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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.

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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,

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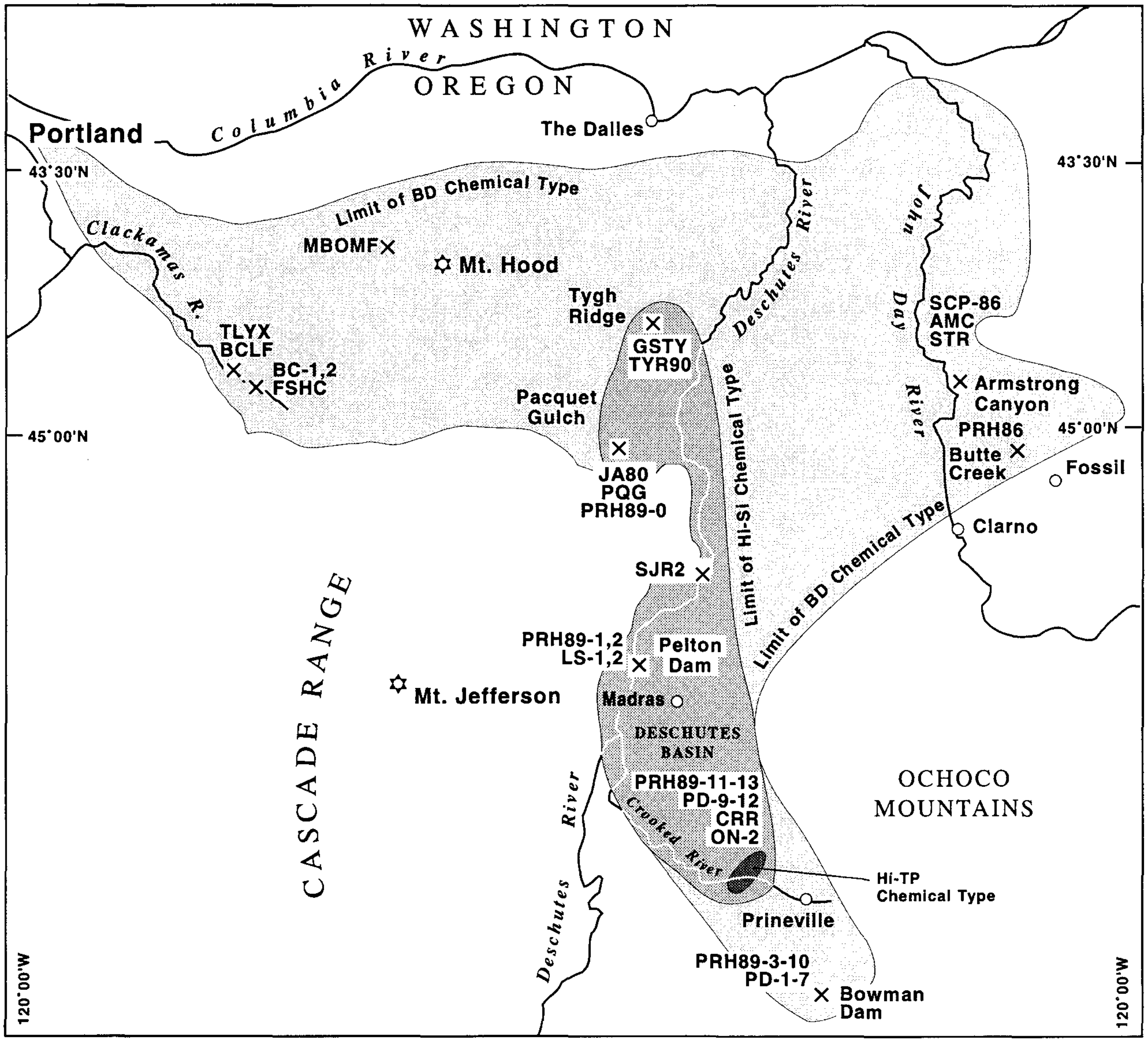

Figure 1. Map showing areal extent of the three Prineville basalt chemical types. Pale shade = BD chemical type; medium shade = Hi-Si chemical type; dark shade = Hi-PT chemical type. Location of samples listed in Tables 1 and 2 are shown.

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

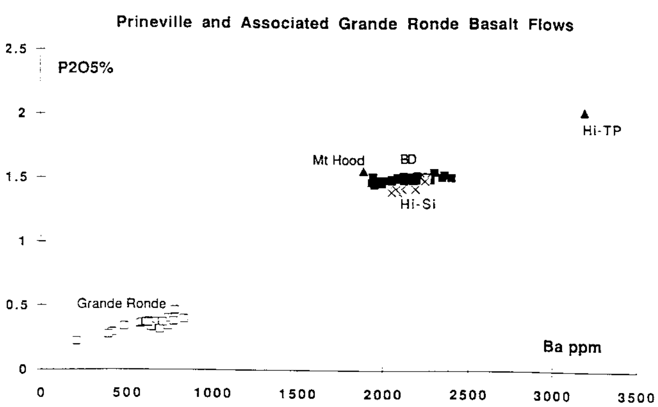

Figure 2. Plot demonstrating the distinction in Ba and P_2O_5 between Prineville basalt and associated flows of Grande Ronde Basalt.

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.

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.

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

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

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

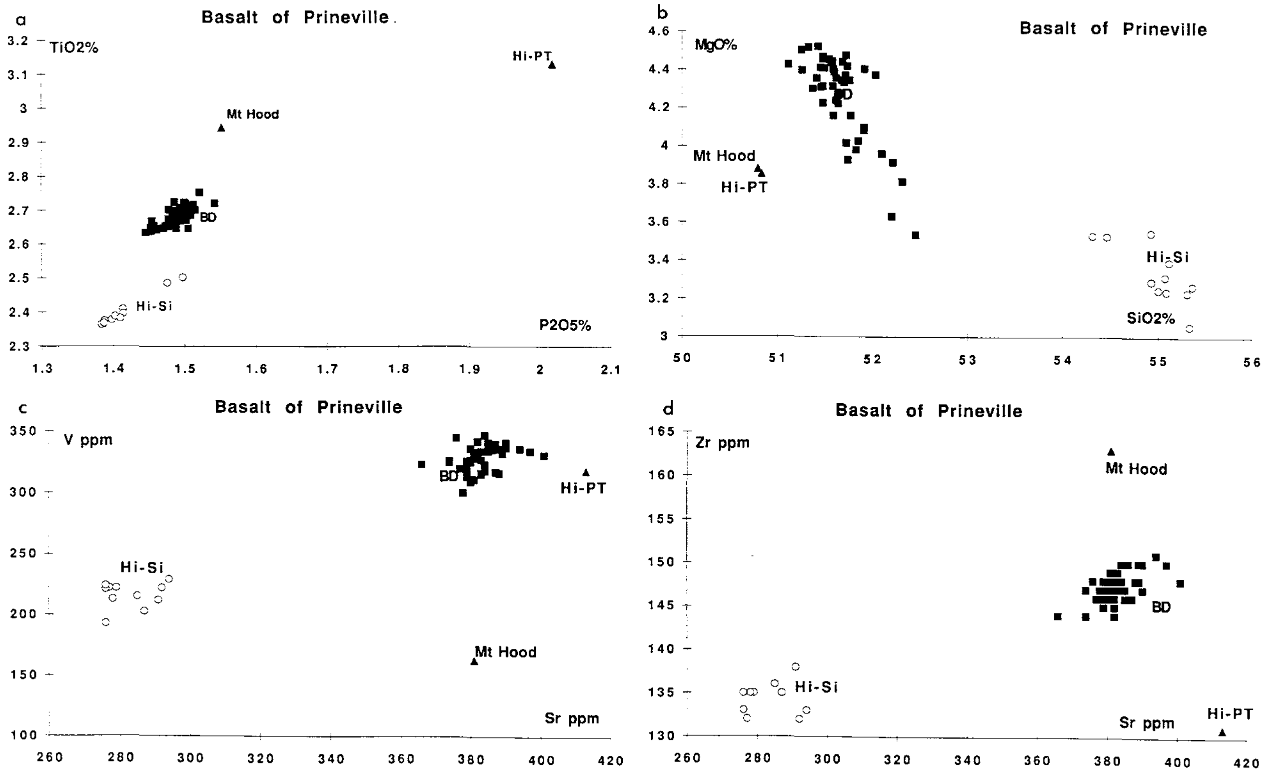

Figure 4. Plot of chemical analyses of flows of the Prineville basalt:(a) TiO_2 vs P_2O_5; (b) MgO vs SiO_2; (c) V vs Sr; (d) Zr vs Sr.

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

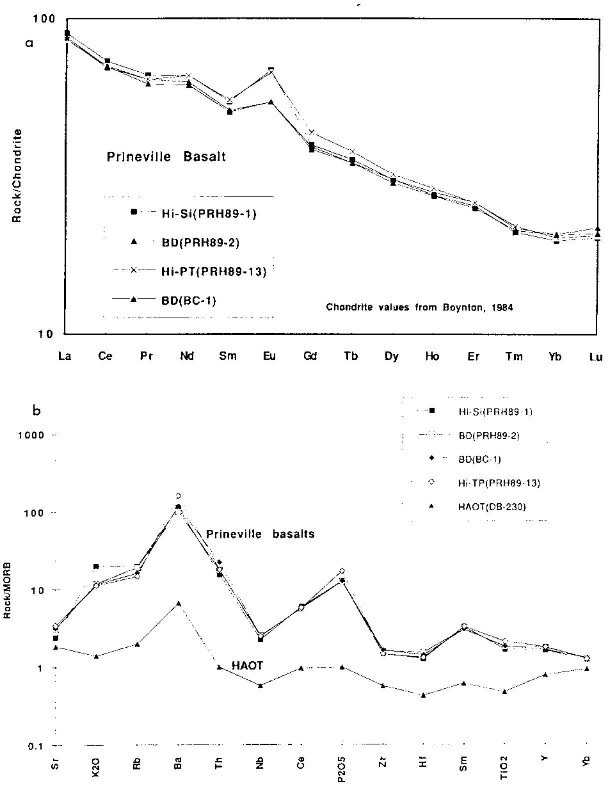

Figure 5. (a) Rare-earth to chondrite ratios for the three Prineville chemical types. (b) Plot of incompatible element abundances ratioed to MORB (mid-oceanic-ridge basalt) values (Pearce, 1983) for the three Prineville chemical types and primitive HAOT from the Powder River volcanic field of Basin and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

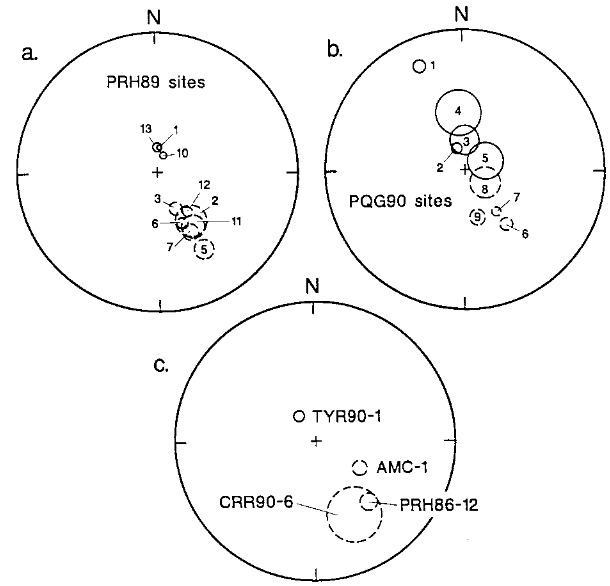

Figure 6. Corrected declinations and inclinations of magnetic poles of Prineville flows: (a) PRH89 sites from Pelton Dam, Bowman Dam and Crooked River; (b) PQG90 sites of Prineville and associated Grande Ronde flows from Pacquet Gulch; (c) sites from the Tygh Ridge (TYR), Armstrong Canyon (AMC), Butte 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
	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	Ronde
			N1	Basalt; Picture Gorge Basalt
	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.

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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).

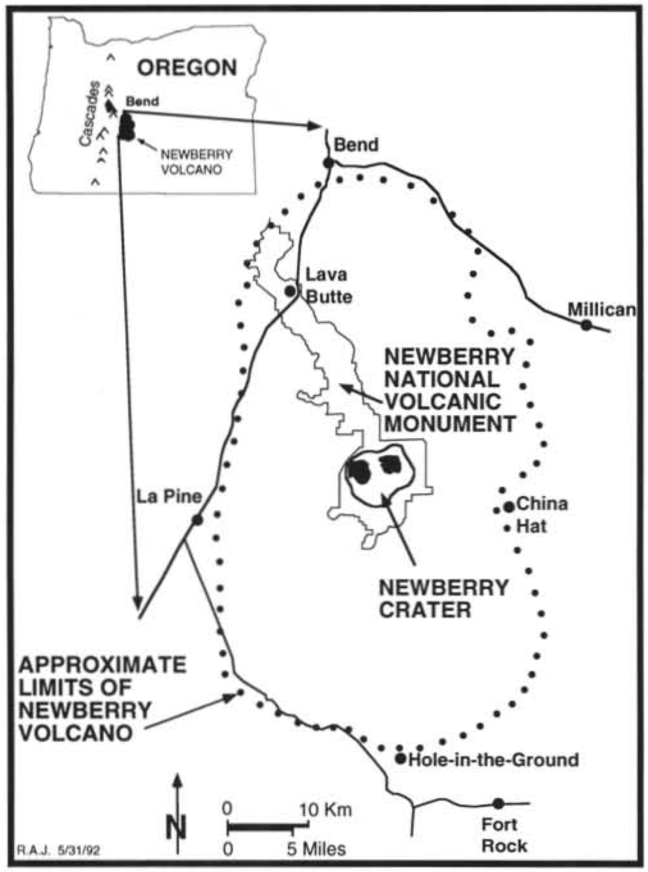

Figure 1. Location of Newberry volcano and Newberry National Volcanic Monument.

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

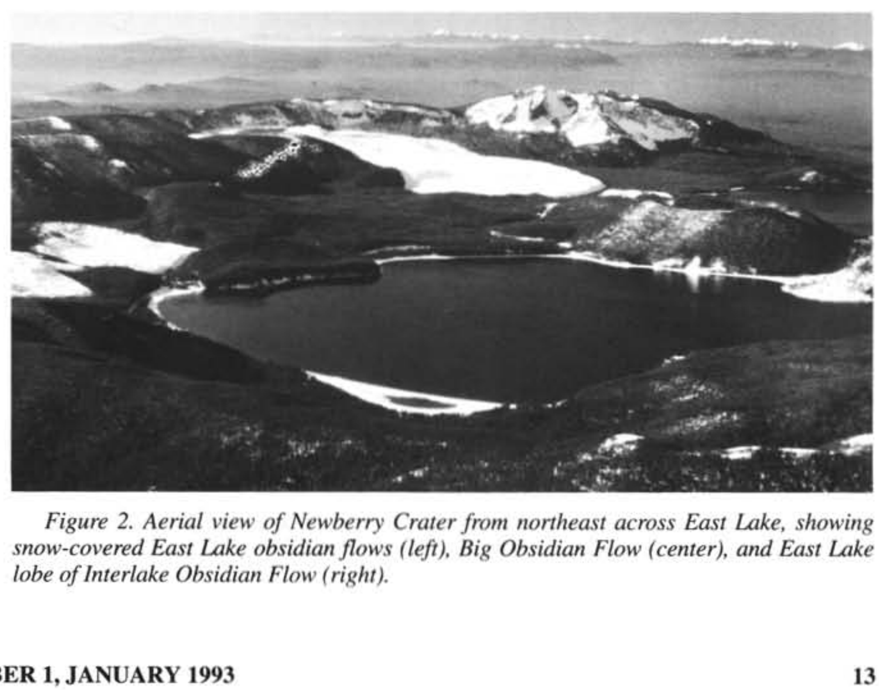

Figure 2. Aerial view of Newberry Crater from northeast across East Lake, showing snow-covered East Lake obsidian flows (left), Big Obsidian Flow (center), and East Lake lobe of Interlake Obsidian Flow (right).

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)		
	1,340±60	Robinson and Trimble (1983)	1,310±40	1,240±50
	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)		
	6,500±300	Meyer Rubin, *in* Linneman (1990)	6,400±130	7,300±130
	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.

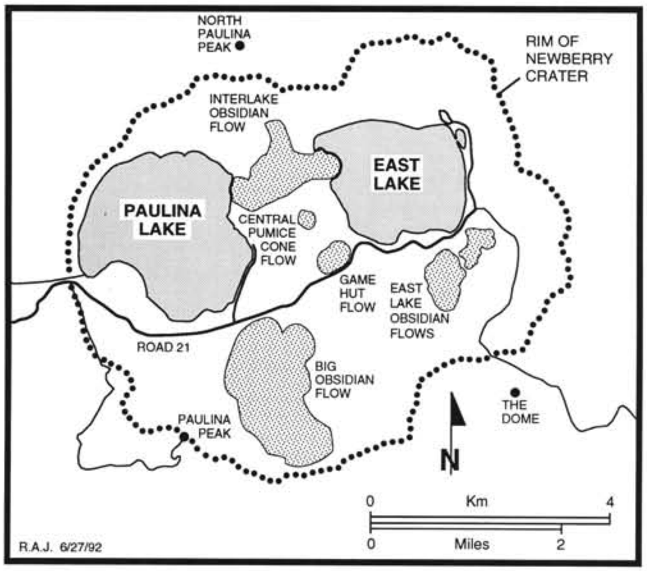

Figure 3. Post-Mazama rhyolite flows in Newberry Crater.

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

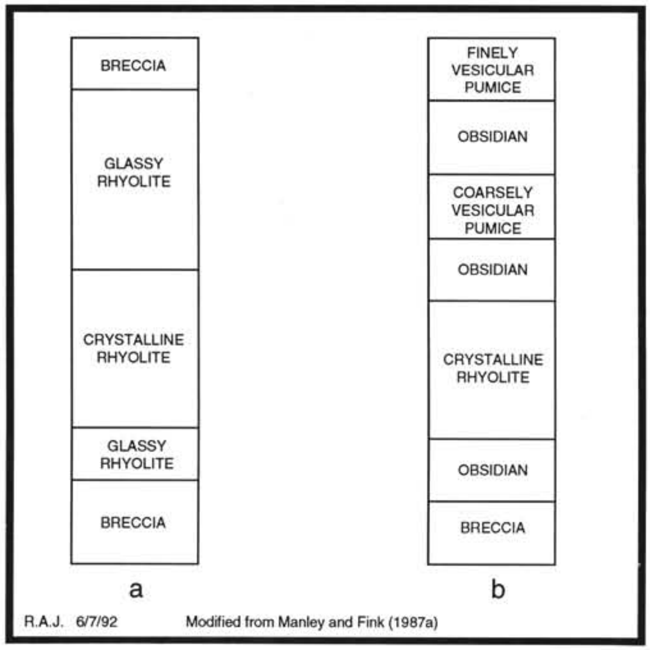

Figure 4. (a) Traditional view of rhyolite flows; (b) new view of rhyolite flows.

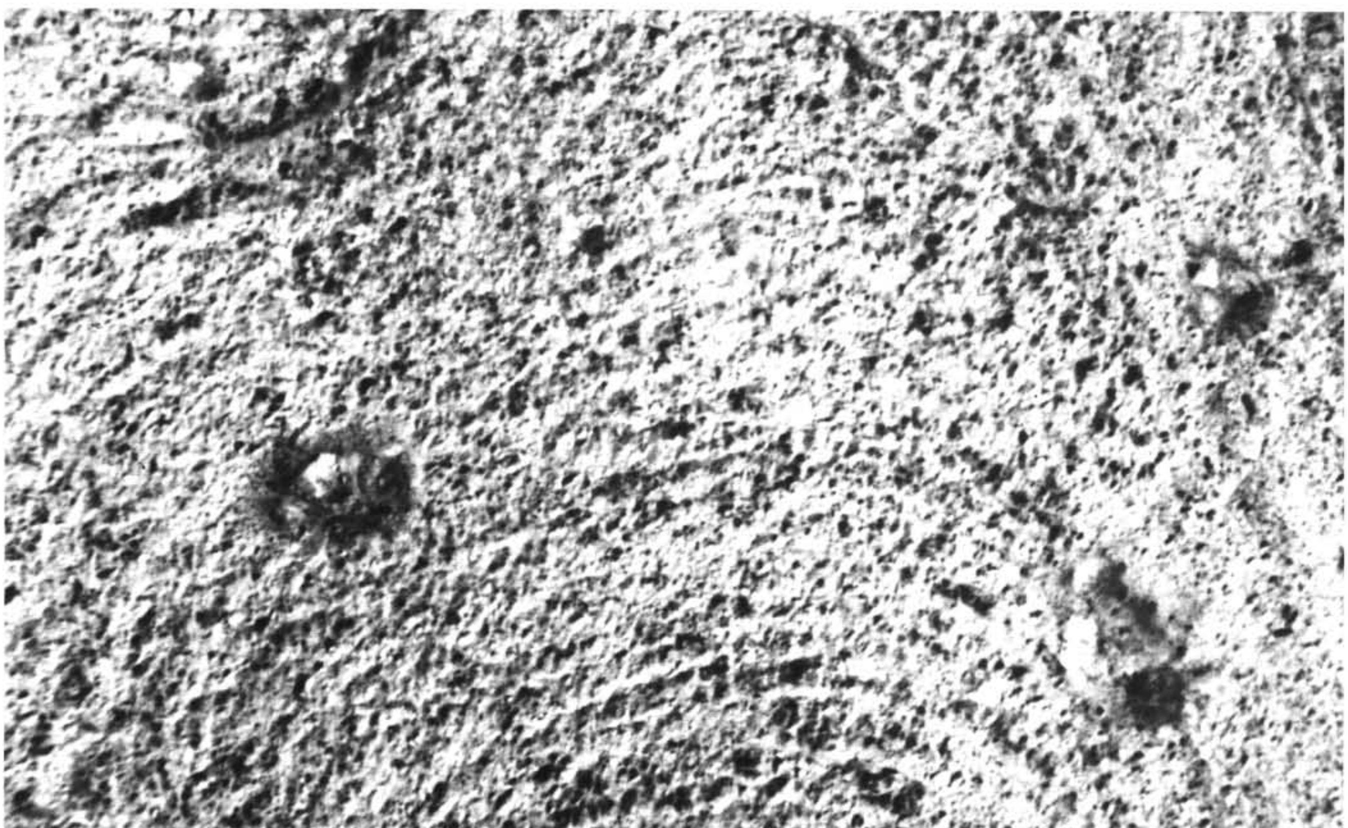

Figure 5. Vertical air photo view of four craters on surface of Big Obsidian Flow. Crater in lower right corner is designated "R"; other craters in view are "S," "Q," and "G," as identified in Figure 6.

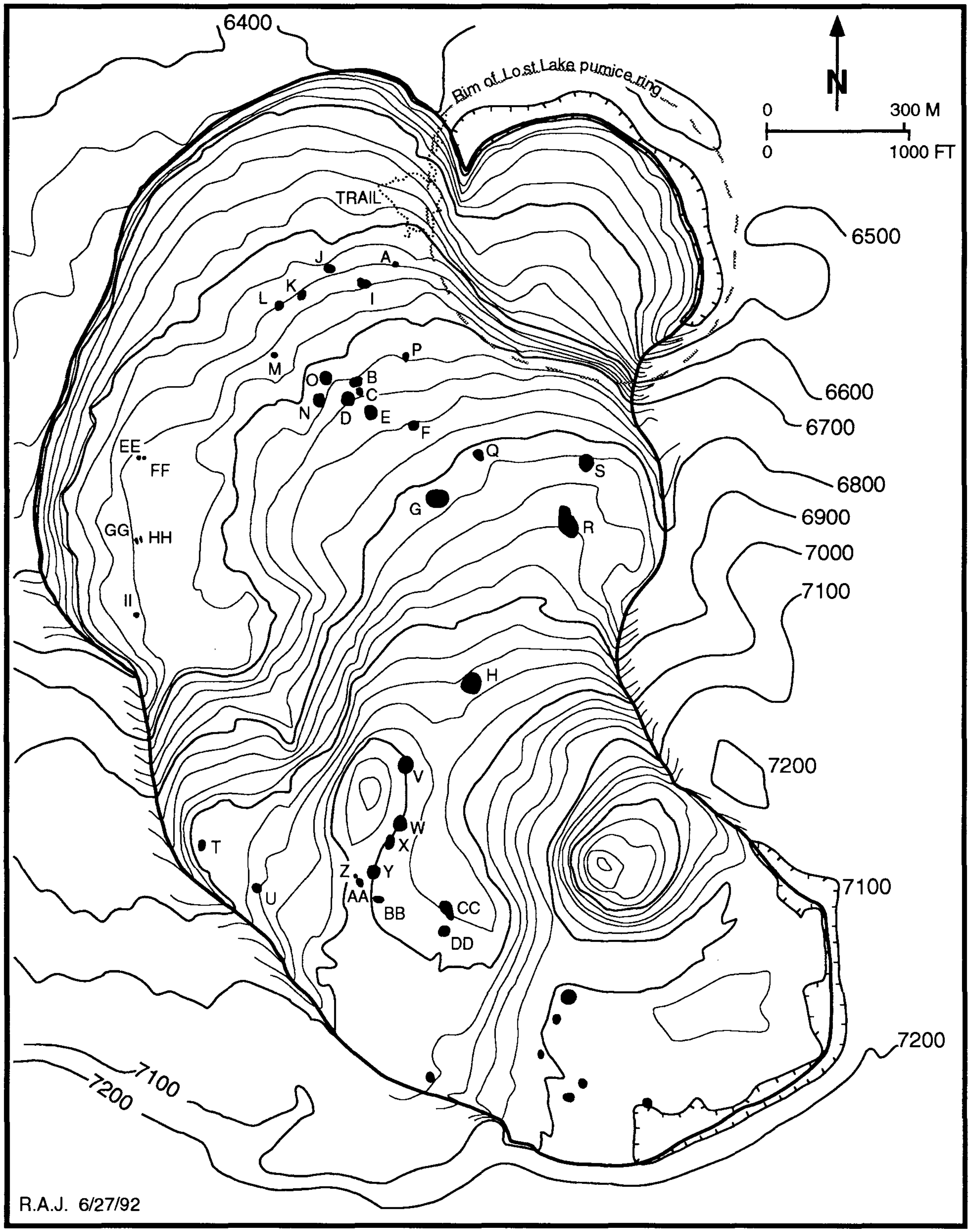

Figure 6. Irregular black dots show size and location of explosion craters on Big Obsidian Flow. Letters are informal names for craters. Route of Big Obsidian Flow Trail is marked.

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.

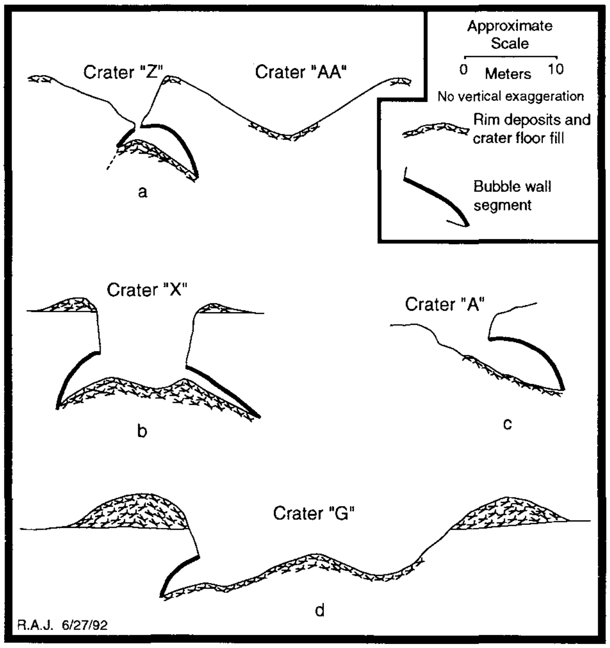

Figure 9. Sketch of cross sections through craters that contain giant bubble wall fragments.

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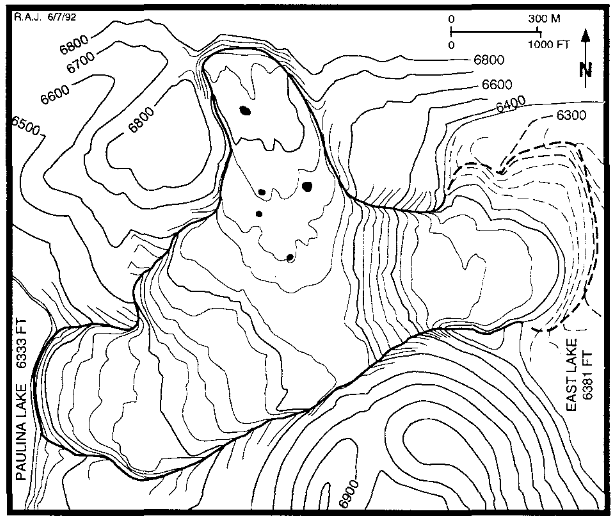

Figure 10. Irregular black dots show size and location of craters on Interlake Obsidian Flow. Dashed lines show contours and flow margin below surface of East Lake. Note that Interlake Obsidian Flow extends into East Lake.

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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
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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.

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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

Port facility at Coos Bay completed during 1992 by Glenbrook Nickel Company for off-loading, crushing, and drying nickel ore, which the company imports from New Caledonia in the South Pacific. Related summary of 1992 mining and mineral exploration in Oregon begins on next page.

MINERAL EXPLORATION ACTIVITY

Since the level of new mineral exploration in Oregon has decreased significantly since this report was started in 1989, the full, tabulated listing of all activities will no longer be published in each issue. Significant changes, however, will continue to be reported on an irregular basis. In this issue, see the summary report on mining and exploration on the following pages.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office of the Oregon Department of Geology and Mineral Industries, 1536 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039, FAX (503) 967-2075. □

ANNOUNCEMENT
from
The Oregon Department of Geology and Mineral Industries

Because of anticipated curtailment of funds, the Oregon Department of Geology and Mineral Industries expects to close its geologic-geochemical laboratory.

A sealed-bid sale will be held for the laboratory equipment and such infrastructure items as benches, fume hoods, and other built-in devices. Following is a partial list of items, most of which are in excellent condition.

Jaw crusher	X-ray diffractometer (XRD)
Cone crusher	Atomic absorption spectrometer
Ring and puck mill	Two centrifuges
Disk pulverizer	Two analytical balances
Hammer and screen mill	Microbalance
Sieve shakers, 8- and 8/12-in.	Toploader balance (4-kg cap.)
Drying ovens	Gold Screw autopanner
Two filter presses	Reflectance meter
Large ultrasonic cleaner	Compressor, 5 hp.
Fire-assay furnace and assay chemicals	

Interested persons may call Jean Pendergrass at (503) 731-4100 for further information.

Capitol display case features geology of Oregon

The Oregon Department of Geology and Mineral Industries (DOGAMI) has provided the current exhibit for the Oregon Council of Rock and Mineral Clubs at the State Capitol in Salem. Installed on January 23, the exhibit was designed to focus attention on the geology of Oregon—one of the state's greatest natural resources.

The case features a computer-generated shaded-relief map of Oregon with mountains, valleys, lakes, and other physiographic features clearly visible. Photographs and explanations of interesting geologic features found in all parts of the state are keyed to the map. Samples of Oregon's rocks, minerals, fossils, and gemstones are included in the case, along with a new brochure, "Oregon's Heritage, Geologic Treasures," which is available at the Capitol Information Desk or from the Nature of Oregon Information Center, Suite 177, 800 NE Oregon St., #5, Portland, OR 97232, phone (503) 731-4444.

Viewers of the exhibit are urged to go out and look at the geology of Oregon, enjoy it, and learn about it by studying books, maps, and brochures; by taking classes at community colleges, colleges, and universities; and by attending or joining local geology or rock and gem clubs.

The display case is located on the main floor of the Capitol building in Salem, in a hall to the west of the Information Desk. Since it was installed in 1982, the case has held displays by many Oregon rock clubs and DOGAMI. The current display will remain in place until May 1. DOGAMI wishes to thank the Oregon Council of Rock and Mineral Clubs for this opportunity to make Oregonians and visitors to the state aware of Oregon's geologic treasures. □

Mining and exploration in Oregon during 1992

by Frank R. Hladky, Resident Geologist, Grants Pass Field Office, Oregon Department of Geology and Mineral Industries

ABSTRACT

The value of Oregon's mineral industry in 1992, including natural gas, was about $245 million, down 12 percent from preliminary 1991 estimates. Domestic nickel production declined slightly, and nickel prices fell, decreasing the value of Oregon's mineral production. The value of sand, gravel, and crushed stone also declined from the previous year. Other industrial minerals values remained essentially unchanged.

Events in the metals industry highlighted the news in 1992. Glenbrook Nickel Company announced temporary slowdowns at its facilities in southwestern Oregon, responding to depressed worldwide nickel prices. Newmont Mining Corporation acquired a 35-year lease of the Atlas Corporation Grassy Mountain project in Malheur County. USDA Forest Service and U.S. Bureau of Land Management officials reported additional requests for environmental assessments.

Regional geologic mapping combined with mineral-resource assessment continued to be of major significance in the activities of the Oregon Department of Geology and Mineral Industries (DOGAMI).

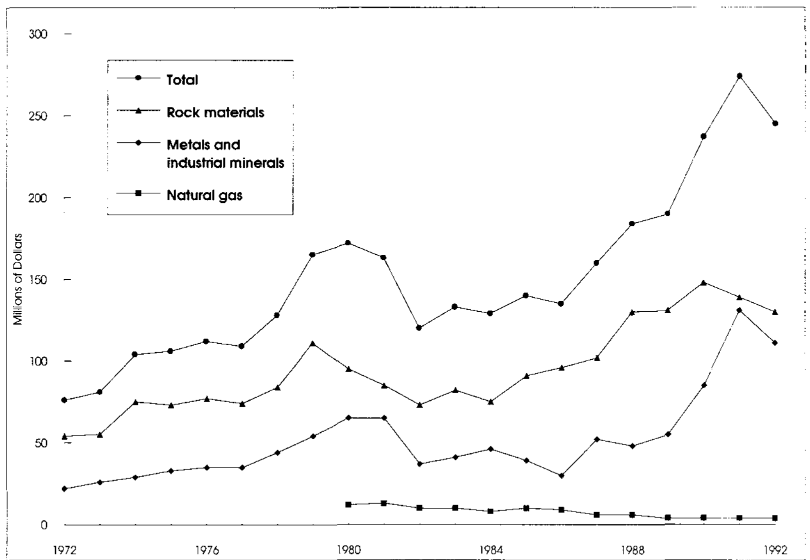


Figure 1. Mineral production value in Oregon for the last 21 years. Data from Table 1.

PRODUCTION HIGHLIGHTS

The value of Oregon's 1992 mineral production, including natural gas, is estimated to be about $245 million, down 12 percent from preliminary 1991 estimates (Table 1 and Figure 1). The U.S. Bureau of Mines (USBM) estimated the value of Oregon's mineral production to be about $199.5 million, excluding nickel and natural gas. The USBM reported advances in the value of portland cement but declines in the value of sand, gravel, and crushed stone. Other industrial minerals production values remained essentially unchanged. The value of domestic nickel production fell as world prices fell and as Glenbrook Nickel Company began shifting from Oregon ore to New Caledonian ore. Glenbrook Nickel Company valued its Oregon nickel production at $41 million. The value of natural gas produced in Oregon during 1992 is estimated to remain unchanged from 1991, about $3.9 million. The cumulative value of natural gas production in Oregon is expected to reach $100 million during 1993.

WESTERN OREGON

At Riddle, Glenbrook Nickel Company (mine site 22 [for all active mine sites, see Figure 2 and Table 2]) produced an estimated 19.3 million pounds of contained nickel from Nickel Mountain ore and 6.4 million pounds from New Caledonian ore. Domestic nickel production in pounds decreased by 17 percent from 1991, but nickel produced from imported ore pushed the combined total up by 23 percent. Glenbrook will produce upwards of 36 million pounds of nickel annually at peak capacity.

Glenbrook Nickel Company, a subsidiary of the Cominco Group, completed its $30 million off-loading, crushing, and drying facility at Coos Bay to handle over 800,000 tons of wet and dry New Caledonian nickel ore per year (Figure 3). The operation employs 25, and an additional 50 are employed trucking ore to Riddle.

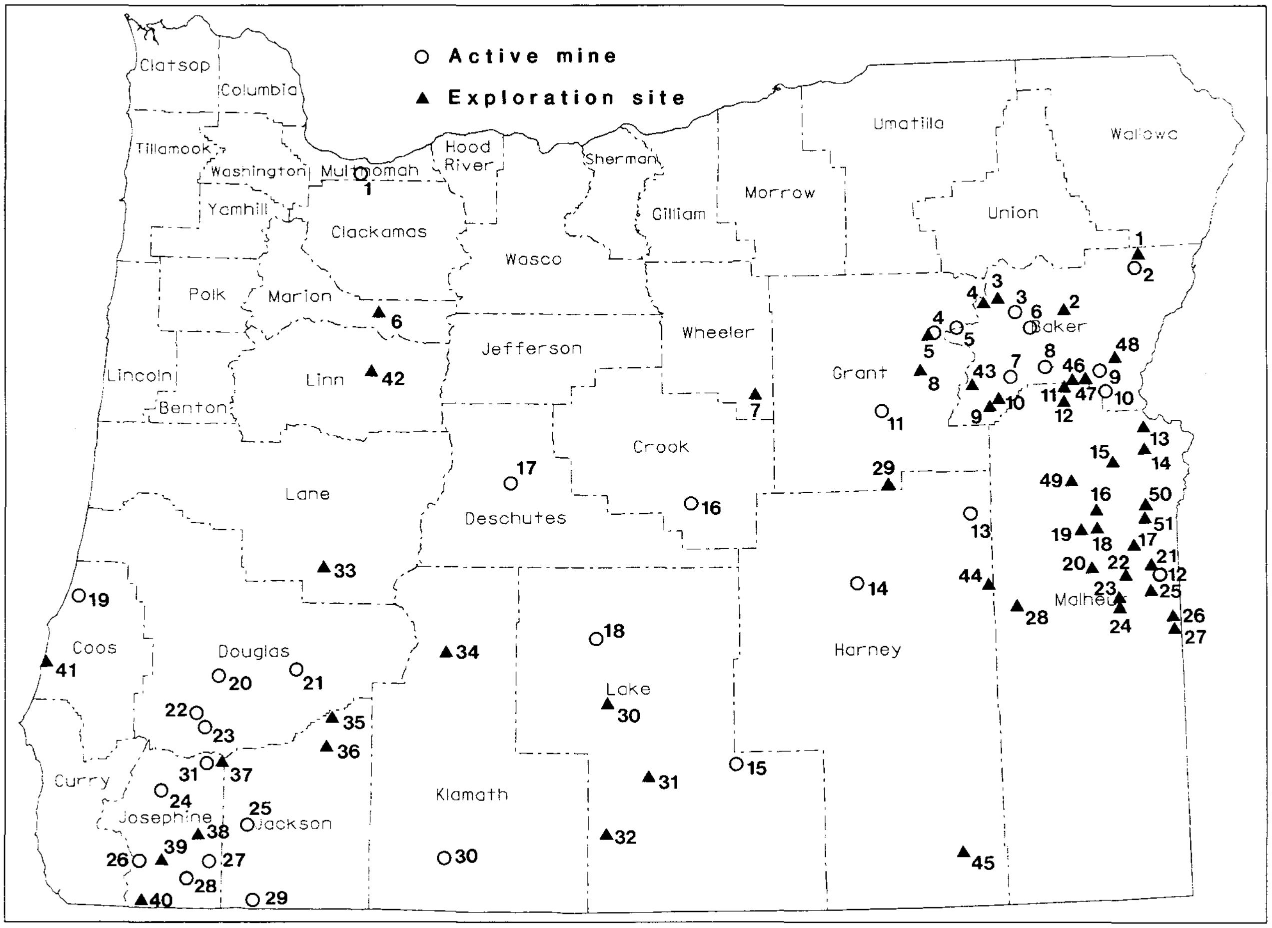
The Coos Bay facility supplements drying and crushing operations at Riddle. The facility can dry up to 119 tons of ore per day in its propane-fired rotary kiln. Conveyors and crushers are enclosed

Table 1. *Summary of mineral production value (in millions of dollars) in Oregon for the last 21 years. Data for 1992, derived from U.S. Bureau of Mines annual preliminary mineral-industry survey and Oregon Department of Geology and Mineral Industries statistics, are based on voluntary reporting and should be considered as minimums.*

	Rock materials[1]	Metals and industrial minerals[2]	Natural gas	Total
1972	54	22	0	76
1973	55	26	0	81
1974	75	29	0	104
1975	73	33	0	106
1976	77	35	0	112
1977	74	35	0	109
1978	84	44	0	128
1979	111	54	+	165
1980	95	65	12	172
1981	85	65	13	163
1982	73	37	10	120
1983	82	41	10	133
1984	75	46	8	129
1985	91	39	10	140
1986	96	30	9	135
1987	102	52	6	160
1988	130	48	6	184
1989	131	55	4	190
1990	148	85	4	237
1991	139	131	4	274
1992	130	111	4	245

[1] Includes sand, gravel, and stone.

[2] For 1992, this includes cement; clays, including bentonite; copper-zinc; diatomite; gemstones, including Oregon sunstone; gold-silver; nickel; perlite; pumice; quartz; silica sand; talc, including soapstone; and zeolites.



EXPLANATION

Active Mines and Areas

1. Columbia Brick Works
2. Bonnanza Mine (placer gold)
3. Deer Creek (placer gold)
4. Big Creek (placer gold)
5. Greenhorn area (placer gold)
6. Elk Creek (placer gold)
7. Pine Creek (placer gold)
8. Dooley Mountain (perlite)
9. Ash Grove Cement West, Inc. (cement and crushed limestone)
10. Rye Valley/Mormon Basin (placer gold)
11. Canyon City (placer gold)
12. Teague Mineral Prod. (bentonite, zeolite)
13. Eagle-Picher Industries (diatomite)
14. Ponderosa Mine (Oregon sunstone)
15. Rabbit Hills (Oregon sunstone)
16. Central Oregon Bentonite/Evergreen Bentonite (bentonite clay)
17. Cascade Pumice/Central Oregon Pumice
18. Oil-Dri Production (diatomite)
19. CooSand (silica sand)
20. Roberts Mountain (limestone)
21. Quartz Mountain (silica)
22. Nickel Mountain (nickel)
23. Silver Peak (copper, zinc, gold, silver)
24. Galice area (placer gold)
25. Bristol Silica and Limestone (silica)
26. Josephine Creek area (placer gold)
27. Jones Marble Quarry (agric. limestone)
28. Sucker Creek area (placer gold)
29. Steatite of Southern Oregon (soapstone)
30. Klamath Falls Brick and Tile
31. Coyote Creek (placer gold)

Exploration Sites and Areas

1. Cornucopia Mine (lode gold)
2. White Swan-U.P. (lode gold)
3. Bourne (gold, silver)
4. Herculean Mine (gold and base metals)
5. Mammoth (gold, silver, copper)
6. Bornite (copper, gold, silver)
7. Spanish Gulch (lode gold)
8. Copperopolis/Standard (copper, gold)
9. Record Mine (copper, silver)
10. Lower Grandview Mine (placer gold)
11. Racey property (lode gold)
12. Shasta Butte (lode gold)
13. Kerby/East Ridge (lode gold)
14. Tub Mountain area (lode gold)
15. Hope Butte (lode gold)
16. H claims (lode gold)
17. Grassy Mountain (lode gold)
18. Harper Basin (lode gold)
19. BCMX (lode gold)
20. Freeze (lode gold)
21. Camp Kettle (lode gold)
22. Dry Creek Buttes area (lode gold)
23. Jessie Page (lode gold)
24. Red Butte (lode gold)
25. South Owyhee Ridge area (lode gold)
26. Bannock (lode gold)
27. Mahogany (lode gold)
28. Stockade area (lode gold)
29. Baboon Creek (limestone)
30. Summer Lake area (lode gold)
31. Paisley area (lode gold)
32. Quartz Mountain (lode gold)
33. Bohemia District (lode gold)
34. Chemult (pumice)
35. Prospect Silica (silica)
36. Al Sarena (lode gold)
37. Martha Mine (lode gold)
38. Marble Mountain (limestone)
39. Eight Dollar Mountain (nickel laterite)
40. Turner-Albright (copper, zinc, gold)
41. Seven Devils area (black sands)
42. Quartzville (lode gold)
43. Pole Creek (lode gold)
44. Buck Mountain (lode gold)
45. Flagstaff Butte area (lode gold)
46. Cave Creek (lode gold)
47. Gold Ridge Mine (lode gold)
48. Gold Hill Mine (lode gold)
49. White Mountain (diatoms)
50. Chalk Butte/Big Red (lode gold)
51. Shell Rock Butte (lode gold)
52. Madison Butte (lode gold)
53. Rough and Ready Creek (nickel)

Figure 2. Mining and mineral exploration sites in Oregon in 1992, excluding sand, gravel, and stone. Active mines are keyed to Table 2; exploration sites are keyed to Table 3.

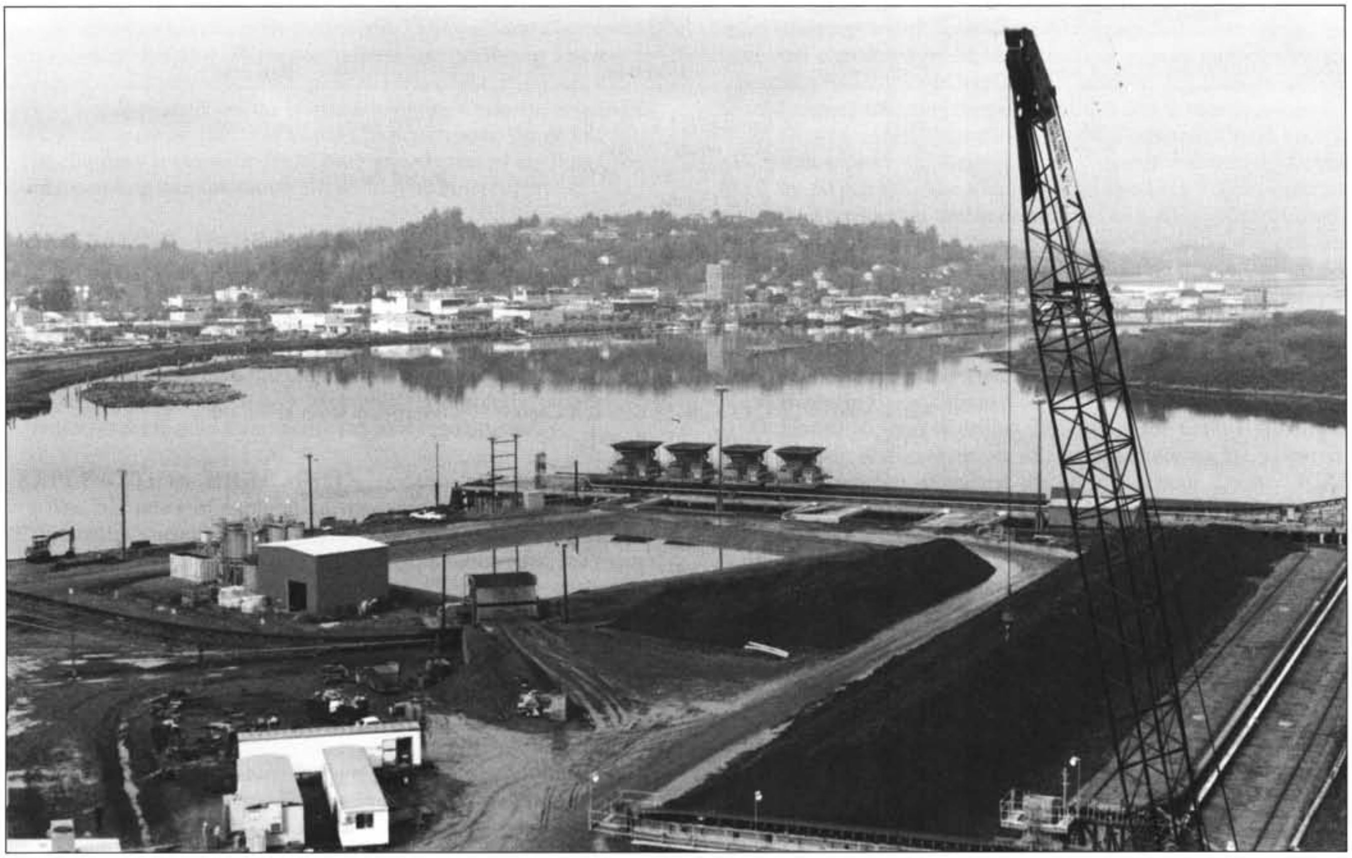


Figure 3. Glenbrook Nickel Company completed its port facility at Coos Bay to handle nickel ore from New Caledonia. Depressed worldwide nickel prices forced temporary closure of the facility at the end of the year.

to prevent dissipation of dust at the site. Dust is collected and cycled to an automated delivery silo, where it is recombined with crushed, dried ore. Wet ore is also hauled from the facility. The site is surrounded by sumps that capture rainwater runoff and direct it to a $2.5-million neutralization plant. Up to 100,000 tons of reddish-brown ore can be stored safely within a few feet of the blue-green Coos Bay estuary.

In November, company officials announced the temporary closure of the import facility. The suspension of operations began December 20. The closure affected jobs at Coos Bay and the 300 jobs at the Riddle smelter. Employees were put on extended furloughs and reduced work weeks or were transferred. The slowdowns were initiated in response to the decline in world prices of nickel, blamed largely on salvage entrepreneurs in the Commonwealth of Independent States, who were dumping nickel on world markets.

