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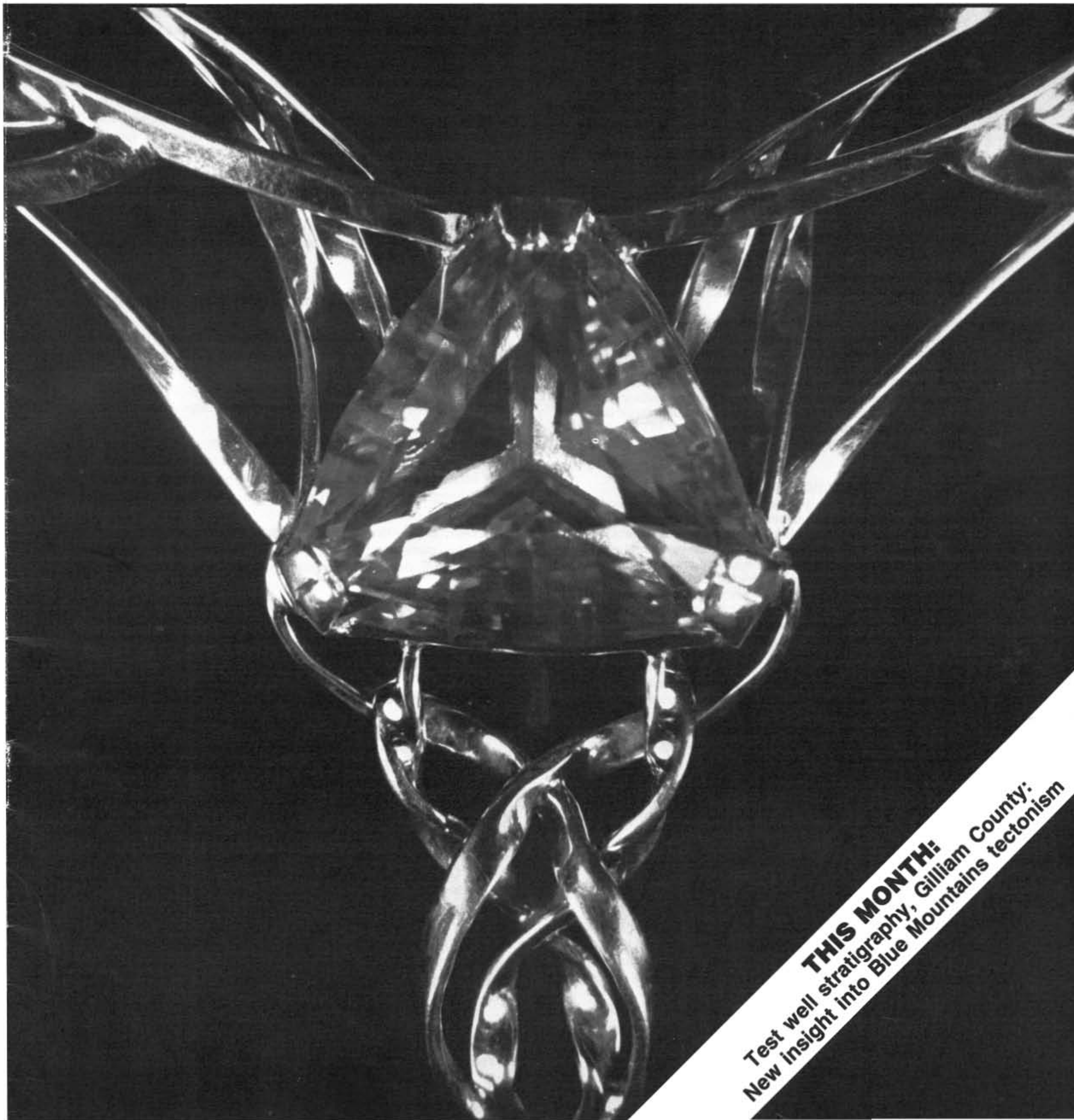

THIS MONTH:
Test well stratigraphy, Gilliam County;
New insight into Blue Mountains tectonism

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the bibligraphic references. Names of reviewers should be included in the "Acknowledgments."

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Setting of an Oregon sunstone. Champagne-yellow, 10.25-carat gemstone from Lake County is owned by the Columbia-Willamette Faceters Guild. Triangular cut by Lois Schwier of Portland, Oregon; setting designed and made by Al Price, French's Jewelers, Albany, Oregon. See related article on sunstones beginning on page 23.

OIL AND GAS NEWS

Mist Gas Storage Project

Oregon Natural Gas Development is continuing to drill wells for the gas storage project, keeping two drilling rigs busy with injection and observation wells. The injection wells are drilled into the depleted Bruer and Flora pools and are completed with 8⅝-in. casing plus a liner through the gas zone. The observation wells are drilled similar to a conventional producing well but are located outside the limits of gas, to measure zone pressures by monitoring the formation waters.

Recent wells include OM 43c-3 in SE¼ sec. 3, T. 6 N., R. 5 W., drilled in December to 3,655 ft as an observation well. OM 41a-10 in NE¼ sec. 10, T. 6 N., R. 5 W., was also drilled in December to a total depth of 3,067 ft. January activity included the drilling of another observation well, OM 12c-3, in NW¼ sec. 3, T. 6 N., R. 5 W., as well as an injection well, IW 34d-3, in SE¼ sec. 3, T. 6 N., R. 5 W. Neither had reached total depth at the time of this writing. OM 12c-3 has a proposed total depth of 3,400 ft, while IW 34d-3 is projected for 2,800 ft.

Future gas storage drilling will include OM 14a-3 in SW¼ sec. 3, OM 32a-11 in NE¼ sec. 11, and OM 44d-3 in SE¼ sec. 3, all in T. 6 N., R. 5 W. □

Gorda Ridge symposium announced

A symposium on the research dealing with mineral exploration of the Gorda Ridge seafloor spreading center will be held May 11-13, 1987, in Portland, Oregon.

The symposium is sponsored by the Gorda Ridge Technical Task Force and will include plenary sessions and workshops on the following subjects:

- Gorda Ridge polymetallic sulfide discoveries.
- Exploration technologies for seafloor massive sulfides.
- Models of mineralization in modern hydrothermal systems.
- Comparative ecology of hydrothermal vent communities and nonvent communities.
- Genetic resources of hydrothermal vent communities.

Further plans may include a two-day field trip to an on-land massive sulfide deposit and a family-oriented trip to the Oregon coast.

For information, contact Greg McMurray, Marine Minerals Coordinator, Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 S.W. Fifth Avenue, Portland, Oregon 97201, phone (503) 229-5580. □

Oregon Academy of Science announces meeting

The Oregon Academy of Science (OAS) will hold its annual meeting for 1987 on Saturday, February 28, at Western Oregon State College (WOSC) in Monmouth.

The meeting will feature a special symposium on the topic "Could there be a devastating earthquake in Oregon?" Organizers of the symposium are R.S. Yeats, Department of Geology at Oregon State University, and D.A. Hull, State Geologist, Oregon Department of Geology and Mineral Industries.

Further information will be available soon from OAS secretary Susan Humphreys, WOSC. Abstract forms for papers may be requested from OAS Proceedings editors Claude Curran and John Mairs, Geography Department, Southern Oregon State College. □

Correction

The name of the previous Chair of the DOGAMI Governing Board was given incorrectly in last month's *Oregon Geology.* The name should have been Sidney R. Johnson of Baker. We apologize for this error. —*Editor*

Stratigraphy of the Standard Kirkpatrick No. 1, Gilliam County, Oregon: New insight into Tertiary tectonism of the Blue Mountains[1]

by T.P. Fox, ARCO Oil and Gas Company, Plano, Texas[2], and S.P. Reidel, Rockwell Hanford Operations, Richland, Washington 99352

ABSTRACT

This study integrates existing geologic knowledge of the Standard of California Kirkpatrick No. 1 with new data recently acquired in an attempt to detail the volcanic stratigraphy of the well. The Kirkpatrick No. 1 penetrated 2,440 ft of the Columbia River Basalt Group (CRBG), 4,255 ft of John Day and possibly Clarno volcanic rocks, and more than 2,000 ft of Mesozoic marine sedimentary rocks. This is the northernmost known occurrence of Mesozoic sedimentary rocks in Oregon. New isotopic dates for the John Day/Clarno(?) rocks and chemical compositions for these rocks and the Columbia River Basalt Group are reported.

The John Day/Clarno(?) sequence consists dominantly of tuffs and fine-grained sedimentary rocks, with about one-quarter of the total section consisting of lava flows. We consider a welded ash-flow tuff at a depth of about 6,100 ft to be correlative to the John Day member *a* basal ash-flow tuff. The remaining 560 ft of Tertiary rock may be a previously unrecognized unit of the John Day Formation or part of the Clarno Formation.

A John Day-age intrusion is present in the Mesozoic rocks and the Tertiary section below the ash-flow tuff. This intrusion possibly has affected the thermal maturity of the rocks and may be responsible for the general lack of datable microfossils in the well samples.

In the CRBG, we interpret that all four magnetostratigraphic units of the Grande Ronde Basalt are present. Picture Gorge and Prineville basalts are not present, although they are intercalated with the Grande Ronde Basalt less than 15 mi to the south. A small fault may cut the CRBG at 760 ft.

Comparison of the Kirkpatrick No. 1 data with the regional geology indicates that uplift of the Blue Mountains began in Clarno time and probably continues today. At least 5,300 ft of uplift has occurred relative to the Kirkpatrick area since deposition of the John Day member *a* tuff. This displacement is attributed to a fault or fault zone interpreted along the north flank of the Blue Mountains uplift.

INTRODUCTION

The Standard of California Kirkpatrick No. 1 was spudded on January 31, 1957, in the SW¼ sec. 6, T. 4 S., R. 21 E., near Condon, Oregon (Figure 1). This well is located north of the Blue Mountains uplift in the southern portion of the Columbia Plateau and is sited at the intersection of a northeast-trending anticline and a northwest-trending anticline. The latter structure shows evidence of strike-slip faulting (Swanson and others, 1981). The Kirkpatrick No. 1 penetrated 2,440 ft of the Miocene Columbia River Basalt Group (CRBG) and 4,255 ft of John Day Formation and possibly Clarno Formation rocks of early Tertiary age. It then was plugged and abandoned on June 22, 1957, at 8,726 ft in Mesozoic marine sedimentary rocks (Figure 2). Although the well is almost 30 years old, the section that was drilled is an important aid in deciphering the geologic history of north-central Oregon.

PREVIOUS STUDIES

The focus of most previous studies of the Kirkpatrick No. 1 has been the lithology and petroleum potential of the Mesozoic sedimentary rocks. These rocks consist of interbedded marine graywacke sandstones, siltstones, and dark-gray argillites. Argillite appears to dominate the sequence. The cuttings commonly have shiny surfaces, suggesting that low-grade metamorphism and/or intense shearing and faulting have affected the sequence. Microfossil and source-rock studies (ARCO letter from J.H. Wiese to H.M. Simpson, November 28, 1972, on file with the Oregon Department of Geology and Mineral Industries [DOGAMI]) indicate that the sedimentary rocks at 7,177-7,184 ft and 7,647-7,653 ft contain pollen of late Jurassic-early Cretaceous age and are mature for oil generation (see also Newton, 1979; Fisk, written communication, 1986). A "meager microfossil assemblage" in the rocks below 6,700 ft also implies this age assignment (Standard of California memo on file with the DOGAMI). Total organic carbon (TOC) contents of the sedimentary section are usually very low. Overall, the Mesozoic sedimentary rocks in the well appear to have marginal hydrocarbon potential, although other tests could be attempted in a more complete investigation.

