State of Oregon
Department of Geology and Mineral Industries
John D. Beaulieu, State Geologist

Geological Map Series

GMS–112

Geologic Map of the Dairy Quadrangle, Klamath County, Oregon

by

Frank R. Hladky,
Oregon Department of Geology and Mineral Industries

2003

CONTENTS

FIGURES

TABLES

Oregon Department of Geology and Mineral Industries Geological Map Series, ISSN 0278–3703
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

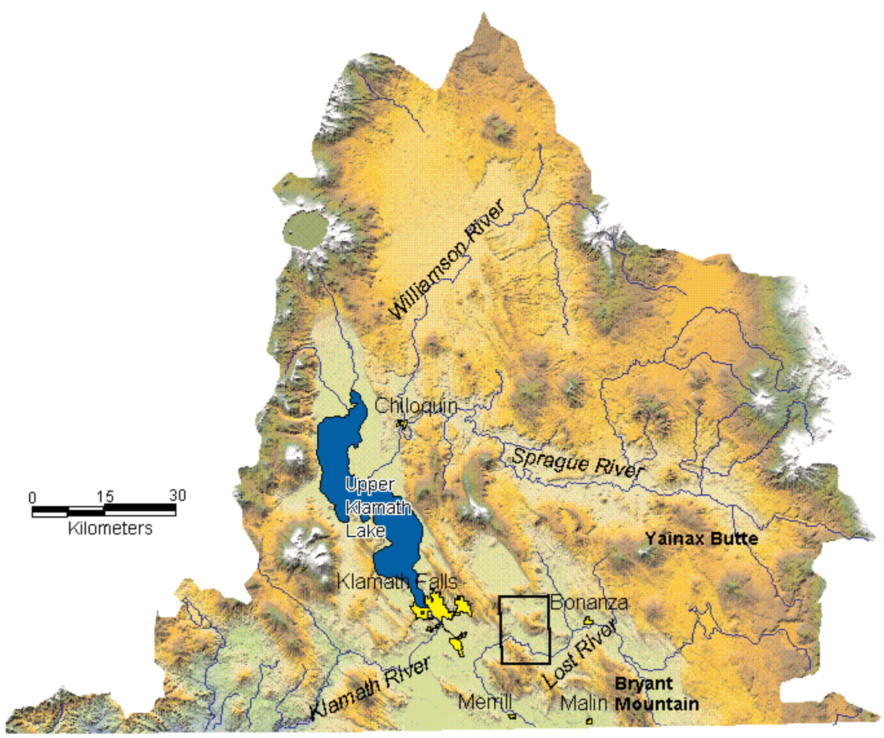
1.0 INTRODUCTION

The Dairy quadrangle is located in the Klamath Basin approximately 10 km (6 mi) east of Klamath Falls, Oregon (Figure 1.1). Northwest-trending valleys and ridges across the quadrangle are typical of the Basin and Range geomorphic province, which extends from Klamath Falls to the Wasatch Range in Utah. Geographic features mentioned in this study are shown in Figure 1.2. The Lost River meanders from east to west across the quadrangle, cutting a gap in a prominent northwest-trending ridge at Olene Hot Springs.

The valleys are elongate, and grassy or marshy, now developed into pasture. The ranges rise more than 460 m (1,500 ft) above the valley floors and are timbered primarily with juniper but also Ponderosa pine and Douglas fir. Most of the timbered land is held by privately owned Jeld-Wen and the Bureau of Land Management (BLM). Elevations range from 1,767 m (5,796 ft) on the ridge south of Olene Hot Springs to 1,246 m (4,088 ft) at the Lost River.

The Dairy quadrangle is one of several 7.5-minute quadrangles being mapped in the Klamath Basin in conjunction with earthquake hazards and groundwater availability studies being conducted by various state and federal agencies. This mapping was funded in part under the STATEMAP program of the U.S. Geological Survey (USGS). This study has delineated geologic structures, including volcanic dikes, vent rocks, and faults, and characterized lithologic units and rock geochemistry, and provided absolute and relative age constraints for volcanism and sedimentation. This data is invaluable for assessing hazard risk and mineral and hydrologic resource potential.

Continental sedimentary rocks were deposited on unexposed volcanic rocks in late Miocene to Pliocene time. Lacustrine mudstones are most common in surface outcrop and drill holes, but sandstone beds and paleosols indicate fluvial and deltaic influences. Beginning about 4.5 Ma and continuing until about 3.8 Ma, extensive basaltic andesitic volcanism built numerous volcanoes that coalesced into ranges. These ranges were built upon the thin sedimentary veneer, concurrent with tectonic extension. Pliocene vol



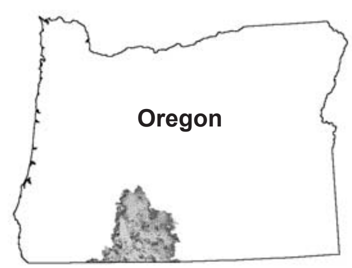


Figure 1.1. Modified shaded-relief map of the Klamath Basin of Oregon, showing the location of the Dairy quadrangle. The Dairy quadrangle is outlined in bold.

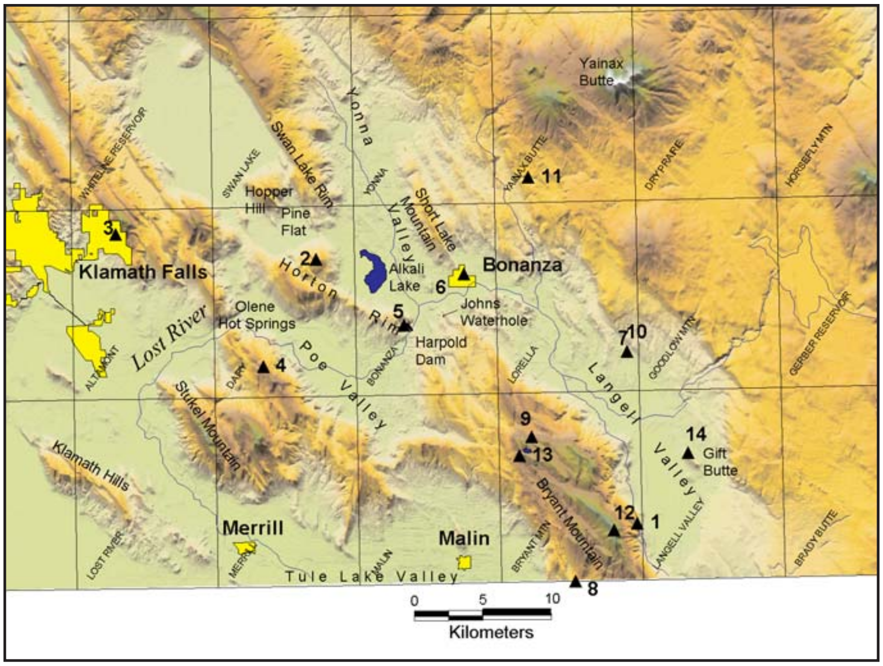


Figure 1.2. Modified shaded-relief map showing the geographic features mentioned in this study and location of samples used for whole-rock $^{40}Ar/^{39}Ar$ radiometric age determinations in the vicinity of the Dairy quadrangle. Location numbers are keyed to Table 1.2.

canism began with surge deposits indicating explosive water-lava interactions near the lava-sediment interface. Large volumes of primarily basaltic andesite lava flows from Strombolian-style eruptions built elongate volcanic edifices that closely follow the predominant northwesterly trend of today's ranges and faults. Dikes, the source conduits for erupting lava flows, also trend mostly northwest. Volcanism ended in Pliocene time. Basin sedimentation continues today. Seismic extension, active Pliocene time, may have occurred as recently as Holocene time. Present sedimentation is focused mainly at alluvial fans near range fronts and at enclosed basins such as Alkali Lake. Although most of the streams are cutting their beds, the Lost River shows little evidence of having eroded its bed during Holocene time.