Also producing in western Oregon, Formosa Exploration, Inc., continues mining zinc and copper ore from a Kuroko-type massive-sulfide deposit at its Silver Peak Mine near Riddle (mine site 23). In the last quarter, Formosa shipped 4,245 tons of copper and zinc concentrates to Japan, up 40 percent from last year. The company received several hundred thousand dollars in funding and technical support from the Metal Mining Agency of Japan (MMAJ) as part of a program to expand company reserves. The operation currently employs more than 80 people (Figure 4).

Columbia Brick Works mined 23,000 yards of clay in Multnomah County (mine site 1). The company reported that brick production was temporarily exceeding sales.

EASTERN OREGON

Eastern Oregon producers continued to be major contributors to the state's industrial minerals production.

Ash Grove Cement West, Inc., near Baker City, remains the largest mineral producer east of the Cascades (mine site 9). Ash Grove anticipated mining about 750,000 tons of limestone, with 500,000 tons being used for cement clinker and about 250,000 tons crushed for sugar rock. The company continues to employ 105 workers, remaining a stable and sizable employer for eastern Oregon.

Eagle-Picher Industries in Harney and Malheur Counties (mine site 13) reported mining about 50,000 tons of diatomaceous earth, a decrease of about 50 percent from last year. Company officials stated that the decrease was due to inventory adjustments and did not reflect a downturn in sales. Their market includes Japan.

Teague Mineral Products in Malheur County (mine site 12) served customers in Hong Kong, Shanghai, the Philippines, and Canada. The company produces bentonite and zeolite products.

Oil-Dri Production Company in Lake County (mine site 18) mined 40,000 tons of diatomaceous earth. The company ships in bag or in bulk and worldwide. The company also implemented an aggressive reclamation effort.

Central Oregon Bentonite in Crook County (mine site 16) reported mining nearly 10,000 tons of bentonite, an increase of about 10 percent. Its neighbor, Evergreen Bentonite, has a similar-size operation and was active this year.

Klamath Falls Brick and Tile (mine site 30) fired an estimated 3 million bricks from 3,000 tons of clay. Two thirds of this years' clay was mined in Oregon, the rest in California. Some of the company's bricks were used in the construction of the new Oregon Museum of Science and Industry (OMSI) in Portland.

Cascade Pumice and Central Oregon Pumice in Deschutes County (mine site 17) continued to contribute significantly to the nation's pumice production.

Several small firms, some from the East Coast, were reported

Table 2. *Active mines in Oregon, 1992 (numbers are keyed to Figure 2)*

No.	Mine name	Company	Commodity	Location	Remarks
1	—	Columbia Brick Works	Brick	Sec. 14, T. 1 S., R. 3 E. Multnomah County	23,000 yards of clay mined.
2	Bonnanza	Bonnanza Mining Company	Placer gold	Sec. 3, T. 7 S., R. 45 E., Baker County	Mined through July.
3	Deer Creek	—	Placer gold	Sec. 30, T. 9 S., R. 38 E., Baker County	Reclaimed.
4	Big Creek	—	Placer gold	T. 10 S., R. 34 E., Grant County	—
5	Greenhorn area	—	Placer gold/lode gold	Tps. 9, 10 S., R. 35 E., Baker and Grant Counties	Testing 200 ton/day mill for Winterville/Parkerville claim group (lode).
6	Elk Creek	—	Placer gold	Tps. 9, 10 S., R. 39 E., Baker and Grant Counties	Small-scale production.
7	Pine Creek	—	Placer gold	T. 12 S., R. 38 E., Baker County	Insufficient water at this site.
8	Dooley Mountain	Supreme Perlite Company	Perlite	Tps. 11, 12 S., R. 40 E., Baker County	—
9	—	Ash Grove Cement West, Inc.	Cement, limestone	Sec. 11, T. 12 S., R. 43 E., Baker County	Production similar to 1991.
10	Rye Valley/ Mormon Basin	—	Placer gold	T. 13 S., Rs. 42, 43 E., Baker County	—
11	Canyon City placers	—	Placer gold	T. 13 S., R. 32 E., Grant County	—
12	—	Teague Mineral Products	Bentonite, zeolite	Secs. 28, 29, T. 23 S., R. 46 E., Malheur County (and nearby Idaho)	Company ships to several nations of the Pacific Rim.
13	Eagle-Picher	Eagle-Picher Industries, Inc.	Diatomite	Tps. 19, 20 S., Rs. 35, 36 E., Malheur and Harney Counties	50,000 tons mined for fiscal 1992.
14	Ponderosa Mine	—	Oregon sunstone	T. 23 S., R. 30 E., Harney County	—
15	Rabbit Hills	—	Oregon sunstone	T. 33 S., Rs. 24, 25 E., Harney County	Eight BLM notices of intent; sunstone extraction is active.
16	—	Central Oregon Bentonite Co./ Evergreen Bentonite Co.	Bentonite	Sec. 4, T. 19 S., R. 21 E., Crook County	Central Oregon Bentonite reported mining about 10,000 tons in 1992; neighboring Evergreen Bentonite was similarly active.
17	—	Cascade Pumice Co./Central Oregon Pumice Co.	Pumice	Tps. 17, 18 S., R. 11 E., Deschutes County	—
18	—	Oil-Dri Production Company	Diatomite	Secs. 14, 21, 23, T. 26 S., R. 16 E., Lake County	Mined about 40,000 tons; extensive reclamation.
19	—	CooSand Corporation	Silica sand	Sec. 34, T. 24 S., R. 13 W., Coos County	Active silica sand mining operation.
20	Roberts Mountain	Mountain Valley Resources	Limestone	Sec. 20, T. 28 S., R. 5 W., Douglas County	Annual production is less than 5,000 tons.
21	Quartz Mountain	Quartz Mountain Silica	Silica	Sec. 2, T. 28 S., R. 1 W., Douglas County	Annual production measured in hundreds of tons.
22	Nickel Mountain	Glenbrook Nickel Company	Nickel	Secs. 28, 29, T. 30 S., R. 6 W., Douglas County	Estimated smelter production of about 13.3 million pounds of contained nickel from Nickel Mountain.
23	Silver Peak Mine	Formosa Exploration, Inc.	Copper, zinc, gold	Sec. 23, T. 31 S., R. 6 W., Douglas County	Shipped 4,245 tons of concentrates to Japan in November.
24	Galice area	—	Placer gold	Tps. 34, 35 S., R. 8 W., Josephine County	Intermittent small-scale mining.
25	—	Bristol Silica and Limestone Co.	Silica	Sec. 30, T. 36 S., R. 3 W., Jackson County	Production between 5,000 and 10,000 tons annually.
26	Josephine Creek area	—	Placer gold	Tps. 38, 39 S., R. 9 W., Josephine County	Patents pending on small operations.
27	Jones Marble quarry	—	Limestone	Sec. 31, T. 38 S., R. 5 W., Josephine County	—
28	Sucker Creek area	—	Placer gold	Tps. 39, 40 S., Rs. 6, 7 W., Josephine County	Seasonal small-scale mining.
29	—	Steatite of Southern Oregon	Soapstone	Secs. 10, 11, T. 41 S., R. 3 W., Jackson County	Estimated 140 tons mined for 1992.
30	—	Klamath Falls Brick and Tile Co.	Brick	Sec. 19, T. 38 S., R. 9 E., Klamath County	3,000 tons of brick clay used; 2,000 tons mined from Oregon.
31	Coyote Creek	Jack Smith	Placer gold	T. 33 S., Rs. 5, 6 W., Josephine County	Reclamationist of the Year for small mines.

busy extracting sunstones from the Rabbit Hills of Lake County this year (mine site 15). The trade reflects an increasing interest in Oregon's state gemstone.

In metals production, the Bonnanza Mining Company worked its placer mine (mine site 2) in Baker County through the end of July. The company is currently reclaiming mined areas along Pine Creek and extending its exploration efforts into nearby properties.

REGULATORY HIGHLIGHTS

The final set of rules pertaining to cyanide heap leaching were approved by the Environmental Quality Commission (EQC) September 1. Regulations of the Oregon Department of Geology and Mineral Industries and the Oregon Department of Fish and Wildlife had been finalized earlier. Newmont Mining Corporation, with its recent acquisition of Grassy Mountain, is currently proposing a cyanide-process gold mine under the new regulations.

EXPLORATION HIGHLIGHTS

The big news in exploration this year was Newmont Mining Corporation's acquisition of Atlas' Grassy Mountain project in Malheur County (exploration site 17 [for all exploration sites, see Figure 2 and Table 3]). Newmont entered into a 35-year lease with Atlas Corporation. The lease also involves the Musgrove Creek Prospect in Idaho. Grassy Mountain has probable reserves of 995,000 oz of gold and 2,467,000 oz of silver.

EASTERN OREGON

In eastern Oregon, USDA Forest Service officials reported that exploration by major mining firms in the Wallowa-Whitman, Umatilla, and Malheur National Forests had declined and the number of small-scale operators requesting environmental assessments had increased considerably. BLM officials in eastern Oregon districts reported generally little exploration activity. Exploration sites in several eastern Oregon counties remained active near year's end.

In Grant County, Formation Capital Corporation held onto its Mammoth project (exploration site 5), though it reduced its claim block by 50 percent. The Mammoth prospect is a copper-gold and gold-silver prospect hosted in Paleozoic rocks. Also in Grant County, Placer Dome leased the Copperopolis and Standard Prospects (exploration site 8). The company was conducting active surface surveys late in the year.

Cracker Creek Gold Mining Company and Cable Cove Mining Company continued small-scale exploration efforts at their Bourne (exploration site 3) and Herculean (exploration site 4) projects, respectively, in Baker County.

Golconda Resources drilled 25 holes at the Gold Hill Mine in Baker County (exploration site 48) and was keeping the property.

Several projects remained active in Malheur County. ICAN Minerals, Ltd., drilled 17 holes at Racey (exploration site 11). As of the last quarter, Western Mining was keeping its Freeze project (exploration site 20). Battle Mountain was keeping its Freezeout claims in the Dry Creek Buttes area (exploration site 22). Cyprus Metals Exploration and Development Company went through a name change but was retaining interests in the Red Butte (exploration site 24) and Mahogany (exploration site 27) projects. The Red Butte project was contingent upon an anticipated BLM recommendation to remove it from Wilderness Study Area designation. Carlin Gold drilled seven holes in the Stockade area (exploration site 28). Malheur Mining hung on to Kerby (exploration site 13). A suit has been brought against the BLM for its environmental assessment of

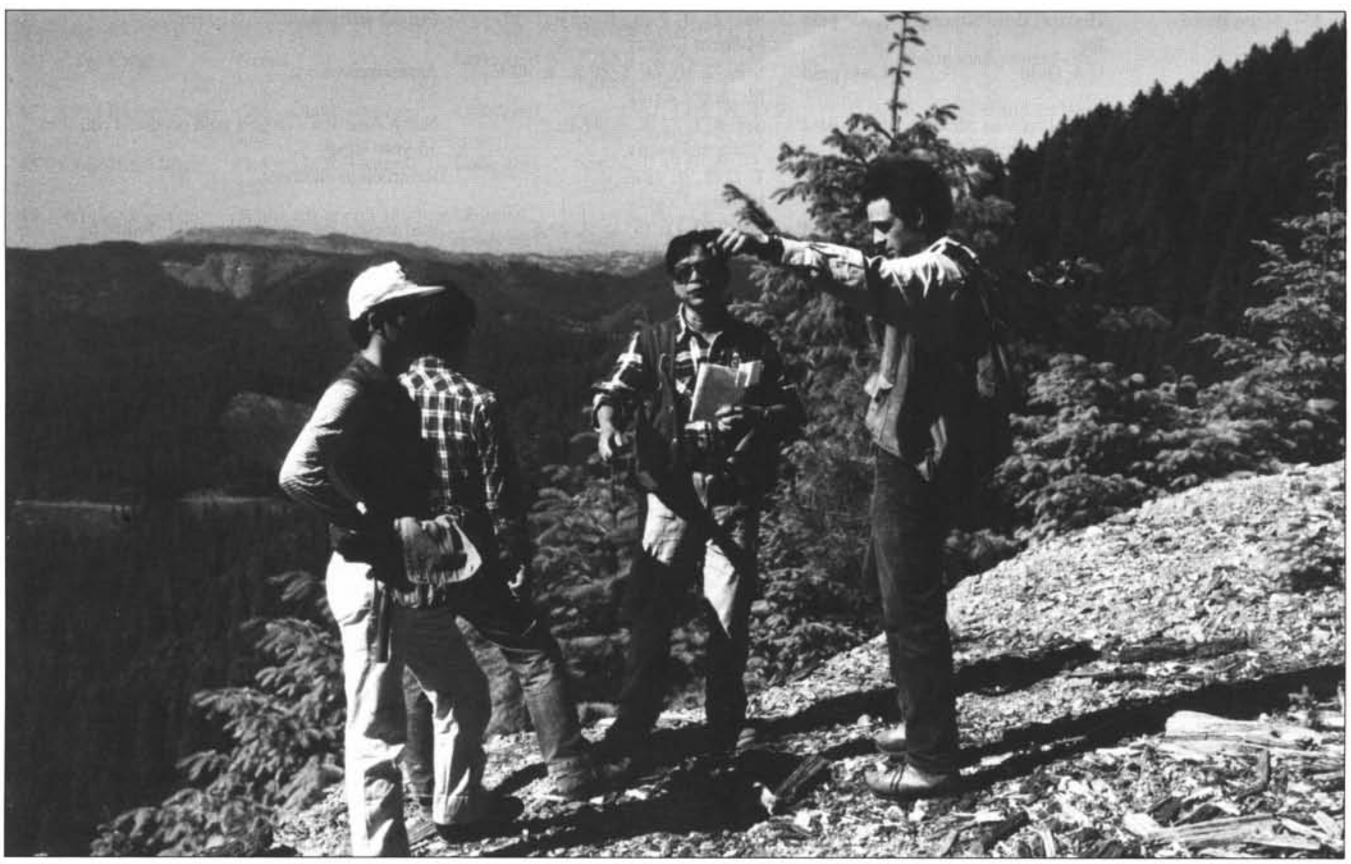


Figure 4. Geologists of Formosa Exploration, Inc., are exploring for additional reserves of zinc and copper ore at the Silver Peak mine near Riddle in Douglas County. From right to left: Chris Sebert and K.I. Lu (both with Formosa), H. Hamaii (Dowa Mining Company), and Y. Kogai (Marubeni Mining Company). Photo by David Hembree, Formosa Exploration, Inc.

Table 3. *Exploration sites in Oregon, 1992 (numbers are keyed to Figure 2)*

No.	Mine name	Company	Commodity	Location	Remarks
1	Cornucopia	UNC Corporation	Lode gold	Sec. 27, T. 6 S., R. 45 E., Baker County	—
2	White Swan	Kennecott	Lode gold	Tps. 9, 10 S., Rs. 41, 42 E., Baker County	Properties allowed to lapse.
3	Bourne	Cracker Creek Gold Mining Co.	Gold, silver	T. 8 S., R. 37 E., Baker County	Assessment.
4	Herculean	Cable Cove Mining Company	Gold, base metals	Sec. 22, T. 8 S., R. 36 E., Baker County	30 tons of concentrates tested.
5	Mammoth	Formation Capital Corporation	Gold, silver, copper	Secs. 8, 17, T. 10 S., R. 34 E., Grant County	Surface evaluation; reduced claim block by 50 percent.
6	Bornite	Plexus, Inc.	Copper, gold	Sec. 36, T. 8 S., R. 4 E., Marion County	Pending EIS record of decision.
7	Spanish Gulch	Placer Gold Development	Lode gold	T. 13 S., Rs. 24, 25 E., Wheeler County	—
8	Copperopolis/ Standard	Placer Dome, Inc.	Lode gold	Secs. 1, 12, T. 12 S., R. 33 E., Grant County	Active surface studies.
9	Record prospect	Manville Corporation	Gold, copper	T. 14 S., Rs. 36, 37 E., Baker County	Manville sells mineral arm to Celite; gives up leases.
10	Lower Grandview	Earth Search Sciences	Lode gold	Sec. 6, T. 14 S., R. 37 E., Baker County	Returned to Grandview Inc.; no further activity.
11	Racey property	ICAN Minerals, Ltd.	Lode gold	Tps. 12, 13 S., Rs. 40, 41 E., Malheur County	Drilled about 5,000 ft in 17 holes.
12	Shasta Butte	Earth Search Sciences	Lode gold	Sec. 29, T. 13 S., R. 14 E., Malheur County	Surface geological/geochemical evaluation.
13	Kerby/ East Ridge	Malheur Mining Company	Lode gold	Secs. 22, 27, T. 15 S., R. 45 E., Malheur County	Maintaining property.
14	Tub Mountain area	Atlas Precious Metals, Inc.	Lode gold	Tps. 16, 17 S., R. 45 E., Malheur County	Atlas turns back its Oregon properties in 1992.
15	Hope Butte	Horizon Gold Shares, Inc.	Lode gold	Sec. 21, T. 17 S., R. 43 E., Malheur County	Project terminated.
16	H claims	U.S. Gold	Lode gold	Secs. 2, 10, 11, T. 20 S., R. 42 E., Malheur County	Assessment work.
17	Grassy Mountain	Atlas Precious Metals, Inc./Newmont Mining	Lode gold	Sec. 8, T. 22 S., R. 44 E., Malheur County	North America's largest gold producer acquires 35-year lease.
18	Harper Basin	Atlas Precious Metals, Inc.	Lode gold	T. 21 S., R. 42 E., Malheur County	Returned to claimant.
19	BCMX	—	Lode gold	Secs. 10, 11, 14, 15, T. 21 S., R. 41 E., Malheur County	Surface geological/geochemical studies by claimant.
20	Freeze	Western Mining Corporation	Lode gold	T. 23 S., R. 42 E., Malheur County	Retaining this year.
21	Camp Kettle	ASARCO, Inc.	Lode gold	T. 23 S., R. 45 E., Malheur County	Project withdrawn.
22	Dry Creek Buttes area	ASARCO, Inc.; Battle Mtn. Explor.; BHP-Utah, Int'l.; Noranda Explor., Inc.	Lode gold	Tps. 23, 24 S., Rs. 43, 44 E., Malheur County	ASARCO withdraws; Noranda drops land positions; BHP-Utah withdraws from its Oregon properties; Battle Mountain retains Freezeout claims.
23	Jessie Page (Quartz Mountain)	MK Gold	Lode gold	Sec. 6, T. 25 S., R. 43 E., Malheur County	Project being reclaimed and terminated.
24	Red Butte	Cyprus Metals Exploration and Development Co.	Lode gold	Secs. 26, 27, 34, 35, T. 25 S., R. 43 E., Malheur County	Project awaiting decision on Wilderness Study Area designation.
25	South Owyhee Ridge area	Noranda Explor., Inc.; Atlas Precious Metals	Lode gold	Tps. 24, 25 S., R. 45 E., Malheur County	Noranda pulled claim posts at Goldfinger and SR claims; Atlas returns leases at Katey.
26	Bannock	Atlas Precious Metals and Manville Corp.	Lode gold	Sec. 11, T. 26 S., R. 46 E., Malheur County	Project terminated.
27	Mahogany	Cyprus Metals and Manville Corp.	Lode gold	Secs. 25, 26, T. 26 S., R. 46 E., Malheur County	Cyprus retains interest; Manville drops out.
28	Stockade area	Carlin Gold	Lode gold	Tps. 25, 26 S., R. 38 E., Malheur County	Drilled seven holes of 400 ft each.
29	Baboon Creek	Blue Mountain Mining	Limestone	T. 19 S., R. 32 E., Grant County	—
30	Summer Lake area	N.A. Tracy Gold Corp.	Lode gold	Sec. 14, T. 30 S., R. 16 E., Lake County	—
31	Paisley area	Atlas Precious Metals, Inc.	Perlite	T. 34 S., Rs. 18, 19 E., Lake County	Atlas retains perlite claims.

Table 3. *Exploration sites in Oregon, 1991 (continued)*

No.	Mine name	Company	Commodity	Location	Remarks
32	Quartz Mountain	Pegasus Gold, Inc.; Quartz Mtn. Gold Corp.; Wavecrest Resources	Lode gold	Secs. 26, 27, 34, 35, T. 37 S., R. 16 E., Lake County	Joint-venture partners maintain project.
33	Bohemia District	—	Lode gold	T. 22 S., Rs. 1, 2 E., Lane County	—
34	—	Chemult Pumice	Pumice	Sec. 21, T. 27 S., R. 8 E., Klamath County	New project utilizing Mazama ash.
35	Prospect Silica	Mountain Valley Resources	Silica	T. 30 S., R. 2 E., Jackson and Douglas Counties	Project awaits USDA Forest Service approval.
36	Al Sarena	Fischer-Watt Gold Company, Inc.	Lode gold	Sec. 29, T. 31 S., R. 2 E. Jackson County	Project was drilled in 1991; reclaimed and let go in 1992.
37	Martha Mine	Dragon's Gold	Lode gold	Sec. 28, T. 33 S., R. 5 W., Josephine County	Project maintenance.
38	Marble Mountain	Campman Calcite Company	Limestone	Sec. 19, T. 37 S., R. 6 W., Josephine County	County approves mine plan; project in marketing.
39	Eight Dollar Mountain	Doug Smith/ Lynn Wegner	Nickel laterite	T. 38 S., R. 8 W., Josephine County	BLM moved toward completed environmental assessment in early 1993.
40	Turner-Albright	Cominco American Resources, Inc.; Savannah Resources, Ltd.	Copper, zinc, gold	Secs. 15, 16, T. 41 S., R. 9 W., Josephine County	Cominco returned property to Savanna.
41	Seven Devils area	Oregon Resources Corp.	Black sands	T. 27 S., R. 14 W., Coos County	Pre-feasibility, testing, planning, and marketing stage.
42	Quartzville	Placer Dome	Lode gold	T. 11 S., R. 4 E., Linn County	Drilled 10 holes and dropped.
43	Pole Creek	Placer Dome	Lode gold	Sec. 4, T. 13 S., R. 36 E., Baker County	Let lapse.
44	Buck Mountain	Teck Resources/ Carlin Gold	Lode gold	T. 24 S., Rs. 36, 37 E., Harney and Malheur Counties	Teck withdrew its interest; Carlin Gold retained property.
45	Flagstaff Butte area	Noranda Exploration	Lode gold	Sec. 5, T. 39 S., R. 37 E., Harney County	Drilled five holes for total of 2,100 ft.
46	Cave Creek	Nerco	Lode gold	T. 12 S., R. 42 E., Baker County	Reclaimed project site.
47	Gold Ridge Mine	Golconda Resources, Ltd.	Lode gold	Sec. 16, T. 12 S., R. 43 E., Baker County	Reclaimed and let lapse.
48	Gold Hill Mine	Golconda Resources, Ltd.	Lode gold	Sec. 1, T. 12 S., R. 43 E., Baker County	Drilled 25 holes for total of about 4,500 ft; holding property.
49	White Mountain	White Mountain Mining	Diatomaceous earth	T. 18 S., R. 41 E., Malheur County	Exploration status.
50	Chalk Butte	Battle Mountain Exploration	Lode gold	T. 20 S., Rs. 44, 45 E., Malheur County	Allowed to lapse.
51	Shell Rock Butte	Western Epithermal	Lode gold	Secs. 12, 13, T. 21 S., R. 44 E.; secs. 5-8, 17, 18, T. 21 S., R. 45 E., Malheur County	Drilled three holes and retaining.
52	Madison Butte	Frank Blair	Lode gold	T. 5 S., R. 27 E., Morrow County	Geochemical analyses of 530 surface samples have identified precious metals (up to 84 ppb gold) in broad, fault-controlled epithermal system.
53	Rough and Ready Creek	Walt Freeman	Nickel laterite	T. 40 S., R. 9 W., Josephine County	Application to patent 4,360 acres.

the project. Western Epithermal drilled at Shell Rock Butte (exploration site 51) and was retaining the property. Earth Search Sciences was conducting surface studies at Shasta Butte (exploration site 12).

Noranda drilled five holes this year at its Flag prospect in the Flagstaff Butte area in Harney County (exploration site 45) and remained interested. Carlin Gold retained its interest at Buck Mountain in Harney and Malheur Counties (exploration site 44). In Lake County, Pegasus Gold once again committed itself to the Quartz Mountain Prospect (exploration site 32).

Frank Blair, an independent geologist, worked on a large, metalliferous epithermal system at Madison Butte in Morrow County (exploration site 52). Extensive surface geochemical sampling (530 samples) has indicated zones anomalous in gold, silver, arsenic, antimony, and mercury within brecciated and silicified arkosic sandstones and volcanic rocks of Eocene to Oligocene age.

WESTERN OREGON

Exploration in Western Oregon in 1992 included a handful of active projects. In southwestern Oregon, smaller operators applied for more patents and environmental assessments. Some drew increasing attention.

Walt Freeman, an independent mining engineer, applied for patent of 4,360 acres of nickel claims in the Rough and Ready Creek drainage of Josephine County (exploration site 53). In addition to nickel, the laterite ore contains high values of chrome and iron.

At Eight Dollar Mountain in Josephine County (exploration site 39), the BLM conducted an environmental assessment of an area designated as an area of critical environmental concern. In January 1993, the BLM approved a plan to allow claimants Doug Smith and Lynne Wegner to mine a 10,000-ton test batch of nickel laterite.

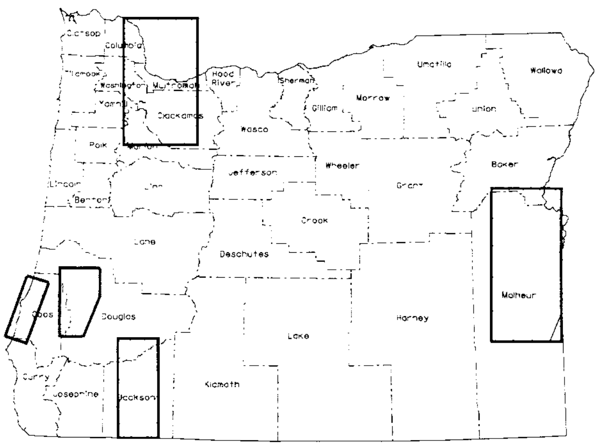


Figure 5. Areas of mapping by the Oregon Department of Geology and Mineral Industries.

Plexus, Inc., maintained an active presence at its Bornite copper porphyry project in Marion County (exploration site 6). The project is in permitting status. The USDA Forest Service is currently reviewing the anticipated environmental impact of the proposed project.

At the Seven Devils area in western Coos County, Oregon Resources Corporation maintains a project (exploration site 41) to further define, test, and market onshore black sands for garnet, chromite, zircon, and titanium. The project is in the pre-feasibility stage.

Meanwhile, Cominco American Resources, Inc., has returned its interest in the Turner-Albright copper, zinc, and gold prospect (exploration site 40) in southern Josephine County to Savanna Resources, Ltd.

DOGAMI ACTIVITIES

A state-wide survey of pumice resources was completed during 1992 and is to be published in early 1993.

Regional geologic mapping and mineral resource assessment continue to be major roles of the Oregon Department of Geology and Mineral Industries (DOGAMI), in addition to its regulatory role. In Jackson and Douglas Counties, DOGAMI geologists are mapping and gathering mineral resource data within the Medford 1° x 2° sheet (Figure 5). In Malheur County, a multi-year effort by DOGAMI, the U.S. Geological Survey (USGS), and geologists from academic institutions is culminating in several geology and mineral resource maps that cover the west half of the Boise 1° x 2° sheet. Mapping in the Portland metropolitan area and in coastal areas is aiding the assessment of earthquake hazards. Mapping in the Tyee Basin of Douglas and Coos Counties is enhancing the understanding of that area's natural gas potential. DOGAMI's geologic mapping activities have the potential of being augmented by the passage of the National Geologic Mapping Act of 1992.

DOGAMI's MILOC computer database of mines and prospects aids state and local jurisdictions in planning in accordance with the state's land use laws.

Current projects are further summarized in the 1991-1997 mission statement, available through the agency's Nature of Oregon Information Center in Portland and field offices in Baker City and Grants Pass.

ACKNOWLEDGMENT

The author thanks the many geologists and corporate officers who provided information for this report. □

ANNOUNCEMENT

39th Annual Pacific Northwest Metals and Minerals Conference:

"METALS, MINERALS, AND MATERIALS: Quality Products With a Quality Environment"

Red Lion Inn, Lloyd Center, Portland, Oregon
May 2-4, 1993

Sponsored by
American Institute of Mining, Metallurgical, and Petroleum Engineers;
American Welding Society;
ASM International;
Association of Engineering Geologists.

Technical sessions (May 3-4)

- Keynote session
- Cyanide abatement and alternatives
- Update on laws and regulations impacting the Northwest mining industry
- Wear
- Joining of materials
- State reviews on recent rineral developments
- Reclamation practices
- Advanced materials I and II
- TQM and manufacturing quality
- New mining operations in Oregon and Washington
- Operating and permitting procedures in Oregon and Washington
- Recycling and waste disposal
- Poster sessions on materials and minerals

Field Trip, $20/person (May 5)

Tour of Oregon Steel Mills, St. John's landfill, and Columbia Steel Casting

Trade Show: 10 booths available

Registration:

U.S. $125—Includes all technical sessions and two luncheons
$99—Early Bird (if received by April 23)
$70—Single day (includes luncheon)
$10—Student (sessions only)

For more information and registration form, please contact

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Oil and gas exploration and development in Oregon, 1992

by Dan E. Wermiel, Petroleum Geologist, Oregon Department of Geology and Mineral Industries

ABSTRACT

Oil and gas leasing activity declined during 1992. Four U.S. Bureau of Land Management (BLM) lease sales were held, with no leases purchased. There were no over-the-counter filings for BLM leases during the year. The total number of federal acres under lease at year's end was 12,145 acres. The State of Oregon conducted no lease auctions and issued one lease consisting of less than 40 acres during the year. The total number of State of Oregon acres under lease at year's end was 25,421 acres.

Five exploratory wells and two redrills were drilled at the Mist Gas Field during the year by Nahama and Weagant Energy Company, and two of them were successful gas wells, while two were suspended and the others plugged and abandoned.

Nineteen gas wells were productive at the Mist Gas Field during the year, and six were suspended wells awaiting pipeline connection at year's end. A total of 2.5 billion cubic ft (Bcf) of gas was produced during 1992 with a value of $3.4 million.

The Oregon Department of Geology and Mineral Industries (DOGAMI) is completing a study of the Tyee Basin located in Douglas and Coos Counties. Several maps and reports have been published on the oil, gas, and coal resources of the area, and others are in preparation.

DOGAMI and the Northwest Petroleum Association (NWPA) sponsored a workshop at which the U.S. Geological Survey (USGS) and Minerals Management Service (MMS) discussed the ongoing national assessment of undiscovered oil and gas reserves. Individuals who have developed information on oil and gas plays in the Pacific Northwest were invited to present them for assessment. A follow-up workshop will be held during 1993.

LEASING ACTIVITY

Leasing activity declined during 1992, which is a continuation of a trend that began during the late 1980s. Activity included four public lease sales by the BLM, and no bids were received at these sales. BLM received no over-the-counter filings for leases during the year. Federal leases that expired or were terminated during 1992 totaled 212,526 acres. Nearly all of these leases were located in eastern Oregon in Wasco, Gilliam, Wheeler, Jefferson, and Crook Counties. The total number of federal acres under lease in Oregon at the end of 1992 amounted to approximately 12,145 acres. The majority of these are located in Crook, Jefferson, and Coos Counties. Total rental income for the year was about $14,145.

During the year, no State of Oregon lease auctions were conducted. One lease consisting of less than 40 acres was issued. State of Oregon leases on approximately 13,579 acres were terminated or expired during 1992. The total number of State of Oregon acres under lease at year's end was about 25,421 acres, and rental income was about $25,421.

Columbia County held no lease sales during 1992.

DRILLING

Five exploratory oil and gas wells and two redrills were drilled in Oregon during 1992. This is about the same level of exploration drilling activity as during 1991, when six exploratory oil and gas wells and one redrill were drilled. All the wells drilled during the year were located at the Mist Gas Field, Columbia County, where most of the state's oil and gas drilling activity has occurred since the field was discovered in 1979.

At Mist Gas Field, one operator was active during the year. Nahama and Weagant Energy Company of Bakersfield, California, operated all the wells drilled during the year, which included five wells and two redrills. Of these, two were successful gas wells: CC 43-33-75 (Figure 1), located in SE¼ sec. 33, T. 7 N., R. 5 W., and drilled to a total depth of 2,548 ft; and the CC 31-15-65 redrill, located in NE¼ sec. 15, T. 6 N., R. 5 W., and drilled to a total depth of 2,546 ft. Two Nahama and Weagant wells were suspended at year's end: Adams 31-34-75, located in NE¼ sec. 31, T. 7 N., R. 5 W., and drilled to a total depth of 3,413 ft; and CC 23-31-65 (Figure 2), located in SW¼ sec. 31, T. 6 N., R. 5 W., and drilled to a total depth of 2,272 ft. The remaining wells drilled during the year were plugged and abandoned: CC 31-15-65, located in NE¼ sec. 5, T. 6 N., R. 5 W., and drilled to a total depth of 2,794 ft; and Wilson 11A-5-65 and Wilson 11A-5-65 redrill, located in NW¼ sec. 5, T. 6 N., R. 5 W., and drilled to depths of 2,765 and 2,770 ft, respectively.

Total footage drilled for the year was 18,102 ft, and average depth per well was 2,586 ft, which is about the same as the 2,523 ft per well drilled during 1992.

During 1992, DOGAMI issued seven permits to drill (Table 1), while nine permits were canceled (Table 2).

Figure 1. Preparations to flow test the Nahama and Weagant Energy well CC 43-33-75. Flow tests are done on all successful gas wells to determine the amount of gas the well is capable of producing and to measure reservoir pressures in the well.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1992*[1]

Permit no.	Operator, well, API number	Location	Status, depth(ft) TD=total depth PTD=proposed TD
456	Nahama & Weagant Adams 31-34-75 36-009-00282	NE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Suspended; TD 3,413.
457	Nahama & Weagant CC 23-31-65 36-009-00283	SW¼ sec. 31 T. 6 N., R. 5 W. Columbia County	Suspended; TD 2,272.
469	Nahama & Weagant CC 31-15-65 and RD 36-009-00294/ -294-01	NE¼ sec. 15 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD 2,794; RD 2,546.
470	Nahama & Weagant CC 43-33-75 36-009-00295	SE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Completed, gas; TD 2,548.
471	Nahama & Weagant Wilson 11A-5-65/ RD 36-009-00296/ -296-01	NW¼ sec. 5 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 2,765, RD 2,770.
472	Nahama & Weagant CC 41-33-75 36-009-00297	NE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD 2,850.
473	Nahama & Weagant CC 22B-25-75 36-009-00298	NW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD 2,023.
474	Nahama & Weagant LF 12A-33-75 36-009-00299	NW¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD 2,148.
475	Nahama & Weagant Adams 12-31-74 36-009-00300	NW¼ sec. 31 T. 7 N., R. 4 W. Columbia County	Permit issued; PTD 1,800.

[1] Permits nos. 456 and 457 were issued in 1991.

DISCOVERIES AND GAS PRODUCTION

Mist Gas Field in Columbia County saw two new successful gas wells, a decrease from the three gas wells drilled during 1991. Nahama and Weagant Energy Company is the operator of the new producers that include the CC 31-15-65 redrill, which is located near the center of the field, and the CC 43-33-75 (Figure 3), which is one of the northernmost producers in the field. Nahama and Weagant operated 19 productive wells during 1992. At the end of the year, the field contained 16 gas producers; in addition, six wells were awaiting pipeline connection.

Gas production for the year totaled 2.5 Bcf, which is a small decline from the 2.8 Bcf produced during 1991. The cumulative field production as of the end of 1992 was 46.3 Bcf. The total value of gas produced for the year was about $3.4 million, which is a small drop from the $3.9 million during 1991. Gas prices ranged from around 13 cents to 16 cents per therm, which is about the same as during 1991. Cumulatively, the total value of gas produced since the Mist Gas Field was discovered in 1979 is about $97 million.

GAS STORAGE

The Mist Natural Gas Storage Project was fully operational during the year, after several wells were added and other modifications completed during 1991. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora Pool, and 13 observation-monitor service wells. The pools have a combined storage capacity of 10 Bcf of gas. This allows for the cycling of reservoirs between approximately 400 and 1,000 psi and will provide for an annual delivery of one million therms per day for 100 days. During 1992, about 6,144,524 mcf of gas was injected and 6,993,803 mcf was withdrawn at the gas storage project.

Figure 2. Drilling operations underway at the Nahama and Weagant Energy well CC 23-31-65, which was drilled at the Mist Gas Field and suspended during 1992.

OTHER ACTIVITIES

DOGAMI will complete a five-year study of the oil and gas potential of the Tyee Basin during 1993. The Tyee Basin is located in Douglas and Coos Counties in the southern Coast Range. The study, which is funded by landowners in the study area and by county, state, and federal agencies, is an investigation of source rock, stratigraphy, and structural framework for those characteristics that are needed to generate and trap oil and gas. During this investigation, DOGAMI has published a number of maps and reports that present a revised understanding of the geologic framework of the Tyee Basin (see reference list below). Additional publications will include a subsurface fence diagram of the basin, a geologic map of the Camas Valley quadrangle, and a summary of the gas and oil potential of the Tyee Basin. The completed publications can be obtained from the Nature of Oregon Information Center (order information on last page of this issue).

During 1992, a report and a map were completed by DOGAMI on the geologic correlation between the Coos Basin (offshore) and the Tyee Basin (onshore). This unpublished report is available for inspection in the library of the DOGAMI Portland office.

DOGAMI and the Northwest Petroleum Association sponsored a meeting and workshop at which the U.S. Geological Survey and Minerals Management Service discussed the currently ongoing na-

Figure 3. Cementing surface casing at the Nahama and Weagant Energy well CC 43-33-75, one of two successful gas producers drilled at Mist Gas Field during 1992. The surface casing consists of large-diameter pipe that is cemented in the well for the purpose of protecting fresh-water resources, anchoring blow-out prevention equipment, and maintaining the integrity of the surface hole. Truck pictured in foreground carries equipment to pump the cement down the hole.

Table 2. *Canceled permits, 1992*

Permit no.	Operator, well, API number	Location	Date issued, canceled	Reason
453	Nahama and Weagant CC 42-3-65 36-009-00279	NE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	5-28-91, 5-29-92	Canceled; expired.
454	Nahama and Weagant CC 22-2-65 36-009-00280	SW¼ sec. 2 T. 6 N., R. 5 W. Columbia County	5-28-91, 5-29-92	Canceled; expired.
462	Nahama and Weagant Oregon 31-36-66 36-007-00023	NE¼ sec. 36 T. 6 N., R. 6 W. Clatsop County	8-01-91, 8-04-92	Canceled; expired.
463	Nahama and Weagant CC 34-8-64 36-009-00288	SE¼ sec. 8 T. 6 N., R. 4 W. Columbia County	8-30-91, 8-31-92	Canceled; expired.
464	Nahama and Weagant CER 12-26-64 36-009-00289	NW¼ sec. 26 T. 6 N., R. 4 W. Columbia County	8-30-91, 8-31-92	Canceled; expired.
465	Nahama and Weagant CER 31-26-64 36-009-00290	NE¼ sec. 26 T. 6 N., R. 4 W. Columbia County	8-30-91, 8-31-92	Canceled; expired.
466	Nahama and Weagant CC 23-19-65 36-009-00291	SW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	9-05-91, 9-05-92	Canceled; expired.
467	Nahama and Weagant Johnston 11-30-65 36-009-00292	NW¼ sec. 30 T. 6 N., R. 5 W. Columbia County	8-31-91, 8-31-92	Canceled; expired.
468	Nahama and Weagant CER 24-22-64 36-009-00293	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	10-07-91, 10-07-92	Canceled; expired.

tional assessment of undiscovered oil and gas reserves. This assessment is using a methodology in which oil and gas plays are evaluated for their future potential reserves. Individuals interested in oil and gas resources in the Pacific Northwest presented plays to be considered for inclusion in the assessment. A follow-up workshop will be held during 1993. Contact DOGAMI for details.

The NWPA remained active during the year. At its regular monthly meetings, speakers gave talks related to energy matters in the Pacific Northwest. For 1993, plans are to hold the annual symposium in Bend, Oregon, during September. The theme will be "Earth Resources and the Pacific Northwest." For details, contact the Northwest Petroleum Association, P.O. Box 6679, Portland, OR, 97228.

TYEE BASIN STUDY REFERENCES

Black, G.L., 1990. Geologic map of the Reston quadrangle, Douglas County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS-68, 4 p., map scale 1:24,000.

Niem, A.R., Niem, W.A., and Baldwin, E.M., 1990, Geology and oil, gas, and coal resources, southern Tyee Basin, southern Coast Range, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-89-3, 95 p., 3 plates. □

Correction

Richard N. Pugh of Cleveland High School in Portland, Oregon was the author whose name we unfortunately left off when we printed his report on the Coos Bay fireball of 1992 in the last issue (January 1993, page 22). We regret the omission all the more because most of the story was immediately repeated—and credited to *Oregon Geology*—in The Wallace Miner (v. 90, no. 3, January 21, 1993), which is published in Kellogg, Idaho. Pugh has been a frequent contributor to *Oregon Geology* for a long time. —*ed.*

Summary of 1993 activities, Oregon Department of Geology and Mineral Industries

Focus	Activity/project	Contact persons	Description and partners
Geologic hazards (Delineation to serve mitigation)	Earthquake hazard inventory	George Priest Ian Madin Matthew Mabey (503) 731-4100	Provide ground-response maps and models for urban and coastal areas, seismic-velocity data from cooperative bore holes, leadership or technical assistance for earthquake scenarios, paleoseismology, active faults, workshops, and policy-centered mitigation. Partners and cooperators include USGS, METRO, PSU, ODOT, EMD, SSPAC, FEMA, and the Department of Higher Education.
	Coastal erosion	George Priest Dennis Olmstead Mark Neuhaus (503) 731-4100	Continue analysis of coastal erosion in a central-coast pilot project, using geologic analysis and historic shoreline data; evaluate results, integrate geologic considerations into a model, and cooperate in outreach efforts to develop mitigative strategies. The partners and cooperators include LCDC, OCZMA, OSU, and local government. Membership on Coastal Natural Hazard Policy Workshop Group and Technical Advisory Committee.
Regulation of extraction of geologic resources (Environmentally sound and safe exploration and production, followed by second beneficial land use)	Surface mined land reclamation	Gary Lynch Allen Throop Frank Schnitzer (503) 967-2039	Provide for safe and environmentally sound surface mining, leading to beneficial second use in cooperation with other agencies, including local government. Includes aggregate, metal mines, cyanide heap leach mines, and exploration. Cooperation with local government is provided in rules and State Agency Coordination Agreement. Partnerships with federal agencies delineated in memoranda of understanding.
	Oil, gas, and geothermal resources	Dennis Olmstead Dan Wermiel (503) 731-4100	Provide for conservation of resource, protection of environment, safety, and second beneficial use of land plus equitable distribution of revenues where necessary. Authority includes exploration, drilling, production, and reclamation. Governing Board functions as Oil and Gas Commission. Partnership with federal agencies defined in memoranda of understanding.
Geologic mapping and data collection (Multidisciplinary geologic data for a broad variety of societal needs)	Northwest Oregon	George Priest (503) 731-4100	Guide in cooperation with Advisory Committee and prepare geologic mapping in northwestern Oregon with emphasis on quadrangles in the Portland area, East Vancouver sheet, etc., and with emphasis on facilitating or attracting mapping efforts by cooperators in support of agency objectives.
	Southwest Oregon	Tom Wiley Frank Hladky (503) 476-2496	Conduct in cooperation with Advisory Committee mapping on a cooperative basis in the east-central Medford 1° x 2° sheet. Emphasis is on the Medford valley. Partners and cooperators include U of O and USGS.
	Southeast Oregon	Mark Ferns (503) 523-3133	Conduct in cooperation with Advisory Committee geologic quadrangle mapping of the Brogan Sheet and the east half of the Boise 1° x 2° sheet for the purposes of guiding wilderness discussion, enhancing the local economy, and delineating geologic hazards. Cooperators and partners include the USGS, PSU, and the Oregon Lottery Commission. Current emphasis is on completion of the 1:100,000-scale final map products.
Public service and information (Getting the information out of government and to the public)	The Nature of Oregon Information Center	Don Haines (503) 731-4444	A multidisciplinary, multi-agency outlet for natural resource agency information. Located in the new state office building. Emphasis is on distribution of information to the public in the Portland metropolitan area for the purposes of general public education, tourism enhancement, and public service. Cooperators include natural-resource agencies, the Oregon Productivity Fund, and USGS.
	Oregon Geology, publications, library	Beverly Vogt (503) 731-4100	To release a broad array of agency and cooperative geologic information to the broad public in a timely and cost-effective manner with publications, a subscription-based periodical, and a technical library coordinated with the State Library System.

Summary of 1993 activities, Oregon Department of Geology and Mineral Industries (continued)

Focus	Activity/project	Contact persons	Description and partners
Economic geology (Facilitating economic diversification, primarily in rural Oregon)	Mineral data base for GIS, planning and policy guidance (MILO)	Jerry Gray (503) 731-4100	A PC-oriented database of 8,500 mines, prospects, and occurrences based on all USGS, BLM, and MLR data and agency unpublished data bases and designed for dBase 3+ retrieval
	Industrial minerals	Ron Geitgey (503) 731-4100	Conduct statewide assessments and regional evaluations of industrial minerals for purposes of rural diversification. Current emphasis is on initial stages of studies with potential for rural economic development or environmental protection, including dimension stone, clay, diatomite, or zeolites. The possible need for targeted aggregate studies is being monitored.
	Geologic Energy	George Priest Jerry Black (503) 731-4100	Serve as source of geotechnical advice for geothermal energy and inventory resources in Cascades and south-eastern Oregon. Continue natural-gas assessment of the southern Coast Range (Tyee Basin) with emphasis on resource targeting through reconnaissance mapping and transect development. Cooperators include BPA, landholders, DSL, Oregon Lottery, OSU, USFS, and BLM.
	Rock and mineral laboratory	Gary Baxter Chuck Radasch (503) 229-6966	Provide quantitative analytical data in support of agency programs through a cooperative lab facility focused on unique tasks with emphasis on sample preparation, quality control, scientific sampling, and proper interpretation of results. Includes curation of samples and voluntary drill cores. Emphasis on minerals with rural economic development potential and data bases with broad range of applications for mining, planning, and environmental interpretations.
Selected planning (Making sure geology, minerals, and hazards are responsibly addressed by decision makers)	Water	Dan Wermiel (503) 731-4100	Link agency geologic mapping and data with state water-quality and water-quantity planning efforts through referrals, delivery of publications, and strategic technical advice, particularly to SWMG members.
	Local government	Dennis Olmstead Dan Wermiel (503) 731-4100; also, technical assistance by regional geologists at Baker City (503) 523-3133, Grants Pass (503) 476-2496, and Portland (503) 731-4100	Prioritize and oversee agency planning involvement. Link planning efforts to necessary agency data bases with emphasis on periodic review and plan amendments. Input is largely in areas of mineral potential and geologic hazards.
	Offshore coordination	Dennis Olmstead (503) 731-4100	Contribute to state offshore policy development through participation in OPAC.

Acronyms:

BLM U.S. Bureau of Land Management
BPA Bonneville Power Administration
DSL Division of State Lands
EMD Emergency Services Division
FEMA Federal Emergency Management Administration
LCDC Land Conservation and Development Commission
METRO Metropolitan Service District
MILO Mineral Information Layer for Oregon
MLR Mined Land Reclamation
OCZMA Oregon Coastal Zone Management Association
ODOT Oregon Department of Transportation
OPAC Ocean Policy Advisory Council
OSU Oregon State University
PSU Portland State University
SWMG Strategic Water Management Group
U of O University of Oregon
USFS USDA Forest Service
USGS U.S. Geological Survey □

Oil and gas leasing in Oregon: The duty of the independent landman

by Randy Helms, CPL, Conoco Inc., PO Box 2197, ML3024, Houston, Texas 77252; and Harriet Person, CPL/ESA, Dominick, Person, and Associates, 917 Western American Circle, Suite 306, Mobile, Alabama 36609

This is one of a series of articles on the oil and gas industry that have been written for Oregon Geology *by people who work in various occupations within the industry itself. Earlier articles in this series have discussed the formation of oil and gas (v. 48, no. 8), the logging of wells (v. 50, no. 7/8), and geophysical exploration (v. 51, no.3).* —*ed.*

THE LAND

Oregon is one of the largest unexplored regions in the lower 48 states. The state has approximately 62 million acres within its boundaries. The vast majority of the nation's public lands are located in the western half of the United States, and Oregon is blessed with a considerable amount of federally owned land available for oil and gas leasing and exploration. In the state of Oregon, some 33 million acres are owned by the federal government, representing a little over 54 percent of the state's total acreage. Over half of that is owned by the USDA Forest Service.

The state and counties combined own over 3 million acres of land, all of which fall under their jurisdiction for leasing. Columbia County, in particular, has experienced a high level of exploratory activity in recent years. By virtue of its vast amount of federal, state, and county lands, Oregon provides a very attractive environment in which to explore for oil and gas.

Although the majority of Oregon's land is federal, state, and county owned, the remaining 46 percent is fee or privately owned. Ironically, in the areas where exploratory interest is the greatest, the majority of the land is owned by private individuals and large timber companies. The companies owning the largest blocks of acreage are Longview Fibre, Hanson Natural Resources, and Weyerhaeuser.

The year 1979 marked the real beginning of the present phase of exploratory activity in Oregon with the discovery of the Mist Gas Field by Reichhold Energy Corporation. After drilling several wells in Columbia County, Reichhold made its initial discovery on May 1, 1979, at a depth of 2,446 ft. Since Reichhold's initial discovery, numerous independents and majors alike have migrated north to Oregon to try their hand at drilling for fame and fortune as they have done in Texas, Oklahoma, Louisiana, and other great oil-producing states.

WHAT IS A LANDMAN?