The John Day/Clarno(?) sequence is immediately above the Mesozoic rocks and below the CRBG. It consists of 4,255 ft of varicolored tuffs and sedimentary rocks with interlayered basaltic to silicic lava flows. Outcrops of the John Day Formation are composed primarily of tuffs with local rhyolite and rhyodacite flows. The Clarno Formation, however, consists of basalt and andesite flows separated by mudflow deposits, saprolites, and thin sedimentary beds (Waters, 1954; Robinson, 1975). Plugs and irregular intrusions of andesite, dacite, and rhyolite are also common in outcrops. Identification of the John Day/Clarno boundary is difficult, even in outcrop, due to the lithologic diversity of the pre-CRBG volcanic rocks (Swanson and Robinson, 1968). Isotopic dating is often utilized to help distinguish the two volcanic units, the Clarno Formation ranging from about 55 to 40 million years (m.y.) (Fiebelkorn and others, 1983) and the John Day Formation from 37 to 19 m.y. (Robinson and others, 1984). Uncertainties in isotopic dates may be responsible for the apparent 3-m.y. gap between the two formations.

The John Day/Clarno boundary in the well is an important

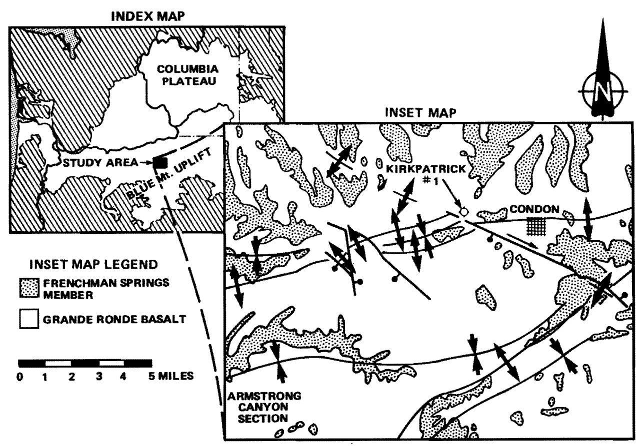

Figure 1. Location map of the Kirkpatrick No. 1. Geology modified from Swanson and others (1981).

[1] *Data summary of the research for this paper is available as Oregon Department of Geology and Mineral Industries Open-File Report O-87-2 (see Fox and Reidel, 1987).*

[2] *Present address: c/o Department of Geology, Colorado School of Mines, Golden, Colorado 80401.*

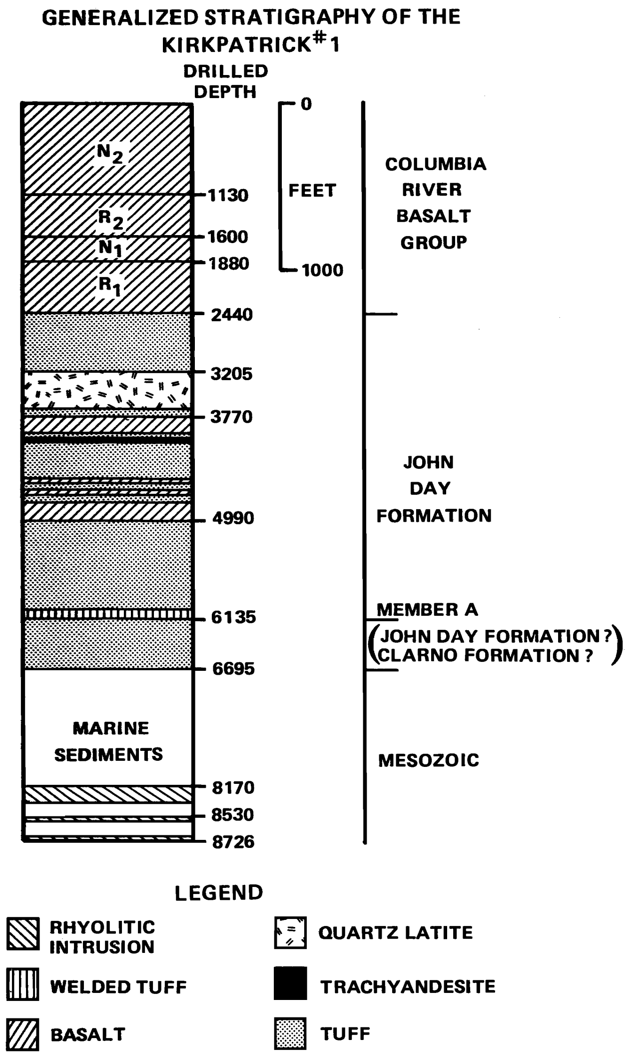

Figure 2. Generalized geology of the Kirkpatrick No. 1. See Fox and Reidel (1987) for detailed description.

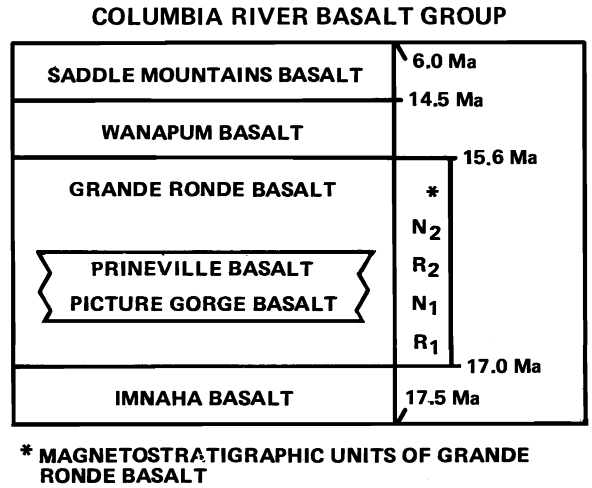

Figure 3. Columbia River Basalt Group stratigraphy. Modified from Swanson and others (1979); dates from McKee and others (1977, 1981) and Long and Duncan (1982).

horizon because its position in the well can provide critical subsurface structural information. Also, the thicknesses of the units can help in interpreting the early Tertiary paleogeography of the area. Wagner and Newton (1969) state that the top of the Eocene volcanics (Clarno) in the well is at a depth of 3,760 ft; however, the American Stratigraphic Company (1967) log for the well reports the contact is at 3,200 ft. The reasons for these identifications are unspecified, and no compositional or age data pertaining to this problem have been published.

The CRBG in Oregon, Washington, and Idaho consists of five formations (Figure 3). The Grande Ronde Basalt accounts for about 85 percent of the volume of the CRBG and consists of four magnetostratigraphic units: from younger to older, the N_2, R_2, N_1, and R_1 units (Swanson and Wright, 1976). The Kirkpatrick No. 1 was spudded in the N_2 magnetostratigraphic unit (Swanson and others, 1981) at a ground elevation of 2,747 ft. A total of 2,440 ft of basalt was drilled, placing the base of the CRBG at 307 ft above sea level. Prior to this study, the CRBG stratigraphy had never been described from the well; therefore, it was uncertain if R_2, N_1, R_1, or flows of the Picture Gorge or Prineville basalts had been penetrated. Regional mapping by J.L. Anderson (in Swanson and others, 1981) shows that R_2 and N_1 Grande Ronde Basalt, flows of the Prineville chemical type, and Picture Gorge Basalt are exposed within 15 mi southwest of the well.

The age of the Grande Ronde sequence is about 17.0 to 15.6 m.y. (McKee and others, 1977, 1981; Long and Duncan, 1982). Both the Picture Gorge Basalt and the Prineville chemical-type basalt are coeval with the Grande Ronde Basalt (Swanson and others, 1979) (Figure 3). Isotopic dating is of little use in distinguishing these basalts. Fortunately, Grande Ronde Basalt is compositionally distinct from Picture Gorge Basalt and flows of the Prineville chemical type (Wright and others, 1973; Swanson and others, 1979), although the magnetostratigraphic units within the Grande Ronde are not easily identified on the basis of composition (Swanson and others, 1979). Reidel (1983), however, demonstrated a correlation between chemical composition and magnetostratigraphy in the Grande Ronde Basalt in the Hell's Canyon area of northeast Oregon. This correlation provides a means of determining the magnetostratigraphy of the Grande Ronde Basalt in boreholes from which only chip samples are available.

METHODS

For this study, samples of the volcanic rocks in the Kirkpatrick No. 1 were taken at 20-ft intervals through the CRBG and at selected points through the pre-CRBG volcanic rocks. The 20-ft sampling interval in the CRBG provided means to determine the potential for vertical contamination during drilling and ditch-sample collection, as well as to evaluate the potential for repeated sections due to faulting. The samples were carefully handpicked to avoid obvious contamination and alteration and were then cleaned and analyzed for oxide compositions at Washington State University using the X-ray fluorescence method of Hooper and Atkins (1969). Isotopic dates were obtained from several cores in the John Day/Clarno(?) section using the potassium-argon (K/Ar) method on whole-rock or feldspar mineral separates from samples. Thin sections were also examined for petrologic relationships. All analytical data are summarized in Open-File Report O-87-2 (Fox and Reidel, 1987) and are on file with DOGAMI.

An examination of the CRBG well cuttings and the mudlog for weathered or vesicular basalt or soil zones provided an indication of the approximate locations of some of the basalt flow tops in the well. These imprecise depths were then correlated with compositional groupings of the basalts and with the geophysical logs from the well to separate flows and flow groups. Using chemical compositions (Table 1), we delineated the stratigraphy of the CRBG and compared it to that determined for the surrounding area by Swanson and others (1981) and for the Hell's Canyon area by Reidel (1983).

Geophysical logs from the well were examined to refine and

Table 1. *Chemical composition of Columbia River Basalt Group samples. All depths are in ft. All analyses are in weight percent. NS=not sampled.*

DEPTH	300-320	320-340	340-360	360-380	380-400
SiO_2	55.38	55.31	NS	55.40	55.40
Al_2O_3	15.06	15.63		15.10	15.23
Fe_2O_3	2.00	2.00		2.00	2.00
FeO	10.67	10.37		10.37	10.25
MgO	3.51	3.47		3.61	3.59
CaO	6.86	7.12		7.09	7.06
Na_2O	2.24	2.29		2.20	2.27
K_2O	1.53	1.17		1.50	1.49
TiO_2	2.23	2.13		2.19	2.19
P_2O_5	0.33	0.32		0.34	0.33
MnO	0.20	0.19		0.19	0.19

DEPTH	400-420	420-440	440-460	460-480	480-500
SiO_2	55.62	55.67	55.73	55.45	55.55
Al_2O_3	15.16	15.09	15.22	15.09	15.14
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.14	10.04	10.03	10.41	10.11
MgO	3.54	3.64	3.65	3.72	3.64
CaO	7.01	7.12	7.10	7.07	7.11
Na_2O	2.31	2.27	2.18	2.12	2.21
K_2O	1.55	1.58	1.55	1.61	1.68
TiO_2	2.14	2.08	2.05	2.04	2.06
P_2O_5	0.32	0.32	0.31	0.31	0.31
MnO	0.20	0.19	0.19	0.19	0.19

DEPTH	500-520	520-540	540-560	560-580	580-600
SiO_2	55.73	54.98	55.50	54.94	54.97
Al_2O_3	15.16	14.91	15.61	15.00	15.07
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	9.99	10.94	10.57	10.66	10.30
MgO	3.66	3.66	3.51	3.62	3.83
CaO	7.11	6.99	6.96	7.40	7.35
Na_2O	2.17	2.37	2.06	2.25	2.27
K_2O	1.59	1.43	0.94	1.38	1.53
TiO_2	2.08	2.19	2.38	2.21	2.16
P_2O_5	0.32	0.33	0.30	0.33	0.33
MnO	0.19	0.19	0.17	0.20	0.20

DEPTH	600-620	620-640	640-660	660-680	680-700
SiO_2	55.28	55.68	54.72	55.40	55.24
Al_2O_3	15.06	15.22	15.06	15.42	15.29
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.20	9.59	9.92	9.51	9.35
MgO	3.76	3.84	4.37	4.26	4.45
CaO	7.14	7.23	7.99	7.33	7.71
Na_2O	2.14	2.26	2.34	2.43	2.35
K_2O	1.78	1.63	1.26	1.31	1.27
TiO_2	2.11	2.05	1.88	1.92	1.87
P_2O_5	0.33	0.30	0.26	0.27	0.27
MnO	0.22	0.20	0.19	0.16	0.20