Crushed rock resources are abundant, particularly on ridges where soil development is minimal. Cinder resources are much less abundant and all surface deposits have been discovered, although most of the resource has not been exploited. Prior studies indicate geothermal resources at Olene Hot Springs.

The quadrangle lies within the seismically active Basin and Range Province. Major faults in the Klamath Falls region have historically generated Richter-magnitude 6.0 and have the potential to produce magnitude 7.3 earthquakes. Some Quaternary-age alluvial fan deposits in the Dairy quadrangle may have developed in response to Quaternary-age fault movement.

1.2 Methodology

Geologic mapping for this project was accomplished by a combination of field traverses both on foot and by vehicle. This fieldwork was conducted in 1999. Fieldwork was aided by visual analysis and interpretation of color infrared aerial photographs and black-and-white digital orthophotoquadrangles, and integration of petrographic thin section analyses, geochemical analyses, and whole-rock $^{40}Ar/^{39}Ar$ radiometric age determinations.

Twenty days over a period of five months were spent in the field mapping the Dairy quadrangle, with five of those days accompanied by an Oregon State University student (OSU) and Department of Geology and Mineral Industries (DOGAMI) employee, Robert Newman, who was assigned independent sampling traverses. Interpreting, reviewing, checking, and digitally compiling field data in the office took substantially longer than the field work.

Geologic contacts observed in the field could often be extended using photographic data. Subtle variations in relief are accentuated when viewed stereographically and often indicate changes in rock type beneath thinning soil cover. Field inspections on a case-by-case basis either confirmed or dispelled this notion. Poor exposure, however, due to lava rock colluvium and soil cover that are extensive on virtually all slopes, made contact delineation difficult even on foot. Rock identifications from the field were compared against petrographic and geochemical data. A review of previous literature combined with the new isotopic ages found in this report helped to determine the age ranges of units. The X-ray fluorescence (XRF) analyses methodology for determining rock geochemistry (Table 1.1) is described in Mertzman (2000). Duncan and others (1997) describe the $^{40}Ar/^{39}Ar$ methodology used for new isotopic analyses cited in Table 1.2 (Location nos. 2-7, 10, and 13-14).

Several strategically located wells were used to add further constraints to subsurface geological interpretations in the cross-sections (see GMS112map.pdf). Summary of the well's logs are shown in Table 1.3. One of the wells, KLAM 13462, is located in the Bonanza quadrangle but is only 500 m from the eastern end of the line of cross section A-A'. Stratigraphic information from this well is important to the construction of the cross section because it indicates that there is more than 600 feet of sedimentary rock beneath Alkali Lake. Except for KLAM 13462 and KLAM 13102, the wells listed in Table 1.3 are within 300 m of the lines of cross section. Most of the well locations are derived from UTM coordinates provided by the Oregon Water Resources Department (OWRD). However, some wells not found in the OWRD database, but whose logs contain pertinent geologic information consistent with the nearby geology, have been included on the map and cross sections (see GMS112map.pdf). Also, how they were located is described in Table 1.3.

On the cross sections, the well locations are projected at right angles to the line of section. Note that when using well data to constrain subsurface structural and stratigraphic relationships in cross section, the well data is deemed pertinent to the fault block into which the well was drilled. The only well where the well's projected location and the actual fault block conflict is KLAM 13102 on section A-A'. The well is located in the fault block immediately east of its projected location on cross section A-A'. This apparent discrepancy arose because of two reasons: (1) the distance KLAM 13102 is from line of section and (2) the angle the line of section crosses the fault. Notwithstanding this issue of perspective, KLAM 13102 indicates 300 feet of sedimentary rock above lava in the fault block in which it was drilled. This relationship has been incorporated into the cross section.

TABLE 1.1. ANALYSES OF MAJOR OXIDE AND SELECTED TRACE ELEMENTS, TRACE METALS, AND RARE EARTH ELEMENTS FROM SAMPLES COLLECTED IN THE DAIRY QUADRANGLE, KLAMATH COUNTY, OREGON.. MAJOR OXIDES REPORTED IN WEIGHT PERCENT AND SELECTED TRACE ELEMENTS, TRACE METALS, AND RARE EARTH ELEMENT IN PARTS PER MILLION (PPM). SAMPLES ANALYZED BY THE LABORATORY OF STANLEY A. MERTZMAN, FRANKLIN AND MARSHALL COLLEGE, LANCASTER, PENNSYLVANIA.