In order to better understand who or what an independent landman is, we must first look at the definition. The definition of a "landman" is divided into three parts: (1) land work, (2) land professional, and (3) landman.

"Land work" is defined as the actual performance or supervision of any one or more of the following functions:

- Negotiating for acquisition or divestiture of mineral rights.
- Negotiating business agreements that provide for the exploration for and/or development of minerals.
- Determining ownership in minerals through the research of public and private records.
- Reviewing the status of title, curing title defects, and otherwise reducing title risk associated with ownership of interests in minerals.
- Managing rights and/or obligations derived from ownership of interests in minerals.
- The unitization or pooling of interests in minerals.

"Land professional" is defined as a person who derives a significant part of his or her income as a result of performing "land work."

Finally then, "landman" is defined as a "land professional" who has been primarily engaged in negotiating for the acquisition or divestiture of mineral rights and/or negotiating business agreements that provide for the exploration and/or development of minerals.

It should be pointed out that the masculine gender in the name "landman" refers to both men and women, as there are a number of women who are "landmen."

There are two types of landmen in the oil and gas business: company landmen and independent landmen. Company landmen, you may have guessed, are actual employees of companies such as Mobil, Exxon, and Conoco. The independent landman is usually hired by the company landman to obtain leases in prospects generated by the company. A company usually utilizes an independent landman for two main reasons: (1) anonymity, so the competition won't know which company is leasing; and (2) saving time for the company landman, who can then conduct regular job functions without being out of the office for extended periods of time.

The primary duty of the independent landman is to obtain oil and gas leases from the various types of mineral owners mentioned above. The oil and gas lease gives an energy company the right to explore for and produce oil and gas. This article will concentrate primarily on who these professionals are and what their relationship is to the mineral owner from whom they lease and to the major and independent companies that hire them.

TERMINOLOGY

Numerous terms are used by a landman during negotiations with a landowner. These terms and their definitions are listed below.

Assignment—In oil and gas terminology, this usually means a transfer of lease or property interest from one party or company to another. Most of the time, a landman will take the lease in his or her own name and assign the lease at a later date to the company that hired him or her.

Delay rental—A sum of money, usually $1 per acre per year, that is payable to the lessor by the lessee for the privilege of deferring the commencement of drilling operations or the commencement of production during the primary term of the lease.

Draft—An order for the payment of money drawn by one person or bank on another. Drafts are depository items, not cash items, and are used in lieu of cash.

Lease bonus—The cash consideration paid to the landowner for the execution of the oil and gas lease.

Lessee—The individual or company entitled under an oil and gas lease to explore, drill, and produce oil and gas.

Lessor—The owner of mineral rights who has executed a lease. The lessor may or may not be the surface landowner.

Oil and gas lease—A document that conveys an estate in real property for a certain term, subject to certain conditions that grant the lessee the right to explore for and to produce oil, gas, and other minerals.

Paid-up lease—A lease effective during the primary term without further payment of delay rentals, the aggregate of rentals for the entire primary term having been paid in advance.

Patent—The original conveyance granting the recipient legal title to public lands and containing all the reservations for easements, rights-of-way, or other interests in land provided by the applicable act or imposed on the land by applicable law.

Primary term—The period of time, typically 5 or 10 years, during which a lease may be kept alive by a lessee, even though there is no production by virtue of drilling operations on the leased lands or the payment of rentals.

Royalty—Landowner's share of production, free of expenses of production. In underexplored wildcat areas, this typically amounts to a share of ⅛, or 12.5 percent.

Wildcat acreage—An area of land with little or no exploratory activity, unproven territory. Sometimes referred to as an underground horizon from which there is no production in the general area.

Mineral reservation—Mineral rights that are held by an owner who is different from the surface owner (severed mineral rights).

Grantee—A person or company who acquires mineral rights through lease or sale.

Grantor—A person or company who gives up or loses mineral rights through lease or sale.

DOING THE HOMEWORK

After a company geologist and/or geophysicist has determined the geologic outline of a prospect, that outline is given to the company landman, who in turn hires the independent landman to commence leasing. The independent is usually, but not always, familiar with the area of interest, so the first step in learning about the area is to obtain ownership maps indicating the configuration of the land to be leased. The independent landman will probably conduct a personal cursory inspection of the surface of the land, looking for homes on the land and other evidence of people in possession of the property as well as location of roads, rivers, streams, and rights of way. During this inspection, any wells on the land that may be producing or abandoned will also be noted.

A large portion of an independent landman's time is spent in the county courthouse and with title companies in the county where the acreage to be leased is located. Prior to contacting the mineral owners, the landman will thoroughly research public records to determine surface and mineral ownership. Records from the last 10 to 20 years are checked to determine if there are valid oil and gas leases on the subject lands. If the public records have no sectional information (an index that lists documents by a geographic description), the landman must determine ownership of the minerals to be able to check for a current lease. The landman also checks with the state governmental authority for records of old wells on the lands. Should there be any physical evidence of old wells, the landman checks the records of the state authority for the status of the wells, plugging records, and all correspondence found in the files. This reflects any problems operators of old wells may have had on the subject lands.

If there appear to be no current leases of record, the landman conducts a detailed search of the records to determine who owns the minerals. The mineral estate may have been severed from the surface ownership in years past. Therefore, the landman will locate the patent for the land or at least begin the search at the turn of the century or at a time when the landman is comfortable that the minerals and surface were still owned by the same person(s).

There are several methods of checking records within a given county. If the records are indexed by sectional information, that will be the place to begin. The landman will record from the sectional index the book and page numbers in the deed records and oil and gas lease records all documents relating to the subject description. The landman will locate those books, read the recorded documents, and make written notes of all information regarding the subject lands. In particular, the landman will pay attention to the type of document (deed, right of way, will, etc.), the grantor (the person conveying the property), the grantee (the person receiving the property), the date of the document, the date the document was recorded, and any reservations (such as mineral reservation) and restrictions in the document.

From these written notes, the landman builds a "chain of title," ideally, from the beginning date to the present, without any breaks in the chain. However, very seldom does that happen. The landman will check the alphabetical index of all documents filed in the deed and oil and gas lease records. There are two of these indices: direct and reverse. The direct is indexed by the last name of the grantor of the lease. The reverse book in indexed by the grantee's last name and is used to find how title is vested in a person where there is a break in the chain of title. The landman checks all documents indexed in the name of the person who owns the land from the date the land was acquired to the date the land was conveyed to the next person. Then all the documents indexed under the next person's name are checked until the land was conveyed to someone else, and the process is continued to the present-day owner. In documents where there are mineral reservations, the name of the owner who retained some or all of the minerals is checked in the same manner described above.

In states such as Oregon, where there is no sectional information, the records search will begin with building a tax chain, that is, securing the names and dates of landowners whose property has been assessed for taxes, usually from the turn of the century to the current date. The landman uses these names to check the alphabetical index as described above, locating the patent and building a chain of title.

The landman utilizes other county records. The mortgage books provide information in the event a note was not paid, or the subject lands were used as collateral and a foreclosure ensued. The landman should be familiar with the state's foreclosure and right of redemption law and limitations on the term of encumbrances. Any unpaid mortgages and unsatisfied judgments and liens are noted, because they will need to be subordinated to the new oil and gas leases before a company will drill a well on the property.

When an owner seems to disappear from the chain of title and later different individuals join in a conveyance or a lease of the property, probate records are checked for any probated will and guardianship or conservatorship. The landman must be knowledgeable of the state's laws of descent and distribution and guardianships.

While searching the records, the landman is watchful for unusual information in the documents, because seemingly insignificant statements there, along with what can be learned in conversations with family and friends, can lead to information about illegitimate children, mentally incapacitated family members, and such. This information is vital when it is time to have the correct owners execute an oil and gas lease.

The landman prepares a complete ownership report of the mineral and surface estates with the information obtained from the public records, noting problems in the chain of title, questions that need to be asked of landowners when they are contacted, and any incapacities of the mineral or surface owner (minors or incompetents). Any restrictions on use of the surface will be included. The landman expresses any environmental concerns discovered in the personal inspection or in the state authority's records that the company should consider before proceeding with acquiring the rights to explore for oil and gas. This report is then submitted to the company landman.

GETTING THE LEASE

After the company landman reviews the report and elects to purchase the oil and gas leases, the independent landman is given an outline of a "buy area" and a monetary authority under which the leases are purchased. The company has "run economics" on the prospect that determine the royalty amount, bonus per acre to be paid, and the primary term under which their economics are realistic for the prospect. The landman then begins contacting the landowners to lease oil and gas rights.

This portion of the independent landman's job is just as important, if not more important than the research in the public records. For many Oregon landowners, this may be their first experience with a landman. It is up to each individual landman to make a favorable first impression, as this may be the start of a 20- to 30-year relationship between the company and landowner. Each landman has the responsibility of maintaining good public relations with every landowner he or she meets. The landman knows that the landowners' feelings and attitudes about the oil and gas industry are formed as a direct result of their initial meeting, and therefore the landman should always act accordingly.

The landman should be cordial, honest, and straightforward when dealing with the potential lessor and should take the time to answer any questions a landowner may have about the lease, future operations on the land, or any other phase of the oil and gas business. If there are any questions that cannot be easily answered, the landman should be willing to find the answers. Once the lease is signed, it should be "filed of record" in the courthouse and a copy transmitted to the company, so that the latter will have a record of how many leases it owns on the subject prospect.

The independent landman performs numerous other duties between the time the executed lease is "filed of record" and the time the well may be spudded. Some of these include the collection of abstracts, title curative work, permitting, and settling damages—functions that are beyond the scope of this paper.

THE PROFESSION

Most landmen are active members of the American Association of Professional Landmen (AAPL), an international organization boasting a membership of over 8,000 Land Professionals. These members are bound by an accepted "Code of Ethics" to inspire and maintain a high standard of professional conduct. The AAPL mission is to promote the highest standards of performance for all land professionals, to advance their stature, and to encourage sound stewardship of energy and mineral resources. Many landmen have obtained the Certified Professional Landman (CPL) designation only after many years of experience, continuing education, and the successful completion of an intensive certification examination. It is generally accepted in the land profession that the CPL designation stands for unquestionable ethics, quality work, and true professionalism.

Questions about this article, AAPL, or landmen in general may be directed to AAPL, 4100 Fossil Creek Boulevard, Fort Worth, TX 76138, Attention Mr. Jack Deeter, Executive Vice President and Chief Executive Officer. The first author, Randy Helms, may be called at (713) 293-3003. □

Statewide study of pumice released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released ***Pumice in Oregon***, a statewide study by staff economic geologist Ron P. Geitgey, that reviews currently producing operations in Oregon and surveys other pumice occurrences to identify possible additional sources for various markets.

The report is DOGAMI Special Paper 25 and consists of a 26-page illustrated text and two plates: one map-sized sheet with tabular and graphic presentations of analytical data and one state map (scale 1:1,000,000) showing deposits, producers, sample locations, and thickness contours of pumice in the Newberry and Crater Lake volcanic areas. The price is $9.

Pumice is a volcanic rock composed of bubbles or vesicles in glass matrix formed by the effervescence of gases and rapid cooling of molten material during an eruption. Pumice is characteristically frothy and lightweight, often with a density low enough to permit it to float on water. The vesicle walls form thin sharp cutting edges when broken, which makes pumice an effective abrasive in both lump and powder forms. These characteristics are responsible for the commercial value of pumice as absorbents, insulators, abrasives, and lightweight aggregates and fillers.

Pumice is produced by two companies in Oregon, primarily for lightweight concrete aggregate and for horticultural uses. Lesser amounts are sold for absorbents, landscaping, and stone-washing garments. The Bend pumice is the primary source of current production, but producers in Bend operate in an increasingly urbanized environment. Pumice deposits from both the Mount Mazama (Crater Lake) and Newberry volcano eruptions have economic potential, but both require additional exploration and testing.

The new report, DOGAMI Special Paper 25, is now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

Preliminary geologic maps for southeastern Oregon on file

As part of its mandate to make geologic information available to the public in a timely manner, the Oregon Department of Geology and Mineral Industries (DOGAMI) has put several 7½-minute quadrangles of southeastern Oregon on open file for examination. These maps are preliminary, hand-colored maps (scale 1:24,000) and are on file in the libraries of the Portland and Baker City offices (addresses on page 26 of this issue).

The maps were produced by the joint efforts of DOGAMI, the U.S. Geological Survey, and the Geology Department of Portland State University as part of a cooperative program to map the west half of the Boise 1° by 2° sheet, an area covering more than 3,000 mi^2 east of longitude 118° and between latitudes 43° and 44° in Malheur County. Two full-color compilation maps of the study area are scheduled for release at a scale of 1:100,000 later this year.

This study was funded jointly by DOGAMI, the Oregon State Lottery, and the U.S. Geological Survey COGEOMAP program.

Listed below are open-file number, quadrangle covered, and author(s) of each of the maps:

O-90-03	Kane Springs Gulch quadrangle	Ferns and Urbanczyk
O-91-03	Keeney Ridge quadrangle	Ferns and O'Brien
O-92-02	Bogus Bench quadrangle	Ferns
O-92-05	Cedar Mountain quadrangle	Ferns
O-92-06	Cow Lakes quadrangle	Ferns and MacLeod
O-92-07	Downey Canyon quadrangle	Ferns and MacLeod
O-92-08	Hooker Creek quadrangle	Ferns and MacLeod
O-92-09	Jordan Craters South quadrangle	Ferns and MacLeod
O-92-10	McCain Creek quadrangle	Ferns
O-92-11	Mustang Butte quadrangle	Ferns
O-92-12	Rockville quadrangle	Ferns and Gilbert
O-92-13	Sacramento Butte quadrangle	Ferns
O-92-14	Saddle Butte quadrangle	Ferns
O-92-15	Wrangle Butte quadrangle	Ferns
O-92-16	Avery Creek quadrangle	Brooks
O-92-17	Rufino Butte quadrangle	Brooks
O-93-02	Burnt Flat quadrangle	Ferns and Williams
O-93-03	Copeland Reservoirs quadrangle	Brooks
O-93-04	Crowley quadrangle	Ferns and Williams
O-93-05	Rinehart Canyon quadrangle	Ferns and Evans

□

Port Orford hoax confirmed

Recent studies have verified a deliberate ruse as to the origin of the"Port Orford meteorite," supposedly discovered by John Evans in 1856 in the Siskiyou National Forest.

National Museum of Natural History scientist Roy S. Clarke, Jr., University of Western Ontario historian Howard Plotkin, and Technical University of Denmark metallurgist Vagn F. Buchwald collaborated on a new publication, number 31 in the Smithsonian Institution scientific series "Smithsonian Contributions to the Earth Sciences": *The Port Orford, Oregon, Meteorite Mystery*. Edited by Clarke, the book reveals that the meteorite specimen is really a piece of the Imilac meteorite shower discovered in Chile around 1820 and that Evans used it as "a prop in a deliberate and elaborate hoax" (Clarke).

The 43-page monograph combines two papers, a historical study by Plotkin, "John Evans and the Port Orford meteorite hoax," (pages 1-24) and a technical study by Buchwald and Clarke, "A mystery solved: The Port Orford meteorite is an Imilac specimen" (pages 25-43).

Plotkin's paper details the history of the mysterious, lost "Port Orford meteorite." The author presents previously unreported evidence indicating that Evans was not the well-trained and well-respected scientist of historical portrayals but rather poorly qualified for the scientific disciplines he served, particularly his geologic field work. Plotkin concludes that Evans' career as a scientist showed "superficial field work, unprofessional conduct, and financial problems" and that these difficulties finally consumed him. According to Plotkin's quite plausible scenario, Evans tried to use the "discovery" of the meteorite to induce Congress into voting for another appropriations bill for his survey of the Oregon Territory and at the same time to extricate himself from a rather desperate personal financial situation.

Plotkin's historical arguments stimulated the thorough metallographic examination of the Port Orford specimen, with particular emphasis on a comparison with the Imilac meteorite shower, that is presented in the second paper by Buchwald and Clarke. Buchwald used his long familiarity with the Imilac meteorite material to subject the Port Orford specimen to an unusually thorough meteorite pairing study, a common method used in meteoritics. The authors conclude from the results that Evans definitely lied when he claimed to have removed the piece from a much larger mass and that the Port Orford specimen is so indistinguishable from specimens of the Imilac meteorite shower that assuming a different origin would strain credulity.

The publication will, it is hoped, bring to an end the myth that had developed since the 1930s and was fanned by fanciful journalistic accounts. Many people searched for the phantom meteorite that was to have a mass of ten tons and was to earn the finder million-dollar profits. The Smithsonian received so many queries that it developed form letters to respond to the most frequently asked questions. In 1964, Smithsonian Assistant Curator Edward P. Henderson collaborated with then Oregon State Geologist Hollis M. Dole on an article published in this magazine, then published under the name *The Ore Bin* (v. 26, no. 7, p. 120-130), in an effort to stop the misguided activities with a critical presentation of the facts. However, the effect was the opposite of what they had hoped for. Even as historian Plotkin began his study in 1986, he was taking up the challenge of then Smithsonian Curator-in-Charge Clarke, who complained about "more than a lifetime's worth of correspondence" and wished "that historians get in there and clean up the mess." That, it seems, has been accomplished now.

Since the Smithsonian book is already out of print, The Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries will make photocopies available for the price of $3. See last page of this issue for ordering information.

—partly from Smithsonian Institution News

Northwest Museum of Natural History finds home

The Northwest Museum of Natural History Association has advanced its museum plans to having found a location for the museum in Portland. According to Museum Association Director Dave Taylor, Portland State University has agreed to allow the Association to occupy the ground floor of the Ondine Building on the Portland State Campus. Located at SW Sixth Avenue and Hall Street, the building is easily accessible by public transportation or automobile. Now the Museum Association enters the next major step in its life, that of remodeling its space and establishing a development office to expand its support base.

The museum is to be opened in 1994, and several exhibit themes are presently being developed, including one centering on the skeleton of the museum's own *Triceratops* dinosaur, one on human origins in East Africa, and one on the plight of the Pacific Northwest salmon. The Geology Department at Portland State University is closing its earth science museum and will loan its collection of fossils, rocks, and minerals to the Museum Association.

Among recent activities of the Museum Association has been the participation in the Young Scholars program funded by the National

Members of the Northwest Museum of Natural History Association pose with a Triceratops *leg bone, which is flanked by other bones still encased in plaster. The bones will be displayed at the museum. Pictured are, in front, Dave Taylor, the Association Executive Director; on the right, Professor Emeritus John E. Allen of Portland State University and an Association honorary trustee; and on the left, Scott Frank, president of the Museum Association's board of trustees. Photo by Greg Paul.*

Science Foundation and cosponsored by the Oregon Museum of Science and Industry (OMSI) and Portland State University. In two disciplines, paleontology and aquatics ecology, high school students conducted field studies and produced research papers.

The Museum Association and Portland State University Continuing Education also offers classes jointly on topics of natural history. These classes are offered for credit to educators and professionals as well as to the general public. Current offerings include "Dinosaurs—field notes from a paleontologist," "Teaching earth science in the Northwest—geology," and "Vertebrate paleontology in the John Day country."

The Northwest Museum of Natural History is a nonprofit educational and cultural institution and welcomes involvement of any kind, such as association membership, volunteer help, or in-kind services and contributions. The address for more information is Northwest Museum of Natural History Association, P.O. Box 1493, Portland, Oregon 97207, phone (503) 725-5900.

—From Museum Association newsletter

Gem and mineral show announced

The Willamette Agate and Mineral Society of Salem, Oregon, announces its 38th annual gem and mineral show, "River of Gems," to be held Friday through Sunday, April 16-18, 1993, at the Polk County Fairgrounds in Rickreall, 10 mi west of Salem. The show will be open on Friday from 9 a.m. to 6 p.m., on Saturday from 10 a.m. to 6 p.m., and on Sunday from 10 a.m. to 5 p.m. Admission is free.

The program will include competitive and noncompetitive displays, creative craft demonstrations, dealer tables, a silent auction, and door prizes. On Friday, tours for schoolchildren will be conducted.

—Society news release

Faceting challenge comes from Australia

All Gem faceters are called to participate in the "1994 Australia vs. the United States Faceting Challenge and Individual International Faceting Championship." The Australia vs. United States competition has been held every two years since 1984 between members of the Australian Facetors' Guild Limited and members of faceting guilds in the United States. The winner becomes the holder of the Challenge Cup until the next competition and is also charged with organizing that competition. The United States last won the 1986 round, and Australia has been holder of the Challenge Cup since winning it back in 1988. However, competition rules include the provision that, since results are based on the scores of the best five entrants, other national teams could be formed, and the competition could be expanded at any time by more groups of at least five entrants from the same country who could compete as a national team.

The individual championship includes not only the entrants in the Challenge but also any individuals from any other country. At the last championship in 1992, this included entries from Canada, Great Britain, Holland, and New Zealand. A special trophy will be awarded to the highest scoring entrant from a country other than Australia or the United States.

Competitors must cut four stones according to given guidelines: an Eagle-Eye cut in cubic zirconia, a Cushion Rectangle Half Barion cut in beryl, a Checkerboard Barion Square cut in synthetic corundum, and a Square Cushion 012 cut in topaz.

The ten top scoring entrants in the overall competition will be invited to compete in the "Biron Competition 1995," which will involve cutting manmade emerald and morganite donated by Biron International of Perth, WA.

Registration forms are due in Australia by the end of October 1993. For more information about the Cup Challenge and for schedule and registration materials, any interested persons in the United States should contact Walter Carss, Route 3, Box 700, Brenham, Texas 77833, telephone (409) 836-6910. From other countries, the contact address is Rupert Pickrell, 1A Spurgin Street, Wahroonga, NSW, Australia, 2076, telephone (02) 489 7731 or, from overseas, 612-489-7731. A copy of the schedule, conditions, and rules is held for inspection in the Portland library of the Oregon Department of Geology and Mineral Industries. □

GeoMedia computer system by USGS teaches children about earth science

A multimedia interactive computer system called GeoMedia, designed to help teach middle-school children (grades four to six) about complex earth-science processes, has been developed by the U.S. Geological Survey (USGS), Department of the Interior.

"The USGS is distributing GeoMedia digital compact disks to teachers who are willing to experiment with this new technology in the classroom," said Denise Wiltshire, chief of the project and a technical-information specialist at the USGS National Center in Reston, Virginia.

"GeoMedia CD-ROMs contain a mix of information on earthquakes, the hydrologic cycle, topographic maps, and other earth-science subjects," Wiltshire said. "Unlike traditional text books on these subjects, GeoMedia is in an interactive computerized format that allows children to plot their own personal path through the scientific information."

GeoMedia is one of several educational products available from the USGS as part of its program to help teachers inform precollege students about how geology, hydrology, and other earth sciences affect them, their communities, the nation, and the world. Other recent products include a series of posters on water resources and a booklet on helping children learn geography.

As the nation's largest earth-science research and information agency, the USGS each year produces about 5,000 new reports, maps, and many forms of computer-readable information on geology, hydrology, cartography, and other earth-science subjects that are available to schools and the general public.

"The GeoMedia digital compact disk contains a wealth of facts on earth-science topics, which are linked together to promote learning at the individual pace of each reader," Wiltshire said.

"For example, students may choose to learn about the forces that create earthquakes by viewing an animated sequence of images. In addition to animation, GeoMedia includes an audible narration to explain scientific concepts. The written descriptions also provide students with the opportunity to review glossary terms for unfamiliar vocabulary.

"GeoMedia opens the doors to communicating earth science to some children who may not respond to traditional teaching methods," Wiltshire added.

Payson Steven, president of InterNetwork, Inc., a design consulting firm in Del Mar, California, that collaborated with the USGS on producing GeoMedia, said that "Children are more apt to comprehend a concept by interacting with the information that sparks their curiosity. Browsing through the information is dynamic and also allows many levels of focus."

To obtain a copy of GeoMedia, write to Project Chief, GeoMedia, U.S. Geological Survey, 801 National Center, Reston, VA 22092. The GeoMedia CD-ROM is available at no cost to teachers and libraries while the supply lasts. **Available for use with Macintosh computers only.** *—USGS news release*

April is Earthquake Preparedness Month

The month of April has been declared Earthquake Preparedness Month, and it is a good opportunity to remember that Oregon, too, especially western Oregon, is not excluded from the dangers of earthquakes that periodically shake the rim around the Pacific Ocean, including the Big Ones, so-called "great" earthquakes with magnitudes of 8 and more.

In recent years, geologic research has produced an increasing amount of evidence of past earthquakes in Oregon west of the Cascades and has helped to heighten awareness of this natural hazard and stimulate efforts to be prepared for the eventuality. And such efforts are being made—by many individuals, organizations, and government agencies, from the State Legislature down to county and city offices and schools. Some of the recent results are discussed here briefly.

USEFUL MATERIALS

The American Red Cross, Oregon Trail Chapter, in its Earthquake Survival Program, distributes a "calender" of single information sheets, one for each month, that focus on essential things to consider or have, in order to "Beat the Quake." The list includes: January, work gloves and sturdy shoes; February, portable radio and batteries; March, home hazard hunt; April, "duck, cover, and hold" (how to protect oneself); May, emergency water supply; June, first aid; July, emergency food; August, flashlight and batteries; September, adjustable wrench; October, smoke detector; November, fire extinguisher; December, how to strap the water heater.

Since 1991, Oregon schools have been required to perform periodic earthquake drills, and the American Red Cross provides an information and guidance package to school principals to help conduct the drill (scheduled this year for April 30), stimulate participation, and assist in publicizing it. The package also includes materials that can help a school to develop its own earthquake preparedness planning, including information on instructional, emergency-management, and community resources and some teaching aids, from a recipe for a "tasty quake" made with gelatin to the scenario describing a magnitude 8.2 earthquake event in a small city ten miles east of Portland.

The address of the Oregon Chapter of the American Red Cross is 3131 N. Vancouver Avenue, P.O. Box 3200, Portland, OR 97208, phone (503) 284-1234.

At the Tillamook County Office of Emergency Management, Jim Gang, Lori Monday, and Liz Kingslien have produced *Rattling the Northwest: Earthquake and tsunami danger in the Pacific Northwest*, a colorful 12-page booklet that explains earthquakes and tsunamis and how to survive them—and does so with few, well-written words and some lively illustrations. The address of the Tillamook County office is 201 Laurel Avenue, Tillamook, OR 97141, phone (503) 842-3412. Similar efforts have been reported to us from Clatsop County and Curry County, taking the forms of both publications and extensive publicity campaigns.

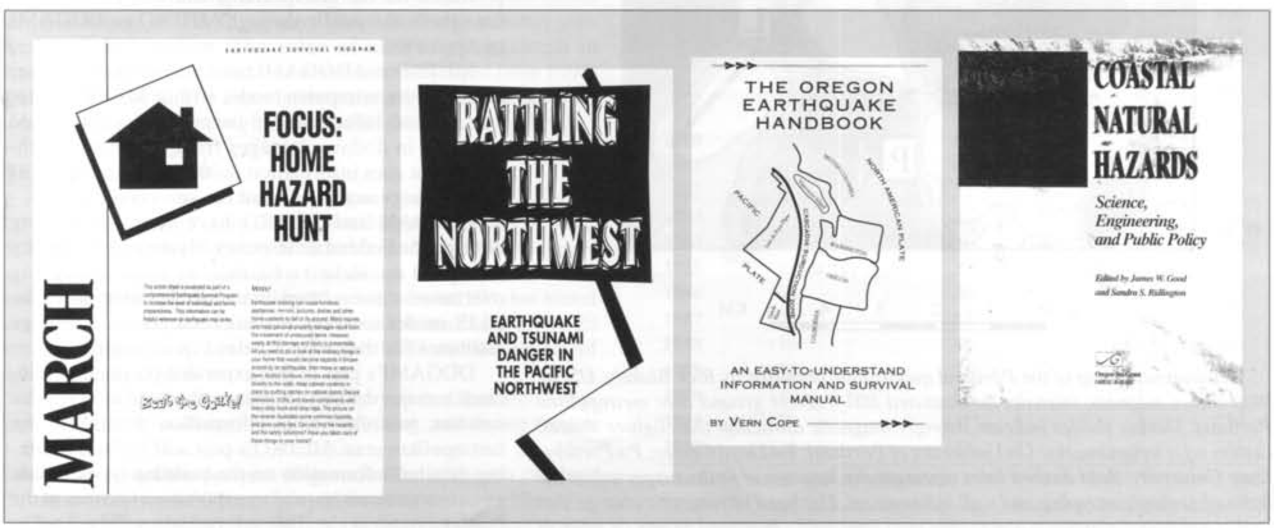
The Oregon earthquake book, by Vern Cope, addresses individuals and families. According to the author, it is "Oregon's first comprehensive earthquake manual." Of its 120 pages, about one third serves to help you understand earthquakes and tsunamis, two thirds deal with being prepared, and some 20 appendix pages, specially marked and bound so that they can be found easily and will stay flat when you open the book to them, contain instructions about what to do during and after an actual earthquake event. The book can be bought from the author, P.O. Box 19843, Portland, OR 97280, for $11.95.

Another book publication, *Coastal natural hazards: science, engineering, and public policy*, focuses on the Oregon coast. It presents the principal papers delivered at a conference held, under the same title, in Newport, Oregon, in October 1991. While it deals with natural hazards more comprehensively, some scientific contributions expressly address seismic hazards. The book was published by the Oregon Sea Grant Program of Oregon State University (number ORESU-B-92-001), Corvallis, OR 97331.

In addition to the sources mentioned above, the book publications are also available at The Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries (DOGAMI). Ordering instructions are on the last page of this issue. Information material is also available from the State of Oregon Emergency Management Division, 603 Chemeketa Street NE, Salem, OR 97310, phone (503) 378-4124.

PORTLAND METROPOLITAN AREA

For the Portland metropolitan area, recent research results reported by scientists of the U.S. Geological Survey (USGS) confirm the possibility that major faults run through the down-



Recent publications and information materials show growing recognition that earthquake hazards must be taken seriously even by Oregonians.

town area of Portland and could locate future earthquakes beneath this area. The following is excerpted from material prepared by Ian Madin of the Oregon Department of Geology and Mineral Industries (DOGAMI) and Tom Yelin and Rick Blakely of the U.S. Geological Survey and presented to the public at a recent press conference given by the USGS, DOGAMI, and the Portland Metropolitan Service District (METRO):

The Portland area has experienced over 100 recorded earthquakes since 1841. The largest of these have been a little over magnitude 5, just large enough to cause minor damage.

Geologists have long suspected that a major fault runs along the northeast side of the Portland Hills. Such a fault was shown on a geologic map of Portland published in 1990 [DOGAMI map GMS-75; see list on page 47 of this issue.—ed.] but was drawn with question marks because its presence was suspected but not confirmed.

Locating faults in the Portland area by geologic mapping is made difficult by heavy vegetation, thick soil, and urban development. However, some geophysical techniques can assist the geologist to "see" below the surface. Certain rock units that underlie the Portland area are more strongly magnetic than other rock units. Locations where faults have placed strongly magnetic rocks next to weakly magnetic rocks hundreds of feet below the surface can be detected by magnetic measurements made above the ground.

To accomplish this, geophysicists from the USGS conducted a detailed aerial magnetic survey of the Portland area in 1992. The survey consisted of nearly 6,000 km (3,700 mi) of flying (back and forth) over an area about 50x50 km (30x30 mi), taking frequent magnetic measurements. A map constructed from these measurements shows many complex geologic features that have yet to be explained. One major feature that is clear, however, is a strong line of magnetic change that is located on top of one of the suspected faults mapped beneath Portland. Other faults are also suspected on the basis of the new magnetic measurements, notably a fault lying beneath Sylvan and Council Crest. The magnetic map will be available soon from the USGS.

It is not known whether any of Portland's past earthquakes have occurred on the faults identified by the magnetic study, and geologists do not know if these faults are capable of producing future damaging earthquakes. Nevertheless, the presence of such pronounced features raises the possibility that future earthquakes might be centered directly beneath downtown Portland.

Further research is planned by the USGS, DOGAMI, and Portland State University to try to determine where, how large, and how frequent future earthquakes in the Portland area might be.

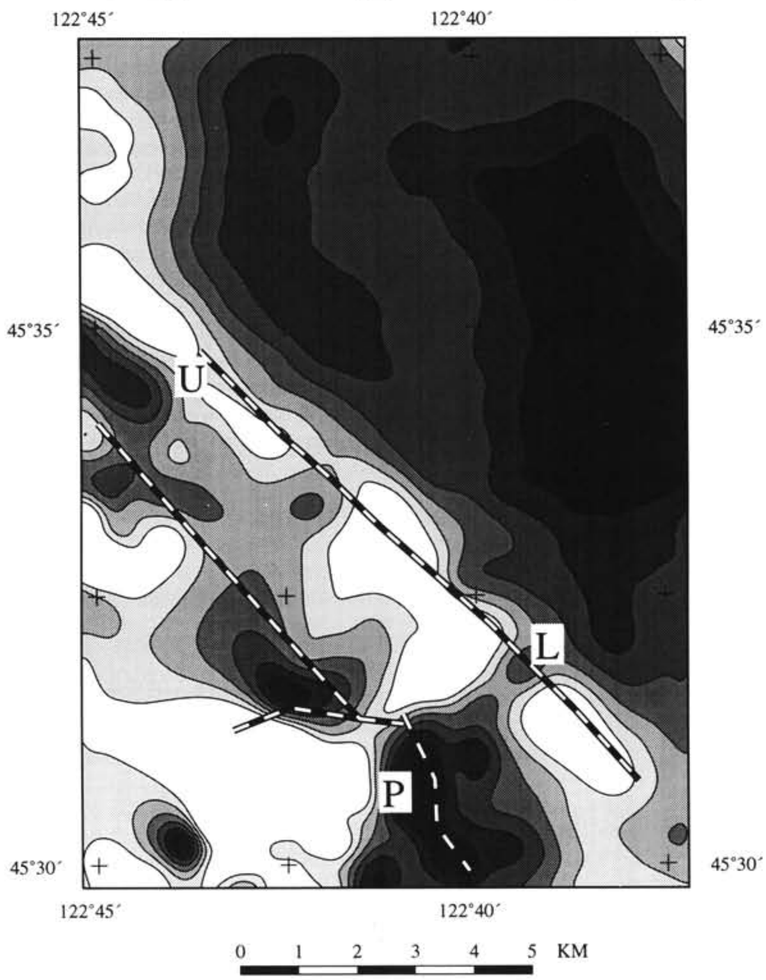
Planning for future earthquakes requires an understanding of what kind of damage might occur and where the damage will be concentrated. In earthquakes around the world, most of the spectacular damage was due to local soil conditions or poor design and construction. In 1992, DOGAMI started a program to produce a map of the Portland core area that depicts the relative degree of any future earthquake damage that is likely to occur because of the given soil conditions. This map, the *Relative Earthquake Hazard Map of the Portland Quadrangle*, is produced for the nonspecialist and will be available for sale to the public through METRO or DOGAMI in April 1993.

METRO and DOGAMI have also worked together to produce a computer model within METRO's Regional Land Information System (RLIS) that would estimate, in dollars, damages from a scenario earthquake that uses information on the structural types of the buildings in the area and the soil conditions.

DOGAMI and METRO have received funding through the Federal Emergency Management Agency to expand the Relative Earthquake Hazard mapping over more of the metropolitan area and to improve the RLIS model to allow realistic and accurate damage estimates for the entire Portland quadrangle.

DOGAMI's part in this expanded program will include a major drilling program, scheduled to begin this summer, to collect soils information throughout the metropolitan area. METRO's part will include gathering detailed information on the building types, water, gas, communications, and transportation lifelines in the Portland quadrangle. This information will be used to produce detailed damage estimates and to guide earthquake hazard reduction policies. □

Aeromagnetic Survey, Portland Quadrangle



Aeromagnetic map of the Portland quadrangle prepared by Rick Blakely, USGS. Map shows magnetic intensity as measured 800 ft above ground over metropolitan Portland. Darker shades indicate stronger magnetic attraction than lighter shades. Letters refer to landmarks: U=University of Portland; L=Lloyd Center; P=Portland State University. Bold dashed lines represent the location of faults suspected on the basis of geologic mapping and well information. The band of magnetic change that strikes northwest-southeast across this map apparently is related to one or more of these faults, The agreement between the magnetic pattern and geologic mapping increases the belief that significant faults lie beneath downtown Portland.

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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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.

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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.

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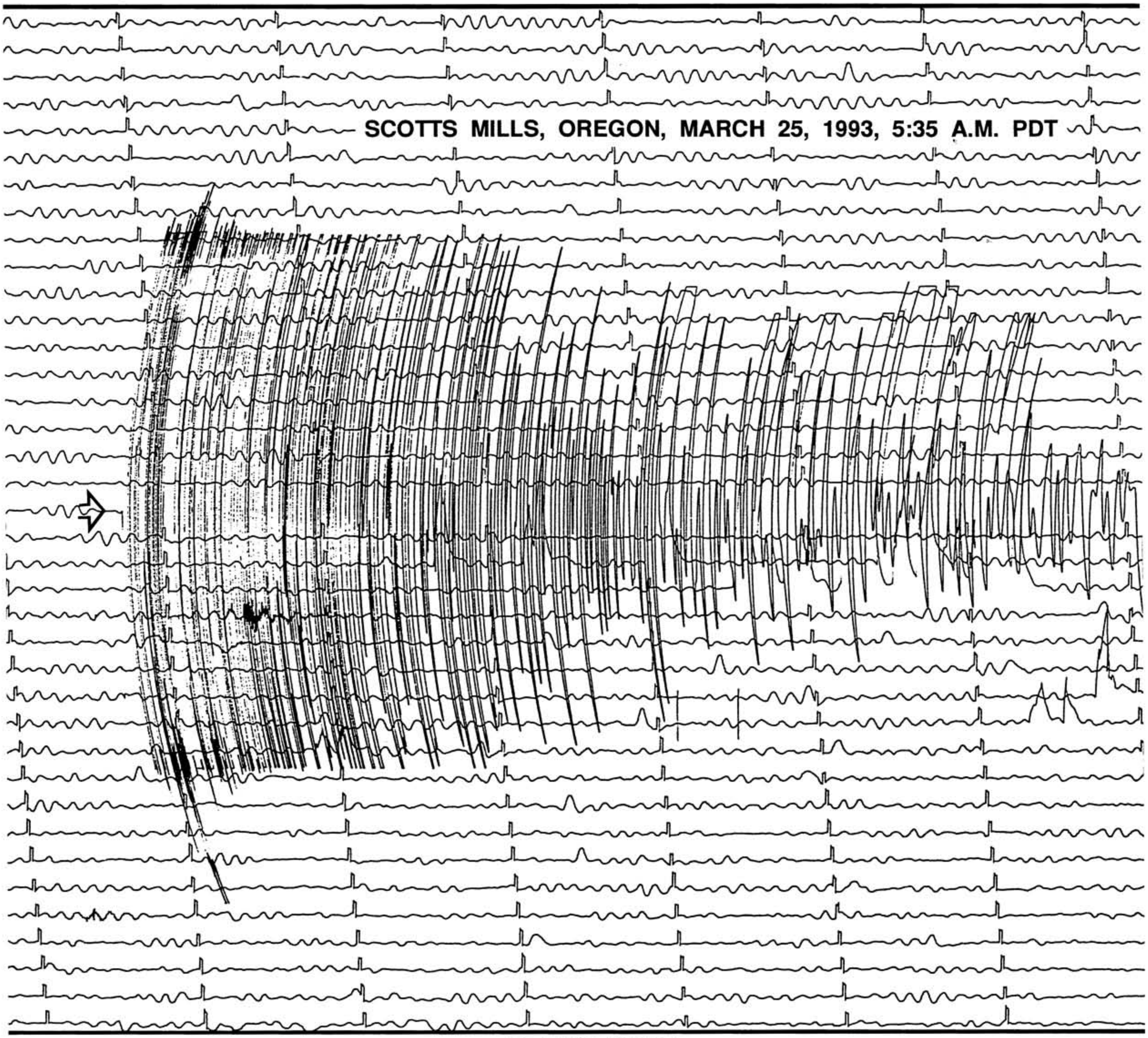

IN THIS ISSUE:

The Earthquake of March 25 at Scotts Mills,
Geology near Blue Lake County Park in Portland, and
Report on New Caldera Complex in Jackson County

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. 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

Seismogram of the Scotts Mills earthquake on March 25, 1993, at 5:35 a.m., as recorded on the seismograph of the Portland State University (PSU) Department of Geology. The trace marked by an arrow shows the response of approximately the first six minutes after the main shock. Each subsequent horizontal trace represents a time interval of half an hour; the tick marks on each trace represent intervals of one minute. Courtesy of the Department of Geology, PSU.

OIL AND GAS NEWS

Reclamation of drill sites at the Mist Gas Field

During March, Nahama and Weagant Energy Co. of Bakersfield, California, reclaimed three drill sites at the Mist Gas Field. The company reclaimed the drill sites CC 31-15-65, CC 43-33-75, and Wilson 11A-5-65, using the patented Soli-bond process, in which drilling material is solidified on site, in the sump, into a stable soil material. The sites were then graded for future beneficial use. This is the first time that this procedure has been used at the Mist Gas Field. The same procedure may be used for reclamation of drill sites in the future.

Recent applications:

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
477	Nahama and Weagant LF 43-32-65 36-009-00302	SE¼ sec. 32 T. 6 N., R. 5 W. Columbia County	Application; 4,700.
478	Nahama and Weagant LF 32-36-65 36-009-00303	NE¼ sec. 36 T. 6 N., R. 5 W. Columbia County	Application; 4,100.
479	Nahama and Weagant CC 42-32-74 36-009-00304	NE¼ sec. 32 T. 7 N., R. 4 W. Columbia County	Application; 1,700.
480	Nahama and Weagant CC 43-8-64 36-009-00305	SE¼ sec. 8 T. 6 N., R. 4 W. Columbia County	Application; 2,150.
481	Nahama and Weagant CC 22B-19-65 36-009-00306	NW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Application; 3,350.
482	Nahama and Weagant CC 41-36-75 36-009-00307	NE¼ sec. 36 T. 7 N., R. 5 W. Columbia County	Application; 1,650.
483	Nahama and Weagant CFW 41-35-75 36-009-00308	NE¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Application; 2,500.
484	Nahama and Weagant CC 42-34-65 36-009-00309	NE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Application; 3,150.

□

ANNOUNCEMENT
from
The Oregon Department of Geology and Mineral Industries

Because of anticipated curtailment of funds, the Oregon Department of Geology and Mineral Industries expects to close its geologic-geochemical laboratory.

A sealed-bid sale will be held for the laboratory equipment and such infrastructure items as benches, fume hoods, and other built-in devices. Following is a partial list of items, most of which are in excellent condition.

Jaw crusher	X-ray diffractometer (XRD)
Cone crusher	Atomic absorption spectrometer
Ring and puck mill	Two centrifuges
Disk pulverizer	Two analytical balances
Hammer and screen mill	Microbalance
Sieve shakers, 8- and 8/12-in.	Toploader balance (4-kg cap.)
Drying ovens	Gold Screw autopanner
Two filter presses	Reflectance meter
Large ultrasonic cleaner	Compressor, 5 hp.
Fire-assay furnace and assay chemicals	

Interested persons may call Jean Pendergrass at (503) 731-4100 for further information.

March 25, 1993, Scotts Mills earthquake—western Oregon's wake-up call

by Ian P. Madin[1], George R. Priest[1], Matthew A. Mabey[1], Steve Malone[2], Tom S. Yelin[3], and Dan Meier[4]

INTRODUCTION

On March 25, 1993, at 5:35 a.m., much of northwestern Oregon and parts of southwestern Washington received an unmistakable wake-up call from Mother Nature. The message came as a magnitude 5.6 earthquake that woke up over a million people to the fact that Oregon is vulnerable to damaging earthquakes. This was probably the largest earthquake in the historical record of northwest Oregon but is surely not the largest that can occur. This event should give us notice that we need to prepare for earthquakes that will be many times larger and far more devastating.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has been delivering this message continually during the last six years while working to map the hazards in heavily populated areas. This article summarizes what we know about the Scotts Mills earthquake, what the threat is from future earthquakes, and what can be done to mitigate loss of life and property from them.

NATURE OF THE EARTHQUAKE

The epicenter of the Scotts Mills earthquake was located at lat 45°02.00'N. and long 122°36.43'W. (sec. 19, T. 6 S., R. 2 E.), about 3 mi (4.8 km) due east of Scotts Mills, which is near Silverton and Mount Angel, Marion County, Oregon (Figure 1). As of April 8, 1993, numerous aftershocks had been located by the University of Washington (UW) seismic network (Figures 1 and 2). A vertical cross section of the aftershock activity is presented in Figure 3. Many more aftershocks were recorded on the closest UW station than were located by the network (Figure 2). Portable seismographs deployed by teams from the U.S. Geological Survey, the University of Oregon, and Oregon State University will allow for the location of many of these aftershocks.

GEOLOGY

No ground rupture, cracking, landsliding, liquefaction, or other surface geologic effects that could reliably be attributed to the Scotts Mills earthquake have come to our attention.

No faults that coincide directly with the epicenter of the Scotts Mills earthquake are known. The closest—and at this point the only—candidate for a causative structure is the Mount Angel fault (Figure 1). This northwest-trending structure was first mapped by Hampton (1972) near Mount Angel and later extended by Werner and others (1992) on the basis of evidence from water wells and seismic reflection lines. However, the mapped extent of the Mount Angel fault ends at least 5 mi (8 km) west of the Scotts Mills epicenter. A geologic map of the epicentral area (Miller and Orr, 1984) shows no significant

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[2] *University of Washington Seismology Lab*
[3] *U. S. Geological Survey, Seattle, WA*
[4] *Woodward Clyde Consultants, Portland, Oregon*

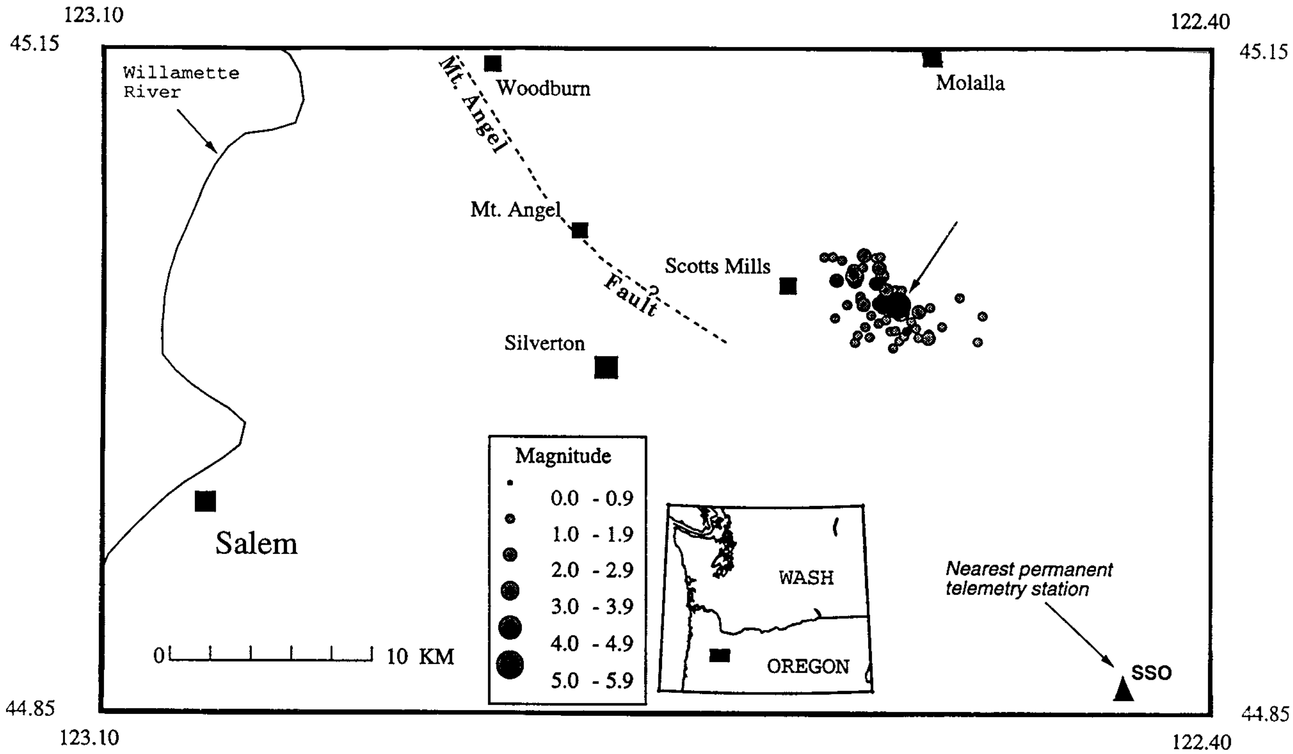

Figure 1. Map showing location of the epicentral area (arrow) of the March 25, 1993, Scotts Mills earthquake (large filled circle), aftershocks during the first two hours (smaller filled circles), and aftershocks through April 8, 1993 (gray circles). Trace of the Mount Angel fault shown by dotted line. Locations were determined with data from the University of Washington telemetry network stations, the closest of which is station SSO at 13.7 mi (22 km) distance (lower right corner of map). Locations are preliminary and subject to revision.