DEPTH	700-720	720-740	740-760	760-780	780-800
SiO_2	55.17	55.28	55.36	55.32	54.88
Al_2O_3	15.32	14.91	15.00	15.13	15.41
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	9.82	10.03	10.17	9.59	9.23
MgO	4.15	3.93	3.89	4.16	4.57
CaO	7.35	7.25	7.12	7.50	8.00
Na_2O	2.42	2.54	2.29	2.49	2.45
K_2O	1.34	1.52	1.55	1.43	1.23
TiO_2	1.96	2.02	2.12	1.90	1.78
P_2O_5	0.28	0.31	0.31	0.28	0.26
MnO	0.19	0.21	0.19	0.19	0.19

DEPTH	800-820	820-840	840-860	860-880	880-900
SiO_2	55.17	55.15	55.08	54.98	55.15
Al_2O_3	15.52	15.42	15.32	14.93	15.05
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	9.31	9.48	9.48	10.18	10.18
MgO	4.58	4.55	4.41	3.85	3.93
CaO	7.71	7.67	7.80	7.63	7.14
Na_2O	2.37	2.27	2.40	2.38	2.54
K_2O	1.18	1.21	1.24	1.45	1.44
TiO_2	1.74	1.80	1.82	2.08	2.06
P_2O_5	0.25	0.27	0.27	0.32	0.31
MnO	0.18	0.18	0.19	0.21	0.19

DEPTH	900-920	920-940	940-960	960-980	980-1000
SiO_2	54.44	54.70	54.37	55.34	55.11
Al_2O_3	15.02	15.06	14.88	16.02	14.95
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.26	10.48	10.95	10.22	10.34
MgO	4.17	4.08	3.98	3.48	3.78
CaO	7.59	7.35	7.14	6.81	7.11
Na_2O	2.63	2.33	2.48	2.23	2.54
K_2O	1.31	1.37	1.40	1.00	1.56
TiO_2	2.07	2.11	2.26	2.35	2.11
P_2O_5	0.31	0.32	0.34	0.38	0.32
MnO	0.19	0.19	0.20	0.17	0.19

DEPTH	1000-1020	1020-1040	1040-1060	1060-1080	1080-1100
SiO_2	55.02	55.09	55.33	55.06	54.90
Al_2O_3	15.15	14.90	15.05	14.90	15.04
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.22	10.65	10.42	10.41	10.51
MgO	3.92	3.80	3.66	3.74	3.86
CaO	7.16	6.96	6.76	7.09	7.04
Na_2O	2.46	2.36	2.51	2.58	2.53
K_2O	1.50	1.59	1.55	1.57	1.53
TiO_2	2.06	2.14	2.20	2.15	2.08
P_2O_5	0.31	0.32	0.32	0.32	0.31
MnO	0.19	0.20	0.19	0.19	0.19

DEPTH	1100-1120	1120-1140	1140-1160	1160-1180	1180-1200
SiO_2	55.78	54.55	56.22	55.68	57.10
Al_2O_3	15.26	15.11	15.06	14.99	15.38
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.44	11.04	10.15	11.16	9.95
MgO	3.30	4.00	3.06	3.18	2.71
CaO	6.29	6.70	6.32	6.19	5.66
Na_2O	2.32	2.41	2.36	2.27	2.43
K_2O	1.67	1.38	2.01	1.65	1.85
TiO_2	2.39	2.28	2.29	2.35	2.39
P_2O_5	0.34	0.34	0.34	0.34	0.36
MnO	0.20	0.20	0.19	0.20	0.16

DEPTH	1200-1220	1220-1240	1240-1260	1260-1280	1280-1300
SiO_2	56.56	56.66	55.00	54.87	54.58
Al_2O_3	15.20	15.27	15.00	15.05	14.94
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.07	9.88	10.34	10.33	10.66
MgO	2.96	2.78	3.68	3.81	3.78
CaO	6.15	5.91	7.02	7.13	7.16
Na_2O	2.37	2.62	2.32	2.44	2.46
K_2O	1.87	2.00	1.66	1.57	1.48
TiO_2	2.30	2.35	2.43	2.29	2.41
P_2O_5	0.35	0.36	0.34	0.32	0.34
MnO	0.17	0.17	0.21	0.19	0.20

DEPTH	1300-1320	1320-1340	1340-1360	1360-1380	1380-1400
SiO_2	55.11	54.82	54.50	54.96	55.43
Al_2O_3	15.17	15.17	15.07	15.32	15.86
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	10.04	10.42	10.58	10.47	10.10
MgO	3.85	4.03	3.72	3.69	3.00
CaO	7.17	7.12	7.16	6.81	6.37
Na_2O	2.40	2.33	2.29	2.32	2.59
K_2O	1.54	1.34	1.62	1.43	1.51
TiO_2	2.22	2.27	2.53	2.45	2.56
P_2O_5	0.32	0.31	0.34	0.34	0.41
MnO	0.19	0.18	0.20	0.21	0.17

DEPTH	1400-1420	1420-1440	1440-1460	1460-1480	1480-1500
SiO_2	55.79	54.48	NS	54.65	54.97
Al_2O_3	15.99	15.42		15.05	15.15
Fe_2O_3	2.00	2.00		2.00	2.00
FeO	9.84	10.51		10.61	10.36
MgO	2.68	3.67		3.56	3.40
CaO	6.22	7.01		6.97	6.76
Na_2O	2.60	2.35		2.53	2.62
K_2O	1.69	1.31		1.63	1.72
TiO_2	2.62	2.55		2.43	2.47
P_2O_5	0.42	0.40		0.36	0.36
MnO	0.17	0.28		0.20	0.18

DEPTH	1500-1520	1520-1540	1540-1560	1560-1580	1580-1600
SiO_2	55.19	54.76	NS	54.68	NS
Al_2O_3	15.13	15.01		15.14	
Fe_2O_3	2.00	2.00		2.00	
FeO	10.35	10.77		10.44	
MgO	3.61	3.59		3.72	
CaO	6.74	6.71		7.02	
Na_2O	2.33	2.48		2.45	
K_2O	1.66	1.67		1.59	
TiO_2	2.45	2.46		2.38	
P_2O_5	0.35	0.36		0.36	
MnO	0.19	0.19		0.21	

DEPTH	1600-1620	1620-1640	1640-1660	1660-1680	1680-1700
SiO_2	52.40	53.01	52.91	52.79	53.02
Al_2O_3	14.79	14.85	14.95	15.03	14.84
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.17	11.78	11.69	11.72	11.81
MgO	4.65	4.50	4.47	4.42	4.34
CaO	8.20	8.06	8.11	8.27	8.03
Na_2O	2.39	2.28	2.41	2.39	2.44
K_2O	0.65	0.79	0.73	0.69	0.79
TiO_2	2.18	2.17	2.17	2.13	2.17
P_2O_5	0.32	0.32	0.33	0.34	0.35
MnO	0.25	0.23	0.22	0.22	0.22

DEPTH	1700-1720	1720-1740	1740-1760	1760-1780	1780-1800
SiO_2	NS	52.59	52.22	51.74	51.86
Al_2O_3		14.64	14.75	14.77	14.74
Fe_2O_3		2.00	2.00	2.00	2.00
FeO		11.96	11.96	12.22	12.33
MgO		4.53	4.75	4.83	4.81
CaO		8.39	8.59	8.78	8.62
Na_2O		2.47	2.40	2.41	2.45
K_2O		0.73	0.64	0.50	0.50
TiO_2		2.12	2.13	2.20	2.16
P_2O_5		0.33	0.33	0.31	0.30
MnO		0.24	0.24	0.23	0.23

DEPTH	1800-1820	1820-1840	1840-1860	1860-1880	1880-1900
SiO_2	52.07	53.11	53.99	53.71	52.02
Al_2O_3	14.68	14.98	15.16	15.23	14.86
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.08	11.60	10.48	10.69	11.78
MgO	4.82	4.43	4.47	4.35	4.79
CaO	8.71	8.14	7.81	7.90	8.84
Na_2O	2.40	2.34	2.47	2.53	2.33
K_2O	0.56	0.75	0.98	0.97	0.55
TiO_2	2.14	2.14	2.12	2.09	2.29
P_2O_5	0.31	0.30	0.31	0.31	0.32
MnO	0.23	0.22	0.21	0.21	0.22

DEPTH	1900-1920	1920-1940	1940-1960	1960-1980	1980-2000
SiO_2	53.30	54.78	53.62	53.73	55.07
Al_2O_3	14.94	15.32	14.99	14.99	15.21
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	11.82	11.05	11.98	11.63	10.58
MgO	4.14	3.57	3.99	4.11	3.71
CaO	7.57	6.86	7.19	7.27	6.85
Na_2O	2.39	2.41	2.35	2.39	2.49
K_2O	0.91	1.20	1.03	0.97	1.17
TiO_2	2.34	2.28	2.30	2.37	2.38
P_2O_5	0.35	0.34	0.33	0.34	0.34
MnO	0.23	0.17	0.20	0.19	0.20

DEPTH	2000-2020	2020-2040	2040-2060	2060-2080	2080-2100
SiO_2	NS	NS	NS	52.78	51.87
Al_2O_3				15.02	14.61
Fe_2O_3				2.00	2.00
FeO				11.83	12.42
MgO				4.42	4.79
CaO				7.96	8.50
Na_2O				2.20	2.35
K_2O				0.92	0.59
TiO_2				2.32	2.31
P_2O_5				0.32	0.31
MnO				0.23	0.24

DEPTH	2100-2120	2120-2140	2140-2160	2160-2180	2180-2200
SiO_2	52.06	52.34	52.47	52.12	52.27
Al_2O_3	14.71	14.55	14.71	14.65	14.65
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.23	12.31	12.02	12.29	12.26
MgO	4.71	4.58	4.55	4.71	4.61
CaO	8.47	8.18	8.25	8.38	8.35
Na_2O	2.30	2.48	2.37	2.33	2.30
K_2O	0.67	0.76	0.82	0.69	0.74
TiO_2	2.29	2.28	2.28	2.29	2.29
P_2O_5	0.31	0.31	0.32	0.31	0.31
MnO	0.24	0.23	0.23	0.23	0.23

DEPTH	2200-2220	2220-2240	2240-2260	2260-2280	2280-2300
SiO_2	52.47	52.52	52.33	52.35	52.39
Al_2O_3	14.64	14.83	14.64	14.70	14.64
Fe_2O_3	2.00	2.00	2.00	2.00	2.00
FeO	12.06	11.98	12.23	12.21	12.25
MgO	4.60	4.50	4.58	4.66	4.51
CaO	8.28	8.15	8.25	8.33	8.18
Na_2O	2.37	2.39	2.38	2.27	2.43
K_2O	0.78	0.80	0.76	0.69	0.75
TiO_2	2.26	2.28	2.27	2.25	2.30
P_2O_5	0.31	0.33	0.32	0.30	0.31
MnO	0.23	0.22	0.23	0.23	0.23

DEPTH	2300-2320	2320-2340	2340-2360	2360-2380	2380-2400
SiO_2	NS	NS	55.13	55.16	54.61
Al_2O_3			15.07	15.04	14.86
Fe_2O_3			2.00	2.00	2.00
FeO			10.97	10.74	11.27
MgO			3.44	3.45	3.51
CaO			6.77	6.89	6.90
Na_2O			2.35	2.45	2.43
K_2O			1.34	1.38	1.34
TiO_2			2.41	2.35	2.48
P_2O_5			0.34	0.34	0.38
MnO			0.19	0.20	0.22

DEPTH	2400-2420	2420-2440
SiO_2	55.04	54.61
Al_2O_3	14.95	14.64
Fe_2O_3	2.00	2.00
FeO	10.75	11.43
MgO	3.34	3.41
CaO	6.85	6.81
Na_2O	2.53	2.60
K_2O	1.41	1.37
TiO_2	2.51	2.50
P_2O_5	0.41	0.42
MnO	0.20	0.22

add to the basalt flow contacts interpreted from the cuttings and their compositions. Siems and others (1974) had used neutron logs to identify CRBG flow contacts in the central Columbia Plateau (Figure 4). Unfortunately, only spontaneous potential and resistivity logs had been run in the Kirkpatrick No. 1, because they were the principal logs in use at the time. Because the Kirkpatrick No. 1 resistivity log has the same response as the neutron logs in the CRBG (Figure 4), it was the only available log that made it possible for us to separate the solid, resistive flow interiors from the scoriaceous and weathered, fairly conductive flow tops and interbeds. A major problem with log interpretation is that fractured or vesicular zones within a flow can be mistaken for a flow contact. Also, during advance of the flow, the flow front may slow due to lateral spreading or the presence of slightly higher topography, and the flow may overtop itself, creating one or several flow lobes that may appear on the log to be individual flows. To avoid confusion, it is wise to use several logs, such as the sonic, neutron, and deep resistivity, and to look for a correlation in response between the logs.

