3.69	6.28	3.79	2.47	0.52	1.02	**100.21**
Q	MJ99-042	MJ99-041	SW	SW	27	40	14	651,499.21	4,658,543.17	Langell Valley	Tgb	Basaltic andesite		56.81	0.89	17.01	2.49	4.64	0.14	3.62	6.22	3.78	2.46	0.52	1.19	**99.77**
R	MJ99-042	MJ99-042	SW	SW	27	40	14	651,499.21	4,658,543.17	Langell Valley	Twv	Basalt	Transitional	47.83	1.14	17.20	2.33	7.50	0.17	8.96	10.82	2.61	0.27	0.17	1.17	**100.17**
S	MJ99-043	MJ99-043	SW	SE	27	40	14	652,020.80	4,658,572.24	Langell Valley	Tcr	Basalt	Basin and Range?	47.75	0.85	17.23	3.47	6.64	0.18	8.93	11.20	2.45	0.20	0.12	1.11	**100.13**
T	MJ99-044	MJ99-044	SE	SE	27	40	14	652,687.94	4,658,570.77	Langell Valley	Tcr	Basalt	Basin and Range?	47.55	0.87	17.41	3.46	6.69	0.18	8.99	11.36	2.46	0.22	0.13	0.94	**100.26**
U	MJ99-046	MJ99-046	NE	NE	33	40	14	650,855.43	4,657,974.56	Langell Valley	Twv	Basalt	Transitional	47.69	0.88	17.55	3.16	6.86	0.19	8.60	11.27	2.58	0.20	0.12	1.17	**100.27**
V	MJ99-056	MJ99-053	SW	NW	16	40	14	649,425.39	4,662,535.02	Langell Valley	Tbl	Basalt	Snake River Plain	47.44	1.58	16.37	3.70	8.10	0.22	7.59	9.76	2.99	0.47	0.43	1.04	**99.69**
W	MJ99-060	MJ99-055	SE	NW	16	40	14	650,057.19	4,662,512.29	Langell Valley	Tml	Basalt	Transitional	48.04	1.05	17.69	4.76	5.66	0.19	7.37	11.03	2.68	0.27	0.18	1.11	**100.03**
X	MJ99-066	MJ99-061	NW	NW	11	40	14	652,791.78	4,664,639.64	Langell Valley	Tdh	Basalt	Basin and Range?	47.90	0.85	17.00	3.57	6.54	0.18	8.71	11.73	2.40	0.16	0.10	0.87	**100.01**
Y	MJ99-072	MJ99-065	SE	SE	7	41	13	638,192.34	4,653,289.35	Bryant Mtn.	Tmiu	Basalt	Basin and Range	47.91	0.67	17.62	3.34	5.80	0.18	8.82	11.60	2.35	0.14	0.11	1.08	**99.62**
Z	MJ99-081	MJ99-071	SE	SW	23	40	12	633,778.89	4,659,917.24	Malin		Basalt		48.25	1.27	16.59	2.03	8.81	0.19	7.92	10.00	2.95	0.36	0.27	0.94	**99.58**
AA	MJ99-082	MJ99-072	NW	SE	24	40	12	635,904.91	4,660,118.94	Bryant Mtn.	Tcj	Basalt	Snake River Plain	47.70	1.43	17.43	4.98	6.79	0.20	6.59	10.01	3.08	0.35	0.33	0.82	**99.71**
BB	MJ99-087	MJ99-078	SW	SW	24	40	12	635,130.46	4,659,935.95	Bryant Mtn.	Tcj	Basalt	Snake River Plain	47.99	1.63	16.76	6.27	6.10	0.20	6.20	9.84	2.99	0.35	0.36	1.02	**99.71**
CC	MJ99-103	MJ99-087	NE	SW	1	41	12	635,767.67	4,655,560.44	Bryant Mtn.	Tsb	Basalt	Basin and Range	47.83	0.85	17.01	3.81	6.07	0.18	8.70	11.55	2.44	0.18	0.13	0.82	**99.57**
DD	MJ99-113	MJ99-103	SW	SW	7	40	13	636,698.98	4,663,115.46	Bryant Mtn.	Tsr	Basalt	Basin and Range	47.15	0.86	17.56	3.41	6.16	0.17	9.05	11.32	2.43	0.12	0.08	1.27	**99.58**
EE	MJ99-134	MJ99-120		E	13	41	12	636,571.54	4,652,443.01	Bryant Mtn.	Tgr	Basalt	Basin and Range	47.48	0.96	16.94	1.38	8.46	0.19	9.08	11.48	2.49	0.22	0.15	0.80	**99.63**
FF	MJ99-142	MJ99-122	SE	SE	6	41	13	638,267.50	4,655,145.43	Bryant Mtn.	Tmiu	Basalt	Basin and Range	47.47	0.89	17.28	1.93	8.08	0.18	8.56	11.05	2.45	0.24	0.15	1.45	**99.73**
GG	MJ99-148	MJ99-127	SE	SW	18	40	13	637,215.28	4,661,390.09	Bryant Mtn.	Tll	Basalt	Snake River Plain	49.21	1.18	17.18	2.24	7.80	0.18	7.15	9.46	3.23	0.59	0.35	0.90	**99.47**
HH	MJ99-149	MJ99-128	NE	SE	19	40	13	637,875.37	4,660,324.81	Bryant Mtn.	Tcj	Basalt	Snake River Plain	48.49	1.27	17.83	4.27	6.75	0.19	6.38	9.41	3.34	0.50	0.28	0.86	**99.57**
II	MJ99-153	MJ99-129	NE	SE	29	40	13	639,604.00	4,658,547.16	Bryant Mtn.	Tpr	Basalt	Snake River Plain	48.42	1.32	16.87	3.78	7.06	0.19	7.47	9.69	3.01	0.45	0.29	1.13	**99.68**
JJ	MJ99-154	MJ99-133		SW	33	40	13	640,159.52	4,657,050.52	Bryant Mtn.	Tba	Basaltic andesite		53.76	1.05	17.43	2.09	6.11	0.17	4.11	6.73	4.04	2.28	0.74	0.89	**99.40**
KK	MJ99-171	MJ99-142	SE	SW	15	41	13	640,953.59	4,653,067.14	Bryant Mtn.	Tba	Basaltic andesite		56.18	0.90	17.20	1.62	5.46	0.14	3.68	6.22	3.77	2.58	0.54	1.11	**99.40**
LL	MJ99-182	MJ99-150	SE	NW	8	41	13	638,823.02	4,654,433.06	Bryant Mtn.	Tsb	Basalt	Basin and Range	47.19	0.87	17.81	4.80	5.50	0.19	7.61	11.73	2.51	0.23	0.14	0.99	**99.57**
MM	MJ99-186	MJ99-151	NE	SW	9	40	13	640,502.64	4,663,546.80	Bryant Mtn.	Thc	Basalt	Snake River Plain	49.26	1.18	17.26	2.69	7.28	0.18	7.27	9.36	3.29	0.59	0.35	0.90	**99.61**
NN	MJ99-198	MJ99-159	NE	NW	26	40	13	643,842.28	4,659,739.88	Bryant Mtn.	Tba	Basaltic andesite		53.98	1.06	17.33	3.49	4.67	0.16	3.86	6.60	4.02	2.17	0.76	1.20	**99.30**
OO	MJ99-203	MJ99-162	NW	NW	23	40	13	643,378.26	4,661,138.48	Bryant Mtn.	Tba	Basaltic andesite		52.59	1.14	17.58	3.95	4.87	0.18	4.25	6.98	4.17	1.91	0.83	0.91	**99.44**
		KM86-51*	NW	SW	18	40	13			Bryant Mtn.		Basalt		47.66	1.47	17.13	3.53	8.16	0.19	7.21	9.99	3.33	0.38	0.30	0.58	**99.93**
		KM86-56*		SE	2	41	13			Bryant Mtn.		Basalt		47.49	0.86	17.50	4.25	5.86	0.18	8.90	11.34	2.64	0.20	0.11	0.86	**100.19**
		KM87-128*	NE	SE	20	41	12			Bryant Mtn.		Basalt		47.94	0.93	16.80	10.34		0.17	9.04	11.80	2.46	0.19	0.20	-0.39	**99.48**

Map number	Sample number	Trace Elements[3]: Rb	Sr	Y	Zr	V	Ni	Cr	Nb	Ga	Cu	Zn	Co	Ba	La	Ce	U	Th	Sc	Pb
A	BRY991116-4	24.3	658	25.9	165	162	46	89	11.4	19.5	59	85	23	805	25	52	1.3	1.6	10	18
B	JN-03	5.9	423	28.7	100	226	152	353	6.5	18.2	75	83	45	286	8	15	0.9	1.1	3	26
C	JN-20	4	553	22.6	79	162	145	225	5.9	18.4	80	71	39	313	12	22	0.8	0.6	4	20
D	JN-25	15.4	711	27.6	149	174	49	85	11.5	19.4	82	95	27	707	25	53	1.8	1.7	8	20
E	MJ99-002	27.2	604	25	175	139	39	61	12.8	19.7	66	85	20	907	29	59	1.5	2.9	17	10
F	MJ99-005	1.0	283	27	58	232	154	201	3.9	17.6	100	61	47	141	6	16	0.9	1.0	32	3
G	MJ99-009	0.5	284	27	50	265	158	208	3.8	16.5	122	67	51	132	3	12	0.9	0.5	37	4
H	MJ99-010	3.3	456	24	45	210	142	206	3.9	16.9	118	57	46	656	1	11	1.0	1.5	30	1
I	MJ99-011	0.7	301	25	50	224	167	196	3.7	16.3	106	64	48	249	2	10	1.6	0.5	32	3
J	MJ99-020	0.9	218	23	47	213	169	198	4.3	15.3	111	62	47	110	1	9	1.2	<0.5	29	2
K	MJ99-030	0.4	335	27	72	239	174	235	3.2	18.3	103	72	46	304	6	15	0.9	0.5	35	3
L	MJ99-031	1.5	388	25	49	223	131	180	3.8	19.3	91	67	44	249	5	14	0.8	1.3	27	3
M	MJ99-033	0.7	355	33	54	220	126	187	3.2	19.0	108	70	45	220	5	8	0.6	1.6	34	2
N	MJ99-034	0.5	358	28	62	243	123	155	2.9	18.9	100	72	46	205	6	12	<0.5	<0.5	34	3
O	MJ99-037	2.2	418	26	45	229	135	145	3.7	20.1	69	71	46	271	4	12	1.2	0.9	28	3
P	MJ99-040	27.1	617	24	171	137	38	63	12.1	20.1	69	81	22	876	27	53	1.9	2.8	18	10
Q	MJ99-041	27.3	618	25	170	139	38	59	12.2	20.2	53	82	21	937	27	51	1.8	2.2	17	9
R	MJ99-042	0.7	327	26	62	206	155	241	4.8	18.1	108	66	45	227	6	15	<0.5	1.2	27	2
S	MJ99-043	0.6	301	26	43	245	164	249	3.5	17.3	98	68	48	192	4	7	0.6	1.4	34	2
T	MJ99-044	0.2	301	26	44	243	169	241	3.2	16.8	102	68	49	185	4	11	0.7	0.8	33	3
U	MJ99-046	1.1	292	26	52	218	147	194	3.7	17.2	95	60	45	170	2	12	1.0	1.3	29	3
V	MJ99-053	2.3	415	30	89	266	138	226	7.1	19.4	67	90	49	454	11	21	1.0	1.3	29	3
W	MJ99-055	2.1	338	28	54	253	134	196	3.8	17.8	114	73	47	290	6	13	<0.5	1.4	34	3
X	MJ99-061	1.3	259	26	46	269	174	292	2.7	17.5	102	73	48	228	2	9	<0.5	1.5	38	2
Y	MJ99-065	1.5	273	24	47	207	161	241	3.1	16.0	79	57	41	142	4	11	1.5	1.3	2	32
Z	MJ99-071	2.3	370	28.6	89	222	125	220	5.1	19.0	104	79	38	246	10	22	0.7	1.4	4	25
AA	MJ99-072	2.3	415	33.6	90	217	119	151	5.9	19.7	81	83	44	301	10	20	<0.5	0.9	3	28
BB	MJ99-078	2.5	400	33.4	102	255	104	154	6.5	19.9	96	89	41	335	12	23	1.0	1.5	4	27
CC	MJ99-087	1.2	328	26.5	48	237	156	288	3.3	16.3	98	69	43	168	6	7	0.7	1.0	3	35
DD	MJ99-103	0.9	286	23.5	57	208	167	258	3.0	16.6	115	60	41	139	2	12	0.8	1.2	2	30
EE	MJ99-120	1.1	317	28.3	51	240	143	254	3.2	17.1	122	65	41	175	3	12	0.8	1.3	3	31
FF	MJ99-122	1.9	312	24.8	51	234	137	208	3.8	16.3	113	68	40	159	3	12	0.6	1.4	3	34
GG	MJ99-127	5.7	527	27.6	93	215	113	222	6.6	19.1	78	78	36	359	14	25	1.2	1.9	4	25
HH	MJ99-128	4.2	565	31.8	86	216	119	201	6.0	20.1	71	82	43	326	14	20	<0.5	1.5	3	23
II	MJ99-129	6.8	665	25	93	253	109	179	7.4	20.0	88	85	41	334	11	30	1.4	5.5	28	5
JJ	MJ99-133	8.8	651	29	130	246	72	129	9.3	19.2	86	89	36	445	16	37	1.5	4.9	26	6
KK	MJ99-142	7.4	650	23.8	99	234	105	191	7.8	18.5	95	76	37	360	13	28	1.4	4.3	23	4
LL	MJ99-150	9.4	974	22.1	106	230	44	90	7.4	21.8	101	80	30	509	16	38	1.2	5.3	24	5
MM	MJ99-151	17.9	623	23.9	171	203	53	105	10.0	21.1	78	88	27	617	20	44	1.6	4.5	20	9
NN	MJ99-159	18.3	629	23.4	165	194	55	111	10.2	21.0	76	81	27	605	21	44	1.6	4.5	21	8
OO	MJ99-162	16.7	641	26.6	175	185	56	121	9.6	19.5	63	86	26	625	21	42	1.3	2.8	21	7
	KM86-51*	<5	446	41	113	235	142	137						283						
	KM86-56*	5	321	30	86	237	191	210						129						
	KM87-128*	5	336	27	44	278	129	241						204					41	

Note: X-ray fluorescence: A through OO; Stanley A. Mertzman, Franklin and Marshall College, Lancaster, Pennsylvania, analyst.