Map no.	Unit	Lithology	Quad	Cadastral location[1]					UTM coordinates[2]		SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	$Fe_2O_3^T$	Rb	Sr	Y	Zr	V	Ni	Cr	Nb	Ga	Cu	Zn	Co	Ba	La	Ce	U	Th	Sc	Pb
				¼	¼	Sec.	T. S.	R. E.	Northing	Easting																																	
980930-5	Tba	Basaltic andesite	Dairy	NW	SW	26	38	10	4676455N	614245E	55.10	0.88	17.22	2.32	5.18	0.15	4.47	7.23	3.61	1.73	0.38	1.61	99.88	8.08	21.6	603	26.0	200	185	49	89	10.6	18.4	81	83	22	913	26	51	2.3	4.8	18	10
990504-1	Tbag	Basaltic andesite	Dairy	NE	NW	23	39	10	4669170N	614530E	52.14	1.11	17.58	4.47	4.01	0.14	3.85	8.51	3.42	1.45	0.60	3.01	100.29	8.93	18.7	618	29.0	178	220	68	102	11.4	19.8	73	91	32	639	26	49	1.1	4.7	25	8
990507-2	Tba	Basaltic trachyandesite	Dairy	SE	SE	5	39	11½	4674000N	619955E	53.83	1.06	18.37	1.60	6.14	0.15	3.74	8.15	4.14	1.21	0.37	1.28	100.04	8.42	14.2	721	25.0	137	205	23	40	8.7	22.0	258	75	23	546	19	41	1.6	4.4	21	6
990507-4	Tba	Basaltic andesite	Dairy	NE	SE	4	39	11½	4674490N	621000E	53.90	0.96	18.56	2.79	5.00	0.15	4.39	8.24	3.96	1.07	0.30	0.82	100.14	8.35	11.7	741	23.0	103	207	34	48	6.8	21.9	97	77	27	474	17	37	1.8	3.8	21	7
990507-5	Tba	Basaltic andesite	Dairy	NE	NE	17	39	11½	4672080N	620170E	52.19	1.14	18.95	2.94	5.21	0.16	4.06	8.10	3.60	1.09	0.48	2.04	99.96	8.73	11.4	691	30.0	158	215	32	59	9.7	21.9	74	92	26	779	26	48	1.3	4.1	23	8
990507-6	Tba	Basaltic andesite	Dairy	NW	NW	16	39	11½	4672030N	620460E	53.96	1.14	17.98	2.35	5.54	0.15	3.93	7.94	3.93	1.42	0.48	1.12	99.94	8.51	15.7	647	24.9	164	209	22	51	10.0	21.7	83	83	22	568	21	38	1.4	5.2	20	8
990510-1	Tba	Basaltic andesite	Dairy	NE	SE	34	38	10	4674825N	613515E	53.42	0.94	17.61	2.54	5.48	0.15	4.94	7.78	3.60	1.51	0.45	1.72	100.14	8.63	16.1	643	28.0	193	186	60	92	11.1	20.8	77	96	29	819	29	50	1.0	3.0	21	9
990511-1	Tba	Basaltic andesite	Dairy	SE	NE	10	39	10	4671910N	614915E	54.09	1.06	17.71	3.06	4.82	0.15	4.14	7.80	3.80	1.46	0.42	1.11	99.62	8.42	17.6	670	28.0	176	176	31	60	10.5	21.4	70	81	22	732	27	52	1.3	4.8	22	10
990513-1	Tbag	Basaltic andesite	Dairy	NE	SE	25	39	10	4666680N	617185E	52.46	0.84	18.26	6.95	1.22	0.13	3.48	7.84	3.49	1.21	0.37	4.11	100.36	8.31	12.5	826	21.0	122	197	56	45	8.2	20.8	87	86	29	578	21	39	1.6	3.9	21	7
990513-2	Tbd	Basaltic trachyandesite	Dairy	NE	SE	25	39	10	4666660N	617155E	53.05	1.08	17.51	0.95	7.48	0.16	4.87	7.94	3.58	1.62	0.50	1.69	100.43	9.26	17.5	596	27.0	165	196	46	74	10.7	20.6	84	87	27	594	21	44	1.3	3.8	24	8
990514-1	Tba	Basaltic trachyandesite	Dairy	NE	SW	23	39	10	4668400N	614875E	52.89	1.15	17.16	1.26	7.34	0.16	5.10	7.83	3.59	1.51	0.55	1.39	99.93	9.42	18.0	599	29.0	178	188	59	126	11.3	20.2	72	88	29	680	29	47	1.8	4.1	21	9
990514-2	Tba	Basaltic trachyandesite	Dairy	--	NE	26	39	10	4667330N	615700E	54.44	1.08	17.38	2.39	5.70	0.16	4.34	7.33	3.90	1.73	0.59	0.92	99.96	8.72	21.2	632	33.0	208	179	37	56	13.0	20.8	78	89	25	821	34	55	1.5	4.6	21	11
990528-4	Tba	Basalt	Dairy	NW	SW	14	39	11½	4671140N	623730E	49.94	1.33	17.05	3.99	6.00	0.18	6.42	8.68	3.33	0.93	0.44	1.79	100.08	10.66	9.5	622	27.0	123	237	80	136	8.5	20.0	76	92	37	465	15	33	1.1	3.0	28	6
990716-3	Tba	Basaltic andesite	Dairy	NW	SE	24	39	10	4668600N	616810E	52.32	1.10	17.17	8.61	0.58	0.17	5.16	8.35	3.33	1.27	0.50	1.81	100.37	9.25	15.3	528	34.0	175	266	57	99	10.5	20.1	103	90	30	623	30	52	1.1	3.5	25	9
990802-1	Tba	Basaltic trachyandesite	Dairy	NE	SW	36	39	10	4665060N	615800E	53.83	1.17	17.41	1.99	6.19	0.17	4.40	7.52	3.89	1.71	0.61	0.95	99.84	8.87	20.2	623	30.0	205	183	37	54	12.8	21.4	72	84	26	786	30	63	1.6	4.8	22	9
990806-2	Tba	Basaltic andesite	Dairy	SE	SW	28	38	11½	4677390N	620730E	53.36	1.05	17.61	2.58	5.45	0.15	5.31	7.93	3.68	1.38	0.39	0.94	99.83	8.64	15.7	662	25.0	150	200	74	93	9.0	20.6	77	82	29	587	18	34	1.0	4.2	22	7
990806-3	Tba	Basaltic andesite	Dairy	SW	NW	1	39	10	4673570N	615650E	54.42	1.09	17.59	3.60	4.14	0.28	3.51	7.78	3.74	1.51	0.47	1.92	100.05	8.20	20.6	695	28.0	182	196	41	80	10.9	21.1	79	85	22	718	23	48	1.4	4.9	22	9
990811-1	Tba	Basaltic trachyandesite	Dairy	NW	NE	6	40	11	4665595N	618300E	53.76	1.16	17.36	2.32	5.98	0.17	4.42	7.52	3.84	1.79	0.60	0.78	99.70	8.97	20.0	619	31.0	203	188	37	56	13.2	20.9	72	90	25	741	24	53	2.0	4.2	22	10
990819-1	Tba	Basaltic trachyandesite	Dairy	--	SW	31	39	11½	4665920N	618095E	53.27	1.16	17.37	2.81	5.61	0.20	4.35	7.62	3.80	1.65	0.61	1.16	99.61	9.04	18.2	625	28.4	201	190	35	68	13.0	21.5	73	87	25	886	27	52	1.0	4.7	20	9
991027-1	Tba	Basaltic andesite	Dairy	SW	SW	34	38	11½	4675520N	622110E	54.09	1.02	18.48	2.59	4.73	0.15	3.54	8.09	3.94	1.27	0.33	1.36	99.59	7.85	15.0	743	23.8	133	185	26	72	7.8	21.0	65	79	23	588	15	35	1.4	2.9	21	8
991027-2	Tba	Basaltic andesite	Dairy	--	NE	31	38	11½	4676910N	618100E	53.17	1.03	17.58	3.22	4.90	0.16	5.16	7.88	3.66	1.23	0.38	1.15	99.52	8.67	16.4	643	24.6	157	184	74	122	8.4	18.9	58	80	27	530	20	37	1.2	3.0	21	8
991027-4	Tba	Basaltic andesite	Dairy	NE	SW	25	38	10	4676335N	615980E	53.01	1.02	17.56	2.92	5.24	0.15	5.27	7.92	3.68	1.26	0.36	1.01	99.40	8.74	17.9	644	24.0	155	165	70	127	8.5	18.9	47	78	26	523	18	35	1.2	3 2	0	8
991027-5	Tba	Basaltic andesite	Dairy	NW	SW	25	38	10	4676335N	615905E	52.78	1.01	18.43	3.34	4.84	0.14	4.48	8.15	3.68	1.00	0.31	1.55	99.71	8.72	13.1	653	24.1	144	169	52	94	8.1	20.3	51	77	25	555	15	39	0.6	2.9	22	7
S1	Tba	Basalt	Dairy	NW	NW	23	39	11½	4670610N	623735E	50.24	1.36	17.04	2.65	6.94	0.18	6.09	8.75	3.40	0.94	0.44	1.99	100.02	10.36	7.7	617	27.1	130	244	76	119	8.5	18.6	85	89	36	409	16	32	1.2	3.7	24	5
S2	Tba	Basaltic andesite	Dairy	SE	SW	16	39	11½	4671050N	620760E	53.87	1.11	17.91	2.52	5.52	0.15	4.21	8.10	3.92	1.35	0.45	0.85	99.96	8.65	14.1	669	24.6	160	201	28	60	9.9	22.2	76	77	22	587	21	41	0.8	4.5	20	7
S3	Tba	Basalt	Dairy	SE	NE	15	39	11½	4671080N	623275E	49.72	1.32	16.88	5.79	4.09	0.17	6.10	8.83	3.25	0.97	0.43	2.90	100.45	10.34	8.3	597	26.3	126	236	77	125	8.3	18.0	78	88	34	397	14	27	1.4	4.1	25	5
S4	Tba	Basalt	Dairy	NW	SW	14	39	11½	4671170N	623650E	50.30	1.36	17.12	3.99	5.80	0.17	5.84	9.00	3.53	0.94	0.45	1.14	99.64	10.44	8.9	645	29.4	130	246	67	118	8.7	19.2	73	86	33	465	16	36	0.7	3.3	26	5
S5	Tba	Basaltic andesite	Dairy	SE	NE	33	38	11½	4676520N	621350E	52.98	1.03	17.53	2.55	5.30	0.15	5.19	8.07	3.61	1.31	0.39	1.38	99.49	8.44	4.2	644	24.2	145	201	69	115	8.7	19.1	44	76	26	505	18	35	1.6	4.5	21	7
S6	Tba	Basaltic andesite	Dairy	NE	NW	34	38	11½	4677120N	622275E	53.40	1.07	17.47	2.12	5.77	0.15	5.13	7.95	3.65	1.52	0.40	1.03	99.66	8.53	15.8	657	24.9	151	200	58	88	8.5	19.4	83	75	26	573	19	37	2.1	4.0	19	6
S9	Tba	Basaltic andesite	Dairy	SE	SE	31	39	11½	4665810N	618535E	52.52	1.15	17.24	3.46	5.42	0.17	5.12	8.00	3.75	1.41	0.51	0.59	99.34	9.48	16.2	591	28.2	177	195	50	98	11.3	19.5	76	84	28	604	23	40	1.1	4.6	22	8
S10	Tbd	Basaltic andesite	Dairy	SW	SW	32	39	11½	4665850N	618915E	53.77	0.88	18.65	8.05	0.13	0.14	3.81	7.70	3.97	1.41	0.43	0.69	99.63	8.19	13.7	824	18.4	125	181	54	62	7.8	21.4	95	84	26	481	16	42	1.1	3.7	20	8

