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

Open-File Report

OFR O-04-07

GEOLOGIC MAP OF THE LORELLA QUADRANGLE, KLAMATH COUNTY, OREGON

By

Gerald L. Black, Oregon Department of Geology and Mineral Industries

2004

TABLE OF CONTENTS

NOTICE

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

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

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

1.0 INTRODUCTION

The Lorella quadrangle is located in south-central Oregon in central Klamath County, approximately 33 km (21 mi) east of Klamath Falls, Oregon and 14 km (8.5 mi) north of the California border. Figure 1.1 is a sketch map showing the locations of geographic features discussed in the text. An index map showing the location of the Lorella quadrangle relative to the rest of Oregon can be found on the map sheet. The principal geomorphic feature of the quadrangle is the Langell Valley, a north-northwest trending fault-bounded valley that is drained by the Lost River, the only perennial stream in the quadrangle.

Other important geomorphic features are Bryant and Goodlow Mountains. A part of the northern end of Bryant Mountain lies in the southwest corner of the quadrangle. Bryant Mountain is an uplifted fault block. Goodlow Mountain is a large basaltic shield volcano; its central vent lies just east of the quadrangle. The west and northwest flanks of the volcano occupy the northeast corner of the quadrangle. The principal geologic structures are north-northwest trending fault-bounded horsts and grabens.

No towns are located in the Lorella quadrangle. The land is principally used for cattle ranching and hay production.

1.1 Previous Work and Methods

The Lorella quadrangle was included as part of two previous geologic maps (Peterson and McIntyre, 1970; and Sherrod and Pickthorn, 1992). This map is the first published at a scale of

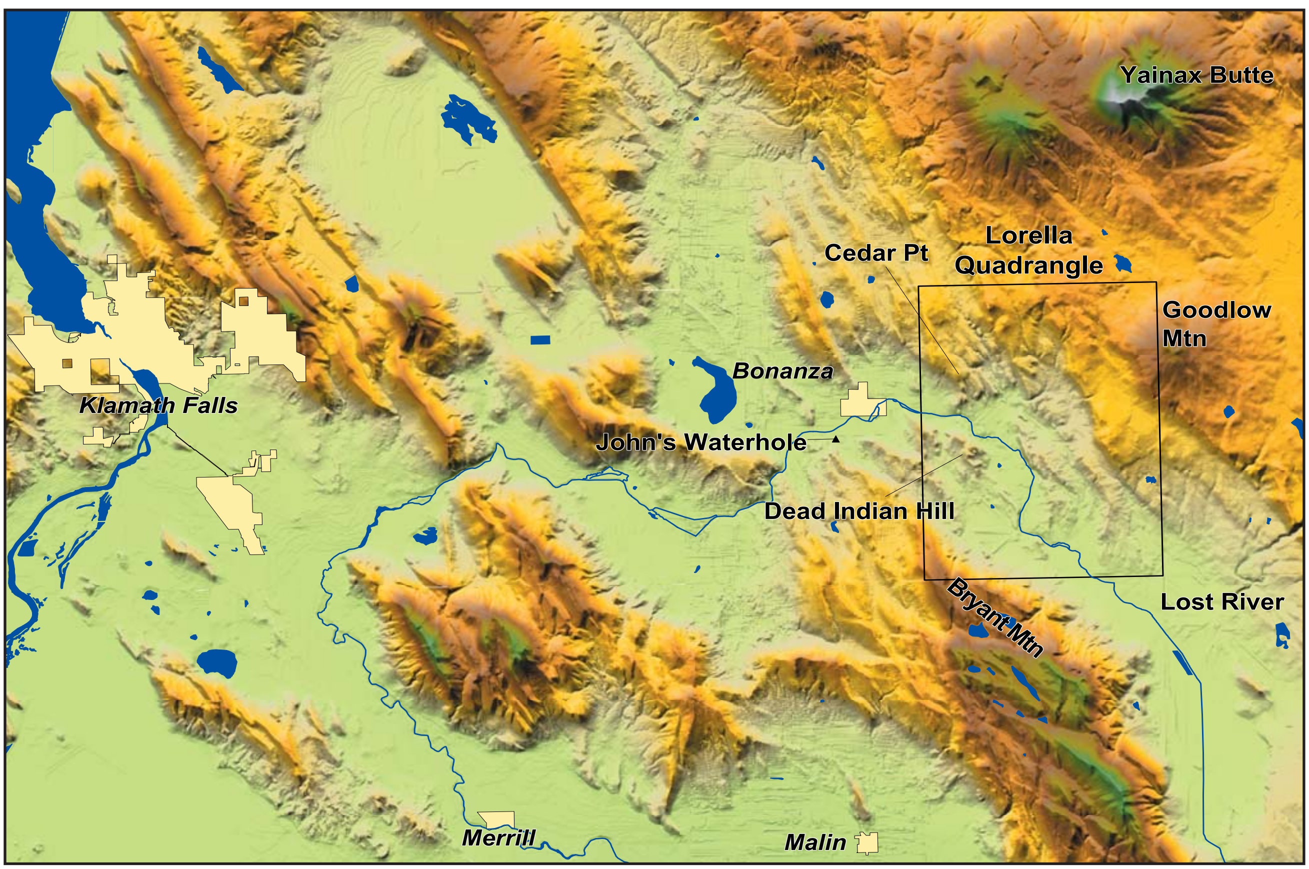


Figure 1.1. Location map, showing quadrangle location on shaded-relief map of southwest Oregon.

1:24000. Fieldwork was completed in the summer and fall of 1999.

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

Hart and others (1984) defined four types of Basin and Range olivine tholeiites. High alumina olivine tholeiites (HAOT) have K_2O values ≤0.39 percent and TiO_2 values ≤1.35 percent. Low potassium low titanium transitional tholeiites (LKLT) have K_2O ≤0.5 percent and TiO_2 ≤2.0 percent. Low potassium high titanium transitional tholeiites (LKHT) have K_2O ≤0.5 percent and TiO_2 >2.0 percent. Snake River Plain olivine tholeiites (SROT) have K_2O >0.5% and TiO_2 >2.0 percent.

Only one HAOT was encountered in the Lorella quadrangle (Table 1.1; sample no. 12). It was a single, isolated exposure, and was lumped with Unit Tbjw on the map.

Many of the samples analyzed from the Lorella quadrangle are calc-alkaline (Figure 1.2). The chemistry of most samples that are tholeiitic is intermediate between average SROT and LKLT chemistries listed by Hart and others (1984) (K_2O was often too high, see Table 1.1). Dr. Robert Duncan of Oregon State University provided two new whole-rock Ar^{40}/Ar^{39}age determinations (Table 1.2) on samples from units in the quadrangle.

Table 1.1. Major Oxide and trace element composition, Lorella quadrangle, Klamath County, Oregon.