[1]UTM Zone 10, 1927 North American Datum.

[2]Major oxides reported in weight percent.

[3]Trace elements in ppm.

*Major oxides and trace element data from Mallin and Hart (1991) and Mallin (1989).

Table 1.2. Previously published and new whole rock radiometric age determinations for selected samples from the Bryant Mountain, Langell Valley, and Brady Butte quadrangles.

Sample Number	Unit	Age (Ma)	Location							Lithology
								UTM Coordinates[1]		
			1/4	1/4	Sec.	T. (S.)	R. (E.)	(N)	(E)	
MJ99-02§	Tba	8.18+/-0.12*	NW	NE	29	40	14	648,751.67	4,659,583.73	Basaltic trachyandesite[2]
MJ99-33§	Tbb	5.25+/-0.58*	SW	SE	31	40	14.5	662,753.64	4,653,211.92	Basalt[4]
MJ99-72§	Tcj	7.33+/-0.77*	NW	SE	24	40	12	635,904.91	4,660,118.94	Basalt[3]
KM86-51†	unknown	5.67+/-0.17*	NW	SW	18	40	13	NA.	NA.	HAOT basalt[3]
KM86-56(1)†	unknown	2.77+/-0.16#		SE	2	41	13	NA.	NA.	HAOT basalt[3]
KM86-56(2)†	unknown	2.65+/-0.13#		SE	2	41	13	NA.	NA.	HAOT basalt[3]
KM86-96†	Tba	7.32+/-0.24#		NE	4	41	13	NA.	NA.	Basaltic andesite[3]
KM87-128†	unknown	4.98+/-0.22#	NE	SE	20	41	12	NA.	NA.	HAOT basalt[3]

Note: Whole rock K/Ar radiometric ages from Mallin and Hart (1991) and Mallin (1989). Whole rock Ar^{40}/Ar^{39} radiometric ages provided by Dr. R. A. Duncan, Oregon State University.

§ Reported in this study.

† First reported by Mallin, 1989.

***** Ar^{40}/Ar^{39} radiometric age.

K/Ar radiometric age.

NA. = not available.

[1]UTM Zone 10, 1927 North American Datum.

[2]Langell Valley quadrangle.

[3]Bryant Mountain quadrangle.

[4]Brady Butte quadrangle.

ANALYTICAL DATA FOR AGE DETERMINATIONS

Sample Number	Weight % K_2O	$^{40}Ar_{rad}$/gm	$\%^{40}Ar_{rad}$
MJ99-02	2.47	NA.	NA.
MJ99-33	0.21	NA.	NA.
MJ99-72	0.35	NA.	NA.
KM86-51	0.39	3.1534	38.66
KM86-56(1)	0.19	0.7667	19.21
KM86-56(2)	0.21	0.7942	18.58
KM86-96	2.28	2.4097	41.39
KM87-128	0.24	1.6977	26.68

2.0 EXPLANATION OF MAP UNITS

The general interrelationships of the map units are shown in Figure 2.1 below. A detailed explanation of the map units follows. The units in Figure 2.1 are chronologically arranged as shown in the time rock chart, where it is apparent that many are coeval.

	Surficial Units
Qmf	Fill (Holocene)
Qml	Modern lake deposits (Holocene)
Qal	Alluvium (Holocene)
Qc	Colluvial and talus deposits (Holocene)
Qf	Alluvial fan deposits (Holocene)
Qls	Landslide deposits (Quaternary)
Qs	Valley floor sediments (Quaternary)
Qg	Stream and deltaic deposits (Pleistocene)
	Sedimentary Units
Tsu	Upper sedimentary deposits (Pleistocene and Pliocene)
Tsu/a	Altered upper sedimentary deposits (Pleistocene and Pliocene)
Tsl	Lower sedimentary deposits (Pleistocene and Pliocene)
	Tertiary Volcanic Units
	East Langell Valley basalt units
Tdh	Basalt of Dog Hollow Reservoir (lower Pliocene)
Tcr	Basalt of Copland Reservoir (Miocene or Pliocene)
Tmu	Upper basalt of Miller Creek (lower Pliocene or upper Miocene)
Tpc	Basalt of Pine Creek (upper Miocene)
Twv	Basalt of Willow Valley (upper Miocene)
Tml	Lower basalt of Miller Creek (upper Miocene)
Ttr	Basalt of Three Mile Reservoir (upper Miocene)
Tbl	Basalt of Boggs Lake (upper Miocene)
	Bryant Mountain basalt units
Tgp	Basalt of the gas pipeline (lower Pliocene)
Tcj	Basalt of Captain Jack Lake (lower Pliocene)
Tms	Basalt of Malin substation (lower Pliocene)
Tmiu	Upper basalt of MillsCreek (lower Pliocene)
Tpr	Basalt of Pope Reservior (upper Miocene)
Tll	Basalt of Long Lake (upper Miocene)
Tlp	Basalt of Long Pine Reservoir (upper Miocene)
Thc	Basalt of Hamaker Creek (upper Miocene)
Twr	Basalt of Worlow Reservoir (upper Miocene)
Trc	Basalt of Russell Canyon (upper Miocene)
Trt	Basalt of the radio tower (upper Miocene)
Tst	Basalt of the steel transmission line (upper Miocene)
Tsr	Basalt of Smith River (upper Miocene)
Tgr	Basalt of Grohs Reservior (lower Pliocene or upper Miocene)
	Basalt andesite flows
Tmil	Lower basalt/basaltic andesite of Mills Creek (upper Miocene)
Tgb	Trachyandesite of Gift Butte (upper Miocene)
Tba	Basalt andesite, undivided (upper Miocene)
Tsb	Sediments and basalt/basaltic andesite flows, undivided (upper Miocene)

Figure 2.1 Map Units.

2.1 SURFICIAL UNITS

Qmf **Fill (Holocene)** Unconsolidated and unsorted boulders, gravel, sand, silt, and soil that have been bulldozed to create the dams of the small reservoirs located throughout the mapped area. Thickness is variable, depending upon the height of the dam.

Qml **Modern lake deposits (Holocene)** Unconsolidated and unsorted sand, silt, and clay, presently being deposited within the seasonal lake margins of the small reservoirs and natural lakes located throughout the mapped area. The lakes and reservoirs catch and store irrigation water, and thus are essentially dry in the Fall. This unit is mapped adjacent to and within the perennial boundaries of Boggs Lake, Copeland Reservoir, and Threemile Reservoir in east Langell Valley, and Smith Reservoir, Harpold Reservoir, Captain. Jack Lake, Long Lake, Lone Pine Reservoir, Worlow Meadow, Pope Reservoir, and some small, unnamed areas on the top of Bryant Mountain In some of the lakes, cobble- to boulder-sized rocks of the nearby or underlying volcanic units lie within or on top of the fine-grained lacustrine sediments. Thicknesses are variable, but may reach several tens of meters in depth in the oldest reservoirs or the natural lakes.

Qal **Alluvium (Holocene)** Unconsolidated channel and overbank stream deposits, including clay, silt, sand, and gravel. The unit is located throughout the mapped area in the bottoms of the present stream drainages, and conforms to the present topography. Exposed older alluvium in banks along the stream channels show typical fluvial sedimentary structures, like trough crossbedding. Sediments fine away from the perennial stream channels. Thicknesses are variable, up to 3 m, with the Miller Creek drainage on the east side of Langell Valley containing the greatest depths.

Qc **Colluvial and talus deposits (Holocene)** Unconsolidated to slightly consolidated, unsorted, angular rock fragments and soil, mantling steep slopes throughout the mapped area. The unit is the result of the gravity-induced downslope movement of materials broken off from overlying units. This unit is mapped only where its thickness is great enough to form a wedge of sediments covering the underlying bedrock. The thicknesses of the deposits are variable, depending upon slope steepness and the weathering of the overlying unit.

Qf **Alluvial fan deposits (Holocene)** Unconsolidated angular to subrounded rock, mud, clay and soil debris flow deposits deposited at the mouths of the steep draws eroded into the valley-bounding fault escarpments. The materials in this unit are the result of fluvial processes, although a significant part of the deposits is the result of catastrophic downslope movements during thunderstorm and spring runoff flood events. The wedges of sediment in these deposits can be quite thick (up to 30 m), and extend up to 0.5 km onto the valley floor.

Qls **Landslide deposits (Quaternary)** Unconsolidated to slightly consolidated chaotic mixtures of angular rock and soil, resulting from debris flow and earthflow slump failures. This unit only occurs on the east and west boundary escarpments of Bryant Mountain In these areas the uppermost rims of the escarpments generated large slides of unknown age and cause. On the east side of Bryant Mountain one slide is extremely large, covering over a square kilometer of area. The debris from this slide extends out onto the valley floor. It covers the fault planes, but has not been cut by the fault movements that created the east Bryant Mountain escarpment. On the west side of the mountain the materials from another smaller slide appear to have flowed over a lower elevation bench, and onto the top of another bench. The thickness of the debris from each slide is highly variable, depending upon the particular spot within the slide deposit. The toes of each slide contain the thickest deposits.

Qs **Valley floor sediments (Quaternary)** Unconsolidated, primarily finer-grained fluvial and lacustrine sediments, possibly including some peaty deposits. This unit covers the valley floors of the Tule Lake and Langell Valleys. In the Langell Valley the unit is principally a dark brown to black, sticky clay, ranging, based on data from well logs, from 0.5 to 10 m in thickness. At the edges of the valley the unit is sandier, and near fault escarpments contains a significant percentage of angular volcanic boulders and gravel. The unit is exposed in the uppermost riverbanks of the Lost River where it flows through Langell Valley. At these localities the unit overlies the upper sedimentary deposits (unit Tsu). On the Tule Lake Valley side of the mapped area the unit is principally brown, sandy silt, but fines to clay away from the Bryant Mountain escarpment. Based on well log data, thicknesses in the Tule Lake Valley are variable, up to 10 m. In both valleys the unit was probably deposited in the lakes and swamps that occupied the valley floors during the Pleistocene and Holocene. Similar materials are presently being deposited in Upper Klamath Lake, to the northwest of the mapped area. The unit also may include a significant aeolian component, especially in the more sandy deposits.

Qg **Stream and deltaic deposits (Pleistocene)** Slightly consolidated sand and gravel deposits located on the east side of Langell Valley, on the south side of the present Miller Creek drainage. The upper part of this unit is a poorly-sorted, rounded, cobble gravel with a sand matrix. The lower part is a well-sorted, bedded and cross-bedded, sand and gravel deposit. The sandy beds contain some root casts and poorly preserved wood. Some of the finer-grained deposits have contorted bedding, as if they are large rip-up clasts created by flood events. The gravel and cobble layers are composed solely of basalt lithologies. No faults cut this unit and its bedding is essentially horizontal. The shape, location, and fluvio-deltaic appearance of the unit suggest that it is a delta deposit from a paleo-Miller Creek channel. The ranchers and farmers of the local Langell Valley area use the gravel in this deposit for paving farm roads and stock pens. Thicknesses in the pit range from 3 to 5 m, and the overall thickness of the unit is variable, up to 10 m.

2.2 Sedimentary Units

In the past geologists have placed all of the pre-Quaternary sedimentary deposits within a single unit, called the Yonna Formation (Newcomb, 1958). Based on fossils found in the Yonna Valley area, Peterson and McIntyre (1970) suggest that the fine-grained sediments are Pliocene age and stratigraphically all lie within the overall Tertiary basalt/basaltic andesite section. Sherrod and Pickthorn (1992) abandoned the Yonna Formation name, because it included significant amounts of pyroclastic tuffs, both silicic and basaltic, which they mapped as separate units.

Isolated outcrops of these pre-Quaternary fine-grained sediments are found throughout the mapped area. Some of these sediments are clearly interbedded with the basalt and basaltic andesite lava flows. In those cases they are mapped here as either the lower sedimentary deposits (unit Tsl) or within the undivided sediments and basalt/basaltic andesite deposits (unit Tsb). Other sedimentary outcrops in the area presumably overly or do not have a visible contact with the lava flows. The exact stratigraphic relations of these deposits to the other sedimentary and volcanic units are less certain, and they are mapped as the upper sedimentary deposits (unit Tsu).

While all of the upper sedimentary deposits (unit Tsu) seem, by their locations, to be younger than the majority of the volcanic units, two pieces of evidence make it difficult to interpret and assign them to a particular place in the overall stratigraphy of the mapped area. First, all of these isolated sedimentary outcrops are located near the valley walls or within small down-faulted grabens, with no direct visible contact with the volcanic stratigraphy exposed in the adjacent escarpments. Second, a review of the well logs in Langell Valley and within the part of the Tule Lake Valley in the mapped area shows that the sediments are variable, up to 150 m in thickness, without a capping basalt section. However, these same sedimentary thicknesses are not found above the basalt and basaltic andesite outcrops on top of Bryant Mountain and above the east side of Langell Valley. The questions then becomes when were these old, principally fine-grained sediments deposited in relation to the overall volcanic flow package, and why are they exposed only in the present patterns and to such great depths in the valleys?

The author has devised three different stratigraphic and erosional scenarios that could explain the present location and sedimentation patterns of the Tsu sediments. Problems exist with each of these explanations, given the evidence presently available within the mapped area. It is likely that the continued mapping program in the entire Klamath River basin and an age analysis of an ash deposit from an unpublished drill core description (Woodward and Clyde, 1994) will shed light on which of the following scenarios or combination of scenarios are responsible for the sedimentary patterns found in the upper sedimentary deposits (unit Tsu).