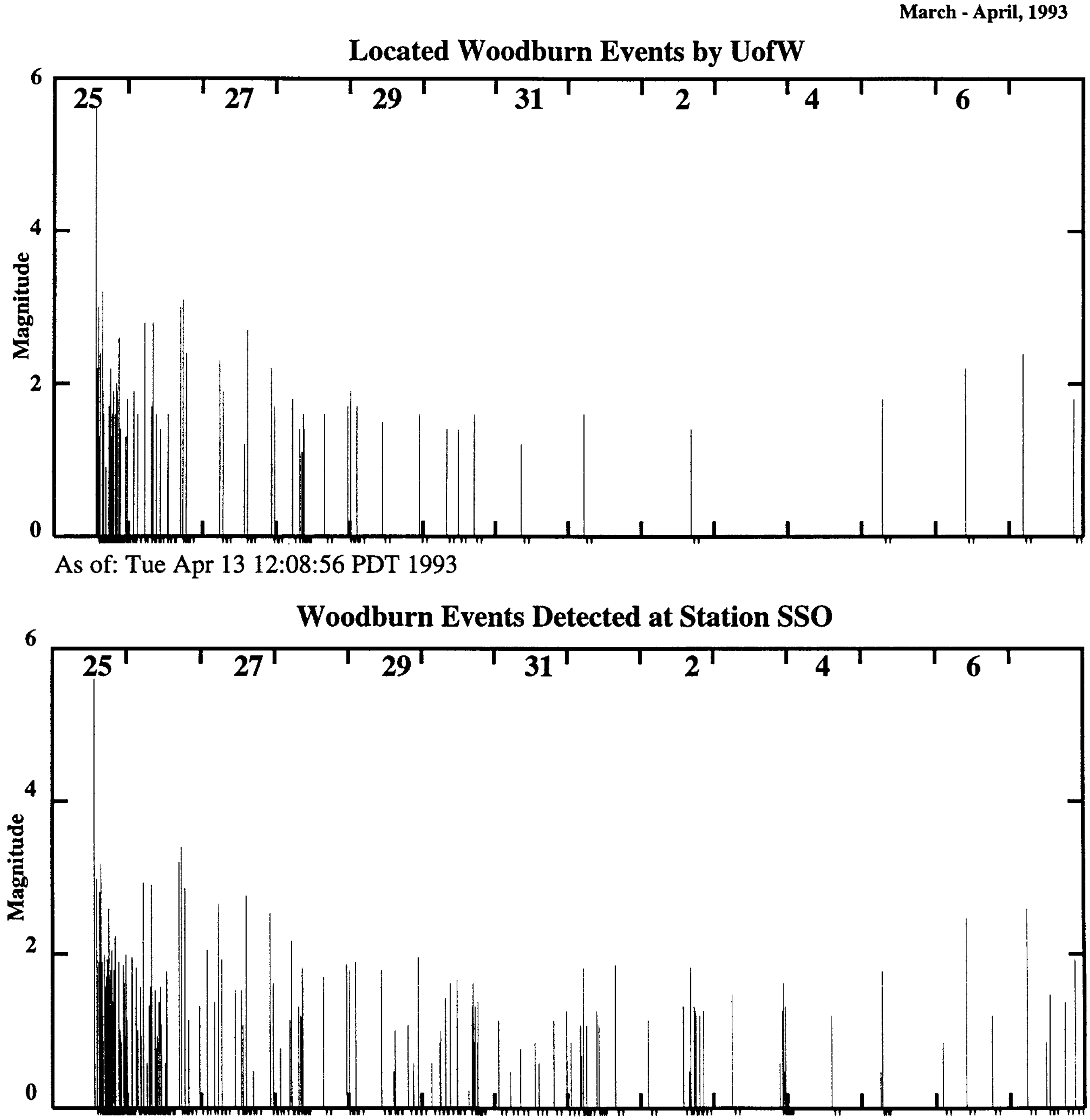

Figure 2. Earthquake magnitude versus time plots for March 25, 1993, Scotts Mills earthquake and first two weeks of aftershocks. Top plot is for earthquakes recorded by the triggered telemetry seismic network, and bottom plot is for events detected on the helicorder records from station SSO (distance 13.7 mi = 22 km).

faulting. Werner and others (1992) suggested that the Mount Angel fault showed right-lateral strike-slip offset with some north-dipping reverse motion and, on the basis of a 1990 earthquake swarm located beneath Woodburn at the north end of the fault, postulated that the Mount Angel fault might be active. So far, we do not know whether the Scotts Mills earthquake occurred on the Mount Angel fault or on another fault that may not even have a surface manifestation.

STRONG-MOTION RECORDING OF THE SCOTTS MILLS EARTHQUAKE OF MARCH 25, 1993

To date, strong-motion recordings of the Scotts Mills earthquake have been processed for four sites. The strongest motions were recorded by three instruments at the U.S. Army Corps of Engineers Detroit Dam located approximately 22 mi (36 km) southeast of the epicenter. The instrument located at the downstream toe of the dam recorded a peak acceleration of 0.06 *g*, while an instrument located in a gallery within the dam recorded a peak of 0.18 *g*.

The other three instruments for which records have been processed are in the area of Portland, Oregon, and Vancouver, Washington. A recently installed digital instrument in Portland recorded a peak acceleration of 0.03 *g*, while older analog instruments at Portland State University in Portland and at the Vancouver Ex-

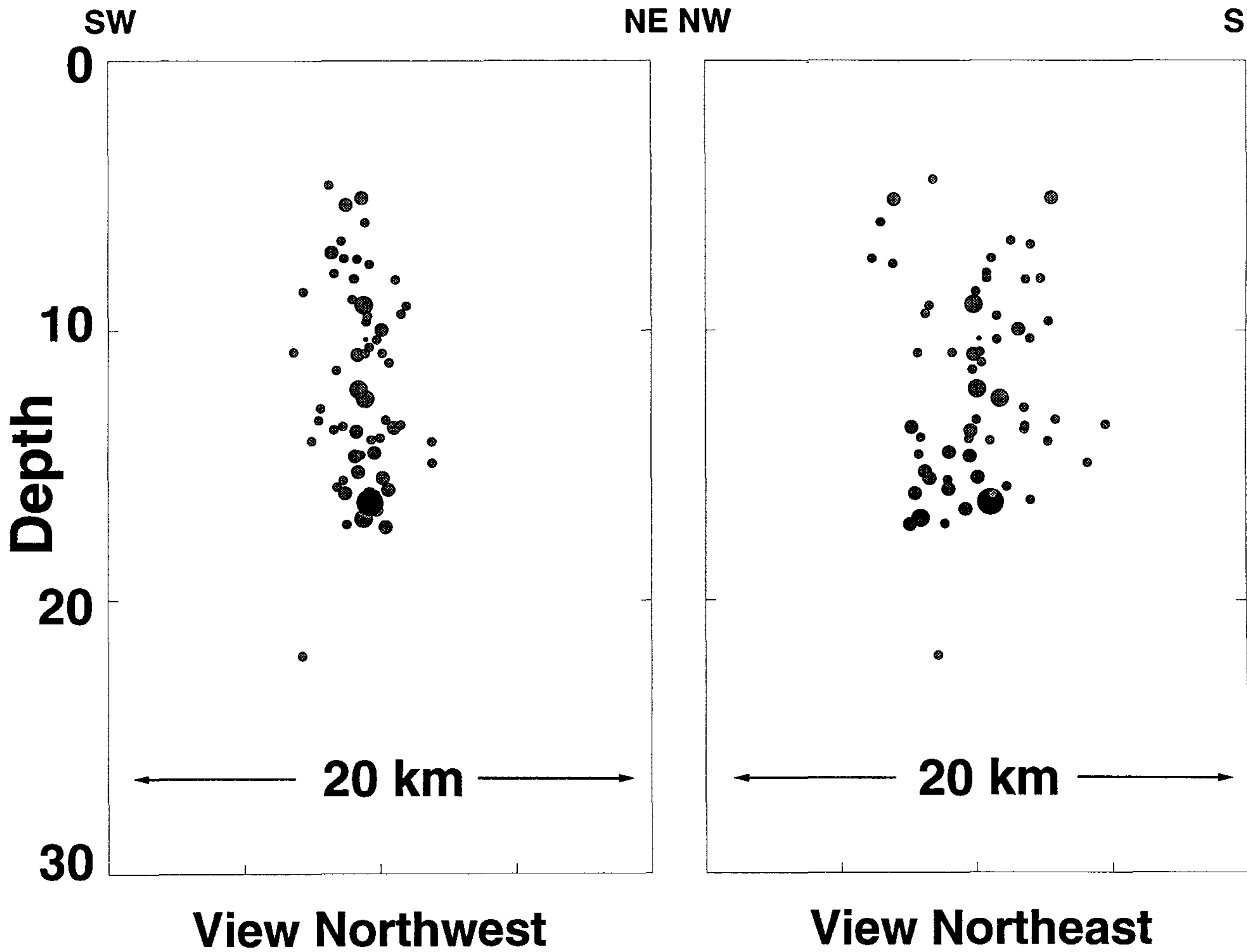

Figure 3. Perpendicular cross sections showing the vertical distribution of the main shock (solid circle) and aftershocks (gray circles) of the March 25, 1993, Scotts Mills earthquake. The depth determinations are preliminary and subject to revision.

tended-Care Division of the Portland VA Medical Center both recorded peak motions of 0.02 *g*. The stations in Portland are approximately 35 mi (56 km) north of the epicenter, and the Vancouver location is approximately 44 mi (70 km) north.

All of these measured motions are consistent with the intensities observed near the respective locations of the instruments. The Portland-Vancouver recordings were all from soil sites, but all the peak accelerations have been plotted in Figure 4, for comparison, with a bedrock attenuation relationship developed by Joyner and Boore (1982).

INTENSITY AND DAMAGE

The earthquake caused significant structural damage to a number of unreinforced masonry (URM) buildings in and around the epicentral area but left most wood-framed houses and buildings unscathed. In Molalla, the unreinforced masonry high school suffered significant damage and remains closed. In Mount Angel, unreinforced masonry buildings at the Benedictine convent and training center, the Benedictine Abbey, and St. Mary's Church and School were significantly damaged. Numerous URM commercial buildings in downtown Woodburn were significantly damaged and remain closed. The Oregon State Capitol in Salem suffered cracking of the inner walls of its rotunda and other minor damage to beams supporting the ceilings of the legislative chambers. A number of chimneys toppled in Scotts Mills, Woodburn, Mount Angel, and Molalla. The Highway 18 bridge across the Yamhill River near Dayton was put out of commission for several days by damage to the supports for the expansion rockers. A passing motorist had all four tires blown out when he hit the resulting ledge.

There were widespread reports of minor damage such as cracked plaster and foundations from as far away as the Portland metropolitan area. Surprisingly, at least 90 buildings located 28 mi (45 km) from the epicenter in the town of Newberg were damaged. Damage assessments by the Oregon Emergency Management Division and the Federal Emergency Management Agency (FEMA) are listed in Tables 1-3. The total damage estimate is about $28,4 million.

The distribution of damage and felt effects is being compiled at the Oregon Department of Geology and Mineral Industries (DOGAMI) to aid in production of an intensity map. This map will help identify areas like Newberg that may be more prone to severe damage in the event of another earthquake. These maps may also be used in the preparation of relative earthquake hazard maps for the Portland and Salem urban areas, currently in preparation by DOGAMI. An intensity questionnaire published in several Oregon newspapers has resulted in approximately 4,000 intensity reports from the public, which have yet to be compiled. A preliminary intensity map derived from this data set is presented as Figure 5.

If you have any personal observations from your own experience, or if you sustained damage to your house, please fill out and send in the form at the end of this article.

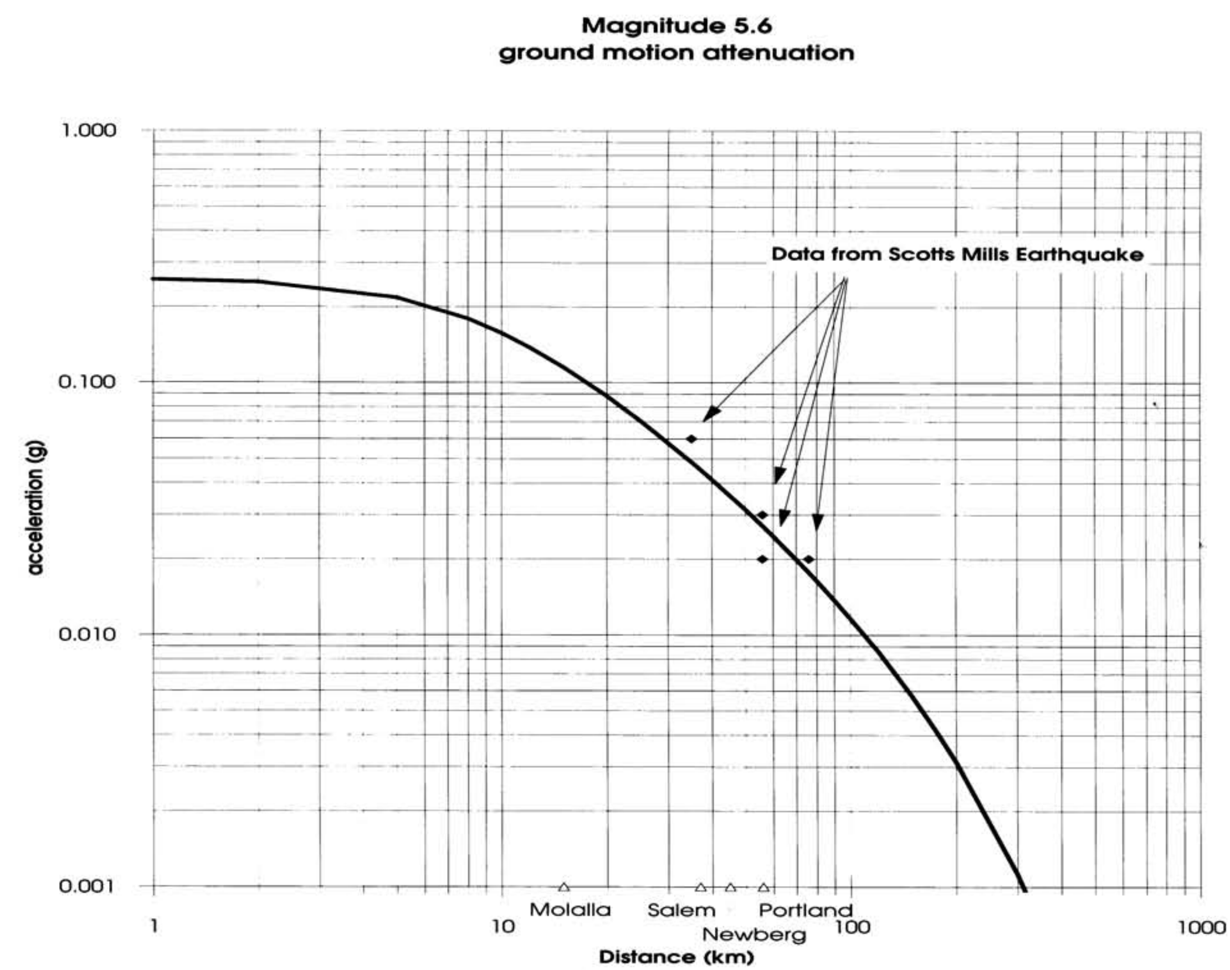

Figure 4. Recorded ground motions plotted with bedrock ground motion attenuation relationship as developed by Joyner and Boore (1982).

Table 1. *Individual assistance damage estimates by FEMA for Clackamas, Marion, and Yamhill Counties. Major damage = building or part of building unsafe; minor damage = some aspect of building function impaired; other damage = cosmetic damage*

	Clackamas	Marion	Yamhill	Totals
Number of residences				
Destroyed	0	0[1]	0[1]	0
With major damage	7[1]	0[1]	9[1]	16
With minor damage	150[1]	0[2]	36[1]	186
With "other damage"	485[2]	428[2]	8[2]	921
Estimated total dollar loss	$1,180,000	$0	$408,500	$1,588,500
Number of businesses				
Destroyed	0	0	0	0
With major damage	6	28	20	54
With minor damage	19	58	17	94
Estimated total dollar loss	$915,000	$4,054,300	$1,270,000	$6,239,300

[1] Based on field inspections guided by county emergency management officials.
[2] Based on data submitted by county emergency management officials and drive-by observations.

Table 2. *Public assistance damage estimates by FEMA, based on field inspections guided by county emergency management officials*

Clackamas County	$4,149,810
Marion County	$1,904,750
Washington County	$0
Yamhill County	$249,400
Total dollar damage	$6,303,960

Note: The above figures do not include estimated damages to state government buildings or to bridges, such as the one damaged on Highway 18, which are part of the Federal Aid Highway System. Damages to state government buildings are covered either by self-insurance or by the state's $300 million re-insurance program and were therefore not inspected by the joint federal-state-local government damage assessment teams. Repairs to the State Capitol rotunda, the largest single earthquake-damaged state building, are estimated at $850,000. These estimates do not include damages to insured properties, such as the Abbey College, the Benedictine Nursing Home, and St. Mary's Church. Dollar damages to these three facilities are estimated to be $15 million.

Table 3. *Damage costs for public facilities estimated by FEMA*

Marion County		
Monitor Cooperative Telephone Co.		$167,750
Monitor Rural Fire Department		$176,000
Monitor Elementary School		$1,000
St. Mary's Public School		$500,000
JFK High School		$100,000
Howard Hall and facilities		$50,000
City Hall, Mount Angel		$30,000
Salud Medical Center		$880,000
	Total	$1,904,750
Clackamas County		
Lake Oswego Fire Station		$11,360
Molalla City Hall/Police Station		$1,450
Molalla High School		$4,000,000
Oregon City Correction Office		$1,000
Canby Philander School		$50,000
Oregon City, City Hall		$4,000
Oregon City, Gardner Elementary School		$15,000
Ogden Junior High School		$10,000
Carus Elementary School		$5,000
Mulino School		$1,000
Molalla Fire Station #1		$50,000
Canby, Wm. Knight Elementary School		$1,000
	Total	$4,149,810
Yamhill County		
McMinnville High School		$3,000
Adams School		$2,500
Columbus Grade School		$200,000
Newby School		$300
Dundee Grade School		$5,000
City of Newburg, City Hall		
Newburg Public Library		$300
Wascher Elementary School		$300
City of Lafayette, Lafayette City Hall		$300
County Fairground, McMinnville		$20,000
Debris removal		$1,000
Protective measures		$16,000
	Total	$249,400
Washington County		
Forest Grove Fire Station		$0
	Grand total	$6,303,960

EXPECTED FUTURE EARTHQUAKES

Northwestern Oregon is vulnerable to earthquake damage from three sources (Figure 6):

Crustal earthquakes occur on faults located within the North American Plate. The Scotts Mills earthquake was a crustal event, as were most of the earthquakes in Oregon's historical record. Scientists are only now beginning to learn about the location and earthquake potential of crustal faults in western Oregon. The historical record suggests that much of western Oregon should anticipate events like the Scotts Mills earthquake, possibly up to magnitude 6.5, at any time.

Intraplate or **Benioff zone earthquakes** are the type that severely rocked the Puget Sound region in 1949 and again in 1965. Those who lived in Portland in 1949 may recall that the Portland area suffered some damaging and frightening effects from that earthquake. Intraplate earthquakes occur within the remains of the ocean floor, which has been shoved (subducted) beneath North America. It is now believed that this type of earthquake could occur closer to Portland or the Willamette Valley, perhaps 25-35 mi (40-60 km) deep directly beneath western Oregon.

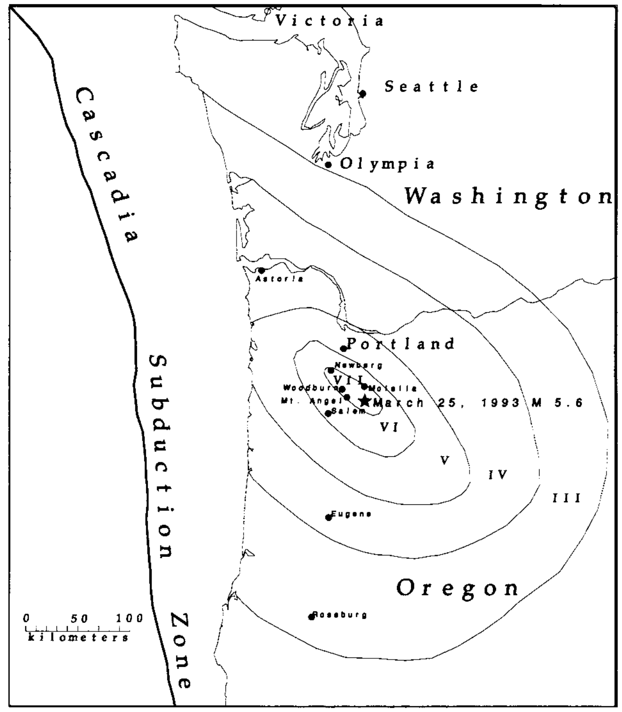

Figure 5. Preliminary Modified Mercalli intensity map for the March 25, 1993, Scotts Mills earthquake.

Great subduction earthquakes occur around the world in subduction zones, where continent-sized pieces of the earth's oceanic crust are shoved deep into the body of the earth. These earthquakes consistently are among the most powerful recorded, often having magnitudes of 8 to 9 on the moment magnitude scale. The Cascadia Subduction Zone, which has long been recognized off the coast of Oregon and Washington, has not had any great subduction earthquakes during our short 200-year historical record. However, in the past five years, a variety of studies have found widespread evidence that these great events have occurred repeatedly in the past, most recently about 300 years ago, in the latter part of the 17th century. The best evidence available suggests that these great earthquakes have occurred, on average, every 350 to 700 years, and there is reason to believe that they will continue to occur in the future.

Northwestern Oregon is clearly threatened by all three types of earthquakes, but there is currently significant uncertainty about exactly where, how frequent, and how big future earthquakes will be. This makes it difficult to rely on a probability-based (probabilistic) approach to hazard mapping, which would provide information about absolute levels of ground shaking to be expected and how often such levels might be reached. Once reliable probabilistic ground motion maps become available, they will be integrated with the relative hazard mapping. This is the approach taken by DOGAMI in its earthquake hazard assessment work in recent years.

MITIGATION MEASURES

Since it is impossible, at present, to predict exactly when or how often earthquakes may occur, DOGAMI has concentrated on mapping those areas that are the most vulnerable to damage regardless of the earthquake source. Maps of these vulnerable areas can then be used by planners to guide development and emergency response measures.

Hazard mapping

DOGAMI earthquake hazard maps show areas most vulnerable to (1) amplification of shaking, (2) liquefaction (formation of quick

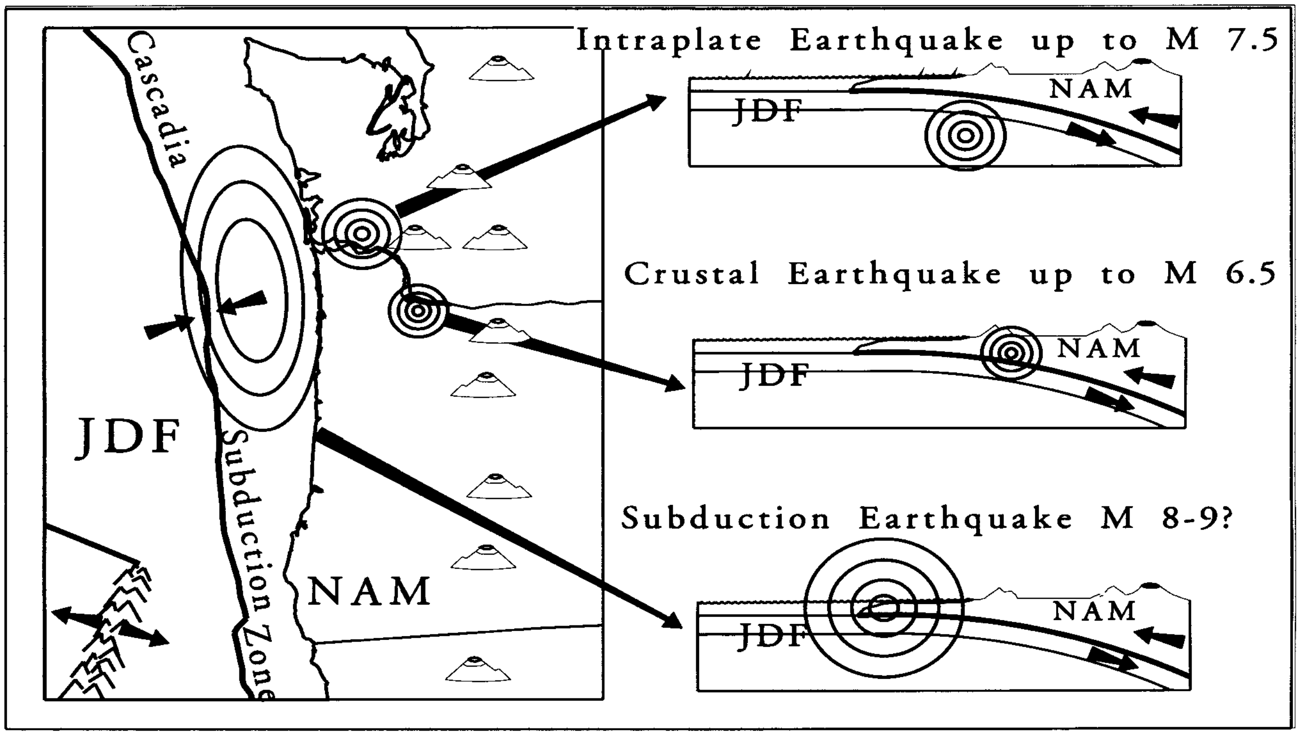

Figure 6. Earthquake source zones in the Pacific Northwest. JDF = Juan de Fuca Plate (subducting); NAM = North American Plate (overriding). Major Cascade volcanoes are shown. Northernmost section of Gorda spreading ridge is shown in southwest (lower left) corner of map. Short arrows indicate direction of plate motion, and centers of concentric circles show example locations of earthquakes, both in the map view and in the cross sections. Concentric ovals west of the coast line schematically represent the rupture zone for a great subduction earthquake (magnitude of approximately 8).

sand or "quick silt"), and (3) landsliding. A relative hazard map of the Portland quadrangle has recently been published in cooperation with Metro (see announcement in this issue). It is a composite map depicting the relative hazard at any site, due to the combination of all three effects. It delineates areas that likely will experience the greatest effects from any earthquake. Those effects could range from people waking from their sleep to buildings collapsing or gas lines rupturing. These simple composite hazard maps can be used by planners, lenders, insurers, and emergency responders for first-order hazard mitigation and response planning. Similar maps are in preparation for the remainder of the Portland urban area and are planned for Salem and the other major Willamette Valley urban areas.

Emergency response and preparedness

Emergency preparedness is generally at a low level in Oregon, because we have experienced few historic earthquakes. Emergency response planning is still in the early stages for the same reason. The region would indeed have great difficulty in responding to a severe earthquake at this time. The Scotts Mills earthquake, by heightening awareness, offers an unprecedented opportunity to change this situation.

The general public would be well advised to take immediate measures to mitigate damage and injury from earthquakes that surely lie in our future. Detailed information on these actions can be found in recent issues of major newspapers and in pamphlets from the American Red Cross and emergency management agencies at the state and local level. Some contacts and references for this information are listed at the end of this article, but, as a minimum, the following steps can be taken immediately:

1. Make sure your family is prepared to spend 72 hours after an earthquake without outside help. This means keeping a supply of drinking water and food, cash, first aid supplies, emergency cooking and lighting equipment, and battery powered radios.

2. Make sure your house is bolted to its foundation. Houses built before 1974 are possibly not bolted down.

3. Strap down your hot water tank using metal straps bolted to the wall studs.

4. Make sure that tall book cases or other heavy objects are secured, so they cannot topple onto someone. The same goes for containers of hazardous liquids.

5. Establish a family emergency plan that specifies what actions to take during and after an earthquake. The plan should establish where and under what circumstances the family will rendezvous from work and school. It will be much easier to make phone calls out of the area than to receive incoming calls, so the plan should specify what out-of-state person to call to coordinate information.

6. Learn how to shut off the gas, power, and water connections to your home in the event that there are breaks or leaks in your home.

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FOR FURTHER READING

Bolt, B.A., 1993, Earthquakes: New York, W.H. Freeman and Company, 331 p.

ADDRESSES FOR FURTHER INFORMATION AND MATERIALS

American Red Cross
P.O. Box 3200
3131 N. Vancouver Avenue
Portland, Oregon 97208
(503) 284-1234.

Oregon Emergency Management Division
595 Cottage Street NE
Salem, Oregon 97310
(503) 378-4124.

EARTHQUAKE QUESTIONNAIRE

The Oregon Department of Geology and Mineral Industries (DOGAMI) needs the help of the public to accurately determine the effects of the March 25, 1993, Scotts Mills earthquake. Please take the time to read this questionnaire and answer the questions as fully as possible. **We need your information even if you did not feel or observe any effects.** This information may allow us to predict which areas might experience the greatest damage in future large earthquakes. Send to **Earthquake Survey, DOGAMI, 800 NE Oregon St., # 28, Portland, OR 97232**

Where were you during the earthquake? Please describe your location, either by a street address or nearest cross streets.

Were you in the open, in a car, in a building? (If you were in a building, list which floor you were on and how many floors the building has.)

What effects did you feel? Describe the sensation, was it barely felt, strongly felt, hard to stand?

What effects did you observe to surrounding objects? (Rocking cars, dishes ratttling on shelves, furniture or machinery shifting).

□

When is a Richter not a Richter?

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, Portland, Oregon 97207

INTRODUCTION

Newspaper stories about earthquakes today nearly always refer to earthquake strength in terms of "Richter magnitudes." It appears to be the quickest measure of what an earthquake means. But it is not by any means the only measure, and until recently I did not realize how many other ways to measure are being used just to indicate an earthquake's magnitude.

SCALES

Magnitude and intensity scales are the two best known systems now in general use for recording the strength of earthquakes.

Intensity scales, based on the degree of violence and resulting destruction, were first developed in 1878 and later refined several times. Since 1931, the version used is the Modified Mercalli (MM) intensity scale, which reports the results of the quake on a scale of intensity by Roman numerals ranging from I (not felt) to XII (catastrophic). Intensity VI can be damaging; intensity VII can destroy structures.

Magnitude has for many years been rated by the Richter magnitude scale (M_L) proposed first in 1935. It uses Arabic numbers on an open-ended logarithmic scale. The number is derived from measuring the wave amplitude recorded by the swing of the needle on a seismograph that has been calibrated to match a theoretical seismograph located 100 km from a quake.

Since the Richter scale is logarithmic, an increase of one unit on the scale corresponds to a tenfold increase in the amplitude of the shaking caused by the quake. Thus a Richter magnitude 7 earthquake is 100 times as large in amplitude as a 5, and an 8 is 1,000 times as large. Moreover, the amount of energy given off by the quake increases about 35 times with each increase by one unit, so that a Richter 7 is more than 1,000 times as energetic as a 5.

WAVES

Earthquakes generate a variety of waves, generally divided into body waves and surface waves. Body waves pass through many of the concentric spheres that make up the Earth: lithosphere (continental and oceanic crust), asthenosphere (a zone of very weak rock below the crust), upper and lower mantle, and outer and inner core. The waves can be reflected and refracted within these zones and at the boundaries between them several times and thus reach the seismograph by several different paths, which has led to the differentiation of a large number of "phases" of body waves.

Scientists distinguish two types of body waves. Those arriving first are called "Primary" or P-waves and are dilatation/compression or "push-pull" waves. Those arriving second are called "Secondary" or S-waves or shear waves.

By contrast, surface waves travel around the Earth's surface and are found only in the vicinity of the surface. They provide important additional information about earthquake waves. They have also been differentiated into several types. Three of them are Love, Rayleigh, and Stonely waves.

MAGNITUDE SYMBOLS

I first discovered other ways of measuring earthquake strength in a report by Waverly Person (1990) in an issue of *Earthquakes and Volcanoes*, published bimonthly by the U.S. Geological Survey. Person lists and describes many of 184 quakes that occurred worldwide between March 1 and December 31, 1990. More than two thirds of the magnitudes were identified by symbols I had never seen before!

In Person's list, six symbols indicate ways in which the magnitude number was derived. The seventh symbol is one that has recently come into use for large earthquakes whose fractures dislocate the surface. The numbers in the third column of Table 1 on the left indicate how often each symbol occurred in the total of 184 reported earthquakes.

Table 1. *Types of measuring earthquake magnitudes in Person (1990)*

No.	Symbol	Times used	Description
1.	M_L	58	Richter magnitude. L (local) reflects the original limitation to California earthquakes occurring within 600 km of a seismograph.
2.	M_S	45	Magnitude derived from surface waves.
3.	m_b	41	Magnitude derived from body waves.
4.	m_{bLg}	17	Magnitude derived from Love (surface) waves
5.	M_D	12	Magnitude derived from duration of earthquake.
6.	C_L	11	Magnitude derived from coda length. The coda ("tail") is the end part of a seismogram that registers continuing waves
7.	M_w	—	Moment magnitude. Derived from the length of the rupture

Two thirds of the listed earthquakes occurred within the United States, only one third outside. During the same time period, a total of 280 quakes occurred in the United States. Of these, 116 occurred in California, 54 in Alaska, 10 in Washington, and 2 in Oregon.

ACKNOWLEDGMENTS

I appreciate the careful review of this note by Ansel Johnson and Paul Hammond, both on the faculty at Portland State University, who helped me get up to speed on a subject that is not my specialty.

REFERENCE CITED

Person, W.J., 1990, Earthquakes, March-December 1990: Earthquakes and Volcanoes, v. 22, no. 6, p. 268-291. □

Earthquake scenario pilot project placed on open file

The Oregon Department of Geology and Mineral Industries (DOGAMI) has placed on open file a report that assesses, in a pilot scenario, the potential damage caused by a moderate earthquake in the Portland metropolitan area.

The report is entitled *Earthquake Scenario Pilot Project: Assessment of Damage and Losses* and has been released as DOGAMI Open-File Report O-93-06.

The pilot earthquake scenario project was undertaken by Metro (Regional Government) and DOGAMI and includes contributions from more than twenty researchers. Its purpose was to develop and provide an information system to support earthquake-preparedness planning in the Portland metropolitan region. The results are presented on 19 pages accompanied by a 16-page appendix.

The scenario is based on an assumed moderate (magnitude 6.5) earthquake, triggered by rupture of a section of the Portland Hills fault zone. It studies the effects on a portion of downtown Portland on either side of the Willamette River, an area that includes 185 buildings, two freeways, two bridges across the Willamette, railroad tracks, lifelines such as electrical power and communication lines, gas and water pipe systems, sanitary and storm sewers, and roadways and overpasses.

The study provides (1) an indication of the dollar amount of damage; (2) an approach for identifying potential liability issues; (3) an indication of areas requiring greater emergency response priority; (4) an indication of the variations in expected loss by structural types of buildings and critical facilities; (5) a data collection system that may assist development of a regional earthquake hazards mitigation program; (6)analytical tools that may be useful in identifying policy issues relating to earthquake planning; and (7) an indication of the nature of recovery and reconstruction processes that may be needed after a moderate earthquake.

Open-File Report O-93-06 is available for inspection at all DOGAMI offices and for purchase in a packet that includes the relative earthquake hazard map of the Portland quadrangle published jointly by Metro and DOGAMI (see discussion below). □

First relative earthquake hazard map released

Metro, Portland's regional service agency, and the Oregon Department of Geology and Mineral Industries (DOGAMI) have jointly published *Relative Earthquake Hazard Map of the Portland, Oregon, 7½-Minute Quadrangle.*

This is the first publication in a program that is planned to provide such maps for the Portland-Vancouver, Salem, Corvallis-Albany, Eugene, and coastal urban areas.

The Portland quadrangle covers an area that extends from Marquam Hill and downtown Portland north to the Columbia River and from 36th Avenue on Portland's east side as far west as Bybee Lake, Forest Park, and Elk Point. The map is at a scale of 1:24,000, where one inch represents approximately 2,000 ft. Its color pattern divides the area into four zones of relative hazard, from greatest (Zone A) to least (Zone D).

Current scientific understanding of the earthquake sources that might affect the Portland area is too limited to allow an accurate assessment of the likely size and location of future earthquakes—the absolute degree of earthquake hazard, so to speak. It is possible, however, to measure and predict the behavior of rock and soil at a given site and predict how that affects what damage is caused during an earthquake.

The damage is caused or aggravated by one or more of three effects: (1) amplification of ground shaking, (2) liquefaction of water-saturated sand, and (3) landsliding triggered by ground shaking. The degree to which the geology of a given site can make the combination of these effects greater or lesser, relatively speaking, is shown by the zones on the map. This information is especially valuable for planners, lenders, insurers, and those involved in emergency planning for earthquakes.

The relative earthquake hazard map, in a way, is a combination of three maps, each of which depicts the geology of the Portland quadrangle with regard to one of the three effects described above. These individual hazard maps will also be published soon. The data sets that produced the maps and allowed the combination of all three are created and stored in computers, so they can be incorporated by various agencies into their own information systems for sophisticated planning of land use, engineering, or emergency management.

The relative earthquake hazard map, together with explanatory text and DOGAMI Open-File Report O-93-06 (see previous article), can be purchased for $10 plus $3 for postage and handling from Metro Data Resource Center, 600 NE Grand Avenue, Portland, OR 97232, phone (503) 797-1720; or from DOGAMI's The Nature of Oregon Information Center, 800 NE Oregon Street, Suite 177, Portland, OR 97232, phone (503) 731-4444. □

Correction

Please note that the street address of the Oregon Emergency Management Division in Salem given on page 45 of the last issue of *Oregon Geology* was incorrect. The correct full address is 595 Cottage Street NE, Salem, OR 97310, phone (503) 378-4124.—*ed*

Geology near Blue Lake County Park, eastern Multnomah County, Oregon

by James N. Bet and Malia L. Rosner, Landau Associates, Inc., 23107 100th Avenue West, Edmonds, Washington 98020

ABSTRACT

Information from well logs, geophysical logs, excavations, and outcrops near Blue Lake County Park in eastern Multnomah County, Oregon, indicates that the stratigraphy and geologic structure are more complex than previously described. These data suggest that the gravel deposits that form the Troutdale gravel aquifer are post-Troutdale Formation in age and that the contact separating the two rock units is an angular unconformity.

Structure contours on the Troutdale Formation show a large dome centered just south of Blue Lake. The Troutdale Formation was severely eroded along the northeast flank of the dome, presumably during Pleistocene catastrophic flooding events. Gravels of the Troutdale gravel aquifer overlie a portion of this eroded surface and thicken significantly toward the south and west.

Well logs and natural gamma logs from the Blue Lake area suggest that the northeast portion of the dome was cut by a northwest-trending fault with vertical displacement of up to 500 ft. Erosion has removed much of the upper portion of the Troutdale Formation north of the fault trace.

The absence of mappable siltstone units in the Troutdale Formation indicates lateral discontinuities that may have been caused by channel incision. These incisions, together with changes in sediment size and source areas, attest to the dynamic depositional environment of the east Portland Basin.

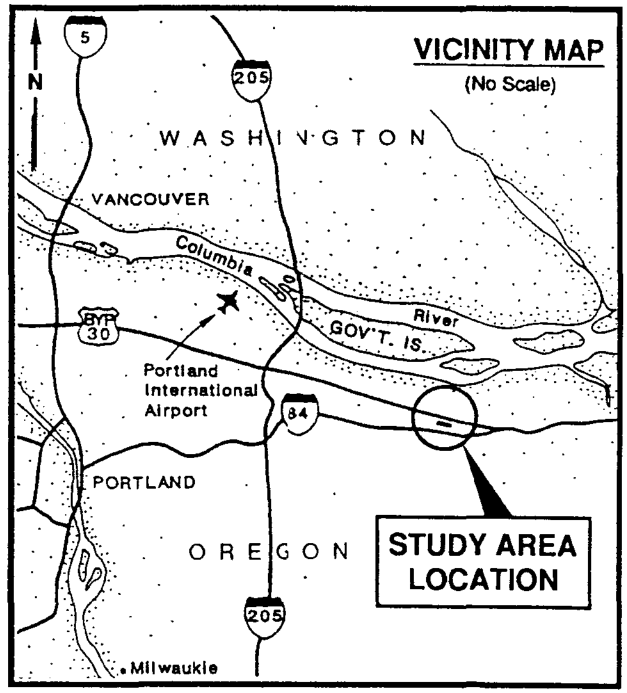


Figure 1. Sketch map showing location of study area.

INTRODUCTION

Several investigations have been completed in the east Portland Basin since Trimble (1963) mapped the geology of east Multnomah County and the City of Portland studied the area in 1977 and 1978 for a potential well field. These investigations focused on the hydrogeology of the east Portland area, with most work concentrated southeast of Blue Lake County Park.

This paper assimilates new geologic data into a model, accounting for the relatively complex stratigraphic and structural relationships displayed in the Troutdale Formation within the study area (Figure 1). Geologic cross sections, structure-contour maps, and isopach maps were constructed on the basis of the interpretation of geologic logs, driller reports, and natural gamma logs when available. Well locations used in this paper are shown in Figure 2. In addition to well logs, outcrops of the Troutdale Formation were examined in the field, and a review of pertinent literature was incorporated into the development of the model. Well logs provided data for geologic interpretations, because outcrops of the Troutdale Formation are rare in the study area.

REVIEW OF PREVIOUS INVESTIGATIONS

Previous work can be divided into geologic and hydrogeologic investigations.

Geologic investigations

Trimble (1963) mapped the geology of east Multnomah County and incorporated most of the previous work into a comprehensive investigation of the area. He described the Troutdale Formation as consisting primarily of vitric sandstone and conglomerate with a deeply weathered surface. Trimble separated and renamed the lower Troutdale Formation the Sandy River Mudstone, basing this separation on differences in lithology and genesis between the Sandy River Mudstone and the Troutdale Formation. Mundorff (1964) complemented Trimble's work by mapping the geology and hydrogeology to the north, across the Columbia River in Clark County, Washington. Mundorff used the designation "lower Troutdale" instead of Sandy River Mudstone.

Tolan and Beeson (1984) refined the range of the Troutdale Formation, using the stratigraphic relationship of Boring Lavas and Columbia River basalts at Bridal Veil, Oregon. On the basis of clast composition and source area they defined two separate and distinct facies within the Troutdale Formation: the "ancestral Columbia River" and "Cascadian stream" facies. The ancestral Columbia River facies, which contains nonlocally derived clasts of quartzite, schist, granite, and rhyolite, is found in the study area. The Cascadian stream facies, which contains predominantly volcanic clasts that were locally derived, is not found in the study area. Tolan and Beeson then subdivided the ancestral Columbia River facies informally into an upper and a lower member. The lower member consists primarily of conglomerates containing numerous exotic clasts and interbedded arkosic sandstones. The upper member consists of interbedded vitric-lithic sandstones and basaltic conglomerates with exotic clasts.

Swanson (1986) examined the geochemistry of the vitric sandstones occurring in the Troutdale Formation. He found that vitric sandstones from Tolan and Beeson's (1984) upper member have distinctive geochemical signatures. Swanson's geochemical work links sandstone outcrops at Blue Lake and Taggart Bluff and vitric sandstone samples from the City of Portland's well field west of Blue Lake (Figure 3) to the upper member of the Troutdale Formation established by Tolan and Beeson (1984) along the east side of the Portland Basin.

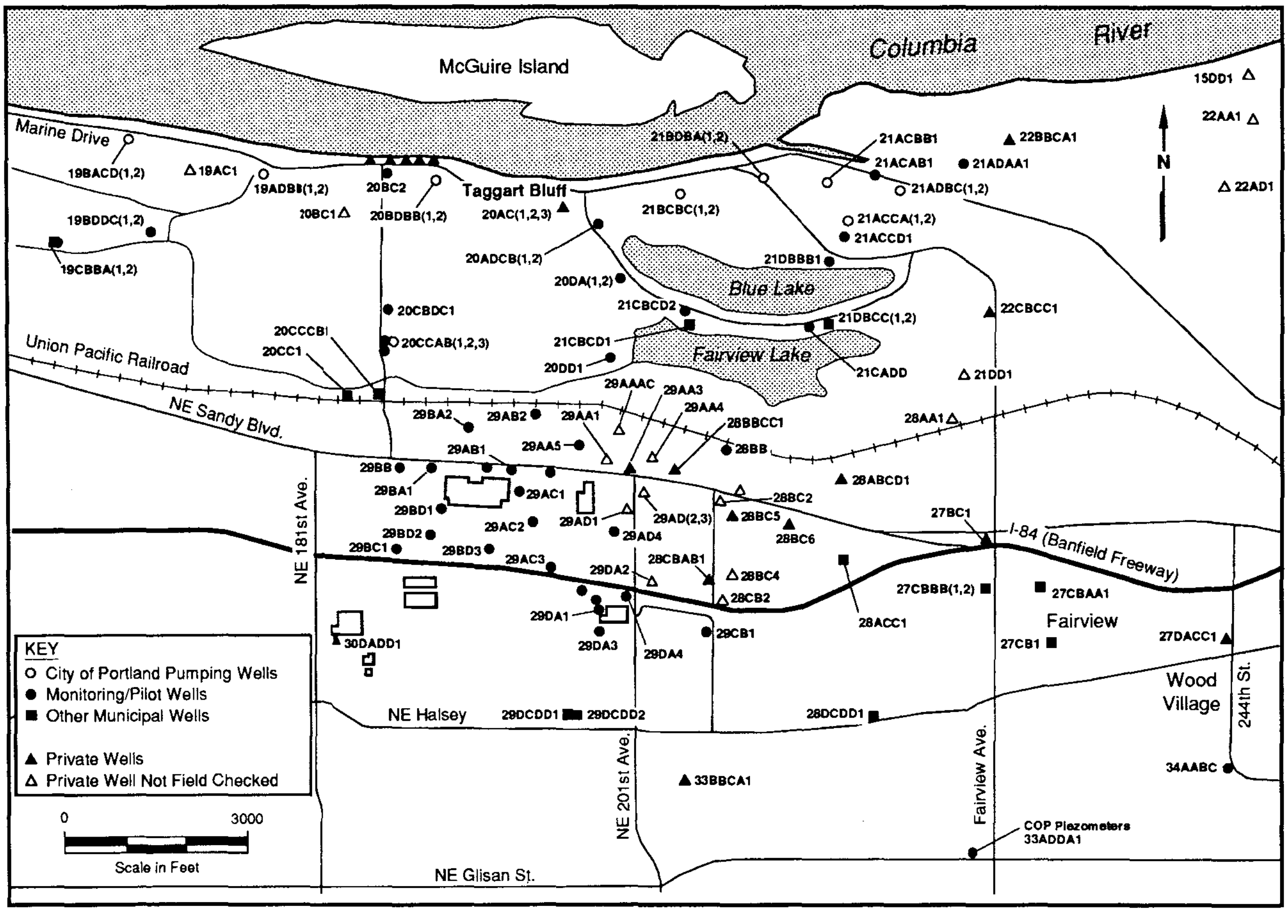


Figure 2. Map of study area with well locations. All well locations are within T. 1 N., R. 3 E.

Davis (1987) conducted gravity surveys along the Lacamas Creek and Sandy River lineaments. He showed that these lineaments are faults and characterized them as linear zones of normal and/or grabenlike failure with displacements approaching 300 m (984 ft). Davis suggested a "dextral stepover" between the Lacamas Creek and Sandy River lineaments, which would be characteristic of dextral step within a dextral strike-slip fault zone.

Hydrogeologic investigations

Hogenson and Foxworthy (1965) broadly defined rock units and their water-bearing characteristics in the east Portland area. Their general description of the Troutdale Formation follows Trimble's work. However, their interpretations of well logs near Fairview (Figure 2) include an overlying gravel deposit significantly younger than and not part of the Troutdale Formation. This gravel, which we identify as Pleistocene-age gravel, comprises an extensive geologic unit along the Columbia River and forms the major portion of the Troutdale gravel aquifer in east Multnomah County.

Willis (1977, 1978) further delineated and defined the hydrogeology of the study area during the development of the City of Portland's well field (Figure 3). He identified three aquifers and two aquitards within what he considered to be the Troutdale Formation and Sandy River Mudstone. Willis (1977) referenced Trimble's 1963 paper and described an "upper section" containing primarily conglomerates and a "lower section" containing primarily vitric sandstones, clays, and siltstone in the Troutdale Formation. He correlated the gravels that comprise the Troutdale gravel aquifer with the "upper section" of the Troutdale Formation. Willis correlated hydrogeologic units below the Troutdale gravel aquifer to the "lower section" of the Troutdale Formation and the Sandy River Mudstone. We find that Trimble (1963) did not divide the Troutdale Formation in this manner and that there is no real basis for this correlation. Willis (1977, 1978) also described a Pleistocene paleochannel cut by an ancestral Columbia River and filled by gravel forming the Blue Lake gravel aquifer.

Hoffstetter (1984) continued Willis' work on the subsurface geology in the Portland well field. He also assigned the gravel of the Troutdale gravel aquifer to the Troutdale Formation but extended the age of the Formation into the Pleistocene. Hartford and McFarland (1989) mapped the lithology, thickness, and extent of hydrogeologic units underlying the east Portland area.