ID number	Sample number	Unit	Location				Lithology	Major Oxides[2]													Trace Elements[3]																		
			UTM Coordinates[1] (N)	UTM Coordinates[1] (E)	Latitude	Longitude		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	Rb	Sr	Y	Zr	V	Ni	Cr	Nb	Ga	Cu	Zn	Co	Ba	La	Ce	U	Th	Pb	Sc
1	Lo-5A	Tb	4676467	637163	42.2303	-121.338	Basalt	48.16	1.47	16.58	7.12	4.07	0.2	7.35	9.04	3.18	0.58	0.35	2	100.1	4.8	453	30.6	105	293	99	160	6.2	17.9	92	92	40	316	11	22	1.6	1.1	5	29
2	Lo-6A	Tbjw	4673405	637308	42.2027	-121.337	Basalt	49.96	1.23	17.66	4.38	4.61	0.15	5.27	9.74	3.61	1.04	0.42	1.67	99.74	10.1	963	24.8	113	226	47	101	7.1	20.3	95	77	29	503	18	35	0.9	2.4	7	27
3	Lo-12F	Tb	4677523	637062	42.2398	-121.339	Basalt	49.25	1.37	18.13	7.89	3.35	0.19	5.47	8.59	3.64	0.69	0.43	1.03	100.03	6.1	671	26.9	97	232	63	90	6.4	19.8	91	85	35	343	11	26	0.9	1.3	4	24
4	Lo-14A	Tbjw	4676530	636622	42.2309	-121.344	Basalt	46.49	1.53	16.32	5.07	6.38	0.19	8.31	9.15	2.62	0.45	0.32	3.42	100.25	3.7	637	30.4	103	230	127	228	7	19.5	61	90	44	290	10	19	<0.5	1.2	3	26
5	Lo-14C	Tbjw	4676530	636622	42.2309	-121.344	Basalt	47.92	1.54	16.8	2.99	8.32	0.2	7.81	9.89	3	0.43	0.33	0.98	100.21	3.5	459	30.5	106	219	110	212	6.6	20.5	76	82	40	289	10	25	1.1	1.9	4	27
6	Lo-21	Tb	4674796	636715	42.2153	-121.344	Basalt	47.88	1.42	17.1	5.35	6.07	0.2	7.18	9.47	2.94	0.49	0.31	1.61	100.02	3.8	519	28.3	96	284	110	166	5.8	18.8	64	93	42	336	13	24	<0.5	1.5	4	29
7	Lo-47	Tba	4675133	634214	42.2188	-121.374	Basaltic andesite	53.35	1.09	17.53	2.37	6.01	0.15	4.84	7.77	3.56	1.62	0.45	1.24	99.98	18.3	630	26.6	175	196	60	108	9.7	19.4	61	92	26	607	22	46	1.8	2.2	7	21
8	Lo-48	Tba	4675882	634535	42.2255	-121.37	Basaltic andesite	53.56	1.1	17.62	2.53	5.86	0.16	4.93	7.68	3.56	1.61	0.45	0.9	99.96	18.5	634	26.7	171	189	59	106	10.1	19.3	64	87	26	606	21	44	2.2	2.7	8	21
9	Lo-53	Tba	4678306	634972	42.2472	-121.364	Basaltic andesite	53.31	1.1	17.53	3.25	5.41	0.16	5.15	7.87	3.62	1.31	0.43	0.95	100.09	14.2	612	26.9	168	169	65	135	9.5	19.6	77	83	27	618	22	41	1.8	2.2	8	21
10	Lo-56B	Tb	4673278	641273	42.2008	-121.289	Basalt	51.42	1.12	18.27	4.22	4.88	0.16	4.92	8.74	3.51	1.14	0.5	1.11	99.99	9.7	742	26.8	131	216	46	88	9	20.3	72	85	28	483	20	43	0.5	2.1	5	23
11	Lo-56E	Tb	4673286	641279	42.2009	-121.289	Basalt	49.62	1.19	17.3	4.17	5.93	0.17	7.19	9.49	3.21	0.6	0.41	0.95	100.23	5.6	542	26.4	94	215	119	227	6.3	18.8	57	83	34	360	13	24	1.4	2.6	5	24
12	Lo-62	Tbjw	4673196	639255	42.2005	-121.313	Basalt	47.55	0.87	17.44	2.15	7.34	0.17	9.81	11.25	2.38	0.15	0.09	1	100.2	0.7	275	21.6	53	207	168	251	2.9	17	94	65	44	110	5	7	0.7	1.2	2	29
13	Lo-66A	Tb	4676247	640272	42.2277	-121.3	Basalt	51.13	1.12	18.69	3.93	5.11	0.16	4.73	8.83	3.55	0.97	0.47	1.26	99.95	7.2	786	25.9	127	215	49	84	8.7	20.2	62	86	28	489	18	39	1	2.7	5	24
14	Lo-67	Tb	4676878	640033	42.2335	-121.303	Basalt	50.74	1.02	18.42	3.31	5.8	0.16	5.11	9.31	3.36	0.65	0.31	1.51	99.7	4.7	669	25.3	100	212	39	99	6.4	20.5	76	79	27	487	20	31	1.1	2.8	5	26
15	Lo-76B	Tb	4666651	634787	42.1423	-121.369	Basalt	47.56	1.32	16.74	6.78	4.83	0.24	6.94	9.84	2.95	0.42	0.28	1.92	99.82	3.1	368	31.4	89	204	126	205	4.7	19.3	106	84	41	351	13	21	1.2	2.2	4	25
16	Lo-77D	Tb	4666601	634711	42.1419	-121.37	Basalt	46.58	1.44	17.23	8.53	3.72	0.19	6.79	10.04	2.86	0.36	0.35	1.6	99.69	1.9	368	29.5	90	235	121	181	6.2	19.6	97	87	43	317	11	19	1.4	1.1	4	29
17	Lo-85	Tbjw	4665952	637075	42.1356	-121.341	Basalt	48.87	1.17	17.02	3.6	6.43	0.18	7.67	9.06	3	0.62	0.35	2.03	100	6.1	487	24.8	91	220	129	226	6.1	17.7	94	82	38	315	13	21	0.8	2.1	5	25
18	Lo-89B	Tb	4673189	644371	42.1995	-121.251	Basalt	50.3	1.19	17.67	5.02	4.93	0.18	6.38	9.37	3.26	0.63	0.36	0.58	99.87	5.3	561	27.5	98	212	84	149	6.6	19	77	84	32	381	13	26	1.1	2.6	5	28
19	Lo-89F	Tb	4673242	644450	42.1999	-121.25	Basalt	50.37	1.17	18.63	4.9	4.98	0.17	5.38	8.67	3.68	0.7	0.31	0.99	99.95	3.7	733	23.5	97	192	81	100	6.8	20.4	75	80	30	452	17	27	0.9	2	5	21
20	Lo-91A	Tb	4671167	641826	42.1817	-121.283	Basalt	49.29	1.13	19.45	4.69	4.84	0.16	5.49	9.89	3.44	0.45	0.25	0.99	100.07	2.8	694	21.6	68	215	71	95	8.7	20.2	62	71	30	303	10	18	0.7	1.7	3	24
21	Lo-97	Tb	4677615	640618	42.24	-121.296	Basalt	49.36	1.36	17.57	6.3	4.73	0.18	5.82	8.7	3.53	0.66	0.39	1.01	99.61	5.7	603	29.5	101	206	85	126	6.9	20.2	90	83	36	450	15	29	0.8	2	5	24
22	Lo-103	Tbec	4671661	638368	42.1868	-121.324	Basalt	51.96	0.85	19.86	3.01	4.58	0.13	4.56	8.98	3.64	0.87	0.21	0.86	99.51	6.1	904	17.1	72	202	48	70	4.5	20.5	88	70	24	318	9	22	1.3	2.5	5	22
23	Lo-109	Tbjw	4671775	634746	42.1884	-121.368	Basalt	48.72	1.25	17.04	4.64	5.4	0.17	6.99	9.44	3.33	0.74	0.37	1.71	99.8	5.7	681	25.1	104	228	109	187	7.2	18.8	78	83	37	346	15	29	2.2	3.6	5	25
24	Lo-176	Tb	4669098	643167	42.1629	-121.267	Basalt	49.81	1.19	17.4	5.9	4.52	0.18	6.74	9.39	3.25	0.62	0.36	0.79	100.15	5.2	532	27.1	95	212	122	222	6.1	19.1	78	83	37	373	11	25	0.6	2.1	5	24
25	Lo-178	Tb	4677825	640035	42.242	-121.303	Basalt	51.12	1.05	18.73	4.59	4.52	0.16	4.96	8.66	3.7	0.76	0.27	1.11	99.63	6.7	748	22.7	86	180	78	107	5.5	21	82	74	29	445	16	25	1.5	2.2	5	24

Note: X-ray fluorescence: 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.

Table 1.2. Whole rock radiometric ages from the Lorella quadrangle, Klamath County, Oregon. ID number and Sample number keyed to Table 1.1.