The John Day and Clarno Formations are best identified by isotopic ages in combination with whole-rock compositions and petrology. The compositions of twenty samples of pre-CRBG igneous rocks from Kirkpatrick No. 1 are presented in Table 2. Four cores from a portion of the John Day/Clarno(?) section were dated using K/Ar methods on whole-rock samples and mineral separates (Table 3).

The resistivity log was useful in the John Day/Clarno(?) section for differentiating resistive lavas and intrusions from relatively conductive tuffs and sediments. Inferences from the logs were then checked with the available lithologic samples. The geophysical logs allowed fairly accurate depths to be assigned to lithologic changes so that the sample contamination by caving, which is probably common in the weaker tuffs, had minimal effect on lithologic description of the penetrated section.

RESULTS AND DISCUSSION

Mesozoic rocks

No research was conducted on the Mesozoic sedimentary rocks. Previous studies indicate that the microfossils are not well enough preserved to date these sediments more accurately, so we have adopted the previous assignment of these rocks as Mesozoic.

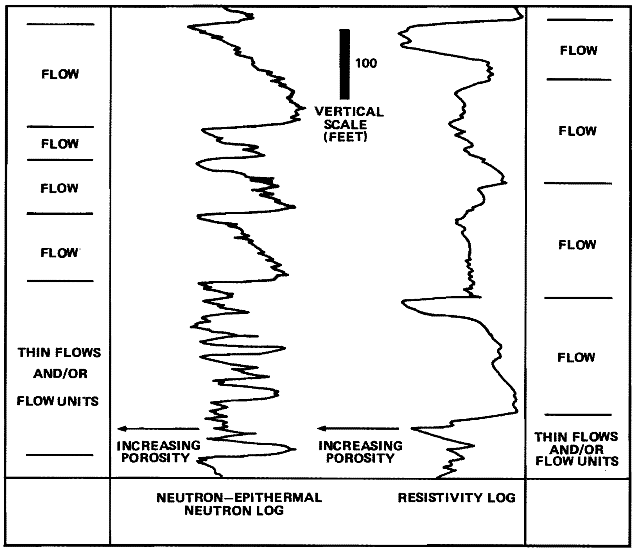

Figure 4. Response of neutron and resistivity logs to basalt flows. Neutron log from Siems and others (1974, Figure 5). Resistivity log from Kirkpatrick No. 1, showing weathered, fairly conductive flow tops and solid, resistive flow interiors and bottoms.

The Mesozoic rocks in the Kirkpatrick No. 1 were probably formed as deep-water turbidites, perhaps similar to the lower Cretaceous sedimentary rocks at Mitchell, Oregon (Kleinhans and others, 1984), the middle to upper Jurassic sedimentary rocks near Suplee, Oregon (Dickinson and Vigrass, 1965), or the undated rocks near Hay Creek and Muddy Ranch (Peck, 1964). The lack of preservation of microfossils in the well may be due to hydrothermal effects of the John Day-age intrusion, discussed in a later section.

The thermal alteration index (TAI) data determined by Fisk (written communication, 1986) and shown in Fox and Reidel (1987) indicate a relatively constant value of 2.7 from the base of the well to about 5,000 ft. Above this depth, the values decrease to a range of 1.8 to 2.0 to at least 1,440 ft. Some of the upper TAI values are slightly erratic, and Fisk attributes this to local thermal events such as volcanic flows, sills, and dikes. Reworking of organic material may also account for some of the erratic values. Fisk suggests the recorded thermal history is one of periodic major, though probably short-term, heating events but points out that there is a general increase in TAI values with depth.

John Day/Clarno(?) rocks

The John Day/Clarno(?) volcanic rocks occur from 2,440 ft to 6,695 ft in the Kirkpatrick No. 1, with a younger John Day-age rhyolite intrusion present in the lower part of the Tertiary section and in the Mesozoic section. The boundary between the John Day and Clarno Formations is transitional and cannot be picked unequivocally on the basis of either age or lithologic data, especially in borehole sections. The age of the earliest John Day deposit in north-central Oregon, a widespread ash-flow tuff named the "*a* member," has been determined to be 37.7±1.1 m.y. (Robinson and others, 1984). The youngest age for the Clarno Formation is about 40 m.y., but Clarno activity may have continued beyond 40 m.y. in some areas (P.T. Robinson, personal communication, 1986). From a petrologic standpoint, the uppermost occurrence of andesitic-basaltic lava flows in the Kirkpatrick No. 1 should mark the top of the Clarno Formation, because the John Day Formation is dominantly rhyolitic. However, the John Day Formation locally contains basalt flows near its base (Robinson and others, 1984), and the Clarno Formation contains some rhyolite flows and tuffs (Robinson, 1975). Fortunately, the John Day basalts tend to be more alkaline and have higher TiO_2 contents than Clarno basalts, thus providing a means to separate the two (Robinson, 1969).

Eight cores were recovered from the well, four of which have been dated (Table 3). Core 9 (8,268-8,278 ft) is a dense, white rhyolitic rock within the Mesozoic sedimentary section. The crystallinity, fresh appearance, and density of the rock suggest that the rock is not a tuff but instead a part of an intrusion. This interpretation is supported by a 28.8±1.2-m.y. age (John Day) that we believe to be correct. Also, similar rock was found and sampled both below core 9 and above it in the basal rocks of the Tertiary section. All of the samples are compositionally identical. No flows of correlative composition were found in the penetrated John Day section, however, indicating that this intrusion did not feed any flows encountered in the borehole.

The interpretation of the rhyolitic rock as a John Day intrusion is consistent with Fisk's (written communication, 1986) data. The beginning of the TAI decrease occurs across a thick basalt flow at 4,740-4,990 ft, and both the intrusive and the volcanics could be responsible for the elevated and erratic TAI values. One possible interpretation is that the TAI data in the lower part of the well may have been, in fact, elevated by thermal effects of a much larger unseen intrusion, of which core 9 is only a part. We can only speculate on this possibility.

The first dated sample above the Mesozoic sedimentary rocks

Table 2. *Chemical composition and CIPW normative minerals of the pre-Columbia River Basalt Group volcanics. All depths are in ft. All analyses are in weight percent. Q=quartz; Or=orthoclase; Ab=albite; An=anorthite; Di=diopside; Hy=hypersthene; Il=ilmenite.*

SAMPLE	1	2	3	4
DEPTH	2600-2680	2860-2900	3080-3140	3380-3400
	tuff	tuff	tuff	quartz latite
SiO_2	64.08	62.91	61.74	69.29
Al_2O_3	15.66	15.05	15.49	13.48
Fe_2O_3	3.93	3.78	4.17	2.73
FeO	4.50	4.33	4.78	3.12
MgO	1.97	2.15	2.20	0.62
CaO	5.11	5.77	5.62	2.98
Na_2O	2.96	2.34	2.38	3.42
K_2O	1.04	2.24	1.86	3.71
TiO_2	1.13	1.04	1.32	0.44
P_2O_5	0.23	0.22	0.27	0.08
MnO	0.15	0.17	0.17	0.12
Q	28.08	24.91	24.63	27.57
Or	6.15	13.24	10.99	21.93
Ab	25.05	19.80	20.14	28.94
An	23.86	23.94	26.09	10.47
Di	---	2.66	0.04	3.21
Hy	8.34	7.49	8.93	2.89
Il	2.15	1.98	2.51	0.84

SAMPLE	5	6	7	8
DEPTH	3460-3480	3580-3600	3700-3720	3820-3880
	quartz latite	tuff	tuff	basalt
SiO_2	70.00	77.32	68.87	48.94
Al_2O_3	13.69	12.74	14.36	15.91
Fe_2O_3	2.79	0.91	3.47	6.28
FeO	3.20	1.04	3.98	7.20
MgO	0.45	0.12	1.50	5.75
CaO	2.36	1.48	2.69	9.41
Na_2O	3.23	2.52	1.46	2.56
K_2O	3.59	3.63	2.24	0.56
TiO_2	0.50	0.19	1.23	2.81
P_2O_5	0.07	0.03	0.14	0.44
MnO	0.11	0.02	0.08	0.15
Q	30.60	45.10	43.03	5.66
Or	21.22	21.45	13.24	3.31
Ab	27.33	21.32	12.35	21.66
An	11.22	7.13	12.43	30.27
Di	---	---	---	10.79
Hy	4.07	1.18	6.30	12.86
Il	0.95	0.36	2.34	5.34

SAMPLE	9	10	11	12
DEPTH	4000-4020	4300-4360	4520-4540	4600-4640
	andesite	tuff	tuff	basalt
SiO_2	53.23	64.44	63.06	49.13
Al_2O_3	15.75	15.59	15.98	15.68
Fe_2O_3	5.89	4.21	4.92	6.00
FeO	6.74	4.82	5.63	3.87
MgO	3.46	1.75	1.96	5.48
CaO	7.85	4.55	2.95	9.14
Na_2O	2.71	1.64	1.49	2.88
K_2O	1.00	1.57	2.14	0.89
TiO_2	2.47	1.22	1.61	3.11
P_2O_5	0.74	0.09	0.18	0.64
MnO	0.16	0.13	0.08	0.19
Q	13.39	35.15	35.76	6.03
Or	5.91	9.28	12.65	5.26
Ab	22.93	13.88	12.61	24.37
An	27.86	21.98	13.44	27.23
Di	5.06	---	---	10.84
Hy	9.91	7.96	8.65	8.62
Il	4.69	2.32	3.06	5.91

SAMPLE	13	14	15	16
DEPTH	4740-4800	4940-4960	6080-6100	6300-6320
	basalt	basalt	tuff	rhyolite
SiO_2	50.92	50.84	73.93	78.67
Al_2O_3	15.62	15.40	12.78	13.35
Fe_2O_3	5.47	5.47	2.75	0.17
FeO	6.27	6.27	3.15	0.20
MgO	6.04	5.75	0.20	0.17
CaO	10.34	10.68	1.89	0.88
Na_2O	2.47	2.53	2.20	1.83
K_2O	0.42	0.34	2.25	4.62
TiO_2	2.02	2.23	0.61	0.04
P_2O_5	0.27	0.31	0.12	0.03
MnO	0.15	0.18	0.12	0.02
Q	6.91	7.18	47.27	48.20
Or	2.48	2.01	13.30	27.31
Ab	20.90	21.41	18.62	15.48
An	30.29	29.66	8.57	4.14
Di	15.32	16.95	---	---
Hy	11.69	9.90	3.23	0.62
Il	3.84	4.24	1.16	0.08

SAMPLE	17	18	19	20
DEPTH	6440-6460	8240-8300	8540-8600	8700-8725
	rhyolite	rhyolite	rhyolite	rhyolite
SiO_2	78.91	79.05	78.80	78.83
Al_2O_3	13.48	13.36	13.12	13.88
Fe_2O_3	0.23	0.18	0.29	0.21
FeO	0.26	0.20	0.33	0.24
MgO	0.07	0.00	0.00	0.00
CaO	0.63	0.87	0.90	0.44
Na_2O	1.94	2.10	3.08	2.38
K_2O	4.34	4.15	3.37	3.92
TiO_2	0.07	0.04	0.06	0.05
P_2O_5	0.04	0.03	0.03	0.03
MnO	0.03	0.03	0.03	0.03
Q	49.57	49.08	45.99	49.01
Or	25.65	24.53	19.92	23.17
Ab	16.42	17.77	26.06	20.14
An	2.86	4.10	4.27	1.99
Di	---	---	---	---
Hy	0.40	0.21	0.32	0.24
Il	0.13	0.08	0.11	0.10

Table 3. *K/Ar ages of volcanic rock cores.*

CORE	DEPTH	LITHOLOGY	AGE (m.y.)	DATED MATERIAL
#1	2737-2756	tuff	41.2 ± 4.5	feldspar
#2	4405-4422	tuff	36.6 ± 2.9	feldspar
#4	6542-6545	tuff	39.7 ± 1.7	whole rock
#9	8268-8278	rhyolite	28.2 ± 1.2	whole rock

is core 4, a dense, fine-grained, gray tuff recovered from 6,542-6,545 ft. An age of 39.7±1.7 m.y. indicates the tuff is probably a late Clarno equivalent. However, the uncertainty in age also allows assignment of the tuff to the John Day Formation.