STRATIGRAPHY AND GEOLOGIC UNITS

Continued evaluation of regional geologic events and development of fluvial facies models and a better understanding of the processes influencing the evolution of the ancestral Columbia River system have resulted in a revision of the depositional environments for the Troutdale formation and the Sandy River Mudstone. These sediments represent a complex fluvial depositional system resulting from a series of facies changes. Factors influencing deposition of the Troutdale Formation include (1) Cascadian basaltic volcanism producing a series of lava flows that repeatedly entered the ancestral Columbia River and were phreatically brecciated (source of vitric-lithic sands); (2) deposition of the vitric sands within the Portland Basin by a range of fluvial regimes (e.g., hyperconcentrated flood-flow to a normal river dominated by sandy bed load); (3) cyclic loss of the normal, coarse-clastic bed load of the ancestral Columbia due to ponding of the river further east, when the upper Ringold Forma-

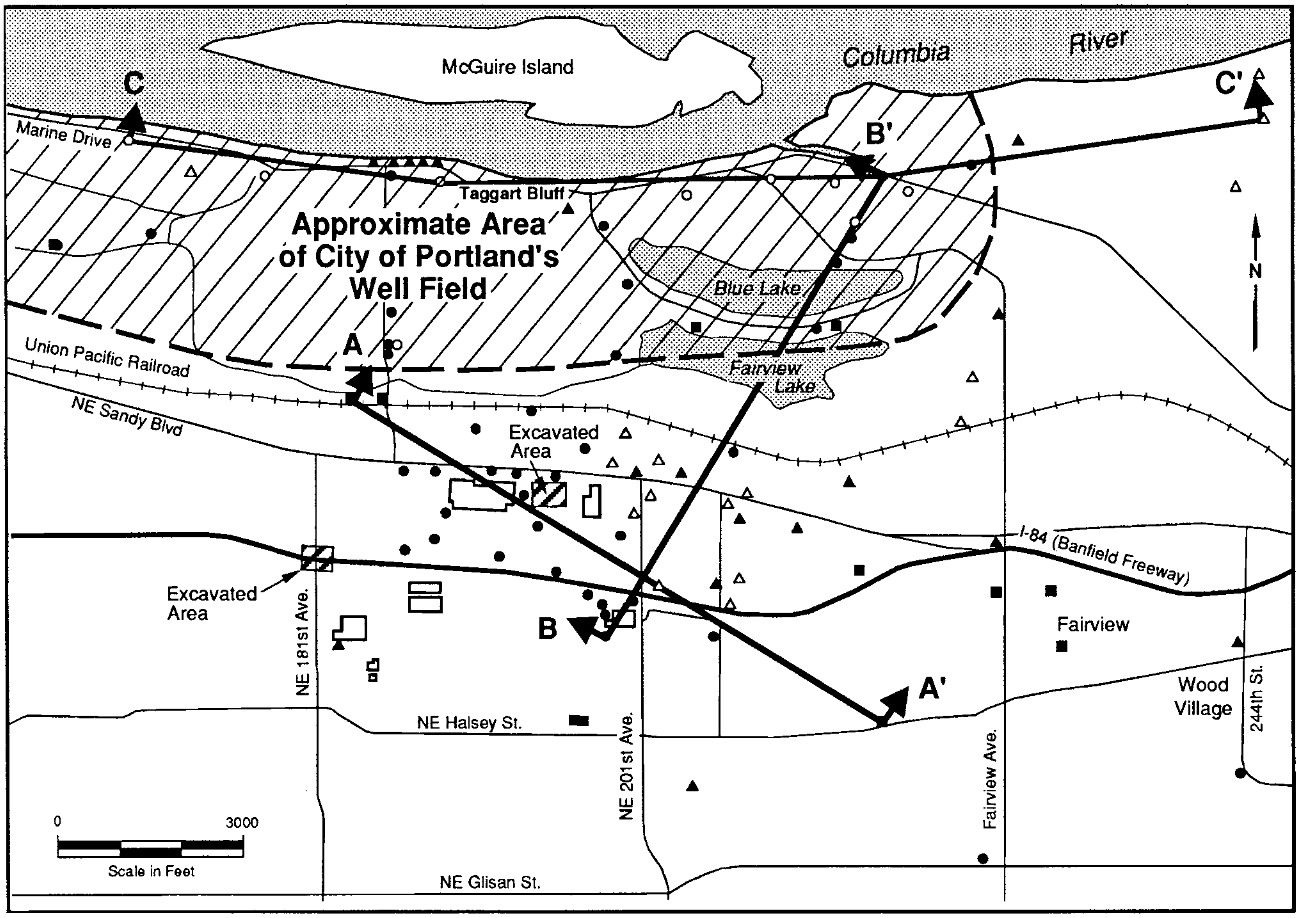


Figure 3. Cross section location map showing part of the City of Portland's well field and excavated areas along NE 181st Avenue and NE Sandy Boulevard. Excavation work occurred during the spring and summer of 1990.

tion in the Pasco Basin area was deposited (Smith and others, 1989); and (4) continued subsidence of the Portland Basin.

Previous investigations near the study area have generally divided the stratigraphic section into (from youngest to oldest) Quaternary systems, the Troutdale Formation, and the Sandy River Mudstone. In this paper, we separate the section into Holocene flood-plain deposits (alluvium), Blue Lake gravel, Pleistocene gravel (subdivided into Pleistocene gravel unit 1 and Pleistocene gravel unit 2), and Troutdale Formation (subdivided into siltstone unit 1, sandstone-conglomerate unit 1, siltstone unit 2, sandstone-conglomerate unit 2, and the Sandy River Mudstone). Recent mapping in the Portland area has challenged the validity of separating the Sandy River Mudstone from the Troutdale Formation (I.P. Madin, Oregon Department of Geology and Mineral Industries, personal communication, 1992). In this paper, we consider the Sandy River Mudstone a facies equivalent to the lower member of the ancestral Columbia River facies of the Troutdale Formation, as described by Tolan and Beeson (1984). The geologic units addressed in this paper and their relationship to hydrogeologic units are shown in Figure 4.

Flood-plain deposits

Recent flood-plain deposits from the Columbia River cover older units along the margins of the existing river. Flood-plain deposits consist of tan to gray, micaceous, sandy silt to silty, fine sand with some gravel. These sediments attain thicknesses as great as 95 ft near the Columbia River.

Blue Lake gravel

The Blue Lake gravels are coarse-clastic sediments filling a deep channel incised by an ancestral Columbia River. Hartford and McFarland (1989) indicate that this unit is comprised primarily of boulder-, cobble-, and pebble-sized clasts in a minor matrix of clayey to sandy silt, which is clast supported. They describe the gravel composition as primarily basalt with some quartzite, granite, and diorite. Thickness of the Blue Lake gravels ranges from 50 to over 200 ft. When saturated, these gravels form the Blue Lake gravel aquifer.

Pleistocene gravel

In the study area, Pleistocene gravels can be subdivided into at least two mappable units. We informally refer to these units as Pleistocene gravel unit 1 and Pleistocene gravel unit 2. Hydrogeologic investigations in the vicinity have used the names "unconsolidated gravel aquifer" and "Troutdale gravel aquifer" when discussing these units (Figure 4). Clast composition and size, massive bedding with matrix-supported clasts, and stratigraphic position suggest that these deposits are related to flooding events associated with Pleistocene outburst floods from glacial Lake Missoula.

Pleistocene gravel unit 1

Pleistocene gravel unit 1 correlates to Trimble's (1963) gravelly phase of the catastrophic flooding events. This unit is isolated in pockets along the present Columbia River flood plain and lower river terraces and may be present as silt deposits forming a veneer on the river terraces farther away from the river. The unit consists of fine to coarse and micaceous silty gravel, sandy gravel, gravelly sand, and silt and contains pebbles, cobbles, and occasional large boulders, which are matrix supported. Clast composition is primarily subrounded to well-rounded basalt with quartzite and granitic rocks (Trimble, 1963). In addition to basalt, large boulders of the Troutdale Formation were also observed in the study area. Cementation in the gravel varies from none to moderate. The thickness of Pleistocene gravel unit 1 ranges up to over 100 ft. The composition of this gravel is similar to that found in Pleistocene gravel unit 2, making it difficult to distinguish in well logs. In some logs, however, Pleistocene gravel unit 1 may be distinguished by the presence of large boulders within and of a clayey surface below the unit (at the top of Pleistocene gravel unit 2).

In the study area, Pleistocene gravel unit 1 was observed in outcrop unconformably overlying Pleistocene gravel unit 2 (Figure 5).

Pleistocene gravel unit 2

Pleistocene gravel unit 2 forms an extensive geologic unit that can be traced in well logs beyond the study area toward the east and west. When saturated, this unit forms the major portion of the Troutdale gravel aquifer (Figure 4).

Most of Pleistocene gravel unit 2 consists of subrounded to well-rounded, fine to coarse and micaceous sandy gravel and silty gravel, with occasional boulders and thin lenses of fine sand and silty sand. Clast composition is primarily basaltic with quartzite and other metamorphic, volcanic, and plutonic rocks, which are matrix supported (Figure 6). Clast composition is similar to conglomerates found in the Troutdale Formation. Clasts of vitric sandstone are also occasionally found, which suggests that some of the deposit is reworked Troutdale Formation. Cementation of the gravel varies from none to moderate. Well logs in the study area indicate that the thickness of Pleistocene gravel unit 2 ranges up to 250 ft.

Well logs from the southeast portion of the study area indicate a red or brown clayey silt, probably at the top of Pleistocene gravel unit 2. This clayey silt was observed in outcrop along NE 181st Avenue (Figure 3) during the recent expansion of the Banfield Expressway (Interstate I-84). The unit contained decomposed and highly weathered pebbles and cobbles. The unit can be traced southeast of the outcrop with certainty only in nearby wells but could extend farther east and west. The red clayey silt is not reported in well logs to the north along the lower terraces and the Columbia River and is assumed to have been removed by erosion.

Cross sections and field observations indicate that the contact between Pleistocene gravel unit 2 and the top of the Troutdale Formation is an angular unconformity. This contact was observed in outcrop during excavation activities along NE Sandy Boulevard in Gresham, Oregon (Figure 7). Pleistocene gravel unit 2 was found

SYSTEM	SERIES	GEOLOGIC SYMBOL (1)		GEOLOGIC UNIT (1)	HYDROGEOLOGIC UNIT (2)
Quaternary		Qa		Alluvium	
	Pleistocene	Qbl		Blue Lake Gravels	Blue Lake Gravel Aquifer
		Qg1		Pleistocene Gravel Unit 1	Troutdale Gravel Aquifer
		Qg2		Pleistocene Gravel Unit 2	
Tertiary	Pliocene	Ttst1	Troutdale Formation (1)	Siltstone Unit 1	Confining Unit 1
		Ttsc1 / Ttss1, Ttcg1		Sandstone-Conglomerate Unit 1 Sandstone Unit 1 Conglomerate Unit 1	Troutdale Sandstone Aquifer
		Ttst2		Siltstone Unit 2	Confining Unit 2
		Ttsc2 / Ttst3		Sandstone-Conglomerate Unit 2 Siltstone Unit 3	Sand and Gravel Aquifer or Sandy River Mudstone Aquifer (3)
		Ttsr		Sandy River Mudstone	
	Miocene				

Figure 4. Generalized stratigraphy for the Blue Lake area with key to geologic symbols used in cross sections and maps and including equivalent hydrogeologic units. Modified from Trimble (1963), Willis (1977, 1978), and Hartford and McFarland (1989). Notes: (1) Geology used in this study. (2) Hydrogeology from Hartford and McFarland (1989). (3) Hydrogeology from Willis (1977, 1978).

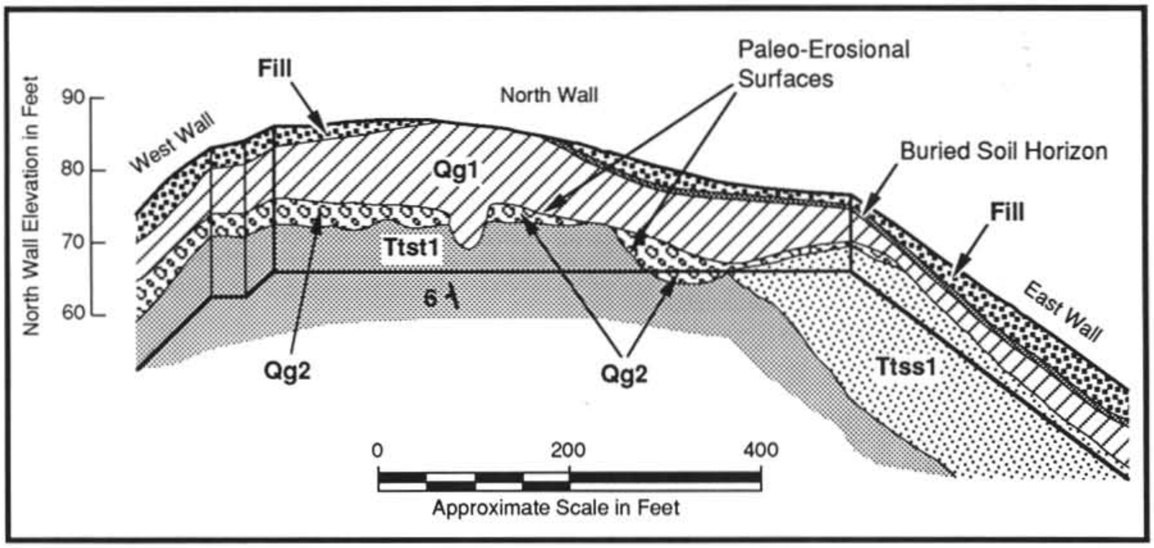


Figure 5. Fence diagram of excavated area along NE Sandy Boulevard (see Figure 3 for location). Qg1= Pleistocene gravel unit 1; Qg2= Pleistocene gravel unit 2; Ttst1= siltstone unit 1; Tss1= sandstone unit 1. In contrast to underlying units, Pleistocene gravel unit 2 is not deformed and unweathered and thickens significantly toward the west. Pleistocene gravel unit 2 was also found to be overlying portions of a major erosional surface located at the top of the Troutdale Formation. These relations indicate an angular unconformity between Pleistocene gravel unit 2 (Qg2) and siltstone unit 1 (Ttst1).

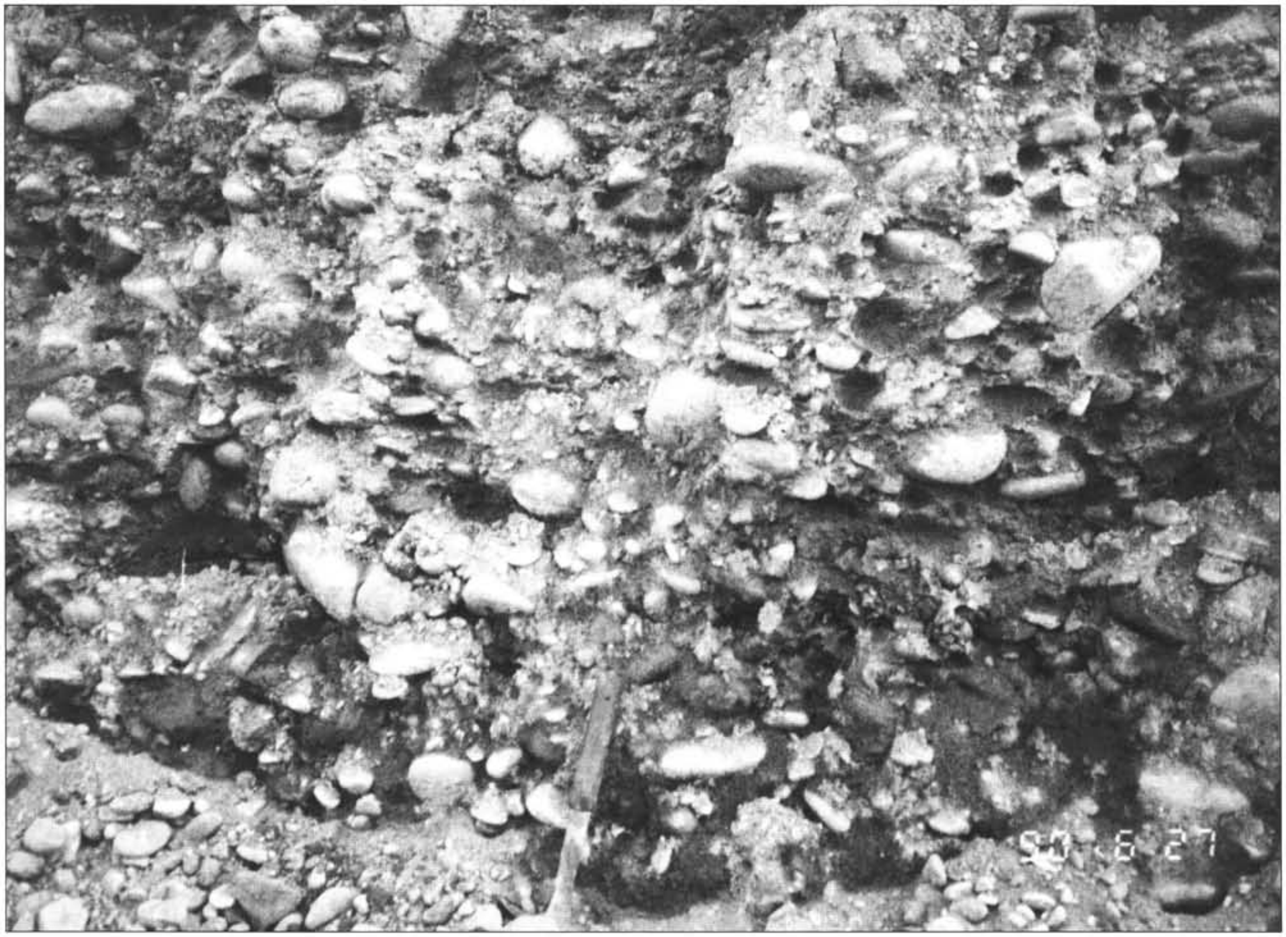


Figure 7. Unconformable contacts exposed during construction activities along NE Sandy Boulevard (see Figure 2 for location). Lower contact is the angular unconformity between Pleistocene gravel unit 2 and the underlying Troutdale Formation. Unit designations are the same as in Figure 5.

overlying portions of a major erosional surface at the top of the Troutdale Formation.

Troutdale Formation

Within the Blue Lake Park area, the Troutdale Formation can be subdivided into five mappable units, informally referred to as siltstone unit 1, sandstone-conglomerate unit 1, siltstone unit 2, sandstone-conglomerate unit 2, and Sandy River Mudstone.

Siltstone unit 1

We consider siltstone unit 1 to be the top of the Troutdale Formation in the study area, based on the following evidence:

- The presence of vitric sandstone associated with the onset of high-alumina basaltic volcanism, which is a diagnostic feature of the Troutdale Formation; vitric sandstone is generally not found in Pleistocene gravel unit 2 or other overlying units.
- The absence of deformation in the overlying units.
- The absence of weathering immediately above the unit.
- The unconformable contact with the overlying units.

Siltstone unit 1 consists of tan, brown, and blue-gray, micaceous, clayey siltstone with organic matter, interbedded with black to tan, vitric-lithic sandstone. The sandstone tends to occur near the top and bottom of the unit and is similar in composition to the sandstone found in sandstone-conglomerate unit 1. We observed deeply weathered sandstone throughout siltstone unit 1. The thickness of siltstone unit 1 ranges up to 120 ft. Hydrogeologically, Hartford and McFarland define siltstone unit 1 as confining unit 1 (see Figure 4).

Figure 8. Eroded surface of sandstone-conglomerate unit 1, typical of outcrops south and east of Blue Lake County Park. Outcrop is located approximately 1,700 ft north of the intersection of 238th Drive and NE Sandy Boulevard.

Sandstone-conglomerate unit 1

Underlying siltstone unit 1 is sandstone-conglomerate unit 1 (Figure 8). Sandstone comprises the upper portion of this unit near the center of the study area. It consists of moderately cemented, black, vitric (sideromelane), medium to coarse sand with basaltic conglomerate lenses. Local alteration of vitric sand to clay (palagonite) forms the cementing agent (Trimble, 1963). Thickness for the sandstone portion of this unit varies from 40 to 80 ft.

The conglomerate underlying the sandstone is clast supported and consists of weakly to moderately cemented, vitric-lithic to arkosic, sandy basalt with quartzite and other metamorphic, volcanic, and plutonic pebbles and cobbles and also includes some thin lenses of blue or gray clayey siltstone and vitric sandstone. Conglomerate thickness varies from 40 to 90 ft. In the southeast portion of the study area, the unit becomes primarily conglomerate. A discontinuous siltstone unit up to 18 ft thick is also sometimes present between the sandstone and conglomerate portions of sandstone-conglomerate unit 1. When saturated, this unit forms the Troutdale sandstone aquifer (see Figure 4).

Sandstone-conglomerate unit 1 crops out at numerous locations in the eastern portion of the study area. We measured bedding attitudes at several outcrops and incorporated these data into the structure-contour maps. All outcrops of this unit examined in the study area displayed an erosional surface with little weathering.

Siltstone unit 2

Underlying the sandstone-conglomerate unit 1 is siltstone unit 2. Siltstone unit 2 is lithologically similar to siltstone unit 1. It consists of a blue-gray, micaceous clayey silt with organic matter and sandstone interbeds. Thickness of this unit ranges to over 100 ft. Hydrogeologically, this unit forms confining unit 2 (see Figure 4).

Sandstone-conglomerate unit 2

Underlying siltstone unit 2 is sandstone-conglomerate unit 2. Lithologically, this unit is somewhat similar to sandstone-conglomerate unit 1 but contains more conglomerate, more frequent interbedding of siltstone, and more interbedded siltstone near the base of the unit. Swanson (1986) identified the geochemical signature of vitric sandstone within this unit, indicating its affinity with the Troutdale Formation. The finer sediments near the base of the unit make it difficult to determine the boundary between sandstone-conglomerate unit 2 and the underlying Sandy River Mudstone. Thickness may be as much as 500 ft in the study area, but few wells have penetrated the unit. When saturated, sandstone-conglomerate unit 2 forms the sand and gravel aquifer (see Figure 4).

Sandy River Mudstone

Underlying sandstone-conglomerate unit 2 is the Sandy River Mudstone. The unit consists primarily of clayey siltstone and sandstone but may also contain some conglomerate. The Sandy River Mudstone unconformably overlies the Columbia River Basalt Group and other volcanic units (Trimble 1963).

STRUCTURE

We further defined structural deformation of the study area through cross sections and structure-contour maps. Structure-contour maps of selected stratigraphic contacts are shown in Figures 9 and 10. Cross section lines are shown in Figure 3. These figures indicate that the structure of the study area is the result of several processes, including folding, faulting, and possibly fluvial channel incision.

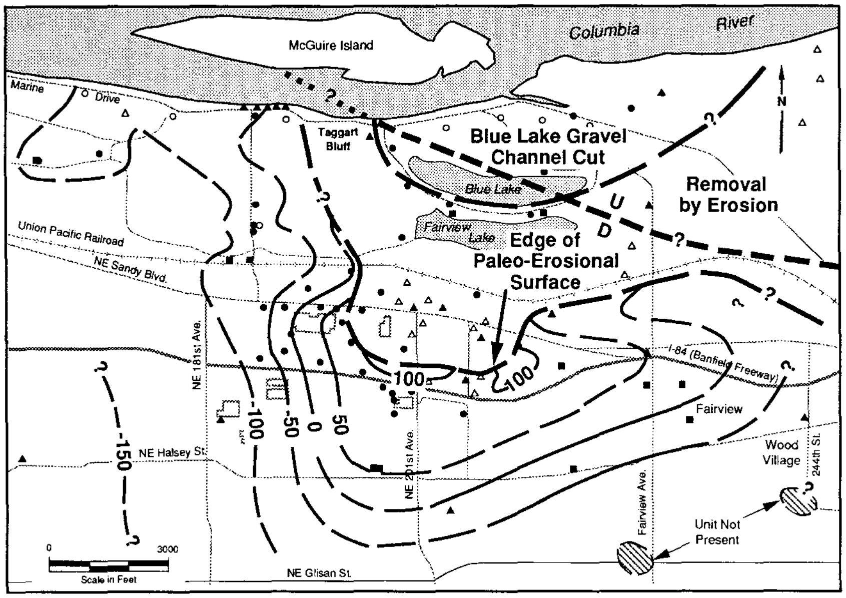


Figure 9. Structure-contour map of top of siltstone unit 1. This unit was partially or completely removed by erosion where indicated ("paleo-erosional surface").

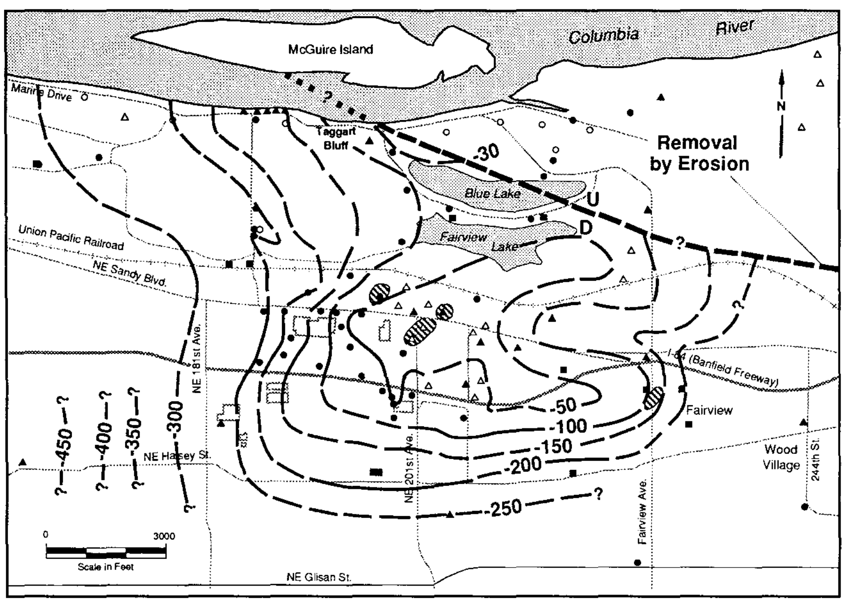


Figure 10. Structure-contour map of top of siltstone unit 2. This unit was removed by erosion north of the fault trace and is interpreted to be missing by channel incision near center of figure (hatched areas on map).

Folding

We conclude from well log data that the Troutdale Formation was folded into a large dome. Structure-contour maps of the top of siltstone unit 1 (Figure 9) and siltstone unit 2 (Figure 10) show the dome forming a structural high centered just south of Blue Lake. The upper portions of the Troutdale Formation (i.e., siltstone unit 1 and sandstone-conglomerate unit 1) have been severely eroded along the northeast flank of the structural high. This erosion presumably occurred during the catastrophic flooding events associated with Pleistocene-age glacial Lake Missoula. Figure 9 shows the lateral extent of this paleo-erosional surface.

Well logs show a general thickening trend in the Troutdale Formation toward the south and west of the study area, which may be related to contemporaneous basin deformation and fluvial deposition. The folding of the Troutdale units together in the study area (Figures 11, 12, and 13) suggests that basin deformation continued after the Troutdale Formation was deposited.

Faulting

Well log and natural gamma log data suggest a fault underlying the Blue Lake gravel north of Blue Lake. Erosion and deposition of Blue Lake gravel and flood-plain deposits apparently removed or covered any surface expression of the fault trace. Vertical offset, defined by the stratigraphy described in well logs, increases along the fault trace toward the northwest to as much as 500 ft. This faulting probably influenced the lateral migration of the ancestral Columbia River as it incised its channel.

Figure 9 shows the estimated trend of the fault. The cross sections shown in Figures 12 and 13 intersect this feature. The fault trace is bounded to the south by outcrops of sandstone-conglomerate unit 1. The northern extent of the fault trace is bounded by bore hole data from wells that penetrated beyond the Blue Lake gravel into what we infer as strata from either the lower portion of sandstone-conglomerate unit 2 or from the upper boundary of the Sandy River Mudstone.

At well 21DBBB1 (Figure 2), sediments below the Blue Lake gravel do not display the characteristic gamma signatures of siltstone unit 1, sandstone-conglomerate unit 1, or siltstone unit 2 seen in gamma logs from wells 20BDBB1, 20CBDC1, and 20CCAB3. However, well 21DBBB1 gamma signatures below the Blue Lake gravel can be correlated to a section near the boundary between sandstone-conglomerate unit 2 and Sandy River Mudstone seen in wells 20CBDC1 and 33ADDA1 (Figure 14). Data from the well 20CBDC1 indicate that the stratigraphic distance between siltstone unit 2 (south of the fault trace) and the boundary between sandstone-conglomerate unit 2 and Sandy River Mudstone (north of the fault trace) is approximately 500 ft. Figure 13 shows that, due to vertical offset, these units are at almost the same elevation near the fault trace. Well log descriptions of sediments underlying the Blue Lake gravel and locations farther east further support this interpretation (wells 21ADAA1, 22BBCA1, 22AA1, and 22AD1, for example). These sediments best correlate to the lower portion of sandstone-conglomerate unit 2 or the upper portion of the Sandy River Mudstone.

During excavation activities along NE Sandy Boulevard (Figure 3), we observed numerous conjugate fault sets near the top of sandstone-conglomerate unit 1 near the structural high. Slickenside features were also observed in siltstone unit 1 and sandstone-conglomerate unit 1 in this same area. These features are indicative of the expansion expected near the top of a structural high.

Channel incision

Well logs indicate that both siltstone unit 1 and siltstone unit 2 are locally absent within the study area. The relatively uniform

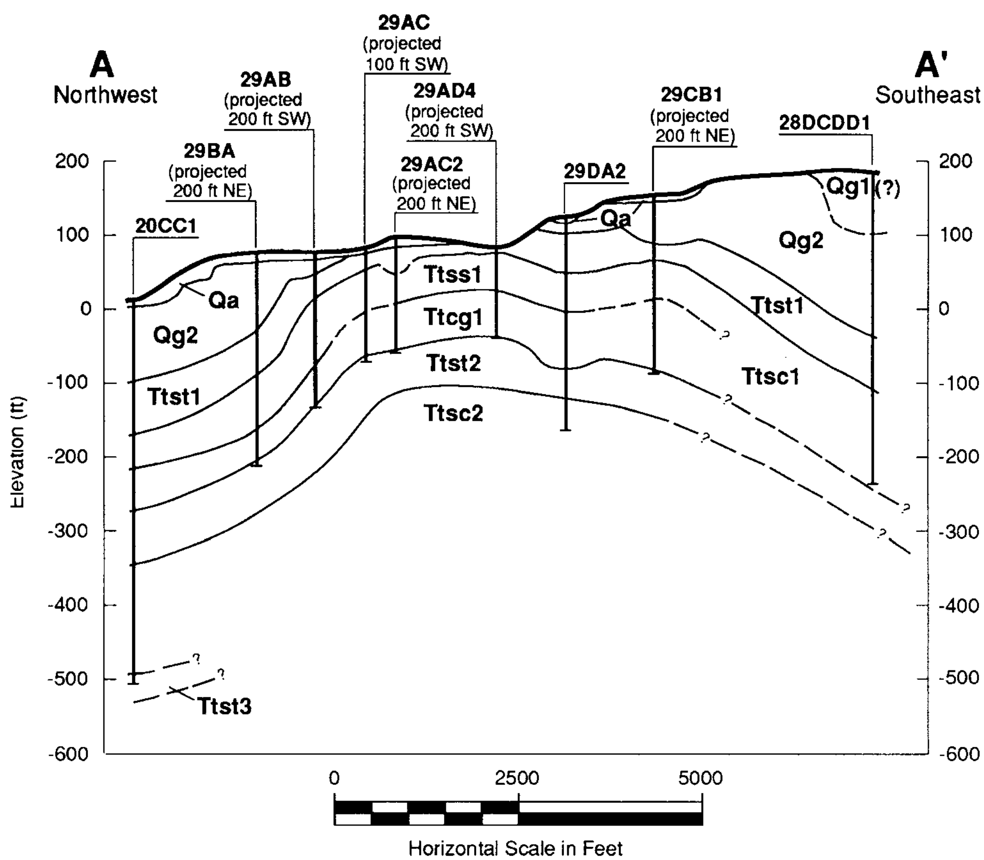
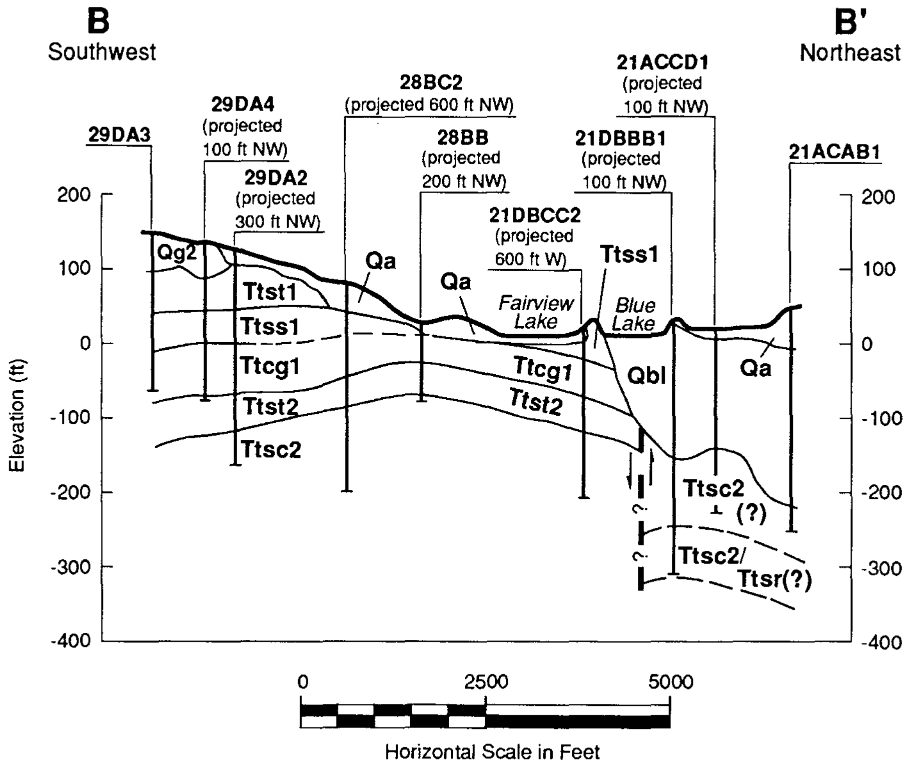


Figure 11. Cross section A-A′ as shown in Figure 3. Qa = alluvium; Qg1 = Pleistocene gravel unit 1; Qg2 = Pleistocene gravel unit 2; Ttst1 = siltstone unit 1; Ttss1 = sandstone unit 1; Ttcg1 = conglomerate unit 1; Ttst2 = siltstone unit 2; Ttsc2 = sandstone-conglomerate unit 2; Ttst3 = siltstone unit 3.

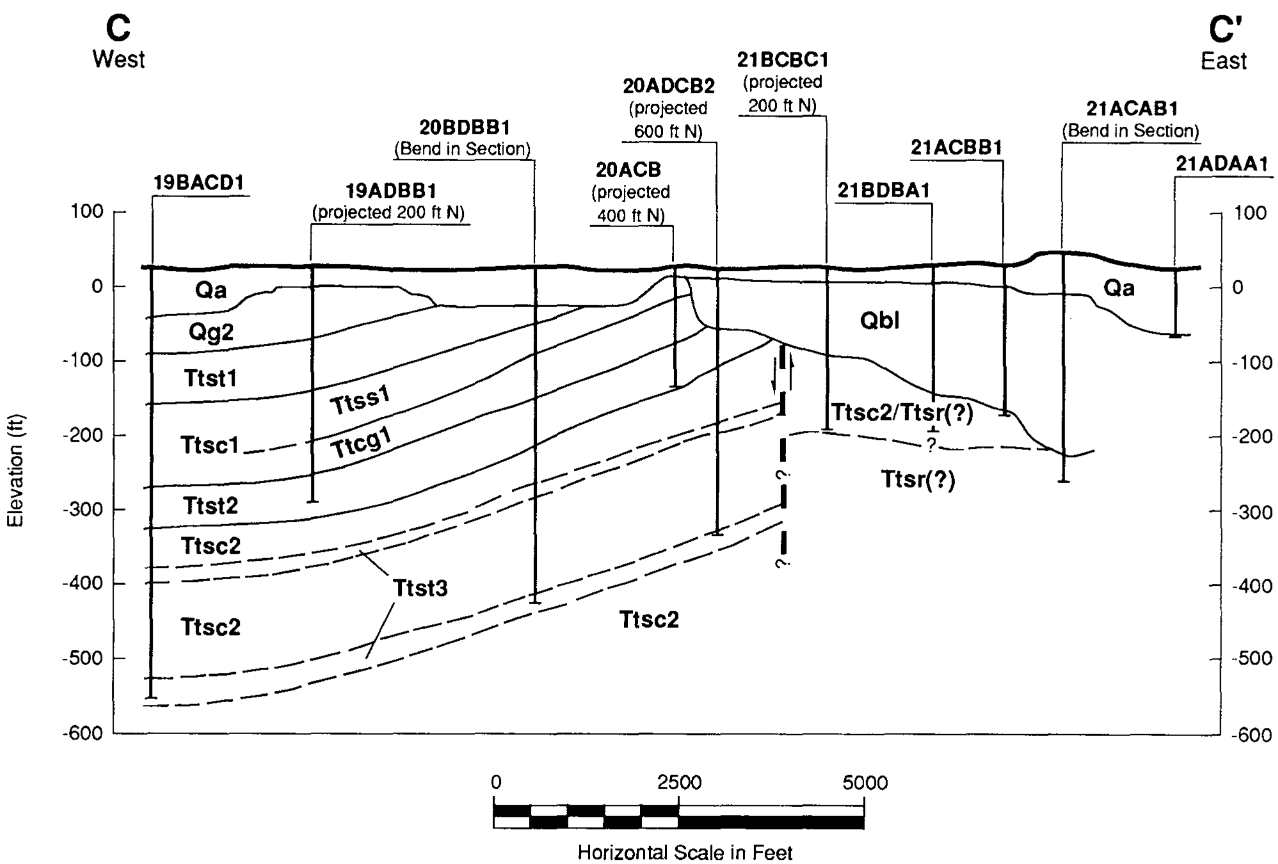


Left:

Figure 12. Cross section B-B′ as shown in Figure 3. Qa = alluvium; Qbl = Blue Lake gravel; Qg2 = Pleistocene gravel unit 2; Ttst1 = siltstone unit 1; Ttss1 = sandstone unit 1; Ttcg1 = conglomerate unit 1; Ttst2 = siltstone unit 2; Ttsc2 = sandstone-conglomerate unit 2; Ttsr = Sandy River Mudstone.

Bottom:

Figure 13. Cross section C-C′ as shown in Figure 3. Qa = alluvium; Qbl = Blue Lake gravel; Qg2 = Pleistocene gravel unit 2; Ttst1 = siltstone unit 1; Ttsc1 = sandstone-conglomerate unit 1; Ttss1 = sandstone unit 1; Ttcg1 = conglomerate unit 1; Ttst2 = siltstone unit 2; Ttsc2 = sandstone-conglomerate unit 2; Ttst3 = siltstone unit 3; Ttsr = Sandy River Mudstone.



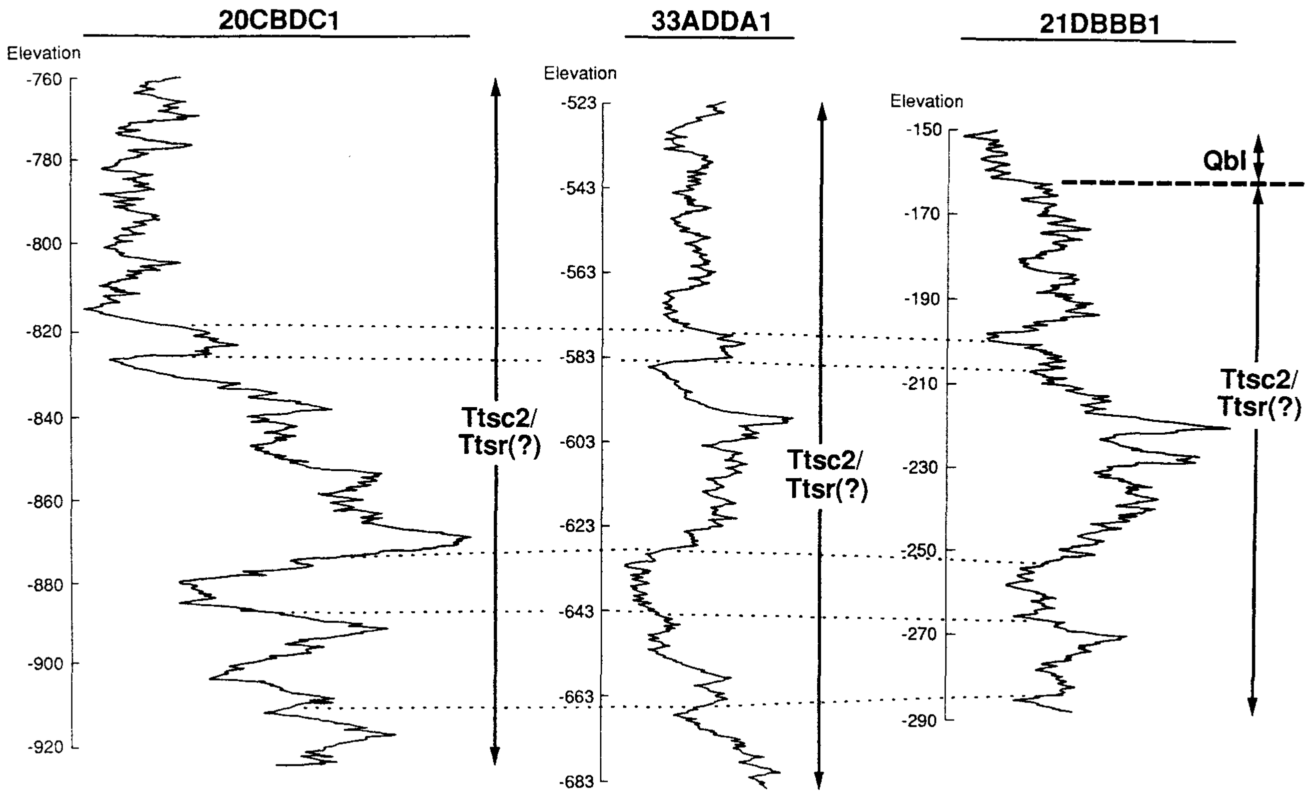


Figure 14. Natural gamma logs showing correlation of bottom of sandstone-conglomerate unit 2 and top of Sandy River Mudstone from three well locations. Dotted lines represent gamma correlations. Increasing radiation is from left to right. Elevations are in feet, mean sea level. Qbl = Blue Lake gravel; Ttsc2 = sandstone-conglomerate unit 2; Ttsr = Sandy River Mudstone. See Figure 2 for well locations.

thickness of mappable units within the Troutdale Formation, coupled with the apparent folding of these units, suggests that the absence of the siltstone units is the result of erosion rather than nondeposition. Based on the presence of the siltstone units at some locations and absence at other nearby locations (e.g., wells 29AD1 and 29AD4, wells 29AD2 and 29AD3, wells 27CBBB1 and 27CBBB2) (Figure 2), we conclude that siltstone units 1 and 2 were partially or completely eroded by channel incision during different erosional events. The channel associated with siltstone unit 2 near the structural high appears to have been filled with conglomerate from sandstone-conglomerate unit 1. Similarly, channels eroded into siltstone unit 1 have been filled with Pleistocene-age gravel or silt deposits.

We observed fluvial cut and fill features and erosional surfaces in the Troutdale Formation in outcrops both inside (Figure 5) and outside the study area (outcrops along the lower Sandy River).

SUMMARY

Through surface and subsurface mapping of the geology in the Blue Lake vicinity, we have identified a number of geologic processes that have combined to form complex stratigraphic and structural relationships within the Troutdale Formation and overlying sediments. Based on these relationships, we have divided the stratigraphy in the study area into flood-plain deposits, Blue Lake gravel, Pleistocene gravel units 1 and 2, and Troutdale Formation.

Evidence from outcrops and well logs indicates that the top of Pleistocene gravel unit 2 was weathered to a red or brown clayey silt that contains decomposed gravel. The presence of this weathered surface suggests that Pleistocene gravel unit 1 is a significantly younger deposit than Pleistocene gravel unit 2. The presence of boulders and matrix-supported clasts in massive bedding of Pleistocene gravel deposits appears to be related to the flooding events associated with Pleistocene outburst floods from glacial Lake Missoula.

Cross sections and field observations indicate that the contact between Pleistocene gravel unit 2 and the underlying Troutdale Formation is an angular unconformity, with Pleistocene gravel unit 2 thickening to the west. Siltstone unit 1, observed in outcrops, is deeply weathered, structurally deformed (fractured), eroded, and overlain by unweathered Pleistocene gravel unit 2 (Figure 5). In addition to the weathering contrast, Pleistocene gravel unit 2 was not structurally deformed and overall appears to be less indurated than the Troutdale Formation. We consider siltstone unit 1 to be the top of the Troutdale Formation in the study area because it contains vitric sandstones, which are not present in Pleistocene gravel unit 2 or any other overlying deposit, and because of the presence of the angular unconformity at the contact with Pleistocene gravel unit 2 or other overlying deposits.

Well log data indicate that the Troutdale Formation was folded into a large dome that forms a structural high near the center of the study area. Subsequent erosion has removed all of siltstone unit 1 and part of sandstone-conglomerate unit 1 along the northeast flank of the dome prior to the deposition of Pleistocene gravel unit 2. Much of this erosion may have occurred during Pleistocene outburst floods from glacial Lake Missoula.

Information from natural gamma logs and other well logs indicates that the northeast portion of the dome has been cut by a northwest-trending fault. Vertical displacement along the fault increases to the northwest to as much as 500 ft. Erosion has removed the upper units of the Troutdale Formation north of the fault trace, and the deep channel incision now occupied by the Blue Lake gravel removed the remaining Troutdale Formation to a point near the boundary between sandstone-conglomerate unit 2 and the Sandy River Mudstone. The fault probably influenced the lateral migration of the channel cut that is now occupied by the Blue Lake gravel.

The variation in presence or absence of siltstone units 1 and 2 at well locations that are in close proximity to each other suggests lateral discontinuities that may have been formed by fluvial channel incision during different erosional events. Well log data indicate that these channels were filled with conglomerate and gravels similar to the overlying units (i.e., sandstone-conglomerate unit 1 and Pleistocene gravel units 1 and 2).

Post-Troutdale deformation, Pleistocene deposition, weathering, and erosion have complicated the stratigraphy in the study area. However, most of the Troutdale Formation and overlying sediment seem to correlate with other parts of the Portland Basin. Whether the major deformation occurring in the study area resulted from a localized event or was caused by other forces during the continued formation of the east Portland Basin is not clear. More detailed mapping and examination of well log data will be needed for a more complete stratigraphic and structural model of the east Portland Basin.

ACKNOWLEDGMENTS

The authors wish to thank Landau Associates, Inc., and the Boeing Company for their support. The authors also thank Terry Tolan, Marvin Beeson, and Rod Swanson for their help during the review process. We also wish to thank Linda Schwarz and Kim Reading for their work on the figures and John Leder, Anna Templin, and Brian Butler for their encouragement.

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NEW DOGAMI PUBLICATIONS

Geology and mineral resources map of the Shady Cove quadrangle, Jackson County, Oregon, by Frank R. Hladky, has been published as map GMS-52. Price is $6.

The two-color geologic map (scale 1:24,000) is accompanied by geologic cross sections and brief discussions of geologic history, structure, and mineral and water resources. A separate sheet contains tables listing geochemical data.

This map is the second of a series of maps planned to provide hazard and mineral-resource data as well as bedrock geology to aid regional planning in the Medford-Ashland area which is experiencing rapid population growth. A map of the Boswell Mountain quadrangle was published as DOGAMI map GMS-70; and an as yet unpublished map of the Cleveland Ridge quadrangle is available for inspection at the DOGAMI field office in Grants Pass (5375 Monument Drive, phone (503) 476-2496).

Geology and mineral resources map of the Harper quadrangle, Malheur County, Oregon, by Mark L. Ferns and James P. O'Brien, has been published as map GMS-69. Price is $5.

Geology and mineral resources map of the Little Valley quadrangle, Malheur County, Oregon, by Howard C. Brooks and James P. O'Brien, has been published as map GMS-72. Price is $5.

The two-color maps (scale 1:24,000) also include geologic cross sections, tables with geochemical data, and brief discussions of geology and resources. The resource potential includes hot-spring-type gold, silica sand, diatomite, and other nonmetallic minerals.

The maps are part of a cooperative effort to map the 1° by 2° Boise sheet in eastern Oregon. In addition the publication of these and earlier maps in this 64-quadrangle project, a group of 20 unpublished quadrangle maps has been placed on open file in the Portland and Baker City offices of DOGAMI.

Geologic map of the Camas Valley quadrangle, Douglas and Coos Counties, Oregon, by Gerald L. Black and George R. Priest, has been published as map GMS-76. Price is $6.

The two-color map (scale 1:24,000) is accompanied by three geologic cross sections. A separate four-page text contains discussions of the geologic history, structural geology, and hydrocarbon potential of the quadrangle. A similar map was published earlier for the adjacent Reston quadrangle as DOGAMI map GMS-68.

The new maps are now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

USGS Director steps down

Secretary of the Interior Bruce Babbitt announced in mid-April that he has accepted, with regrets, the decision of Dallas Peck, Director of the U.S. Geological Survey (USGS), to step down from his post after a distinguished federal career spanning more than four decades, including 12 years as Director of the Survey. Peck, an internationally known authority on volcanism and the geology of California and the Pacific Northwest, will return to full-time research at the USGS. He will stay on as Director of the USGS until a successor is named. The director of the USGS has traditionally been appointed by the President from nominations provided by the National Academy of Sciences (NAS). Secretary Babbitt has begun the process of consulting with NAS about the selection of a new director.

—USGS news release

Ancient caldera complex revealed

From a news release issued by the Oregon Department of Geology and Mineral Industries, Grants Pass office, Frank R. Hladky and Thomas J. Wiley, geologists

Rocks of an ancient caldera complex are exposed 30 mi north of Medford. The southern margin of this volcanic feature was identified by geologists of the Oregon Department of Geology and Mineral Industries (DOGAMI), who were mapping the geology of the McLeod and Trail quadrangles in Jackson County. Calderas are large, circular volcanic basins such as Crater Lake or Yellowstone. The igneous rocks beneath a caldera are referred to as a caldera complex.

The caldera complex is located 4 mi north of Lost Creek Lake along the upper reaches of Elk Creek in the Western Cascades. It is comprised mostly of silicic rocks, generally rhyodacitic in composition, that define a chaotic assemblage of dikes, sills, stocks, vent breccias, and tuffs several miles across. U.S. Geological Survey (USGS) scientists led by James G. Smith reconnoitered the area during the late 1970s and determined that broad sheets of ash-flow tuff had been erupted 28 to 25 million years ago during late Oligocene time. They also mapped silicic intrusive stocks along the upper reaches of Elk Creek and the Rogue-Umpqua divide. Stocks originate as large bodies of viscous igneous magma that migrate upward through the Earth's crust and sometimes breach the surface. The field evidence led the USGS geologists to first suspect the existence of a large caldera complex.