ID number	Sample number	Unit	Location				Lithology	Location or depth	Weighted Mean Plateau Age (Ma)	Isochron Age(Ma)	Total Fusion Age (Ma)
			UTM Coordinates[1] (N)	UTM Coordinates[1] (E)	Latitude	Longitude					
5	Lo-14C	Tbjw	4676530	636622	42.2309	-121.3444	Basalt		4.64 +/- 0.07	4.62 +/- 0.08	15.51 +/- 0.65
25	Lo-178	Tb	4677825	640035	42.242	-121.3027	Basalt				7.24 +/- 0.41
	LDW	Tbjw	4667820	643708	42.1513	-121.2607	Basalt	87 ft	4.65 +/- 0.34	4.58 +/- 0.23	4.4
	LDW	Tbjw (?)	4667820	643708	42.1513	-121.2607	Basalt	905-910 ft	5.79 +/- 0.12	5.59 +/- 0.12	6.2

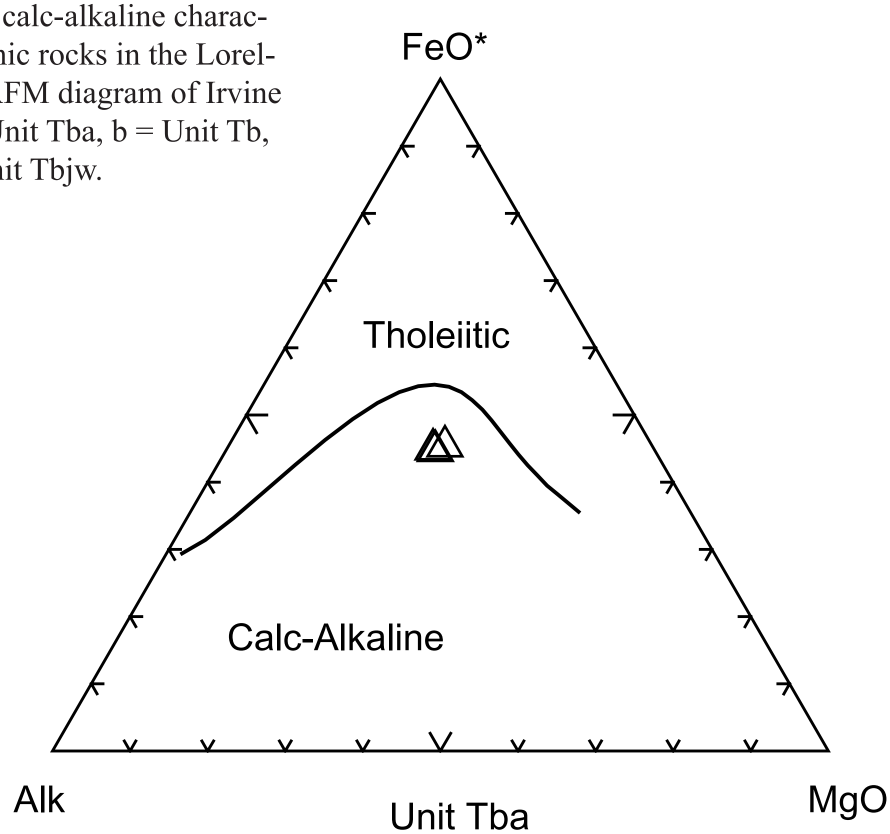
Note: Whole rock Ar40/Ar39 radiometric ages provided by Dr. R. A. Duncan, Oregon State University.

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

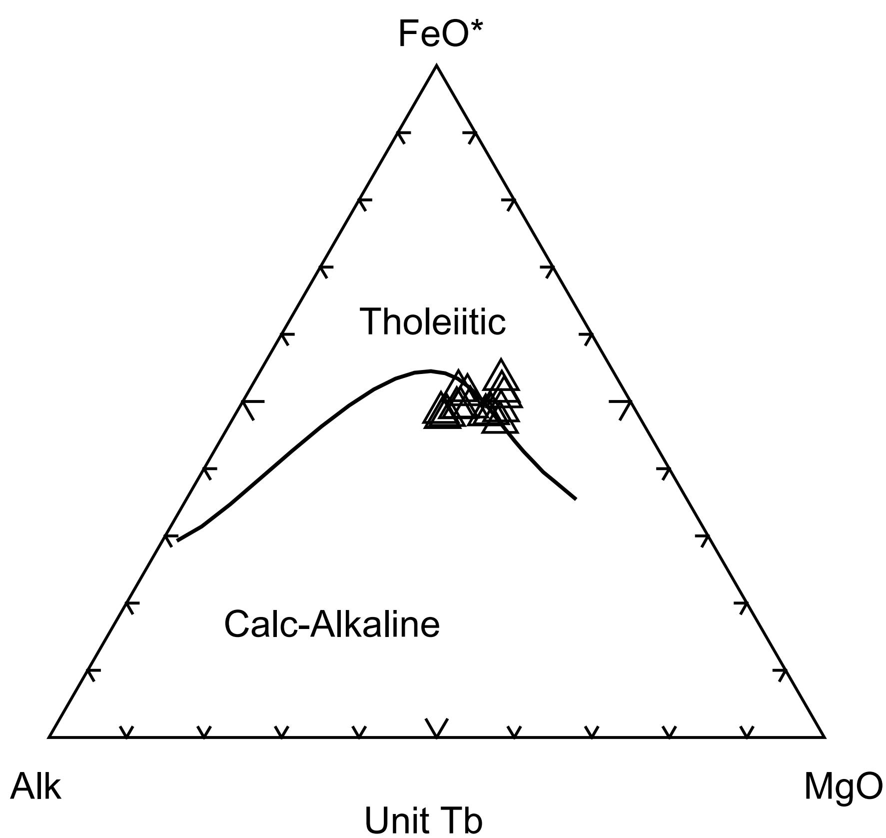
LDW = Lorella deep well

Figure 1.2. Tholeiitic and calc-alkaline characteristics of selected volcanic rocks in the Lorella quadrangle, using the AFM diagram of Irvine and Baragar (1971). a = Unit Tba, b = Unit Tb, c = Unit Tbec, and d = Unit Tbjw.

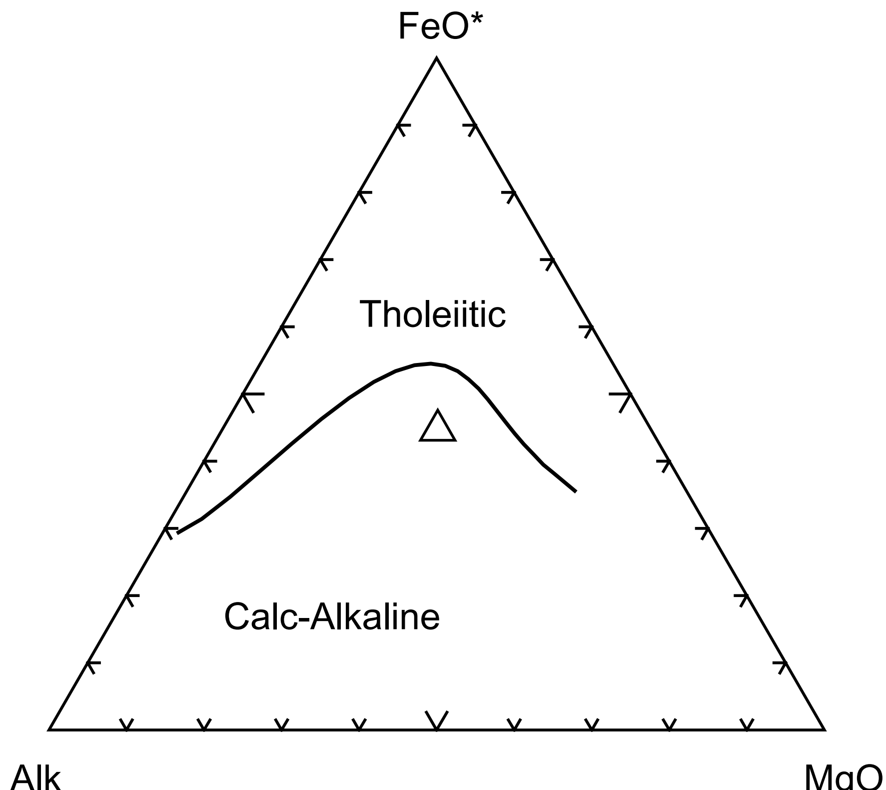
a.



b.