[1] Cadastral location referenced to Willamette Meridian and Base Line

[2] UTM Zone 10, 1927 North American Datum

TABLE 1.2. WHOLE-ROCK ^{40}AR/^{39}AR AGE DETERMINATIONS FOR SELECTED SAMPLES IN THE DAIRY QUADRANGLE AND FROM THE ADJACENT AREA. SAMPLE LOCATION NUMBERS ARE KEYED TO FIGURE 1.2.

Location nos. (Figure 1.2)	Map nos.	UTM coordinates Northing	Easting	Quadrangle	General geographic locale	Lithology	Age (Ma)
1		4655201	644507	Bryant Mountain	First flow exposed up from West Langell Valley Road	Basalt	2.61±0.15[1]
2	990507-4	4674490	621000	Dairy	Horton Rim	Basaltic andesite	3.85±0.06[2]
3		4676314	606355	Altamont	Base of Hogback Mountain	Basaltic andesite	4.01±0.22[2]
4	990513-2	4666660	617155	Dairy	Dike 4 km southeast of Olene Hot Springs	Basaltic trachyandesite	4.06±0.03[2]
5		4669670	627440	Bonanza	Lowest unaltered basalt in county quarry near Harpold Dam	Basalt	4.38±0.06[2]
6		4673420	631830	Bonanza	Outskirts of town of Bonanza	Basaltic andesite	4.44±0.04[2]
7		4667775	643760	Lorella	87-ft depth, Lorella Deep Well	Basalt	4.65±0.34[2]
8		4350945	639996	Bryant Mountain	Highest flow, east side of Tule Lake Valley	Basalt	4.97±0.22[1]
9		4661527	636794	Bryant Mountain	Highest flow, south end, Harpold Reservoir	Basalt	5.67±0.17[1]
10		4667775	643760	Lorella	905-ft depth, Lorella Deep Well	Basalt	5.79±0.12[2]
11		4680497	636495	Yainax Butte	Near Yainax Butte	Basalt	6.88±0.60[1,3]
12		4654703	642792	Bryant Mountain	Summit of Bryant Mountain	Basaltic andesite	7.32±0.24[1]
13		4660140	635880	Bryant Mountain	Bryant Mountain	Basalt	7.33±0.77[2]
14		4660380	648200	Langell Valley	Gift Butte Basaltic	trachyandesite	8.18±0.12[2]

[1] K-Ar age determination.
[2] Whole-rock ^{40}Ar/^{39}Ar age determination, weighted mean plateau age by R. A. Duncan.
[3] Plagioclase was the material dated.

TABLE 1.3. DRILL-HOLE DATA ALONG CROSS-SECTIONS A-A' AND B-B', DAIRY QUADRANGLE. WELLS LISTED IN ORDER FROM LEFT TO RIGHT ALONG LINE OF SECTION.

OWRD Drill-hole no.	Interval (ft)	Material
Section Line A-A"		
KLAM 13104*	0-96	Lava
96-450	Shale	
	450-545	Lava
KLAM 13106*	0-46	Basalt
	46-420	Shale
	420-425	Sandstone
KLAM 13102*	0-300	"Chalk rock" and sandstone
	300-400	Basalt
KLAM 13100†	0-4	Fill
	4-16	River mud
	16-750	Chalk
	750-758	Lava
KLAM 13097*	0-120	Claystone
KLAM 13469§	0-14	Clay
	14-61	Lava and cinders
KLAM 13462§	0-647	Shale and sandstone
	647-763	Lava
Section Line B-B'		
KLAM 11421§	0-27	Lava boulders and cobbles
	27-469	Clay, shale, seams of sand
KLAM 13498§	0-460	"Diatomite"

Note: Location for drill-hole no. KLAM 13462 on adjacent Bonanza quadrangle, projected 500 ft east into line of section.
*Centroid of quarter-quarter section from well log.
† Meets and bounds description from well log, constrained by county park boundary (owner), and field inspection.
§OWRD located-well database UTM coordinate.

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
Qal	**Alluvium (Holocene)**
Qaf	**Alluvial fan deposits (Holocene and Pleistocene)**
Qap	**Playa deposits (Holocene and Pleistocene)**
Qc	**Colluvium (Holocene and Pleistocene)**
Qs	**Lacustrine sediments (Holocene and Pleistocene)**
	Volcanic Units
Tba	**Tertiary basaltic andesite (Pliocene)**
Tbag	**Tertiary basaltic andesite agglutinate (Pliocene)**
Tvc	**Basaltic andesite cinder deposits (Pliocene)**
Tvl	**Lahar deposits (Pliocene)**
Tvb	**Volcanic breccia (Pliocene)**
Tvs	**Volcanic surge deposits (Pliocene)**
Tms	**Mudstone, siltstone, and sandstone (Pliocene and Miocene)**
Ts	**Sandstone (Pliocene and Miocene)**
Tm	**Diatomaceous and tuffaceous mudstone (Pliocene and Miocene)**
Tbu	**Basaltic andesite [shown only in cross sections] (Miocene?)**
	Intrusions
Tbd	**Basaltic andesite dikes (Pliocene)**

Figure 2.1. Map Units.

2.1 Surficial Units

Qal **Alluvium (Holocene)** Unconsolidated silt, sand, and minor gravels deposited along the Lost River. Thickness of this unit is generally 1-3 m (3-10 ft).

Qaf **Alluvial fan deposits (Holocene and Pleistocene)** Poorly sorted and unconsolidated, sand, soil, gravel, and boulders in fan-shaped deposits. Typically deposited at and near the mouths of intermittent-highland streams and form where they debouch onto flatter terrain. Unit thickness is typically a few meters but as much as 20 m (60 ft).

Qap **Playa deposits (Holocene and Pleistocene)** Cream to white, silt, mud, and alkali salts deposited in Alkali Lake in Yonna Valley. Unit thickness is variable, to about 10 m (30 ft).

Qc **Colluvium (Holocene and Pleistocene)** Unconsolidated to slightly consolidated, poorly sorted soil and fragments of bedrock that are displaced downslope by gravity-induced creep. Unit may include some landslide deposits. Found on moderate to steep slopes. Unit thickness is typically a few meters, but as much as 20 m (60 ft).

Qs **Lacustrine sediments (Holocene and Pleistocene)** Unconsolidated very light gray or white and pale-pinkish-tan or very light brown silty sand and silty mud. These sediments were originally deposited in shallow lakes, now they are under cultivation. Thickness of the unit is about 12 m (40 ft).

