OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

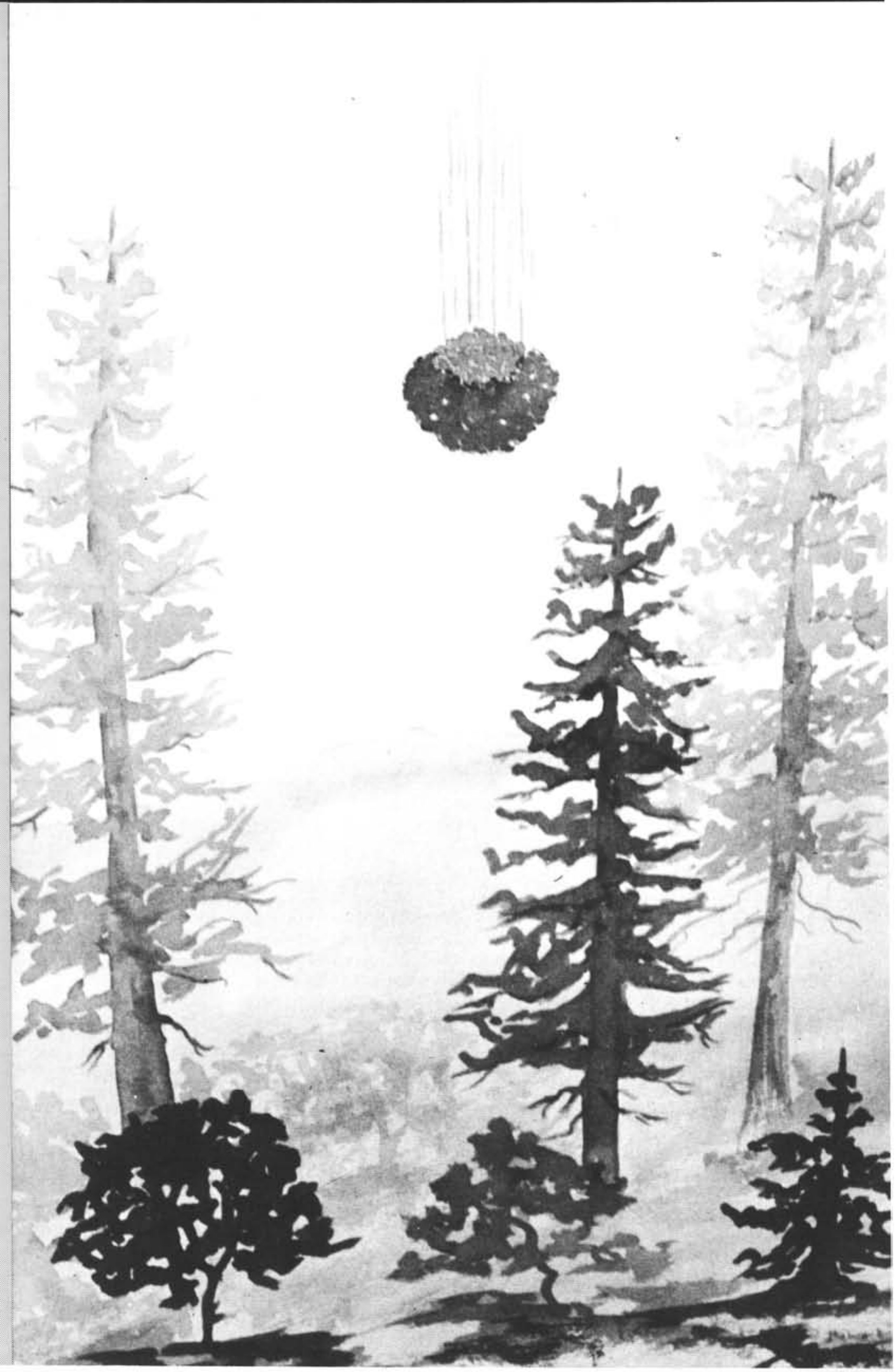
VOLUME 55, NUMBER 1 **JANUARY 1993**

IN THIS ISSUE:

The Prineville basalt, north-central Oregon

Explosion craters and giant gas bubbles at Newberry Crater

The Coos Bay fireball of February 1992, Oregon's brightest



OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 55, NUMBER 1 JANUARY 1993

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.

Baker City Field Office: 1831 First Street, Baker City 97814, phone (503) 523-3133, FAX (503) 523-9088.
Mark L. Ferns, Resident Geologist.

Grants Pass Field Office: 5375 Monument Drive, Grants Pass 97526, phone (503) 476-2496, FAX (503) 474-3158.
Thomas J. Wiley, Resident Geologist.

Mined Land Reclamation Program: 1536 Queen Ave. SE, Albany 97321, phone (503) 967-2039, FAX (503) 967-2075.
Gary W. Lynch, Supervisor.

The Nature of Oregon Information Center: Suite 177, 800 NE Oregon Street # 5, Portland, OR 97232, phone (503) 731-4444, FAX (503) 731-4066, Donald J. Haines, Manager.

Second class postage paid at Portland, Oregon. Subscription rates: 1 year, $8; 3 years, $19. Single issues, $2. Available back issues of *Ore Bin/Oregon Geology* through v. 50, no. 4, $1. Address subscription orders, renewals, and changes of address to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232. Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. POSTMASTER: Send address changes to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232.

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. If manuscript was prepared on common word-processing equipment (IBM compatible or Macintosh), a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, 3.5-inch high-density diskette 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 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*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic 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 the Oregon Department of Geology and Mineral Industries.

Cover photo

Painting by B. June Babcock of the fireball that occurred over southwestern Oregon on February 24, 1992. The artist saw this view from Sams Valley north of Medford, Oregon. Fireball is in the process of reigniting after the initial flash when the front of the fireball was torn off by atmospheric friction. Black portion is dust cloud. Report of the event is printed on page 22.

OIL AND GAS NEWS

Drilling at Mist Gas Field

Nahama and Weagant Energy Company of Bakersfield, California, concluded a multi-well drilling program at the Mist Gas Field, Columbia County, during November. The final two wells drilled were the Wilson 11A-5-65, located in NW¼ sec. 5, T. 6 N., R. 5 W., which reached a total depth of 2,765 ft, was redrilled to a total depth of 2,770 ft, and plugged and abandoned; and the Columbia County 31-15-65, located in NE¼ sec. 15, T. 6 N., R. 5 W., which reached a total depth of 2,794 ft and was redrilled to a total depth of 2,564 ft and suspended. This results in a total of five wells and two redrills at the Mist Gas Field during 1992, of which one is completed and producing gas, one is plugged and abandoned, and the remainder are suspended. Nahama and Weagant Energy was the operator and Taylor Drilling Company, Chehalis, Washington, was the drilling contractor for the wells.

NWPA holds workshop

The Northwest Petroleum Association (NWPA) held a workshop during November at which the U.S. Geological Survey and the U.S. Minerals Management Service presented information and discussed the work being done on the national assessment of undiscovered oil and gas resources on the federal outer continental shelf, in state waters, and onshore. Individuals were able to present hydrocarbon plays in the Pacific Northwest for possible formal designation as assessment plays. A follow-up workshop is expected to be sponsored by the Oregon Department of Geology and Mineral Industries (DOGAMI). It is to be held in early 1993 to further discuss those plays selected for assessment. Contact Dan Wermiel at the Portland office of DOGAMI for further information.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
473	Nahama and Weagant CC 22B-35-75 36-009-00298	NW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Application; 2,023.
474	Nahama and Weagant LF 12A-33-75 36-009-00299	NW¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Application; 2,148.
475	Nahama and Weagant Adams 12-31-74 36-009-00300	NW¼ sec. 31 T. 7 N., R. 4 W. Columbia County	Application; 1,800.

□

U.S. POSTAL SERVICE STATEMENT OF OWNERSHIP, MANAGEMENT, AND CIRCULATION

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-29-92. Published bimonthly, 6 issues per year, annual subscription price $8. Address of publication office, publisher's business office, editor, and owner: 800 NE Oregon St., # 28, Portland, OR 97232. Publisher and owner: Oregon Department of Geology and Mineral Industries; editor: Klaus K.E. Neuendorf; managing editor: Beverly F. Vogt, Publications Manager. No bondholders. Circulation during last 12 months/of single issue, respectively: Net press run 3000/3000; paid circulation est. 200/200; mail subscription 1554/1533; total paid circulation 1754/1733; free distribution 394/434; total distribution 2148/2167; not distributed 852/833; return 0/0; total 3000/3000. I certify that the statements made by me above are correct and complete.

Klaus K Neuendorf, Editor

The Prineville basalt, north-central Oregon

by P.R. Hooper[1], W.K. Steele[2], R.M. Conrey[1], G.A. Smith[3], J.L. Anderson[4], D.G. Bailey[1], M.H. Beeson[5], T.L. Tolan[5], and K.M. Urbanczyk[1]**

ABSTRACT

The Prineville basalt was erupted at the same time as flows of Grande Ronde Basalt of the Columbia River Basalt Group (CRBG), interfingering with those flows along the southern side of the Columbia River between longitudes 120°00′W. and 122°75′W. in north-central Oregon. The Prineville is distinguished from the Grande Ronde flows and all other flows of the CRBG by its unusually high concentrations of P_2O_5 and Ba and by the inferred location of its vents, which are far west of any known CRBG vents. In this paper, a systematic review of the major and trace element composition of the Prineville has been supplemented by the measurement of the paleomagnetic direction of the flows. We used drilled core from 26 sites in an attempt to determine the number of Prineville flows present, the areal distribution of each, and their precise stratigraphic relationship to CRBG flows.

We conclude that the Prineville basalt includes flows of three distinct compositions. The earliest, the Bowman Dam (BD) chemical type flows, are the most widespread and voluminous. They were erupted at the end of the CRBG R_2 magnetostratigraphic unit and continued locally across the magnetic transition (dated at 15.7 ± 0.1 Ma) into the N_2 magnetostratigraphic unit. These flows cover a large triangular area of $>11{,}000$ km^2 from Portland to the John Day River system in the north and to a southern apex just south of Bowman Dam.

The second eruptive episode of Prineville basalt produced more siliceous flows (Hi-Si chemical type) in the middle of the CRBG N_2 magnetostratigraphic unit, immediately prior to the eruption of the Winter Water flow. Their areal distribution is more restricted, forming a narrow north-south corridor along the Deschutes River in the central part of the area covered by the earlier Prineville flows. The BD and Hi-Si Prineville flows are separated by either sedimentary interbeds or N_2 Grande Ronde flows of the CRBG. A single location of the third type of Prineville basalt (Hi-TP chemical type), also of normal magnetic polarity, occurs just west of Prineville. This appears to be a single flow that filled a synclinal depression running SW-NE north of the Crooked River. Its age is poorly constrained, but it appears to be younger than other Prineville chemical types.

We conclude that the Prineville basalt is best excluded from the CRBG and instead grouped with the similar Miocene eruptions south of the Olympic Wallowa lineament, which appear to be related to lithospheric extension.

INTRODUCTION

Basalt flows with unusually high Ba and P_2O_5 contents occur over a large part of north-central Oregon south of the Columbia River. Uppuluri (1974) recognized and described the thickest succession of these flows near Prineville Dam (later renamed Bowman Dam; Figure 1) and called them the Prineville chemical type. That name is retained here in the more appropriate form "Prineville basalt" (Tolan and others, 1989), although other names have been suggested (Goles, 1986; Smith, 1986).

At Bowman Dam, the Prineville flows lie between John Day deposits of Oligocene age and olivine basalts of late Miocene and/or Pliocene age. Nathan and Fruchter (1974) found a flow of similar composition at Butte Creek, a tributary of the John Day River where it cuts through the Blue Mountains uplift, 150 km to the north-northeast of Bowman Dam, and at Tygh Ridge near the Deschutes River, south of The Dalles, Oregon (Figure 1). In these more northerly areas, one or more flows with Prineville composition are interleaved with flows of Grande Ronde Basalt, Columbia River Basalt Group (CRBG; Figure1). Later mapping of large parts of north-central Oregon by Beeson and Moran (1979), Anderson (1978, 1987, and unpublished data) and Smith (1986) have shown this distinctive chemical type to be present between the Clackamas River (long 122°75′W.) and the John Day River (long 120°00′W.) and from just south of the Columbia River in the north, through the Deschutes Basin, to Bowman Dam in the south (Figure 1; Tolan and others, 1989).

No feeder dikes or vents have been found for these flows, and there has been disagreement about both the number of flows present and their magnetic polarity, as determined with a portable fluxgate magnetometer (Anderson, 1978; Smith, 1986). This disagreement has resulted in uncertainty concerning the correlation of these flows between outcrops and their relationship to the flows of the Columbia River basalt. It has been suggested that the Prineville basalt should be included within the Grande Ronde Basalt Formation of the CRBG (Smith, 1986), excluded from the CRBG (Goles, 1986), or excluded from the Grande Ronde Basalt but included in the CRBG (Reidel and others, 1989); and Swanson and others (1979) suggested that those flows in contact with Grande Ronde flows be included while those not in such contact be excluded from the CRBG.

For this paper, most of the sites recorded by Uppuluri (1974) and Smith (1986) and those recorded by Anderson (1987, and unpublished data) within and to the north of the Deschutes Basin have been drilled to determine their magnetic direction with more accuracy. This was done both in an effort to provide data that could be used with chemical analyses and field criteria to define and correlate different Prineville flows and as part of a broader tectonic study of crustal rotation during the Basin and Range extension of north-central Oregon.

Six cores were drilled at most sites. The cores were oriented by sun compass and cross-checked with a magnetic compass. The direction of remanent magnetization of the flows was determined by measurement with a Schonstedt SSM-1A spinner magnetometer at Eastern Washington University. The natural remanent magnetization (NRM) of all cores was measured and then remeasured after cleaning by alternating field (AF) demagnetization in a peak field selected by study of the behavior of the magnetization of one specimen from each site during serial AF demagnetization. The peak cleaning fields used varied from 40 to 70 mT (millitesla). In several, but not all, of the reversely magnetized sites, the original thermal remanent magnetization (TRM) of the lava was masked by a normal-polarity viscous overprint that was removed by the AF demagnetization in a relatively low alternating field.

Prineville basalt flows are fine grained and aphyric with an intergranular texture in which small clumps of augite grains lie between interlocking laths of labradorite. Olivine, opaque oxides, and apatite needles are associated with the augite, and the amount of dark-brown tachylitic glass varies up to 50 percent by volume. The labradorite is normally zoned to andesine, and both glass and olivine may be altered to a brown amorphous saponite (Uppuluri,

---

[1] *Department of Geology, Washington State University, Pullman, WA 99164.*

[2] *Department of Geology, Eastern Washington University, Cheney, WA 99004.*

[3] *Department of Geology, University of New Mexico, Albuquerque, NM 87131.*

[4] *Department of Geology, University of Hawaii, Hilo, HI 96720.*

[5] *Department of Geology, Portland State University, Portland, OR 97207.*

**Present addresses: D.G. Bailey, Dept. of Geology, Hamilton College, Clinton, NY 13323; K.M. Urbanczyk, Dept. of Geology, Sul Ross State University, Alpine, TX 79832.*

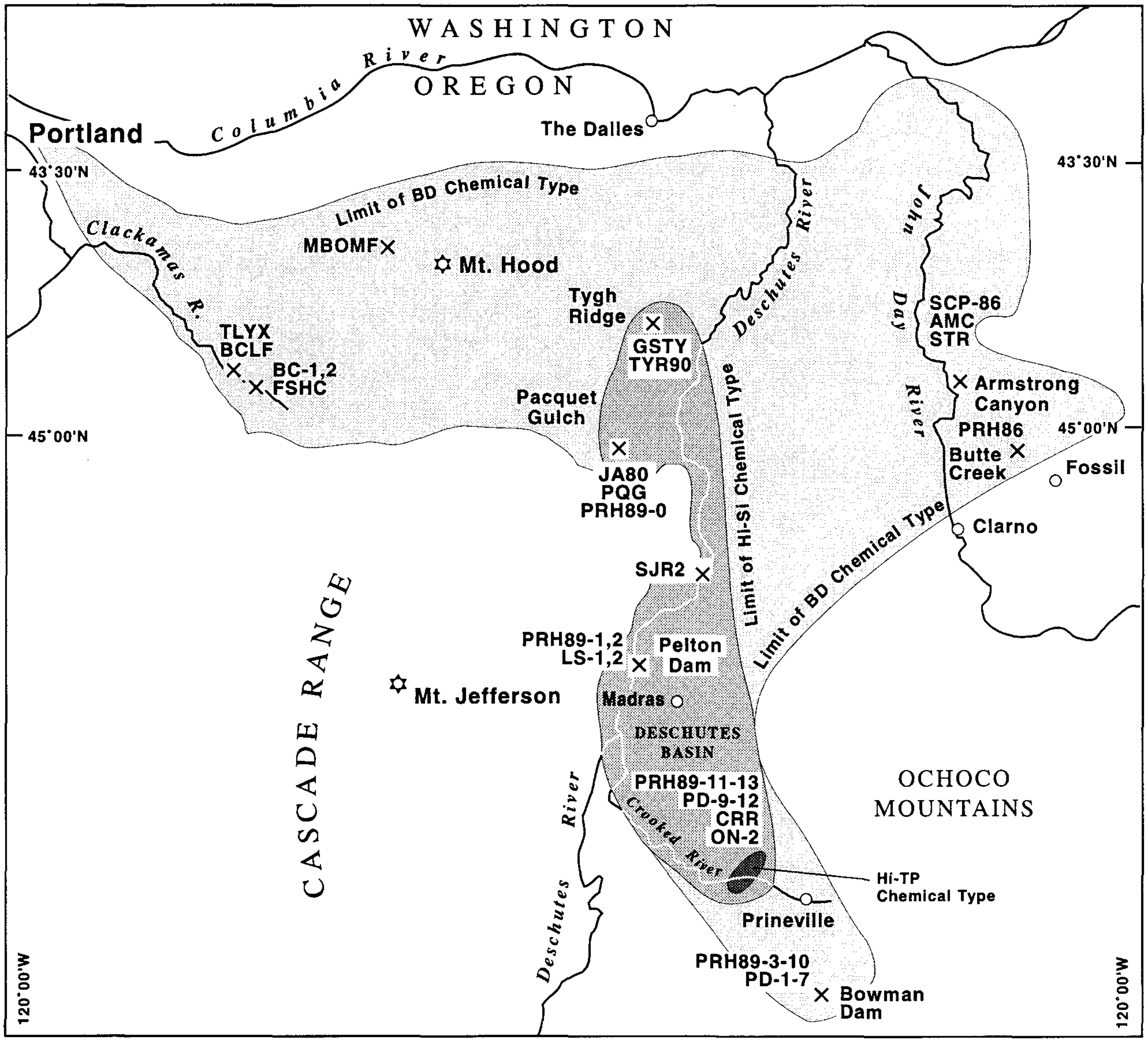


Figure 1. Map showing areal extent of the three Prineville basalt chemical types. Pale shade = BD chemical type; medium shade = Hi-Si chemical type; dark shade = Hi-PT chemical type. Location of samples listed in Tables 1 and 2 are shown.