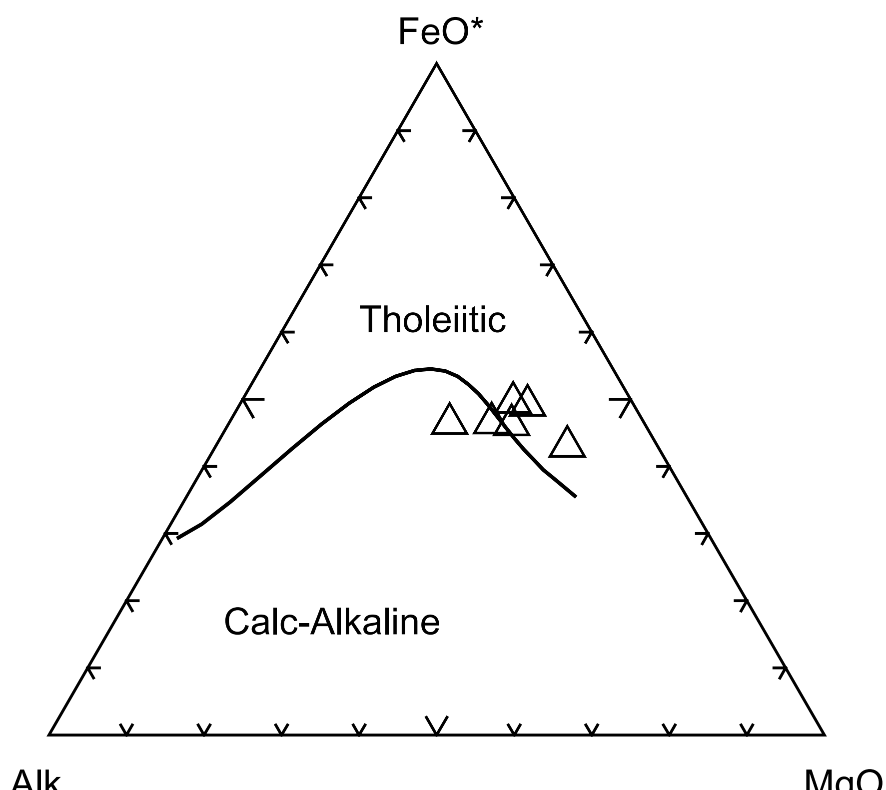


c.



Unit Tbec

d.



Unit Tbjw

2.0 EXPLANATION OF MAP UNITS

2.1 Surficial Units

Qds Dredge spoils (Holocene)—Spoil piles of silt and sand resulting from the dredging of the Lost River channel. Thickness ~5m (16 ft).

Qal Alluvium (Holocene)—Unconsolidated deposits of silt, sand, and minor gravel deposited primarily by the Lost River. Older alluvium exposed on the margins of channels shows typical fluvial structures. Sediments fine away from the modern channel. Usually represented on the map as Qal/Ts to indicate the thin veneer of alluvium over older sedimentary rocks. Thickness generally 1-3 m (3-10 ft).

Qws Windblown sand (Holocene)—Light brown, well sorted, fine to very fine sand and sandy silt. Composed primarily of subequal amounts of volcanic rock fragments and plagioclase. Plagioclase is angular to subangular while volcanic rock fragments are rounded to well rounded. Most commonly occurs as a thin veneer overlying the Basalt of Johns Waterhole (Unit Tbjw) and is probably largely derived from weathering products of that unit. Supports stands of large Ponderosa Pine. Thickness generally less than 0.3 m (1 ft) but locally reaches 1 m (3.3 ft).

Qls Landslide deposits (Holocene and Pleistocene)—Unconsolidated deposits of silt, sand, and boulders resulting from gravity-induced slope failure. Two very large failures, both greater than one square kilometer in area, are present on the northeast side of Bryant Mountain. Both landslides cover, but are not cut by, the fault that forms the northeast Bryant Mountain escarpment. Thickness is highly variable.

Qf Alluvial fan deposits (Holocene and Pleistocene)—Fan-shaped deposits of poorly sorted, unconsolidated, soil, sand, gravel, and boulders. Deposited at and near the mouths of steep draws eroded into the valley-bounding fault escarpments where they debouch onto flatter terrain. Thickness usually a few meters, but as much as 20 m (65 ft).

2.2 Volcanic Units

Tbec Basalt of East Canal (Pliocene)—A series of one to three lava flows intracanyon against Units Ts and Tbjw in secs. 17 and 20, T. 39 S., R. 13 E. The rocks are water-affected basalts that are generally identical to the basaltic lava flows of Unit Tbjw (see below). At the north end of the mapped exposure, however, Unit Tbec consists of a single flow of dark gray, hypocrystalline, seriate, compact, calc-alkaline, plagioclase olivine basaltic andesite (Figure 1.2). Hand specimens consist of phenocrysts of plagioclase (1 mm to rarely 5 mm, 5-7 percent of the rock) and olivine (≤1 mm, ~1 percent of the rock) set in a dark gray to black tachylitic groundmass. This lava flow plots in the calc-alkaline field on the AFM diagram of Irvine and Baragar (1971) (Figure 1.2).

Two early Pliocene dates provide maximum ages for Unit Tbec. The first is 4.58 ± 0.34 Ma, obtained at a depth of 27 m (87 ft) from a basaltic lava flow in the Lorella deep well (Table 1.2) (Frank Hladky, personal communication). This well is part of a study of the regional groundwater regime, which was drilled to a depth of 306 m (1005 ft) in the Lorella quadrangle (sec. 35 a and b, T. 39 S., R.12 E.). Figure 1.3 shows an abbreviated lithologic log of the Lorella deep well (designated LDW in Table 1.2). The second is 4.36 ± 0.26 Ma obtained at a depth of 10 m (33 ft) on biotite from an ash deposit in borehole B-8 (Margaret Jenks, personal communication). Unit Tbec may be as young as late Pliocene because it is intracanyon against rocks higher in the stratigraphic section, and therefore presumably younger, than the dated rocks. The maximum total thickness of Unit Tbec is 37 m (120 ft).

Tbjw **Basalt of Johns Waterhole (Pliocene)—**Mottled brown- and gray weathering, dark gray to black olivine basalt. Caps low ridges and knobs within the Langell Valley. Hand specimens appear glassy and are compact and dense with a hackly fracture. Olivine (one to two percent, generally ≤1 mm) is typically the only phenocryst mineral present. Individual flows are thin (≤5 m thick), forming low, rounded, slabby- to platy-jointed outcrops. Sub horizontal joint spacing is 2–5 cm. A blocky, cooling-joint overprint is sometimes present. Named for exposures near Johns Waterhole in the Bonanza quadrangle, west of the Lorella quadrangle (Figure 1.1).

Exposures are poor near Johns Waterhole, but basalts with both altered and unaltered groundmasses are present. Alteration there is typically more prevalent near the contact with underlying sedimentary units. Where the flows have strongly interacted with water, thin sections indicate that glass is completely altered to palagonite and all void spaces are filled with zeolites, so that the rock is virtually impermeable. All flows examined were normally polarized. Chemically the rocks are similar to those of Unit Tb, and straddle the tholeiitic/calc-alkaline field of Irvine and Baragar (1971). In the Bonanza quadrangle (west of the Lorella quadrangle) all analyzed samples of unit Tbjw are calc-alkaline, though they plot very close to the tholeiite field (Frank, Hladky, personal communication). That flows of Units Tbjw and Tb are chemically similar is expected, as Unit Tbjw differs only in that flows were erupted onto water-saturated sediments.

The flows always overlie, and in some places are invasive into, sedimentary rocks, typically tuffaceous mudstones. A bright red bake zone in the sedimentary rock is nearly always present. Pillow structures were not observed in the basalt, so it's likely they were erupted onto swampy ground rather than into significant depths of standing water. Their position low in the basin and their interaction with sedimentary rocks indicates that they are the youngest lava flows in the area. Three early Pliocene dates provide ages for unitTbjw (Table 1.2). The first is 4.58 ± 0.34 Ma, obtained at a depth of 27 m (87 ft) from a basaltic lava flow interbedded with sedimentary rocks in the Lorella deep well (Frank Hladky, personal communication; Figure 1.3). The second is 4.36 ± 0.26 Ma obtained at a depth of 10 m (33 ft) on biotite from an ash deposit in borehole B-8 (Margaret Jenks, personal communication). A third date was obtained on a single lava flow that had a water-affected lower portion and a relatively unaltered-appearing upper portion. The upper part of the flow is diktytaxitic glomeroporphyritic olivine basalt while the lower portion is typical water-affected basalt. Chemistry for the two portions of the flow is very similar (Table 1.1; sample nos. 4 and 5). A date on the upper part of the flow yielded an age of 4.62 ± 0.08 Ma (Table 1.2; sample no. Lo-14C).