2.2 Volcanic Units

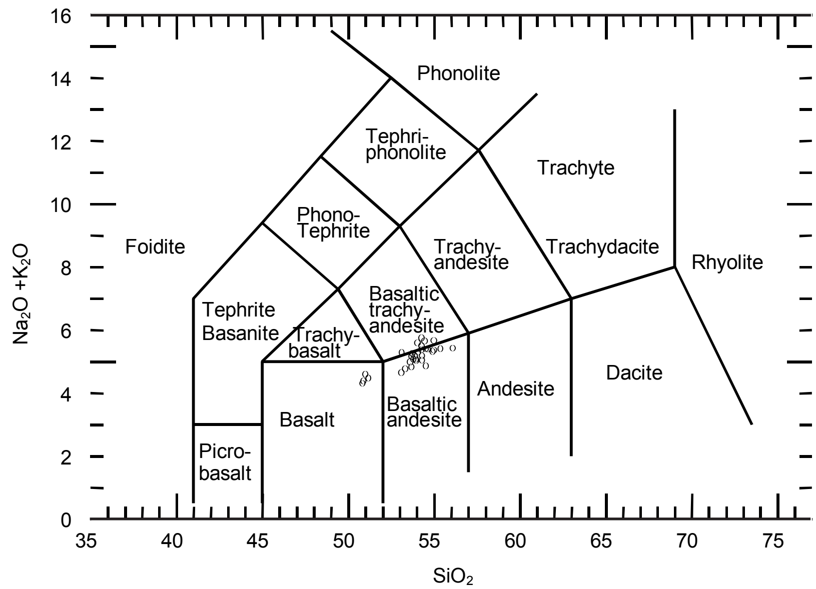
Tba **Tertiary basaltic andesite (Pliocene)** Gray- or reddish-brown-weathering, dark gray, fine-grained seriate basalt, basaltic andesite, and trachybasaltic andesite. Unit is characterized by plagioclase and olivine that show a complete gradation from phenocryst to groundmass sizes. Some lava flows have a trachytic texture (plagioclase laths in subparallel alignment). Contains up to 15 percent olivine as large as 1 mm as phenocrysts and groundmass that is typically fresh, although up to a tenth may be iddingsitized. From one-third to one-half of the rock is plagioclase up to 2 mm, typically as individual grains, but glomerocrystic in a few flows. Groundmass typically forms slightly more than half the rock, and contains very fine plagioclase (smaller than 0.05 mm), clinopyroxene, petrographically isotropic glass, and traces of magnetite. Poor exposure hampers mapping of individual flows. The rocks range chemically from basalt to basaltic andesite to basaltic trachyandesite (Figure 2.2), with only slight differences in the total alkali content between the rock types. Following the classification of Irvine and Baragar (1971), chemical analyses indicate all the rocks are calc-alkaline (Table 1.1; Figure 2.2).

A whole-rock $^{40}Ar/^{39}Ar$ weighted mean plateau age of summit lava near Horton Rim is 3.85 ± 0.06 Ma (Table 1.2, location no. 2, map no. 990507-4; Figure 1.2). There is a whole-rock age of 4.01 ± 0.22 Ma from a flow near the base of a thick section at Hogback Mountain in the adjacent Altamont quadrangle (Table 1.2, location no. 3; Figure 1.2) and a whole-rock $^{40}Ar/^{39}Ar$ plateau age of 4.44 ± 0.04 Ma from a basaltic andesite in the town of Bonanza in the adjacent Bonanza quadrangle to the east (Table 1.2, location no. 6; Figure 1.2). Cumulatively, this age data indicate the flows in the unit Tba were erupted across the region over a period of about a half a million years and produced several of the volcanic accumulations that form today's ridges and hills. Maximum thickness of the unit is about 600 m (2,000 ft).

Tbag **Tertiary basaltic andesite agglutinate (Pliocene)** Dark-gray or reddish-brown, fine-grained seriate and trachytic basaltic andesite agglutinate. These lava flows are blocky and agglutinous and are petrographically and chemically similar to unit Tba. However, in the field the unit is texturally distinct because of their rough irregular or angular blocky surfaces. Penetrative iron oxidation, open voids, and zeolite void-filling mineralization are typical. The units maximum thickness is about 300 m (1,000 ft).

Tvc **Basaltic andesite cinder deposits (Pliocene)** Partly consolidated to loose, reddish-brown or reddish-gray lapilli, ash, and minor tuff with sporadic agglutinate bombs. Thickness is variable, typically less than 30 m (100 ft).

Tvl **Lahar deposits (Pliocene)** Pale-olive-gray, massive, poorly sorted, unwelded, poorly consolidated basaltic andesitic lithic tuff. Contains sporadic irregular, decimeter-scale blobs and lenses of pale olive-green mudstone and clasts of angular volcanic lithics that distinguish this unit as a fluidized mud- and grain-flow deposit. One



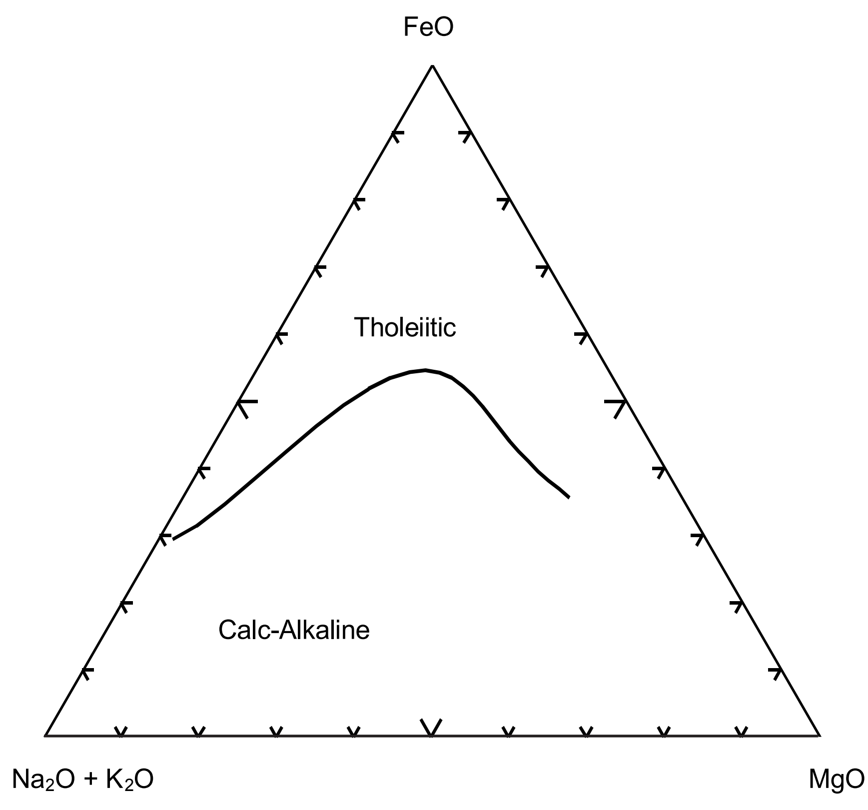


Figure 2.2. Rock classification from Le Bas and Streckeisen (1991) (top) and after Irvine and Baragar (1971) (bottom) for basaltic lava rocks in the Dairy quadrangle. Major oxide and selected trace element, trace metal, and rare-earth element data are found in Table 1.1. Data were normalized and recalculated anhydrous prior to plotting.

occurrence was found near the east-central margin of map. Thickness of the unit is about 30 m (100 ft).

Tvb **Volcanic breccia (Pliocene)** Tan, yellow, and reddish-brown, welded, highly vesicular basaltic andesitic lithic block-and-ash tuff. Composed of variously argillized and iron oxidized sub-angular clasts of dark-gray and reddish-brown basaltic andesite blocks, bombs, and lapilli set within an argillized, iron-oxidized tuffaceous matrix. Typical of altered Strombolian-type near-vent deposits. One occurrence was found near the west-central margin of map. Maximum thickness of this unit is about 100 m (330 ft).