In the first scenario the Tsu sediments were all laid down within the basalt and basaltic andesite flow section, as suggested by Peterson and McIntyre (1970). When normal faulting formed the present valleys and changed the positions of these units, the sediments were exposed in the lower parts of the section. Erosional retreat of the upper volcanic units within the fault escarpment faces then left the sediments exposed adjacent to the escarpments in the valley floors. Two problems arise with this scenario. First, the fine-grained, and relatively unconsolidated nature of the sediments makes them poor candidates for exposure from erosion, especially in relation to the resistant overlying volcanic flows. In fact, if this scenario is the case, then it seems more logical that the sediments presently exposed at the base of the section would be completely hidden and covered with talus from the overlying volcanic flows. This scenario is even less likely when it is observed that some sedimentary exposures are located on the valley floor as much as 1 km from the fault escarpment. Second, the well logs clearly show that the Langell and Tule Lake Valleys are floored by deep thicknesses of sediment, instead of an upper section of volcanic flows, which according to this scenario should be present.

In the second scenario the Tsu sedimentary sections that are exposed at or near the valley floors would have been deposited after the entire volcanic section was in place, but before the main normal faulting formed the present mountains and valleys. In this case the sedimentary deposits would have made a sheet of fairly uniform thickness above all of the lava flows. The normal faulting that subsequently downdropped the valleys protected the thick valley floor section of sediments from erosion. When the same sedimentary section was uplifted on the tops of the horst blocks, they were gradually eroded away. Fossil fish bones found within the valley floor fine-grained sediments suggest a Pliocene or Miocene age for the valley floor sediments (Gerald R. Smith, 2000, personal communication). In addition, the fine-grained character, horizontality, continuity, and appearance of the sedimentary layers are all very similar to the lacustrine sediments that the author had previously studied in Pliocene Lake Idaho in the Snake River Plain (Jenks and Bonnichsen, 1989; Jenks, Bonnichsen, and Godchaux, 1992). However, the principal difficulty with this scenario is the erosion that it requires to remove the entire 100 m or more of sediments from the top of Bryant Mountain. This problem, plus the question of "Where did all that sediment go?" still need to be answered. In addition, this scenario requires that the normal faulting that created the present valley and ridge terrain be a fairly young (<1-2 my) phenomenon in the geologic history of the area. Presently, the published and unpublished age determinations do not help with dating the onset of the normal faulting.

In the third scenario the Tsu sedimentary sections were deposited over a 4-to-6 million-year period as the normal faulting created the present valleys. The sediments would all have been deposited as the separate basins deepened, in relatively small and shallow lakes similar to the present Upper Klamath Lake, and the former Tule Lake that occupied the Klamath Basin valleys in historic time. The principal problem with this scenario is the extreme fine-grained character of all of the exposed sedimentary sections. Even in well logs from locations that are right next to, or within a very short distance (<0.5 km) of the major fault escarpments in the area, the majority of the sedimentary section is made up of clays, silts, and sands. Only the uppermost parts (up to 10 m) of these logs record boulder and cobble gravels. The rest of the sedimentary sections in the well logs record only well-rounded sediments, up to medium pebble gravel in size. Casual observation of the areas presently adjacent to the escarpments surrounding Upper Klamath Lake and other similar lake basins shows that cobble and boulder deposits are always present, and extend for up to 0.5 km into the lake basin. Thus, it seems logical that if such deposits are presently accumulating, they are equally likely to have happened at the same locations over the period that the faults were moving and the Tsu sediments were deposited. Thus, in this scenario the well logs of the wells located near the major fault escarpments should record large quantities of coarse sand- to boulder-sized sediments throughout their sections. Indeed, fluctuating lake levels should have moved the coarse-grained materials even further into the centers of the basins/valleys. Because the well logs record only fine-grained sediments, it argues that they must have been deposited under different circumstances than the present day lake basins.

Tsu **Upper sedimentary deposits (Pliocene)** Tan to reddish brown sands, silts, and clays, uncemented, layered to massive, and partially to slightly consolidated. This unit is located on the east side of Langell Valley in the areas of Boggs Lake and the Woolen Canyon. On the east and west sides of Bryant Mountain, the unit is located in the low hills and valleys next to the major valley-bounding escarpments. Most of these sedimentary sections contain thin layers or stringers of well-rounded pebble to cobble gravel, composed entirely of basaltic rocks. The sand, silty sand, and silt layers generally contain variable quantities of rounded white pumice and subangular black glassy basalt cinder fragments. Some layers are composed entirely of white pumice lapilli, with chips up to 1 cm in size. The clay layers are massive and light-colored. Bedding ranges from massive to thinly bedded and a few outcrops contain small cross-beds. Some layered outcrops show signs of rip-up clasts and other soft-sediment deformation features. In general, the layers throughout any of the exposures are uniform in thickness across the outcrop and do not contain large, cross-cutting trough cross-beds. In some of the exposures the sediments are made up entirely of palagonitic, sand- to small-pebble sized, layered basaltic tuff. Because of the poor exposure and lack of continuity of this unit, it is difficult to estimate its thickness. On the west side of Langell Valley abundant clam and snail fossils and sparse fish fossils are contained within a sand layer at one locality. On the Tule Lake Valley side of Bryant Mountain two more fish localities are present, one within the mapped area. These fossils have tentatively been identified as Pliocene or Miocene in age (Gerald R. Smith, 2000, personal communication).

Tsu/a **Altered upper sedimentary deposits (Pliocene or Miocene)** Tan to light yellow, cemented, medium- to coarse-grained sandstone. This unit, which is cemented with silica probably by hot spring activity, is located on the west side of Langell Valley near the former townsite of Hot Springs (Figure 1.1). It contains some cross-bedding, but generally shows planar bedding. Some pumice-rich layers, with rounded and sand- to pebble-sized clasts, were observed. Other areas contain small pebble gravel layers. The probable siliceous nature of the cement is reinforced by the presence in some layers of well-preserved petrified wood. The base of the unit is not exposed, but exposure thicknesses are variable, up to 3 m.

Tsl **Lower sedimentary deposits (Miocene)** Pinkish-tan to dark reddish-brown sands, sandy silts, and clays, layered to massive, poorly consolidated and uncemented. These sediments are poorly and sporadically exposed between the basalt and basaltic andesite layers throughout the mapped area. In some areas these sediments were baked to a red-brick color and hardness by the heat of the overlying lava flow. The unit is typically unbedded and massive. The silts and sands contain variable percentages and sizes of rounded white pumice fragments and subangular, glassy, black basalt cinders. Some locations also contain white to beige clay beds and stringers of small pebble gravel. The presence of sandy soils on benches between the basalt and basaltic andesite flows throughout the stratigraphic section suggests that this unit may be present over a much broader area than its actual exposure would suggest. The maximum exposed thickness of this unit is 5 m.

2.3 TERTIARY VOLCANIC UNITS

2.3.1 East Langell Valley basalt units

All of the basalt units described in this section are located on the east side of Langell Valley, and exposed in the low fault escarpments found throughout that area. Ar^{40}/Ar^{39} whole-rock age determinations (Table 1.2) by Dr. Robert Duncan at the Oregon State University bracket these basalt units. A 5.25 ± 0.58 Ma age on the youngest basalt unit in the area, which erupted from Brady Butte to the east of the mapped area, is the upper limit. An 8.18± 0.12 Ma age is at least the uppermost age for the oldest unit in the area, the basaltic andesite flows (unit Tba). The individual flows that make up these units are generally horizontal and relatively thin (1-3 m). Their standard outcrop contains a 10-20 cm vesicular bottom, a massive, jointed middle of variable thickness, and a scoriaceous to cindery flow top (0.3-0.5 m).

The units all have Al_2O_3 contents of >17 percent (Table 1.1). With the exception of one unit, the basalt of Boggs Lake (unit Tbl) potassium percentages range for these units from 0.16 to 0.32 percent, and TiO_2 percentages range from 0.84 to 1.14 percent (Table 1.1; Figure 3). These values place these basalt units in the low-K_2O, low-TiO_2 transitional tholeiites (LKLT) of Hart and others (1984). Some of these units tend toward the even more primitive Basin and Range tholeiites. All of the east Langell Valley basalt units principally erupted and were deposited under subaerial conditions. However, most of the units also have some areas that interacted with water at the time of their eruption. In these areas the flows are either pillowed or water-affected (Jenks and Bonnichsen, 1989; Jenks, Bonnichsen, and Godchaux, 1992). Water-affected lava flows strongly interact with water at the time of their eruption, but do not pillow. The water interaction causes the microscopic, glassy, interstitial areas within the flows, at the time of emplacement and cooling, to be altered to palagonite and other clay minerals. Unlike subaerially emplaced flows, when erosion or fault displacement subsequently expose the water-affected flows to the atmospheric elements, they rapidly decompose to clay and soil. This propensity explains the lack of good exposure for water-affected basalt and thus for many of the flows within these units. In the eastern Langell Valley area the units that make up and underly the East Langell Valley Rim dip slightly to the south and southwest.

Tdh **Basalt of Dog Hollow Reservoir (Pliocene or Miocene)** Gray, weathering to a light purple and green mottled appearance, olivine-phyric basalt. The unit is located in the far northeast corner of the mapped area. It is one of the youngest units in the area, and overlies an area of lower sedimentary deposits (unit Tsl). It is also above an area of undivided sediments and basalt/basaltic andesite flows (unit Tsb). The flows of the unit are typically exhibit flow banding and, within their more massive areas, contain rounded scoriaceous areas. One location has a

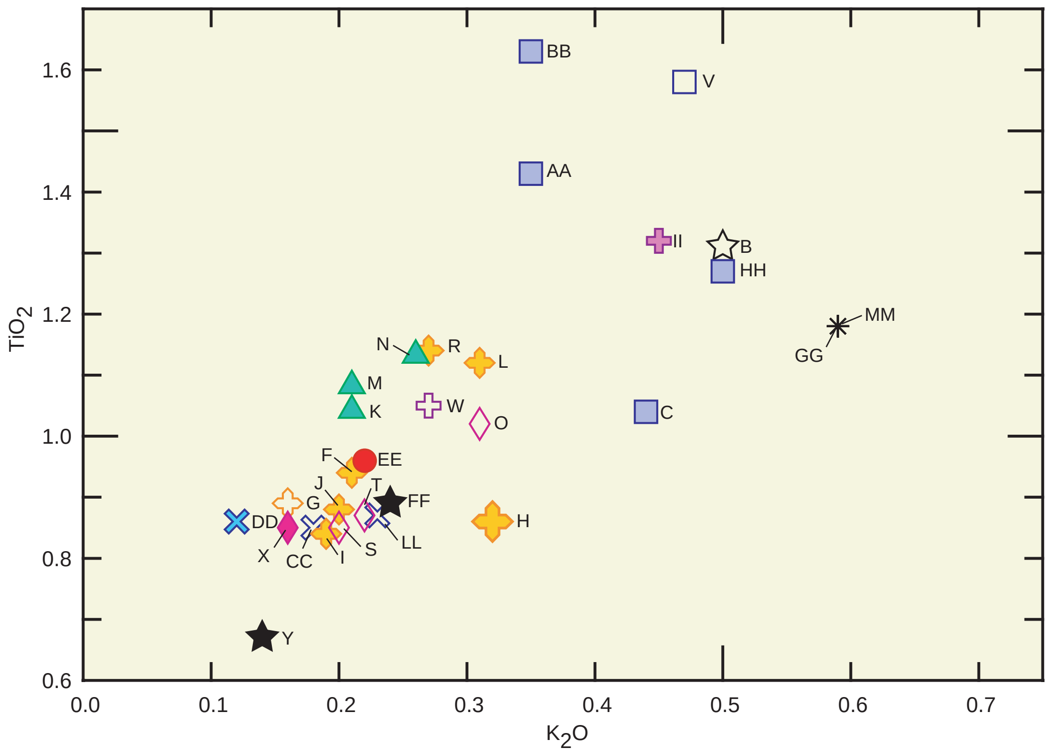

Figure 2.2. Ti_2O vs. K_2O plot of only the basalt samples for Bryant Mountain and Langell Valley quadrangles, Klamath County, Oregon. Symbols with map numbers keyed to Table 1.1.

red scoriaceous layer at the base of the unit. In the field the unit is recognizable by its visible olivine crystals in a fine-grained, non-diktytaxitic groundmass. In thin section the olivine phenocrysts are 0.2-0.7 mm, with groundmass plagioclase up to 0.3 mm and olivine up to 0.05 mm. The rock also contains abundant opaque minerals, and the olivine phenocrysts near the opaques typically have iddingsite rims. The dominant groundmass texture is ophitic crystals of pyroxene. The paleomagnetism of the unit is equivocal, with some flows yielding normal readings and others equivocal or reversed readings. The chemistry of the unit is a standard, high alumina, olivine tholeiite (HAOT) (Hart and others, 1984), with slightly lowered K_2O (0.16 percent) and P_2O_5 (0.10 percent) values (Table 1.1; map number X), suggesting some Basin and Range affinities (Hart and others, 1984). No vent area was definitely located for the unit, but its stratigraphic position, proximity, and phenocryst content suggest that it erupted from Hill 5150 (upper elevation), to the northeast of the mapped area in the Gerber Reservoir quadrangle, SE¼SE¼, sec. 25, T. 39 S., R. 13 E. The total thickness of this unit is variable, up to 10 m.