Figure 1.3. Abbreviated lithologic log of the Lorella deep well (LDW). Data provided by Frank Hladky of the Department of Geology and Mineral Industries.

Lorella Deep Well (1005-feet)
Drilled by Schneider Equipment, Inc. and Drilling Co.
Cheyne Property
November 1999

Note: this log derived from Frank Hladky (DOGAMI) sketch
Note: this sketch is rounded to nearest 5 feet

Depth (ft)	Hydrology	Tempature	Casing	Lithology
0				land surface
5				
10				soil
15	static = 6 ft			
20				
25				tan silt
30				
35				white diatamaceous mudstone
40				
45				
50	50 gpm			weathered basalt
55				
60				
65				brown silt and sandstone
70			casing	
75			depth	white mudstone
80			= 92 ft	tan silt
85				
90	static = 13.5 ft			
95				
100		55 F		olivine basalt
105	10 gpm			
110				
115				
120	add water			paleosol
125				
130	12 gpm			olivine basalt
135				
140				
145	25 gpm	55 F		brown basalt and jasper
150				
155				black basalt
160				
165				
170	60 gpm			brown basalt
175				
180				black basalt
185				
190				
195				brown basalt
200				
205				
210				
215				
220				
225				
230				
235				

Depth (ft)	Hydrology	Tempature	Lithology
240			black basalt
245			
250	static = 26.5 ft		voids, big fracture
255	at 2:58 pm		
260			
265			
270			
275			
280			greenish clay
285			
290			
295			friable basalt
300			
305			
310			mudstone and silt
315			
320		Variable	
325	150 gpm	Temperature	pumice
330		55 to 56 F	
335			
340			
345			clay
350			silt and clay
355			
360			pumice
365			ash and clay
370			
375			
380			
385			
390			coarse ash with clay
395			
400			
405			
410			
415			coarse ash
420			
425			
430			
435	more water		lithic sandstone
440			
445			fine ash and sediment
450			
455			clay
460			
465			
470			
475			
480			lithic sandstone and ash
485			
490			
495			
500			clay
505	static = 27.5 ft		
510	5 gal/ 2 sec		
515			

Depth (ft)	Hydrology	Tempature	Lithology
520			
525			
530			
535			basalt with celadonite
540			
545			
550			
555			
560		Temp rise	
565			
570			celadonitic claystone
575			
580			
585		Temp drops	
590			
595			basalt with celadonite
600			
605			
610			
615			tan clay
620			basalt
625			clay
630			basalt with blue-green celadonite
635			
640			
645			
650			
655			
660			
665			
670			
675			fresh olivine basalt
680			
685			
690			
695			
700			celadonitic basalt
705			
710			
715			
720			
725			
730			
735			
740			
745			
750			
755			green clay
760			red cinder
765	static = 30 ft		clay
770			
775			silty clay
780			
785			
790			sandstone
795			
800		Temp drop	

Depth (ft)	Hydrology	Tempature	Lithology
805			
810			
815			3 basalt layers separated by 4 clay layers
820			(basalt, clay, basalt, clay, basalt, clay)
825			
830			
835			
840			basalt
845			
850		Temp drop	
855			drop in drilling air pressure
860			
865			basalt with minor clay alteration
870			vesicular basalt
875			
880			
885			fresh olivine basalt
890			
895			
900			
905			trace of celadonite in basalt
910			
915			fresh olivine basalt
920			brown iron oxide basalt
925			
930			zeolitic and celadonitic basalt
935			zeolitic and celadonitic basalt
940			zeolitic and celadonitic basalt
945			zeolitic and celadonitic basalt
950	static = 30 ft		porphy+E24ritic and frsh basalt
955			
960		Temp drop	
965			celadonite
970			bright red clay
975			brown clay
980			brown basalt breccia with some clay
985			
990			scoria and breccia (jasper, celadonite, and zeolite vug fill
995			
1000			
1005	static = 41 ft		
			total depth = 1005 feet

Vents for flows of Unit Tbjw were not encountered. Because of the palagonitic alteration of the glass in Unit Tbjw, the rocks rapidly decompose to a grus-like mixture of soils and clays when exposed to the atmosphere. This mixture probably provides the source material for the wind-reworked sediments of Unit Qws. Unit Tbjw is very thin, often only a single flow thick. Water affected basalt lava flows occur throughout the sedimentary section, however, and are inter-bedded with sedimentary rocks at the base of Bryant Mountain (Unit Tsb). Maximum thickness on the northeast side of Dead Indian Hill is 75 m (250 ft).

Tba **Basaltic andesite (Miocene)—**Dark gray- to black-weathering, dark gray basaltic andesite (Le Bas and Streckeisen, 1991). Caps Cedar Point in the northwest part of the quadrangle. Hand specimens are fine grained and compact, containing ~1 percent olivine in phenocrysts of ≤1 mm. Individual flows are 7-9 m thick, vesicular throughout, and platy jointed on a scale of 4-8 cm. Joints are the result of aligned stretched vesicle trains. All exposures examined were either normally polarized or indeterminate. Chemically Unit Tba is composed of calc-alkaline basaltic andesite with low total iron, CaO, and MgO, and relatively high total alkalis (Table 1.1; sample nos. 7,8, and 9). Unit Tba is identical to basaltic andesite mapped by Hladky (2003) in the Bonanza quadrangle to the west. Hladky (2003) obtained a whole rock Ar-Ar date of 4.44 ± 0.04 Ma from a lava flow in the town of Bonanza. Both units are chemically similar to basaltic andesites (Unit Tba) mapped by a Jenks (2004) in the Bryant Mountain and Langell Valley quadrangles to the south. However, those basaltic andesites are much older. Mallin and Hart (1991) obtained a date of 7.32 ± 0.24 Ma on a basaltic andesite flow on Bryant Mountain, and Jenks (2004) obtained a date of 8.18 ± 0.12 Ma on her Unit Tba. The source of unit Tba is unknown. Total thickness exceeds 240 m (800 ft) in the Lorella quadrangle.

Tbc **Basaltic cinder deposits (Pliocene and Miocene)—**Reddish-brown or gray lapilli and ash with occasional agglutinate bombs. Partly consolidated to loose. Volcanic edifices no longer exist. Most deposits occur on the traces of mapped faults. Thickness is variable, generally less than 30 m (100 ft).

Tb **Tertiary basalt (Miocene)—**Dark gray- to black-weathering, medium gray olivine basalt. Occurs on Bryant Mountain in the southwest corner of the map and underlies most of the northeast portion of the map. Hand specimens are fine grained, slightly diktytaxitic, and glomeroporphyritic. Glomerocrysts of olivine and plagioclase can make up as much as 10-15 percent of the rock, but in most samples are 2-3 percent. Individual lava flows are typically 4-5 m thick (range from 2 to 7 m), have irregular blocky joints, and are vesicular throughout. Flow bases and tops are highly vesicular. Both normal and reversely polarized flows were encountered. Chemically the rocks are similar to those of unit Tbjw, and straddle the tholeiitic/calc-alkaline field of Irvine and Baragar (1971) (Table 1.1; Figure 1.2). Vents for Unit Tb were not encountered in the map area, but Yainax Butte, a large composite cone in the quadrangle north of the Lorella quadrangle, and Goodlow Mountain, just off the east edge of the quadrangle are possible sources for many of the flows (Figure 1.1).