1973). Grain size and the proportion of glass vary considerably within each flow, but no clear petrographic differences between types of Prineville basalt have been recognized.

Samples from all cored flows and some uncored flows were analyzed for 27 major and trace elements by XRF at Washington State University (Hooper and Johnson, 1989). These analyses are compared with reanalyses of samples previously analyzed by Anderson (1978) and Smith (1986). Four samples were analyzed for rare-earth and other trace elements by ICP/MS at Washington State University. No isotope data are available.

Representative chemical analyses are given in Table 1, and magnetic analyses are shown in Table 2. A full set of 60 analyses, including the reanalyses, is available from the first author, on request. In this paper, we combine the magnetic and analytical data with the field stratigraphic data to correlate the various flows of the Prineville basalt, within which we recognize three chemical types. We discuss the distribution of each type and its age, and then we discuss the probable mode of eruption, the relation of the Prineville basalt to the CRBG, and finally the tectonic significance of this relationship.

FLOW CORRELATION

It is apparent from Tables 1a, 1b, and Figure 2 that the various flows that constitute the Prineville basalt are characterized by concentrations of Ba (1,900-3,200 ppm) and P_2O_5 (1.4-2.0 percent) much greater than those of the associated Grande Ronde Basalt flows (300-900 ppm Ba and <0.50 percent P_2O_5). This clear distinction makes the Prineville flows potentially valuable as stratigraphic markers.

The largest number and thickest sequences of Prineville basalt flows occur in the Prineville and Bowman Dam areas at the southern limit of the known outcrops (Figure 1), as originally described by Uppuluri (1974) and Smith (1986). With the benefit of the earlier descriptions, the type section at Bowman Dam has been remeasured

Table 1a. *Representative major and trace element analyses of Prineville flows (continued on next page).*

Sample	TLYX-3	TLYX-4	PQG90-6	PQG90-7	PQG90-9	GSTY-4	SJR-2	AMC-1	AMC-2	PRH86-12	PRH89-2
Locality	Clack.R	Clack.R	PacquetG	PacquetG	PacquetG	Tygh Rid	S.JCT Rd	Armstr.C	Armstr.C	Butte Cr	Pelton D
Chem. type	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD
Mag. pol.	R	R	R	R	R	U	R	R	R	R	R
						Oxide %					
SiO_2	51.59	51.92	51.76	52.03	51.85	51.70	51.62	51.46	51.60	51.72	51.73
Al_2O_3	13.92	14.07	13.87	13.99	13.95	14.09	14.08	13.79	13.98	13.66	14.08
TiO_2	2.691	2.720	2.670	2.699	2.693	2.656	2.696	2.673	2.692	2.646	2.674
FeO*	12.24	11.79	12.30	11.81	12.20	12.16	12.16	12.53	12.22	12.62	12.03
MnO	0.247	0.250	0.245	0.231	0.227	0.242	0.233	0.244	0.240	0.243	0.241
CaO	8.08	8.05	7.97	8.08	8.07	8.01	8.15	8.02	8.07	7.94	8.11
MgO	4.40	4.40	4.34	4.37	4.03	4.33	4.24	4.41	4.39	4.37	4.48
K_2O	1.85	1.72	2.00	1.99	2.24	1.87	1.87	1.91	1.91	1.83	1.76
Na_2O	3.49	3.58	3.35	3.29	3.23	3.45	3.45	3.48	3.40	3.50	3.42
P_2O_5	1.488	1.502	1.486	1.502	1.505	1.489	1.508	1.488	1.502	1.471	1.478
						Element ppm					
Ni	10	12	31	12	8	11	15	7	11	12	15
Cr	13	17	68	9	15	21	12	9	13	9	17
Sc	37	37	37	38	38	44	41	39	44	36	35
V	317	326	330	342	336	327	337	320	333	331	313
Ba	2,150	2,407	2,286	2,158	2,167	2,197	2,198	2,132	2,145	2,129	2,014
Rb	39	30	41	41	42	39	41	40	41	39	38
Sr	379	374	382	382	388	380	390	377	382	382	379
Zr	148	147	144	146	148	146	147	146	148	145	145
Y	46	47	50	51	51	50	50	50	51	50	52
Nb	10.8	10.1	10.0	9.0	11.0	14.0	11.0	9.0	11.0	9.7	10.0
Ga	18	19	18	21	17	20	23	19	20	21	19
Cu	24	29	24	27	28	29	27	25	24	26	37
Zn	127	128	123	124	124	126	125	121	123	119	126
Pb	8	6	9	9	6	7	5	5	10	8	6
La	28	24	23	22	24	28	29	17	44	25	35
Ce	37	53	48	36	52	41	57	42	50	53	43
Th	5	3	4	2	2	3	3	4	6	5	5

All analyses by XRF at Washington State University. Accuracy and precision data given in Hooper and Johnson, 1989. Major elements are normalized on a volatile-free basis with total Fe given as FeO. Magnetic polarity of drilled core by Eastern Washington University (see details in Table 2). N = normal, R = reverse, U = undetermined, I = indeterminate (large A_{95}).

and resampled. We also drilled the Prineville flows to determine their precise magnetic direction. Of the six flows exposed in vertical sequence in the type section, the lower three have reversed magnetic polarity (Table 2; see also Figure 6), the fourth and fifth flows have indeterminate magnetic polarity (large A_{95}; Table 2), and the top flow has normal magnetic polarity (a in Figure 3). All six flows have a restricted chemical composition (SiO_2 = 51.2-52.5 percent; Zr = 144-151 ppm; Sr = 366-401 ppm; TiO_2 = 2.63-2.75 percent; P_2O_5 = 1.44-1.54 percent). We designate this composition the Bowman Dam (BD) chemical type and divide it into a lower, magnetically reversed unit (BD1) and an upper, magnetically normal unit of one flow (BD2), which are separated by the two flows with indeterminate polarity.

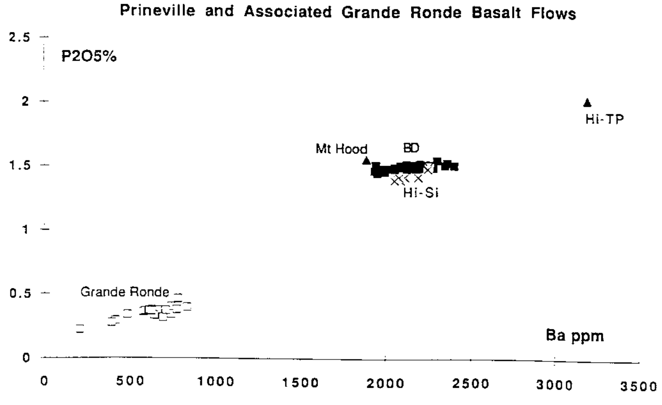


Figure 2. Plot demonstrating the distinction in Ba and P_2O_5 between Prineville basalt and associated flows of Grande Ronde Basalt.

In the Crooked River valley, 30 to 40 km northwest of Bowman Dam and due west of the town of Prineville (Figure 1), many isolated outcrops of flows with the high incompatible element concentrations typical of the Prineville have been sampled (see also Smith, 1986). They include flows of reversed polarity and Bowman Dam chemical composition (BD1) but also flows of two other chemical compositions (Figure 4). Of these, one flow is significantly more siliceous than the Bowman Dam chemical type and has normal magnetic polarity (Hi-Si chemical type). The other has extremely high incompatible element concentrations and normal magnetic polarity (Hi-PT chemical type). This last flow was sampled by Smith (1986) and again in this study at a neighboring locality; both of these locations lie close to the axis of a northeast-trending syncline (Figure 1). The single Hi-PT chemical type flow has not been found elsewhere, nor in contact with any other flow.

Over much of the Deschutes Basin (Figure 1), two Prineville flows are exposed, separated by a sedimentary interbed (Smith, 1986). The lower flow belongs to the BD1 unit with reversed polarity; the upper flow belongs to the more siliceous chemical type (Hi-Si) with normal polarity.

At Pacquet Gulch, due north of the Deschutes Basin (Figure 1), a total of five flows of Prineville type are present (Anderson, 1987, and unpublished data), interleaved with Grande Ronde flows (b in Figure 3). At the base is a BD1 flow separated from underlying

Table 1a. *Representative major and trace element analyses of Prineville flows (continued; also on next page).*

Sample	CRR90-2	CRR90-4	CRR90-6	PRH89-11	PRH89-12	PRH89-5	PRH89-6	PRH89-7	PRH89-8	PRH89-9	PRH89-10
Locality	CrookedR	CrookedR	CrookedR	CrookedR	CrookedR	BowmanD	BowmanD	BowmanD	BowmanD	BowmanD	BowmanD
Chem. type	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD	BD
Mag. pol.	R	R	R	R	R	R	R	R	I	I	N
	Oxide %										
SiO_2	51.77	51.92	51.66	51.83	52.32	51.46	51.62	51.57	51.48	51.58	51.54
Al_2O_3	13.96	13.97	13.86	14.20	14.13	13.87	13.91	13.84	13.79	13.90	13.87
TiO_2	2.684	2.649	2.645	2.702	2.700	2.698	2.685	2.669	2.668	2.653	2.642
FeO*	12.15	12.19	12.44	12.12	11.76	12.49	12.29	12.48	12.77	12.38	12.45
MnO	0.234	0.231	0.243	0.243	0.238	0.246	0.246	0.245	0.245	0.244	0.241
CaO	8.02	7.98	7.92	8.10	8.16	8.06	7.98	7.94	8.00	7.97	7.96
MgO	4.16	4.10	4.28	3.98	3.81	4.31	4.36	4.44	4.31	4.44	4.45
K_2O	2.12	2.19	2.13	1.91	1.96	1.95	2.01	1.96	2.02	1.94	1.93
Na_2O	3.42	3.33	3.37	3.42	3.41	3.43	3.40	3.36	3.26	3.41	3.44
P_2O_5	1.484	1.453	1.461	1.503	1.516	1.489	1.510	1.495	1.455	1.474	1.462
	Element ppm										
Ni	12	11	9	10	11	9	8	12	11	11	12
Cr	13	12	14	9	11	9	16	11	13	11	13
Sc	40	37	36	39	39	35	35	36	38	41	38
V	311	340	318	341	340	327	320	322	327	325	341
Ba	2,262	2,001	1,987	2,094	2,208	2,107	2,245	2,215	1,991	1,954	1,943
Rb	42	41	43	40	40	42	44	40	43	42	40
Sr	381	385	384	390	387	380	384	379	383	380	385
Zr	148	150	150	150	146	146	147	145	149	148	146
Y	49	52	50	53	50	49	52	51	50	51	50
Nb	9.0	11.0	9.0	9.9	9.4	12.0	10.7	11.5	11.0	11.4	11.1
Ga	21	19	18	23	20	21	19	19	19	21	18
Cu	32	31	28	29	27	27	27	30	27	39	24
Zn	118	122	127	125	122	122	121	121	121	254	118
Pb	9	9	6	10	7	5	6	8	8	9	7
La	24	31	20	34	3	27	13	27	21	32	13
Ce	47	33	39	64	38	36	47	55	54	46	33
Th	5	4	4	5	3	3	5	3	6	7	4

Grande Ronde flows by a 15-ft interbed and separated by another Grande Ronde flow from two more overlying BD1 flows. Above this, the magnetic polarity changes from reverse (below) to normal (above), with two Grande Ronde flows overlain by two Prineville flows of Hi-Si chemical type and topped by the Grande Ronde Winter Water flow. The Winter Water flow is known to lie in the middle of the CRBG N_2 magnetostratigraphic unit (Reidel and others, 1989).

Some 70 km west of Pacquet Gulch in the valley of the Clackamas River, two flows of BD1 were recorded by Kienle (1971), Anderson (1978), and Beeson and Moran (1979) and reanalyzed in this study (Table 1a). A single flow of Prineville BD1 unit is found to the east of Pacquet Gulch in Armstrong Canyon in the John Day drainage and again at Butte Creek to the south-southeast. At least one flow can be traced in the field down the canyon of the John Day River almost as far north as the Columbia River (Figure 1; Anderson, 1987, and unpublished data).

The single Prineville flow in the Butte Creek section is of BD chemical type and reversed magnetic polarity (BD1), not the normal polarity recorded by Nathan and Fruchter (1974) with a fluxgate magnetometer (Tables 1 and 2). The magnetic polarity of the flows in the Butte Creek section are shown in full in Figure 3 (c). This section (Bailey, 1989) plays a critical role in the regional stratigraphic correlations of the CRBG. At the base, flows of normal polarity of both Picture Gorge and Grande Ronde chemical composition are interleaved. These are overlain by three flows of reverse polarity, the bottom two being of Grande Ronde composition and the top flow (Buckhorn flow of Nathan and Fruchter, 1974) of Prineville (BD) chemical type. We know from the regional mapping of Swanson and others (1981) that these upper Grande Ronde flows belong to the CRBG R_2 magnetostratigraphic sequence. From this single section we can, therefore, demonstrate that the magnetically normal flows that form the bottom of the Picture Gorge stratigraphic succession (Bailey, 1989) belong to the N_1 magnetostratigraphic unit, and we can be sure that the whole Picture Gorge subgroup belongs to the N_1-R_2 units of the CRBG, not the N_0-R_1 units as originally suggested by Watkins and Baksi (1974). We can also determine that the Prineville flow at Butte Creek falls within the R_2 CRBG magnetostratigraphic unit.

CHEMICAL VARIATION

While the Prineville basalt is distinctive in its high concentrations of P_2O_5 and Ba, compared to the concentrations of these elements in the surrounding flows of Grande Ronde Basalt, there is also significant chemical variation between the various Prineville flows. On many element/element and oxide/oxide plots, the chemical analyses of Prineville flows fall into three groups (Figure 4). By far the largest number of samples belong to the Bowman Dam (BD) chemical type. At the type section are at least six flows of this composition, of which the lower three have reversed magnetic polarity (BD1; a in Figure 3), and the top flow has normal magnetic polarity (BD2). At Pacquet Gulch are three such flows interspersed between flows of Grande Ronde Basalt, all with reversed magnetic polarity (b in Figure 3). The BD chemical type is also the most widespread of the three types, defining the maximum geographic extent of the Prineville basalt (Figure 1).