Tcr **Basalt of Copeland Reservoir (Pliocene or Miocene)** Gray, weathering to light purple and green mottled appearance, non-porphyritic basalt. The unit covers most of the uppermost flat on the east side of the mapped area. It is one of the youngest volcanic units on the east side of the mapped area, and overlies some areas of lower sedimentary deposits (unit Tsl). In several locations this unit overlies the basalt of Willow Valley (unit Twv). In locations where this unit overlies undivided sediments and basalt/basaltic andesite flows (unit Tsb) it is possible that some Twv flows are included within this unit. In the field this units is recognizable because of its non-diktytaxitic groundmass and lack of visible phenocrysts. A thin section of the rock does show some to sparse olivine phenocrysts, ranging in size from 0.7 to 1.3 mm. The olivine phenocrysts generally have thick iddingsite rims. The groundmass texture is subophitic to ophitic, with plagioclase crystals up to 0.4 mm and olivine crystals up to 0.1 mm. The opaque minerals generally occupy the areas between the groundmass pyroxene crystals. The unit is a standard HAOT that verges on Basin and Range affinities (Hart and others, 1984), with no distinctive values (Table 1.1; map numbers O, S, and T). It is possible that this unit was erupted from Hill 5068 (upper elevation), in the center of sec. 23, T. 40 S., R. 14 E. The flows in this area are extremely scoriaceous, with abundant disturbed flow banding. This unit varies from just 2-3 flows up to many flows, and thus its thickness also is variable, up to 20 m.

Tmu **Upper basalt of Miller Creek (Pliocene or Miocene)** Gray to light gray, diktytaxitic, non-porphyritic basalt. Located on both sides of Miller Creek, the unit overlies the lower basalt of Miller Creek (unit Tml). Its appearance suggests that it may be the northward continuation of the basalt of Willow Valley (unit Twv). However, this conclusion is speculative. The unit consists of flow-on-flow, discernable flow banding to massive basalt, with some water-affected areas. At one locality the unit lies above a red-baked, sandy siltstone, and is less diktytaxitic. Total thickness of the unit is approximately 10 m.

Tpc **Basalt of Pine Creek (Miocene)** Gray, mottled basalt with rare olivine phenocrysts. The unit is located in a small area in the northeast part of the mapped area. It forms the floor of the upper Pine Creek valley, and overlies undivided sediments and basalt/basaltic andesite flows (unit Tsb). Its most outstanding outcrop characteristic is the extreme flow banding that gives the unit a platy appearance. On weathered surfaces the unit has a "spotty" or mottled appearance, which in other units is the result of an ophitic to subophitic groundmass texture. Total thickness of the unit is approximately 5 m.

Twv **Basalt of Willow Valley (Miocene)** Light gray, diktytaxitic, medium grained, generally non-porphyritic basalt. This unit is the most widespread mapped unit, covering much of the upland areas on the east side of Langell Valley. It is an upper unit on the East Langell Valley Rim, and is downfaulted twice to underlie two different elevation levels in the Woolen Canyon area. It also crops out as a series of benches on the south end of the east-facing valley-bounding escarpment of Bryant Mountain, west of the Malone Dam. In that area it appears to have erupted and flowed up against a pre-existing high of basaltic andesite (unit Tba). This relationship is repeated in the area of Gift Butte on the east side of the Langell Valley, where the unit flowed up against Gift Butte, another pre-existing high of basaltic andesite (unit Tba). As one of the units exposed within the East Langell Valley Rim it overlies basaltic andesite flows (unit Tba) and underlies the basalt of Copeland Reservoir (unit Tcr). On the lower benches and rims of the southeast side of Langell Valley this unit is the uppermost unit, and overlies the basalt of Three Mile Reservoir (unit Ttr). In several locations, the basalt flows of this unit are overlain by or overlie sedimentary deposits, in particular a tan to reddish brown massive sandy siltstone, which contains abundant chips of basaltic cinders and white pumice. The basalt of Willow Valley was generally emplaced subaerially, although some isolated areas are water-affected. In particular the unit forms a small pillow delta, breccia and cinder tuff deposit that is exposed in a quarry on the north side of the Willow Reservoir Road. In the southern part of its exposure, the flows of this unit are conspicuously more numerous and thinner (1-2 m) than in other exposures. Some massive outcrops of this basalt have vertical bubble trains, with the bubbles enclosing large plagioclase and pyroxene crystals. Other typical outcrop features include a flaggy, scoriaceous top and some flow banding. The unit is recognizable in the field by its distinctive light gray color, diktytaxitic texture, medium grain-size, and typical lack of visible phenocrysts. In some thin sections olivine phenocrysts are visible, but they are small (0.15-1.0 mm) and have distinctive iddingsite rims. The pyroxene crystals are intergranular to subophitic, and groundmass plagioclase and olivine range up to 0.7 and 0.1 mm, respectively. Opaques range from sparse to minor. Several analyzed samples (Table 1.1, map numbers F, H, I, J, L, R, and U) show a consistently HAOT chemistry (Hart and others, 1984), with Al_2O_3 ranges of 17.19-17.90 percent. Sample J, which was affected by water, has a distinct reversal in the usual MgO and CaO amounts, 10.17 percent and 9.66 percent respectively, as well as a lower Na_2O value, 2.13 percent, than the other Twv samples, and a high LOI (4.36 percent). The paleomagnetism of the unit is consistently strongly reversed, which is unusual for the basalt units within the mapped area. The total thickness of this unit is unknown, but exposures show at least 10 m, and up to 20 m.

Tml **Lower basalt of Miller Creek (Miocene)** Dark gray, non-porphyritic, mottled basalt. This unit is located in the Miller Creek drainage, and lies below the upper basalt of Miller Creek (unit Tmu). It has an unknown relationship with the basalt of Boggs Lake (unit Tbl) and the basalt of Willow Valley (unit Twv). In the field the unit is recognizable from its "spotted" and mottled appearance, lack of phenocrysts, and fine-grained to glassy texture. In a thin section the unit contains very sparse glomeroporphyritic clots of olivine in the range of 0.4-1.0 mm. It has an ophitic groundmass texture with abundant opaque minerals between the pyroxene crystals. The groundmass plagioclase and olivine crystals are variable, up to 0.5 and 0.1mm, respectively. Several of the flows are flaggy, show little signs of flow banding, and appear to be water-affected. The abundant areas of rounded scoriaceous materials are a distinctive feature of this unit, and in one location it has a top that verges on scoriaceous. In two of the fault-bounded ridges the flow banding appears to tilt to the southwest, but this may only be a local feature caused by the faulting. This unit chemically is an HAOT (Hart and others, 1984), with an Al_2O_3 content of 17.69 percent (Table 1.1, map number W), but no other distinguishing characteristics. The total thickness of this unit is unknown, since the base is not exposed, but the exposure is variable, up to 8 m.

Ttr **Basalt of Three Mile Reservoir (Miocene)** Gray, weathering to dark brown, non-porphyritic, diktytaxitic basalt. This unit is sporadically exposed as the lower unit in the spillway of the Threemile Reservoir and in the low rims on the southeast side of Langell Valley. At all of its exposures the unit is water-affected, which causes it to weather easily and therefore be poorly exposed. The basalt of Willow Valley (unit Twv) everywhere overlies it. Samples of the rock are distinguishable in the field by their diktytaxitic texture, fine to medium-grain, and olivine phenocrysts. In a thin section the olivine phenocrysts are sparse, have iddingsite rims, and range from 0.1-0.7 mm in length. Groundmass plagioclase and olivine crystals are variable, up to 0.5 and 0.1 mm, respectively. The rock also contains intergranular pyroxene crystals. The unit has an HAOT chemistry (Hart and others, 1984), with an Al_2O_3 content of 17.96 percent (Table 1.1, map number G). It also has the lowest K_2O and P_2O_5 values (0.16 and 0.10 percent, respectively) of any of the basalt units in the eastern Langell Valley basalt section. Its normal paleomagnetic signature differentiates it from the overlying basalt of Willow Valley (unit Twv). Because only the upper part of the unit is exposed, its total thickness is unknown.

Tbl **Basalt of Boggs Lake (Miocene)** Gray, glomeroporphyritic basalt. This unit is exposed over a small area on the west side of Boggs Lake, on the east side of Langell Valley. Its relation to other basalt units in the area is uncertain, but it appears in one location to overlie the lower basalt of Miller Creek (unit Tml) and may underlie the basalt of Willow Valley (unit Twv). In one part of its exposure, it overlies yellow-brown sandy silt, which contains basaltic cinders and white pumice (unit Tsl). In the field it has a distinctive appearance, with abundant single crystals and glomerocrysts of olivine, as well as some glomeroporphyritic clumps of plagioclase and olivine. The flows exhibit flow banding due to large stretched vesicles, and their massive parts contain rounded scoriaceous areas. In thin section the olivine phenocrysts range from 0.2-2.0 mm, and the plagioclase crystals are 0.7-1.3 mm in length. The groundmass has an ophitic texture, with abundant opaques, and plagioclase and olivine crystals up to 0.3 and 0.05 mm, respectively. This unit has a distinctive chemistry from the other basalt units in the E. Langell Valley section (Table 1.1, map number V). It is not an HAOT, with an Al_2O_3 content of only 16.37 percent. In fact, it has more affinity with Snake River Plain type (SROT) basalts (Hart, and others, 1984) with its higher Na_2O, K_2O, and P_2O_5 percentages (2.99, 0.47, and 0.43 percent, respectively) and its lower values for MgO (7.59 percent) and CaO (9.76 percent). In the exposures of this unit, it appears to be a single flow, with a general thickness of 3-5 m.

2.3.2 Bryant Mountain basalt units

All of the following units are located in the north and west parts of Bryant Mountain. Subsequent to the eruption of the flows, faulting has altered their positions from horizontal to gently dipping in various directions. The dip slopes of these basalt units are most apparent on the southern part of Bryant Mountain, near the California border. All of the basalt flows appear to have flowed against, and now dip away from, an older high of basaltic andesite flows. The author did not find any vent areas for these flows. The single vent area proposed by Sherrod and Pickthorn (1992) for the top of Bryant Mountain appears, instead, to be a series of slightly more scoriaceous, reddish, thin lava flows. The individual flows that make up these units were erupted onto a relatively flat terrain and are relatively thin (1-3 m). Their standard outcrop contains a 10-20 cm vesicular bottom, a massive, jointed middle, and a scoriaceous to cindery flow top (0.3-0.5 m). However, most of the units also have some areas that interacted with water at the time of their eruption. In these areas the flows are water-affected (Jenks and Bonnichsen, 1989; Jenks, Bonnichsen, and Godchaux, 1992).

The uppermost basalt unit throughout the northern part of Bryant Mountain, the basalt of Captain Jack Lake (unit Tcj), has a whole-rock Ar^{40}/Ar^{39} age determination by Dr. Robert Duncan at Oregon State University, of 7.33 ± 0.77 Ma (Table 1.2). This age is anomalously older than K-Ar ages on similar basalt units in the area (Table 1.2), which range from 5.0-6.5 Ma (Sherrod and Pickthorn, 1992; Mallin, 1989; Mallin and Hart, 1991). It is possible that the low K_20 percentage of this unit (0.35-0.40 percent) accounts for this anomalously low age. Mallin (1989) and Mallin and Hart (1991) published two whole rock K/Ar ages on basalt units within the Bryant Mountain quadrangle. However, the published locations of these dated samples are not precise, making the them difficult to place within the specific basalt units in this present mapping. The 5.67 ± 0.17 Ma age on a sample in the northern part of the area is within either the basalt of Captain Jack Lake (unit Tcj), or the undivided sediments and basalt/basaltic andesite flows (unit Tsb). The southern dated sample location on the east rim above the Malin power substation has an age of 4.98 ± 0.22 Ma. The possible basalt units in this area are the basalt of Malin substation (unit Tms) and the basalt of Russell Canyon (unit Trc). Mallin and Hart (1991) also report a 2.71 ± 0.1 Ma average age determination (Table 1.2) for a location on the east side of Bryant Mountain. However, the location information for this analysis is so insufficient that it cannot be correlated with any of the units in this present mapping. The basalt units are all stratigraphically younger than the basaltic andesite flows in high area that they flowed against, which has a published K/Ar age of 7.32 ± 0.24 Ma (Mallin, 1989; Mallin and Hart, 1991).

Chemically, the basalt units located on Bryant Mountain are very interesting, because they fall into two, relatively distinct chemical populations (Figure 2.2; Table 1.1). These populations are also spatially, petrographically, and perhaps stratigraphically distinct. The first, and apparently stratigraphically older, population of units is located mainly on the south and west sides of Bryant Mountain, in the area around and north of the Malin power substation. The units show lower K_2O, Na_2O, and TiO_2 percentages, and higher MgO and CaO percentages, similar to the more primitive Basin and Range-affinity high aluminum olivine tholeiites (HAOT) described by Hart and others (1984). In addition, these units are not diktytaxitic, but instead all display subophitic to ophitic textures. It is possible that this texture is the result of the eruption of a series of more fluid lavas (Stan Mertzman, 2000, personal communication). The nearest units of this chemical type to the Bryant Mountain area are some 1.0 Ma flows in the Keno area, to the west of the mapped area (Mertzman, 2000, personal communication).

The second, and apparently stratigraphically younger, population of units is located on the north end of Bryant Mountain. All of these analyses show higher K_2O, Na_2O, and TiO_2 percentages, and lower MgO and CaO percentages (Figure 2.2; Table 1.1). These values are similar to the Snake River Plain affinity tholeiites (SROT) of Hart and others. (1984). These units are all diktytaxitic, with intergranular to slightly subophitic textures. It is possible that this texture is due to faster crystal growth after the eruption of more viscous lavas (Stan Mertzman, 2000, personal communication). The closest area of Snake River Plain type flows to the Langell Valley/Bryant Mountain area is east of Lakeview, toward Jordan Valley, Oregon (Mertzman, 2000, personal communication). However, a single unit of this type, the basalt of Boggs Lake (unit Tbl), does outcrop on the east side of Langell Valley.