DOGAMI's new, more detailed mapping confirmed the presence of a caldera complex of great size and locally delineated its southern margin. The new mapping is sufficiently detailed to differentiate between the chaotic collage of silicic tuffs, dikes, and breccias, which is indicative of intracaldera rocks, and bedded ash-flow tuffs, which are indicative of extracaldera rocks.

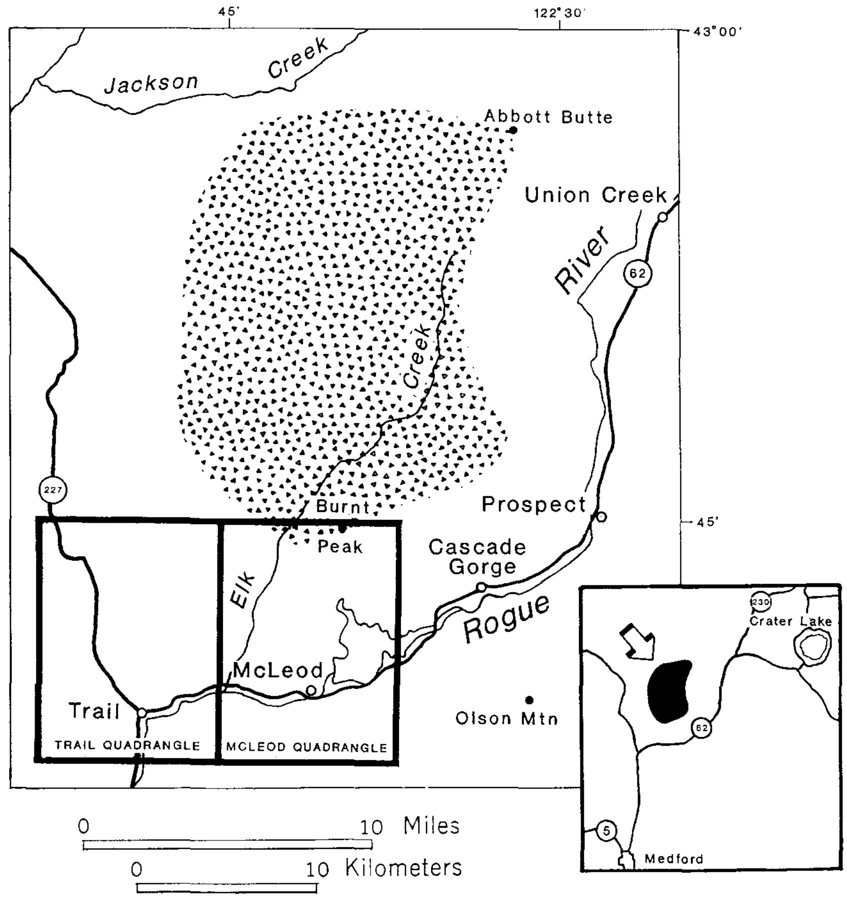

Figure 1. Sketch map showing location of caldera complex (patterned area), including relation to the quadrangles DOGAMI geologists have been mapping.

The size of the caldera complex has not yet been fully determined. Similar rocks, however, have been found to crop out in an area of roughly oval shape that extends approximately 15 mi north-south and 10 mi east-west. Further study will also be required to determine whether this tract of silicic rocks represents a single caldera system or several.

The original caldera shape has been nearly obliterated by 25 million years of erosion and burial by younger volcanic rocks. In most places, the rocks of the caldera complex have deteriorated from millions of years of weathering. Basalt and andesite lava flows have covered much of the caldera complex, especially on its east side. Thick soil, landslides, and dense vegetation have obscured many of the rocks of the caldera complex. These conditions have hampered efforts to map the caldera complex. Other conditions, however, have helped geologists: Elk Creek and its tributaries have cut deeply into the volcanic structure for perhaps millions of years; the Burnt Peak forest fire of 1987 removed large tracts of vegetation north of Burnt Peak; and logging roads have cut through the soil cover of mountain slopes.

Caldera complexes sometimes contain bodies of metal ore, originally deposited from hydrothermal fluids. USGS geochemists sampled the area during the late 1970s and early 1980s and determined that many of the rocks within the caldera complex were mineralized. DOGAMI geologists also found evidence of hydrothermal alteration in rocks of the caldera complex, this time near the old Burnt Peak lookout. Located 8 mi northeast Burnt Peak, the old Al Sarena gold and silver mine is thought to lie within the caldera complex. Between 1909 and 1918, the Al Sarena mine produced precious metals then valued at $24,000. Two years ago, the Al Sarena mine was redrilled and sampled by the Fisher-Watt Gold Company. Although the company decided not to pursue exploration any further, company geologists did identify as much as 2 million tons of low-grade ore containing gold, silver, and lead. □

Culbertson reappointed to Board

Ronald K. Culbertson, member and currently chairman of the Board of the Oregon Department of Geology and Mineral Industries, has been reappointed to another term on the Board by Governor Roberts, and the reappointment has been confirmed by the Oregon Senate. Culbertson's new term in this position will extend until mid-1996. □

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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

Rare—and lucky—photo of a fireball over Oregon: The Chemult fireball of July 27, 1992. Photo was taken by Scott McAfee from near Crater Lake Lodge. The fireball came out of the zenith, increasing in brightness. See related report by Pugh and McAfee on page 90.

OIL AND GAS NEWS

Drilling begins at Mist Gas Field

Nahama and Weagant Energy of Bakersfield, California, began drilling for natural gas at the Mist Gas Field, Columbia County, during May. The first well drilled was the Longview Fibre 12A-33-75, located in sec. 33, T. 7 N., R. 5 W., Columbia County. The well was drilled to a total depth of 2,475 ft and is currently suspended. The second well of the multi-well program is the Longview Fibre 12B-35-65, located in sec. 35, T. 6 N., R. 5 W., Columbia County, where drilling operations are underway.

NWPA elects officers, announces symposium

At its monthly meeting on May 14, the Northwest Petroleum Association (NWPA) announced the newly elected officers and directors for 1993-94: President, Nancy Ketrenos; Vice president, Bert Mueller; Secretary, Dick Bowen; and Treasurer, Dan Wermiel. The new directors are John Taylor (western Washington), Harry Jamison (eastern Oregon/Washington), Jeff Pennick (Land), Bill Holmes (Legal), and Bob Deacon and Lise Katterman (at large).

The association's 10th annual symposium will be held September 26-28, 1993, at the Inn of the Seventh Mountain in Bend, Oregon. Theme of the symposium will be "Earth Resources and the Pacific Northwest." The technical session will include papers on oil and gas play assessment, minerals, geothermal resources, coastal tectono-stratigraphy, the Paleogene Willamette Basin, coal-bed methane, and gas transmission activity. A field trip will be conducted in the Bend-Newberry National Volcanic Monument area and will highlight the geothermal potential and volcanology of central Oregon.

The NWPA meets for monthly luncheon programs and an annual symposium. For details on the meetings and the symposium, contact the NWPA, P.O. Box 6679, Portland, OR 97228-6679.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
485	Carbon Energy Intl. JCLC Menasha 28-1 36-011-00025	SW¼ sec. 28 T. 26 S., R. 13 W. Coos County	Application; 1,650.
486	Carbon Energy Intl. WNS Menasha 32-1 36-011-00026	SW¼ sec. 32 T. 26 S., R. 13 W. Coos County	Application; 1,600.
487	Carbon Energy Intl. Coos County Forest 7-1 36-011-00027	SE¼ sec. 7 T. 27 S., R. 13 W. Coos County	Application; 4,250.

□

Grants Pass offers video viewing

The Grants Pass field office of the Oregon Department of Geology and Mineral Industries (DOGAMI) offers a collection of more than 60 videotapes to visitors for in-office viewing.

The collection includes (1) programs for introductory study of various geologic disciplines and the geologic processes those disciplines deal with, (2) presentations of the geology of particular localities, (3) descriptions of mines and mining operations, (4) descriptions of scenic geology and natural history, and (5) a program set for science teachers, presenting ideas, suggestions, and examples for classroom activities.

The videotapes can be viewed at the DOGAMI Grants Pass field office Monday through Friday from 1:00 to 5:00 p.m. Address and phone number are listed in the left-hand column on this page. Interested persons should contact the office for further information or for viewing appointments. □

Lithofacies and depositional environment of the Spencer Formation, western Tualatin Valley, Oregon

by Robert O. Van Atta and Richard E. Thoms, Department of Geology, Portland State University, Portland, Oregon 97207

ABSTRACT

The Spencer Formation is a prime natural gas target in the Willamette Valley of western Oregon. It is coeval with the Cowlitz Formation from which gas is produced in the Mist Gas Field of northwestern Oregon. Like the Cowlitz Formation, it includes a clean arkosic sand that is nearly 300 m thick in the Humble Oil Miller No.1 test hole near Albany, Oregon. This paper is based upon detailed studies of both cores and excellent surface outcrops in the western Tualatin Valley of northwestern Oregon. In this area, the most northerly occurrence of the Spencer Formation, it overlies the Yamhill Formation, which is mostly carbonaceous mudstone, with apparent conformity and is overlain by the Pittsburg Bluff Formation. The Spencer Formation can be informally divided into two members: (1) a lower, highly micaceous sandstone (62 m), and (2) an upper member that is micaceous siltstone and mudstone (308–400 m). Locally, the lower member includes a very permeable sandstone that is lithologically indistinguishable from the gas-producing unit known as the "Clark and Wilson sand") of the Mist Field.

Diagenesis of the Spencer Formation in the area of this study was limited to production of some chlorite, smectite, and mixed-layer smectite/illite. Percentages of the authigenic clays are greater in the upper part of the lower member and in the upper member, reflecting a somewhat greater content of volcanic detritus. Vitrinite reflectance of 0.22 indicates a low degree of thermal maturity.

Depositional environments represented in the Spencer range from outer- to mid-neritic (lower part, lower member) to shallow neritic, nearshore, and lagoonal (upper part, lower member) to mid-neritic to upper bathyal depths (upper member).

Based on sandstone framework grain modal composition, the provenance of the Spencer Formation includes both proximal volcanic rocks derived from the east and distal plutonic as well as medium- to high-grade metamorphic rocks probably derived from the region of the present-day northern Cascade Range and the northern Rocky Mountains.

INTRODUCTION

The earliest recorded hydrocarbon exploration activity in the Willamette Valley was in 1934–35, when three wells were drilled in Marion, Benton, and Linn Counties. No other drilling activity was recorded until 1957. From 1957 to 1981, 34 additional wells were drilled to test the Spencer Formation in Benton, Linn, Marion, and Polk Counties (Baker, 1988).

The Spencer Formation is correlative to the productive Cowlitz Formation "Clark and Wilson sand" (Bruer and others, 1984) in the Mist Gas Field, upper Nehalem River basin, northwestern Oregon (Figure 1), and throughout this paper comparisons are made between the arkosic sandstone in the Spencer Formation in the western Tualatin Valley and the arkosic "Clark and Wilson sandstone" of the Cowlitz Formation. The Spencer Formation is considered a potential reservoir for natural gas because of high permeability and porosity in a sandstone member, "Spencer sand" of Bruer and others (1984), and there have been gas shows where it has been penetrated in the northern Willamette Valley. Thus, much of the recent exploration effort in the Willamette Valley has concentrated on the Spencer Formation.

One small gas discovery occurred in the Spencer Formation in 1981 at the American Quasar Hickey 9–12 well in Linn County. Production lasted for five months (Olmstead, 1989) and was abandoned because production volume of gas became subcommercial. To date, no economic gas accumulations have been found.

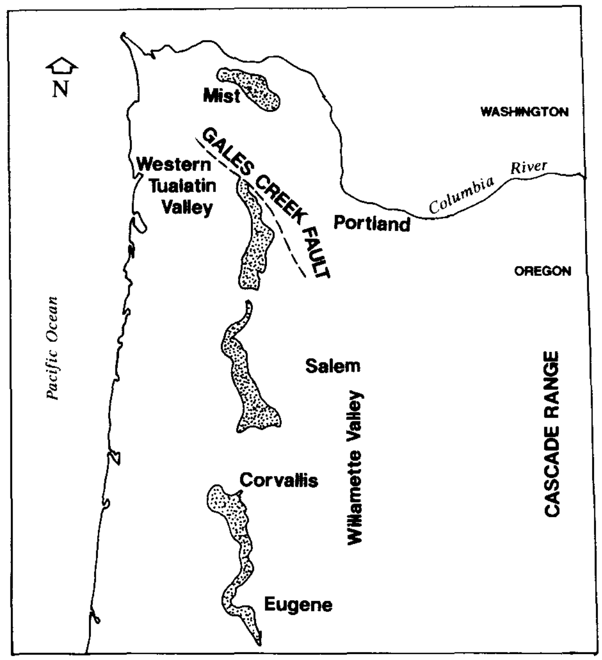


Figure 1. Sketch map of northwestern Oregon. Areas discussed in text are indicated by stippled pattern.

Data presented in this paper were obtained during a detailed study of the stratigraphy and paleontology of Paleogene rocks of the western Tualatin Valley conducted by the authors and by David Taylor, a visiting researcher at Portland State University. Other sources of data not obtained in this study are cited where necessary.

Paleoecologic interpretations proposed in this paper are based upon the following sources: Abbot (1954), Keen (1960), Keen and Coan (1974), and Moore (1976) for mollusks; Ingle (1980) and McKeel (1984) for the foraminifers; and Frey (1975) for trace fossils.

Purpose

The purpose of this paper is to present the results of a detailed study of the Spencer Formation in the northernmost part of its outcrop extent in an effort to determine its environment of deposition, provenance, and correlation to that of the arkosic sandstone of the Cowlitz Formation in the region of the Mist Gas Field 50 km to the north. The western Tualatin Valley area affords a nearly complete stratigraphic section of the Spencer Formation. Additionally, relatively unweathered cores from the lower member of the formation provide the opportunity for petrologic comparison with generally weathered surface samples.

Previous work

Schlicker (1962) first demonstrated that sandstone above the Yamhill Formation in the western Tualatin Valley is correlative to the Spencer Formation. McWilliams (1968) includes the Yamhill-Gales Creek area in his study of paleogene lithostratigraphy and biostratigraphy of west-central Oregon.

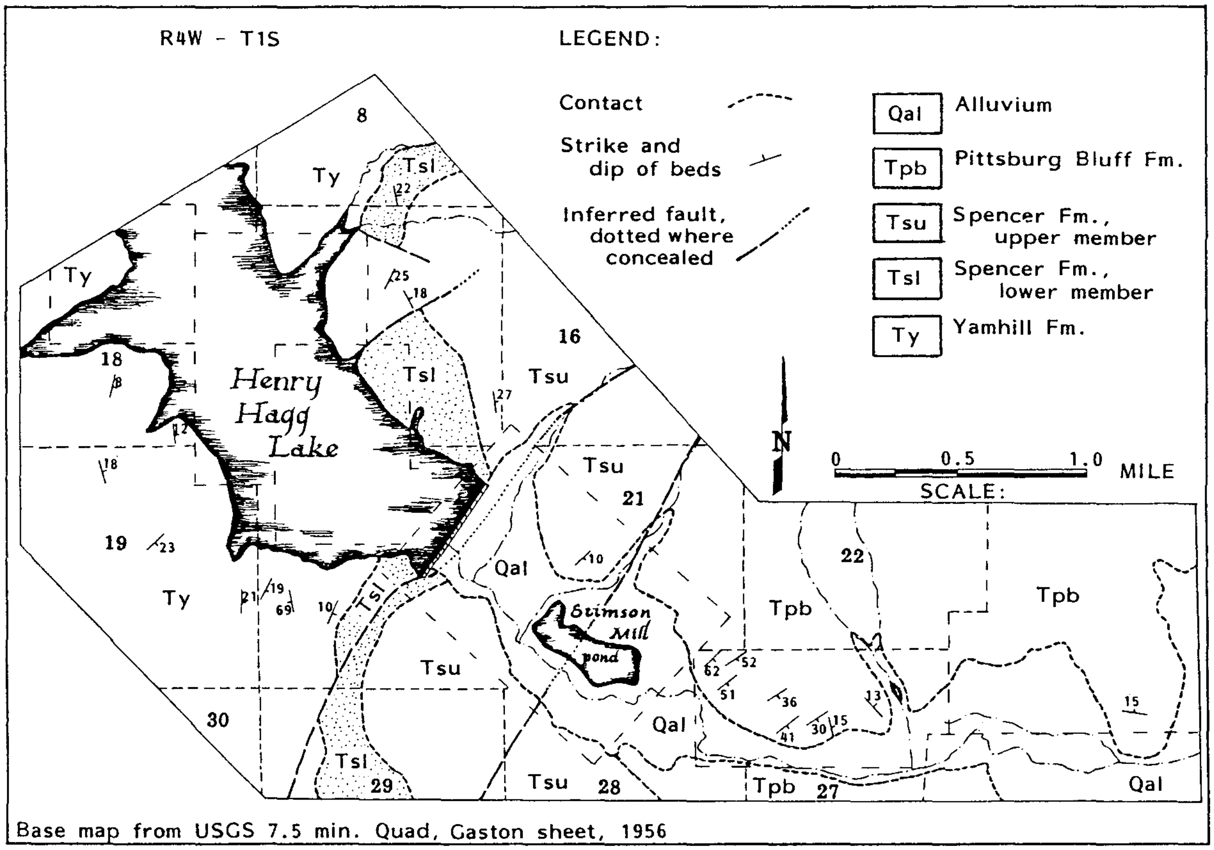


Figure 2. Geologic map of the Scoggins Valley area, Washington County, Oregon.

Al-Azzaby (1980) made a detailed study of the sedimentology and stratigraphy of the Spencer Formation in the western Tualatin Valley. He described two informal members of the Spencer Formation in the western Tualatin Valley area, a lower arkosic sandstone and an upper silty sandstone and mudstone that in this paper are combined in a lower member. The upper member in this paper is the mudstone that Al-Azzaby called "Stimson Mill beds."

Cunderla in 1986 completed a study of stratigraphic and petrologic trends within the Spencer Formation, including chemistry and diagenesis, from Corvallis to Henry Hagg Lake. The "lower and upper members" (informal) of his study are equivalent to the lower part and upper part, respectively, of the lower member (informal) distinguished in this report.

The most recent study of the Spencer Formation is that of Baker (1988). Her work was concentrated in the west-central Willamette Valley and focused on stratigraphy and depositional environments that were determined from both surface and subsurface data.

Regional stratigraphic relations

In Washington State, the Spencer Formation is correlative to the Skookumchuck, Spiketon, and Renton Formations of the Puget Group and the younger part of the sandstone of Scow Bay in western Washington.

In Oregon, the Spencer Formation can be correlated with the upper middle and upper members of the Coaledo Formation in the southern Coast Range of Oregon and, in the central Coast Range, with siltstone and volcanic rocks of the Nestucca Formation and Yachats Basalt.

Bruer and others (1984) consider the Spencer Formation to be coeval and continuous with the Cowlitz Formation of northwestern Oregon, although nowhere can the Spencer Formation be mapped from the western Tualatin Valley to the Cowlitz Formation in the upper Nehalem River basin, largely because of offset along the Gales Creek fault (Van Atta, unpublished mapping, 1985; Figure 1). Bruer and others also regard permeable arkosic sandstone in the Spencer Formation as coeval with the "Clark and Wilson sand" of the Cowlitz Formation.

The middle to lower upper Eocene (Narizian) Spencer Formation, named by Turner (1938), crops out in a generally narrow, somewhat sinuous band that trends north-south in western Oregon (Figure 1). The type locality is 16 km southwest of Eugene, in the vicinity of Spencer and Coyote Creeks, where the unit is about 77 m thick.

In the southern part of the outcrop belt (Drain to Eugene), the Spencer Formation unconformably overlies either the Tyee Formation or the Lorane Shale and is conformably overlain by the nonmarine Fisher Formation (Hoover, 1963; Gandera, 1977). In the central area (Monroe to Salem), the Spencer Formation is underlain unconformably by either the mid-Eocene Tyee Formation (south of Corvallis) or the lower upper Eocene Yamhill Formation (Corvallis and Albany), depending upon stratigraphic assignment of a thick sandstone lens ("Miller sand," informal; Bruer and others, 1984) lying between the Spencer and Tyee Formations to either the Yamhill or Spencer Formation. In the subsurface, in the eastern and southern parts of the central Willamette Valley, south of Corvallis, the Spencer is underlain by either mudstone, volcaniclastic rocks, or basaltic volcanic rocks of the Yamhill Formation (Baker, 1988).

In the eastern and southern parts of the central Willamette Valley, northwest of Eugene (Figure 1), the upper member (informal) of the Spencer is intercalated with basaltic volcanic rocks that Baker (1988) has termed "eastern Willamette volcanics" (informal). It is

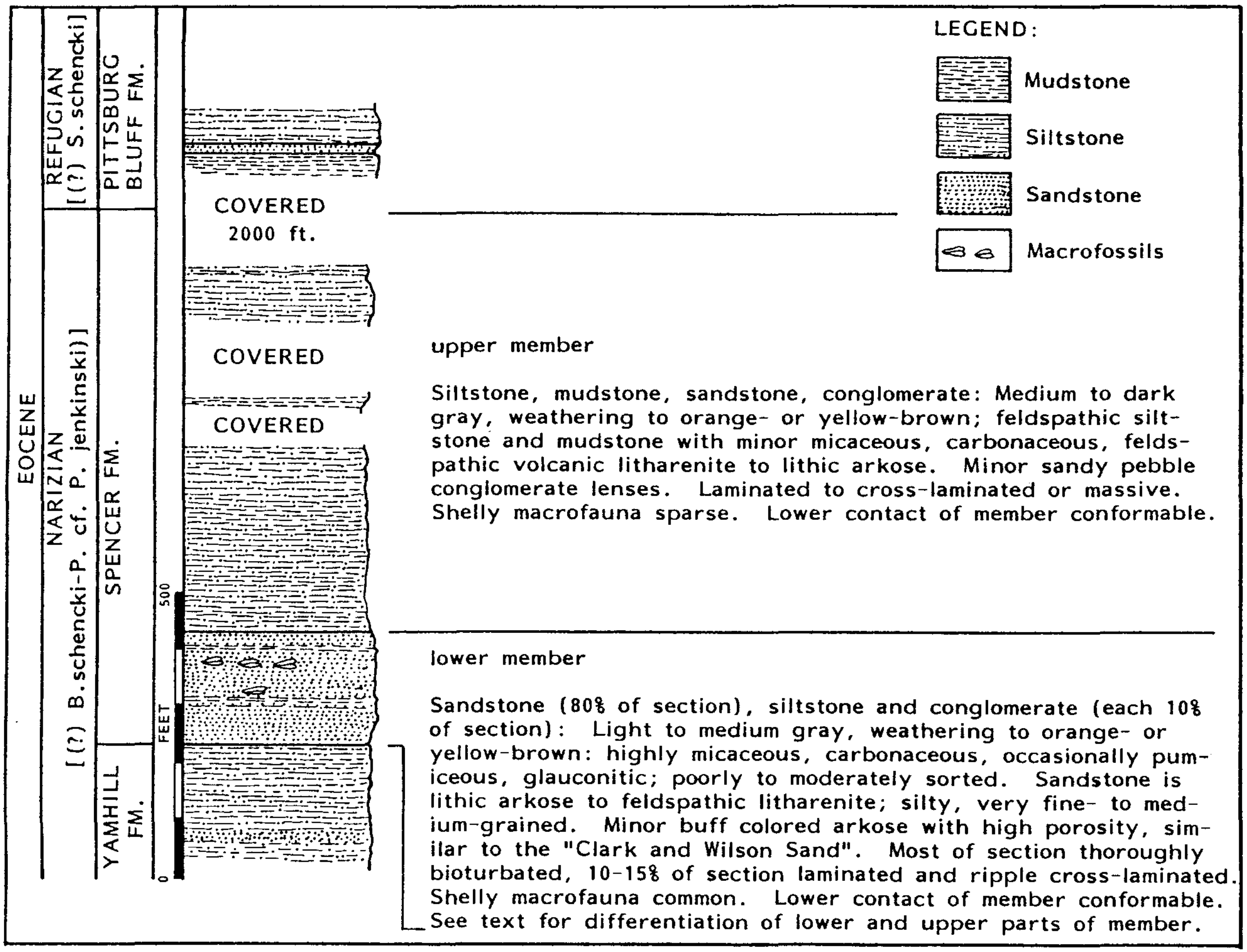


Figure 3. Stratigraphic column for Scoggins Valley, to the east and along north side of Henry Hagg Lake, Washington County, Oregon.

overlain unconformably in the central area by the uppermost upper Eocene to middle Oligocene Eugene Formation.

In the western Tualatin Valley from Yamhill, Oregon, to the Gales Creek fault, the Spencer Formation overlies the Yamhill Formation with apparent unconformity (Al-Azzaby, 1980; Cunderla, 1986), although in the vicinity of Hagg Lake, the Spencer appears conformable over the Yamhill (Van Atta, unpublished mapping, 1985).

The thickness of the Spencer Formation is quite variable throughout its extent. From south to north, its thickness is 45–145 m just east of Drain (Hoover, 1963), 620–840 m north and south of Eugene (Gandera, 1977), 1,385 m near Corvallis (Vokes and others, 1954; Baldwin and others, 1955), and about 615 m in the northernmost outcrop area (Figure 1). Baker (1988) believes, however, that the near-doubled thickness in the central area (Corvallis) may be the result of uncertainty concerning the age of the "Miller sand" (informal; Bruer and others, 1984), as noted above.

Gandera (1977) informally defined two members of the Spencer Formation in its type locality. North of the type locality, Baker (1988) finds that the Spencer Formation consists of two members (informal), traceable from the Corvallis area northward to the western Tualatin Valley: a lower member that consists of micaceous arkosic silty sandstone and siltstone and an upper member that is arkosic to lithic arkosic sandstone and mudstone. From the Corvallis area southward to the type locality, it does not appear possible to separate the formation into mappable members (Cunderla, 1986; Baker, 1988).

Baker (1988) found that the lower sandstone-rich part of the Spencer Formation in the central area can be divided into a lowermost more arkosic part, and an upper part that is more lithic with volcanic rock fragments and with plagioclase feldspar more abundant than potassium feldspar. The lower member is more lithic (volcanic) in both lower and upper parts south of Corvallis as compared to its composition to the north.

The informal members of the Spencer Formation described in the literature may or may not be traceable throughout its occurrence in western Oregon, and any formal proposal to divide the Spencer into an upper and a lower member must await further work.

METHODS

Samples for petrographic study were collected from surface outcrops exposed in Scoggins Valley (Figure 2) and from shallow cores (maximum 77-m depth) that had been taken in the 1970s from these same formations in conjunction with dam-site foundation studies conducted by the U.S. Bureau of Reclamation. The cores were logged for detailed description of primary sedimentary structures and occurrence of fossils. Eight cores in the Spencer Formation (maximum thicknesses 37 m in lower part of lower member, 54 m in upper part of lower member) were studied and sampled. In addition, five samples were taken from core of the "Clark and Wilson sand," Cowlitz Formation (Texaco Clark and Wilson 6–1 well, Columbia County, Oregon, at 943–952 m).

Textural analyses for grain size distribution in the sand-size fraction (-1.0 to +4.0 phi) were done for 56 core samples (28 and 23 samples from the Spencer Formation, lower member, lower part and upper part, respectively; 5 from "Clark and Wilson sand"). Sand-silt-clay ratios were also determined for 66 samples of the lower member of the Spencer Formation (38 from lower part; 28 from upper part).

The size parameters of sandstone samples were determined with a 2-m settling tube. The output of the tube's strain gauge was fed to a programmed microprocessor coupled with a programmable calculator. The calculator was programmed to read out raw and smoothed data tables and to print histograms. Size-frequency data were used to calculate the coarsest 1 percent, phi median, mean, standard deviation, and skewness according to the size parameters of Inman (1952) and Folk and Ward (1957). Moment measures were calculated by means of a computer program created at the School of Oceanography at Oregon State University.

Thin sections from core (24 from Spencer Formation; 4 from "Clark and Wilson sand"), impregnated with colored epoxy, were used to determine and to estimate texture, including pore types, shapes, and distribution. Detrital modes were determined according to the procedures of Dickinson and Suzek (1979). In addition, porosity and diagenetic effects were examined in 10 samples of the lower member of the Spencer Formation by scanning electron mi-

Table 1. *Size parameters of -1 to 5 phi fraction, Spencer and Cowlitz Formations*

Unit, location, sample type	Coarsest 1 percent (phi) Average	Coarsest 1 percent (phi) Range	Median size (phi) Average	Median size (phi) Range	Sorting (σ^0) Average	Sorting (σ^0) Range	Skewness (phi) Average	Skewness (phi) Range	Number of samples
Spencer Formation, lower member (core samples)									
Upper part, Patton and Scoggins Valleys	1.59	—	2.97	1.94-3.60	0.58	0.35-0.84	0.45	–0.17-0.72	16
Lower part, Scoggins Valley	2.43	0.98-2.97	2.80	2.63-3.33	0.39	0.11-0.59	0.38	–0.62-1.97	28
Spencer Formation, western Tualatin Valley (Al-Azzaby, 1980; surface samples)									
Upper part, lower member	—	—	3.72	2.71-4.59	1.91	1.29-2.59	0.74	0.62-0.88	9
Lower part, lower member	—	—	4.09	3.36-4.51	1.84	1.28-2.42	0.72	0.57-0.82	6
Stimson Mill beds (=upper member, this report)	—	—	4.16	3.45-5.46	2.30	1.81-2.74	0.69	0.65-0.74	4
Cowlitz Formation, upper Nehalem River basin									
Arkosic sandstone (surface samples, Van Atta, 1971)	—	—	3.15	2.50-3.70	1.24	0.73-1.99	0.52	0.28-0.74	7
Clark and Wilson sand, Texaco Clark and Wilson 6-1 well (core samples)	2.82	2.71-3.16	2.95	2.78-3.15	0.50	0.44-0.60	0.14	–0.16-0.38	5

Table 2. *Composition averages of sandstone of the Spencer and Cowlitz Formations, based on number of samples as indicated for each unit. Values in percent, except P/K ratio. Qm=monocrystalline quartz; Qp=polycrystalline quartz; F=feldspar; P/K=plagioclase/potash feldspar ratio; Lvm=lithic volcanic and metamorphic rock fragments; L=total lithic rock fragments*

Unit, location, number and type of samples	Qm	Qp	F	P/K	Lvm	L	Mica	Modal composition: QFL Q	F	L	Modal composition: QmPK Qm	P	K
Spencer Formation, lower member													
Upper part, Patton and Scoggins Valleys, 4 core samples	19.2	4.7	34.0	1.3	7.4	13.9	4.5	35	49	16	36	35	29
Lower part, Scoggins Dam, south abutment, 3 core samples	8.9	1.5	43.0	0.5	9.4	9.6	6.8	16	68	16	17	20	63
Spencer Formation, western Tualatin Valley (from Al-Azzaby, 1980)													
12 surface samples; equal to upper part, lower member, this report	30.4	5.6	56.2	1.6	6.4	6.5	4.5	36	56	8	35	40	25
6 surface samples; equal to lower part, lower member, this report	24.2	3.9	61.0	0.9	9.4	9.5	6.7	28	61	11	28	35	37
Cowlitz Formation, upper Nehalem River basin													
Texaco Clark and Wilson 6-1 well, 4 core samples	16.9	2.2	46.0	0.7	1.6	2.5	10.2	27	67	6	24	25	51
Cowlitz Formation, previous work													
Van Atta, 1971, 11 samples	40.0	2.3	38.2	1.1	2.0	8.1	8.2	46	44	10	51	26	23
Timmons, 1981, 6 samples	14.3	7.3	54.5	0.7	6.0	16.2	6.6	26	67	7	21	33	46
Jackson, 1983, 10 samples	26.6	1.7	41.2	1.3	2.8	4.9	9.3	38	55	7	39	34	27

croscopy (SEM). Percent porosity and permeability to air of five of these samples were determined by Core Labs, Inc., Dallas, Texas.

X-ray diffraction analysis of four samples (three from Spencer Formation, one from "Clark and Wilson sand") correlated clay mineralogy with the thin-section and SEM-petrographic studies.

A geologic map of the study area in the vicinity of Henry Hagg Lake, western Tualatin Valley, is given in Figure 2. Figure 3 presents a stratigraphic section of the Spencer Formation compiled from surface data and subsurface information taken from cores. The balance of this paper will concern itself with this region of study.

LITHOFACIES

Lower member

Texture: The rocks of the lower part of the lower member of the Spencer Formation are classified mostly as silty sandstone or sandstone (Folk, 1974). The upper part of the lower member includes silty and muddy sandstone with some interbedded mudstone and sandy siltstone (Figure 4). The upper part is sometimes pebbly with volcanic rock and quartzite clasts up to 12 mm in size. Both parts have angular mudstone clasts up to 6 mm in size.

Compared to the upper part of the lower member, the lower part is somewhat finer and has a narrow range in mean grain size, is well sorted (standard deviation), and is strongly skewed (Table 1 and Figure 5). Samples from the upper part show a much broader range of sorting and skewness, with one-third (nine) of the samples tested showing strong coarse (negative) skewness.

Table 3. *Comparison of lithology and trace fossils, upper and lower parts of the lower member, Spencer Formation*

	Lower part	Upper part
Primary structure		
Massive bedding (bioturbation)	Common	Present
Laminae	Present	Common
Indistinct laminae	Present	Present
Cross-laminae	Present	Present
Indistinct cross-laminae	Present	?
Ripple laminae	—	Present
Textural variants		
Pebbles	—	Common, basalt and mudstone
Mudstone clasts	Present	Present
Coarsening upward cycles	Common	Present
Fining upward cycles	Common	Common
Accessories		
Mica	Abundant	Abundant
Pumice	Common	—
Traces/fossils		
Bioturbation	Abundant	Common
Burrows	Common	Abundant
Mollusk shell		
Articulated	Present	Common
Disarticulated	Common	Abundant
Broken	Common	Very abundant
Wood fragments	Present	—
Plant debris	Abundant	—
Carbon	Common	Flood
Carbon partings	Common	Common

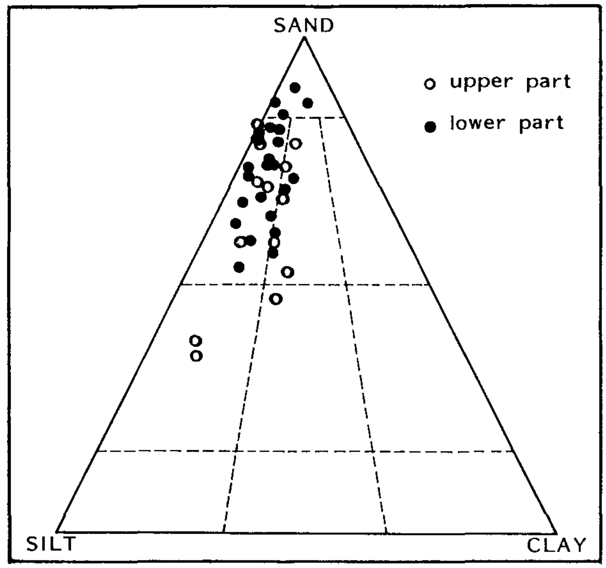


Figure 4. Sand-silt-clay ratio, Spencer Formation, lower member.

The textural size parameters of the "Clark and Wilson sand" in the upper Nehalem River basin are comparable to those of the lower member of the Spencer Formation in the western Tualatin Valley. Samples from cores of the Texaco Clark and Wilson 6–1 well were taken at 943–952 m depth, and samples from other test holes were taken from about 100 m lesser depth in the "Clark and Wilson sand" that may be comparable to the upper part of the lower member of the Spencer Formation (Table 1).

Plots of the coarsest 1 percent (C) vs. the median size (M) in millimeters (Figure 6), produced with the method of Passega (1957), show that values for the lower part of the lower member of the Spencer Formation (28 samples) are tightly grouped. The plots all fall in the turbidity current field. This would indicate rather uniform processes of sediment transport and deposition. However, other evidence of turbidity current deposition in the lower part of the lower member (e.g., Bouma sequences) is absent. It is more likely that simple tractive currents (contour currents?) account for the uniformity of CM values. Plots of C vs. M values for core samples of "Clark and Wilson sand" from the Texaco Clark and Wilson 6–1 well show this sandstone to be like the lower part of the lower member of the Spencer Formation (Figure 6).

In contrast, the upper part of the lower member of the Spencer Formation shows a coarser first percentile for most samples and a very wide deviation in plots of this versus the median size. Part of the plot falls in the field typical of beach processes (Passega, 1957).

Sedimentary features, lower part of lower member: The lower part of the lower member of the Spencer Formation in the Scoggins Valley section as exposed on the north side of Henry Hagg Lake (Figure 3) and in subsurface cores (Table 2) consists of about 25–30 m of massive to faintly laminated, fine- to very fine grained, medium-gray to greenish-gray, highly micaceous, carbonaceous lithic arkose to feldspathic litharenite. Very thin (1.2–2.5 cm) pumiceous beds with reverse grading of pumice suggest an air fall combined with waterlaid sedimentation. Most beds are massive. Both coarsening upward and fining upward sequences can be seen. The lower part of the lower member of the Spencer Formation in the western Tualatin Valley is lithologically quite similar to the Spencer Formation to the south in its type locality near Eugene.

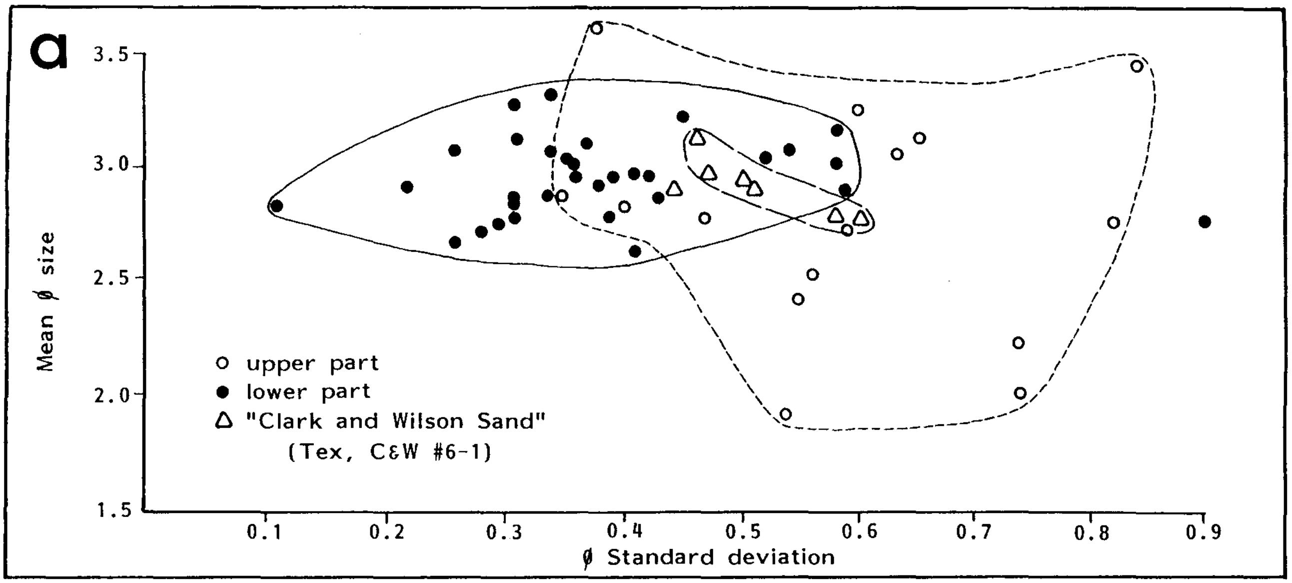
Carbonized wood and plant debris are common. Mollusks, chiefly pelecypods, are represented by infrequent whole valves and some articulated valves but mainly by common disarticulated and broken valves. This strongly suggests a transported association.

Primary structures observed are listed by unit in Table 3.

Sedimentary features, upper part of lower member: Cores taken in Scoggins Valley and in Patton Valley, immediately south of Scoggins Valley (Table 2) yielded samples of the upper part of the lower member. The rock consists of 0.5- to 9-m-thick beds of light-gray to medium-gray (weathers orangish to yellowish brown, especially where it is glauconitic) silty sandstone, pebbly sandstone, and sandy siltstone. In composition, it is a highly micaceous, carbonaceous, glauconitic lithic to feldspathic litharenite with angular to subangular grains. Laminae are composed almost entirely of biotite with minor muscovite.

Creamy gray arkose with high porosity and permeability composes a part of the section. This "clean" (< 5 percent clay) arkose appears only as two 0.3-m beds in cores in the Scoggins section, on the north side of Henry Hagg Lake, but thickens southward, with beds of 9 m thickness in cores in Patton Valley and beds of several tens of meters thickness in hills 0.8 km south of Patton Valley. The upper part of the lower member differs from the Spencer in the Corvallis area in that it includes these interbeds of "cleaner," highly feldspathic sandstone, very similar to the "Clark and Wilson sand" of the Mist area.

Primary structures seen in the upper part of the lower member (Table 3) include laminations and ripple cross-laminations. Massive, bioturbated beds are few. Tubular burrows (counter to bedding) are more common here than in the lower part, consisting of two distinct sizes (4–5 mm and 15–25 mm in diameter). They frequently exhibit well-preserved linings of mica, mud, and green clay (glauconite?).



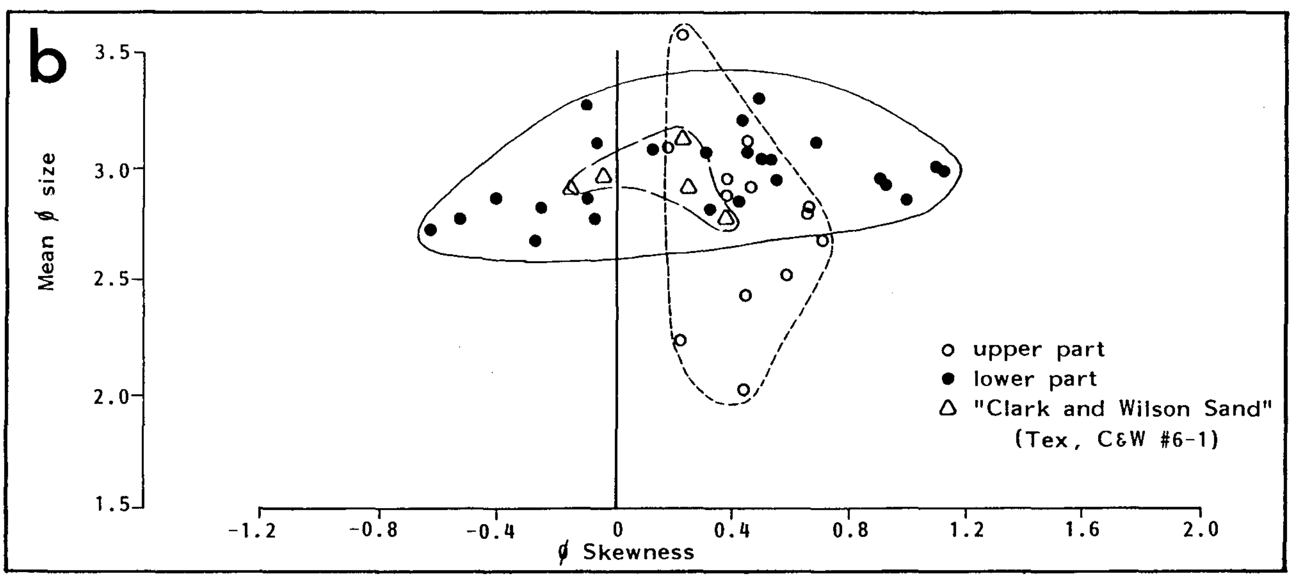


Figure 5. Texture comparison between the lower member of the Spencer Formation, and the "Clark and Wilson sand," of the Cowlitz Formation (Texaco Clark and Wilson 6-1 well), showing (a) mean phi (ϕ) size and phi standard deviation; (b) mean phi and phi skewness.

Table 4. *Permeability[1] and porosity[2] in selected samples, lower member, Spencer Formation, western Tualatin Valley, and Cowlitz Formation, upper Nehalem River basin, Oregon*

Unit, sample number, depth	Permeability (md)	Porosity (%)	Pores: Type[3]	Pores: Shape	Pores: Clay[4]	Size (μ)	Distribution	Sand-silt-clay ratio
Spencer Formation, lower member, upper part								
DH 105-0216, 32 m	—	17.6*	I(D)	Polygonal	—	30-150	Random	—
DH 105-0217, 33 m	—	0.1*	I, M (S)	Linear	—	2-3	Interlaminar (mica)	74-16-9
DH 105-0219, 50 m	167.0	26.3	I, M (D)	Polygonal	Clay in throat	1-3	Random	79-13-8
DH 103-0228, 30 m	1,500	28.8	I (D)	Polygonal	Little authigenic clay	50-100	Random, irregular	84-13-3
DH 103-0229, 42 m	0.6	23.3	—	—	—	—	—	84-9-7
DH 51-0285, 34 m	—	13.2*	I(M)	Polygonal, linear	Smectite closes pore throats	5-10	Random	72-18-1
DH 48-0287, 11 m	—	1.0*	M, F (I)	Linear	Clay bridges pores; throats closed	1-3	Random	—
Spencer Formation, lower member, lower part								
DH 6-0011, 4 m	—	8.0*	I	Linear	Smectite lining; pore throats closed	10-40	Random	73-19-8
DH 6-0016, 17 m	—	10.0	I	Linear	Smectite lining; pore throats closed	5-10	Random	66-22-12
DH 12-0020, 12 m	—	1.0	I, M (F)	Polygonal, linear	—	1-2	Random	45-53-4
DH 12-0022, 17 m	—	12.6*	I (D)	Polygonal, linear	Smectite partly closes pore throats	20-70	Random	82-14-4
Cowlitz Formation, Clark and Wilson sand								
Texaco Clark and Wilson 6-1, 0305	—	13.2*	I (F)	Polygonal, linear	Smectite lining; pore throats closed	10-30	Random	—

[1] Permeability to air; clean, dry core segments. Core Laboratories, Inc. Values in millidarcies (md).
[2] Porosity: Boyle's Law determination with helium. Core Laboratories, Inc. Values marked with * were determined in thin section.
[3] Pore types: I=intergranular; D=dissolution; M=microporosity; F=fractured; S=shrinkage.
[4] Clay determined by X-ray diffractometry.

Table 5. *Porosity and permeability of surface samples, Spencer Formation, according to Schlicker (1962)*

No.	Location	Permeability (md)	Porosity (percent)
1	SE corner sec. 20, T. 1 S., R. 4 W.	184	36
2	SE¼ sec. 32, T. 1 S., R. 4 W.	202	32.2
3	NE¼ sec. 16, T. 2 S., R. 4 W.	1,130	31.7
4	SE¼ sec. 30, T. 3 S., R. 4 W.	812	41.3
5	SW¼ NW¼ sec. 30, T. 3 S., R. 3 W.	736	1.2
6	NW¼ sec. 24, T. 3 S., R. 4 W.	1,850	41.1
7	NE¼ sec. 1, T. 3 S., R. 4 W.	2,200	40.7
8	NW¼ sec. 15, T. 2 S., R. 4 W.	4,510	41.5
9	NE¼ SE¼ sec. 32, T. 1 S., R 4 W.	3,510	32.9

Fossils include articulated and single valves and broken fragments of pelecypods. Rare gastropods are also found. Some mollusks, such as *Solen*, are found in living position. Pelecypods, including the genera *Volsella*, *Solen*, *Nuculana*, *Pitar*, *Spisula*, *Venericardia*, and *Acila* are more numerous than in the lower part. Some shell concentrations form coquinoid biostromes. The overall appearance is that of a transported association mixed with a few deeper water (at least subtidal) *in situ* forms.

Carbonized plant debris is common in both parts of the lower member but can make up 5–10 percent of some beds in the upper part, where wood fragments up to 40 cm in length may be found. *Toredo*-bored wood is also found in the upper part. Wood fragments and carbonized plant debris appears to be detrital.

According to Al-Azzaby (1980), thin (1-cm) layers of coal are very common in the upper part of the lower member of the Spencer Formation just south of Hagg Lake. It appears that this coal is detrital. A 30-cm-thick bed of coal is reported on the bank of a small creek (SW¼ sec. 36, T. 2 S., R. 4 W.) just off Woodland Loop Road, about 6.6 km east of Yamhill, Oregon. This was worked as a coal prospect until 1907 (Oregon Department of Geology and Mineral Industries, 1951). It is not known whether the coal is rooted or not, since it is not now possible to locate this coal bed.

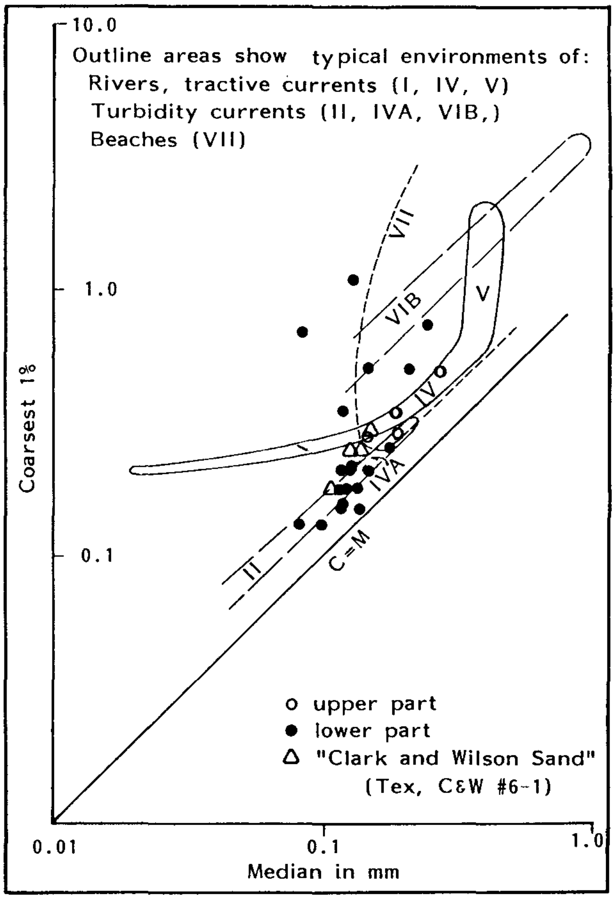


Figure 6. CM diagram of Spencer Formation, lower member, and "Clark and Wilson sand" (Texaco Clark and Wilson 6-1 well).