Within the BD chemical type, there is limited variation in the concentration of the incompatible elements (Figure 4a) but a relatively constant ratio between these elements. More obvious variation is present in the MgO/SiO_2 ratio (Figure 4b). In neither case is this variation related to geographic location or stratigraphic position where that is observed; instead, it is most probably due to minor crystal fractionation during or just prior to eruption. Minor alteration

Table 1a. *Representative major and trace element analyses of Prineville flows (continued).*

Sample	TYR90-1	PQG90-2	PQG90-3	PRH89-1	CRR90-1	CRR90-7	PRH89-13	Mt.Hood	BCR-1		Instr.Precision	
Locality	Tygh Rid	PacquetG	PacquetG	Pelton D	CrookedR	CrookedR	CrookedR	MB-OMF	WSU	Given		
Chem. type	Hi-Si	Hi-Si	Hi-Si	Hi-Si	Hi-Si	Hi-Si	Hi-PT	?	1*	2*		
Mag. pol.	N	N	N	N	N	N	N	U	—	—	S.D.	SD Rel%
					Oxide %							
SiO_2	54.93	55.01	55.32	54.47	55.34	54.32	50.84	50.80	55.43	55.42	0.050	0.080
Al_2O_3	14.38	14.44	14.39	14.20	14.51	14.21	13.75	14.49	13.84	13.72	0.020	0.160
TiO_2	2.409	2.396	2.378	2.501	2.383	2.485	3.132	2.943	2.238	2.244	0.005	0.220
FeO*	9.66	9.87	9.49	10.14	9.38	10.25	12.12	11.87	12.33	12.51	0.014	0.110
MnO	0.222	0.208	0.212	0.221	0.227	0.230	0.229	0.248	0.183	0.187	0.001	0.380
CaO	6.21	6.22	6.17	6.38	6.12	6.40	8.79	9.60	7.04	7.03	0.008	0.110
MgO	3.54	3.25	3.23	3.52	3.06	3.53	3.85	3.88	3.52	3.47	0.028	0.810
K_2O	3.15	3.43	3.23	2.99	3.39	3.36	1.67	1.80	1.73	1.73	0.000	0.000
Na_2O	4.08	3.77	4.18	4.08	4.18	3.74	3.61	2.82	3.33	3.33	0.014	0.420
P_2O_5	1.414	1.414	1.398	1.498	1.410	1.476	2.019	1.553	0.366	0.366	0.002	0.470
					Element ppm							
Ni	13	13	12	11	9	9	17	9	16	5	0.000	0.000
Cr	7	8	6	10	9	6	13	16	18	18	1.370	7.600
Sc	35	35	34	38	36	41	45	41	33	34	2.700	7.700
V	222	203	222	222	213	229	318	334	399	396	6.600	1.700
Ba	2,119	2,197	2,079	2,258	2,085	2,253	3,202	1,895	675	650	16.870	2.500
Rb	38	49	37	39	45	44	29	39	47	47	0.970	2.100
Sr	277	287	279	292	278	294	413	381	330	325	0.800	0.260
Zr	132	135	135	132	135	133	131	163	190	172	1.060	0.610
Y	49	49	49	48	48	48	53	50	37	37	0.530	1.400
Nb	9.0	11.0	11.0	10.6	10.0	10.0	8.6	12.6	13.5	15.0	0.810	5.900
Ga	20	17	19	20	22	21	19	21	20	20	—	—
Cu	20	24	19	32	21	22	38	35	18	13	1.700	15.500
Zn	110	111	109	121	115	112	129	163	120	126	1.420	1.200
Pb	5	10	10	5	9	4	5	3	18	16	1.230	11.400
La	20	19	26	36	15	30	31	21	26	21	8.250	39.100
Ce	45	54	58	39	52	40	25	60	54	50	7.900	14.700
Th	2	4	1	2	4	3	4	7	6	5	1.370	22.500

1* Average of 10 analyses (Hooper and Johnson, 1989).
2* Values recommended by Flanagan, 1976, 1984.

in these generally very fresh rocks is also a possible cause.

The younger, more siliceous unit is represented by two flows at Pacquet Gulch and by one flow at all other localities where it occurs. Flows of this unit always have normal magnetic polarity and always lie above flows of BD chemical type when the two types are present in the same section. The Hi-Si flows show a similar variation in the concentrations of the incompatible elements and in their MgO/SiO_2 ratios (Figure 4), as does the BD chemical type. Two samples collected from the same flow at Pelton Dam (Figure 1), one (LS-1) by Smith (1986) and the second collected in this study (PRH8901), show a greater variation in both these chemical parameters than do all other Hi-Si flows at the same or any other geographic location. As both samples were analyzed at the same time, analytical bias cannot be the cause (see Hooper and Johnson, 1989, for data on accuracy and precision of analyses); again, very small degrees of crystal fractionation and/or subsequent alteration are the probable causes.

The single analyzed sample of the Hi-PT flow on the Crooked River (Tables 1a

Table 1b. *Rare earth and other trace element concentrations of Prineville flows by ICP/MS*

	PRH89-1	PRH89-2	BC-1	PRH89-13	BCR-1		
	Hi-Si	BD	BD	Hi-PT	WSU	Gladney '89	Abbey '83
La	27.88	26.61	26.94	26.56	27.1	24.9	27
Ce	59.16	56.49	56.9	57.06	53.2	53.7	53
Pr	8.08	7.82	7.57	7.83	6.3	6.8	7
Nd	39.57	37.73	36.92	39.5	28.1	28.8	26
Sm	10.64	9.97	9.87	10.77	6.88	6.59	6.5
Eu	5.04	3.99	3.99	4.95	1.95	1.95	2
Gd	10.29	9.95	10.14	11.26	6.9	6.68	6.6
Tb	1.69	1.65	1.65	1.79	1.15	1.05	1
Dy	9.91	9.9	9.66	10.28	7.16	6.34	7
Ho	1.97	2.01	1.96	2.07	1.45	1.26	1.2
Er	5.34	5.48	5.25	5.46	3.97	3.63	3.5
Tm	0.68	0.70	0.69	0.71	0.54	0.56	0.60
Yb	4.13	4.32	4.3	4.22	3.55	3.38	3.4
Lu	0.65	0.70	0.67	0.66	0.56	0.51	0.50
Ba	2,220	1,984	2,266	3,129	683	681	680
Th	3.06	3.46	4.39	3.51	5.5	5.98	6.1
Nb	7.9	8.9	8.8	8.7	12.5	14.0	19.0
Y	51.3	51.8	55.6	57.6	40.0	38.0	40.0
Hf	3.04	3.66	3.39	3.13	4.69	4.95	5
U	1.07	1.22	1.46	1.22	1.48	1.75	1.7
Pb	7.3	6.7	7.3	6.3	13.3	13.6	14.0
Rb	37.7	40.4	35.6	31.7	46.4	47.2	47.0
Cs	0.59	1.65	1.17	1.12	0.96	0.96	0.96

a.

Bowman Dam Section			
Lat 44°06′			
Long 120°47′			
Top			
3,550′	PRH8910	N	BD
3,540′	PRH8909	I	BD
4,000′	PRH8908	I	BD
3,230′	PRH8905	R	BD
3,090′	PRH8907	R	BD
3,070′	PRH8906	R	BD
Base			

b.

Pacquet Gulch Section			
Lat 45°04′			
Long 121°17′			
Top			
2,950′	PQG9001	N	GRB
2,900′	PQG9002	N	Hi-Si
2,870′	PQG9003	N	Hi-Si
2,790′	PQG9004	N	GRB
2,750′	PQG9005	N	GRB
2,710′	PQG9006	R	BD
2,670′	PQG9007	R	BD
2,630′	PQG9008	R	GRB
2,590′	PQG9009	R	BD
Interbed			
2,460′	PQG9010	U	GRB
Base			

c.

Butte Creek Section		
Lat 45°03′		
Long 120°19′		
Top		
PRH8612	R	
PRH8611	R	GRB
PRH8610	R	GRB
PRH8609	N	PGB
PRH8608	N	GRB
PRH8607	N	GRB
PRH8605	N	PGB
PRH8604	N	GRB
PRH8603	N	PGB
PRH8602	N	PGB
PRH8601	N	PGB
Base		

Figure 3. Three sections from (a) Bowman Dam, (b) Pacquet Gulch, and (c) Butte Creek, showing the chemical type and polarity of the flows against stratigraphic height.

Table 2. *Paleomagnetic data for cored samples of the Prineville basalt and associated Grande Ronde (GR) flows*

Sample	Location	Latitude	Longitude	No. cores	Decl.(°)	Incl.(°)	A_{95}%o	Polarity
PRH89-01	Pelton Dam	44°42′05.1″	121°13′55.2″	5	4.9	69.5	1.9	Normal
PRH89-02	Pelton Dam	44°41′44.1″	121°13′427″	6	146.5	-43.8	11.2	Reverse
PRH89-03	1 km south of Bowman Dam	44°05′40.5″	120°47′00.9″	6	154.6	-56.3	4.7	Reverse
PRH89-04	1 km south of Bowman Dam	44°05′40.5″	120°47′00.9″	3	143.1	6.9	180	Indeterminate
PRH89-10	Bowman Dam, 3,550′	44°07′06.1″	120°47′12.2″	6	17.3	75.3	1.8	Normal
PRH89-09	Bowman Dam, 3,540′	44°06′57.6″	120°47′12.2″	3	164	0.3	47.4	Indeterminate
PRH89-08	Bowman Dam, 3,400′	44°06′55.1″	120°47′12.2″	3	26.4	-53.6	180	Indeterminate
PRH89-05	Bowman Dam, 3,230′	44°06′44.4″	120°47′10.7″	6	149.6	-23.6	5.3	Reverse
PRH89-07	Bowman Dam, 3,090′	44°06′48.9″	120°47′17.8″	6	152.8	-36.7	5	Reverse
PRH89-06	Bowman Dam, 3,070′	44°06′48.9″	120°47′17.8″	6	155.1	-44.5	3.6	Reverse
PRH89-11	Crooked River	44°15′00.0″	120°55′53.4″	2	148.3	-39.1	7.7	Reverse
PRH89-12	Crooked River	44°23′13.8″	121°00′30.3″	6	144.5	-50.2	3	Reverse
PRH89-13	Crooked River	44°20′17.4″	120°59′20.4″	6	359.3	69.5	3.2	Normal
PRH86-12	Butte Creek	45°03′21.0″	120°18′55.0	4	142.5	-41.5	2.3	Reverse
AMC-1	Armstrong Canyon	45°09′264″	120°25′24.8″	6	123.2	-48.9	4.8	Reverse
PQG 90-1	Pacquet Gulch, 2,950′ (GR)	45°04′15.8″	121°17′55.0″	6	337.1	12.0	3.0	Normal
PQG 90-2	Pacquet Gulch, 2,900′	45°04′11.8″	121°17′58.3″	6	342.3	71.0	2.7	Normal
PQG 90-3	Pacquet Gulch, 2,870′	45°04′09.1″	121°17′56.3″	6	2.8	66.3	10.7	Normal
PQG 90-4	Pacquet Gulch, 2,790′ (GR)	45°04′07.4″	121°17′462″	4	355.2	45.9	16.3	Normal
PQG 90-5	Pacquet Gulch, 2,750′ (GR)	45°04′04.8″	121°17′44.6″	6	62.9	72.1	14.5	Normal
PQG 90-6	Pacquet Gulch, 2,710′	45°04′04.0″	121°17′45.1″	6	143.7	-37.6	3.8	Reverse
PQG 90-7	Pacquet Gulch, 2,670′	45°04′02.5″	121°17′44.7″	6	143.7	-48.5	2.4	Reverse
PQG 90-8	Pacquet Gulch, 2,630′ (GR)	45°04′00.7″	121°17′48.0″	3	120.4	-70.6	11.9	Reverse
PQG 90-9	Pacquet Gulch, 2,590′	45°04′00.7″	121°17′55.6″	6	166.0	-49.7	5.0	Reverse
TYR 90-1	Tygh Ridge	45°17′46.6″	121°10′139″	6	329.6	65.6	3.0	Normal
CRR 90-6	Crooked River	44°20′457″	120°58′43.5″	6	155.2	-27.8	17.0	Reverse

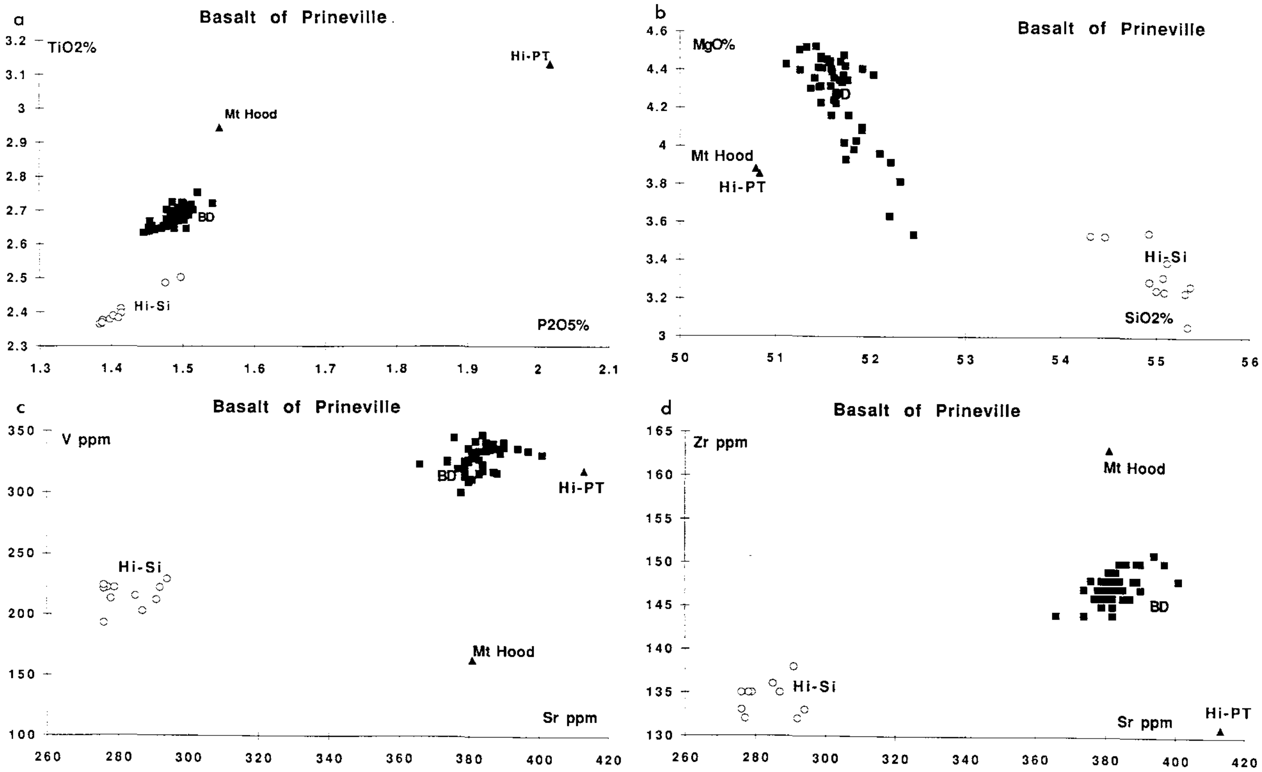


Figure 4. Plot of chemical analyses of flows of the Prineville basalt:(a) TiO_2 vs P_2O_5; (b) MgO vs SiO_2; (c) V vs Sr; (d) Zr vs Sr.

and 1b) may represent a more evolved fraction of the BD chemical type, but its relatively low silica content (Figure 4b) suggests that its origin is more complex.

Finally, a single sample recovered as chips from a deep borehole on the western side of Mount Hood (Figure 1; Beeson and Moran, 1979) has the generally high P and Ba that typifies the Prineville basalt but cannot be assigned to any of the three distinct chemical types discussed above. The sample most resembles the Hi-PT flow from Crooked River in its high P and Ti concentrations but has much lower Ba and much higher Ti (Figure 4). The sample almost certainly implies that one flow of Prineville basalt reached the Mount Hood area, but it has clearly been contaminated in the sampling process.

The rare-earth element (REE) patterns of all three chemical units are very similar (Figure 5a), indicating generally high absolute REE concentrations and small positive Eu anomalies. Spider diagrams for the three units (Figure 5b) are also similar for all three Prineville chemical types and the low high-field-strength (HFS) element concentrations—especially the low Nb and Ta and high large-ion-lithophile (LIL) element and light REE concentrations—are typical of crustal rocks and of rocks associated with arc magmatism (Pearce, 1983). In these properties, the Prineville basalt resembles other basalts erupted in the late Miocene south of the Olympic Wallowa lineament (OWL) and apparently associated with Basin and Range extension (Hooper and Hawkesworth, in preparation). Those authors suggest that these other basalt flows, which include the Picture Gorge Basalt, are chemically and isotopically distinct from the main CRBG and were derived from a recently enriched subcontinental lithospheric mantle.

MAGNETIC POLARITY

The results of the drilling program show that the Prineville flows began to erupt a magma of BD chemical type during the R_2 magnetostratigraphic period of the CRBG and that eruption continued on into the N_2, with no significant change in the chemical composition of the magma. Subsequently a similar but slightly more siliceous magma was erupted in the middle of the N_2 magnetostratigraphic period, immediately prior to the eruption of the Winter Water unit of the Grande Ronde Basalt (CRBG; Reidel and others, 1989). Previous suggestions that more than one magnetic reversal occurred during the eruption of the Prineville basalt are incorrect. They were based on what have proved to be unreliable measurements with a portable fluxgate magnetometer (Nathan and Fruchter, 1974; Smith, 1986).

The two sections that contain multiple BD Prineville flows (Bowman Dam and Pacquet Gulch) show a similar migration of magnetic poles with time (Table 2 and Figure 6; sites PRH8906, -7, and -5 at Bowman Dam and sites PQG9007 and -6 from Pacquet Gulch). This observation strengthens the flow correlation between these two areas and suggests that the central Deschutes Basin acted as a single tectonic unit since the Prineville eruptions. The magnetic direction of the drill core from Armstrong Canyon has a slightly anomalous declination; the more obviously so, because the Butte Creek flow, which is further east, seems to have a direction similar to that of flows in the Deschutes Basin. The cause for the discrepancy is not clear, but it could be tectonic.