Sherrod and Pickthorn, 1992, obtained a date of 6.88 ± 0.60 Ma on a basalt flow near Yainax Butte. An Ar-Ar date of 7.24 ± .41 Ma was obtained on sample 25 in the north central part of the quadrangle (Table 1.1 and Table 1.2; sample no. Lo-178). This date should provide a maximum age for the onset of faulting in the area. The dated lava flow is intracanyon into a small, local depression. The main fault scarp is located approximately 250 m (820 ft) west (downslope) from the margin of the lava flow. Had the main scarp been present during the eruption, the flow almost certainly would have flowed over it. That it did not is evidence that the main fault scarp was not present when the flow was erupted. The maximum thickness of Unit Tb is not known, but a water well adjacent to a small reservoir in sec. 26a, T. 39 S., R. 13 E. reached a depth of 246 m (810 ft); all but 24 m (79 ft) was basalt. On Bryant Mountain the unit is as much as 360 m (1180 ft) thick.

Tsb **Basalt and sediments, undivided (Miocene)—**Poorly exposed basalt flows with interbedded sedimentary rocks. Unit Tsb is mapped on the lower reaches of Bryant Mountain in the southwest corner of the quadrangle. Poor exposures are found principally along logging roads and creek banks. The basalt flows have interacted strongly with water, causing the glassy parts of the flow to be altered to palagonite during emplacement and cooling. When these altered flows are exposed to the atmosphere, they rapidly decompose to soils and clays and are subsequently covered by colluvium from the steeper slopes above. The interbedded sedimentary rocks are tuffaceous fine sandstone, siltstone, and mudstone. The thickness of unit Tsb reaches 500 m (1640 ft).

Tbu **Undivided basalt and basaltic andesite (Miocene)—**Undivided basalt (Unit Tb) and basaltic andesite (Unit Tbm of Jenks, 2004). Shown only in the subsurface in the cross section.

2.3 Sedimentary Units

Ts **Undifferentiated sandstone, siltstone, and mudstone (Pliocene and Miocene)—**Interbedded diatomaceous tuffaceous mudstone, sandstone, and siltstone with occasional interbeds of silicic non-welded ash-flow tuff. Exposed in road cuts and canal banks along the margins of the valley. White- to cream-colored tuffaceous mudstone in which diatoms can frequently be observed with a hand lens is the most common lithologic type. Snail and fish fossil localities in other quadrangles indicate that the mudstone is lacustrine in origin. Sandstone and siltstone exposures usually show fluvial sedimentary structures, and probably represent deltaic facies. The amount of sandstone tends to increase from west to east in the quadrangle. Unit Ts is equivalent to the Yonna Formation of Newcomb (1958), a name since abandoned (Sherrod and Pickthorn, 1992).

Using isotopic ages, Pickthorn and Sherrod (1990) have constrained the age of continental sedimentary rocks in the region as between 6.0 and 3.3 Ma. The Lorella deep well encountered interbedded sedimentary rocks and lavas to a depth of 253 m (830 ft), and basalt thereafter (Figure 1.3). In the well, a date of 4.58 ± 0.34 Ma was obtained on a basalt sample at 26 m (87 ft) and a date of 5.79 ± 0.12 Ma was obtained on a basalt sample from 276 m (905 ft) (Frank Hladky, personal communication). A date of 4.36 ± 0.26 Ma was obtained at a depth of 10 m (33 ft) on biotite from an ash deposit in borehole B-8 (Margaret Jenks, personal communication). Thick sections of sedimentary rock occur in all water wells in the Langell Valley, but are present only in very minor amounts in wells on the upthrown sides of the major fault blocks. Thickness is highly variable but exceeds 122 m (400 ft) in some water wells in the Langell Valley.

3.0 STRUCTURE

The Lorella quadrangle lies in the northern part of the Basin and Range physiographic province. The Basin and Range is characterized by large-scale north- to northwest-trending grabens separated by intervening horsts, and is the result of extensional tectonics.

The Lorella quadrangle is dominated by large relatively continuous north- to northwest-striking normal faults with subsidiary north- and northeast-striking normal faults. Principal structural features are a part of the Bryant Mountain horst in the southwest corner of the quadrangle, the Dead Indian Hill and Cedar Point horsts, the Langell Valley graben, and the three large down to the southwest fault scarps in the northeast part of the quadrangle.

Only a portion of the Bryant Mountain horst is located in the Lorella quadrangle. Coworker Margi Jenks in the quadrangles to the south and southeast mapped most of it. The normal fault on the northeast side of the mountain forms the southwest boundary of the Langell Valley graben. Jenks (2004) reports as much as 750 m of structural relief on this fault and notes that because the faults on the east side of the graben are of generally low structural relief (i.e., ~120 m) the Langell Valley may be a half- or trapdoor-graben with the hinge on the east and most of the movement on the west.

In the Lorella quadrangle, three north-northwest striking down to the southeast normal faults control the east side of the Langell valley. On none of these faults is the structural relief known for certain, as it proved impossible to correlate stratigraphic units across the faults. Based on topography, the westernmost of the three faults has a minimum of 213 m (700 ft) of structural relief on the north end of the fault, but much less on the south end where it "scissors out".

On the middle fault, adjacent to the Lorella deep well (secs. 35 a and b, T. 39 S., T. 12 E.), there is a minimum of 380 m (1,245 ft) of structural relief. The well did not encounter any basalt flows similar to the flows capping the upthrown side of the fault (Frank Hladky, personal communication). However, on the basis of topography, this fault also appears to be scissoring out to the southeast. The easternmost fault (Goodlow Rim, cutting the west flank of Goodlow Mountain) has a minimum of 183 m (600 ft) of structural relief. Thus there does not appear to be a trapdoor effect in the Lorella quadrangle, though, as two of the three bounding faults appear to be rapidly decreasing in throw to the southeast, that feature may be present in the Langell Valley quadrangle.

Dead Indian Hill is a complexly faulted horst block of relatively low structural relief (90 m; 300 ft). Capping rocks are lava flows of Unit Tbjw (Basalt of Johns Waterhole). These water-affected basalts were erupted onto what was probably a marshy surface. Further evidence of lava water interaction is provided the presence of abundant fine-grained palagonite tuff (tuff-cone deposits) float at the contact between the sedimentary rocks (Unit Ts) and the capping lava flows (Unit Tbjw). However, in place tuff cone deposits were not observed on Dead Indian Hill. Based on stratigraphic relationships, the faulting on Dead Indian Hill may be somewhat younger than the faulting on the main Langell Valley graben-bounding faults, and will be discussed in more detail below.

Cedar Point is a horst block situated in the northwest corner of the quadrangle. It is one of a series of northwest-striking horst ridges that extend from the adjacent Bonanza quadrangle northwest into the Yonna quadrangle. Cedar Point is the southern limit of the easternmost of those ridges. Based on topography, structural relief is a minimum of 216 m (710 ft).

The age of the faulting in the Lorella quadrangle is problematic. Other authors have suggested that the onset of major Basin and Range faulting in the region was Pleistocene, or perhaps late Pliocene (Peterson and McIntyre, 1970; Sherrod and Pickthorn, 1992). However, Hart and others (1984) and Murray (in press) think that the onset of faulting in the region occurred much earlier, in the late Miocene, at about 7 Ma. Without young lava flows that bracket the faulting the problem is difficult but not insoluble. The answer lies in the relationship of the sedimentary rocks to the surrounding lavas. Jenks (2004 has listed three scenarios that could account for the distribution of sedimentary rocks and lavas observed today.

The first idea, suggested by Peterson and McIntyre (1970), is that the sediments were interbedded in the basalt section. When faulting occurred, the sediments were located at the base of the section on the upthrown side. As erosion forced the retreat of the scarps, the sediments were exposed at the base of the scarps. There are several problems with this scenario. Given the poorly indurated nature of the sediments, it is more likely that they would be covered by talus from overlying flows than exposed in low hills as far as 1 km from a fault now located in the valley floor.

Second, all well logs in the Langell Valley show a significant thickness of sedimentary rock. If the scenario was correct, the wells should encounter the basalt that sits on top of the section on the upthrown side of the fault.

Third, relatively deep wells (>245 m) on the upthrown side of the eastern boundary faults encounter virtually no sedimentary rocks. They should penetrate through the basalt into the sedimentary rocks exposed at the base of the scarp, but they do not. Finally, age dates on lava flows interbedded with sedimentary rocks in the Lorella deep well and on the sedimentary rocks themselves in borehole B-8 indicate an early Pliocene age, younger than the capping lava flows (see descriptions of Units Tb and Ts).