Tgp **Basalt of the gas pipeline (Pliocene or Miocene)** Gray to light gray, plagioclase-phyric basalt. This unit is located on the extreme west side of the mapped area, and continues into the adjoining Malin quadrangle. Stratigraphically, the unit is above the basalt of Captain Jack Lake (unit Tcj), and is overlain by upper sedimentary deposits (unit Tsu). Outcrops of the unit do not show flow banding and hand samples contain rare plagioclase phenocrysts. The rock is medium-grained and slightly diktytaxitic to somewhat mottled. The paleomagnetism of the unit is equivocal, with only one location giving a normal reading for 2 out of 3 samples. The unit is relatively thin, with a maximum of 10 m.

Tcj **Basalt of Captain Jack Lake (Pliocene or Miocene)** Gray to light gray, highly diktytaxitic, coarse-grained basalt with seriate plagioclase crystals. Some exposures also contain olivine phenocrysts and others have glomerocrysts of the larger plagioclase crystals and olivine. This unit is located throughout the northern part of Bryant Mountain., and in most areas it is the capping basalt on the ridge-tops. Therefore, it is stratigraphically above the basalt of Long Lake (unit Tll), the basalt of Lone Pine Reservoir (unit Tlp), the basalt of Smith Reservoir (unit Tsr), the basalt of Hamaker Canyon (unit Thc), and undivided sediments and basalt/basaltic andesite flows (unit Tsb). The unit is thickest, with numerous, thin (2-3 m) flows, in the northwest corner of the mapped area. In its southern exposure it appears to be only a single, massive flow. It is associated, above and below, with both basaltic palagonitic tuff and sedimentary deposits, and in a few areas appears to have interacted with water. In the field it is distinguished by its prominent seriate plagioclase crystals, its coarser grain, and its openwork, highly diktytaxitic texture. In the thin sections a few exposures contain olivine phenocrysts, which range from 0.8-1.5 mm. The groundmass olivine crystals are variable, up to 1.0 mm and have iddingsite rims. The seriate plagioclase crystals range from 0.1 mm up to 4.0 mm. The pyroxene is intergranular, and some thin sections contain more opaque minerals than others. The chemistry of this unit (Figure 2.2; Table 1.1, map numbers C, AA, BB, and HH) shows a Snake River Plain (SROT) affinity (Hart and others, 1984), with lower MgO (6.2-7.3 percent) and CaO (9.41-10.01 percent) values, and higher TiO_2 (1.04-1.63 percent), Na_2O (2.99-3.34 percent), and K_2O (0.35-0.50 percent) values. The paleomagnetism of the unit is consistently strongly reversed. Dr. Robert Duncan, Oregon State University, determined an Ar^{40}/Ar^{39} whole-rock age of 7.33 ± 0.77 Ma for a sample of this unit from station number MJ99-82 (Table 1.1). The maximum thickness of the flows of this unit is 65 m.

Tms **Basalt of Malin substation (Pliocene or Miocene)** Gray, olivine-phyric basalt. This unit is only located in the far southwest corner of the mapped area, on the ridge to the east of the Malin power substation. It overlies the basalt of the radio tower (unit Trt), and has been traced south into California. In the field the unit is recognizable because it contains some olivine phenocrysts and rare, large (up to 0.5 cm), plagioclase crystals. The rock is not diktytaxitic, but has a mottled appearance. In addition, the flows contain areas of rounded scoria and flow banding. Throughout its exposure the unit dips uniformly 25°-35° to the southeast. It is thin, only up to 8 m.

Tmiu **Upper basalt of Mills Creek (Pliocene or Miocene)** Gray, glomeroporphyritic, ophitic basalt. This unit caps the rims to the west of the Malin power substation in the southwest corner of the mapped area. It overlies the basalt of the steel transmission line (unit Tst) and the basalt of the radio tower (unit Trt), as well as undivided sediments and basalt/basaltic andesite flows (unit Tsb). The flows of this unit are extremely flowbanded, with large areas of rounded scoria. Some outcrops also have large vesicles and contain several thin (1 m) individual flows. In the field the unit is distinguishable from others by its large (up to 2 cm) glomerocrysts of plagioclase and olivine. The individual plagioclase and olivine crystals within the clots range from 0.6-5.5 mm, and 0.4-4.0 mm, respectively. Groundmass plagioclase and olivine crystals are variable in size, up to 0.6 mm and 0.05 mm respectively, with the plagioclase crystals enclosed within ophitic pyroxene crystals. Chemically, this unit has Basin and Range-type basalt affinities (Hart and others, 1984) (Figure 2.2; Table 1.1, map numbers Y and FF). Compared to the SROT lava flows, it has higher CaO (up to 11.6 percent) and MgO (up to 8.82 percent) values, and lower K_2O (up to 0.24 percent) and P_2O_5 (0.15 percent) values. The paleomagnetism of this unit is normal, and its thickness is variable, up to 25 m.

Tpr **Basalt of Pope Reservoir (Miocene)** Gray, fine-grained, mottled, non-porphyritic basalt. This unit caps the highest ridge on the west side of Bryant Mountain, as well as the next lowest elevation rim to the west. It overlies the basalt of the steel transmission line (unit Tst), and one or more of its flows may be included within the Tsb unit mapped to the east. Some of its flows contain contorted flow banding and rounded areas of scoria, but most of the unit is massive. Observations in the field show that the unit is consistently fine-grained and mottled, and generally has no phenocrysts. Only one location contained sparse, olivine phenocrysts. However, a thin section of this unit shows abundant olivine phenocrysts ranging in size from 0.3-1.0 mm, with iddingsite alteration. The groundmass plagioclase and olivine crystals range up to 0.8 and 0.1 mm respectively. The rock is diktytaxitic, with intergranular pyroxene, and abundant opaque minerals. The single sample that was chemically analyzed shows Snake River Plain-type (SROT) basalt affinities (Figure 2.2; Table 1.1, sample II). Therefore, this unit is similar to the other stratigraphically younger basalts exposed in the northern part of Bryant Mountain. Thickness of this unit is variable, up to 20 m.

Tll **Basalt of Long Lake (Miocene)** Gray, moderately diktytaxitic, fine- to medium-grained, olivine-phyric basalt. This unit is located in the ridge west and south of Long Lake. It underlies the basalt of Captain Jack Lake (unit Tcj), and may be equivalent in age to the basalt of Lone Pine Reservoir (unit Tlp). The flows of this unit have scoriaceous tops and outcrop as a series of small ledges. In the field this unit is distinguishable for its large and numerous crystals and clumps of olivine. The amounts and sizes of these crystals appear to decrease downslope and down-section to the south. A thin section of the unit shows that the olivine phenocrysts range from 0.3 to 1.0 mm. A single "ratty", untwinned plagioclase xenocryst, measuring 0.8 mm, was also noted. The groundmass plagioclase crystals are variable in size, up to 0.8 mm, and the groundmass olivine crystals are up to 0.1 mm. The pyroxene crystals are intergranular, and the rock contains abundant opaques. The chemistry of the unit has Snake River Plain (SROT) affinities (Hart and others, 1984) (Figure 2.2; Table 1.1, map number GG) with higher values for TiO_2 (1.18 percent), Na_2O (3.23 percent), and K_2O (0.59 percent). The single paleomagnetic determination was normal. The total exposed thickness of the unit ranges from 5 to 65 m, but the base of the unit is not exposed.

Tlp **Basalt of Lone Pine Reservoir (Miocene)** Gray, slightly diktytaxitic, olivine-phyric basalt. This unit is located in the west-central part of Bryant Mountain. Stratigraphically, it is beneath the basalt of Captain Jack Lake (unit Tcj), and may be equivalent in age, based on its stratigraphic position, to the basalt of Long Lake (unit Tll) and the basalt of Russell Canyon (Trc). The flows of this unit are distinguishable in the field by their numerous, smaller, individual olivine phenocrysts, which in most outcrops have been entirely altered to iddingsite. The lithology has a fine-grained groundmass. Thin sections of the rock reveal abundant, small (0.2-1.4 mm) olivine phenocrysts and confirm the change to iddingsite, which was observed in the field. Like the basalt of Long Lake (unit Tll) the thin section for this unit contained a single larger (0.8 mm) plagioclase xenocryst that is untwinned and "ratty" with numerous small inclusions. The groundmass pyroxene is intergranular, and the plagioclase and olivine groundmass crystals are variable in size, up to 0.7 and 0.2 mm, respectively. The chemistry of this unit is very similar to the basalt of Long Lake (unit Tll) with Snake River Plain basalt (SROT) affinities (Hart and others, 1984) (Figure 2.2; Table 1.1, map number B) showing higher percentages of TiO_2 (1.31 percent), K_2O (0.50 percent), and P_2O_5 (0.29 percent). The single paleomagnetic reading on this unit is weakly reversed. Because of this signature, it is possible that this unit is an olivine-phyric equivalent of the basalt of Smith Reservoir (unit Tsr). The base of this unit is not exposed, but exposures generally range from 10-30 m thick.

Thc **Basalt of Hamaker Canyon (Miocene)** Medium- to light-gray, slightly diktytaxitic to non-diktytaxitic, olivine-phyric basalt. This unit is located on the northeast rim of Bryant Mountain, in the area of Smith Reservoir, as well as on a bench slightly above the Langell Valley floor, west of the townsite of Hot Springs (Figure 1.1). Stratigraphically the unit is beneath the basalt of Captain Jack Lake (unit Tcj), and above the basalt of Smith Reservoir (unit Tsr). Its lithology and stratigraphic position suggest that this unit may be the same unit as the basalt of Long Lake (unit Tll) or the basalt of Lone Pine Reservoir (unit Tlp), but its spatial isolation makes a direct correlation speculative. In most of its outcrops this unit is massive and blocky, with few vesicles and no rounded scoriaceous areas. A thin section of this unit contains abundant olivine (0.5-2.0 mm) and sparse plagioclase (0.2-0.8 mm) phenocrysts, as well as a few glomerocrysts of plagioclase and olivine. The pyroxene crystals are intergranular and the groundmass plagioclase and olivine crystals are variable, up to 0.5 and 0.2 mm, respectively. The olivine crystals are not altered to iddingsite. The chemistry of the unit shows a Snake River Plain basalt (SROT) affinity (Hart and others, 1984) (Figure 1.3; Table 1.1, map number MM), with higher values for TiO_2 (1.18 percent), K_2O (0.59 percent), and P_2O_5 (0.35 percent). The paleomagnetism of this unit is reversed. The thickness of this unit is variable, up to 30 m.

Twr **Basalt of Worlow Reservoir (Miocene)** Gray, non-diktytaxitic, fine-grained basalt with some olivine phenocrysts. This unit is located on the east-central rim of Bryant Mountain., east of Long Lake. It is stratigraphically above the basalts of Long Lake (unit Tll) and Smith Reservoir (unit Tsr). The unit is distinguishable in the field because it contains some to sparse smaller olivine phenocrysts and is fine-grained. In outcrop it tends to be massive, jointed, and does not exhibit flow banding. Sherrod and Pickthorn (1992) mapped one area of this unit as vent deposits, but this author found no evidence for a vent anywhere in this unit's exposures. The base of the unit is not exposed, and it has a variable thickness, up to 35 m. However, some of this thickness may be the result of repeated sections caused by fault displacements.

Trc **Basalt of Russell Canyon (Miocene)** Gray to light-gray, non-diktytaxitic, non-porphyritic to slightly olivine-phyric, basalt. This unit is located on the east rim above the Malin power substation in the southwest corner of the mapped area. Stratigraphically, it is above and thins against the undivided basaltic andesite flows (unit Tba). It may be the same unit or the stratigraphic equivalent to the basalt of Lone Pine Reservoir (unit Tlp), because they are both beneath the basalt of the Malin power substation (unit Tms). The unit may also be age equivalent to the basalt of Pope Reservoir (unit Tpr). It also overlies an area of lower sedimentary deposits (unit Tsl) on the east rim of its exposure. In the field the unit is distinguishable because it contains rare to some, individual olivine crystals, as well as some olivine glomerocrysts. The lithology is fine-grained and mottled, with numerous rounded areas of scoria. The outcrops are extremely flowbanded, and the weathered surfaces have a characteristic light green and purple spotted appearance. The paleomagnetism is uniformly normal. The thickness of this unit is variable from a single flow (5 m), to a repeated section, on a fault offset, of up to 75 m.

Trt **Basalt of the radio tower (Miocene)** Gray to greenish-gray, non-diktytaxitic, coarse-grained basalt that in some exposures is olivine-phyric. The unit is located in the area of the old radio tower south of the Malin power substation on the west rim of Bryant Mountain. It is below the upper basalt of Mills Creek (unit Tmiu), and its appearance suggests that it may be the same lithology as the basalt of Grohs Reservoir (unit Tgr). However, the spatial separation of valley floor (unit Tgr) and rim exposures (unit Trt), makes this correlation speculative. Like the basalt of Grohs Reservoir (unit Tgr), this unit has an unusual coarse-grained, non-diktytaxitic (mottled) groundmass, with scoriaceous areas containing euhedral pyroxene crystals that are visible to the naked eye. Near the radio tower the flows of this unit are cindery and somewhat unconsolidated, suggesting that this may be near the vent of the unit. The cinders have been mined for road material. Most of the flows of this unit are flowbanded, although there are also more massive areas. The olivine phenocrysts are variable from flow-to-flow in both their size and abundance. This unit is fairly thin, with a variable exposure, up to 20 m.

Tst **Basalt of the steel transmission line (Miocene)** Gray, non-diktytaxitic, olivine-phyric basalt. Located in the southwest part of the mapped area, this unit makes up the lower parts of the high elevation basalt rims from the Malin power substation to the Pope Reservoir area. Stratigraphically, it is beneath the basalt of Lone Pine Reservoir (unit Tlp), the basalt of Pope Reservoir (unit Tpr), the upper basalt of Mills Creek (unit Tmiu), and some of its flows may be included in the undivided sediments and basalt/basaltic andesite flows (unit Tsb). Based on their appearance, some of the flows included in this unit may be correlative with the basalt of Grohs Reservoir (unit Tgr), but the spatial separation of the two units (valley floor vs. rim) makes a definite correlation speculative. The flows of this unit emerged consistently with flow banding, with some layers approaching an unconsolidated cindery texture. Rounded scoriaceous areas are another prominent textural feature. The unit is mottled (non-diktytaxitic), with variable sizes and amounts of olivine phenocrysts. Paleomagnetic measurements yield a normal polarity. The base of the unit has not been identified, but exposures are variable, up to 35 m.