DISCUSSION

The composite stratigraphy of the Prineville basalt and its relationship to Grande Ronde flows where the two types interfinger in the north are summarized in Figure 7. Earlier descriptions of Prineville-type basalt flows have been reported from other places (two flows near Red Top Springs, for example, by Goles, 1986) but prove not to have a Prineville composition as defined here. Earlier workers (Uppuluri, 1974; Smith, 1986) also report more flows and more magnetic reversals than the present reevaluation has shown. It is now evident that magma of Prineville BD chemical type began

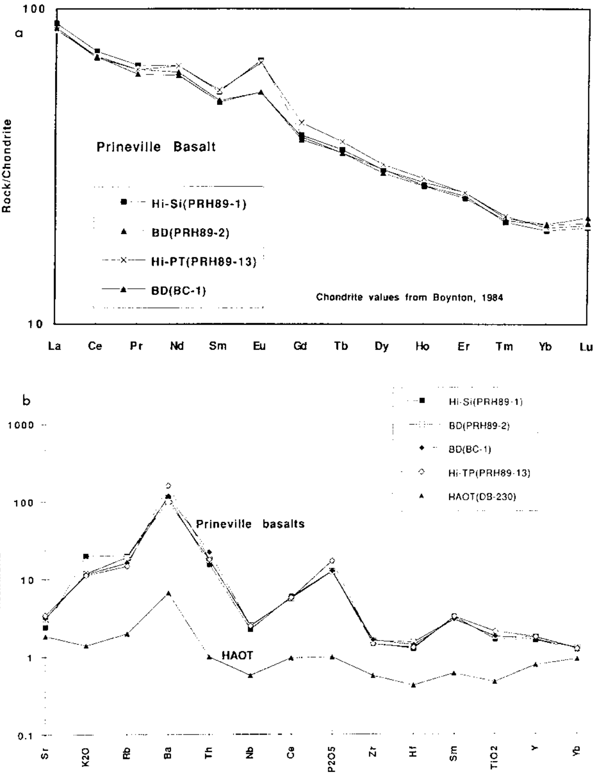


Figure 5. (a) Rare-earth to chondrite ratios for the three Prineville chemical types. (b) Plot of incompatible element abundances ratioed to MORB (mid-oceanic-ridge basalt) values (Pearce, 1983) for the three Prineville chemical types and primitive HAOT from the Powder River volcanic field of Basin and Range affinity (Bailey, 1990).

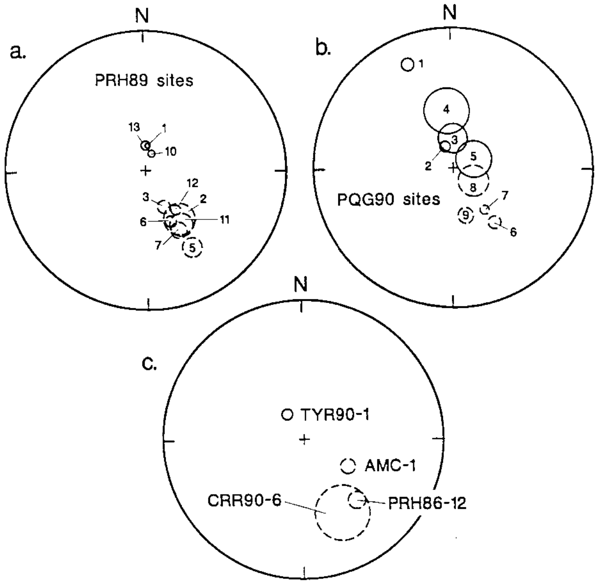


Figure 6. Corrected declinations and inclinations of magnetic poles of Prineville flows: (a) PRH89 sites from Pelton Dam, Bowman Dam and Crooked River; (b) PQG90 sites of Prineville and associated Grande Ronde flows from Pacquet Gulch; (c) sites from the Tygh Ridge (TYR), Armstrong Canyon (AMC), Butte Creek (PRH8612), and Crooked River (CRR9006) areas. See Table 2 for site identification. Circle for each site represents the 95-percent confidence limit for the cores from each site. Solid circles plot in the lower hemisphere and have normal polarity; dashed circles plot in the upper hemisphere and have reverse polarity.

to erupt in the Deschutes Basin toward the end of the CRBG R_2 magnetostratigraphic period and, in the Bowman Dam area, continued across the R_2-N_2 boundary. At least six flows of essentially identical composition were erupted in this period and covered a large triangular area from Portland to the John Day River system in the north to a southern apex just south of Bowman Dam (Figure 1). Later, a further eruptive episode produced magma of Prineville type, but of slightly more siliceous composition. This later eruption occurred in the middle of the CRBG N_2 magnetostratigraphic period, immediately before the eruption of the Winter Water unit of the CRBG. Only two of these Hi-Si flows, of significantly less volume than the earlier flows of BD chemical type, were erupted, and these were confined to a north-south zone close to the present-day Deschutes River (Figure 1). Finally, what appears to have been a very small flow of even higher incompatible element concentrations (but lower SiO_2) was erupted during N_2, but the timing of this eruption relative to the more siliceous type is not well constrained.

The lower flow at Pelton Dam (BD1) has been dated at 15.7 ± 0.1 Ma (Smith, 1986), which agrees well with the most recent date of the CRBG R_2/N_2 boundary (15.8 ± 0.3 Ma) given by Baksi (1989).

Neither dikes nor any physical evidence of magma venting (scoria, welded spatter, small irregular dikelets and tephra deposits) can be related to the Prineville basalt, but the thicker sequences and greater number of flows at the Bowman Dam and Pacquet Gulch localities suggest that these areas represent the most probable sites of Prineville magma eruption. The direct line between the two areas (SSE-NNW) parallels the trend common to both the feeder dikes of the CRBG further east and the graben walls that formed later to the south of the OWL and are associated with the eruption of the Powder River basalts of Basin and Range affinity (Bailey, 1990). It is possible that the Prineville flows were fed from a fissure system joining these two areas, but it must be emphasized that no dikes with Prineville composition have been found in the poorly exposed area between the two sites and that both the location and physical nature of the Prineville eruptions remain speculative.

Whether the chemically distinct Prineville flows should be included within the CRBG, with which they are locally interfingered, is largely a question of semantics, and any answer is unlikely to satisfy everybody's prejudices. The inclusion of the Prineville within the CRBG may be justified in so far as the flows represent large eruptions that appear to have formed at least small sheet flows, were contemporaneous with the CRBG, and may have been vented from similar north-northwest fissures. On the other hand, they can be excluded from the CRBG on the basis that they were erupted hundreds of kilometers west of the fissures that fed the Clarkston basalt, that their volume is much less than that of the larger CRBG flows, and that their chemical composition is unusually distinct.

Recent work along the southern margin of the Columbia Plateau (Swanson and others, 1981; Hooper and Conrey, 1989; Bailey, 1990; Hooper and Swanson, 1990; Hooper and Hawkesworth, in preparation) has emphasized significant chemical and isotopic differences between the sheet flows of the Clarkston basalt (Imnaha, Grande Ronde, and Wanapum Basalts) and the much smaller eruptions associated with grabens developed after 15 Ma during Basin and Range-related east-west extension on the southern side of the OWL. It is becoming increasingly apparent that these represent two distinct types of magmatism, one of them associated with a mantle plume (Hooper and Hawkesworth, in preparation) and the other, high-alumina olivine tholeiite (HAOT;

EPOCH	AGE* (Ma)	Basalt of Prineville composite stratigraphy	CRBG magnetostratigraphic units	CRBG lithostratigraphic units
Pliocene		olivine basalts		
Miocene	6 - ~14.5			Saddle Mountains Basalt
	14.5-15.3			Wanapum Basalt
	15.3 ?			Eckler Mountains Basalt
	15.6	GRB flows (Winter Water Unit) 2 Hi-Si flows 2 GRB flows sedimentary interbed 1 BD flow	N2	Grande Ronde Basalt Picture Gorge Basalt
	15.8±0.3		R2/N2 boundary	
	15.7±0.1	>6 BD flows (interlayered with GRB flows in north & locally with thin sediments in south)	R2	
			N1	
	16.5		R1	
	16.5-17.0		N0	Imnaha Basalt
Oligocene		John Day Formation		

* From Tolan and others (1989) and Baksi (1989).
CRBG=Columbia River Basalt Group; GRB= Grande Ronde Basalt;
Hi-Si=High silica type of Prineville basalt;
BD=Bowman Dam chemical type of Prineville basalt

Figure 7. Composite stratigraphy of the Prineville basalt flows.

Hart and others, 1984) associated with the lithospheric extension between the OWL and the Brothers Fault Zone (Hooper, 1990). The post-15-Ma magmas erupted south of the OWL bear the chemical and isotopic signature of other Basin and Range-related rocks (Hart and others, 1984; Hooper and Hawkesworth, in preparation). They are physically, chemically, and isotopically distinct from the Clarkston basalt. Such parameters as Nb/Zr and Nb/Y ratios, isotope ratios, and the overall pattern of incompatible element abundances as illustrated in a rock/MORB (mid-oceanic-ridge basalt) "spider" diagram, frequently invoked as indicators of source composition, can be used to illustrate these differences.

While it is difficult to relate the Prineville basalt to either the Clarkston basalt or the HAOT, because the Prineville is so much more evolved chemically, nevertheless, on the basis of such criteria, the Prineville basalt tends towards the Basin and Range category. It has the trace element abundance pattern that reflects a major contribution from a lithospheric source (Figure 5b), whether that source is an enriched subcontinental mantle or crust. The HFS element ratios are more similar to those of the the Basin and Range rocks of northeastern Oregon than to the Clarkston basalt, albeit they have been slightly modified by extreme fractionation. We conclude that the new data on the Prineville basalt support the growing realization that these two types of magmatism—one related to a mantle plume and flood basalt eruption and one related to Basin and Range extension—are fundamentally different. The work of documenting and understanding these differences is critical to a realistic interpretation of the relationship between magmatism and its immediate tectonic setting in the Pacific Northwest during the Miocene.

In conclusion, therefore, we recommend that the Prineville basalt be excluded from the CRBG. It should, instead, be grouped with the numerous small basaltic eruptions that occurred from the middle to late Miocene over much of northeastern Oregon, south of the OWL (Goles, 1986), and appear related to lithospheric thinning during the Basin and Range extension.

ACKNOWLEDGMENTS

Many workers on the Columbia Plateau have contributed to our awareness and knowledge of the Prineville basalt. This paper has relied heavily on the previous work of Steve Reidel, Gordon Goles, and Don Swanson, among many others, to whom we are particularly grateful for sharing their knowledge and ideas with us so freely. Access to the Pacquet Gulch section was provided by permit from the Tribal Council of the Confederated Tribes of the Warm Springs Reservation and by the help of Mr. Richard Dodge of Pine Grove, Oregon.

REFERENCES CITED

Anderson, J.L., 1978, The stratigraphy and structure of the Columbia River basalt in the Clackamas River drainage: Portland, Oreg., Portland State University master's thesis, 136 p.

———1987, The structural geology and ages of deformation of a portion of the southwest Columbia Plateau, Washington and Oregon: Los Angeles, Calif., University of Southern California doctoral dissertation, 283 p.

Bailey, D.G., 1990, Geochemistry and petrogenesis of Miocene volcanic rocks in the Powder River volcanic field, northeastern Oregon: Pullman, Wash., Washington State University doctoral dissertation, 341 p.

Bailey, M.M., 1989, Revisions to stratigraphic nomenclature of the Picture Gorge Basalt Subgroup, Columbia River Basalt Group, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 67-84.

Baksi, A.K., 1989, Reevaluation of the timing and duration of the extrusion of the Imnaha, Picture Gorge, and Grande Ronde Basalts, Columbia River Basalt Group, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 105-112.

Beeson, M.H., and Moran, M.R., 1979, Columbia River Basalt Group stratigraphy in western Oregon: Oregon Geology, v. 41, no. 1, p. 11-14.

Boynton, W.V., 1984, Cosmochemistry of the rare earth elements: Meteorite studies, *in* Henderson, P., ed., Rare earth element Geochemistry: Amsterdam, Elsevier, p. 63-115.

Flanagan, F.J., 1976, Descriptions and analyses of eight new USGS rock standards: U.S. Geological Survey Professional Paper 840, 192 p.

———1984, Three USGS mafic rock reference samples, W-2, DNC-1, and BIR-1: U.S. Geological Survey Bulletin 1623, 54 p.

Goles, G.G., 1986, Miocene basalts of the Blue Mountains Province in Oregon; 1. Compositional types and their geological settings: Journal of Petrology, v. 27, p. 495-520.

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

Hooper, P.R., 1990, The timing of crustal extension and the eruption of continental flood basalts: Nature, no. 345, 246-249.

Hooper, P.R., and Conrey, R.M., 1989, A model for the tectonic setting of the Columbia River basalt eruptions, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 293-306.

Hooper, P.R., and Hawkesworth, C.J., in preparation, Isotopic and geochemical constraints on the origin and evolution of the Columbia River basalt: Journal of Petrology.

Hooper, P.R., and Johnson, D., 1989, Major and trace element analyses of rocks and minerals by automatic X-ray spectrometry: Pullman, Wash., Washington State University, Department of Geology, Open-File Report, 17 p.

Hooper, P.R., and Swanson, D.A., 1990, The Columbia River Basalt Group and associated volcanic rocks of the Blue Mountains, *in* Walker, G.W., ed., Geology of the Blue Mountains region of Oregon, Idaho, and Washington: Cenozoic geology of the Blue Mountains region: U.S. Geological Survey Professional Paper 1437, p. 63-99.

Kienle, C.F., 1971, The Yakima Basalt in western Oregon and Washington: Santa Barbara, Calif., University of California doctoral dissertation, 171 p.

Nathan, S., and Fruchter, J.S., 1974, Geochemical and paleomagnetic stratigraphy of the Picture Gorge and Yakima Basalts (Columbia River Group) in central Oregon: Geological Society of America Bulletin, v. 85, p. 63-76.

Pearce, J.A., 1983, Role of sub-continental lithosphere in magma genesis at active continental margins, *in* Hawkesworth, C.J., and Norry, M.J., eds., Continental basalts and mantle xenoliths: Nantwich, U.K., Shiva Publishing, Ltd, p. 230-249.

Reidel, S.P., Tolan, T.L., Hooper, P.R., Beeson, M.H., Fecht, K.R., Bentley, R.D., and Anderson, J.L., 1989, The Grande Ronde Basalt, Columbia River Basalt Group; stratigraphic descriptions and correlations in Washington, Oregon, and Idaho, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 21-54.

Smith, G.A., 1986, Stratigraphy, sedimentology, and petrology of Neogene rocks in the Deschutes Basin, central Oregon: A record of continental-margin volcanism and its influence on fluvial sedimentation in an arc-adjacent basin: Corvallis, Oreg., Oregon State University doctoral dissertation, 467p.

Swanson, D.A., Anderson, J.L., Camp, V.E., Hooper, P.R., Taubeneck, W.H., and Wright, T.L., 1981, Reconnaissance geologic map of the Columbia River Basalt Group, northern Oregon and western Idaho: U.S. Geological Survey Open-File Report 81-797, 5 sheets, scale 1:250,000.

Swanson, D.A., Wright, T.L., Hooper, P.R., and Bentley, R.D., 1979, Revisions in stratigraphic nomenclature of the Columbia River Basalt Group: U.S. Geological Survey Bulletin 1457-G, 59 p.

Tolan, T.L., Reidel, S.P., Beeson, M.H., Anderson, J.L., Fecht, K.R., and Swanson, D.A., 1989, Revisions to the estimates of the areal extent and volume of the Columbia River Basalt Group, *in* Reidel, S.P., and Hooper, P.R., eds., Volcanism and tectonism in the Columbia River flood-basalt province: Geological Society of America Special Paper 239, p. 1-20.

Uppuluri, V.R., 1973, A stratigraphical and compositional study of basalts of the Columbia River Group near Prineville, central Oregon: Eugene, Oreg., University of Oregon master's thesis, 87 p.

———1974, Prineville chemical type: A new basalt type in the Columbia River Group: Geological Society of America Bulletin, v. 85, no. 8, p. 1315-1318.

Watkins, N.D., and Baksi, A.K., 1974, Magnetostratigraphy and oroclinal folding of the Columbia River, Steens, and Owyhee basalts in Oregon, Washington, and Idaho: American Journal of Science, v. 274, no. 2, p. 148-189. ☐

Maps for southeast Oregon released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released new geologic maps of the Namorf and Westfall quadrangles in the Owyhee region in Harney County. Economic resource potential for diatomite and some minerals for rock collectors has been identified in the area. The potential for metallic minerals appears low, although gold resources may occur in the Namorf quadrangle.