The second scenario assumes that the entire basalt section was in place before sedimentary deposition occurred. A uniform sequence of sedimentary rock was then deposited on top of the basalt. After faulting occurred, the sediments in the valleys were protected from erosion, while the sediments on the upthrown side were eroded off. There are several problems with this scenario also. It requires the complete removal of a sedimentary section of up to 150 m (500 ft) from the various footwalls (or alternatively requires several competent geologists working in different quadrangles to completely miss its presence, a more plausible alternative) even though there is absolutely no evidence of an integrated stream network capable of removing that package of rock. At least some of that section was armored with water-affected basalt (Unit Tbjw), so that it's inconceivable that the entire section has been removed. In addition, water well data in the Lorella quadrangle indicates that the sedimentary package thins over several of the intragraben horsts, implying that faulting occurred before or during sedimentation.

In the third scenario, sedimentation did not begin until after the initiation of faulting. As faulting progressed, deepening the basins, more and more sediment accumulated. In essence, the graben-bounding faults are a kind of growth fault, and the sedimentary package is both banked against and cut by the bounding faults. The floors of the grabens would be swampy, so that as the plumbing systems associated with the basin-bounding master faults developed, lava flows erupting along those master faults and out in the developing basins would tend to be water affected. The main criticism of this scenario revolves around the fine-grained nature of the sedimentary section. It has been suggested that along the margins of the valleys, near the faults, the sedimentary section should have a significant coarse-grained component as a result of erosion from adjacent steep scarps.

Water wells in these locations do show boulder and cobble gravels in their upper parts, but not throughout the entire section. Dr. Michael Cummings of Portland State University has addressed this criticism as follows: When the structures begin to develop, relief is low and the developing basins become the locus of low-energy streams and lakes. Because the developing structures often obstruct drainages, the basins tend to be occupied by sluggish streams, swamps, and shallow lakes. Thus during the early stages of basin development the basin is essentially sediment starved and the grain size of sediments is typically very fine grained.

As the structures continue to develop and relief becomes more prominent, coarse sediment is still not delivered to the basins because catchment areas on uplifted blocks are small, and streams that do develop often flow down the slope of the uplifting block away from the developing basins. Only in the latest stages of basin development do catchment areas enlarge to the point that they can deliver limited amounts of coarse-grained material to the basin. The small-scale alluvial fans along Goodlow Rim are evidence of the limited catchment areas and areal extent of coarser-grained deposits; as is the presence of coarse-grained deposits only in the upper parts of water wells in the region. Based on this reasoning, it appears that scenario three or some minor variation is responsible for the relationship of sedimentary rock and lava flows in the area.

Several age dates help bracket the onset of faulting in the area. A K-Ar date of 6.88 ± 0.60 Ma (Sherrod and Pickthorn, 1992) is from a lava flow just north of the Lorella quadrangle, near Yainax Butte, on the upthrown side of the westernmost of the three major northwest-striking bounding faults. Two Ar-Ar dates were obtained as part of the mapping in the Lorella quadrangle. The first is a date of 7.24 ± .41 Ma obtained on a lava flow at location 25 (Table 1.2). For reasons explained in the description of Unit Tb, this date is expected to provide a maximum age for the onset of faulting in the Lorella quadrangle. The second date of 4.62 ± 0.08 Ma was obtained on a water-affected basalt at location 5 (Table 1.1). There are two Ar-Ar dates from the Lorella deep well, 4.58 ± 0.34 Ma from a depth of 27 m (87 ft) and 5.79 ± 0.12 Ma from a depth of 276 m (905 ft) (Frank Hladky, personal communication). Finally, a date of 4.36 ± 0.26 Ma was obtained at a depth of 10 m (33 ft) on biotite from an ash deposit in borehole B-8 (Margaret Jenks, personal communication).

If explanation two for the distribution of the sedimentary rocks is correct (basalt, then sedimentary deposition), then the onset of Basin and Range faulting is somewhat younger than the 4.36 Ma date obtained near the top borehole B-8. It could easily be late Pliocene or Pleistocene. However, given the problems with the scenario two explanation, it is much more likely that scenario three is a better explanation for the distribution of sedimentary rocks. In this case, the 6.88 Ma date obtained from north of the Lorella quadrangle and the 7.24 Ma date from location 25 bound the onset of Basin and Range faulting. Thus the onset of Basin and Range faulting in the region occurred in the late Miocene, at about 7 Ma, as proposed by Hart and others (1984) and Murray (in press).

The faulting that produced the low-relief intragraben horsts that are capped by water-affected basalt may be somewhat younger than the graben-bounding master faults. These faults may be late Pliocene or Pleistocene structures as indicated by the 4.58 Ma date from 27 m (87 ft) in the upper part of the Lorella deep well, the date of 4.36 Ma from a depth of 10 m (33 ft) in borehole B-8, and the 4.62 Ma date from location 5. However, they are long-lasting structures. Water well data indicate that the sedimentary package thins over the top of the horst blocks, and that thick sequences of Unit Tb are present at relatively shallow depths beneath them. The Pliocene dates at relatively shallow depths in the basin indicate that the rate of sediment accumulation is very slow.

4.0 GEOLOGIC HISTORY

The oldest rocks in the region are the calc-alkaline basaltic trachyandesites of Bryant Mountain that are exposed in the Bryant Mountain quadrangle. Thin flows were erupted over a subdued topography in the late Miocene (dates of 7.32 and 8.18 Ma) (Mallin and Hart, 1991; Jenks, 2004). While these rocks do not crop out in the Lorella quadrangle, they are assumed to be present in the subsurface.

Normal faulting probably began shortly (~7 Ma) after emplacement of the basaltic trachyandesites. Jenks (in press) notes that slightly younger tholeiitic basalts with Basin and Range affinities thin against "highs" of the older basaltic andesite. Tholeiitic basalts with Snake River Plain (SRP) affinities are probably slightly younger yet (dates for both groups are in the range of 5-7 Ma, Jenks (in press)). In the Lorella quadrangle, on Bryant Mountain, these SRP tholeiites overlie a thick sequence of interbedded sedimentary rock and water-affected basalt (Unit Tsb), providing further evidence of ongoing fault movement.

As faulting progressed through the late Miocene and Pliocene, basins continued to develop and were filled with lacustrine and fluvial deltaic sediments. Tholeiitic and calcalkaline lava flows erupted from the master graben-bounding faults and from the basin interiors and produced the water-affected basalts of Unit Tbjw.

In the Pliocene, faulting occurred within the grabens as attested by relatively low structural relief horsts capped by water-affected basalt (e.g., Dead Indian Hill). The sources for at least some of these lava flows were located on the major bounding faults. Basaltic cinder deposits are commonly located there, and there is abundant hydroclastic surge deposit float adjacent to some of the faults. Though no in place surge deposits were found in the Lorella quadrangle, tuff cones are common in other areas in the region (e.g., the Yonna and Sprague West quadrangles, Black, unpublished mapping in progress). In the Lorella quadrangle, the amount of fluvial deltaic-sandstone in the sedimentary section increases toward the east, indicating that the fluvial sources feeding the lakes lie in that direction. Also interbedded in the sedimentary section are thin beds of non-welded vitric ash-flow tuff. The amount of ash-flow tuff in the sedimentary section also tends to increase eastward in the quadrangle.

Volcanism in the Lorella quadrangle had essentially died out by the late Pliocene, as evidenced by the dates of 4.58 Ma at 27 m (87 ft) in the Lorella deep well (Table 1.2), 4.42 Ma for sample No. 5, and 4.36 Ma from a depth of 10 m (33 ft) in borehole B-8.

During the Pleistocene a single large pluvial lake called Lake Modoc flooded the Langell Valley (Dicken, 1980). After Lake Modoc receded for the final time the Lost River established a drainage down the axis of the Langell Valley. Sedimentation during this period was primarily the result of periodic flooding events and resulted in the deposition of overbank deposits. In historic times local ranchers deepened and channelized the Lost River for flood control and to drain the swampy parts of the valley.