Tvs Volcanic surge deposits (Pliocene)-Dark-tan to gray, planar stratified, poorly sorted moderately bedded block-and-ash tuff and thinly to massively bedded lapilli-ash tuff (terminology after Dietrich and Skinner, 1979). Coarse facies consists of more than 75 percent subangular to angular basaltic andesite blocks in argillically or palagonitically altered volcanic lapilli and ash (now mostly clay) matrix. Blocks and lapilli, in coarse facies, range from 1 to 15 cm. Fine facies consists of more than 75 percent ash and is gradational with coarse facies. Typically planar to massive bedded. Unit's maximum thickness is 210 m (700 ft).

Tms **Mudstone, siltstone, and sandstone (Pliocene and Miocene)** Most readily located by its predominant white to cream-colored mudstone component, this unit also contains some poorly exposed beds of stratified olive-green sandstone (see the description for unit Ts below) and siltstone, and massive to hackly pale-pinkish-gray to pale-orange paleosols. Where exposed, the paleosols have been recolonized with modern roots, making the determination of root traces difficult; however, the paleosols can be distinguished by abrupt upper surfaces with overlying stratified sandstones and internally by their soil structure, characterized by peds and cutans. The peds and cutans impart a hackly texture and this texture is due to the network of irregular planes (cutans) surrounding more stable aggregates of soil material (peds). Cutans are typically skins of clay or irregular networks of slickensides due to compaction (Retallack, 1988). Paleosols are massive and poorly bedded with fair induration. As a unit, consistent with the lithologic description and stratigraphic placement of the Yonna Formation (Newcomb, 1958), which name was abandoned by Sherrod and Pickthorn (1992).

In the Dairy quadrangle, Tertiary sedimentary rocks are mainly exposed at the major valley floors, although locally they are interbedded within Pliocene lava flows in the mountain ranges. Using isotopic ages, Pickthorn and Sherrod (1990) constrained the age of continental sedimentary rocks in the region at between 6.0 and 3.3 Ma. Recent age data of overlying lava flows (Table 1.2, location no. 5; Figure 1.2) indicates that some of these Tertiary sedimentary rocks at the valley floors are older than 4 Ma in the Dairy and Bonanza quadrangles. Thickness exceeds 30 m (100 ft). Divided into the following units:

Ts **Sandstone (Pliocene and Miocene)** Olive-green, well-sorted, fine-grained volcanic sandstone. Typically thinly to medium bedded. Locally contains decimeter-scale cross-beds and scoured surfaces. Composed of 50 percent broken plagioclase, 30 percent olivine crystals, and 20 percent dark-gray angular glass and rock fragments, all ranging between 0.2 and 1 mm in size. Maximum thickness of the unit is about 30 m (100 ft).

Tm **Diatomaceous and tuffaceous mudstone (Pliocene and Miocene)** White to cream-colored diatomaceous tuffaceous mudstone. Massive and poorly bedded. Fair induration. Where deeply weathered, the unit may be only weakly indurated, locally forming a plastic silty clay with interbeds of unindurated silt or fine sand. Sand and silt interbeds are a minor component, less than about 5 percent of unit. Thickness of the unit is highly variable;

however, well log information in Poe Valley (Table 1.3, OWRD drill-hole no. KLAM-13100) indicates that the unit's thickness locally is in excess of 230 m (750 ft).

Tbu **Basaltic andesite (Miocene?)** Shown only in cross section. In 1998, OWRD identified a dark-gray to black basaltic lava in numerous drill holes in the subsurface of Poe Valley (Figure 1.2). This lava is the oldest unit shown in cross section A-A' (see GMSmap112.pdf). Analyses of samples collected from the 1,005-ft Lorella Deep Well yielded an undated calc-alkaline basalt at 680 feet and a tholeiitic basalt at 905 feet with a whole-rock $^{40}Ar/^{39}Ar$ weighted mean plateau age of 5.79 ± 0.12 Ma beneath the sedimentary section (Table 2.1, location no. 10; Figure 1.2). The Lorella Deep Well is a double completion monitoring well in the Lorella quadrangle and identified compositely as KLAM 52096 and KLAM 52204 (T. 39 S., R. 12 E., sec. 35; Figure 2.1, location nos. 7 and 10). Logs for the well are available at OWRD's Website (http://www.wrd.state.or.us). Oldest known basaltic rocks in the region include lava flows with whole-rock ages of 6.88 ± 0.60 Ma near Yainax Butte (Table 2.1, location no. 11; Figure 1.2), 7.33 ± 0.77 Ma at Bryant Mountain (Table 2.1, location no. 13; Figure 1.2), and 8.18 ± 0.12 Ma at Gift Butte (Table 2.1, location no. 14; Figure 1.2). Presumably unit Tbu includes rocks of similar and older age. The units maximum thickness is unknown.

2.3 Intrusions

Tbd **Basaltic andesite dikes (Pliocene)** Dark-gray to black fine-grained basaltic andesite and basaltic trachyandesite dikes. Contains up to 10 percent olivine smaller than 1 mm set in a very fine grained felsic to glassy matrix. On the ridge crest south of Olene Hot Springs are distinctive cordwood-like dikes due to horizontally oriented columar-jointing. The dikes often project up to 2 m above ground level. A sample collected from a cordwood dike returned a whole-rock $^{40}Ar/^{39}Ar$ weighted mean plateau age of 4.06 ± 0.03 Ma (Table 2.1, location no. 4, map no. 990513-2; Figure 1.2). At Olene Hot Springs, the unit is penetratively argillically altered and iron-oxidized. Mapped as a unit where substantially more extensive than can be shown with a dike symbol.

3.0 GEOLOGIC HISTORY

3.1 Landforms and Structure

The principal landforms in the quadrangle are a series of ridges and valleys that generally trend northwest. The meandering Lost River cuts across the fabric of the ridge and valley landscape. As shown in Figure 1.2, the principal valleys (basins) and ridges (ranges) from southwest to northeast across the quadrangle are an unnamed ridge west of Poe Valley, Poe Valley, Horton Rim, Hopper Hill, Pine Flat, Swan Lake Rim, and Yonna Valley. Most of the valleys are bounded by faults. Exposures in the ridges reveal faults that are parallel or subparallel to the master range-bounding faults. Additional faults have been mapped in the quadrangle than shown on previous reconnaissance maps (Peterson and McIntyre, 1970; Sherrod and Pickthorn, 1992). The mountain ranges are primarily coalescing basaltic andesitic volcanoes, and erosion has exposed several vent deposits. That these volcanic piles parallel the major range-bounding faults indicates northwest-southwest oriented extension likely was dominant during Pliocene volcanism.

Major valleys and ridges are dominated by different rock types. Between an unnamed ridge, which is cut by the Lost River at Olene Hot Springs and Horton Rim, lies Poe Valley. The predominant rock type at and near the floor of Poe Valley is chalky-colored mudstone, with lesser amounts of sandstone, siltstone, and basaltic tuff surge deposits. Basaltic andesitic lava flows are the predominant rock type exposed on ridges.

A series of north- and northwest-striking faults frame the ridge west of Poe Valley. Mapping and well log data indicate that the volcanic rocks, primarily basaltic andesite lava flows, that form this ridge are underlain by white, chalk-colored mudstone (colloquially referred to as "chalk rock") that can be seen offset in the range-bounding faults, particularly in the vicinity of Olene Hot Springs. There, the Lost River has cut through the mountain range exposing massive white mudstone overlain by volcanic breccia, surge deposits, and spatter, which are in turn overlain by lava flows. Segments of the faults are exposed in road and railway cuts, and measured dips range from 60 to 70 degrees.