Geology and Mineral Resources Map of the Westfall Quadrangle, Malheur County, Oregon, by Howard C. Brooks and James P. O'Brien, has been released as map GMS-71; and **Geology and Mineral Resources Map of the Namorf Quadrangle, Malheur County, Oregon**, by Mark L. Ferns and James P. O'Brien, has been released as map GMS-74. Both are two-color maps at a scale of 1:24,000 (one inch on the map equals about 2,000 feet on the ground). They show rock units, structural features, and sample locations and are accompanied by tables of sample analyses and descriptions and discussions of geology, structure, and mineral and water resources. The price for each map is $5.

The Namorf and Westfall 7½-minute quadrangles are adjacent to each other and carry the names of locales west of Vale in Malheur County. The rocks in the quadrangles reflect a volcanic history that dates back to Miocene time, approximately 16 million years.

Production of the map was funded jointly by DOGAMI, the Oregon State Lottery, and the COGEOMAP Program of the U.S. Geological Survey as part of a cooperative effort to map and evaluate the mineral resources of the Oregon portion of the 1° by 2° Boise sheet in eastern Oregon.

The new DOGAMI maps GMS-71 and GMS-74, are now available from the Nature of Oregon Information Center in Portland (see order information on back page) and from the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. ☐

Teaching help for earthquakes offered

Help for science teachers K-12 whose curriculum includes earthquakes, earthquake preparedness, and related earth-science topics is available from the Seismological Society of America. Resources listed include reference information, videotapes, computer hardware and software, and databases. For a copy of "Seismology: Resources for Teachers," send a self-addressed, stamped envelope to SSA, 201 Plaza Professional Building, El Cerrito, CA 94530-4003. SSA can also be reached by phone: (510) 525-5474; or FAX: (510) 525-7204.

—From Geotimes

Explosion craters and giant gas bubbles on Holocene rhyolite flows at Newberry Crater, Oregon

by Robert A. Jensen, Engineering Geologist, Deschutes National Forest, Bend, Oregon 97701

ABSTRACT

Forty-seven explosion craters pockmark the surface of the Big Obsidian Flow and Interlake Obsidian Flow within Newberry Crater in central Oregon. The craters range from 12 to 60 m in diameter and from 5 to 14 m in depth. Discontinuous rings of rubble form rims around the craters. At the bottom of four of the craters are parts of spherical cavities or giant gas bubbles that are up to 15 m in diameter and filled to varying degrees with rubble that has collapsed from the crater walls above.

Rhyolite flows are thought to develop layers as gases exsolve from the flow. The surface layer is finely vesicular pumice; beneath this is a layer of obsidian underlain by coarsely vesicular pumice. Giant gas bubbles in the Newberry Crater flows probably form and grow beneath or within the coarsely vesicular pumice and rise upward into the obsidian layer within several meters of the surface, where they burst explosively. The blast creates a steep-walled crater rimmed with blocks of pumice and obsidian. Debris from the explosion falls back into the crater, partially or completely obscuring the giant bubble.

INTRODUCTION

Newberry volcano in central Oregon (Figure 1) has long been known for its diversity of volcanic landforms and rock types (Russell, 1905; Williams, 1935; MacLeod and others, 1982). Newberry Crater at the summit of Newberry volcano (Figure 2) is the centerpiece of the recently (November 1990) established Newberry National Volcanic Monument, which contains some of Oregon's youngest and most intriguing volcanic features. Among the volcanic treasures of Newberry Crater are six rhyolite flows (Figure 3) ranging in age from 6,400 to 1,300 ^{14}C years (Table 1). The surfaces of two of these, the Big Obsidian Flow (1,300 ^{14}C yr B.P.) and the Interlake Obsidian Flow (about 6,300 ^{14}C yr B.P.), remain essentially pristine. The other four flows are mantled by Newberry pumice or vegetation. All flows occurred after the cataclysmic eruption of Mount Mazama (Crater Lake) that blanketed the area with ash about 6,845 ^{14}C yr B.P. (Table 1).

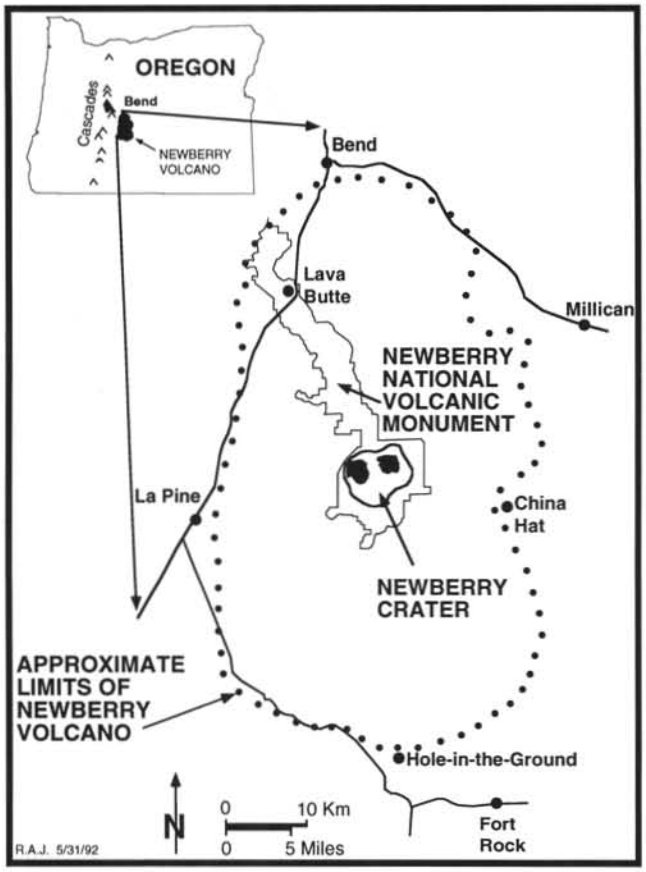


Figure 1. Location of Newberry volcano and Newberry National Volcanic Monument.

Using aerial photographs, I identified 42 small craters on the Big Obsidian Flow and five craters on the Interlake Obsidian Flow. I have visited 40 of these craters and have observed that large spherical cavities occur beneath some of these craters. The craters apparently formed above giant gas bubbles as the bubbles burst explosively near the flow surface.

RHYOLITE FLOWS

All of the post-Mazama rhyolite flows within Newberry Crater have similar chemistry (SiO_2 = 73.3-74.0 percent, MacLeod and Sherrod, 1988). The glassy surface of these flows consists of irregular hills and ridges of rubble. Various forms of pumice and obsidian make up the rubble. Even though these flows are called "obsidian flows," the amount of obsidian exposed on the surface is only 10 percent or less; the other 90 percent comprises various forms of pumice (frothy glass).

Traditionally, a rhyolite lava flow has been

Figure 2. Aerial view of Newberry Crater from northeast across East Lake, showing snow-covered East Lake obsidian flows (left), Big Obsidian Flow (center), and East Lake lobe of Interlake Obsidian Flow (right).

viewed as a body of flow-banded crystalline rock enclosed by a rubble of glassy rock (a in Figure 4). Studies over the last decade have shown that these flows develop distinctive layers as gases exsolve out of their interiors (Fink, 1983; Fink and Manley, 1987; Manley and Fink, 1987a). The flow surface develops a finely vesicular white pumice layer that becomes highly fractured and broken from motion of the flow. This surficial pumice grades downward into a dense glassy zone (obsidian) at a depth of 3 to 5 m. The obsidian is underlain by an irregular, coarsely vesicular pumice layer that in turn grades downward into another glassy zone (b in Figure 4).

Near the margin of larger flows, parts of the least dense coarsely vesicular pumice rise as buoyant diapirs to the surface and distort the layering, while the flow is still in motion. This distortion of the layering exposes the obsidian and coarsely vesicular pumice at the surface. This is particularly evident in the distal areas of the Big Obsidian Flow, where bands of darker coarsely vesicular pumice and obsidian alternate with the lighter colored finely vesicular pumice.

CRATERS ON THE BIG OBSIDIAN FLOW

Forty-two small craters are scattered across the surface of the Big Obsidian Flow (Figures 5 and 6). They are generally circular, 12 to 60 m in diameter, and 5 to 14 m deep, but some are elongate and divided by a low rim. These craters are typically rimmed by discontinuous rings of blocky obsidian and pumice from the flow interior. The rim deposits are generally less than 1 m thick but approach 2 m at some of the larger craters.

In his description of the Big Obsidian Flow, I.C. Russell (1905, p. 108) may have been describing some of these craters when he wrote: "The surface, although generally a plain, is uneven and has hills and hollows resembling those of a glacial moraine but is composed of angular fragments consisting of pumice, scoriae, obsidian, and a few imperfectly shaped bombs. The explanation of this seems to be that mild steam explosions took place in it which threw it into piles, leaving depressions where the explosions occurred. . ."

A majority of the craters occur in groupings of five or more craters, but many remain scattered singly or in pairs. Two areas of the Big Obsidian Flow notably lack craters. One is the central western area where the surface flow banding is highly contorted. The other is the northeast area within the Lost Lake pumice ring.

At the bottom of four of these craters are parts of spherical bubblelike cavities as much as 15 m in diameter (Figures 7 and 8). In all cases the floor of the bubbles has been buried under rubble from the crater walls. The best preserved bubble is beneath a small crater, Crater "Z" (a) in Figure 9, about 12 m in diameter and 5 m

Table 1. *Selected carbon-14 ages from Newberry volcano. From complete listing of carbon-14 ages for Newberry volcano in MacLeod and others (in preparation).*

Geologic event	Carbon-14 age[1] (^{14}C yr B.P.)	Reference	Weighted mean age (^{14}C yr B.P.)	Recalculated age[2] (calendar yr B.P.)
Big Obsidian Flow	No carbon-14 date[3]			
Ash flow from Big Obsidian Flow vent	1,270±60	Pearson and others (1966)	1,310±40	1,240±50
	1,340±60	Robinson and Trimble (1983)		
	1,390±200	Meyer Rubin, *in* Peterson and Groh (1969)		
East Lake obsidian flows	No carbon-14 date[4]			
North Summit flow	6,090±60	Peterson and Groh (1969)	6,090±60	7,000±150
Central Pumice Cone flow	No carbon-14 date[5]			
Game Hut obsidian flow	No carbon-14 date[6]			
Interlake Obsidian Flow	No carbon-14 date[7]			
East Lake tephra	6,220±200	Meyer Rubin and W.E. Scott (unpublished data, 1985)	6,400±130	7,300±130
	6,500±300	Meyer Rubin, *in* Linneman (1990)		
	6,550±300	Meyer Rubin, *in* Linneman (1990)		
Mazama ash, climatic eruption of Mount Mazama (Crater Lake)	6,845±50[8]	Bacon (1983)	6,845±50	7,640±50

[1] Carbon-14 ages based on Libby half-life of 5,568 yr. Years before present (yr B.P.) measured from 1950 A.D.

[2] Generalized from program in Stuiver and Reimer (1986) that computes intercepts and range (one confidence interval). Radiocarbon age curve is not linear and may have multiple possible calendar ages (intercepts) for a given ^{14}C age. Recalculated age as reported here is midpoint between oldest and youngest intercepts, rounded to nearest ten years; reported error is range (one confidence interval as calculated by the program).

[3] Hydration-rind age of 1,400 calendar years in Friedman (1977). Too old, based on stratigraphic position related to carbon-14 dated units; overlies ashflow from Big Obsidian Flow vent.

[4] Hydration-rind age of 3,500 calendar years in Friedman (1977).

[5] Hydration-rind age of 4,500 calendar years in Friedman (1977). Too young, based on stratigraphic position related to carbon-14 dated units; lies between East Lake tephra and North Summit flow.

[6] Hydration-rind age of 6,700 calendar years in Friedman (1977). Too young, based on stratigraphic position related to carbon-14 dated units; lies between East Lake tephra and North Summit flow.

[7] Hydration-rind age of 6,700 calendar years in Friedman (1977). Too young, based on stratigraphic position related to carbon-14 dated units; lies between East Lake tephra and North Summit flow.

[8] Weighted mean age of four charcoal samples (Bacon, 1983): 6,780±100; 6,830±110; 6,880±70; 6,840±100.

deep. A person can enter this bubble through a small hole in the crater floor. Inside, this bubble is approximately 7 m in diameter and nearly complete. The floor is covered by a cone of rubble (blocks of pumice and obsidian) that fell through the hole at the entrance. The interior walls show relatively smooth flow-banded rhyolite. Smaller bubbles up to 0.5 m in diameter occur behind the main bubble wall and form bulbous protrusions into the main bubble. Some walls between the smaller bubbles and the main bubble are ruptured and torn.

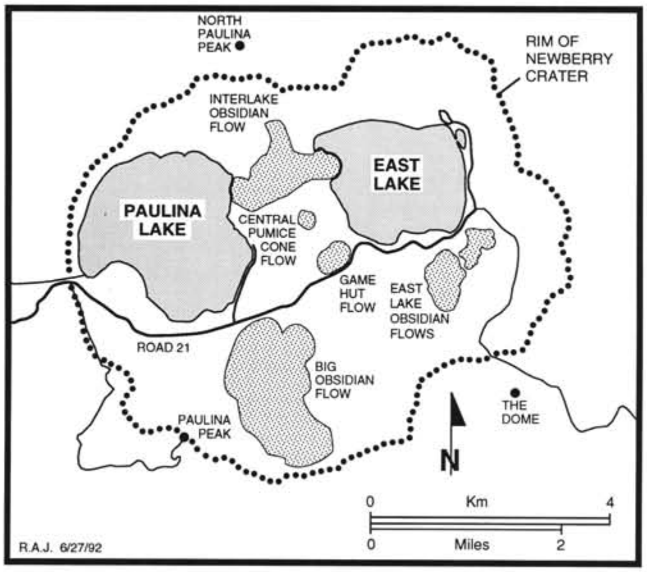


Figure 3. Post-Mazama rhyolite flows in Newberry Crater.

The giant bubbles under the other three craters are less completely preserved (b, c, and d in Figure 9). They are generally a bubble-wall segment beneath a thick, massive obsidian overhang with a fan of blocky debris forming a slope to the back wall of the

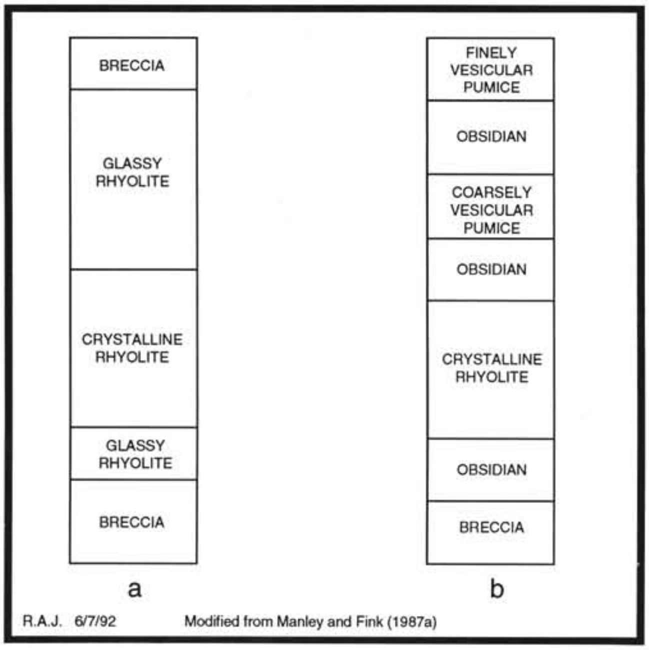


Figure 4. (a) Traditional view of rhyolite flows; (b) new view of rhyolite flows.