Clay mineralogy: The clay in the lower part of the lower member of the Spencer Formation includes mostly detrital smectite. A few percent, at most, is authigenic. Variable lesser percentages of kaolinite, chlorite, and mixed layer illite/smectite are also present; the chlorite appears to be mostly authigenic. In the upper part of the lower member, smectite makes up about 50 percent, kaolinite about 35 percent, and chlorite about 15 percent of the clay present. As in the lower part of the lower member, a few percent of smectite and chlorite appears to be authigenic, while the illite/smectite is mostly authigenic. According to Cunderla (1986), mixed layer illite/smectite is more abundant in the upper part of the lower member of the Spencer Formation. This is similar to the clay mineralogy of the Cowlitz Formation in the upper Nehalem River basin (Van Atta, 1971).

Samples of the "Clark and Wilson sand" analyzed for this study showed only smectite clay present.

Throughout the Spencer Formation, the clay minerals are mostly detrital. Scanning electron microscopy reveals that, when smectite and chlorite are present, a small amount is authigenic on grain surfaces in pore spaces (Figure 7a). Samples with a high porosity but low permeability have more authigenic clay, which reduces pore sizes and blocks pore throats.

Porosity and permeability: Porosity and permeability (P/P) in the Spencer Formation vary widely (Table 4). Values of 23.3 percent and 0.6 millidarcies (md) (Sample 0229, DH 103) and 28.8 percent and 1,500 md (Sample 0228, DH 103), measured in core taken in a drill hole in Patton Valley, are typical. The sand content of these two rocks differs by only 1 percent , but the sand in the more permeable rock is coarser, and there is only about half as much clay in it as in the less permeable rock. Table 4 compares measured values of porosity and permeability together with clay present, description of pores, and sand/silt/clay ratios for both the Spencer Formation and the "Clark and Wilson sand" in the Texaco Clark and Wilson 6–1 well.

The arkosic sandstone with the very high permeability (Sample 0228, Patton Valley, Table 4) is very similar to an arkosic sand that makes up most of the section (about 400 m) in Williams Canyon, about 2.5 km south of Patton Valley. It appears that this permeable sandstone thins and thickens (< 1 m to several tens of meters, at least) over a distance of about 16 km. The most probable interpretation would be that the permeable sandstone represents the filling of a major submarine channel. Since mud rocks of the overlying upper member of the Spencer Formation and underlying Yamhill Formation provide a good seal, such buildups of high-P/P sandstone in the Spencer could be excellent reservoirs.

However, scanning electron microscopy (Figure 7) shows that even a small amount of additional clay, some of which appears to be authigenic, is effective in reducing pore throat size to cause a much lower permeability. An arkosic sandstone (Sample 0219) from a test hole in the upper part of the lower member of the Spencer Formation in Patton Valley has a fair porosity (26.3 percent), but authigenic smectite has reduced pore throat size so that permeability is only 167 md (Table 4 and Figure 7b). Samples 0219 and 0228 have very similar sand/silt/clay ratios (79–13–8 and 84–13–3, respectively, Table 4) so that even a 5-percent difference in clay content is effective in drastically reducing permeability. Such differences in permeability in the Spencer sandstones appear to be the rule rather than the exception.

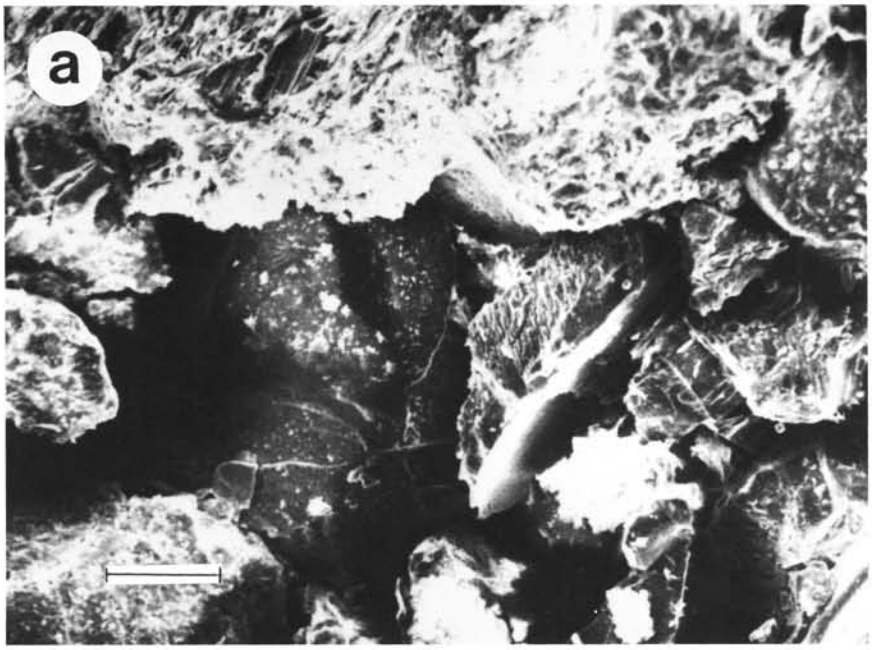
Schlicker (1962) reported highly variable values of permeability for nine surface outcrop samples of Spencer Formation sandstone, as shown in Table 5.

The friability of most surface outcrops of sandstone of the Spencer Formation makes it difficult to collect and transport undisturbed samples. Some of the extremely high porosity and permeability values reported by Schlicker could be due to the way in which samples were collected, although Schlicker (oral communication, 1987) did not believe that this was the cause of the variability. Weathering and partial removal of fines by ground water percolation could also account for some of the exceptionally high permeabilities.

Measurement of P/P in surface outcrops of Cowlitz Formation arkose in the upper Nehalem River basin, reported by Newton and Van Atta (1976), show a range of 30.9–36.2 percent and 31–823 md, respectively. Newton and Van Atta also reported porosity and permeability measurements of arkosic sandstone samples from the Texaco Clark and Wilson 6–1 well. These values show a wide variance (10–37.8 percent and 3–1,302 md).

In summary, arkosic sandstone in the lower member of the Spencer Formation usually has a high porosity (20–30 percent), and the permeability may range from very low to very high values, depending upon the amount of silt and detrital clay and/or the occurrence of authigenic clay, which may or may not plug pore throats. Most porosity is intergranular, with occasional fracture, shrinkage, and microporosity. Pores are usually polygonal in shape, but some are linear. The clay is generally smectite, although some detrital chlorite is present. Authigenic smectite clay most commonly lines pore spaces and reduces pore throat size so as to cause very low permeability.

Diagenesis: In the sandstones, some of the authigenic clay present was probably derived from volcanic rock fragments and plagioclase, which are present in the upper part of the lower member and in the upper member of the Spencer Formation (Table 2). Armentrout and Suek (1985) regard reservoir potential of upper Eocene feldspathic-quartzose sandstones of western Oregon and Washington to be dependent upon the presence or absence of volcanic rock fragments that might be diagenetically altered to pore-filling clay. It does not appear, however, that diagenetic clay forms a very large percentage



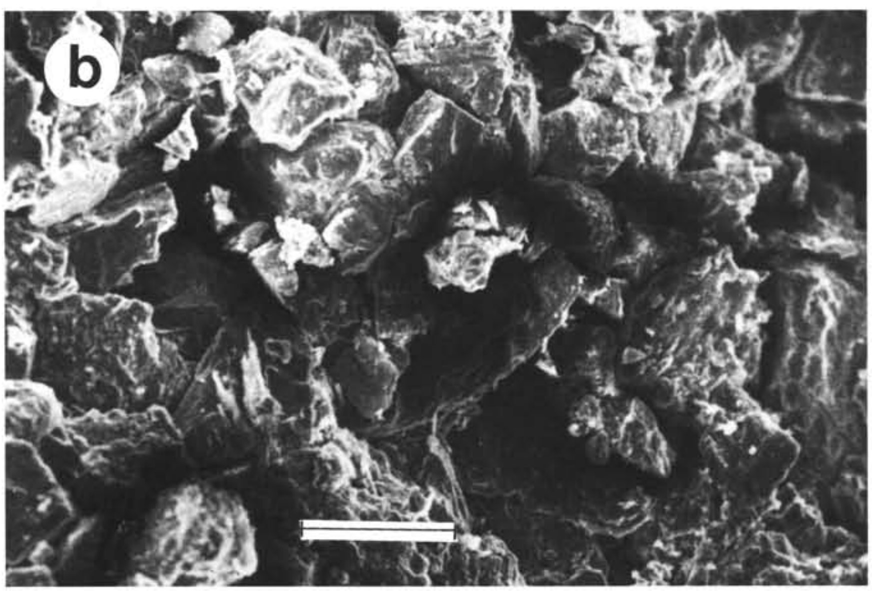


Figure 7. Scanning electron micrographs, Spencer Formation, upper part of lower member. Top (a), DH 103, sample 0228, 30-m depth, arkose, P/P values 28.8 percent / 1,500 md. Scale bar = 100 µm. Bottom (b), DH 105, sample 0219, 50-m depth, arkose, P/P values 26 percent / 167 md. Scale bar = 5 µm.

of the clay fraction of the Spencer Formation sandstone that is being described here, in the present study. The immature nature of carbon, revealed by vitrinite reflectance (0.22), is indicative of shallow burial, which tends to agree with the lesser amount of diagenetic clay in these rocks.

In a study of diagenesis of Spencer Formation sandstone, Cunderla (1986) showed that authigenic potassium feldspar occurring as overgrowths on detrital potassium feldspar and as euhedral crystals is common in the upper part of the lower member (equivalent to his "upper member"). Cunderla also found authigenic heulandite in one subsurface core sample. He stated that the chemical breakdown of plagioclase feldspar, hornblende, and pyroxene and the degradation of volcanic rock fragments led to the enrichment of pore waters in Ca^{++}, K^{+}, and Na^{+}, eventually allowing the precipitation of authigenic feldspar, heulandite, and some authigenic smectite. Water in wells penetrating the Spencer sandstone in the mid-Willamette Valley to the south of the western Tualatin Valley shows high concentrations of the ions listed above as well as several other ion species (Frank, 1974; Gonthier, 1983). Cunderla's SEM and energy dispersive spectrometry (EDS) study showed that authigenic chlorite is probably present because of degradation of biotite.

Contact: The contact between the lower and upper parts of the lower member of the Spencer Formation, as seen in surface outcrops and in cores, is both conformable and gradational. The lower member and the upper member intertongue, but locally the contact is gradational over an interval of about 3–5 m.

Upper member

The upper member of the Spencer Formation, as exposed from the Scoggins Dam eastward along the north side of Scoggins Valley, consists of 308–400 m of medium- to dark-gray micaceous, carbonaceous, feldspathic siltstone and mudstone with minor muddy sandstone and thin pebble conglomerate lenses. The siltstones and mudstones are medium to thickly bedded (0.1–1 m), display thin plane laminations (0.1–0.3 cm), and ripple cross-lamination. The beds are burrowed and are occasionally thoroughly bioturbated. Macrofossils, including *Acila decisa*, *Cochlodesma bainbridgensis*, and *Dentalia* sp., are present and locally may be common. Carbonized wood is locally abundant.

Al-Azzaby (1980) referred to these interbedded and overlying mud rocks, sandstone, and conglomerate as the "Stimson Mill beds" (informal). He considered them lithologically distinct and mappable in this area. It appears, however, because of the presence of identical, thick (0.1–1 m) interbeds of mudstone and siltstone in cores (DH 48 and DH 51, Scoggins Valley) in the upper part of the lower member of the Spencer Formation, that there is insufficient reason to warrant separation of the mudstone into another stratigraphic unit of formation rank.

Contact: The contact with the overlying Pittsburg Bluff Formation was not observed, occurring in a covered interval that probably masks a fault in the vicinity of the contact (Figure 2). The contact is probably unconformable, however, owing to the fact that the Keasey Formation (early Refugian) does not appear to be present in the western Tualatin Valley region, as it is in the upper Nehalem River basin, where it occurs between the Cowlitz and the Pittsburg Bluff Formation.

DISCUSSION

Depositional environment

We interpret from the borehole data (Figures 5 and 6; Tables 1 and 3) that the lower part of the lower member of the Spencer Formation was deposited in a mid- to outer-shelf environment, probably under fairly uniform conditions of sedimentation, such as would prevail under storm wave influence and contour current transport. This is based upon a narrow range in mean phi size and good sorting (Figure 5; Table 1).

In contrast to the lower part, the upper part of the lower member was deposited in a shallower, nearer shore environment in which a wider range of sedimentation processes prevailed. These include storm wave influence, long-shore transport, and proximity of shore and fluvial sedimentation. In this environment, a wider range of sizes of sediments might have been available from various sources, particularly coarse sediment. The presence of an abundance of carbonaceous material and coal (in certain sections) suggests a shallow inner-neritic depth to near-shore to nonmarine environment. Clean arkosic sand may have been deposited as offshore bars.

Kulm and others (1975) found that the mean size and standard deviation of the sand fraction of Holocene southern Oregon mid-shelf sediments are much more tightly grouped compared to the same size parameters of sediments deposited in shallower shelf environments. They also found that skewness of size distribution of mid-shelf sediments showed a much larger range of values than skewness on sediments inshore. The same relationships can be seen in plots of mean phi size vs. standard deviation and mean phi size vs. skewness (Figure 5) of sand-sized fractions from the lower and upper parts of the lower member of the Spencer Formation. This tends to support the conclusion that the lower part of the lower member of the Spencer Formation was deposited in a mid- to outer-shelf environment, while the upper part was deposited in an inner-shelf environment.

In addition to these petrographic indicators, the upper part of the lower member yields a diverse and common macrofauna dominated by pelecypods. Localized shell concentrations and widely distributed fragmental material, which forms several coquinoid layers, indicate reworking and a fairly high energy environment. Trace fossils include both probable upward escape burrows and dwelling burrows, some of which are lined with mica, mud, and sometimes glauconitic material. The fauna is indicative of a shallow but somewhat offshore environment, with water depths of inner neritic to inner tidal.

The upper member contains a macrofauna that, although poorly preserved, indicates a water depth of greater than 23 m. This is substantiated by the finer grained character of the sediment, chiefly siltstone and mudstone. Foraminiferal faunules from the upper member suggest deposition in marine waters of upper bathyal depth.

Most earlier interpretations of the depositional environment of the Spencer have placed it as paralic to inner sublittoral (Armentrout and others, 1983). Thin, low-grade coal is often present in the upper parts of some sections. Baker inferred in her study of sedimentary textures and structures (including detailed examination of hummocky cross-stratification), trace fossils, and body fossils that the lower, predominately sandy member of the Spencer Formation in the central area of its outcrop belt was deposited in inner shelf to littoral depths. The siltstone and mudstone of the upper member was found by Baker to have been deposited at mid- to upper-bathyal depths.

This regressive-transgressive nature of the stratigraphic sequence of the lower and upper members of the Spencer Formation in the western Tualatin Valley is similar to the regressive-transgressive sequence of the "Clark and Wilson sand" and the overlying mudstone of the Cowlitz Formation in the upper Nehalem River basin to the north (R.G. Deacon, personal communication, 1986).

Provenance

The sediments of the Spencer Formation probably originated in a proximal basaltic terrane (undissected magmatic arc) with influx of material fron a more distal plutonic and metamorphic terrane (continental block). The arkose of the upper part of the lower member is almost solely formed of continental block sediment (Figure 8). The sands of central and northern Oregon shelf and littoral environments today are very similar in composition, as the Columbia River (which originates in the northern Rocky Mountains) and streams draining the Oregon Coast Range have contributed most of the Holocene sediment (Cooper, 1958; Scheidegger and others, 1971).

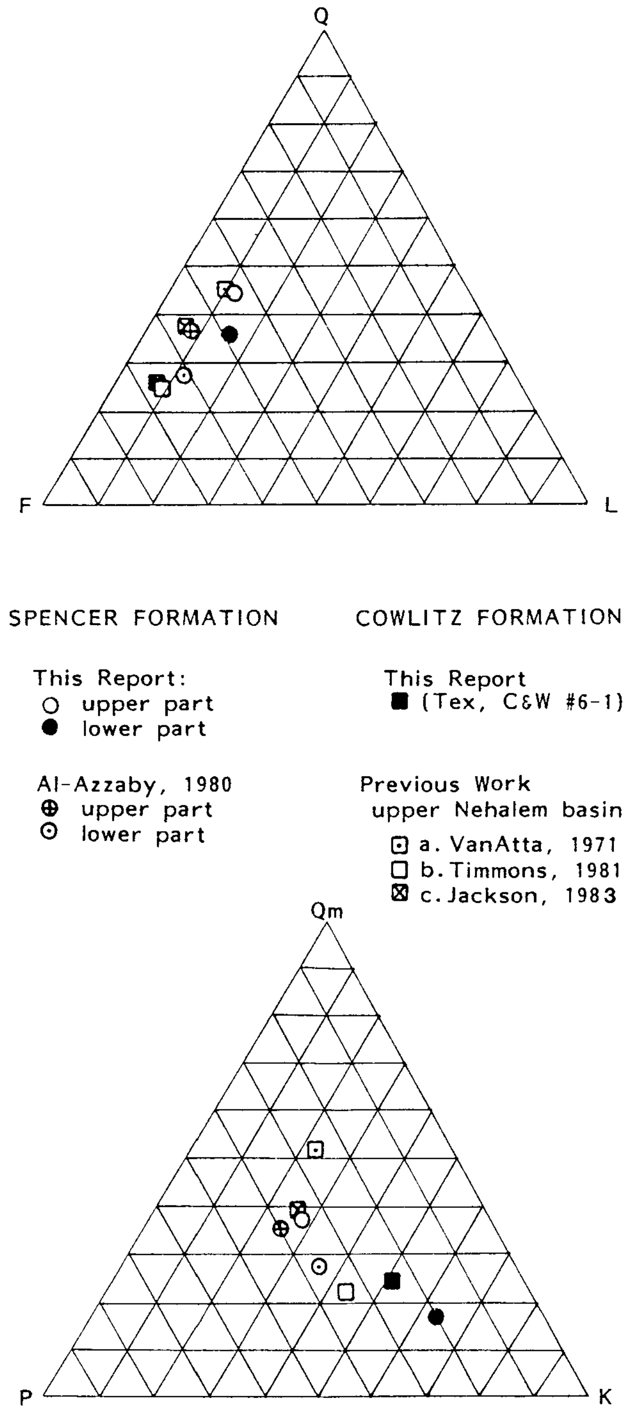


Figure 8. QFL and QmPK content, Spencer Formation, lower member sandstones.

The presence of a fair amount of quartz, good percentages (23–76) of potassium feldspar, and large amounts of mica require that a plutonic and metamorphic provenance contributed a significant amount of sediment. This is most pronounced in the upper part of the lower member of the Spencer Formation. There, thin beds of arkosic sandstone, much like the thicker "Clark and Wilson sand" in the upper Nehalem River basin, are also entirely of plutonic and metamorphic origin. Very little volcanic detritus is found in arkosic sandstone of the upper part of the lower member (Table 2).

During Narizian time, the ancestral northern Cascades of Washington and eastern Laramide plutons were the closest plutonic and metamorphic source areas that might have contributed the amount of quartz and potassium feldspar and large amounts of mica (Miller and Bradfish, 1980). The plutonic and metamorphic rocks of the Klamath Mountains to the south do not have enough potassium feldspar, nor are the metasediments and metavolcanics there rich enough in mica (Heller and Ryberg, 1983).

In the upper Nehalem River basin, eruptive centers (Goble Volcanics?) on the Narizian shelf seem to have been coeval with sedimentation in surrounding environments (Wilkinson and others, 1946; Armentrout and Suek, 1985). However, no volcanics are found intercalated with the Spencer Formation in the western Tualatin Valley borderlands area. Because of this, it is most likely that volcanic components were derived from a region lying close by, in southwestern Washington, where basalt is found intercalated with the Cowlitz Formation.

Clean arkosic sand that makes up from a few to as much as 400 m of the Spencer section in the central and northern Willamette Valley does not appear to be present in the Corvallis area (Cunderla, oral communication, 1987), although thin arkose beds are present in the area of Lorane, south of Eugene. This suggests that Spencer sands deposited in the central and northern area are related to a Narizian depocenter associated with a master stream system that would have originated in a plutonic and metamorphic terrane. Such a provenance likely would have been in the northern Rocky Mountains and/or the northern Cascade Mountains of Washington. The present-day Columbia River is just such a master stream (Whetten and others, 1969), and sands of the lower Columbia are noted as being much like Paleogene and Neogene lithic arkose sandstones of northwestern Oregon and southwestern Washington (Van Atta, 1971; Niem and Van Atta, 1973; Kadri and others, 1983).

The Spencer Formation in the western Tualatin Valley and the Cowlitz Formation in the upper Nehalem River basin appear to be equivalent in terms of age, lithofacies, and environment of deposition.

ACKNOWLEDGMENTS

We are indebted to David Taylor for assistance in field work, logging of core, measuring sections, and macropaleontology done in connection with the petrology of this study. Jon Bounds, C. Susan Evans, and Char Corkran also assisted in field and laboratory work and core description. Geologic maps and columnar sections were prepared by Ann Taylor and Chris Thoms. Chris Thoms drafted the graphic illustrations for this paper. Robert G. Deacon reviewed earlier drafts of the manuscript and gave helpful discussions and interpretations.

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Environmentally responsible aggregate mine operators honored at awards ceremony

Outstanding operators of six of the over 750 aggregate mines in Oregon were recognized on May 22, 1993, at the 1993 Annual Convention of the Oregon Concrete and Aggregate Producers Association (OCAPA) at the Inn of the Seventh Mountain in Bend.

The Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries (DOGAMI) annually presents awards to mines that employ outstanding environmental operational techniques or have accomplished exemplary reclamation. Nominees for the awards are solicited from a wide variety of sources, and an awards committee of representatives from industry, government, and environmental groups selects the winners.

This year's award plaques were presented to the winners by John D. Beaulieu, Deputy State Geologist, and Frank Schnitzer, Reclamationist, of DOGAMI.

Outstanding Reclamation Award — given for an operation that goes beyond rule requirements and has an innovative approach to reclamation. The award committee voted to give this year's award to two outstanding operators.

The first is Morse Brothers, Inc., Builders Supply of Corvallis, for reclamation of a gravel pit on a farm site, producing a 50-acre pond with an island that provide wildlife habitat, flood water storage capacity, artificial wetlands, and excellent fishing and future recreation potential for the residents of Corvallis and the surrounding areas. Part of the reclamation was voluntary because it occurred on land mined before 1972 that was exempt from reclamation requirements.

The second recipient is Cascade Pumice, a pumice mining operation at Laidlaw Butte near Tumalo. Cascade Pumice controls approximately 720 acres at this location. Of the 250 acres that have already been reclaimed, 120 acres were done voluntarily. Cascade Pumice restores mined land to approximate original contours. During 1992, an area of 60 acres was backfilled and topsoiled, and 90 acres were seeded. In a location that is surrounded by residences, Cascade Pumice waters mine areas daily during the dry season to support both seeding and dust-control, constructs visual berms to reduce impact on nearby residences, and has left a larger setback than required by law.

Outstanding Operator Award — given to operators who have done an outstanding job of mine development and/or daily operation, including preventing impacts on water quality or other natural resources, having no significant enforcement actions in the last ten years, going beyond rule requirements, using innovative techniques that improve quality of operation, and operating in such a way as to reduce reclamation liability.

This year's award was given to Cobb Rock, Inc., for the Beaverton Quarry on Cooper Mountain near Beaverton. Cobb Rock has maintained highwall benching during active mining and periods of inactivity, thereby improving slope stability, providing a safer work place for employees, and reducing reclamation requirements to a minimum. Cobb Rock has received safety awards on many levels, the latest being the Mine Safety and Health Administration's Certificate of Achievement for 1991—and will undoubtedly receive it again, because it had no lost time due to accidents or injuries in 1992.

Small Operator Reclamation Award — given for the same criteria as for Outstanding Operator Award, only for smaller scale operations. It was awarded this year to S-C Paving Company, a sand and gravel operation at the Burdick Pit on a dairy farm along the Trask River several miles east of Tillamook.

The current operator took over in 1985, facing the immediate task of removing an illegal solid waste landfill left by the previous operator. After the site was cleaned up, the original four acres were backfilled, and new topsoil was added. Four to five additional acres were put into operation, and a two-acre pond was created. Alders have been established, and part of the area may be used for fish rearing. When the mining is completed, the remainder of the site will be backfilled to original grade.

Good Neighbor Award — given for unselfishly working with neighbors and the community in a spirit of cooperation to reflect a positive image of the mining industry. The awards committee chose to present this award again to two operators.

The first winner, Morse Brothers Builder's Supply gravel operation near Corvallis, received the Award because, in addition to award-winning reclamation activities, the company helps neighboring farmers by sharing equipment with them—the action of a truly good neighbor.

The second awardee is the Johnson Construction Co. Crusher Quarry of Seaside. The company voluntarily provides public access to the Necanicum River in an area of high use by maintaining a boat ramp. The company also participates in the Salmon and Trout Enhancement Program for the benefit of sport anglers and the local community and cooperates with local fisheries biologists to develop land use practices that protect aquatic resources.

Agency Award — given separately because reclamation is often underwritten as part of an associated highway construction project, and government sites are exempt from bonding requirements.

The award was given this year to the Oregon State Highway Division, Region 4, at Annie Creek in Klamath County, where an abandoned gravel pit with dangerously steep walls was turned into a snow play area, while at the same time it was producing fill for a nearby road construction project—in the middle of a summer camping and winter ski area. □

Recipients of the 1993 reclamation awards

Outstanding Reclamation Award
Morse Brothers, Inc., Builder's Supply, Corvallis
Cascade Pumice, Laidlaw Butte, Tumalo

Outstanding Operator Award
Cobb Rock, Inc., Beaverton Quarry, Beaverton

Small Operator Reclamation Award
S-C Paving Co., Burdick Pit, Tillamook

Good Neighbor Award
Morse Brothers, Inc., Builders Supply, Corvallis
Johnson Construction Co., Crusher Quarry, Seaside

Agency Award
Oregon State Highway Division, Region 4, Annie Creek, Klamath County

Glaciation in the central Coast Range of Oregon

by Ewart M. Baldwin, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403

INTRODUCTION

Glacial cirques are present along the northern edges of several of the prominent, sill-capped peaks in the central Coast Range of Oregon (Figure 1). These were first observed by the writer when he was mapping in the Dallas and Valsetz quadrangles[1] (Baldwin, 1947). In 1945, a disastrous forest fire had swept northward from the Valsetz area, denuding most of the upper Boulder Creek and Laurel Mountain area. Salvage logging had removed many of the remaining blackened trees, so that the area was quite bare and cirques were easy to see. Today, the area is covered by a young forest, which, while it is favorable for the economic future of Oregon, hides much of the geologic evidence. Later mapping in the Spirit Mountain (now Grand Ronde) quadrangle (Baldwin and Roberts, 1952) revealed evidence of glaciation on the north edge of Saddleback Mountain in the extreme south end of the quadrangle. Saddleback Mountain extends across the Salmon River into the southeastern corner of the Hebo quadrangle.

The glacial cirques are nearly all carved in late Oligocene-early Miocene sills, although some of them may have been eroded to the middle Eocene sedimentary rocks below. Stream flow at the extreme headwaters of the streams is not sufficient to excavate the rounded cirques, nor is there the V-shaped valley that running water would produce. Some ponds and small lakes may be the result of landsliding, but the cirques under discussion are in solid intrusive granophyric gabbro seldom given to sliding. If a block did slide, the debris should contain largely blocks of the gabbro, whereas debris down slope differs in size and distribution of rock types. It is true that boulders of gabbro a foot or two in diameter are common at the base of the steeper slopes, but these likely were pushed or carried by ice to a lower level. Gravity might cause some of these boulders to float, even if there were no glaciation, but such boulders make up a small part of the unconsolidated debris down slope.

Marys Peak is 4,097 ft in altitude, the highest peak in the Coast Range. Laurel Mountain is more than 3,700 ft high, and Mount Hebo reaches 3,153 ft. None of these altitudes compare with the general level of glaciation in the Cascade Range to the east. However, during the Wisconsin stage of the Pleistocene glaciation, Puget Sound was filled with a thick sheet of ice as far south as Tenino near Olympia, and alpine glaciation was widespread in the Olympic Peninsula and in the Cascade Range of Washington and Oregon. There should have been a regional chill affecting other parts of the Northwest such as the Coast Range of Oregon. Maximum glaciation brought lowering of the sea by as much as 400 ft, and since altitude is calculated from sea level, all the peaks were 400 ft higher during maximum cooling, which might help in explaining the presence of glaciers.

The Oregon Coast Range is an area of great precipitation. Valsetz, when it existed as a weather station, frequently recorded 120-150 in. of precipitation per year. When the writer was working in the area, frequent winter snow storms would bring several feet of snow, only to be followed by warmer rain sweeping in off the ocean, melting much of the snow, and causing floods. This might be repeated a time or two during a winter. Snow even now accumulates on the northern edges of the peaks and lasts into June. If a regional chill caused the greater part of the precipitation to fall as snow, it could and probably would accumulate in great enough depth to last throughout the year and gradually accumulate as glacial ice. The precipitation is more than adequate if climatic conditions favored the buildup of ice. The cirques are on the north-northeastern edges of the peaks where the ice would be shielded from much of the sun's heat. It is possible that unusual periods of cloudiness also helped to protect the buildup of ice.

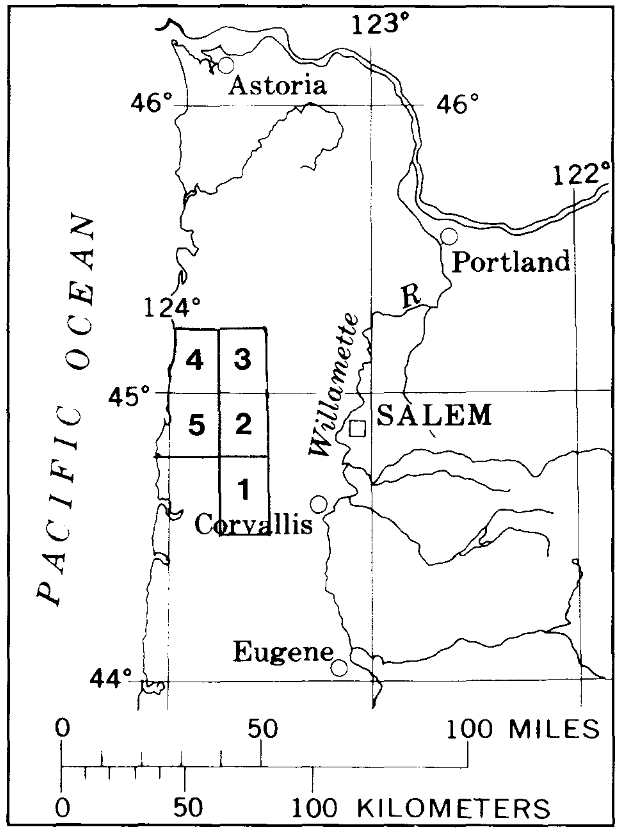

Figure 1. Northwestern Oregon map showing location of areas discussed in text. Numbers identify quadrangles: 1 = Marys Peak; 2 = Valsetz; 3 = Grand Ronde; 4 = Hebo; 5 = Euchre Mountain.

MARYS PEAK

Marys Peak (Figure 2) is the highest peak in the Coast Range and should have some of the better developed glacial features. Two small basins on the northeastern edge are shaped like cirques. The heads of several of the more northerly flowing streams are not well rounded, yet snow and ice should have accumulated. Owing to the steep gradient, the ice may have slipped down the steep slope only to melt at the base. The quadrangle was mapped by Baldwin (1955), who mapped three areas of unconsolidated material on the lower slopes and suggested that they were landslides. However,

[1] *Unless specified, quadrangle names mentioned in this paper refer to 15-minute quadrangles. For easier reference to current map indexes, the following lists the 7½-minute quadrangles into which the 15-minute quadrangles have been divided. Beginning at the northwest corner, clockwise:*
Euchre Mountain: Devils Lake, Stott Mountain, Euchre Mountain, Mowrey Landing.
Grand Ronde: Niagara Creek, Springer Mountain, Grand Ronde, Midway.
Hebo: Nestucca Bay, Hebo, Dolph, Neskowin.
Marys Peak: Nortons, Summit, Marys Peak, Harlan.
Valsetz: Warnicke Creek, Laurel Mountain, Fanno Ridge, Valsetz. —*ed.*

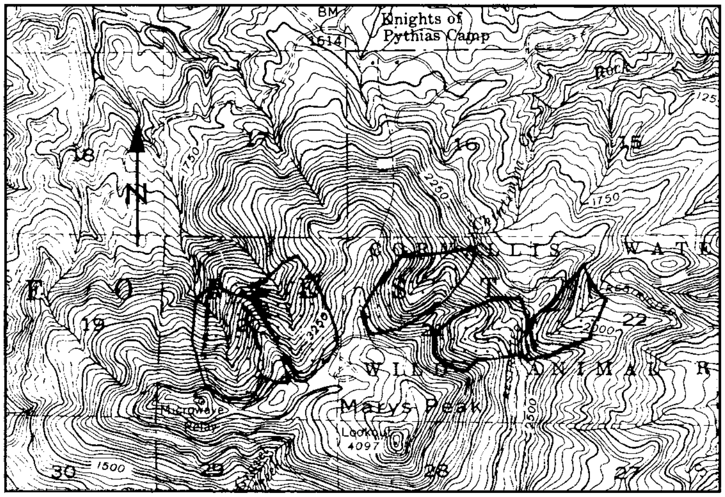

Figure 2. Cirques (outlined) in SE corner of the Marys Peak quadrangle.

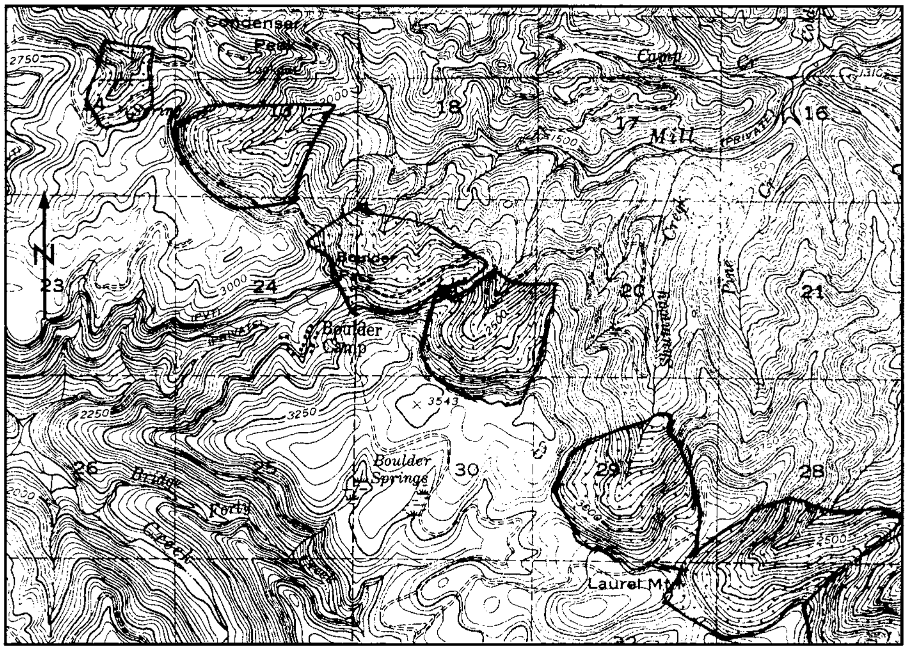

Figure 3. Cirques (outlined) in north-central part of the Valsetz quadrangle.

blocks of sill that would have resulted when pieces of the rim broke off were not present. Scattered rounded boulders were present throughout the material. Sills in the Coast Range are quite stable, and at no place in the study area could the rounded heads of streams be attributed to sliding of sizable masses of gabbro. The writer now has assigned the unconsolidated material to glacial delivery and not to landslides.

LAUREL MOUNTAIN

Laurel Mountain is in the northern part of the Valsetz quadrangle (Figure 3). It is the slightly upturned edge of a large sill that extends southward to Fanno Ridge overlooking Valsetz and westward from the vicinity of Riley Peak into the Euchre Mountain quadrangle. In many places, the sill is 400 or 500 ft thick but even thicker at Fanno Ridge. The area is accessible by private road that extends westward from Black Rock on the Little Luckiamute River and utilizes an abandoned railroad grade past Riley Peak to Boulder Camp, an abandoned logging camp. A road continues through Boulder Pass and on down Mill Creek to Buell in the broad Yamhill River valley.

One of the best developed cirques lies east of Boulder Camp, in the SE¼ sec. 19, R. 7 W., T. 7 S. This is the only cirque where some relatively well-developed lateral moraines were seen. The road down Mill Creek cuts through the lower end of one of the lateral moraines at about one mile from Boulder Pass. The moraine on the northwestern edge of the cirque is better developed. The presence of lateral moraines points to the movement of glacial ice. Since the cirque basins are short, seldom reaching half a mile in length, the ice should have been pushed over the edge, tumbled down the steeper parts of the stream gradient, and melted at the foot of the slope. One would expect to find glacial morainal material at the lower levels. Although boulders of gabbro a foot or two in diameter are common, appreciable morainal material at the lower levels is present only on the lower slopes of Marys Peak.

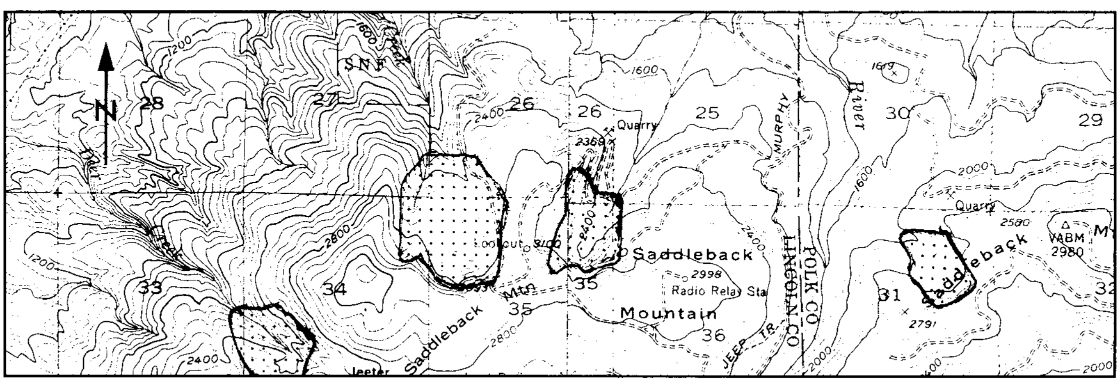

Figure 4. Cirques (outlined) in southernmost part of the Grand Ronde and Hebo quadrangles.

Figure 5. Cirques (outlined) at Mount Hebo in the northern part of the Hebo and Grand Ronde quadrangles.

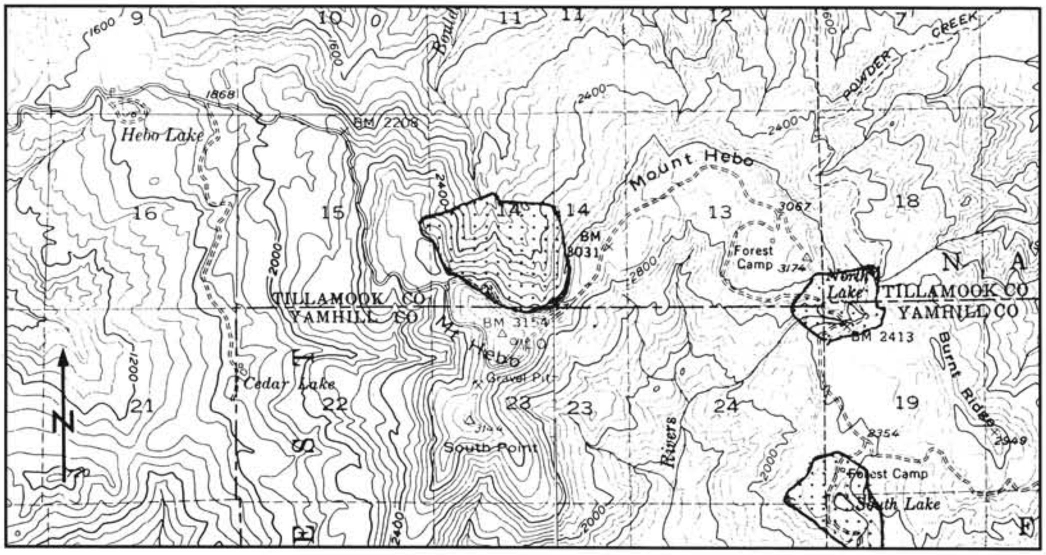

Figure 6. Air photo of North Lake, Grand Ronde quadrangle Photo by William Eaton.

SADDLEBACK MOUNTAIN

Saddleback Mountain is in the southernmost part of the Grand Ronde (formerly Spirit Mountain) quadrangle (Figure 4), which was mapped by Baldwin and Roberts (1952). The sill continues westward across the headwaters of the Salmon River into the southeast corner of the Hebo 15-minute quadrangle, which was mapped by Snavely and Vokes (1949). The Dolph 7½-minute quadrangle, which covers the southeastern quarter of the Hebo 15-minute quadrangle, has been mapped by Snavely and others (1991). Several cirques are present along the northern edge of this intrusive body, but one of the most evident is in the southeast corner of the Hebo quadrangle. A circular basin is carved in the sill, and hummocky material extends northward. It contains several ponds and marshes. The writer does not consider this a landslide, for, as noted, the sills are rather stable areas and the hummocky topography below appears to be glacial in origin. Many large blocks of sill that would result from sliding are not present in the material below the rim.

MOUNT HEBO

Mount Hebo is in both the Hebo and Grand Ronde 15-minute quadrangles (Figure 5). The mountain is capped by a gabbro sill. The northern side drops off steeply toward the Nestucca River valley. The head of Boulder Creek has a basin that was probably occupied by ice and may have been largely shaped by ice. To the east, several small basins are present at the head of tributaries of Powder Creek and may be in part shaped by ice.

There are several lakes on Mount Hebo. North Lake (Figure 6) and South Lake in the Grand Ronde quadrangle appear to be excavated in solid sill and appear to be of glacial origin. South Lake is longer than it is wide and appears to be dammed by glacial material. Both North and South Lakes occupy positions sheltered from the sun, where snow could accumulate.

On the southwestern side of Mount Hebo, below the sill, are two lakes, Hebo and Cedar Lakes. Neither of these seem to be in ice-sculptured sill material, and they could be landslide lakes. Both lakes are on the sunny side of the mountain and would get what warmth the sun could give. Unless there was unusual buildup of snow or unusual cloudiness, it is difficult to make a case for a solely glacial origin of Hebo or Cedar Lakes.

CONCLUSION

Small glaciers must have been present in the central part of the Oregon Coast Range during stages of late Pleistocene glaciation. The size and distribution may be debatable. This discussion does not exhaust the study of possible glaciation, and it is hoped that further attention will be given to this interesting subject.

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The Chemult, Oregon, fireball of July 1992

by Richard N. Pugh, Science Chair, Cleveland High School, Portland, Oregon, and Scott McAfee, Student Research Assistant, Governor's Office of Emergency Services, Bay Area Regional Earthquake Preparedness Project, State of California

The last major fireball of 1992 over Oregon (see cover photo) occurred on July 27 at 1:07 a.m. PDT (8:07 GMT). A report on it has been published in the *Bulletin of the Global Volcanism Network*, v. 17, no. 9 (September 30, 1992), p. 18.

The fireball was reported by 20 observers. The area in which it was observed extended northeast to Umatilla, south to Klamath Falls, and west to the Rogue River. The object entered the atmosphere over the Fort Rock basin, Lake County, with the end point of its trajectory near Chemult in Klamath County. Most people saw the fireball coming down at a very steep angle.

The duration of the fireball was up to seven seconds. It was brighter than a full moon, lighting up an area of 2,500 km^2 like bright daylight. Its apparent size was two to four times the diameter of a full moon, and its shape was round. Reported colors ranged from blue-green-white to yellow-red-orange. Most observers reported a long blue-green-white tail. Many reported "sparks," and several reported flaring of the fireball. However, there were no reports of fragmentation.

A 10-second sonic boom was heard at Willamette Pass (40 km northwest of Chemult) and Crater Lake (40 km southwest of Chemult). A short, heavy sonic boom was heard 45 km northwest of Paisley, Lake County. These reports of sonic booms indicate that meteorites were produced. However, the low number of observers, the remoteness of the probable fall area, and the nature of the terrain make the chances of recovery very slim.

Everyone in the area of Lake and Klamath Counties who saw or heard this event, should contact Dick Pugh, Cleveland High School, 3400 SE 26th Avenue, Portland, OR 97202, phone (503) 280-5120. □

Jerry Gray retires from DOGAMI

Jerry J. Gray retired from the Oregon Department of Geology and Mineral Industries (DOGAMI) on June 30, 1993. A native of Hesperia, Michigan, and graduate of Michigan State University, Gray joined DOGAMI as an independent contractor in 1972 to establish the Mined Land Reclamation Program. He became a permanent staff member in 1974. After working with the Mined Land Reclamation Program until 1976, he continued as an economic mining geologist, with emphasis on conducting and supervising studies related to economic and statistical mineral economics, mineral statistics, mining methods, mining law, and prospecting.

Jerry J. Gray

Prior to working with DOGAMI, Gray was employed by the U.S. Bureau of Mines in Albany, Oregon, and Anaconda Company in Butte, Montana. He also served in the U.S. Army, working as a geologist in the Geochemical Section of the Signal Corps Engineering Laboratories at Fort Monmouth, New Jersey.

During his years with DOGAMI, Gray wrote numerous articles and field trip guides on mining and mineral resources for the *Ore Bin* and *Oregon Geology*. He also conducted a variety of studies related to economic geology and authored many reports including those on mineral and/or rock resources in Coos, Curry, Umatilla, Benton, Polk, Marion, Yamhill, Linn, Clackamas, Columbia, Multnomah, and Washington Counties. He conducted a study of the geology and mineral resources of 18 Wilderness Study Areas in Harney and Malheur Counties that identified several previously unrecognized areas with gold potential. He was senior author of papers on the mineral potential of the Fall Creek mining district, bench testing of silica sand, and the mineral assessment of the southwest quarter of the Stephenson Mountain 30- by 60-minute quadrangle. He was senior author of the mineral resources map of offshore Oregon and coauthor of the geologic map of offshore Oregon and a bibliography of offshore Oregon. He also authored a Special Paper on bentonite in Oregon.

In recent years, Gray prepared and later updated a computerized data base of mineral information for Oregon by county (MILOC), which contains location, commodity, and other data for an estimated 7,899 mineral occurrences, prospects, and mines. The entries are located with latitude, longitude, and UTM coordinates, so that the data base can be used with geographic information systems. This data base was originally released as Open-File Report O-92-2 and will be released in late summer in updated form as Open-File Report O-93-8.

Jerry has become widely known to industry geologists, amateur rock hounds, and recreational gold miners for his wealth of knowledge about the mineral resources of Oregon. In his retirement he plans to continue to explore the mineral resources of Oregon and be active with the mining groups he has worked with over the years. He and his wife Cecelia also plan to travel. □

Oregon State Geologist to head Association of American State Geologists

Donald A. Hull, State Geologist for Oregon and Director of the Oregon Department of Geology and Mineral Industries since 1979, will become President of the Association of American State Geologists (AASG) on June 30, 1993. He will succeed Morris Leighton, State Geologist of Illinois.

According to Dr. Hull, "This year, AASG activities will emphasize implementation of the National Geologic Mapping Act and continued cooperative relations with Federal agencies." His term lasts for one year.

AASG was organized in 1908. Its members represent the state geologic surveys in all 50 states and Puerto Rico. AASG members meet annually to exchange information, discuss issues of common interest, develop new initiatives, and consider other topics related to state geologic survey operation and budgets. The leaders meet in Washington, D.C., to confer with officials of Federal agencies, members of Congress, and staff members of Congressional committees who have responsibility for matters relating to geology, energy and mineral resources, natural hazards, and the environment.

Although responsibilities of various state geological surveys differ from state to state, depending on the enabling legislation and traditions under which each survey developed, almost all state surveys function as a basic geologic information source for the public and for their state government's executive, legislative, and judicial branches. Some surveys, including Oregon's, also have regulatory responsibilities for oil, gas, and geothermal exploration and development, and land reclamation during and after mining. They also prepare geologic maps showing distribution of rock formations, specialized maps that are useful to environmental management such as those pointing out areas of potential hazards, or mineral resource maps identifying locations of potentially economic industrial or metallic mineral deposits. State surveys, including Oregon, also maintain repositories of subsurface rock cores and samples. □

DOGAMI geologic-geochemical laboratory closes

Because of curtailment of funds, the Oregon Legislature directed the Oregon Department of Geology and Mineral Industries (DOGAMI) geologic-geochemical laboratory to close its doors on June 30, 1993. Also lost to DOGAMI and the citizens of Oregon were the skilled services of its two geochemists, Gary Baxter and Charles "Chuck" Radasch.