Tsr **Basalt of Smith Reservoir (Miocene)** Gray, non-porphyritic, diktytaxitic, fine- to medium-grained basalt. The unit forms the lower ledges in the ridges surrounding Smith Reservoir as well as exposures in an area northeast of Long Lake. Stratigraphically, this unit is beneath the basalt of Captain Jack Lake (unit Tcj), the basalt of Hamaker Canyon (unit Thc), and the basalt of Worlow Reservoir (unit Twr). The basal contact of the unit was not precisely located, so some of the lower flows of this unit may be included in the underlying undivided sediments and basalt/basaltic andesite flows (unit Tsb). In general, outcrops of this unit are massive, with only slight amounts of flow banding. Exposures of this unit are identifiable in the field because the unit is not porphyritic, is fine- to medium-grained and is slightly to strongly diktytaxitic. A thin section of this rock confirms the non-porphyritic nature of the rock, with only a single, 0.9 mm olivine phenocryst. The groundmass pyroxenes are subophitic, and the rock has slight amounts of opaques. The groundmass plagioclase crystals are variable in size, up to 1.0 mm in length, and the olivine crystals have iddingsite rims and also are variable in size, up to 0.2 mm. Chemically, this unit is similar to the Basin and Range affinity basalt flows (Hart and others, 1984) with lower K_2O (0.12 percent) and TiO_2 (0.86 percent), and higher MgO (9.05 percent) and CaO (11.32 percent) values (Figure 2.2; Table 1.1, map number DD). The paleomagnetic measurements at two locations showed a reversed polarity. Total thickness is unknown, but the exposures are variable, up to 35 m.

Tgr **Basalt of Grohs Reservoir (Pliocene or Miocene)** Gray to greenish gray, non-diktytaxitic, olivine- and pyroxene-phyric basalt. This unit is located around the Grohs Reservoir, in the Tule Lake Valley floor in the southwest corner of the mapped area. Because its outcrops are isolated, it has no known, conclusive stratigraphic relation with the other basalt units on the top of Bryant Mountain. However, flows that, in the field, appear to be similar in appearance to this unit are included in the basalt of the radio tower (unit Trt) and the basalt of the steel trans-

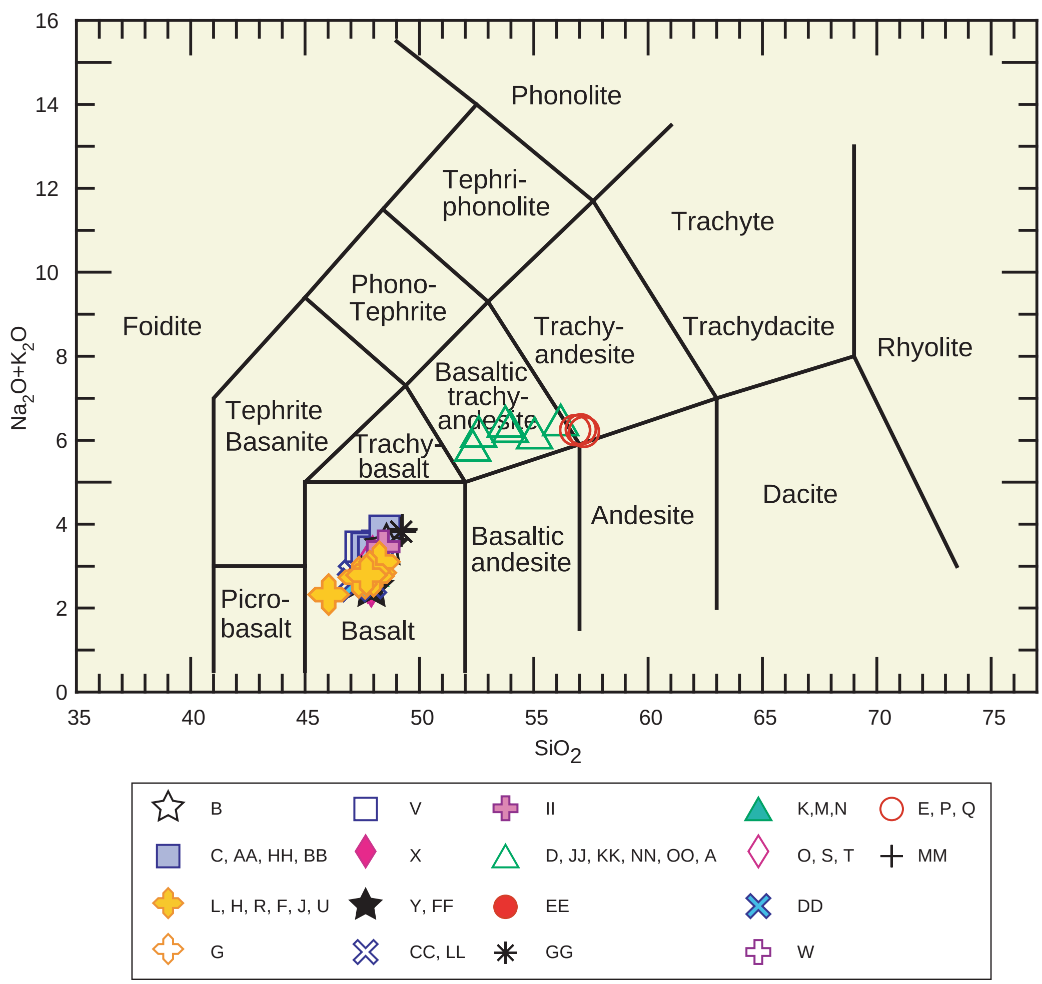

Figure 2.3. Total alkalis vs. silica plot of only the basalt samples for Bryant Mountain and Langell Valley quadrangles, Klamath County, Oregon., from Table 1.1.

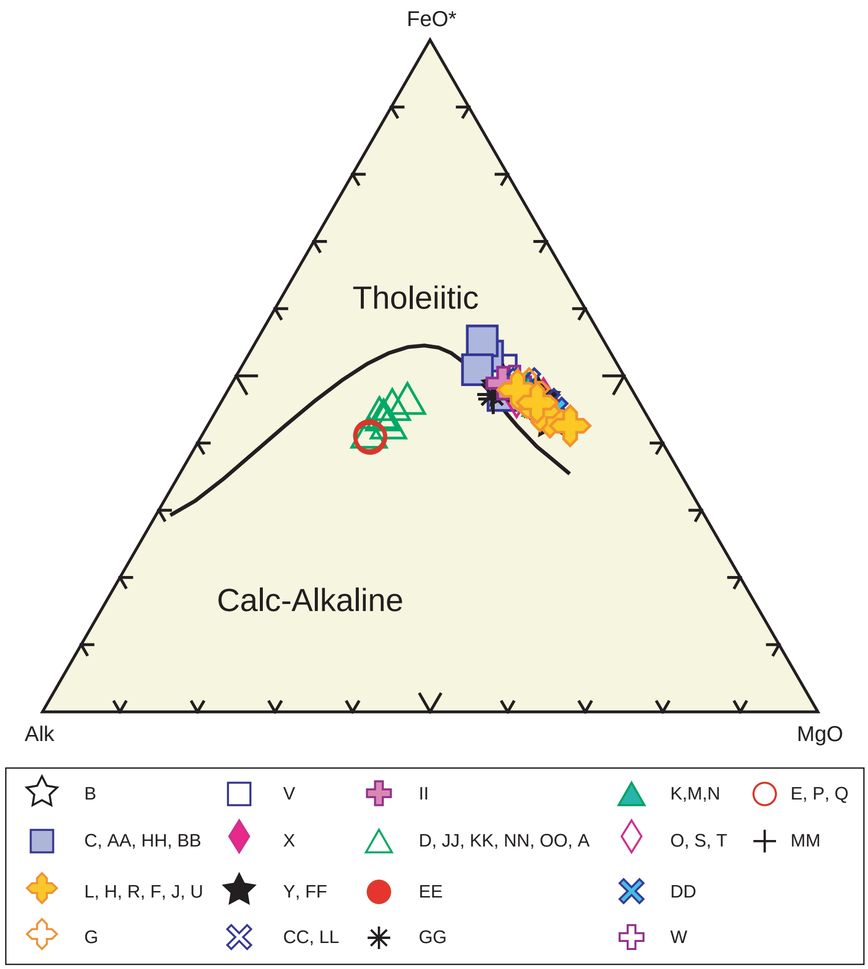

Figure 2.4. Ternary plot of FeO-Total alkalis-MgO showing the tholeiitic vs. calc-alkaline composition line of Irvine and Barager (1971) for only basalt sample from Table 1.1.

mission line (unit Tst). The flows of this unit are unusual because they contain alternating massive, light greenish gray, mottled layers, and highly vesicular layers that contain euhedral dark green to black pyroxene crystals. The mottled layers have a spotted and coarse-grained "sugary" appearance on their weathered surfaces. The alternating vesicular and massive layers give the unit its characteristic flowbanded appearance, and some parts of the flows contain rounded, scoriaceous areas. The high vesicularity of the flows suggests that exposures of the unit may be near-vent. A thin section of the unit shows no olivine or plagioclase phenocrysts, but instead large, euhedral, subophitic, clinopyroxene crystals. The plagioclase groundmass crystals are variable in size, up to 1.4 mm, and the groundmass olivine crystals are up to 0.15 mm, with no iddingsite alteration. The thin section also contains sparse opaque minerals. Despite its unusual appearance, the rock is basalt in composition, with Basin and Range flow affinities in its chemistry (Hart and others, 1984). It has low TiO_2 (0.96 percent) and P_2O_5 (0.15 percent) values, and high MgO (9.08 percent) and CaO (11.48 percent) percentages (Figure 2.2; Table 1.1, map number EE). The base of the unit is not exposed, although one area appears to be only a single flow overlying some sedimentary layers. Exposures of this unit are variable, up to 12 m.

2.4 BASALTIC ANDESITE FLOWS

The oldest volcanic flows within the mapped area are distinctly different both chemically and in their appearance from the younger basaltic section. Chemically, the flows fall within the basaltic trachyandesite and the trachyandesite areas of the IUGS volcanic classification system (LeBas and Streckeisen, 1991) (Figure 2.3), and within the calc-alkaline area of the FeO-MgO-alkaline ternary diagram (Figure 2.4). In their appearance the basaltic andesite flows are much more viscous than the younger basalt flows. They have thick, red, scoriaceous flow tops with common disturbed flow banding. The flows are generally glassy, although some of the upper flows appear to be somewhat crystalline. Exposures of these units are poor, and in some skid-trail exposures the flows appear to be water-affected. This alteration would account for the generally poor exposure. However, because of a lack of access, the largest area of these flows on the highest parts of Bryant Mountain could not be examined in detail. The relationship of the younger basalt flows to these flows suggests that the basaltic andesite flows were higher areas or "hills" when the basalt flows were erupted. The basalt flows thin against and surround the "hills" of the basaltic andesite flows. Two age determinations (Table 1.2) from two different areas of this lithology suggest a middle Miocene age of eruption for the basaltic andesite group of flows (Mallin, 1989; Hart and Mallin, 1991, new age determination by Dr. Robert Duncan, Oregon State University).

Tmil **Lower basalt/basaltic andesite of Mills Creek (Miocene)** Black to dark gray, basaltic breccia, cinders, and extremely scoriaceous flows. This unit is located in the lower part of the Mills Creek drainage, on the southwest side of the mapped area. Stratigraphically, it is below a section of undivided sediments and basalt/basaltic andesite flows (unit Tsb). On the south side of the creek, this unit is overlain in by a 20-30 m section of fine-grained sediments, which is included in the Tsb unit. In appearance the flows of this unit are more similar to the basaltic andesite units than the basalt units within the mapped area. It is the only clearly near-vent volcanic rocks in the mapped area, containing partially to completely cemented volcanic breccia and cinder deposits that thin to the north, away from the Mills Creek channel. In the central part of the exposure, the more cemented parts of the vent facies have eroded and form small hoodoos. The uppermost part of the unit is a single flow that contains stretched vesicles. In appearance the unit is aphanitic, with a cryptocrystalline groundmass. The unit is strongly normal in its paleomagnetic signature. The base of the unit is not exposed, but the exposures in the creek range from 12-30 m. At the east end of the exposure the unit ends abruptly, and is probably faulted.

Tgb **Trachyandesite of Gift Butte (Miocene)** Dark-gray to black, aphanitic, glassy to very fine-grained, basaltic andesite flows. This unit is located on the east side of Langell Valley, making up the entire Gift Butte, as well as the low hill (upper elevation 4200') to the southwest of Gift Butte. Additionally, the lower two flows in the main East Langell Valley Rim near Woolen Canyon are mapped as this unit. Stratigraphically the flows of this unit are beneath the some lower sedimentary deposits (unit Tsl) and the basalt of Willow Valley (unit Twv). Indeed, Gift Butte appears to be a hill around which the younger basalt of Willow Valley (unit Twv) flowed. It is likely that the flows of this unit continue within the sediment and basalt/basaltic andesite flows, undivided (unit Tsb) both north and south of the unit's mapped area in the East Langell Valley Rim. However, exposures were too poor to conclusively include those areas within this unit. In the field this unit is aphanitic in appearance, extremely glassy, and hard. In thin section the rocks contain only very rare larger plagioclase phenocrysts that are zoned and "wormy". Groundmass plagioclase are blocky rather than laths, range up to 0.4 mm, and are trachytic in their alignment in some samples. The olivine groundmass crystals are tiny, ranging only up to 0.1 mm and in some samples slightly altered to iddingsite. Chemically the trachyandesite of Gift Butte differs from the other basaltic trachyandesite rocks in the mapped area (unit Tba and unit Tsb). It has higher SiO_2 and total alkalis percentages, which place it well within the calc-alkaline (Figure 2.4) and trachyandesite ranges (Figure 2.3). A sample from the north end of Gift Butte (sample number MJ99-02) gave an Ar^{40}/Ar^{39} whole-rock age of 8.18± 0.12 Ma (Table 1.2). Thus, it is similar in age, to perhaps older than the basaltic andesite, undivided (unit Tba), which is found in the Bryant Mountain area. The exposed thickness of this unit in Gift Butte and the East Langell Valley Rim reaches 70 m.