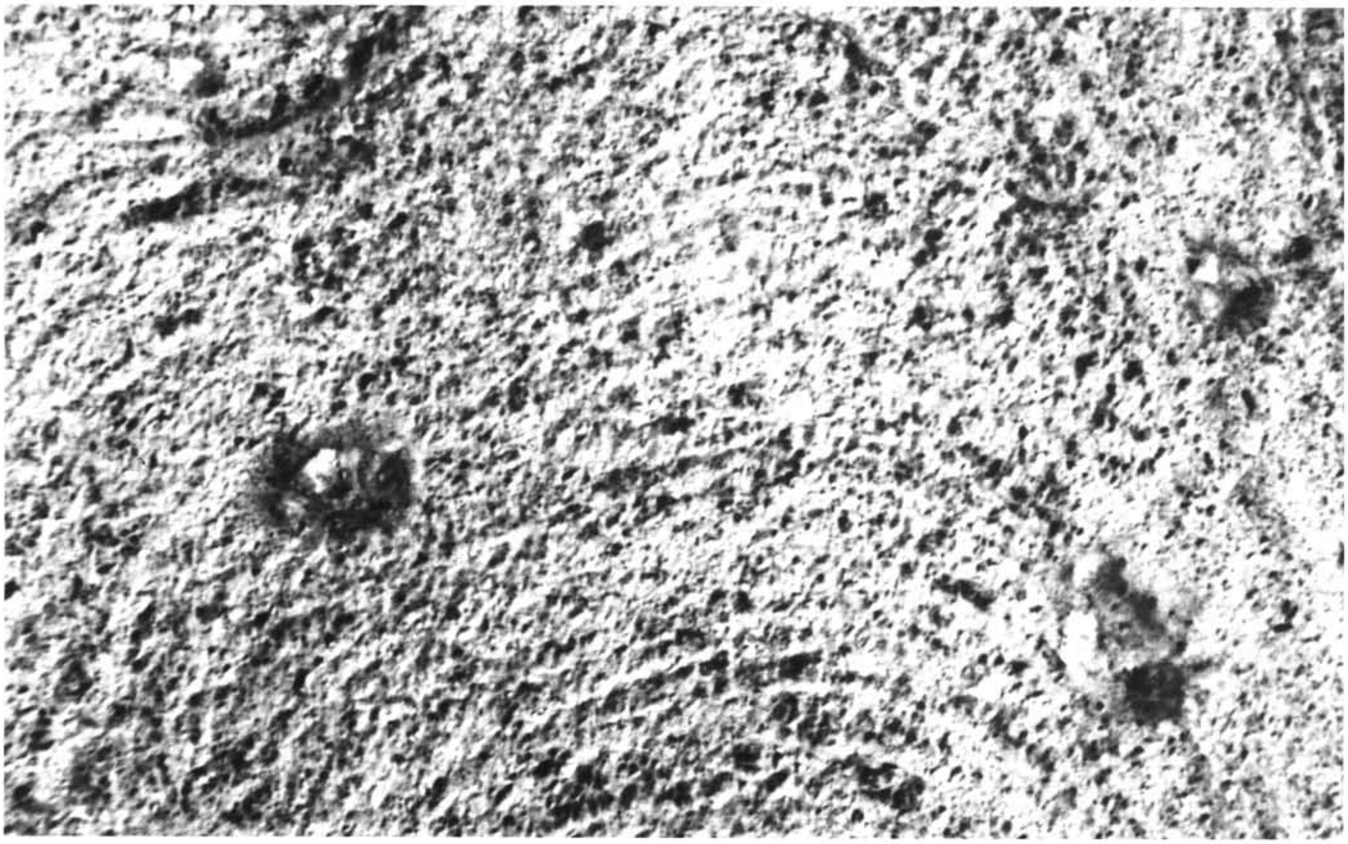


Figure 5. Vertical air photo view of four craters on surface of Big Obsidian Flow. Crater in lower right corner is designated "R"; other craters in view are "S," "Q," and "G," as identified in Figure 6.

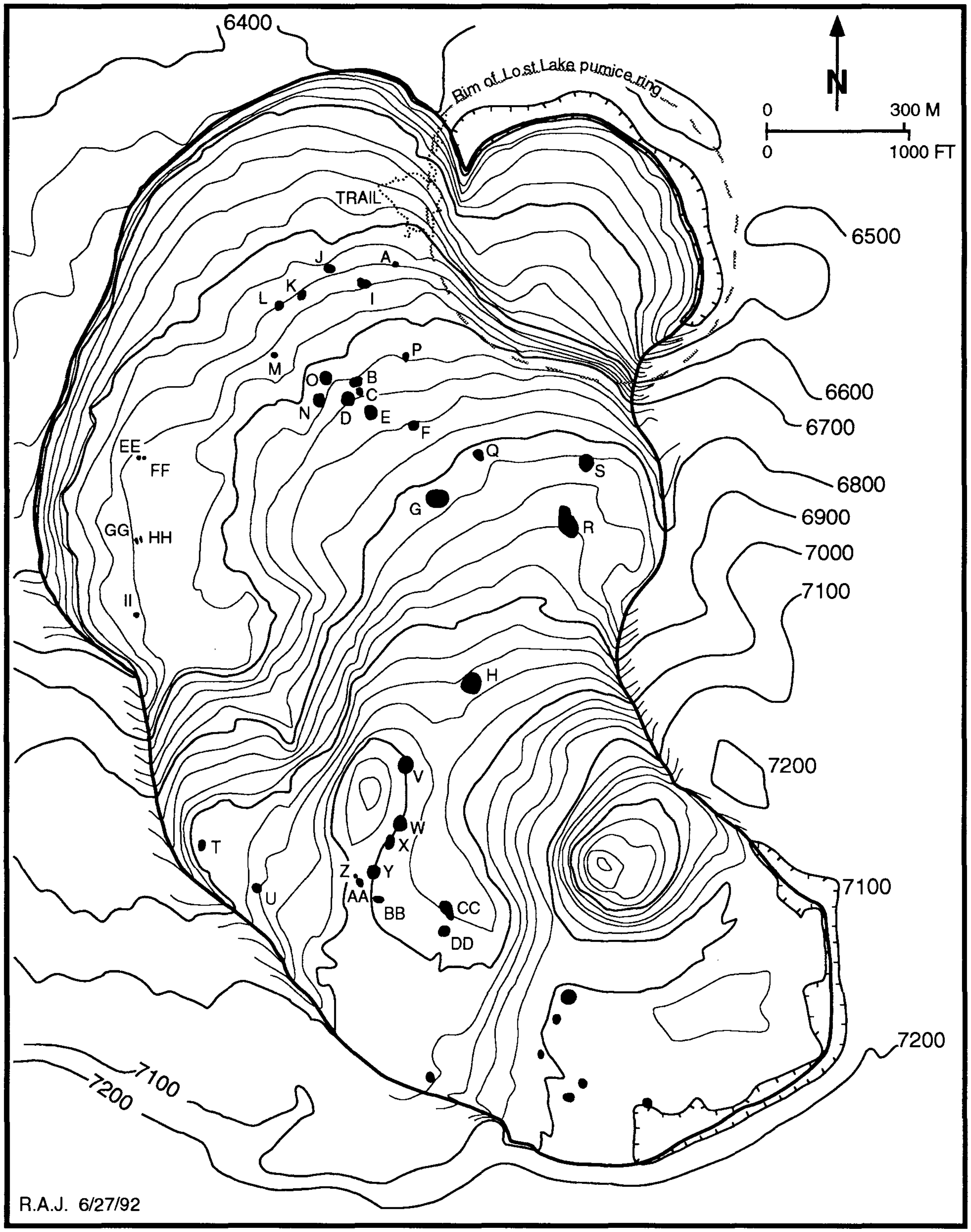


Figure 6. Irregular black dots show size and location of explosion craters on Big Obsidian Flow. Letters are informal names for craters. Route of Big Obsidian Flow Trail is marked.

Figure 7. Entrance to spherical bubblelike cavity below Crater "A" (Figure 6).

bubble. The continuously curving bubble walls suggest that the walls continue well below the rubble in all giant bubbles. Giant bubbles may exist under all craters, but rubble from the crater walls fill them.

Where a bubble wall is exposed in cross section, the flow-banded rhyolite of the bubble wall can be seen to grade outward into massive obsidian. The flow-banded rhyolite of the bubble wall consists of numerous thin layers (1-3 mm each) like the layers of an onion.

CRATERS ON THE INTERLAKE OBSIDIAN FLOW

The Interlake Obsidian Flow possesses five craters (Figure 10). These craters are shallower than those on the Big Obsidian Flow, with gentler crater-wall slopes and no observable spherical cavities. The lack of observable bubblelike cavities may result from the greater age of this flow, about five times older than the Big Obsidian Flow. Over time, the bubbles presumably fill with rubble due to frost wedging and thermal expansion and contraction.

CRATERS ON OTHER RHYOLITE FLOWS

No craters are known to exist on the East Lake obsidian flows. If they exist, they may be hidden under a layer of Newberry pumice from the explosive phase of the Big Obsidian Flow eruption. Heavy vegetation obscures evidence of explosion craters on the flows associated with the Central Pumice Cone.

Six craters have been photo-identified on the Rock Mesa rhyolite flow on the southwest flank of South Sister, but none have been identified on the Devils Hill chain of rhyolite domes and flows on the southeast flank of South Sister.

Craters of similar morphology have been reported on the Glass Mountain rhyolite flow at Medicine Lake Volcano in California (Green and Short, 1971; Fink and Manley, 1989), but no evidence of large spherical cavities has been observed below the floors of craters that have be examined (J.H. Fink, personal communication, 1991).

FORMATION OF GIANT BUBBLES AND CRATERS

The explanation for these craters prior to the work of Fink (1983) involved steam eruptions that resulted when a flow contacted surface waters. For example, Green and Short (1971) included a photo of some of the small craters on the Glass Mountain rhyolite flow at Medicine Lake volcano in California and suggested they were due to explosive activity as the flow moved over wet ground. MacLeod and others (1982) mentioned the scattered small craters on the surface of the Big Obsidian Flow and suggested that they might be of phreatic origin. However, the locations of the craters on the flows suggest an internal origin, not one from steam generated beneath the flow. On the Interlake Obsidian Flow, the five known explosion craters are located near the vent in the final lava erupted from the vent. If the obsidian flow buried surface water or snow, it seems unlikely that explosion craters would have formed after such a considerable amount of lava had passed over the site. Also, the explosion craters are positioned over an original landscape that was probably topographically high and ridgelike, a surface unlikely to host any significant amount of water. On the Big Obsidian Flow, about a third of the craters are located near the vent. Furthermore, the craters penetrate the flow only to a depth of about 15 m, despite a flow thickness of 30 m or more. This suggests that these craters were formed by processes within the flow rather than by interaction of the flow base with surface water, wetlands, or snow.

Manley and Fink (1987b) noted that the locations of small explosion pits on several Holocene rhyolite flows were inconsistent with the flows' overriding snow or standing water. They suggested that the craters were the result of explosive release of vapor from the zone of coarsely vesicular pumice. Fink and Manley (1989) suggested that the surface layers (finely vesicular pumice and obsidian) of rhyolite flows form a cap that is virtually impervious to exsolving gases trapped beneath. This gas-charged zone becomes the frothy, coarsely vesicular pumice layer. They further suggested that diapirs of coarsely vesicular pumice rise to the surface and generate explosions to form the craters. This may be a partial explanation for some craters; on the Big Obsidian Flow, however, fewer than a third of the craters occur in conjunction with distinct surficial evidence (alternating dark and light bands) of such diapirs. Six craters occur in a series of these bands, and part of a bubble wall is preserved in one of them. The remaining craters occur in areas where most of the surface is finely vesicular pumice. The occurrence of obsidian and coarsely vesicular pumice seems to be associated with the craters or with scattered outcrops that form no larger pattern.

Apparently, exsolving gases gradually coalesce to form growing bubbles that slowly rise toward the surface. As these bubbles reach the impervious surface layers, they continue to coalesce to form giant bubbles. When the pressure in these bubbles exceeds the strength of the surface layers, the bubbles vent explosively and form steep-sided craters with rims of rubbly debris. Fallback of roof material and collapse of overly steep crater walls widen the craters, fill the floor with rubble, and obscure evidence of the bubbles in most of the craters, although enough evidence remains to suggest the process of crater formation.

The bubble walls also preserve evidence that smaller gas bubbles were still migrating toward the giant bubble at the time of rupture to the surface. In places where a cross section through the main bubble wall is found, smaller bubbles can be seen behind the main bubble wall. Where the wall material between bubbles was thin enough at the time of rupture of the giant bubble, the walls of the smaller bubbles can be seen to have ruptured into the giant bubble. Where the intervening walls were thicker, the smaller bubbles form bulbous protrusions into the main bubble.

Groups of craters may be located in areas where the dissolved-gas content of the lava was higher. A higher dissolved-gas content would have allowed the formation of more bubbles in these areas. Also, some of the larger craters show evidence of multiple explosions, such as elongated form and low rim deposits crossing the floor of the crater. These multiple craters suggest the contemporaneous explosions of multiple giant bubbles. One preserved bubble wall segment occurs in a crater within a crater: Crater "G" (d) in Figure 9.

The two areas on the Big Obsidian Flow that lack craters can be explained in two ways. The central western area, where the surface flow banding is highly contorted, appears to be the earliest lobe of the flow; the subsequent flow activity produced additional deformation that has probably destroyed most craters in this area. Five small, difficult-to-identify craters occur in this area. The lack of craters within the Lost Lake pumice ring is probably due to the steep slope of the pumice ring down which the flow moved to enter the ring. This probably disrupted the coarsely vesicular pumice layer sufficiently to break up any bubbles that were forming, and insufficient gas remained to reform them.

Figure 8. Interior of spherical bubblelike cavity below Crater "A." Ice-floored pool in center usually remains all summer.

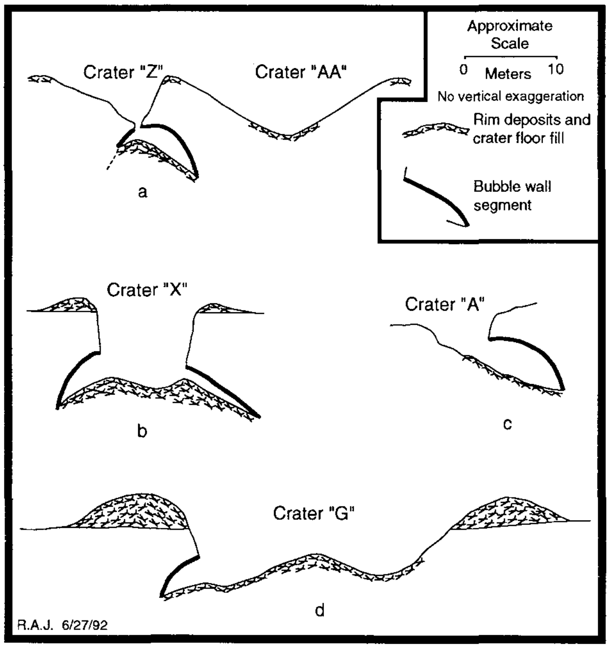


Figure 9. Sketch of cross sections through craters that contain giant bubble wall fragments.

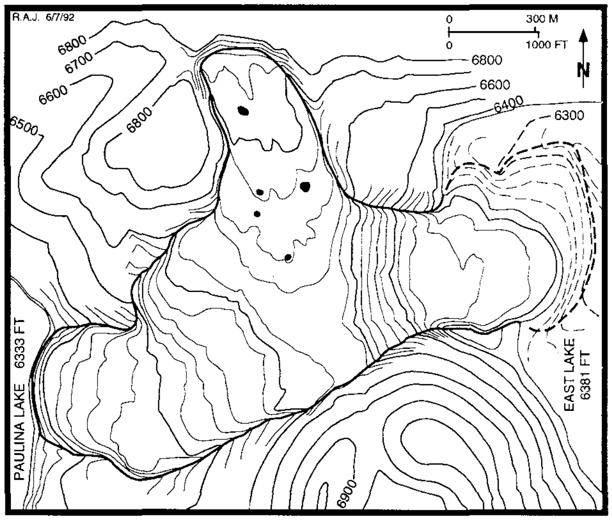


Figure 10. Irregular black dots show size and location of craters on Interlake Obsidian Flow. Dashed lines show contours and flow margin below surface of East Lake. Note that Interlake Obsidian Flow extends into East Lake.

ACKNOWLEDGMENTS

I would like to thank Bruce Nolf, Larry Chitwood, and Dave Sherrod for their encouragement to write this article and their suggestions, comments, and review.

REFERENCES CITED

Bacon, C.R., 1983, Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A.: Journal of Volcanology and Geothermal Research, v. 18, p. 57-115.

Fink, J.H., 1983, Structure and emplacement of a rhyolitic obsidian flow: Little Glass Mountain, Medicine Lake Highland, Northern California: Geological Society of America Bulletin, v. 94, p. 362-380.

Fink, J.H., and Manley, C.R., 1987, Origin of pumiceous and glassy textures in rhyolite flows and domes: Geological Society of America Special Paper 212, p. 77-88.

———1989, Explosive volcanic activity generated from within advancing silicic lava flows: International Association of Volcanology and Chemistry of the Earth's Interior, Proceedings in Volcanology 1, p. 167-179.

Friedman, I., 1977, Hydration dating of volcanism at Newberry Crater, Oregon: U.S. Geological Survey Journal of Research, v. 5, no. 3, p. 337-342.

Green, J., and Short, N.M., eds., 1971, Volcanic landforms and surface features: A photographic atlas and glossary: Springer-Verlag, New York, 519 p.

Linneman, S.R., 1990, The petrologic evolution of the Holocene magmatic system of Newberry volcano, central Oregon: Laramie, Wyo., University of Wyoming doctoral dissertation, 193 p.

MacLeod, N.S., and Sherrod, D.R., 1988, Geologic evidence for a magma chamber beneath Newberry volcano, Oregon: Journal of Geophysical Research, v. 93, no. B9, p. 10,067- 10,079.

MacLeod, N.S., Sherrod, D.R., and Chitwood, L.A., 1982, Geologic map of Newberry volcano, Deschutes, Klamath, and Lake Counties, Oregon: U.S. Geological Survey Open-File Report 82-847, scale 1:62,500.

MacLeod, N.S., Sherrod, D.R., Chitwood, L.A., and Jensen, R.A., in preparation, Geologic map of Newberry volcano, Deschutes, Klamath, and Lake Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series, scale 1:62,500 and 1:24,000.

Manley, C.R., and Fink, J.H., 1987a, Internal textures of rhyolite flows as revealed by research drilling: Geology, v. 15, p. 549-552.

———1987b, Endogenic explosive activity on rhyolite flows [abs.]: Geological Society of America Abstracts with Programs, v. 19, p. 758.

Pearson, F.J., Davis, E.M., and Tamers, M.A., 1966, University of Texas radiocarbon dates IV: Radiocarbon, v. 8, p. 453-466.