Core 2 (4,405-4,422 ft) is a light gray-brown tuff. An age of 36.6±2.9 m.y. allows this tuff to be correlated to the basal John Day member *a* tuff and core 4.

Core 1 (2,737-2,756 ft) is also a light gray-brown tuff, but it contains micaceous flakes, suggesting the tuff was either reworked by streams or subject to alteration. The sample yielded a Clarno age of 41.2±4.5 m.y., which we consider to be a suspect date because the rock is then out of stratigraphic sequence. There appears to be no evidence of fault-repeated stratigraphy in the pre-CRBG section. Alternatively, we interpret the sample to be reworked or altered.

In summary, the best age data for the John Day/Clarno(?) sequence bracket the boundary age at 37 m.y. The dates are so close, however, that they cannot differentiate the John Day and Clarno Formations.

Whole-rock compositions were useful in grouping and identifying the pre-CRBG rocks in the Kirkpatrick No. 1. Cross, Iddings, Pirsson, and Washington (CIPW) norms (Table 2) were calculated for each sample, but we emphasize that the correlations suggested here are preliminary and should be confirmed with other techniques.

Samples 1, 2, 3, 6, 7, 10, and 11 (Table 2) are rhyolitic and dacitic air-fall tuffs, a lithology commonly assigned to the John Day Formation but not unknown in the Clarno Formation (Robinson, 1975). There appears to be no systematic compositional change coincident with stratigraphic position. Sample 6 has such a unique composition that it is almost certainly altered (Figure 5).

Samples 4 and 5 are from a 315-ft-thick quartz latite flow at 3,205 ft. This is the uppermost flow in the pre-CRBG sequence and probably was previously chosen as the top of the Clarno Formation for this reason.

Samples 8, 9, 12, 13, and 14 are intermediate and mafic lava flows. Sample 9 is compositionally similar to a trachyandesite, and the others are basaltic.

Based on petrologic data, the John Day/Clarno boundary should be placed at the top of the flow from which sample 8 was taken (3,765 ft), which is close to where Wagner and Newton (1969) placed it. However, as stated previously, the John Day basalts contain more than 2 percent TiO_2 by weight and are more alkaline than the Clarno basalts (Robinson, 1969). Figure 6 illustrates that samples 8, 12, 13, and 14 have a TiO_2 content more similar to basalts in the John Day Formation. Andesitic rocks (up to 62 weight percent SiO_2) and sample 9 have also been plotted for comparison. However, the samples were found to be low in alkalies relative to the John Day basalts. Recalculation of the compositions after adjusting the Fe_2O_3/FeO ratio to 0.25 (Robinson, 1969) has little effect on the total alkali composition of the samples. Why the basalts in the well have relatively low alkali contents in comparison to their TiO_2 contents is unclear; this may reflect minor alkali alteration of the samples. With this in mind, we view the SiO_2/TiO_2 data as more reliable and suggest that the basalt flows are part of the John Day Formation.

Sample 15 is a rhyodacitic ash-flow tuff stratigraphically between the units dated at 36.6 and 39.7 m.y. A thin section of the sample chips reveals crushed and welded pumice fragments in the chips. The composition of sample 15 is very similar to the average for the basal ash-flow tuff of member *a* in the John Day Formation (Figure 7). Departures from the average for calcium and sodium are not unusual; these two elements are highly mobile. In fact, Hay (1963) reports that the calcium content increases and the sodium content decreases in an altered John Day tuff, and our samples mimic this trend. The age determination is also consistent with the correlation. Therefore, a correlation of sample 15 to the basal ash-flow tuff of the John Day Formation seems reasonable.

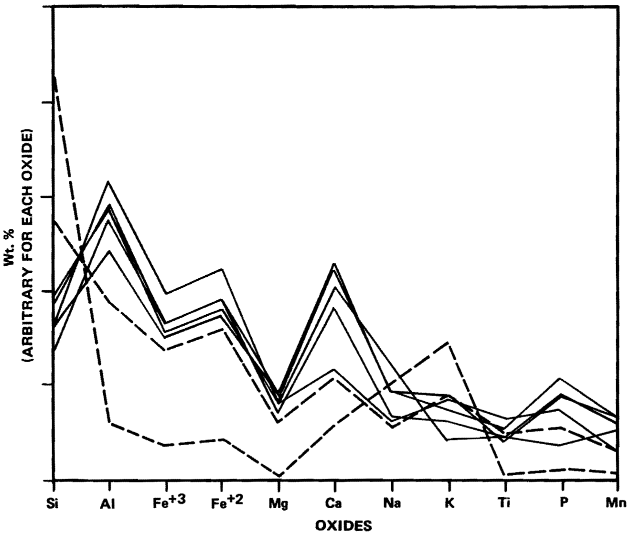

Figure 5. Comparison of oxide compositions of the air-fall tuffs from the John Day Formation. Samples 6 and 7 (dashed) are interpreted to show evidence of chemical alteration.

If sample 15 is considered to be the base of the John Day Formation as recognized in outcrop, then the tuff in the Kirkpatrick No. 1 between 6,135 ft and 6,695 ft can either be considered a part of the Clarno Formation or a previously unrecognized unit within the John Day Formation. Based on the available data, we suggest that the tuff is a newly recognized unit of the John Day Formation, because air-fall tuffs are more common in this formation than in the Clarno. A detailed study of this unit is necessary to resolve this important stratigraphic problem.

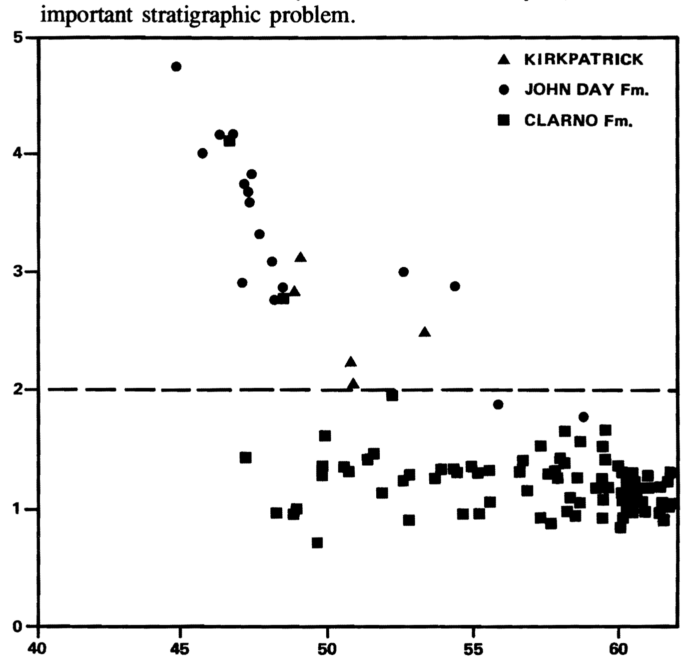

Figure 6. SiO_2/TiO_2 variation diagram for basalts and andesites exclusive of the Columbia River Basalt Group. Data from Robinson (1969) and Rogers and Ragland (1980).

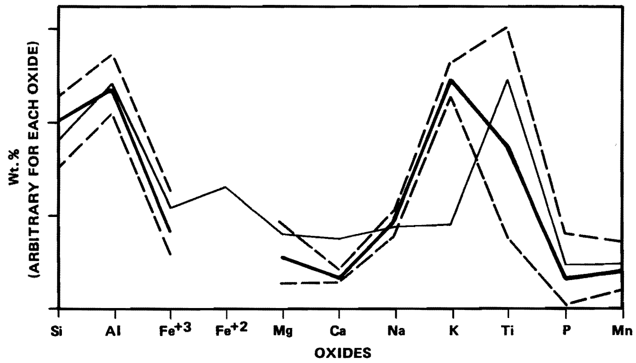

Figure 7. Comparison of sample 15 (solid line) to John Day member a *basal ash-flow tuff average (heavy line) and range (dashed lines). Data from Robinson (unpublished data, 1986).*

Samples 16 to 20 are all compositionally and lithologically similar to core 9, which was taken from the John Day-age rhyolitic intrusion in the Mesozoic sedimentary rocks. Based on the position of these samples, the intrusion is present in the Mesozoic sedimentary rocks and at least up to the lower part of the Tertiary section below the John Day member *a* correlative unit. We suggest that the intrusion has increased the TAI and corroded the microfossils in the sedimentary rocks below 5,000 ft in the well.

Any discussion of whole-rock composition needs to consider the effects of diagenetic alteration on the composition of the lavas. Diagenesis has obviously altered the air-fall tuffs (e.g., Hay, 1963), but compositional changes in the flows are not evident, except possibly for the alkalies to a minor extent. Samples 4 and 5 and samples 13 and 14 are dual samples that show nearly identical compositions within, respectively, a quartz latite flow and a basalt flow. This suggests no chemical alteration has occurred in the interior of these flows.

Columbia River Basalt Group

The Grande Ronde Basalt consists of four magnetostratigraphic units, the N_2, R_2, N_1, and R_1 units (Figure 3), that compositionally fall into two fields: low-MgO and high-MgO (Wright and others, 1973; Swanson and others, 1979). Reconnaissance field mapping of the CRBG in the Condon area by J.L. Anderson (in Swanson and others, 1981) shows that the Grande Ronde Basalt is the youngest CRBG unit present at the well site. Anderson's mapping identified at least three of the four Grande Ronde magnetostratigraphic units (N_2, R_2, and N_1) in the vicinity of the well.

Flows of the Prineville chemical-type basalt (Cockerham, 1974; Swanson and others, 1979; Smith, 1986) are intercalated with N_2 and R_2 Grande Ronde Basalt flows (J.L. Anderson, personal communication, 1986) west and south of the Condon area. In Armstrong Canyon, 12 mi southwest of the Kirkpatrick No. 1, a single Prineville flow is found at the base of the N_2 magnetostratigraphic unit (Figure 8). This flow has a distinctive composition that easily distinguishes it from the Grande Ronde Basalt.

South of the Condon area, Picture Gorge Basalt flows interfinger with and underlie the R_2 Grande Ronde Basalt (Cockerham, 1974; Swanson and others, 1981; Bailey, 1986). It is not known how far flows of the Picture Gorge Basalt extend north of the axis of the Blue Mountains uplift; however, vents and dikes of the basalt occur north of the axis. Previously, these vents and dikes were identified as part of the Grande Ronde Basalt (Swanson and others, 1981) but reexamination and analysis of them by Reidel and Tolan (unpublished data, 1986) shows that they are Picture Gorge Basalt.

The total thickness of the CRBG stratigraphy in the Kirkpatrick No. 1 is approximately 2,440 ft. Our interpretation of the geophysical logs indicates there are at least 25 flows (Fox and Reidel, 1987). Thicknesses of individual flows typically range from 50 to 80 ft but can be as great as 240 ft.

During the drilling of the Kirkpatrick No. 1, chip samples from the CRBG were collected at 20-ft intervals, beginning at 300 ft. Oxide compositions (Table 1) indicate that the entire CRBG section consists of Grande Ronde Basalt and that there are at least 16 compositionally distinct units. The shallowest samples collected are of a low-MgO/low- to intermediate-TiO_2 compositional type; this compositional type persists to 640 ft. From a depth of 640 to 1,130 ft, the basalts are of high- to intermediate-MgO/low-TiO_2 compositions. From 1,130 to 1,600 ft, the basalts are of low-MgO/high-TiO_2 compositions. High-MgO/high-TiO_2 flows occur from 1,600 to 2,310 ft, with the lowest flows having low-MgO/high-TiO_2 compositions.