Tba **Basaltic andesite, undivided (Miocene)** Dark-gray to black, aphanitic, glassy to very fine-grained, basaltic andesite flows. This unit is exposed in several locations throughout the mapped area, as both small and large exposures. It dominates the south half of Bryant Mountain, forming the south central and highest elevation parts of the mountain. It is also located on the west side of Langell Valley, in the low hills that are adjacent to the valley floor below the Bryant Mountain escarpment. All of the younger basaltic units in the mapped area thin against and overlie this unit. As it is mapped, this unit overlies the undivided sediments and basalt/basaltic andesite flows (unit Tsb) unit. However, this contact is arbitrary, because in most areas a lack of exposure and, on Bryant Mountain, a lack of access precluded tracing the exact boundaries between this unit and the (presumably) older or equivalent section of basalt and basaltic andesite flows. Sherrod and Pickthorn (1992) mapped this unit as parts of their Units Two and Three of the Basin and Range basalts. Outcrops of this unit range from numerous, thin (1-3 m) subaerial flows, to flows that appear to have interacted with water and that are now weathered to form unbroken slopes with no outcrop. The flows generally contain large, stretched vesicles that give the unit a characteristic platy appearance. In many locations botryoidal opal covers the joint and vesicle surfaces. Some flows have red, extremely scoriaceous tops, with contorted flow banding. Another distinguishing characteristic of this lithology in the field is its glassy to very fine-grained texture. It has a conchoical fracture and is very hard, often causing a shower of sparks when struck by a rock hammer. Thin sections of this unit contain some olivine phenocrysts (0.2-1.0 mm). The rock is not diktytaxitic and does not contain intergranular or ophitic pyroxene. The groundmass plagioclase crystals (up to 0.6 mm) are blocky, contain many fine crystals and glass inclusions, and show some trachytic alignment. The olivine crystals in the groundmass are tiny, ranging up to 0.1 mm, with some to abundant iddingsite alteration. All of the samples have abundant opaque crystals mixed into the glassy groundmass. Chemically, this unit is a basaltic trachyandesite according to the IUGS volcanic classification system (LeBas and Streckeisen, 1991) (Figure 1.4). The flows of this unit appear to be generally chemically uniform throughout their disconnected exposures (Table 1.1, map numbers A, D, JJ, KK, NN, OO), with high total alkali (5.85-6.46 percent) and SiO_2 (52.33-57.06 percent) values (Figure 2.4). It is different in chemistry from the calc-alkaline rocks to the west the mapped area, in the Dairy and Bonanza quadrangles (Hladky, 2003). However, Black (in press) reports an area of this basaltic trachyandesite chemical type in the northern part of the Lorella quadrangle. Mallin and Hart (1991) published a whole-rock K/Ar age of 7.32 ± 0.24 Ma for a sample of this unit located near the lookout at the summit of Bryant Mountain. This age could be considered a minimum age for this unit, because it is from the unit's uppermost flows. Although some of the flows of this unit have equivocal or possibly reversed paleomagnetism, the majority of measured samples had a strong normal signature. The total thickness of this unit could be more than 300 m.

Tsb **Sediments and basalt/basaltic andesite flows, undivided (Miocene)** Poorly exposed basalt and basaltic andesite lava flows with interbedded sedimentary materials. This unit is mapped on the lower slopes of the main valley-bounding escarpments on both the east and west sides of Bryant Mountain. In addition, it is mapped under the basalt flows within the principal escarpment on the east side of Langell Valley, the East Langell Valley Rim. Exposures of the flows and sediments of this unit are principally found in logging roadcuts on the sides of

Bryant Mountain In these areas the flows appear to be water-affected. This means that they strongly interacted with water at the time of their eruption. Subsequent to their exposure on fault scarps, they rapidly decompose to clay and soil, giving this unit its characteristic poor exposure. The interbedded sediments are also rarely exposed. However, in a few roadcut exposures, the few exposed sediment layers are thin and similar in composition to the upper and lower sedimentary deposits (units Tsu and Tsl). As it is presently mapped, the contact between this unit and the individual basalt units and the basaltic andesite units is arbitrary. Therefore, it is likely that the northern parts of this unit contain a high percentage, or may be completely composed of basalt flows, while the southern exposures consist principally or entirely of basaltic andesite flows. The base of this unit is not exposed, and its exposure is variable, up to 500 m.

3.0 GEOLOGIC HISTORY

3.1 STRUCTURE

The mapped area lies within the extensional Basin and Range tectonic province that dominates the physiography of the state of Nevada, and extends into southern Idaho and south-central Oregon. Within the mapped area the predominant grain of the structure mimics the overall trends of the Basin and Range province--large, north-to-northwest-trending graben valleys, separated by large horst mountain blocks.

The two principal structural features that dominate the mapped area are the Langell Valley graben and the Bryant Mountain horst (Figure 3.1). In addition, a major, down-to-the-southwest, set of north and northwest trending faults separates the Bryant Mountain horst from the northeast part of the Tule Lake Valley on the west side of the mapped area. The Langell Valley graben is bounded on the east side by a number of smaller displacement (up to 120 m) faults. The most prominent valley-bounding rims on this side of the valley, particularly East Langell Valley Rim, trend almost due north, with a slight component to the northeast (Figure 3.1). On the west side of the graben the fault zone separating the Langell Valley graben from the Bryant Mountain horst has up to 750 m of total relief. Thus, it is possible that the Langell Valley graben is actual-

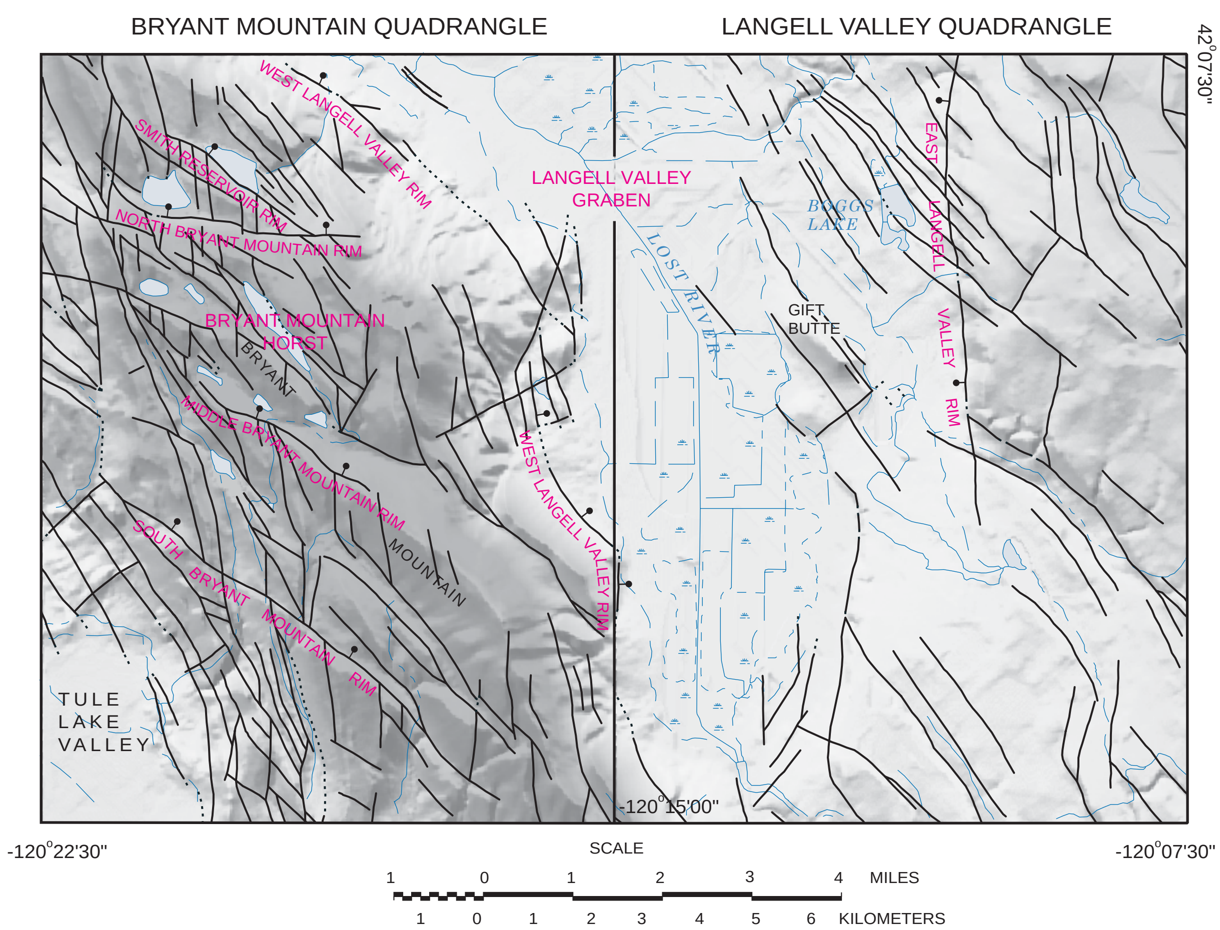

Figure 3.1 Shaded relief map of the Bryant Mountain and Langell Valley quadrangles, Klamath County, Oregon, showing mapped faults and named structural features. Fault contact shown as solid line where approximately located, dashed lines where concealed; ball and bar on downthrown side for faults mentioned in text.

ly a half- or trapdoor-graben, with the hinge area on the east and the major graben-forming movement on the west side of the valley. The small northwest-trending horst and graben features in the area of Boggs Lake are the most prominent expression of the hinge area of the half-graben. These northwest-trending faults offset the older north-trending East Langell Valley Rim. A similar north-trending, lower elevation rim with a smaller displacement (up to 40 m) makes the actual valley edge of Langell Valley south of Gift Butte (Figure 3.1). It is this southern rim that gives this part of the valley its overall more northerly trend, while the northern part of the valley has a more northwest trend.

Numerous similar smaller displacement faults are located within the central part of the overall Bryant Mountain horst (Figure 3.1). The majority of these faults trend between N. 30° W. and N. 40° W. However, a significant number of faults, particularly in the north part of the mountain, have trends that closely approximate due-north. These due-north faults have been truncated by the northwest trending faults. Measured strikes in the southwest part of the mapped area, on several small faults within the major fault zone that separates the Bryant Mountain horst from the Tule Lake Valley, have azimuths trending N. 6° W., N. 35° W., and N. 30° W. However, the most interesting faults on the mountaintop are three major structures, the North, Middle, and South Bryant Mountain Rims (Figure 3.1). These faults run across or nearly across the width of the mountain and trend between N. 65° W. and due west. These structures offset all of the other faults in the area, and thus must be the youngest structural features on the top of the mountain. A similar major east/west trending structure is located in the Malin quadrangle to the west of the mapped area, and may be the westward continuation of the North Bryant Mountain Rim. The North Bryant Mountain Rim has an apparent throw of over 100 m. It is possible that there is some dip-slip component to this fault, because the north and northwest trending faults that are offset by this fault appear to be offset to the west on the downthrown side of the fault.

The age of the faulting within the mapped area is problematic. Some geologists in the area (Peterson and McIntyre, 1970; Sherrod and Pickthorn, 1992) have suggested that the onset of major Basin and Range faulting in this region was Pleistocene, or perhaps late Pliocene. Other authors (Hart, and others, 1984, Murray, in press, Black, in press) postulate a much older 7.0 Ma or Miocene age for the onset of this high-angle Basin and Range faulting. Because the age of the volcanic units within the mapped area is early Pliocene to middle Miocene, there are no younger lavas with which to bracket the age of the faulting that cuts these units. From the relatively young, undissected appearance of the fault scarps, and the lack of established streams coming off of the Bryant Mountain horst, it is possible to infer that the ages of the major northwest-trending faults that formed the Langell Valley and Bryant Mountain are relatively young. However, these faults also do not appear to have moved within the recent past, because none of the talus slopes or landslide debris fans in the area shows any signs of offsets.

Peterson and McIntyre (1970) suggest that the Klamath Basin area may have undergone a period of warping that produced broad, gentle folds that affected the older basaltic andesite and sedimentary sections. Within this mapped area, there appears to be some evidence that this older warping did occur. The younger basalt lavas both on Bryant Mountain and in the Gift Butte area appear to have flowed around and thin against relatively low and broad pre-existing highs of the basaltic andesite flows. In fact, on the south side of Bryant Mountain, near and south of the California state line, the younger lava flows appear to be consistently dipping away from the higher elevation basaltic andesite flows, suggesting further (younger?) regional changes in dip after the basalt flows were emplaced.

While none of the major fault planes are exposed within the mapped area, it appears that the dip of the normal faults is similar to the 50°-60° dips measured in other Klamath Basin areas on similar faults. The dip of one of the small faults within the western Bryant Mountain fault zone measured 40°. Thus, it can be assumed that the faulting within the map area is principally high-angle normal faulting of the Basin and Range type. Near and within some of the larger and smaller fault planes, the volcanic flows have been bent. In one case, in NW¼, sec. 20, T. 40 S., R. 13 E., a series of basalt flows within a fault plane appear to be nearly vertical. Bent lava flows near fault planes are widespread throughout the mapped area, suggesting that drag on the faults is the principal reason for any significant local changes in the dips of the lava flows in the mapped area.