Peterson, N.V., and Groh, E.A., 1969, The ages of some Holocene volcanic eruptions in the Newberry volcano area, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 31, no. 4, p. 73-87.

Robinson, S.W., and Trimble, D.A., 1983, U.S. Geological Survey, Menlo Park, California, radiocarbon measurements III: Radiocarbon, v. 25, no. 1, p. 143-151.

Russell, I.C., 1905, Preliminary report of the geology and water resources of central Oregon: U.S. Geological Survey Bulletin 252, 138 p.

Stuiver, M., and Reimer, P.J., 1986, A computer program for radiocarbon age calibration: Radiocarbon, v. 28, no. 2B, p. 1022-1030.

Williams, H., 1935, Newberry volcano of central Oregon: Geological Society of America Bulletin, v. 46, p. 253-304. ☐

Letter to the editor

I wish to offer corrections for "A history of geologic study in Oregon," by Orr and Orr, in *Oregon Geology*, v. 54, no. 5, September 1992.

At the time that he enrolled on the Williamson expedition, Dr. John Strong Newberry had no academic appointment. He was actually a well-trained medical doctor who was embarking on his first official expedition as a geologist. It was not until 1866 that he assumed the Chair of Geology and Paleontology in the School of Mines at Columbia College, New York City (cf. *Bulletin of the Geological Society of America*, v. 4, September 1893, p. 396). He retained this position until his death 26 years later.

I also take issue with the Orrs' statement that "Newberry was able to study the geology of the. . . John Day regions in great detail," describing beds as "white, others pink, orange, blue, brown, or green." Newberry did *not* travel to the John Day River region. A careful reading of his description and route shows that he was instead describing the dramatic and colorful strata displayed in the Deschutes Formation in the region of the confluence of the Deschutes and Metolius Rivers near what is now Cove Palisades State Park. Farther downstream he would have passed through some John Day Formation, but less dramatic than the upstream Deschutes Formation.

I consider these minor corrections to an admirable article.

—Stuart G. Garrett, MD
21663 Paloma Drive
Bend, OR 97701

THESIS ABSTRACTS

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

Geology of the Krumbo Reservoir quadrangle, southeastern Oregon, by Jenda A. Johnson (B.S., Oregon State University, 1992), 56 p.

The geology of the Krumbo Reservoir quadrangle, which is located on the west side of the Steens Mountain escarpment in southeastern Oregon, consists of a bimodal assemblage of Miocene olivine basalt and rhyolite ash-flow tuff characteristic of northwestern Basin and Range volcanism. The assemblage contains three major stratigraphic markers, the Steens Basalt (~16 Ma), the Devine Canyon Ash-Flow Tuff (~9.5 Ma), and the Rattlesnake Ash-Flow Tuff (~6.7 Ma). Locally exposed units of limited extent are upper Miocene olivine basalt, emplaced between Devine Canyon and Rattlesnake time, and tuff and tuffaceous sedimentary rocks that underlie the Devine Canyon Ash-Flow Tuff. The entire study area is underlain by the chemically homogeneous lava flows of Steens Basalt. The Steens Basalt is unconformably overlain by a sequence as thick as 30 m of tuff and tuffaceous sedimentary strata and, locally, by the Devine Canyon Ash-Flow Tuff (maximum thickness 17 m). The basalt of Hog Wallow lies conformably above the Devine Canyon Ash-Flow Tuff in the northern part of the map area. The Rattlesnake Ash-Flow Tuff, which includes some poorly exposed tufaceous sedimentary strata at its base, conformably overlies the Devine Canyon Ash-Flow Tuff and forms the capping unit in the map area. The ash-flow tuffs form mesas and flat-topped ridges. The rhyolite ash-flow tuffs spread laterally over tens of thousands of square kilometers in southeastern Oregon.

Two different sets of faults form conspicuous escarpments in the map area: (1) north-striking faults that parallel Basin and Range faults and (2) numerous closely spaced west-northwest-striking faults that parallel the Brothers fault zone. In the map area, the Devine Canyon Ash-Flow Tuff changes map pattern from sheet-forming in the northwest to lobe-forming in the southeast. The elongate erosional remnants of the Devine Canyon Ash-Flow Tuff parallel the Brothers fault zone and probably result from inverted topography as a consequence of thicker deposition of the tuff in paleodrainages. It seems likely that this zone marks the ancient change in slope from flat ground with surface water present on the northwest to better drained ground south and southeastward. Dutch Oven, a closed depression 1.5 km in diameter, is a relict secondary hydroexplosion crater that formed when the hot Rattlesnake pyroclastic flow interacted with surface water: the resulting steam blasted through the overlying deposits, leaving a large pit. At least six such pits are found in the Rattlesnake Ash-Flow Tuff in this part of Harney Basin.

Process of sea-cliff erosion on the Oregon coast: From neotectonics to wave runup, by Shyuer-Ming Shih, (Ph.D., Oregon State University, 1992), 135 p.

Sea-cliff erosion is a significant problem along the Oregon coast in that many communities have been built on terraces affected by bluff retreat. There is considerable coastwide variability in the rates of cliff erosion. This variability is attributed in part to tectonic activity that is causing differential interseismic uplift along the coast. Analyses of geodetic survey data and tide-gauge measurements have established rates of local sea-level rise along the entire coast, including areas lacking direct tide measurements. A littoral cell around the Lincoln City area on the central Oregon Coast is experiencing the smallest degree of tectonic uplift and this results in the highest rate of local sea-level rise and significant sea-cliff erosion. High cliffs cut into a Pleistocene marine terrace, consisting of semi-consolidated sands, back the beaches over the length of the littoral cell and supply coarse-grained sands to the beaches in the south of the cell. Dissections of multimodal grain-size distributions of the beach and cliff sands have shown that coarse-fraction modes are resistant to longshore wave dispersion, and this produces a marked longshore variation in the coarseness of beach sand, in the beach morphology, and in the nearshore processes affecting the cliff-toe erosion.

Two years of monthly beach-profile surveys at eleven beaches along the Lincoln City littoral cell have shown that there is a significant difference in volumetric changes between beaches of different sand sizes. The coarse-grained reflective beaches are much more dynamic in profile changes, and the total quantity of sand moved under a given storm is much greater than on the fine-grained dissipative beaches. Rip-current embayments are also more important to cliff erosion on the reflective beach, producing bluff retreat that has a high degree of spatial variability and is extremely episodic. Risk assessments based on the probability curve of the extreme runup have demonstrated that the height of the cliff-beach junction and the beach slope are important factors in controlling the risk of cliff-toe erosion. Runup measurements using video techniques on three beaches having contrasting morphologies suggest that the maximum runup calculation based on the empirical relationship derived by Holman and Sallenger (1985) appears to be valid, although the permeability effects might have contributed to a significance deviation in the prediction of maximum runup on a sediment-starved beach.

Gravity maps, models, and analysis of the greater Portland area, Oregon, by Paul T. Beeson (M.S., Portland State University, 1990), 79 p.

Growing concern over earthquakes in the Pacific Northwest has prompted the mapping and location of near-surface faults in the Portland, area, Oregon. Visible evidence of faults is poor, which requires the use of geophysical methods to assist in mapping and defining structures in the basin. Gravity maps and models may help in addressing this problem.

Two free-air gravity models were produced. The first model constructed from existing data crosses the basin from Petes Mountain northeast to the Columbia River. The second model is from a gravity survey along Forsythe Road near Clackamas Heights.

The line crossing the basin confirms previous models that located a 320-m down-to-the-east offset of the Columbia River Basalt Group rocks. This model tested and confirmed the hypothesis that the gravity high near Oak Grove, Oregon, was caused by an Eocene basalt high rather than by an intrusive related to the Boring Lava. Mount Scott was modeled as a 2.87-g/cm^3 basalt high with a sediment-filled channel along the southwest flank. The east side of the basin is modeled as faulted, confirming previous work.

The Clackamas Heights line was designed to locate the Portland Hills fault, but due to the depth to the fault and lack of subsurface control of the Waverly Heights basalt, the position of the fault could not be determined.

Complete Bouguer, free-air, and residual Bouguer anomaly maps were produced from 1,600 data stations compiled from previous gravity surveys. These maps are consistent with the state maps produced by Berg and Thiruvathukal in 1967 but show more detail. The prominent features on the maps are a gravity low centered over the Tualatin basin and a gravity high near Oak Grove, Oregon. At their western edges, the maps show the high-gravity north-south contours caused by the Coast Range. The east edge of the map exhibits north-south low-gravity contours caused by the Cascade Mountain Range.

The Portland basin has been called a pull-apart basin associated with wrench tectonics. This investigation supports the idea that the Portland and the Tualatin basins are related to the strike-slip motion and are formed by that motion. □

In memoriam: Herbert G. Schlicker

He was born July 30, 1920, in Grangeville, Idaho, and was raised on a farm in the Salem, Oregon, area. He served in the U.S. Army's 96th Bombardier group during World War II and was captured and held as prisoner of war in Germany. In 1948, he married Bethene G. Futter.

Herbert G. Schlicker

He graduated from Oregon State College, now Oregon State University, in 1949 and earned a master's degree in geology from the college in 1954. After working as a soils engineer with the Oregon Highway Department and as a geologist for a Louisiana oil company, he joined the Oregon Department of Geology and Mineral Industries (DOGAMI) in 1955. He retired from service with DOGAMI in 1980 to become founder of Schlicker and Associates, a geologic consulting firm.

During his almost 25 years with DOGAMI, he provided leadership in many new ways. Together with Lloyd Staples of the University of Oregon, he was instrumental in bringing about the registration of geologists in Oregon. He was first to chair the Oregon Board of Geologist Examiners and served on that board for many years. He also planned and conducted numerous geology and engineering geology studies for DOGAMI, including the Department's first rock material resource assessment, *Gravel Resources in Relation to Urban Development in the Salem Area* (1961), and, together with consulting geologist Robert Deacon, its first engineering geology study, *Engineering Geology of the Tualatin Valley Region, Oregon* (1967). His last geologic study, *Geology and Geologic Hazards of Northwestern Clackamas County, Oregon*, was published as DOGAMI Bulletin 99 in 1980.

As a geologist with DOGAMI, he was principal author, investigator, or compiler of 26 published studies and coauthor of four. He also produced more than 100 unpublished reports and geologic studies for state and local government agencies and the U.S. Geological Survey. In addition, he provided engineering geology information to individuals, companies, and government bodies.

His professional activity included serving in the chair of the geology section of the Oregon Academy of Science and of the Engineering Geologists of Oregon and as chair and treasurer of the Oregon section of the American Institute of Professional Geologists. He was a member of the Advisory Committee of the Association of Engineering Geologists and of the Hazards Committee of the American Institute of Professional Geologists.

To his colleagues in the Oregon Department of Geology and Mineral Industries and to the many people who worked with him professionally, he was also a dear friend, whose quiet sense of humor, great story-telling ability, and legendary skill as an airplane pilot are often remembered.

Herbert G. Schlicker died in his Clackamas home on November 13, 1992, after a long illness. □

OMSI moves to great new facility

by John E. Allen, Honorary Life Member of OMSI

The Oregon Museum of Science and Industry (OMSI) in Portland has completed its move to a new location.

OMSI's new address is now 1945 SE Water Avenue, Portland, OR 97214-3354. The museum can be contacted by several phone numbers: Main number is (503) 797-4000; for advance ticket sales (503) 797-5600, or toll-free for long distance 1-800-957-6654; recorded information about hours, rates, and events is available at (503) 797-OMSI. Seven other numbers give recordings on various theaters, shows, and events.

OMSI summer hours, from Memorial Day to Labor Day, are Saturday through Wednesday, 9:30 a.m. to 7 p.m.; Thursday and Friday, 9:30 a.m. to 9 p.m. Winter hours are Saturday through Wednesday, 9:30 a.m. to 5:30 p.m.; Thursday and Friday, 9:30 a.m. to 9 p.m.

Basic admission is $6.50 for adults, $4 for children, and $5.50 for senior citizens. The 70-mm supermovie OMNIMAX, with a separate outside entrance, costs the same. Admission to the planetarium (Sky Theater) is $4, $3, and $3.50, respectively. Combination tickets are available at reduced prices.

Annual memberships range from $50 for individuals to $85 for families, offering free museum admission and reduced prices for OMNIMAX, Sky Theater, and the Laser Light Show.

Construction began in February 1991 for this $40-million facility that covers 210,000 ft^2 on an 18½-acre site on the east bank of the Willamette River in downtown Portland. The museum opened with great fanfare on October 18, 1992.

OMSI was designed for 100,000 visitors per year but until recently had already handled 600,000. It is expected that annual visitors will exceed a million in 1993.

This remarkable "next-generation" museum is three times the size of the old one and contains, beside the $6-million OMNIMAX and a new $2-million planetarium called "Sky Theater," five exhibition halls ranging from 6,000 to 14,000 ft^2, a restaurant, a science store, and, importantly, 800 spaces for parking in two parking lots. The core, a renovated power-plant building, and the new additions give a feeling of openness and spaciousness that had been lacking in the old OMSI building. OMSI can easily accommodate parties of up to 4,300 for conventions, weddings, and the like. The annual banquet and meeting of the Portland Chapter of Sigma Xi will be held at OMSI.

In its nearly 50-year-long history, OMSI has never received any government subsidies. It has always operated on memberships, sales, admissions, and private donations. The fund drive for the new facility was kicked off by the Portland General Electric Company donation of its 82-year-old steam generating station and the land around it. Several trusts and the National Science Foundation then each donated more than a million dollars, and many thousand private contributors gave from $25 to $100 each.

The goal of OMSI has always been to draw television's nonthinking viewers and observers deeper into science, giving them an enjoyable educational experience as it makes them think. Classes and summer camps have always been parts of OMSI's program, and the museum is now becoming "customer-service oriented."

As much as possible, the exhibits in the six large areas of earth science, life science, information science, physical science, and two others for changing or visiting exhibitions are "interactive," which is now considered to be much more than just pushing a button. Visitors can design and try out model trucks, windmills, and paper airplanes, using four wind tunnels. They can see how their own building designs react to simulated earthquakes with vibrating shaking tables. Both children and adults can load and unload simulated cargo with a 1-ton, 15-ft steel crane. In the electronics lab, they can construct circuits and radios. In another area, they can make their own holograms. Many of the exhibits from the old building were renovated and moved to the new facility, but overall, 70 percent of the exhibits are new.

The new human embryology exhibit, when finished, will be the most extensive of its kind in the world. It will display between 40 and 50 human embryo and fetus specimens (from old, European university collections), representing different stages of development in the womb. In the new information-science area, visitors can beam messages into space with a 20-ft tower, experiment with video telephones and learn how satellites work. They will be able to walk about with cellular phones in different simulated geographic areas.

The traveling exhibits, now being cooperatively built and shown by a consortium of seven museums, occupy their own area, and they are what makes the new OMSI a world-class museum. Each exhibit may cost from $100,000 to $1,000,000 (cost of "Star Trek," the last exhibit built by OMSI). Some of the shows now on tour include "Super Heroes: A High-Tech Adventure," "Nature's Fury," "Designer Genes," and "1492: Two Worlds of Science." "Science Circus" will arrive soon.

The 330-seat OMNIMAX theater has a five-story, domed screen and a 6-channel, state-of-the-art audio system that surrounds you a you experience the world's latest 70-mm-film cinematic technology. The first showing is "Ring of Fire," illustrating the destructive volcanic activity of the Pacific Rim. The first showing in the new 200-seat Murdock Sky Theater is "Cosmic Fury," a 35-minute show narrated by James DePreist, the director of the Oregon Symphony. ☐

Seismic Safety Policy Advisory Commission publishes report

The Oregon Seismic Safety Policy Advisory Commission (SSPAC) was put into place by the 1991 Legislature to reduce the exposure of Oregon to earthquake hazards.

Specific activities were to include influencing government policy, improving public understanding, supporting research, implementing mitigation, and guiding preparation for response and recovery.

Recent geologic and geophysical research in the Pacific Northwest and in Oregon in particular now demonstrate the very real possibility of a large earthquake for western Oregon.

A report summarizing the activities and recommendations of the SSPAC has been completed and submitted to Governor Barbara Roberts and the Legislators for consideration during the 1993 Legislative Session. Chair person Roger McGarrigle stated, "Policies for earthquake mitigation developed and implemented in Oregon at the state and local level and in the private and public sectors may no longer be adequate." He further stated, "We recognize the need to balance need against cost benefit and also to begin to recognize societal priorities in the mitigation of earthquake risk."

Copies of the report are available from the Nature of Oregon Information Center located in the new state office building in Portland, Oregon. The address is Suite 177, 800 NE Oregon Street, and the phone number is (503) 731-4444. Cost of the publication is $5.00 ☐

The Coos Bay fireball of February 24, 1992—Oregon's brightest

At 12:11 a.m., Pacific Standard Time, on February 24, 1992, a very bright fireball occurred over southwestern Oregon and northwestern California (see cover illustration). More than sixty people reported the sighting (Pugh 1992).

The fireball was seen in an area extending from Corvallis, Oregon, in the north, to Coalinga, California, in the south; and from Bend, Oregon, in the east to 10 mi west of Cape Mendocino, California, over the Pacific Ocean in the west.