Several basaltic cordwood dikes trend northwesterly along the ridge crest south of Olene Hot Springs. These dikes, cutting through lava flows, agglutinate, and surge deposits, are feeders for the volcanic pile. One of these dikes has a whole-rock $^{40}Ar/^{39}Ar$ age of 4.06 ± 0.03 Ma (Table 1.2, location no. 4, map no. 990513-2). In addition to the northwest alignment of volcanic accumulations, the dikes' orientation are further evidence that the volcanoes formed from rifts that paralleled the principal northwest alignment of Basin and Range faults.

Some drill holes penetrate sediment more than 750 feet thick, mostly diatomaceous mudstone that overlies basaltic lava (unit Tbu). The sedimentary rocks are highly variable in thickness. Drill-hole data indicate a greater thickness of sedimentary rocks on the west side of Poe Valley, particularly near faults, as seen in cross section A-A' (see GMS112map.pdf). However, the available drill hole data indicate some shoaling (decreasing thickness) of sedimentary rocks toward the ridges as can be seen in the cross section. The greater thickness of sedimentary rocks near faults indicates the basin was extending during sedimentation. The deeper lavas of unit Tbu have not been found at the surface in the quadrangle.

The sedimentary section includes mostly lacustrine beds but also areally less extensive coarser-grained sandstone. The sandstone is interpreted to be deposits from streams that fed Miocene (?) and Pliocene lakes. The upper contact of the sedimentary sequence in Poe and Yonna valleys, although undulatory at the outcrop scale, is relatively flat at map scale. Dips in the sedimentary units are typically steepened near faults, locally as part of small-amplitude, meter-scale drag-folds, indicating fault-related forces have produced most of the mapped deformation. The elevation of the lower sedimentary contact is poorly constrained because of the paucity and variable accuracy of drill-hole data. There is enough data, however, to show that sediment thickness varies greatly. Near faults, thickness may change abruptly.

At the unnamed ridge at Olene Hot Springs, faults and stratigraphy reveal a step-wise down-dropping of strata toward valley floors along faults with displacement of a few meters to tens of meters. West of the ridge, sense of displacement is generally down-to-the-west. East of the ridge, sense of displacement is mostly down-to-the-east As can be seen in cross section A-A' (see GMS112map.pdf), the cumulative effect is to elevate the ridges in lava-capped horst blocks while lowering the valley floor. Elevated topographic benches on the west side of Poe Valley both north and south of the Lost River are geomorphic expressions of step-wise displacement, as shown on the map by the step-wise displacement of strata. North-striking faults east of Olene Hot Springs merge with northwest-striking faults of greater displacement.

Horton Rim is an elongate, curvilinear basaltic andesite volcano that trends northwest in its western segment and east-west in its eastern segment. The west flank of Horton Rim is a relatively smooth, westward- to southwestward-dipping, curvi-planar lava surface. This curvi-planar surface probably reflects original dips, because, although mudstone strata beneath the lava flows are locally warped, the mudstone-lava contact is relatively flat at map scale. Faulting and erosion have modified the elongate form of Horton Rim.

There is little evidence that faults of major displacement bound the east side of Horton Rim. Therefore Yonna Valley is a topographic low largely because it is a site between sites of Pliocene constructional volcanism

3.2 History of Volcanism and Sedimentation

The rocks exposed in the Dairy quadrangle record geologic history since late Miocene time. Sedimentary rocks, primarily diatomaceous and tuffaceous mudstones, were deposited onto an irregular terrain, probably of subdued relief, of volcanic rocks probably beginning in late Miocene and continuing into Pliocene time. The greatest age of the sedimentary strata in the quadrangle is unknown, although Pickthorn and Sherrod (1990) present evidence for about 6 Ma for a maximum age for sedimentary rocks in the Klamath Basin to the northwest. Perhaps the deepest wells in Poe Valley penetrate sediments that old. Mudstone locally attained a thickness of a few hundred meters. Small areas of volcanic lithic-crystal sandstone attest to the streams that fed sedimentary basins between growing volcanic highlands. Because sedimentation continued during volcanism, some interbedding of volcanic and sedimentary strata occurred. Some sedimentary outcrops southeast of Olene Hot Springs (for example, T. 39 S., R. 10 E., sec. 25, and T. 40 S., R. 11 E., sec. 6) are nearly totally encased by effusive volcanic products, showing that some sedimentary basins were isolated during the tectonic uplift and constructional volcanism that occurred between 4.5 and 3.8 Ma. In the adjacent Bonanza quadrangle to the east, basaltic surge deposits and basaltic pillow deltas attest to water-lava interactions in lacustrine environments.

Pliocene volcanoes erupted lava along generally northwest-trending rifts onto sedimentary strata. These Pliocene volcanoes produced elongate lava accumulations several hundred meters thick, whose remnants are today's prominent ridges. Faulting modified these volcanoes, producing ridges that are generally fault-bounded. Some prominent feeder dikes for these volcanoes are exposed on the ridge south of Olene Hot Springs. A whole-rock $^{40}Ar/^{39}Ar$ age of 4.06 ± 0.03 Ma for a cordwood-like dike indicates the Pliocene age of the ascending lava (Table 1.2, map no. 990513-2; see GMS112map.pdf). Various age data in the region indicate active Pliocene volcanism from 4.5 to about 3.8 Ma. A whole-rock $^{40}Ar/^{39}Ar$ age of 3.85 ± 0.06 Ma from summit lava near Horton Rim is the youngest age for the volcanic structures dated in the Dairy quadrangle and is inferred to indicate the approximate end of Pliocene volcanism in the Dairy and adjoining Bonanza quadrangles (Table 1.2, map no. 990507-4, see GMS112map.pdf)..

The Dairy quadrangle is devoid of Quaternary volcanic rocks. Active tectonism and modest sedimentation have occurred in Quaternary time. Hot springs remain active at

Olene Hot Springs and Klamath Falls. Tectonism in the region was front-page news as recently as 1993, when damaging earthquakes struck along the West Klamath Lake fault zone west of Klamath Falls. Some of the quadrangle's faults may have Quaternary-age movement, because relatively young alluvial fans have developed in response to offset on some of the downthrown blocks.

Alkali Lake in Yonna Valley continues to receive fine-grained sediments, and dries sufficiently to produce alkali salts around its perimeter. Dicken (1980) claimed the lake is a remnant of pluvial Lake Modoc, a Pleistocene lake that stretched from modern Upper Klamath Lake to Langell Valley and south into California, and covered the bottoms of Yonna and Poe Valleys. Other geologists who have worked the area are skeptical that Lake Modoc was ever that extensive (David Sherrod, 2000, personal communication.). Terraces related to Lake Modoc were not found in the Dairy quadrangle, and if the lake produced more subtle evidence of its existence, such as sediments, they have been largely modified by soil development, colluviation, and agriculture. A more pausible hypothesis is that several, disconnected lakes occupied valley floors during and since Pleistocene time.

The Lost River meanders in its present flood plain, and before the advent of manmade controls, deposited silt and mud across its flood plain. Most of the streams in the quadrangle are eroding their beds, at least in their upper reaches. The Lost River, however, has a meandering pattern indicating virtually no bed erosion and erosion to fine sediments across its flood plain. Modern deposition is focused at alluvial fans near range fronts and in enclosed basins such as Alkali Lake. There is no evidence, yet, that alluvium in the Dairy quadrangle is older than Holocene.

4.0 GEOLOGIC RESOURCES AND HAZARDS

4.1 Mineral Resources

The Dairy quadrangle has moderate to high potential for mineral resources for crushed rock and cinders. Five quarries for these materials are shown on the geologic map of the quadrangle (see GMS112map.pdf). The Dairy Pit located in the northeast corner of the quadrangle and the Rad Rock Pit located on the south edge of the quadrangle are listed in the statewide mineral-resources database (Gray, 1993). The other three quarries are not.