3.2 VOLCANIC AND SEDIMENTATION HISTORY

The oldest units within the mapped area (see GMS117map.pdf) are the undivided basaltic andesite unit (unit Tba), the trachyandesite of Gift Butte (unit Tgb) and the undivided sediments and basalt/basaltic andesite flows (unit Tsb). The thin, fairly viscous flows of these calc-alkaline units were erupted over a subdued topography as horizontal sheets. The whole-rock radiometric age determinations of 7.32 ± 0.24 and 8.18± 0.12 Ma (Table 1.2) place these eruptions in the late Miocene period. Some of these flows were affected by contact with water, which is the reason for the subdued topography that now is characteristic of these units. No vent area has been located for any of these flows, although much of their extent could not be surveyed in detail, due to property access problems. Interbedded with and above these flows are sedimentary deposits (units Tsu and Tsl), which appear to have been deposited in broad lacustrine environments. After their eruption these basaltic andesite units formed high areas in the landscape. Whether these highs were formed by erosion, faulting, or broad folding is unknown, since subsequent Basin and Range faulting has overprinted and obscured the exact relations of these units to each other and to the younger basaltic units.

Following this initial period of more calc-alkaline lava eruptions, a sequence of basaltic lava flows were erupted from vents that are both buried and visible in today's terrain. The Bryant Mountain basalt flows fall into two distinct spatial and chemical groups. The sequence of flows that erupted and flowed up against the pre-existing basaltic andesite highs, and now are located in the southwest and west central parts of the mountain, have Basin and Range volcanic province affinities (Hart and others, 1984) in their chemistries. These lavas are more primitive, with high CaO and MgO signatures (Figure 2.2; Table 1.1). In contrast the flows that are presently located in the north part of the mountain have more affinity with Snake River Plain province volcanism. The compositions of these units are more evolved with higher K_2O, Na_2O, and TiO_2 percentages (Figure 2.2; Table 1.1). The stratigraphic relations of all the basalt units suggest that the Basin and Range affinity flows are older than the Snake River Plain affinity flows. In addition, chemical analysis of samples from a series of cores drilled on the top and sides of Bryant Mountain show a change from Snake River Plain to Basin and Range affinities with depth (Table 1.1). However, as noted in the Age Determination section 1.2.2, the differences in the previously published and new age determinations make the exact age relations of these basalt flow populations uncertain. However, it appears that all the basaltic flows on Bryant Mountain erupted in the range of 5.0-7.0 Ma.

The basalt flows that are exposed in the east rims of Langell Valley do not fall into either the Snake River Plain or Basin and Range affinity fields (Figure 2.2; Table 1.1). Instead, most of the flows appear to be transitional in chemistry, with a mix of higher and lower percentages in all of the indicator elements. Only one of the units in this part of the mapped area, the basalt of Boggs Lake (unit Tbl), has a distinct Snake River Plain affinity chemistry. Two other units, the basalt of Dog Hollow Reservoir (unit Tdh) and the basalt of Copeland Reservoir (unit Tcr), show some Basin and Range volcanic province affinities (Table 1.1). The east Langell Valley flows appear to have been erupted within the same time range as the flows located on the top of Bryant Mountain, approximately 5.0-7.0 Ma.

All of the basalt flows in the mapped area erupted onto a fairly subdued terrain. Evidence of this subdued terrain is the thin and laterally consistent nature of the individual flows and the absence of pillowed and ponded areas in almost all of the flows. Some of the flows in the lower parts of the volcanic section definitely interacted with water, suggesting that they flowed into bodies of water or swampy areas. However, no intrusive relationships were found within the interbedded sediments exposed in the mapped area, and even these water-affected flows are thin and laterally consistent. Both during and possibly after the eruption of the basalt flows, layers of fine-grained lacustrine sediments were deposited. In some places a definite contact is visible between these sediments and the over- or underlying basalt flows. In other areas, as discussed in the descriptions of the sedimentary units, the individual sedimentary exposures do not appear to be in direct depositional contact with the basalt or basaltic andesite units. Thus, their stratigraphic position within the history of the mapped area is uncertain. Identified fossils from similar beds throughout the region (Peterson and McIntyre, 1970; Gerald R. Smith, 2000, personal communication) suggest a Pliocene/Miocene age for all the lacustrine sediments. However, this information does not help with the exact placement of isolated individual sedimentary exposures within the overall stratigraphic sequence.

From regional age determinations on younger lava flows, it appears that the Basin and Range extensional faulting that formed the Bryant Mountain horst and the Langell Valley graben probably began in the late Pliocene or early Pleistocene. The entire stack of lava flows and sediments in the Bryant Mountain and Langell Valley quadrangles has been broken by this high-angle normal faulting. Some tilting of the fault blocks also took place. Particularly on the south end of Bryant Mountain, the basalt flows and underlying sediments form hogbacks in relation to the older basaltic andesite units. The older north- and northwest-trending faults were subsequently cut by a series of east-west trending faults that drop the north part of Bryant Mountain down in steps to lower elevations.

During the Pleistocene the Langell Valley, along with other similar valleys in the Klamath and Tule Lake areas, were probably flooded and may have contained more extensive lakes than presently exist in those valleys. The Miller Creek drainage, on the east side of the Langell Valley appears to have flowed into a shallow lake forming a gravel delta. After the retreat of this lake, the present Miller Creek channel eroded the north side of the gravel delta. It is interesting that a similar gravel delta is not found in the Lost River channel or in the nearby well logs in the south end of the valley, where the Pleistocene ancestral Lost River presumably entered the southern end of the Langell Valley.

Sometime after the formation of the steep valley walls on the east and west sides of Bryant Mountain, several large earthflow slump landslides occurred. It is possible that some of these slides were precipitated by seismic events in the region. None of them appear to have been formed within historical time, as they are all well-forested with mature trees.

After the Holocene, when the lake in the Langell Valley became a swamp, the Lost River established a channel down the center of the valley. Small alluvial fans spread out into the valley from the small draws that have eroded back into the valley-bounding fault escarpments. In historic times the local ranchers and their irrigation districts deepened and channelized the Lost River and Miller Creek channels for flood abatement purposes and to drain the remaining swampy parts of the valley.

4.0 GEOLOGIC RESOURCES AND HAZARDS

4.1 MINERAL RESOURCES

Only four locations within the mapped area have been systematically mined by the local ranch and farm community as sources for gravel or aggregate (see GMS117map.pdf). The largest pit, the Langell Valley Pit, is located just south of the Miller Creek crossing of the East Langell Valley road. The pit exploits the older (Pleistocene?) gravel fan produced by an older channel of Miller Creek (unit Qg). The local community still uses the pit run, unsorted gravel for paving their driveways and feedlots. The mined unit is quite extensive, and will probably remain the principal source for gravel within the valley for the foreseeable future.

The other three pits, the Willow Valley Road pit, on the east side of Langell Valley beside Willow Valley Road, and two others in the center part of west Langell Valley, the Edwards and Biaggi gravel pits, have all been extensively mined in the past, but are presently inactive. The Willow Valley pit excavated a pillow delta that is an areally limited feature within the basalt of Willow Valley (unit Twv). The pillows are well-formed and the extensive palagonitized cinder deposits between the pillows give the mixture the necessary amount of fine-grained materials for a good roadbed.

Both of the west Langell Valley pits are within the Tsu unit of sedimentary deposits. The gravel pebbles and cobbles in both of these pits are smaller in size than the ones in the Langell Valley Pit. In addition, the extent of these deposits is much smaller, and it is likely that the present pits have already exploited the major parts of the deposits. In terms of future sources, all of the basalt and basaltic andesite units in the area are excellent road metal sources. However, it is unlikely that these units will be exploited because of the costs involved with blasting and crushing the rock.

4.2 WATER RESOURCES

A number of springs are located along both eastern and western edges of Langell Valley. On the east side of the valley the springs all issue from the same horizon in the East Langell Valley Rim escarpment that forms the principal eastern wall of the valley. In spite of the various locations of the springs on the topographic maps, they all actually issue from beneath the lowest elevation exposed basalt flow within the Tsb unit, approximately halfway up the escarpment. It is possible that the general south-southwest dip of the basalt units is the same as the general dip and direction of the groundwater flow in this area. In that case the springs reflect the exposure of that flow in the valley-bounding fault escarpment. Although there are no exposures of any size to test the concept, the character of the colluvium at the level of the springs suggests that a sandy silt sedimentary layer may underlie the basalt flows. If this is true, then the sediment may act as a confining layer for the groundwater flows. Some of the springs dry up in the late summer, but several of them flow with enough quantities to feed small stock tanks year-round.

On the west side of the valley the spring locations are related to the fault locations, rather than to a specific stratigraphic horizon. The largest spring in the area, Ralston Spring, is located in SW¼ sec. 26, T.40 S., R. 13 E. In late October of 1999 the spring was bubbling up briskly within the spring box, and its water fills a good-sized stock water pond. The location of this spring is at the intersection of two faults. Several other smaller, annual springs are also located along the same or similar fault trends within the same area. The most interesting springs are the hot and cold springs located within 50 m of each other on the ranch presently owned by Walter and Dorothy Smith in SE¼, sec. 9, T. 40 S., R. 13 E. According to Mr. Smith, the cold spring was used in the 1930's to cool milk from the Smith family's dairy, and the hot spring, with a present temperature of approximately 150° F, is presently used to geothermally heat their house. Other springs in the same area are also warm, but not hot enough to provide geothermal heating.

Numerous wells have been drilled within both the Langell and Tule Lake Valleys for use as domestic, stock, and irrigation water sources. Studies of the well logs, as part of this geologic mapping project, show that the high production wells (1000-3500 gpm) have several similar geologic characteristics. First, they are generally located near the edges of the main Langell and Tule Lake Valleys, close to the major valley-bounding fault escarpments. Second, their upper sections contain significant thicknesses (50-150 m) of the upper sedimentary deposits (unit Tsu) that floor the main part of Langell Valley. Finally, they all are drilled to a sufficient depth to reach the underlying basalt/basaltic andesite section. In contrast wells that were drilled at higher elevations, are away from the main fault escarpments, and start within the basalt section tend to be poorer producers (50-300 gpm). In general, all of the wells appear to receive some of their production from the sand and pebble gravel layers within the sedimentary deposits, with the deeper irrigation wells producing from cinder layers or rubbly flow tops or bottoms located within the basalt and basaltic andesite sections. Jerry Grondin of the Oregon Water Resources Department (OWRD) is presently writing a report on an extended water level monitoring program and groundwater modelling project, as part of a regional Lost River basin groundwater study.

4.3 GEOTHERMAL RESOURCES

A 1978 report issued by the Geo-Heat Center of the Oregon Institute of Technology shows three areas within Langell Valley of greater-than-average potential for hot water (Lienau, 1978). Two of these three areas are within the mapped area, on opposite sides of the Langell Valley. A survey of measured temperatures as documented in the local well logs shows slightly elevated temperatures for all of the wells in the valley. The temperatures range from 58°-100° F, with a majority in the range of 60°-70° F. The two identified areas of hot water are located on the east side of Langell Valley between Gift Butte and the Willow Valley Road, and on the west side of the valley in the area of the abandoned townsite of Hot Springs. The east Langell Valley hot water area has well temperatures that range from 62° F (water well KLAM 14897) to 79° F (water well KLAM 14892). (Water well identification numbers are from the OWRD 1998 GRID database.) None of the landowners use the warm water from these wells for any geothermal purpose.

The west Langell Valley hot water area has documented well temperatures that range from 56° F (water well KLAM 10513) to 100° F (water well KLAM 14862). As noted in the discussion of groundwater resources, a local rancher reports that one of his wells, which he uses to geothermally heat his house, has temperatures in the range of 150° F (Walter Smith, 2000, personal communication). In that same area a 1970 map of the thermal springs and wells in Oregon (Bowen and Peterson, 1970) lists the Big Hot Spring (also called the Oregon Hot Spring and Turner Hot Spring) as having a maximum temperature of 142° F and a flow of 40 gpm.

Walter Smith (2000, personal communication) reports that during the early part of the 20th century the Oregon Hot Springs Hotel was located at the spring, and the hotel's foundations and a large pool are still visible today. Mr. Smith remembers that the hotel was approximately 18-20 m long and on the first floor contained 6 to 8 individual hot bathtub rooms, as well as a dining room and an area for massages and rubdowns. Mr. Smith believes that the hotel probably closed in the mid-1940's. Several firms have contacted Mr. Smith about commercial ventures using the hot springs, but at the present time the area is a pasture.

4.4 EARTHQUAKE AND MASS WASTING HAZARDS

No earthquakes have been reported as having epicenters within the mapped area. However, area residents report that they felt the 1993 series of earthquakes that rocked the nearby Klamath Falls area. In addition, some older Langell Valley residents report that the San Francisco 1906 earthquake was felt in the area, and that afterwards some Langell Valley springs experienced flow changes. The possible relatively recent age of the faults that bound Langell Valley and Bryant Mountain, discussed in the structural section of this report, suggests that earthquake activity has been an important part of the recent geologic history of the area.

The principal hazards related to earthquakes in the area are mass wasting movements, either as slides or large block rockfalls. The author of this report found a recent (within the last 5 years) fall of several large blocks on an east-facing escarpment above the upper end of Mills Creek in the southwest corner of the mapped area. The blocks, with sizes up to a large delivery truck, had destroyed a segment of the powerline road. The slide was recent enough that the brush had not yet grown back. As discussed in the description of the landslide deposit unit (unit Qls), several large landslides of ancient age are located on both sides of the Bryant Mountain horst. In addition, the author found a recent debris flow in sec. 21, T. 40 S., R. 13 E., which probably originated from the failure of a logging road built in the headwall of the largest ancient slide in the mapped area. Because it is likely that the ancient slides originated as the result of seismic activity, it is possible that similar earthquake-generated slides will happen in the future.

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