The amount of mixing or contamination between samples from different flows during the drilling process is negligible. This conclusion is based upon several lines of evidence. First, the data in Table 1 (and Fox and Reidel, 1987) show no obvious mixing or gradational changes between basalt flows. All contacts are abrupt. Second, we can correlate compositionally distinct flows in the upper portion of the well to a surface section collected in Armstrong Canyon (Figure 8) (Reidel and Tolan, unpublished data, 1986). The compositions of these distinctive flows from the canyon to the well are virtually identical.

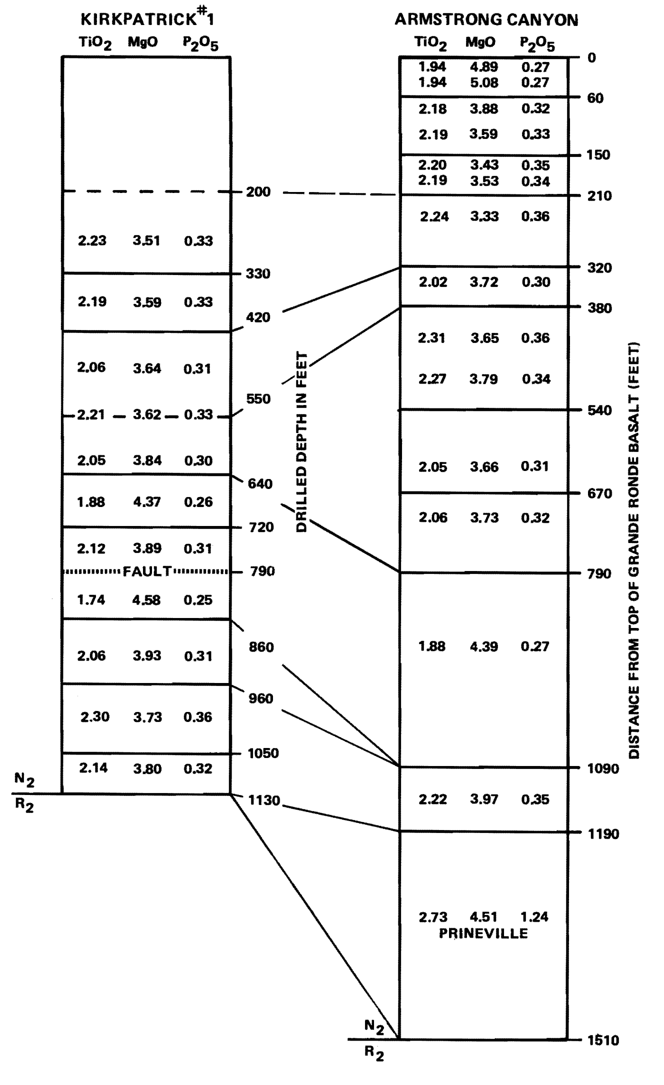

Figure 8. Comparison of TiO_2, MgO, and P_2O_5 for the N_2 section of the Columbia River Basalt Group between the Kirkpatrick No. 1 and the Armstrong Canyon section of Reidel and Tolan (unpublished data, 1986; see Figure 1).

All four of the Grande Ronde magnetostratigraphic units are probably present in the Kirkpatrick No. 1. The N_2 unit is defined by correlation of flow compositions from the well to Armstrong Canyon (Figure 8). The unit is about 1,190 ft thick in the canyon and 1,130 ft thick in the well.

A fault with less than 100 ft of offset is interpreted to be present at 760 ft in the N_2 magnetostratigraphic unit in the well. A low-MgO unit at 720-760 ft may be a repeat of a unit from 860-960 ft. Both are overlain by high-MgO units of similar composition (640-720 ft and 760-860 ft). At Armstrong Canyon and elsewhere in this area, this sequence of high- to intermediate-MgO/low-TiO_2 flows occurs only once in the N_2 unit. Nowhere in surface sections do we observe a repeat in compositions such as that in the Kirkpatrick No. 1. Therefore, the most likely explanation for what we see in the well is a fault repeating part of the N_2 section.

In the surrounding area, the R_2 magnetostratigraphic unit consists of a sequence of low-MgO/high-TiO_2 flows (Reidel and Tolan, unpublished data, 1986) that correlate to a depth of 1,130 to 1,600 ft in the Kirkpatrick No. 1. These flows are similar in composition to R_2 flows described by Reidel (1983) in the Salmon and Snake River area farther east.

The N_1 magnetostratigraphic unit typically consists of high-MgO/intermediate-TiO_2 flows intercalated with some high-TiO_2 flows (Reidel, 1983). The only N_1 flow exposed in the immediate area is of high-MgO/intermediate-TiO_2 composition. The composition of this flow resembles that of flows found from 1,600 to 1,880 ft in the well. The base of the N_1 unit is not exposed in the area, so the N_1-R_1 contact in the well is uncertain. The flow encountered from 1,880 to 2,000 ft may be of the N_1 high-TiO_2 "H" group flows of Reidel (1983), but this correlation is uncertain.

The flows of the R_1 magnetostratigraphic unit are dominated by high-MgO/high-TiO_2, making them distinctive among the Grande Ronde flows (Reidel, 1983). Basalt flows having compositions similar to the R_1 unit occur from 1,880 ft to the base of the basalt and are correlated to the R_1 unit.

The major difference between the basalt sequence in the Kirkpatrick No. 1 and the surrounding area appears to be the absence of Picture Gorge and Prineville flows and the thinning or disappearance of individual flows of the N_2 magnetostratigraphic unit. This suggests that the stratigraphic difference may be related to a combination of tectonic growth of the anticlines and the volume and origin of the individual flows. Data do not permit a distinction of the two at the present time. Based on interpretations from other parts of the plateau (e.g., Reidel, 1984), we suggest that tectonic growth of the structures may be the dominant factor controlling flow presence or absence.

Tectonic implications

The addition of the Kirkpatrick No. 1 stratigraphic data aids considerably in the paleogeographic interpretation of the north-central Oregon region for the early Tertiary. If the interpretations of this study are correct, the total John Day thickness in the well is 4,255 ft, compared to 1,750 ft in outcrop near Fossil (P.T. Robinson, written communication, 1986). Apparently, the John Day Formation has been eroded or preferentially not deposited on the Blue Mountains uplift, as previously suggested by Rogers (1966), Fisher (1967), and Swanson and Robinson (1968). Conversely, the Clarno Formation is 5,800 ft thick near Ashwood (Waters and others, 1951), thins to 3,000 to 4,000 ft near Clarno (Taylor, 1960), is less than 500 ft thick on Arbuckle Mountain southeast of Heppner (Shorey, 1976), and may be absent at the Kirkpatrick well site. This suggests that Clarno igneous activity was concentrated in the Blue Mountains uplift and did not extend significantly northward from this area.

The amount of uplift in the Blue Mountains can be approximated by the structural offset of the John Day member *a* ash-flow tuff. This tuff is at an elevation of 2,000 ft near the town of Fossil (Robinson, 1975), whereas in the well it is about 3,300 ft below sea level, suggesting that over 5,300 ft of uplift occurred in the Blue Mountains relative to the Kirkpatrick well (18 mi distant) in the last 37 m.y. This amount of uplift suggests a possible fault or fault zone that may coincide with a steep gravity gradient along the north edge of the Blue Mountains uplift (Riddihough, 1984; Riddihough and others, 1986).

The geologic data suggest a long period of uplift for the Blue Mountains during the Tertiary, beginning in the middle Eocene. Immediately prior to that time, the Blue Mountains area was not a topographic high. The Herren formation of Shorey (1976), a thick sedimentary unit of Paleogene age below the Clarno Formation around Arbuckle Mountain and elsewhere in the Blue Mountains, contains paleocurrent indicators suggesting northwesterly flow of streams across the axis of the Blue Mountains uplift (Trauba, 1975; Shorey, 1976; Gordon, 1985). During the remainder of the Eocene, the Blue Mountains became topographically high because of Clarno volcanism and probable structural uplift. By and during the Oligocene, the Blue Mountains were high enough to act as a topographic barrier to John Day ash flows erupted west of the uplift, causing thinning of the formation over the uplift (Robinson and others, 1984).

The Blue Mountains were still rising and the Columbia Basin was subsiding during the eruption of the CRBG, as shown by the thinning of the CRBG from the Kirkpatrick No. 1 to the north flank of the Blue Mountains uplift. The Blue Mountains have continued to grow since the Miocene. Grande Ronde N_2 and R_2 flows that were once continuous across the uplift have been eroded away, exposing the Mesozoic igneous core of the uplift (Swanson and others, 1981), and the N_2 and R_2 units have been turned to $30°$ dips off the north side of the uplift (Hogenson, 1964). The pinchout of Picture Gorge Basalt and Prineville basalt flows in the vicinity of the Kirkpatrick No. 1 is probably due to local structural control.

SUMMARY AND CONCLUSIONS

The pre-CRBG volcanic rocks penetrated in the Kirkpatrick No. 1 probably belong to the John Day Formation. Tertiary rocks below the tuff that correlates to the *a* member are interpreted as a newly identified unit of the John Day Formation. Alternatively, this unit may belong to the Clarno Formation, but a more detailed study of the unit is needed.

We have identified a John Day-age intrusion in the Mesozoic section and in the newly identified John Day unit. We suggest that the intrusion has increased the thermal maturation of the sedimentary rocks below 5,000 ft and also has caused a deterioration of microfossils. As a result, the oil-generation potential of the Mesozoic rocks in this area has been slightly overestimated, and the deterioration of microfossils has made it difficult for biostratigraphers to assign a definite age to the Mesozoic rocks.

By correlating the John Day member *a* welded ash-flow tuff from outcrop to its position in the well, we have determined that the Blue Mountains have been uplifted at least 5,300 ft relative to the well location in the last 37 m.y. This amount of structural relief over a relatively short distance indicates that a major fault is active on the north edge of the Blue Mountains uplift. An identified regional gravity lineament may coincide with this fault.

Chemical and magnetic stratigraphy of the CRBG section allows identification of basalt flow groups and even individual flows penetrated in the drill hole when these data are combined with geophysical logs. In the Kirkpatrick well, we conclude that every magnetostratigraphic unit of the Grande Ronde Basalt is present, despite the fact that the CRBG section is only 2,440 ft thick. No flows of the Picture Gorge Basalt or Prineville chemical type are present in the Kirkpatrick No. 1 basalt section. Thinning of the CRBG at the Kirkpatrick No. 1 location indicates that the area was a slight topographic high in the Miocene.

ACKNOWLEDGMENTS

We wish to thank ARCO Oil and Gas Company, Rockwell Hanford, and the U.S. Department of Energy for support of this study. Thanks also to Shell Western Exploration and Production for providing the dates for cores 4 and 9 and most of the thin sections. This manuscript has benefitted from reviews by P.T. Robinson, G.A. Smith, T.L. Tolan, and N.P. Campbell; however, the final content is our responsibility. Reidel was supported by the U.S. Department of Energy, contract no. DE-AC06-77RL01030, as part of the Basalt Waste Isolation Project.

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Standard Kirkpatrick well data released in open-file report

Stratigraphy of the Standard Kirkpatrick No. 1, Gilliam County, Oregon, by T.P. Fox, formerly of ARCO Oil and Gas Company, and S.P. Reidel, Rockwell Hanford Operations, presents details of lithology, contacts, electric logs, chemical composition, and isotopic ages from the well as an expanded stratigraphic column printed on a 30- by 55-in. ozalid sheet. The publication, which was released as Open-File Report O-87-2, was designed to supplement the data discussed in the paper beginning on page 15 of this issue.