5.0 GEOLOGIC RESOURCES AND HAZARDS

5.1 Mineral Resources

The Lorella quadrangle has moderate potential for crushed rock resources, particularly along basalt-capped ridge tops where soil development is minimal and low potential for cinders. Quarries for these materials are shown on the map. Two of the four mapped cinder deposits currently have intermittently active quarries associated with them. The statewide mineral resource database (Gray, 1993) lists only one resource in the Lorella quadrangle: a small rock quarry located at sec. 17a, T. 39 S., R.12 E. in Unit Tbjw.

5.2 Water Resources

Numerous water wells have been drilled in the Langell Valley for domestic, stock and irrigation purposes. The Oregon Water Resources Department (OWRD) is currently writing a report on an extended water level monitoring program that includes many of these wells. This study is part of a regional Lost River basin groundwater study. Jenks (2004) made some very interesting observations relating well production to well location. She noted that high production wells (1000-3500 gpm) are generally located at the margins of the valley close to the valley-bounding faults. She further noted that their upper section contained significant thicknesses of fine-grained sedimentary rock (50-150 m) and that they were drilled deep enough to reach the underlying basalt/basaltic andesite aquifers.

Lower production wells (50-300 gpm) were drilled away from the fault scarps and/or were collared in the basalt section. Hladky (2003) noted that for wells penetrating the same basalt aquifer but with vastly different yields, clay-mineral alteration was the culprit in diminishing yields. The clay (usually celadonite) alteration was detected by surface magneto-telluric measurements by University of Oregon geophysicist Harve Waff. The alteration was also seen by down-hole cameras in the Smith Well on East Langell Valley Road (1 mi east of Lorella) and in the deeper (> 500 ft) basalt aquifer in the Lorella Deep Well. Celadonitic alteration was also noted in the well cuttings.

5.3 Geothermal Resources

The low-temperature geothermal database for Oregon (Black; 1994a, 1994b) lists ten water wells in the Lorella quadrangle with temperatures greater than 20° C (68° F). Of these ten, nine range between 20° and 22° C (68°-72° F). One well is 26° C (79° F). These temperatures are adequate for heat pump usage and marginally adequate for space heating, but little else.

5.4 Earthquake and Mass Wasting Hazards

There is a moderate earthquake hazard in the Lorella quadrangle. Faults in the area are considered to be active, though probably with recurrence intervals of several thousand years (Black and others, 2000). That the regional earthquake hazard is real, however, is demonstrated by the events in northwest of Klamath Falls in 1993 when an M 3.9 foreshock was followed by two mainshocks of M 5.9 and M 6.0 (Wiley and others, 1993). Aftershocks continued for several months.

Many buildings in Klamath Falls sustained serious damage. The county courthouse had to be condemned and rebuilt. For structures with foundations on bedrock, the risk is small unless the epicenter is very close. If a structure is located close to (i.e. at the foot of or on the flank of) one of the steep fault escarpments, there is a serious risk of earthquake-induced landslides and rockfalls from ridge-capping basaltic units. For structures towards the center of the valley and not on bedrock, ground-shaking amplification may be a problem. If an earthquake should occur in the spring when groundwater tables are high, liquefaction is a slight to moderate hazard depending on the nature of the underlying soils. The details relating to these various hazards are discussed in detail in Black and others (2000) and several other relative hazard maps available from the Oregon Department of Geology and Mineral Industries (e.g., Madin and Mabey, 1996).

6.0 ACKNOWLEGEMENTS

Funding for this mapping was provided by Grant No. 99-FG-20-0115 from the U.S. Bureau of Reclamation, Department of the Interior. The author is grateful to the ranchers and landowners throughout the area who gave permission to map on their lands. Glenn and Linda Barrett of Barrett Livestock were particularly helpful. Gerald Grondin of the Oregon Water Resources Department provided maps of located water wells for the quadrangle. I spent several pleasurable days in the field with Jay Newman, our summer intern from Oregon State University. Long discussions with coworkers George Priest, Margi Jenks, Bob Murray, and Frank Hladky were not only helpful, but a lot of fun. Whole-rock XRF analyses were provided by Dr. Stanley A. Mertzman, Franklin and Marshall College, Lancaster, Pennsylvania. Ar-Ar dates were provided by Dr. Robert Duncan, Oregon State University, Corvallis, Oregon. Finally, I wish to thank Dr. Michael Cummings of Portland State University, and Dr. George Priest, Margaret Jenks, Ian Madin, and Frank Hladky for their helpful reviews. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. Any errors are someone else's fault.

7.0 REFERENCES

Berggren, W.A., Kent, D.V., Flynn, J.J, and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, V. 96, n. 11, p. 1407-1418.

Black, G.L. Wang, Z., and Priest, G.R., 2000, Relative earthquake hazard map for the Klamath Falls metropolitan area, Klamath County, Oregon: Oregon Department of Geology and Mineral Industries Interpretive Map Series, IMS-19

Black, G.L., 1994, Low-temperature geothermal database for Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-94-8, 178 p.

Black, G.L., 1994, Digital data and selected text from low-temperature geothermal database for Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-94-9, 1 diskette.

Dicken, S.N., 1980, Pluvial Lake Modoc, Klamath County, Oregon, and Modoc and Siskiyou Counties, California: Oregon Geology, v. 42, no. 1, p.179-187.

Geological Society of America, 1998, Geological Society of America geological time scale: Boulder, CO.

Gray, J.J., 1993, compiler, Mineral information layer for Oregon by county (MILOC93) database: Oregon Department of Geology and Mineral Industries Open-File Report O-93-8, 2 diskettes.

Hart, W.K., Aronson, J.L., and Mertzman, S.A., 1984, Areal distribution and age of low-K, high-alumina olivine tholeiite magmatism in the northwestern Great Basin: Geological Society of America Bulletin, v. 95, p. 186-195.

Hladky, F.R., 2003, Geologic map of the Bonanza quadrangle, Klamath County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-116.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, no. 5 p. 523-548.

Jenks, M., 2004, Geologic map of the Bryant Mountain and Langell Valley quadrangles, Klamath County Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-117.

Le Bas, M.J., and Streckeisen, A.L., 1991, The IUGS systematics of igneous rocks: London, Journal of the Geological Society, v. 148, p. 825-833.

Madin, I.P., and Mabey, M.A., 1996, Earthquake hazard maps for Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–100.

Mallin, K., and Hart, W.K., 1991, New K-Ar ages of mafic lavas from the Basin and Range-Cascade transition zone in northeastern California and southern Oregon: Isochron/West, no. 57, p. 8-11.

Murray, R.M., in press, Geologic map of the Wocus quadrangle, Klamath County, Oregon: Oregon Department of Geology and Mineral Industries

Newcomb, R.C., 1958, Yonna Formation of the Klamath River basin, Oregon: Northwest Science, v. 32, no. 2, 41 p.

Oregon Water Resources Department, 1998, GRID: Groundwater resource information distribution, south-central Oregon, Klamath and Lake Counties, May 1998, CD-ROM, 2 disks.

Palmer, A.R., 1983, The decade of North American geology 1983 geologic time scale: Geology, v. 11, p. 503–504.

Peterson, N.V., and McIntyre, J.R., 1970, The reconnaissance geology and mineral resources of eastern Klamath County and western Lake County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 66, 70 p.

Pickthorn, L.B.G., and Sherrod, D.R., 1990, Potassium-argon ages from Klamath Falls area, south-central Oregon: Isochron/West, no. 55, p. 13-17.

Reichen, L.E., and Fahey, J.J., 1962, An improved method for the determination of FeO in rocks and minerals, including garnet U.S. Geological Survey Bulletin 1144B, p. 1-5.

Sherrod, D.R., and Pickthorn, L.B.G., 1992, Geologic map of the west half of the Klamath Falls 1° by 2° quadrangle, south-central Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I-2182, scale 1:250,000.

Wiley, T.J., Sherrod, D.R., Keefer, D.K., Qamar, A., Schuster, R.L., Dewey, J.W., Mabey, M.A., Black, G.L., and Wells, R.E., 1993, Klamath Falls earthquakes, September 20, 1993—including the strongest quake ever measured in Oregon: Oregon Geology, v. 55, no. 6, p. 127-134.