The path of the fireball was north to south, entering the atmosphere southwest of Coos Bay and disappearing west of Trinidad, California, over the Pacific Ocean. Most observers reported a very steep angle of descent of 70° to 90°.

The magnitude was much brighter than a full moon, illuminating over 25,000 mi^2 as if it were broad daylight. The initial flash of light was reported as lasting up to 3 seconds. There were many reports of moving shadows. The duration of the entire event was 5 to 6 seconds.

The apparent size of the fireball was reported from one to eight times the diameter of a full moon, with two to three times the diameter being the most common.

Most observers saw a round to teardrop-shaped object that was green-blue-white. It had a long, pulsating, yellow-orange-red tail producing many "sparks and flames."

The fireball was quite dim after the initial flash. It became brighter as it moved downrange and flared near the end of its path, breaking into three to ten fragments.

There were several reports of electrophonic sound. Electrophonic sounds are produced by very low frequency electromagnetic waves that occur in the wake of the fireball and then are transduced to some object on the ground that produces sound. These sounds are heard at the same time the fireball is seen. (Keay, 1980). In Coos Bay, a house reportedly "trembled" for several seconds, and a metal lamp in the house made a "static-sizzling" sound for 2 to 3 seconds.

Other reports from Coos Bay included the following: People standing near a three-story building heard a "hissing" sound and felt something; one person sitting in an automobile heard a "crackling" sound; one person standing near a chain-link fence reported a "hissing" sound. One person in an automobile north of Coos Bay at Florence, Oregon, heard a "bang" and a "pop." One person near Winston, Oregon, felt a shock or concussion. Another person, also in an automobile north of Klamath falls, Oregon, reported feeling pressure on his chest. All of these sounds were heard at the same time the fireball was seen.

No sonic booms or rumblings were reported. So far, there is no evidence that any material from this event reached the Earth's surface. With the end point of the fireball's path over the ocean, recovery would be very unlikely, even if meteorites had been produced. However, it appears to be the brightest fireball on record over Oregon.

REFERENCES CITED

Keay, C.S.L., 1980, Anomalous sounds from the entry of meteor fireballs: Science, v. 210 (October 3, 1980), p. 11-15.

Pugh, R.N., 1992, Fireballs: Smithsonian Institution Global Volcanism Network, March 31, v. 17, no. 3, p. 18.

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGICAL MAP SERIES

	Price	√
GMS-4 Oregon gravity maps, onshore and offshore. 1967	4.00	
GMS-5 Powers 15-minute quadrangle, Coos and Curry Counties. 1971	4.00	
GMS-6 Part of Snake River canyon. 1974	8.00	
GMS-8 Complete Bouguer gravity anomaly map, central Cascade Mountain Range. 1978	4.00	
GMS-9 Total-field aeromagnetic anomaly map, central Cascade Mountain Range. 1978	4.00	
GMS-10 Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	4.00	
GMS-12 Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	4.00	
GMS-13 Huntington and parts of Olds Ferry 15-minute quadrangles, Baker and Malheur Counties. 1979	4.00	
GMS-14 Index to published geologic mapping in Oregon, 1898-1979. 1981	8.00	
GMS-15 Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	4.00	
GMS-16 Free-air gravity and complete Bouguer gravity anomaly maps, southern Cascades, Oregon. 1981	4.00	
GMS-17 Total-field aeromagnetic anomaly map, southern Cascades, Oregon. 1981	4.00	
GMS-18 Rickreall, Salem West, Monmouth, and Sidney 7½-minute quadrangles, Marion and Polk Counties. 1981	6.00	
GMS-19 Bourne 7½-minute quadrangle, Baker County. 1982	6.00	
GMS-20 S½ Burns 15-minute quadrangle, Harney County. 1982	6.00	
GMS-21 Vale East 7½-minute quadrangle, Malheur County. 1982	6.00	
GMS-22 Mount Ireland 7½-minute quadrangle, Baker and Grant Counties. 1982	6.00	
GMS-23 Sheridan 7½-minute quadrangle, Polk and Yamhill Counties. 1982	6.00	
GMS-24 Grand Ronde 7½-minute quadrangle, Polk and Yamhill Counties. 1982	6.00	
GMS-25 Granite 7½-minute quadrangle, Grant County. 1982	6.00	
GMS-26 Residual gravity, northern, central, and southern Oregon Cascades. 1982	6.00	
GMS-27 Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1° x 2° quadrangle. 1982	7.00	
GMS-28 Greenhorn 7½-minute quadrangle, Baker and Grant Counties. 1983	6.00	
GMS-29 NE¼ Bates 15-minute quadrangle, Baker and Grant Counties. 1983	6.00	
GMS-30 SE¼ Pearsoll Peak 15-minute quadrangle, Curry and Josephine Counties. 1984	7.00	
GMS-31 NW¼ Bates 15-minute quadrangle, Grant County. 1984	6.00	
GMS-32 Wilhoit 7½-minute quadrangle, Clackamas and Marion Counties. 1984	5.00	
GMS-33 Scotts Mills 7½-minute quadrangle, Clackamas and Marion Counties. 1984	5.00	
GMS-34 Stayton NE 7½-minute quadrangle, Marion County. 1984	5.00	
GMS-35 SW¼ Bates 15-minute quadrangle, Grant County. 1984	6.00	
GMS-36 Mineral resources of Oregon. 1984	9.00	
GMS-37 Mineral resources, offshore Oregon. 1985	7.00	
GMS-38 NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	7.00	
GMS-39 Bibliography and index, ocean floor and continental margin off Oregon. 1986	6.00	
GMS-40 Total-field aeromagnetic anomaly maps, Cascade Mountain Range, northern Oregon. 1985	5.00	
GMS-41 Elkhorn Peak 7½-minute quadrangle, Baker County. 1987	7.00	
GMS-42 Ocean floor off Oregon and adjacent continental margin. 1986	9.00	
GMS-43 Eagle Butte and Gateway 7½-minute quadrangles, Jefferson and Wasco Counties. 1987	5.00	
as set with GMS-44 and GMS-45	11.00	
GMS-44 Seekseequa Junction and Metolius Bench 7½-minute quadrangles, Jefferson County. 1987	5.00	
as set with GMS-43 and GMS-45	11.00	
GMS-45 Madras West and Madras East 7½-minute quadrangles, Jefferson County. 1987	5.00	
as set with GMS-43 and GMS-44	11.00	
GMS-46 Breitenbush River area, Linn and Marion Counties. 1987	7.00	
GMS-47 Crescent Mountain area, Linn County. 1987	7.00	
GMS-48 McKenzie Bridge 15-minute quadrangle, Lane County. 1988	9.00	
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00	
GMS-50 Drake Crossing 7½-minute quadrangle, Marion County. 1986	5.00	
GMS-51 Elk Prairie 7½-minute quadrangle, Marion and Clackamas Counties. 1986	5.00	
GMS-53 Owyhee Ridge 7½-minute quadrangle, Malheur County. 1988	5.00	
GMS-54 Graveyard Point 7½-minute quadrangle, Malheur and Owyhee Counties. 1988	5.00	
GMS-55 Owyhee Dam 7½-minute quadrangle, Malheur County. 1989	5.00	
GMS-56 Adrian 7½-minute quadrangle, Malheur County. 1989	5.00	
GMS-57 Grassy Mountain 7½-minute quadrangle, Malheur County. 1989	5.00	
GMS-58 Double Mountain 7½-minute quadrangle, Malheur County. 1989	5.00	
GMS-59 Lake Oswego 7½-minute quadrangle, Clackamas, Multnomah, and Washington Counties. 1989	7.00	
GMS-61 Mitchell Butte 7½-minute quadrangle, Malheur County. 1990	5.00	
GMS-63 Vines Hill 7½-minute quadrangle, Malheur County. 1991	5.00	
GMS-64 Sheaville 7½-minute quadrangle, Malheur County. 1990	5.00	
GMS-65 Mahogany Gap 7½-minute quadrangle, Malheur County. 1990	5.00	
GMS-67 South Mountain 7½-minute quadrangle, Malheur County. 1990	6.00	
GMS-68 Reston 7½-minute quadrangle, Douglas County. 1990	6.00	
GMS-70 Boswell Mountain 7½-minute quadrangle, Jackson County. 1992	7.00	
GMS-71 Westfall 7½-minute quadrangle, Malheur County. 1992	5.00	
GMS-74 Namorf 7½-minute quadrangle, Malheur County. 1992	5.00	
GMS-75 Portland 7½-minute quadrangle, Multnomah, Washington, and Clark Counties. 1991	7.00	

BULLETINS

33 Bibliography of geology and mineral resources of Oregon (1st supplement, 1936-45). 1947	4.00	
35 Geology of the Dallas and Valsetz 15-minute quadrangles, Polk County (map only). Revised 1964	4.00	
36 Papers on Foraminifera from the Tertiary (v. 2 [parts VII-VIII] only). 1949	4.00	
44 Bibliography of geology and mineral resources of Oregon (2nd supplement, 1946-50). 1953	4.00	
46 Ferruginous bauxite, Salem Hills, Marion County. 1956	4.00	
53 Bibliography of geology and mineral resources of Oregon (3rd supplement, 1951-55). 1962	4.00	
61 Gold and silver in Oregon. 1968 (reprint)	20.00	
65 Proceedings of the Andesite Conference. 1969	11.00	
67 Bibliography of geology and mineral resources of Oregon (4th supplement, 1956-60). 1970	4.00	
71 Geology of lava tubes, Bend area, Deschutes County. 1971	6.00	
78 Bibliography of geology and mineral resources of Oregon (5th supplement, 1961-70). 1973	4.00	
81 Environmental geology of Lincoln County. 1973	10.00	
82 Geologic hazards of Bull Run Watershed, Multnomah and Clackamas Counties. 1974	8.00	
87 Environmental geology, western Coos/Douglas Counties. 1975	10.00	
88 Geology and mineral resources, upper Chetco River drainage, Curry and Josephine Counties. 1975	5.00	
89 Geology and mineral resources of Deschutes County. 1976	8.00	
90 Land use geology of western Curry County. 1976	10.00	
91 Geologic hazards of parts of northern Hood River, Wasco, and Sherman Counties. 1977	9.00	
92 Fossils in Oregon. Collection of reprints from the *Ore Bin*. 1977	5.00	
93 Geology, mineral resources, and rock material, Curry County. 1977	8.00	
94 Land use geology, central Jackson County. 1977	10.00	
95 North American ophiolites (IGCP project). 1977	8.00	
96 Magma genesis. AGU Chapman Conf. on Partial Melting. 1977	15.00	
97 Bibliography of geology and mineral resoures of Oregon (6th supplement, 1971-75). 1978	4.00	
98 Geologic hazards, eastern Benton County. 1979	10.00	
99 Geologic hazards of northwestern Clackamas County. 1979	11.00	
100 Geology and mineral resources of Josephine County. 1979	10.00	
101 Geologic field trips in western Oregon and southwestern Washington. 1980	10.00	
102 Bibliography of geology and mineral resources of Oregon (7th supplement, 1976-79). 1981	5.00	
103 Bibliography of geology and mineral resources of Oregon (8th supplement, 1980-84). 1987	8.00	

MISCELLANEOUS PAPERS

5 Oregon's gold placers. 1954	2.00	
11 Articles on meteorites (reprints from the *Ore Bin*). 1968	4.00	
15 Quicksilver deposits in Oregon. 1971	4.00	
19 Geothermal exploration studies in Oregon, 1976. 1977	4.00	
20 Investigations of nickel in Oregon. 1978	6.00	

SHORT PAPERS

25 Petrography of Rattlesnake Formation at type area. 1976	4.00	
27 Rock material resources of Benton County. 1978	5.00	

OREGON GEOLOGY
Suite 965, 800 NE Oregon Street # 28, Portland, OR 97232

Second Class Matter
POSTMASTER: Form 3579 requested

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

SPECIAL PAPERS

	Price	√
2 Field geology, SW Broken Top quadrangle. 1978	5.00	
3 Rock material resources, Clackamas, Columbia, Multnomah, and Washington Counties. 1978	8.00	
4 Heat flow of Oregon. 1978	4.00	
5 Analysis and forecasts of demand for rock materials. 1979	4.00	
6 Geology of the La Grande area. 1980	6.00	
7 Pluvial Fort Rock Lake, Lake County. 1979	5.00	
8 Geology and geochemistry of the Mount Hood volcano. 1980	4.00	
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00	
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00	
11 Theses and dissertations on geology of Oregon. Bibliography and index, 1899-1982. 1982	7.00	
12 Geologic linears, N part of Cascade Range, Oregon. 1980	4.00	
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00	
14 Geology and geothermal resources, Mount Hood area. 1982	8.00	
15 Geology and geothermal resources, central Cascades. 1983	13.00	
16 Index to the *Ore Bin* (1939-1978) and *Oregon Geology* (1979-1982). 1983	5.00	
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00	
18 Investigations of talc in Oregon. 1988	8.00	
19 Limestone deposits in Oregon. 1989	9.00	
20 Bentonite in Oregon: Occurrences, analyses, and economic potential. 1989	7.00	
21 Field geology of the NW¼ Broken Top 15-minute quadrangle, Deschutes County. 1987	6.00	
22 Silica in Oregon. 1990	8.00	
23 Forum on the Geology of Industrial Minerals, 25th, 1989, Proceedings. 1990	10.00	
24 Index to the first 25 Forums on the Geology of Industrial Minerals, 1965-1989. 1990	7.00	
26 Onshore-offshore geologic cross section, northern Coast Range to continental slope. 1992	11.00	

OIL AND GAS INVESTIGATIONS

	Price	√
3 Preliminary identifications of Foraminifera, General Petroleum Long Bell #1 well. 1973	4.00	
4 Preliminary identifications of Foraminifera, E.M. Warren Coos County 1-7 well. 1973	4.00	
5 Prospects for natural gas, upper Nehalem River Basin. 1976	6.00	
6 Prospects for oil and gas, Coos Basin. 1980	10.00	
7 Correlation of Cenozoic stratigraphic units of western Oregon and Washington. 1983	9.00	
8 Subsurface stratigraphy of the Ochoco Basin, Oregon. 1984	8.00	
9 Subsurface biostratigraphy of the east Nehalem Basin. 1983	7.00	
10 Mist Gas Field: Exploration/development, 1979-1984. 1985	5.00	
11 Biostratigraphy of exploratory wells, western Coos, Douglas, and Lane Counties. 1984	7.00	
12 Biostratigraphy, exploratory wells, N Willamette Basin. 1984	7.00	
13 Biostratigraphy, exploratory wells, S Willamette Basin. 1985	7.00	
14 Oil and gas investigation of the Astoria Basin, Clatsop and northernmost Tillamook Counties, 1985	8.00	
15 Hydrocarbon exploration and occurrences in Oregon. 1989	8.00	
16 Available well records and samples, onshore/offshore. 1987	6.00	
17 Onshore-offshore cross section, from Mist Gas Field to continental shelf and slope. 1990	10.00	

MISCELLANEOUS PUBLICATIONS

	Price	√
Geology of Oregon, 4th ed., E.L. and W.N. Orr and E.M. Baldwin, 1991, published by Kendall/Hunt (add $3.00 for mailing)	25.00	
Geologic map of Oregon, G.W. Walker and N.S. MacLeod, 1991, published by USGS (add $3.00 for mailing)	11.50	
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	6.00	
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00	
Geothermal resources of Oregon (published by NOAA). 1982	4.00	
Mist Gas Field Map, showing well locations, revised 1992 (Open-File Report O-92-1, ozalid print, incl. production data)	8.00	
Northwest Oregon, Correlation Section 24. Bruer and others, 1984 (published by AAPG)	6.00	
Oregon rocks and minerals, a description. 1988 (DOGAMI Open- File Report O-88-6; rev. ed. of Miscellaneous Paper 1)	6.00	
Oregon Minerals Tax Force, Mineral taxation feasibility study, 1992	5.00	
Oregon Seismic Safety Policy Advisory Commission, Report to the Governor and the Legislative Assembly for 1991-1993, 1992	5.00	
Mining claims (State laws governing quartz and placer claims)	Free	
Back issues of Oregon Geology	2.00	
Color postcard: Oregon State Rock and State Gemstone	1.00	

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request. The Department also sells Oregon topographic maps published by the U.S. Geological Survey.

ORDER AND RENEWAL FORM

Check desired publications in list above or indicate how many copies and enter total amount below. Send order to **The Nature of Oregon Information Center, Suite 177, 800 NE Oregon Street, Portland, OR 97232**, or to **FAX (503) 731-4066**; if you wish to order by phone, have your credit card ready and call **(503) 731-4444**. Payment must accompany orders of less than $50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: $8 for 1 year, $19 for 3 years.

Renewal ___ / new subscription___ to *Oregon Geology*: 1 year ($8) or 3 years ($19) $__________
Total amount for publications marked above: $__________
Total payment enclosed or to be charged to credit card as indicated below: $__________

Name____________________
Address____________________
City/State/Zip____________________

Please charge to Visa__ / Mastercard__, account number: ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐
Expiration date: ☐☐ ☐☐
Cardholder's signature ____________________