Copies of Open-File Report O-87-2 are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $5. Orders under $50 require prepayment. □

Oregon sunstones

by Ronald P. Geitgey, Oregon Department of Geology and Mineral Industries

An exhibit of some of the mineral products of Oregon is on display on the main floor of the State Capitol Building until May. The exhibit, prepared by staff members of the Department of Geology and Mineral Industries, presents information on and examples of the production of natural gas, rare metals, gold, soapstone, industrial minerals, and gemstones. The centerpiece of the display is a collection of Oregon sunstone gems as unmounted, faceted stones and in finished pieces of jewelry, showing the full range of colors in which sunstone is found. The stones were mined in Lake and Harney Counties, cut by members of the Columbia-Willamette Faceters Guild, and set in gold mountings crafted by Oregon jewelers. *—Editor*

Oregon sunstone, also known as heliolite, is a transparent feldspar with colors ranging from water clear through pale yellow, soft pink, and blood red to (extremely rare) deep blue and green. The color appears to vary systematically with small amounts of copper and may depend on both the amount and the size of individual copper particles present in the stone. Pale yellow stones have a copper content as low as 20 parts per million (ppm) (0.002 percent), green stones contain about 100 ppm per million (0.01 percent), and red stones have up to 200 ppm (0.02 percent) copper (Hofmeister and Rossman, 1985). Some of the deeper colored stones have bands of varying color, and a few stones are dichroic, that is, they show two different colors when viewed from different directions.

Many stones appear to be perfectly transparent at first, but when they are viewed in just the right direction, a pink to red metallic shimmer flashes from within the stone. This effect is called "schiller" or "aventurescence" and is caused by light reflecting from minute parallel metallic platelets suspended in the sunstone. When viewed along their edges, the platelets are invisible to the naked eye; when viewed, however, perpendicular to their surfaces, they reflect light simultaneously from each platelet, creating a mirror effect. Earlier studies of the Lake County feldspar (Stewart and others, 1966) suggested that the platelets were hematite (iron oxide), but the most recent research concludes that they are flat crystals of copper metal (Hofmeister and Rossman, 1985).

The terms "sunstone" and "heliolite" (from Greek *helios*, meaning "sun," and *lithos*, meaning "stone") have been used for at least two centuries for feldspars exhibiting schiller. The Lake County occurrence was first reported in 1908 (Aitkens, 1931), and the presence of the schiller effect was the original reason for naming the stones sunstones. For decades, however, the term "sunstone" has been used for these Oregon gem feldspars both with and without schiller. The problems of nomenclature were reviewed by Pough (1983).

The Oregon sunstones are a calcium-rich variety of plagioclase feldspar named labradorite, a common mineral in basaltic lava flows. All three known sunstone occurrences shown on the index map (Figure 1) are in small basalt flows that superficially resemble basalt flows elsewhere in the state that contain large feldspar phenocrysts or megacrysts. However, feldspars in those flows are typically cloudy to opaque and relatively small compared to those in the sunstone flows, which are clear, glassy, and can be up to 2 or 3 in. in one dimension. No detailed information has been collected on the geology, petrography, or chemistry of the known sunstone flows, so no meaningful comparisons can be made between them or with other flows in the area. The sunstone flows appear to be small; the Lake County occurrence covers about 7 sq mi, and the two Harney County occurrences are probably less than 1 sq mi each. Considering the regional geology and the wide separation between the flows, it is probable that there are more sunstone occurrences in the area.

Sunstones are mined from the soil and partially decomposed rock formed by weathering of the lava flows. The surface debris is dug with pick and shovel and sieved through a quarter-inch screen, and the sunstones are separated from rock fragments by hand. In some local areas, the lava flows are weathered to a depth of several feet, and good stones have been recovered from pits dug into these zones. Hard-rock mining techniques have been used on unweathered parts of the flows, but the sunstones are often shattered along with the lava, and recovery of large unbroken stones is difficult.

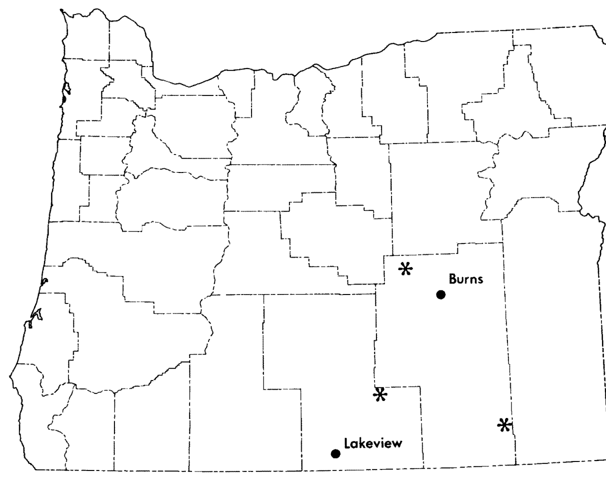

Figure 1. Index map of sunstone areas in Oregon.

Except for part of the Lake County occurrence, all three producing areas are held by mining claims and are not available for collecting without permission of the claim owners. About 2 sq mi of the Lake County flow have been withdrawn from mineral entry and established by the U.S. Bureau of Land Managment (BLM) as a free public collecting area. This sunstone area was described earlier by Peterson (1972) and is located off the northeast flank of the Rabbit Hills about 25 mi north of Plush and 80 mi northeast of Lakeview. Maps, directions, and information on road conditions are available from the BLM District Office in Lakeview.

Varieties of feldspars used as gemstones are valued for their colors or optical effects. Being typically translucent to opaque, they are normally cut in rounded forms or cabochons. Transparent gem feldspars, particularly calcium-rich varieties, that can be cut as faceted stones are rarer (Figure 2). Occurrences of transparent labradorite have been reported from Arizona, California, New Mexico, and Utah, but few gems have been produced from those areas. Oregon sunstones are uncommon in their composition, clarity, and range of colors, and they occur in sufficient abundance to permit sustained production of faceted gems.

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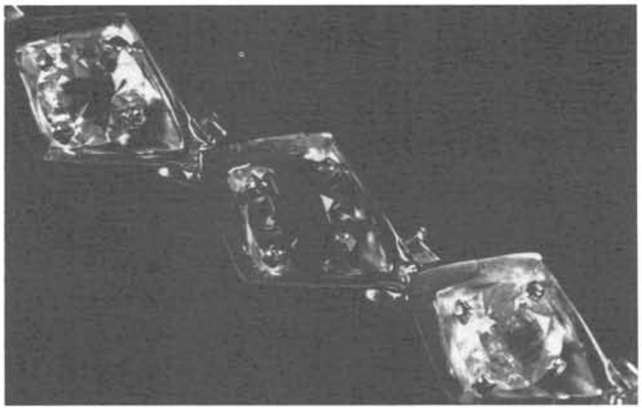

Figure 2. Section of bracelet composed of 16 one-carat, brilliant-cut sunstones from all three known deposits in Lake and Harney Counties. Colors include water clear, pale yellow, pink, and red. Stones cut by various members of the Columbia-Willamette Faceters Guild; gold setting designed and made by Al Price, French's Jewelers, Albany, Oregon. Bracelet was presented to the State of Oregon by the Oregon Retail Jewelers Association.

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State Map Advisory Committee publishes report for 1986

The State Map Advisory Committee for Oregon (SMAC) has released its eighth annual report: A summary of its activities and of the accomplishments and the current status of map production and coordination in Oregon for 1986.

The 55-page report was produced under the chairmanship of State Deputy Geologist John D. Beaulieu and published by the Oregon Department of Geology and Mineral Industries (DOGAMI) as Open-File Report O-87-1. It lists the members of the Oregon SMAC and its Subcommittee for Maps and Standards and the chairpersons of SMAC's in the other western states. The release further contains reports on SMAC meetings and work sessions; a report to the Regional Western Mapping conference held at Menlo Park, California; the 1986 annual report of the State Resident Cartographer; status reports on cooperation in digital base maps and standards; and a listing of the Committee's activities and accomplishments from 1979 through 1986.

The Oregon SMAC is an innovative committee consisting of representatives from Federal agencies, State agencies, local government, and private industry. Its purpose is to focus mapmaking activities in Oregon and to prevent duplication of mapping efforts. Over the years, the efforts of this committee have helped to bring millions of dollars into Oregon for mapping and map production in a coordinated fashion. The map product most familiar to the general public, the standard 7½-minute topographic map, is produced by the U.S. Geological Survey in cooperation with other agencies participating in SMAC. Other activities of the committee deal with computer mapping and a variety of other types of maps of various scales.

The new report, *Eighth Annual Report of the State Map Advisory Committee for Oregon, 1986,* is available now at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 S.W. Fifth Avenue, Portland, OR 97201. The purchase price is $5. Orders under $50 require prepayment. □

Geologic map of Cave Junction area, Klamath Mountains, released

A new geologic map released by the Oregon Department of Geology and Mineral Industries (DOGAMI) describes the geology of a portion of southwestern Oregon's old gold mining areas in the Klamath Mountains and the site of the rare mineral josephinite.

Geologic Map of the Northwest Quarter of the Cave Junction Quadrangle, Josephine County, Oregon, by staff geologist Len Ramp, has been published in DOGAMI's Geological Map Series as map GMS-38 and consists of two plates, each approximately 3½ by 2½ ft large.

The full-color map on Plate 1 (scale 1:24,000) includes the area of the Illinois River valley near Kerby and Cave Junction and the drainage of Josephine Creek to the west and is combined with an explanatory text. The map identifies 15 sedimentary, volcanic, and metamorphic rock units, most of them of Mesozoic and Paleozoic age (approximately 150 to 250 million years old). It also portrays the geologic structure, presents a geologic cross section, and identifies mines and mining prospects of the area. The text portion includes explanations of the rock units; a time-rock chart; a general discussion of the geologic setting, structure, and mineral deposits; and a table providing detailed information on the 26 mines and prospects identified within the area.

Plate 2 contains a sample-location map and four tables listing results of chemical analyses of 104 rock samples and of hand-panned concentrates from 70 stream-sediment samples.

Copies of the new map, GMS-38, are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $6. Orders under $50 require prepayment. □

DOGAMI display featured at Capitol Building

As part of its fiftieth anniversary celebration, the Oregon Department of Geology and Mineral Industries is presenting a display, Minerals and Metals in Oregon's Economy, at the State Capitol in Salem. The exhibit has been installed in the display case donated to the State in 1983 by the Oregon Council of Rock and Mineral Clubs.

Two necklaces and a bracelet containing faceted Oregon sunstones (see cover photo and article on sunstones in this issue) are featured in the center of the display case. Included in the display case are specimens of other faceted and unfaceted Oregon sunstones, gold, various industrial minerals, soapstone, and rare metals including titanium. The case also contains a sample of core from the Clark and Wilson sandstone, the reservoir rock at the Mist Gas Field.

The display was installed in mid-January and will remain in place until mid-May. □

Students win awards at NMA convention

A Washington State University student presented the most outstanding research paper at the Northwest Mining Association (NMA) convention in Spokane in early December 1986.

Jeffrey W. Brooks took home a Hewlett-Packard calculator, the top prize in NMA Student Poster Session. His paper was entitled "Mineralogy, Paragenesis, and Fluid Characteristics of the Mammoth Revenue Epithermal Au-Ag Vein."

"The Geology and Mineralization at the Champion Mine: An Epithermal Au-Base Metal System in the Bohemia Mining District, Oregon," earned $75 for University of Oregon student Kurt T. Katsura. □

New studies reveal details on sea-floor hydrothermal activity

Two reports on studies of materials obtained from the ocean floor at the Gorda Ridge and nearby seamounts have been released by the Oregon Department of Geology and Mineral Industries (DOGAMI). They are part of the continuing investigations conducted under the auspices of the Gorda Ridge Technical Task Force to evaluate the environmental, engineering, and economic aspects of possible leasing of polymetallic minerals on Gorda Ridge, a sea-floor spreading center off the coast of southern Oregon and northern California that lies within the U.S. Exclusive Economic Zone (EEZ).

Hydrothermal precipitates from basalts on the Gorda Ridge and the President Jackson seamounts, by K.J. Howard and M.R. Fisk of the Oregon State University College of Oceanography, has been published as DOGAMI Open-File Report O-86-18. The 30-page report presents analyses of precipitates that were deposited on rocks on the ocean floor at or near the sites of hydrothermal activity on the Gorda Ridge and the nearby seamounts.