The cinder deposits are partly quarried. Crushed-rock resources are abundant, particularly along ridge tops or in the upper elevations where soil development is minimal. Diatomaceous sediments or clays are possible resources for some industrial minerals uses (cat litter, absorbents, pond sealers) but agricultural uses have been already established on the deposits.

4.2 Groundwater

Numerous water wells are located in the quadrangle and are plotted on the map with their OW RD drill-hole log number. Drill-hole data provide important structural and stratigraphic controls on geologic interpretations as noted above. The original drill-hole logs are available for viewing on the Internet at http://www.wrd.state.or.us. Wells in basaltic lava units produce copious amounts of water, typically several hundreds to thousands of gallons per minute. However, wells in sedimentary and volcaniclastic units typically produce 10s to a couple of hundred gallons per minute. The Oregon Water Resources Department is currently monitoring water levels in many of these wells to gain important information on the dynamics of the area's groundwater regime.

4.3 Geothermal

The quadrangle lies about 10 km west of extensive, known geothermal resources near Klamath Falls (Oregon Department of Geology and Mineral Industries, 1982). Hot springs at Olene Hot Springs were used historically for scalding hogs, according to a local eyewitness (I. F. "Buck" Rogers, 1999, oral communication). Although not currently utilized, studies indicate reservoir temperatures of 60° C (140° F) (Reed, 1982).

4.4 Earthquake Hazards

The Dairy quadrangle lies within the Basin and Range Province, a seismically active region stretching from Klamath Falls to the Wasatch Front in Utah. The Klamath Falls region is recognized as one of Oregon's principal areas for damaging earthquakes (Madin and Mabey, 1996). Earthquake hazard zones for the Klamath Falls metropolitan area have been published by Black and others (2000). Seismicity in south-central Oregon was first demonstrated historically in 1968 by a swarm of earthquakes in the Adel-Warner Lakes area east of Lakeview (130 km east of Dairy). This swarm included shocks as powerful as Richter-magnitude 5.1. (Couch and Johnson, 1968; Jacobson, 1986).

Closer to the Dairy quadrangle, Quaternary faults near Klamath Falls with the potential for damaging earthquakes were recognized and delineated previously (Hawkins and others, 1989; Sherrod and Pickthorn, 1992). Quaternary faults occur on either side of Upper Klamath Lake and southeast of Klamath Falls along the Klamath Hills and Stukel Mountain, all part of the Klamath graben described by Sherrod and Pickthorn (1992). Quaternary seismicity on the west side of the Klamath graben was confirmed on September 20, 1993. A foreshock with Richter magnitude 3.9 was followed by a magnitude-5.9 shock and a magnitude-6.0 earthquake (Wiley and others, 1993). Aftershocks continued for several months. Seismicity originated west of Klamath Falls along the West Klamath Lake fault zone. The West Klamath Lake fault zone is estimated to be capable of generating 6.0 to 7.3 magnitude earthquakes (Bacon and others, 1999).

This and prior studies have not recognized Quaternary-age fault scarps in the Dairy quadrangle, although some alluvial fan deposits may have, in fact, accumulated in response to Quaternary age fault movement in the quadrangle. There are, however, exposed Quaternary-age faults of the Klamath graben less than 10 km from Poe Valley (Sherrod and Pickthorn, 1992). Young faults imply that activity not only has occurred recently, but that the time period between events is short, in geological terms. Although the earthquake recurrence interval for the Klamath Falls area is unknown, Bacon and others (1999) use strain-rate data to estimate an average recurrence of every 3,000 to 7,000 years. The relatively short distance from the mapped area to major, young faults means that ground shaking will be readily felt, particularly on sites where soft ground exists. Steep areas will be subject to both rock fall and avalanche hazards.

5.0 ACKNOWLEDGMENTS

The author appreciates the many interested local residents and landowners. Glenn and Linda Barrett, Barrett Livestock; Bill Kennedy, Lost River Ranch; Craig Ditman, Jeld-Wen Timber and Ranches; Susan House and David Fairclo, Olene Land and Livestock; Glenn Lorenz, Glenn T. Lorenz Cattle Co.; Tom DeJong, Tom DeJong Dairy; Thys De Hoop, Holland's Dairy Inc.; Bruce Jensen; Ray Hamel; Ed Cochran; Gary Voight; I. F. "Buck" Rodgers and many others were crucial in lending their support and access to lands. I thank Tom Cottingham, BLM, who lent aerial photographs. Field discussions with Jerry Grondin (OWRD), Margi Jenks and Jerry Black (DOGAMI), and Kevin Knutson (USGS) were invaluable to the project. The field assistance of Robert Newman is also appreciated. Whole-rock XRF analyses were providedby Stanley A. Mertzman, Franklin and Marshall College, Lancaster, PA. New isotopic ages from the Dairy and Bonanza quadrangles were provided by Robert A. Duncan, Oregon State University. The suggestions and thorough review of David R. Sherrod ((USGS) contributed significantly to the quality of the report and is greatly appreciated.

This study was supported by the U.S. Geological Survey, Department of the Interior, under assistance award no. 99HQAG0036. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

6.0 REFERENCES

Bacon, C.R., Lanphere, M.A., and Champion, D.E., 1999, Late Quaternary slip rate and seismic hazards of the West Klamath Lake fault zone near Crater Lake, Oregon Cascades: Geology, Vol. 27, no. 1, p. 43-46.

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

Couch, R.W., and Johnson, S., 1968, The Warner Valley earthquake sequence: May and June, 1968: Ore Bin, Vol. 30, no. 10, p. 191-204.

Dicken, S.N., 1980, Pluvial Lake Modoc, Klamath County, Oregon, and Modoc and Siskiyou Counties, California: Oregon Geology, Vol. 42, no. 11, p. 179-187.

Dietrich, R.V., and Skinner, B.J., 1979, Rocks and rock minerals: New York, John Wiley and Sons, 319 p.

Duncan, R.A., Hooper, P.R., Rehacek, J., Marsh, J.S. and Duncan, A.R., 1997, The timing and duration of the Karoo igneous event, southern Gondwana. Journal of Geophysical Research, Vol. 102, no. B8, p. 18,127-18,138.

Gray, J.J., 1993, compiler, Mineral information layer for Oregon by county (MILOC), 1993 updates: Oregon Department of Geology and Mineral Industries Open-File Report O-93-8, two 5-in. diskettes.

Hawkins, F.F., Foley, L.L., and LaForge, R.C., 1989, Seismotectonic study for Fish Lake and Fourmile Lake Dams, Rogue River Project: U.S. Bureau of Reclamation, Denver, Colo., Geotechnical Engineering and Geology Division, Seismotectonic Report 89-3, 26 p.

Hladky, F.R., in prep, Geologic map of the Bonanza quadrangle, Klamath County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series, scale 1:24,000.

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, Vol. 8, no. 5 p. 523-548.

Jacobson, R.S., 1986, Map of Oregon Seismicity: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-49, scale 1:1,000,000.

Le Bas, M.J., and Streckeisen, A.L., 1991, The IUGS systematics of igneous rocks: London, Journal of the Geological Society, Vol. 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.

Mertzman, S.A., 2000, K-Ar results from the southern Oregon-northern California Cascade Range: Oregon Geology, Vol. 62, no. 4, p. 99-122.

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

Oregon Department of Geology and Mineral Industries, 1982, Geothermal resources of Oregon, 1982: National Oceanic and Atmospheric Administration (for U.S. Department of Energy), scale 1:500,000.

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, Vol. 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.

Retallack, G.J., 1988, Field recognition of paleosols: Geological Society of America Special Paper 216, 20 p.

Reed, M.J., 1983, Assessment of low-temperature geothermal resources of the United States - 1982: U.S. Geological Survey Circular 892, 73 p.

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, Vol. 55, no. 6, p. 127-134.