Analysis of the samples in this study shows these deposits to be primarily hydrothermal clays and iron-manganese oxides. Minor amounts of sulfides, and possibly sulfates, arsenides, or arsenates, may be present in some samples.

While the greatest concentration of hydrothermally produced massive sulfides is found in the so-called "chimneys" at the center of major vents in the ocean floor, similar precipitates are found in a wide area around them. Identification of these minerals could point the way to active hot springs and associated massive sulfide deposits. Such deposits may also be economically important because of the wide range of elements that are dissolved in the hot water and their potentially large areal extent.

Sediment studies on the Gorda Ridge, by R. Karlin and M. Lyle, oceanographers from the University of Washington and Oregon State University, respectively, has been released as DOGAMI Open-File Report 0-86-19. The 76-page report presents sediment studies of seventeen gravity cores taken from the Gorda Ridge, including lithologic, magnetic, and chemical data.

The authors conclude that recent volcanic activity and related hydrothermal activity can be discerned and dated by analyzing sulfide-rich tuffaceous flow deposits and sulfur from plume material preserved in the sediments. They estimate occurrences of recent volcanic activity about 2,400 and 3,000 years ago at two volcanic centers in the southern end of the Gorda Ridge area.

Both open-file reports are available now at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201. The purchase price for each report is $5. Orders under $50 require prepayment. □

ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that we feel are of general interest to our readers.

GEOLOGY OF THE NORTHWEST ONE-QUARTER OF THE PRINEVILLE QUADRANGLE, CENTRAL OREGON, by David J. Thormahlen (M.S., Oregon State University, 1984)

The northwest one-quarter of the Prineville quadrangle is underlain by Tertiary and Quaternary volcanic and volcaniclastic rocks of the Columbia River Basalt Group, and the Clarno, John Day, Rattlesnake, and Deschutes Formations.

The Clarno Formation is dominated by pyroxene-bearing andesites but also contains olivine-bearing basalts, oxyhornblende-bearing dacite and rhyodacite flows, and intrusives. Many of these rocks are deeply weathered, and some have been strongly silicified.

The John Day Formation in the area consists of large rhyolite domes and flows, thick tuffaceous deposits, minor trachyandesite flows and welded ash-flow tuffs. The stratigraphy of these John Day rocks is similar to the section exposed in the Ashwood area but lacks some of the upper ash-flow tuff units. Fossil-bearing tuffs found within the area are similar to tuffs in the John Day and Crooked River basins and contain fossil leaves that are similar to the Bridge Creek flora.

A single flow of the Columbia River Basalt Group is found in the southwest part of the thesis area. This flow has normal magnetic polarity and is similar to the Prineville chemical-type basalt. The entablature of this flow is glassy and very thick. It resembles exposures found at Butte Creek and along the Deschutes River at Pelton Dam and near Gateway.

Exposures of the Rattlesnake ignimbrite tongue in the northwest part of the thesis area are the westernmost recognized outcrops of the ignimbrite. Two other exposures of the Rattlesnake ignimbrite were found to the south in Swartz Canyon and near Little Bear Creek. These exposures indicate a previously unrecognized channel for the ignimbrite that trended northwest from its source, entered the Crooked River drainage, and traveled at least as far northwest as Grizzly.

The Deschutes Formation is represented by a diktytaxitic basalt flow, epiclastic tuffaceous sediments, and air-fall pumice. These deposits lie along the eastern margin of the Deschutes Basin.

Structural upwarping along the Blue Mountains anticline has caused local tilting and folding of the rocks in the area. Most of the Clarno and John Day rocks dip gently to the south. The Deschutes Formation appears to be undeformed.

Hydrothermal activity led to the formation of several mineralized breccias that contain abundant silica, lesser amounts of goethite and manganite, and traces of silver and mercury.

THE STRATIGRAPHY, GEOCHEMISTRY, AND MINERALOGY OF TWO ASH-FLOW TUFFS IN THE DESCHUTES FORMATION, CENTRAL OREGON, by Debra May Cannon (M.S., Oregon State University, 1985 [thesis compl. 1984])

Two ash-flow tuff units of the upper Miocene-lower Pliocene Deschutes Formation in central Oregon were studied in detail because of the widespread distribution, diverse compositions, and stratigraphic importance.

The Lower Bridge tuff is a double-flow simple cooling unit that is poorly welded. The upper flow grades from rhyolite in the lower part to dacite in the upper part. A white 1.5- to 5-ft accretionary lapilli air-fall deposit often underlies the two ash-flow sequences. Phenocrysts in the pumice lumps are plagioclase (An_{35-45}), pargasite, hypersthene, augite, ilmenite, apatite, and magnetite. The compositional change from rhyolite to dacite in the upper flow suggests that it was formed by eruption of successively lower parts of a zoned magma body.

The McKenzie Canyon tuff is a multiple flow compound cooling unit that overlies the Lower Bridge tuff. It may have covered 160 km^2 and had a volume of 0.7 km^3. It was erupted onto irregular terrain resulting in variable thicknesses. Up to three light-colored, rhyolitic ash-flow deposits are overlain by two red columnar-jointed units. The red color and welding of the upper two members are the distinguishing physical features of the McKenzie Canyon tuff. The lower nonresistant silicic flows are often absent in the northern part of the study area. The facts that the units decrease in thickness and in elevation northward and that the average pumice size becomes smaller suggest a source to the south. Another distinguishing feature of the upper red flow(s) is the prevalence of white (rhyolite), black (andesite), banded (rhyolite and andesite), and collapsed pumices. A few dacite pumice clasts (mixed) are also present. In the lower silicic flows, black or banded pumices are found only in minor amounts, and collapsed pumices are absent. Collapsed pumices in the upper flow(s) occur only throughout the welded section in nearly horizontal orientations.

The white pumice is a high-K rhyolite with phenocrysts of oligoclase/andesine (An_{29-31}), hypersthene, augite, magnetite, ilmenite, and zircon. The black pumice is medium-K and high -Ti and -Fe andesite that contains labradorite (An_{60-65}), olivine (Fo_{82}), augite, hypersthene, and magnetite. The percentage of black pumice increases upward in the upper flow. Banded pumice is a combination of rhyolite and andesite magmas and represents the co-eruption of these two compositions. Evidence of complete mixing of the magmas, i.e., homogeneous dacite pumice, is minor. Collapsed pumices have the same composition as rhyolite or banded pumices.

The McKenzie Canyon tuff was possibly derived from two separate magmas. As mafic magma was injected into a silicic magma chamber, ensuing convection and vesiculation probably caused the formation of banded pumice. This hypothesis is based on the following relationships: (1) phenocrysts and bulk chemistry of rhyolite and andesitic pumices are of distinct compositions, (2) a paucity of phenocrysts occurs in the andesitic pumices, and (3) Harker diagrams of major element chemistries show that the two magmas have divergent regression lines.

The McKenzie Canyon tuff upper flows are unusual among banded pumice-bearing tuffs because of the aphyric nature of the andesite and the probability that the rhyolite and andesite magmas are not derived from the same magma chamber.

THE DESCHUTES FORMATION — HIGH CASCADE TRANSITION IN THE WHITEWATER RIVER AREA, JEFFERSON COUNTY, OREGON, by Gene M. Yogodzinski (M.S., Oregon State University, 1986 [thesis compl 1985])

The Whitewater River area is located directly east of Mount Jefferson in the Cascades of central Oregon. Approximately 90 mi^2 (230 km^2) were mapped (scale 1/24,000), and four new K-Ar ages and 151 major-element analyses were obtained in a study of the stratigraphic and magmatic transition from the Miocene-Pliocene Deschutes Formation on the east to the Pliocene-Pleistocene High Cascades on the west.

Deschutes strata in the Whitewater River area overlie andesites, dacites, and rhyodacites of late Miocene age (8-11+ m.y.) along an erosional unconformity. The oldest Deschutes rocks exposed in the Whitewater River area are approximately 6 m.y. old, and the youngest are probably between 4.5 and 5 m.y. old. The oldest High Cascade rocks exposed in the Whitewater River area are approximately 4.3 m.y. old. There is no evidence for a hiatus in volcanic activity between Deschutes and High Cascade time in the Whitewater River area. Late Pleistocene explosive volcanism, probably from Mount Jefferson, is evidenced in a hornblende rhyodacite pyroclastic-flow deposit that occurs within the glacial stratigraphy and is tentatively thought to be between approximately 60,000 and 20,000 years old.

Deschutes strata are dominated by pyroclastic lithologies (mostly ash-flow tuffs), with some lava flows and minor epiclastic sediment. Compositions range mostly between basaltic andesite and dacite. Many Deschutes-age rocks are aphyric; high in FeO, TiO_2, and alkalies; and low in MgO, CaO, and Al_2O_3. They define a tholeiitic trend extending at least from basaltic andesite to dacite that can largely be derived through fractional crystallization of plagioclase, olivine, magnetite, and clinopyroxene from a parent magma, probably of basaltic composition. These rocks are compositionally similar to "tholeiitic anorogenic andesites" that are most commonly associated with areas of crustal extension.

Rocks of High Cascade age in the Whitewater River area are mostly lava flows that range in composition from basalt (high-alumina, olivine tholeiite) to rhyodacite. The High Cascade suite forms a calc-alkalic associaton that is typical of subduction-related magmatic arcs. Fractional crystallization of the basalts leads to iron enrichment. Fractional crystallization of the basaltic andesites might lead to calc-alkalic compositions, but the mineral phases necessary to deplete the magmas in FeO, TiO_2, and CaO (magnetite and clinopyroxene) are not common phenocryst phases in the basaltic andesites or andesites.

Two northwest-trending, down-to-the-west normal faults with some possible strike-slip motion have been mapped in the upper Whitewater River area, directly west of Lion's Head. Motion on these faults occurred after approximately 4 m.y. ago but probably began prior to that time. There is between 200 and 400 ft (60 and 120 m) of apparent vertical separation on the western side of these faults. There may be a large, northwest-trending fault running from the south end of Green Ridge through Bald Peter and the Whitewater River area, but this structure is largely buried by younger volcanic rocks. There is no evidence for a northern extension of the north-trending Green Ridge faults, and there is no evidence for large structural displacement in the lower Whitewater River along north- or northwest-trending structures.

The Deschutes Formation-High Cascade transition in the Whitewater River area is marked by a switch in the eruptive style and in the dominant magmatic compositions during Deschutes and High Cascade times. Volcanism in the Whitewater River area does not appear to have been episodic with respect to volume and/or intensity; rather, the character of magmatism has varied with time and with the tectonic style through the period immediately prior to and following the formation of the High Cascade graben.

GEOLOGY, ALTERATION, AND MINERALIZATION OF A SILICIC VOLCANIC CENTER, GLASS BUTTES, OREGON, by Michael J. Johnson (M.S., Portland State University, 1984)

Glass Buttes, a Pliocene silicic volcanic complex within the High Lava Plains province of Oregon, was erupted approximately 5.0 to 5.8 million years ago. Geologic mapping revealed that the eastern portion of the complex is underlain by rhyolitic glass domes, flows, and rare pyroclastic flows. Basalt flows are interlayered with and onlap the silicic glass. Younger basalt flows, erupted from local vents, overlie silicic glass and onlapping basalts.

The eastern end of Glass Buttes is hydrothermally altered at the surface; a weak geothermal anomaly coincides with the altered areas. Alteration, localized by northwest-trending normal faults, occurs primarily as opalite replacement of rhyolite glass with associated cinnabar, alunite, clay-rich vein material, hematite, and hyalite. Alteration paragenesis at the surface was defined, and physicochemical conditions during hydrothermal activity were inferred from alteration minerals and assemblages and trace-element content of alteration minerals.

Alteration identified in the subsurface is interpreted to be related to an older hydrothermal system. Carbonate, pyrite, quartz, and minor smectite and chlorite occur in vugs and fractures and partially replace subsurface basalt. Abundant fine-grained disseminated pyrite occurs in permeable units. Pyrite separates from disseminations and veins within basalt and permeable glassy units contain up to 13 ppm Au. The pyrite samples are also anomalous with respect to arsenic and antimony. □

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