Baxter came to DOGAMI in 1973 after working with Hyster Company of Portland as a materials engineer and after working with Aerojet-General Corporation of Sacramento, California, as a laboratory technician. During Baxter's years with DOGAMI, the laboratory broadened its focus from being an assaying facility for metallic-mineral ores to handling systematic physical testing of samples for evaluation of the quality of industrial mineral deposits and providing needed support to DOGAMI geologic mapping projects.

Radasch joined DOGAMI in 1987 after working as a technician and chemist for Teledyne Wah Chang, Albany, and as a research technician for Battelle Northwest Laboratories, Richland, Washington. During his tenure with DOGAMI, Radasch also helped with many other projects, including organization and maintenance of the sample collection. □

Wampler joins DOGAMI's MLR staff

The Mined Land Reclamation (MLR) Program of the Oregon Department of Geology and Mineral Industries (DOGAMI) has increased its staff by the addition of Peter Wampler, who has joined the program as an environmental specialist.

Wampler is currently a student at Oregon State University, where he is completing a Master of Science degree in geology. His studies also include a minor in geography, concentrating on geographic information systems. He received a Bachelor of Science degree in geology from Western Washington University in 1987. His thesis

(Continued on next page)

CORRECTION

FOR *OREGON GEOLOGY*, VOLUME 55, NUMBER 3

A very unfortunate error occurred on pages 63 and 64 of the May 1993 issue, in the article "Geology near Blue Lake County Park, eastern Multnomah County, Oregon," by James N. Bet and Malia L. Rosner: The Figures 6 and 7 were inadvertently switched, so that page 63 shows Figure 7 (without a caption), and page 64 shows Figure 6 with the caption for Figure 7.

We deeply regret this mishap and hope to correct the situation at least somewhat with this notice and the following instructions:

Please use the reprinted captions below for your copy of *Oregon Geology*: Cut them along the lines around the text and affix the caption for Figure 7 below the photo at the bottom of page 63 and the caption for Figure 6 in such a way that it covers the caption that says "Figure 7" under the photo at the top of page 64.

Figure 6. Closeup of Pleistocene gravel unit 2 exposed during construction activities along NE Sandy Boulevard (see Figure 2 for location). Matrix-supported clasts are typical of the unit within the study area.

Figure 7. Unconformable contacts exposed during construction activities along NE Sandy Boulevard (see Figure 2 for location). Lower contact is the angular unconformity between Pleistocene gravel unit 2 and the underlying Troutdale Formation. Unit designations are the same as in Figure 5.

work is the culmination of several summers of mapping the geology and alteration surrounding the Zortman Mine in east-central Montana.

Prior to graduate school, Wampler worked as an exploration geologist in Nevada, Idaho, and Montana. In Nevada, he was involved in grass-roots exploration for sediment-hosted gold deposits, and in Salmon, Idaho, he performed mapping and drill-core logging to evaluate an advanced gold prospect along the west flanks of the Beaverhead Mountains.

Wampler was born near Richland, Washington, and spent the greater part of his early life in Bellevue, Washington. He lived in Italy for one year while his father worked for the U.S. Army Corps of Engineers in Saudi Arabia. He is an avid mineral collector and enjoys hiking, fishing, gold panning, gardening, and just about any other activity that takes place outdoors. □

BLM offers new version of *Archaeology of Oregon*

Until recently, archaeological finds on the Oregon coast showed only 3,000 years of human inhabitation. An archaeological project in the 1980s at Lake Tahkenitch unearthed evidence of an 8,000-year-old campsite. These finds and several more dramatic discoveries are included in the latest version of *Archaeology of Oregon*, a book that was first published in 1984 and whose latest edition went out of print in 1992.

Archaeology of Oregon, third revised edition, 1993, was written by C. Melvin Aikens, professor at the University of Oregon, and published by the U.S. Bureau of Land Management (BLM), Oregon State Office. It provides a complete overview of the prehistory of Oregon and incorporates the latest findings of archaeological importance in Oregon—some of them published here for the first time.

An introductory chapter explains what archaeology is about in general and what its study objects are in the Pacific Northwest; a concluding chapter places the Oregon scene in perspective in the North-American context. Between them, five chapters treat the archaeological record of the original Oregonians according to five regions of Oregon that remind (not surprisingly) of the geomorphic divisions of the state.

The book describes tools and prehistoric weapons used by Native Americans of the Oregon country and shows how individuals and groups adapted to the various environments.

The 302-page, richly illustrated book, whose plasticized cover will stand some field-trip use, is both an introduction and a reference tool. It is a bargain for $9.50 at The Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries in the State Office Building in Portland (see page 96 for address and other ordering information). —*From BLM news release*

GSA annual meeting offers education

In conjunction with its annual meeting, October 25-28, 11993, in Boston, the Geological Society of America (GSA) offers twelve continuing education courses, which are held immediately before or after the annual meeting. Participation in these does not require registration for the annual meeting. The following list is restricted to titles, dates, and enrollment limits of the classes:

1. GIS and the geosciences. October 23; 100.
2. Urban geology: Foundation for inner city health. October 23; 25.
3. Asia: A continent built and assembled over the past 500 million years. October 23-24; 50.
4. Contaminant hydrogeology: Practical monitoring, protection, and cleanup. October 23-24; 40.
5. Fracture mechanics of rock. October 23-24; 50.
6. Alternative pedagogies in geological sciences: A workshop. October 24; 40.
7. Application of sedimentological information to hydrogeological problems. October 24, 50.
8. Computer mapping at your desk that really works. October 24; 30.
9. Environmental/engineering geology and land-use planning, an interface between science and regulations. October 24; 50.
10. Geochemistry and stable isotopes of paleosols. October 24; 50.
11. Isotope hydrology. October 24; 50.
12. Fractals and their use in earth sciences. October 29-30; 50.

The address for further information is GSA Annual Meeting, P.O. Box 9140, Boulder, CO 80301-9140. Deadline for preregistration to the meeting is September 24. —*GSA news release*

USBM has state mineral summaries now available by fax

The U.S. Bureau of Mines (USBM) now offers information through an easy-to-use automated fax response system. The MINES FaxBack service allows callers to retrieve information and order publications for immediate delivery to their fax machines. MINES FaxBack works from any Group III-compatible fax machine that is equipped with a touch-tone telephone (either a built-in handset with touch-tone capability or a separate touch-tone telephone plugged into the fax machine's phone jack). After calling MINES FaxBack, the requester is guided by a series of voice messages that assist the caller in ordering the desired documents. The caller pays for the phone call that also includes the time needed to deliver the requested document to the caller's fax machine.

The first-time caller who is not familiar with the MINES FaxBack system is instructed to listen to a short description of the system and then is advised to try the system by requesting the MINES FaxBack catalog. The main catalog lists the catalogs arranged by mineral commodities for which there are publications on the MINES FaxBack for distribution to the caller's fax machine.

The state mineral summary for Oregon is Document 984193 and consists of four pages. The procedure is summarized in the following directions:

1. Use the touch-tone handset attached to your fax machine or connect a touch-tone telephone to the fax machine's telephone jack. 2. Dial (412) 892-4088.

3. Listen to the menu options and punch in the number of your selection, using the touch-tone telephone.

4. After completing your selection, press the start button on your fax machine. —*USBM news release*

Dear *Oregon Geology* subscriber,

The Oregon Department of Geology and Mineral Industries is conducting a survey of its readers. We want to know more about them and what they want from *Oregon Geology* as we make decisions about how to serve them best in the future. Please check the most appropriate responses in this survey, and do not put your name on the survey. Return it to **Publications Manager, Oregon Department of Geology and Mineral Industries, Ste. 965, 800 NE Oregon St. #28, Portland, OR 97232**, as soon as possible. We'll publish the results in an upcoming issue of *Oregon Geology*. Please use one survey form per respondent.

Thank you for your help and interest.

1. What is your gender? Check one category.

female___ male___

2. What is your age? Check one category.

under 18___
18-34___
35-45___
46-64___
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3. What is the highest level of education you have achieved? Check one category.

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4. What is your occupation? Check **all** categories that apply.

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educator___
government employee___
natural resource agency employee___
legislator___
planner___
politician___
work in forestry industry ___
work in health care field___
scientist___
own a business___
work in tourism industry___
work in sales___
work in computers or software___
farmer___
prospector or explorationist___
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7. Why do you subscribe to *Oregon Geology*? Check **all** categories that apply.

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good idea___ doesn't matter to me___ bad idea___

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17. Additional brief comments related to *Oregon Geology*:

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Again, thank you for your help!

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Mist Gas Field Map, showing well locations, revised 1992 (Open-File Report O-92-1, ozalid print, incl. production data)	8.00	
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OREGON GEOLOGY

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VOLUME 55, NUMBER 5 SEPTEMBER 1993

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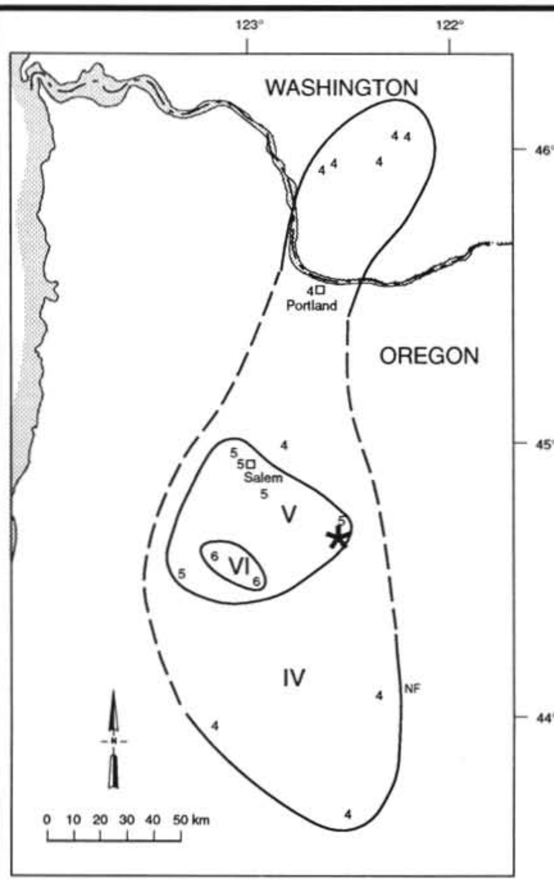

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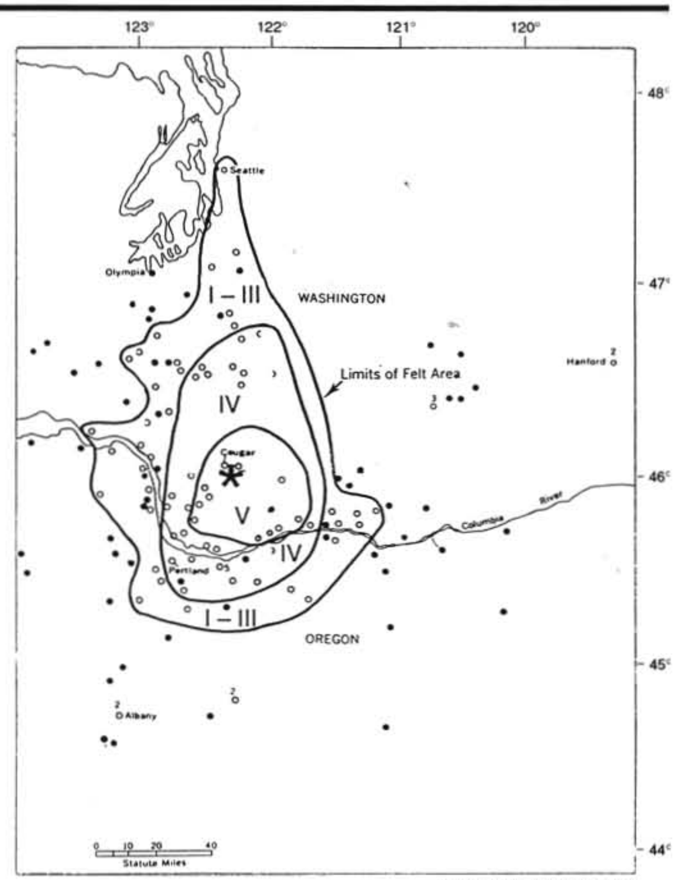

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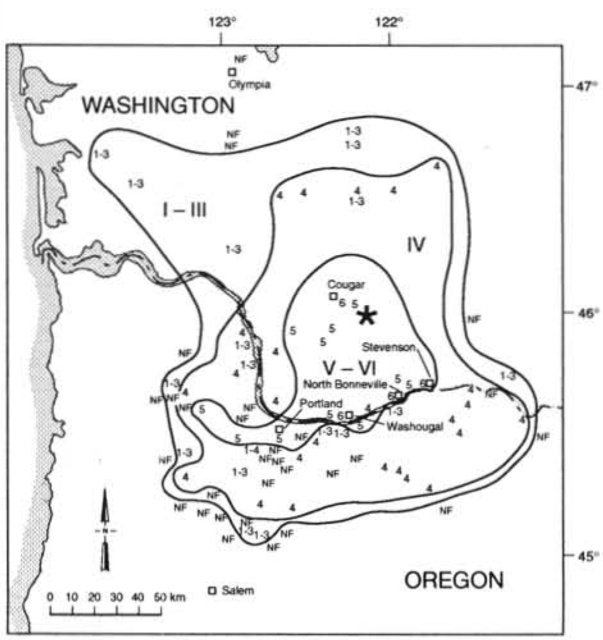

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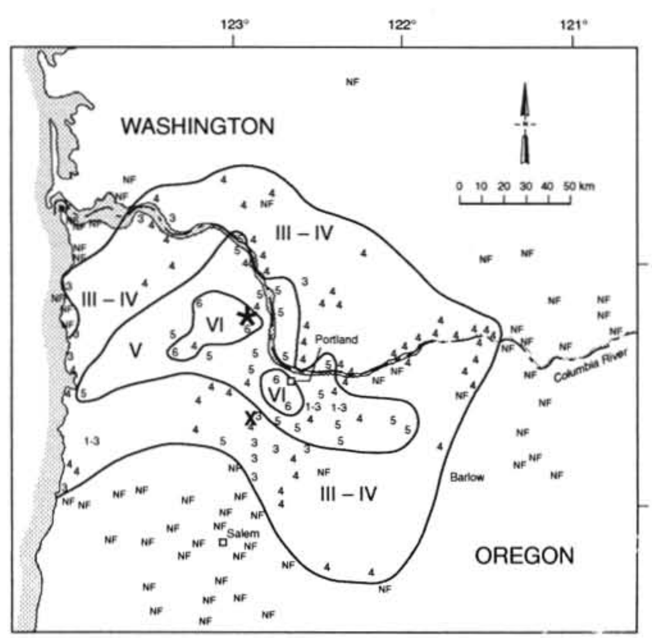

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The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors 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 illustration

Isoseismal maps for significant earthquakes in 1961 near Portland. "X" indicates additional epicentral locations as described in text. Related article about historical earthquakes in and around Portland begins on page 116.

OIL AND GAS NEWS

Drilling continues at Mist Gas Field

At the Mist Gas Field in Columbia County, Nahama and Weagant Energy Company of Bakersfield, California, continues the multiple-well drilling program that began during May. Longview Fibre 12A-33-75 (TD 2,475 ft) was completed as a successful gas well; Longview Fibre 12B-35-65 (TD 3,727 ft) is currently suspended; CFW 41-35-75 (TD 3,331 ft), Adams 31-34-75 RD (TD 3,419 ft), and CC 41-36-75 (TD 1,792 ft) were plugged and abandoned; CC 22B-19-65 is currently suspended at a total depth of 2,940 ft; and at LF 31-36-65, drilling operations are underway.

NWPA symposium approaching fast

Registration materials are still available for the Northwest Petroleum Association (NWPA) 10th annual symposium, which will be held September 26-28, 1993, at the Inn of the Seventh Mountain in Bend, Oregon. The symposium will include a field trip to the Newberry National Volcanic Monument. For further information, contact the NWPA, PO Box 6679, Portland, OR 97228-6679.

Mist Gas Field celebrated

During this summer, the Mist Gas Field, which was discovered in 1979 and has currently 17 productive wells and an underground natural gas storage facility, reached $100 million in revenues from natural-gas production. In recognition of this milestone, the Oregon Department of Geology and Mineral Industries, Northwest Natural Gas Company, Oregon Natural Gas Development Corporation, and Nahama and Weagant Energy Company held a celebration on September 11 at the field. The field is a successful endeavor between private industry, government, and public organizations, in which landowner rights and the environment are protected, while the natural gas generates tax and royalty revenues and provides employment and other direct benefits for residents of Columbia County.

Revised *Mist Gas Field Report* released

The *Mist Gas Field Report* is now available in its annually updated version. See the more detailed announcement on page 114 in this issue of *Oregon Geology*.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
488	Nahama and Weagant Adams 14-31-74 36-009-00310	SE¼ sec. 31 T. 7 N., R. 4 W. Columbia County	Permit issued; 2,700.
489	Nahama and Weagant HNR 42-27-64 36-009-00311	NE¼ sec. 27 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,500.
490	Nahama and Weagant HNR 24-22-64 36-009-00312	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,700.
491	Nahama and Weagant HNR 31-21-64 36-009-00313	NE¼ sec. 21 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,100.
492	Nahama and Weagant CFW 23-33-74 36-009-00314	NW¼ sec. 33 T. 7 N., R. 4 W. Columbia County	Permit issued; 1,700.
493	Nahama and Weagant CC 24-19-65 36-009-00315	SW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Application; 3,000.

□

Field trip guide to Cascadia paleoseismic evidence along the northern Oregon coast: Evidence of subduction zone seismicity in the central Cascadia margin

Revised from Friends of the Pleistocene Field Trip Guide, 1993

by Curt D. Peterson, Mark E. Darienzo, Scott F. Burns, and William K. Burris, Department of Geology, Portland State University, Portland, Oregon 97207-0751, phone (503) 725-3022

SUMMARY

Broad pocket beaches, low marine terraces, and numerous small estuaries are characteristic features of the northern Oregon coast, the middle part of the Cascadia coastline that extends from British Columbia to northern California. Like the middle child, the northern Oregon coast provides the link between the northern and southern ends of the Cascadia margin. Perhaps less dramatic in relief but not in beauty, this central Cascadia coastline differs significantly from the jagged coastlines of northern Washington and southern Oregon/ northern California. The apparent geologic quiescence of the northern Oregon coast does not reflect the catastrophic earthquakes that have struck the region in recent prehistoric time.

On this field trip, we explore the northern half of the Oregon coastline for geologic evidence of subduction zone seismicity. Such evidence includes multiple events of abrupt coastal subsidence, tsunami inundation, and shaking-induced liquefaction of unconsolidated sediments. The earthquake evidence is recorded in late Holocene tidal-basin deposits (300–5,000 years old) and in uplifted marine terrace deposits of late Pleistocene age (80,000–120,000 years old). A total of 16 field localities showing evidence of earthquake-induced subsidence, tsunami generation, liquefaction, and/or debris flows are discussed in this field trip guide (Figure 1).

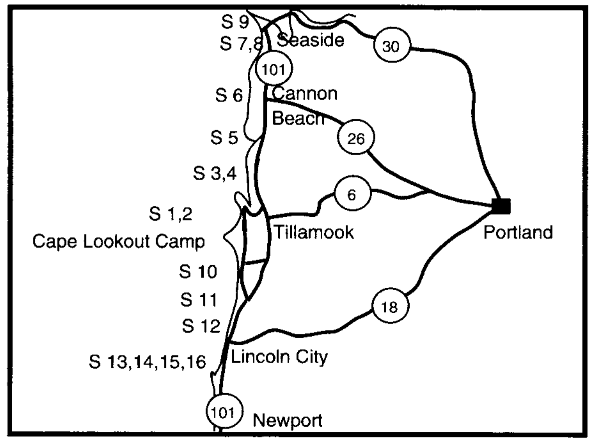

Figure 1. Regional highway map with field trip stops (S 1–16).

INTRODUCTION

The potential for great earthquakes in the Cascadia Subduction Zone (CSZ) (Figure 2), where the Juan de Fuca Plate is being subducted under the North American Plate, is one of the most controversial topics in Quaternary geology of the Pacific Northwest. In the last dozen years, expert opinions on the nature of seismicity along this margin have ranged from terminated subduction to aseismic subduction to the potential for great (M_W 9) subduction zone earthquakes (Heaton and Kanamori, 1984). Late Quaternary deposits of the central CSZ are reported to show evidence of episodic coastal subsidence and tsunami deposition (Figure 3) (Atwater, 1987; Darienzo and Peterson, 1990), coseismic sediment liquefaction (Peterson and Madin, 1992), and coseismic debris flows (Darienzo, 1991; Gallaway and others, 1992). However, the reported evidence of episodic coastal subsidence and associated tsunami deposition as been interpreted by some to possibly represent spit breaches, storm surges, or other aseismic mechanisms. In this field trip guide, we discuss field sites that discriminate between seismic and aseismic mechanisms causing episodic marsh burial. However, these sites must be viewed within the larger neotectonic context of the central Cascadia margin to evaluate their relevance to the paleoseismicity debate.

REGIONAL NEOTECTONIC FRAMEWORK

The central Cascadia margin, both offshore and onshore, is now known to be riddled with faults and folds in the upper North American Plate (Figure 4). Some faults possibly extend downward to the plate interface or even into the lower Juan de Fuca Plate (Goldfinger and others, 1992; Vern Kulm, Oregon State University, personal communication, 1993). Are these faults active, and if so,

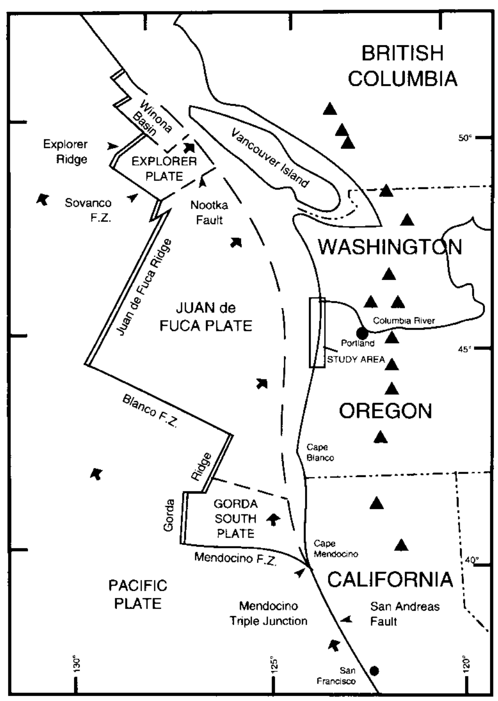

Figure 2. Tectonic framework of the Cascadia Margin and location of field trip area (plate motions indicated by bold arrows).

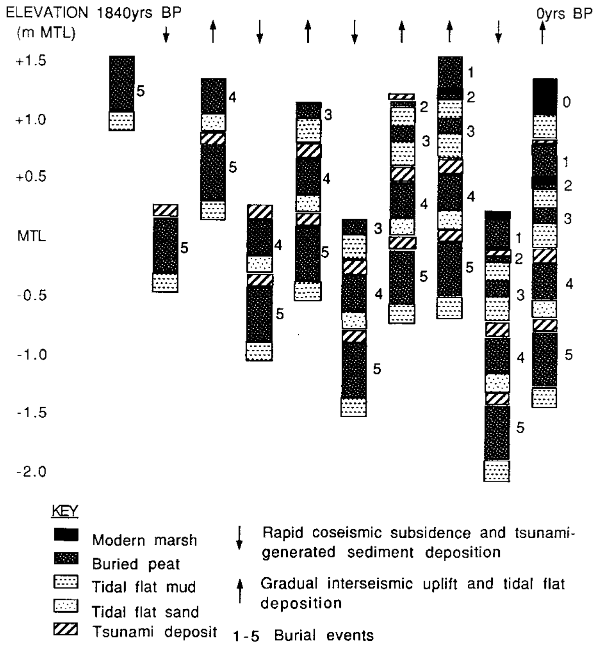

Figure 3. Stratigraphic stacking model of rapid coseismic subsidence followed by gradual sedimentation and post-seismic tectonic rebound that produced the upper 2.5 m of the stratigraphic record at Netarts Bay. The amount of subsidence is determined from estimates of modern and paleoenvironmental tidal elevations. After Darienzo and Peterson (1990).

what accounts for their combined lack of historic seismicity? How have these folds and faults affected the coastal stratigraphic record? The northern Oregon coastal terraces (late Pleistocene in age) show relatively less vertical deformation than do corresponding terraces from the southern and northern ends of the margin (Figure 5). We ascribe the larger rates of coastal inelastic deformation (faults and folds) in the southern Cascadia margin to its being closer to the deformation front, i.e., the leading edge of the North American Plate (Peterson and others, 1991). The larger rates of coastal inelastic deformation of the Cascadia margin in northern Washington might be due to its proximity to the margin bend, i.e., the bulge in the downgoing slab at the Olympic Pensinsula (Figure 2). A compensatory bulge in the downgoing slab at the margin bend might increase the width of the locked zone and its associated upper-plate deformation in the Olympic Peninsula (Crosson and Owens, 1987).

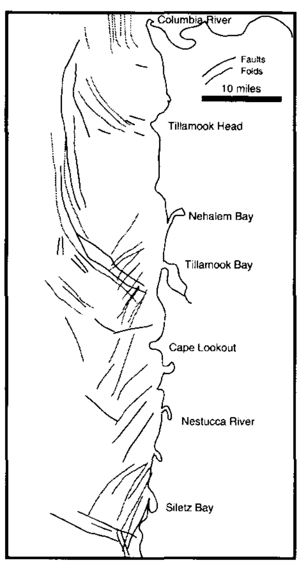

Figure 4. Coastal section of the offshore neotectonic map. Redrawn from Goldfinger and others (1992).

In addition to the inelastic deformation, there is the predicted component of cyclic elastic deformation associated with episodic

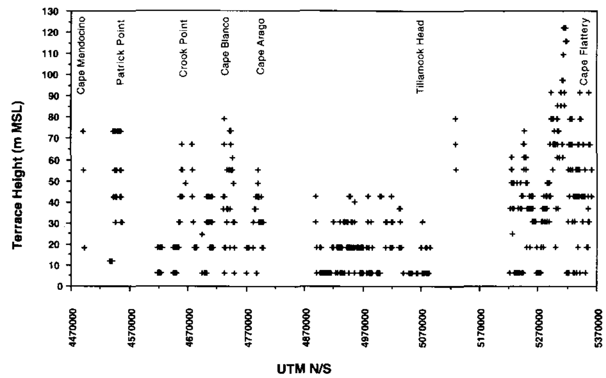

Figure 5. Plot of lowest-terrace surface elevation versus distance (UTM) along the Cascadia margin. From Peterson and others (1991).

dislocation of a strongly coupled megathrust (Heaton and Kanamori, 1984). Alternating conditions of aseismic coastal uplift and coseismic coastal subsidence are predicted for coastlines landward of a zero isobase of upper plate flexure (Figure 6). Preliminary maps of episodic coastal subsidence or continuous subsidence have been established from buried marsh records in late Holocene wetland deposits of the central Oregon coast (Briggs and Peterson, 1992). The initial results of this mapping suggest that the central Cascadia coastline converges with the predicted zero isobase of elastic flexure in central Oregon (Figure 7). The apparent coincidence of both diminished terrace deformation and the zero isobase of elastic deformation in the central Oregon coast might denote the landward limit of the locked zone (Peterson and Briggs, 1992). All of the marsh settings observed in this field trip (northern Oregon coast) should fall in the realm of elastic coseismic subsidence, if the assumptions above are valid.

Finally, direct evidence of earthquake rupture length, which is related to earthquake magnitude, has proven to be elusive in the central Cascadia margin. Because of the relatively poor precision

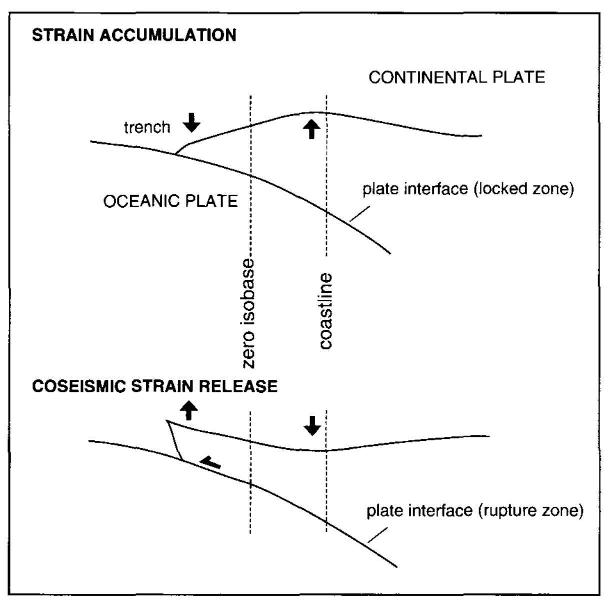

Figure 6. Simplified cross section of zero isobase, plate subduction, and deformation cycles. From Darienzo (1991).

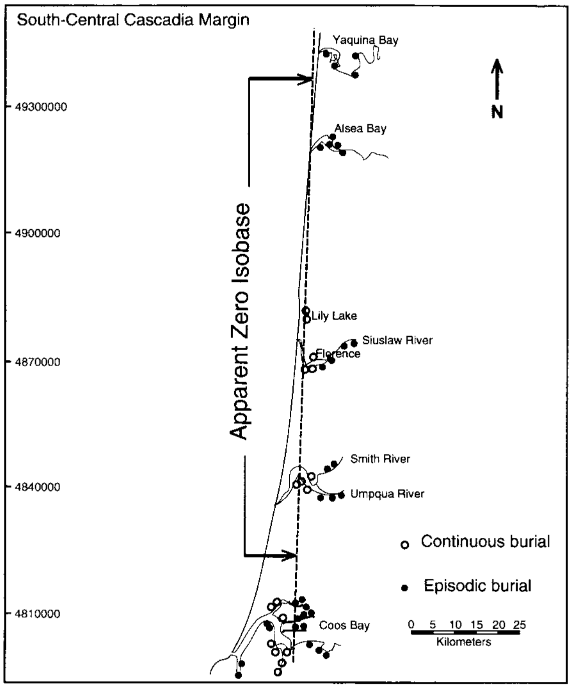

Figure 7. Map of core sites showing episodic burial (solid circles) and continuous burial (open circles) in central Oregon (unpublished map relating to Briggs and Peterson, 1992). Continuous burial cores are thought to lie on zero-isobase of upper plate flexure (see Figure 6).

of radiocarbon dating, it has not been possible to use that method to prove that the entire coast subsided at the same time in one catastrophic earthquake. Dendrochronology (tree ring dating) has successfully constrained the age of the last subsidence event(s) (approximately 300 years ago) in coastal wetlands of southern Washington (Yamaguchi and others, 1989).

What is required to test the model that large earthquakes affected many areas along the coast simultaneously (event synchroneity) is a unique stratigraphic record of coastal subsidence and corresponding tsunami inundation that can tie widely separated bays to distinct regional events (Figure 8) (Peterson and Darienzo, 1992). Such a record might exist in the northern Oregon coast, where the last five Cascadia Subduction Zone (CSZ) subsidence events apparently establish a unique regional sequence (Figure 9) (Darienzo, 1991). This sequence includes the following events:

- Event 1. Subsidence + tsunami at approximately 300 calendar years before present (Cal. Yr. BP).
- Event 2. Northward-decreasing subsidence + tsunami at approximately 800±200 radiocarbon years before present (RCYBP).
- Event 3. Subsidence + no tsunami (possible exception at Seaside) at approximately 1,100±200 RCYBP.
- Events 4 and 5. Each with subsidence + tsunami, both roughly in the range of 1,500–1,800 RCYBP.

If confirmed, this central Cascadia earthquake sequence might ultimately provide a link to bridge the paleoseismic records of the southern and northern regions of the Cascadia Subduction Zone.

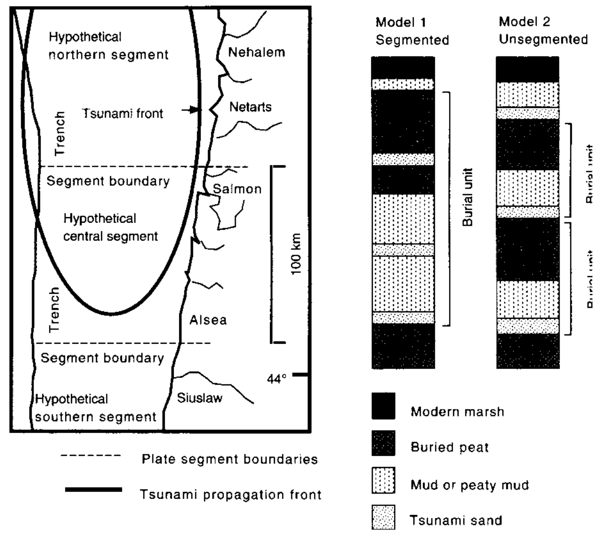

Figure 8. Two models of marsh development and tsunami deposition used to discriminate rupture segments in the northern Oregon coast. One-to-one correspondence between buried peat (coastal subsidence) and tsunami deposition at adjacent bays indicates event synchroneity between bays. From Peterson and Darienzo (1992).

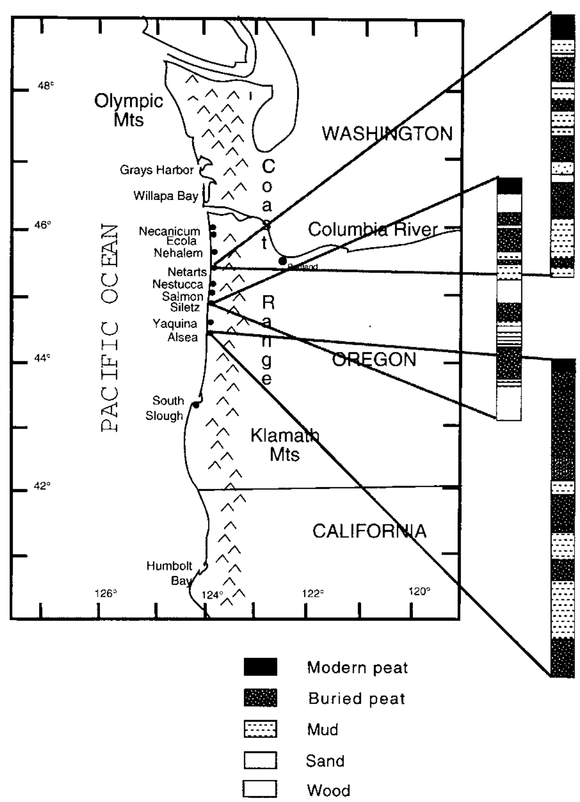

Figure 9. Representative stratigraphy of three sites (Netarts Bay, Siletz Bay, and Alsea River) on the northern Oregon coast. These sites record five coseismically buried peats (indicated by numbers next to stratigraphic column) in approximately the last 2,000 years, suggesting regional synchroneity of the events.

SITE DESCRIPTIONS

Warning: Oregon beaches are renowned for sneaker waves. While viewing these stops, please keep an eye on the ocean and your companions if you venture near the surf zone. Also, to minimize impact on rural coastal communities, park well off the roadside and keep to public access paths. Finally, Stops 1, 2, 8, 11, and 14 can be fully viewed only at low tide. Consult tide tables and plan your trip accordingly.

Stop 1. Netarts marsh, Netarts Bay

Location (Figure 10): Netarts Road about half a mile north of the Cape Lookout campground. Park on the side of the roadway. Walk out onto the bay marsh at a road culvert, about 150 ft north of the debris-flow chute. The modern debris-flow deposits extend out on the marsh about 150 ft west of the road culvert. Continue another 150 ft west, beyond the debris flow fan, to the cutbank of a small tidal channel to view the prehistoric marsh stratigraphy. **Requires low tide to see all outcrops.**

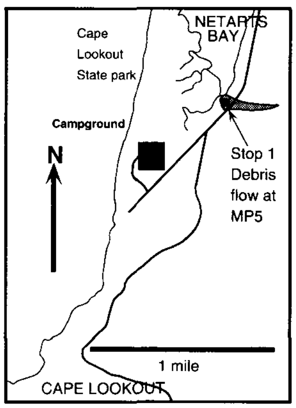

Figure 10. Location of Stop 1. MP = mile post.

Features: Type section of episodic coastal subsidence and tsunami deposition in the northern Oregon coast. Also, rapid recolonization of modern (aseismic) debris flow on marsh, confirming submergence mechanism of prehistoric peat burial.

Site description: Netarts Bay is a shallow lagoon bounded by Cape Meares and Cape Lookout (two basaltic headlands), a sand spit, and the Coast Range (Figures 1 and 11). We consider the Netarts Bay marsh stratigraphy to be the type section for paleoseismological evidence of Cascadia earthquakes in the last 3,000 years along the northern Oregon coast (Figure 12) (Darienzo, 1991). Buried peats are overlain by distinct tsunami sands and/or barren to rooted tidal flat muds. The development of the marsh stratigraphy over the last couple of thousand years, including the last five coseismic burial events, is a combination of tectonic and eustatic sea-level rise processes (Figure 3). The record of alternating uplift and coseismic subsidence (1–1.5 m [3–5 ft] of vertical deformation) is preserved by eustatic sea-level rise and sedimentation in the protected bay wetlands.

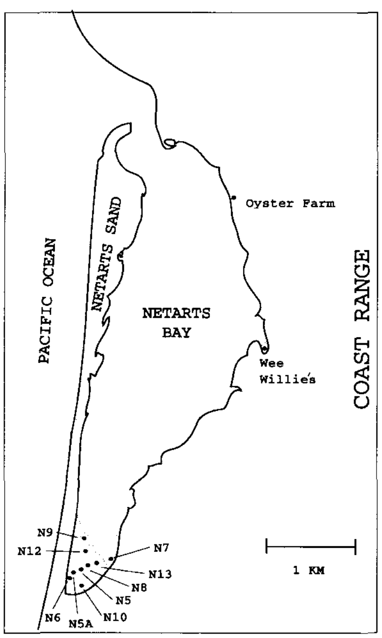

Figure 11. Sketch map of Netarts Bay showing core site locations.

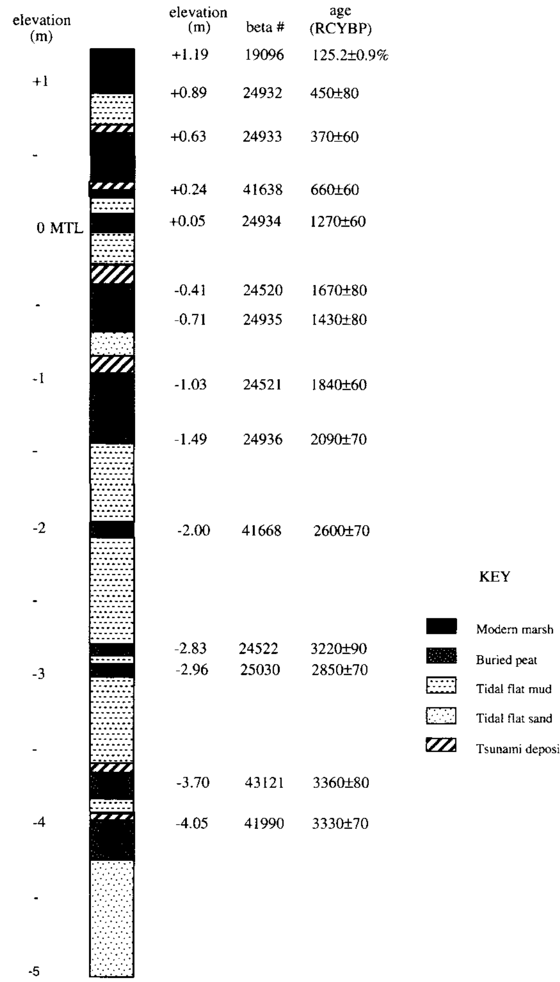

Figure 12. Generalized stratigraphy of buried peats and tsunami deposits with corresponding radiocarbon ages in Netarts Bay. Beta number is radiocarbon laboratory sample number.

In December 1990, a small debris flow (4 x 10^3 m^3 [141 x 10^3 ft^3] at the source) covered a 5 x 10^3 m^2 (54 x 10^3 ft^2) area of modern, transitional salt marsh (average elevation + 1.3 m [4 ft] mean sea level [MSL]) in the southeast margin of Netarts Bay (C.D. Peterson and others, unpublished data, 1991). The debris-flow sediments overlying the marsh include gravel, sand, and mud (1–50 cm [0.4–20 in.] in thickness) that fanned out onto the preexisting marsh surface (Figure 13). Salt marsh plants, dominated by *Deschampsia caespitosa*, rapidly recolonized the debris-flow deposit, completing dense vegetative cover within one year. The resulting marsh burial deposit is characterized by lateral discontinuity, chaotic internal structure, very poorly sorted sediments, and abundant plant shoots. In the absence of relative sea-level rise, this catastrophic burial process was unable to terminate marsh growth or yield any burial sequences characteristic of older (prehistoric) subsidence events at this site.

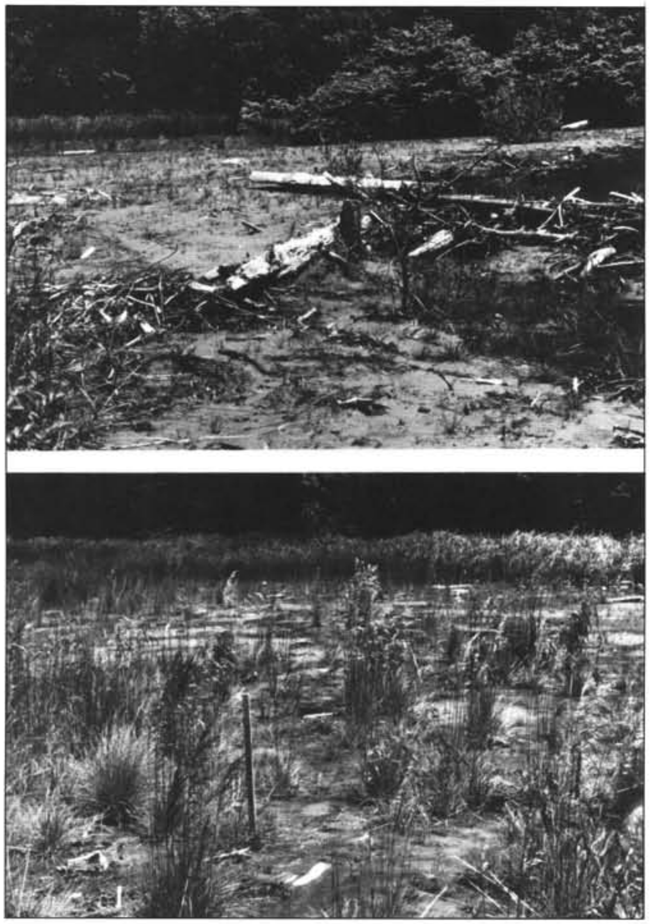

Figure 13. Photographs of debris flow on marsh at Stop 1, both taken six months after the marsh burial. Dense vegetative cover was complete within 12 months after burial by the debris flow.

Stop 2. Wee Willie's, Netarts Bay

Location (Figure 14): Netarts Road 3¼ mi north of Cape Lookout State Park campground entrance. Park near Wee Willie Restaurant. Walk out onto the small marsh and view buried peats/tree roots in tidal creek cutbanks. Continue southwest around a bay terrace point, about 300 ft from the parking lot, to the Pleistocene terrace deposits that front the bay shoreline. Continue about half a mile south along the exposed terrace deposits. **Requires low tide.**

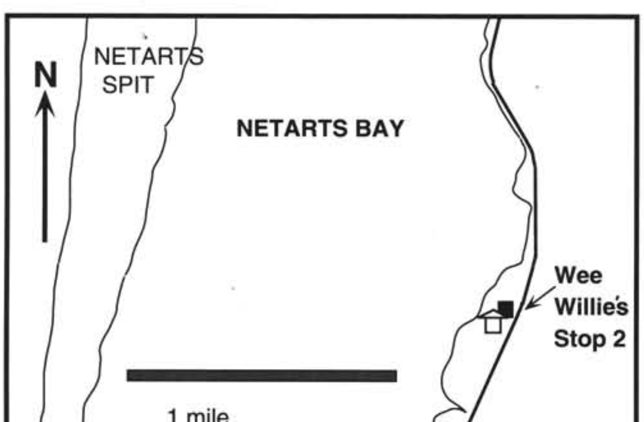

Figure 14. Location of Stop 2.

Features: Late Holocene record of coseismically buried peats and tsunami-deposited sands in marsh cores and cutbanks (Figure 15). Late Pleistocene analogs of abruptly buried peats in adjacent bay terrace deposits.

Site description: At the marsh at Wee Willie's (Figures 11 and 14), coseismically buried peats are visible in cutbanks and deeper cores. Protruding tree roots in the buried peats are indicators of forested wetlands and demonstrate past episodes of tectonic uplift above the reach of tidal range sedimentation. The prehistoric records of the last three CSZ subsidence events can be seen in the tidal creek cutbanks including Event 1 (buried peat and tsunami sand), Event 2 (tsunami sand in rooted mud), and Event 3 (buried peat but no tsunami deposit). At least six coseismic burial events have been documented in deeper cores of the site at Wee Willie's. The oldest dated peat is about 2,600 radiocarbon years before present (RCYBP). Sharp contacts between peats and overlying tsunami sands or bay muds correspond to equally abrupt changes from (1) fresh-water diatoms to brackish-water diatoms and/or (2) fossil *Juncus* rhizomes (high marsh) to *Triglochin* rhizomes (low marsh to colonizing tidal flat species). All of these paleotidal indicators point to episodic events of rapid marsh submergence. The lack of such records in some central Oregon marsh sites (Briggs and Peterson, 1992) rules out eustatic or regional sea-level changes as the mechanism responsible for the episodic submergence. The marsh burial events recorded in Netarts and other northern Oregon bays are the result of tectonic subsidence.

Late Pleistocene analogs to the buried marshes at Wee Willie's are found at many locations in marine terrace deposits of the central Oregon coast (Mulder, 1992). Perhaps the best exposed buried Pleistocene peats are those that occur in the youngest uplifted terrace deposits, assumed to be the Whisky Run terrace at about 80,000 years old (80 ka), that rim Netarts Bay (Figure 16). At least 11 subsidence events are recorded in continuous drill cores and exposed bay cliffs at this site (Figure 17). These sections are thought to represent about a 5,000-year period (maximum) of

Figure 15. Photograph of Friends of the Pleistocene field trip participants viewing cutbanks in small tidal creek of the marsh at Wee Willie's.

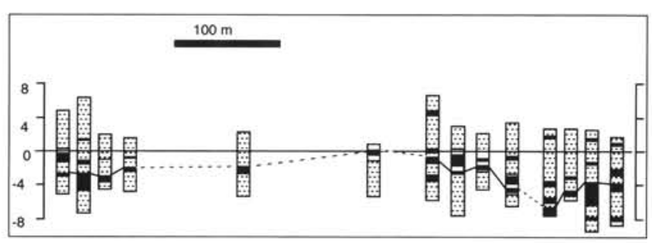

Figure 16. Cross section of buried peat horizons in late Pleistocene bay terrace deposits. From Mulder (1992).

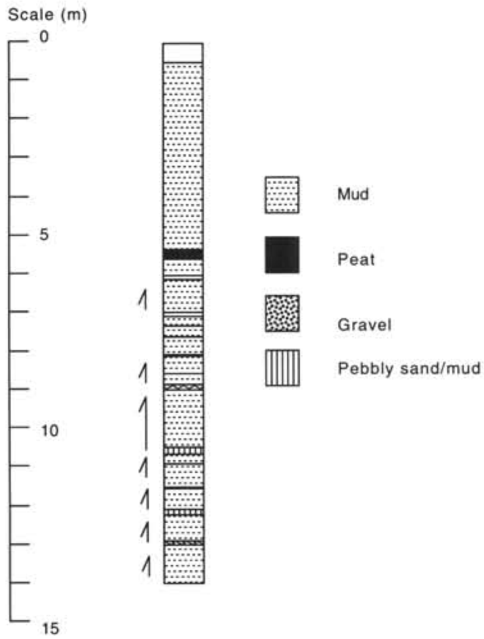

Figure 17. Core log from a drill site, located 1,600 ft (0.5 km) southeast of Wee Willie Restaurant, in late Pleistocene marine terraces. Black lines show buried peats, and arrows show grain-size fining-up trends associated with interseismic emergence. From Mulder (1992).

deposition, yielding an approximate average recurrence interval of not more than 500 years (Mulder, 1992). The terrace deposits also show subtle signs of liquefaction including muddy flow bands and small vertical dikes but no large-scale warping (folds) or vertical offsets (faults). The lack of substantial inelastic deformation of the terrace deposits here argues against the episodic subsidence originating from local faults (Figure 4). By contrast, local faults and folds are thought to dominate the coastal subsidence record in southern Oregon (Peterson and Briggs, 1992) and northernmost California (Clarke and Carver, 1991).

Stop 3. Cape Meares overlook

Location (Figure 18): Three Capes Highway, 12 mi east of Cape Meares. Park on the side of the roadway where the Tillamook Bay and spit can be viewed (Figure 19).

Features: Overview of Tillamook Bay to the north, including fringing bay marshes and major historic spit breach. Large landslide area is visible to the west, on the north side of Cape Meares.

Site description: Tillamook Bay has experienced some significant changes in historic time, including rapid sedimentation following the Tillamook burn, extensive dike construction for pasturage, and a major spit breach from 1952 to 1956 (Glenn, 1978). However, these historic changes are small by comparison to the late Holocene subsidence events that flooded all of the tidal marshes surrounding the bay. Evidence of episodic events of abrupt sea-level rise (1–2 m [3–6 ft] subsidence) is recorded by bay muds overlying supratidal peats in wetland deposits at the north, south, and west ends of the bay (Figure 20). There are also late Pleistocene buried peats exposed in sea-cliff terrace deposits just north of Cape Meares (see Stop 4 below). As with Netarts Bay, the late Pleistocene Tillamook estuary extended much farther seaward than does the present bay.

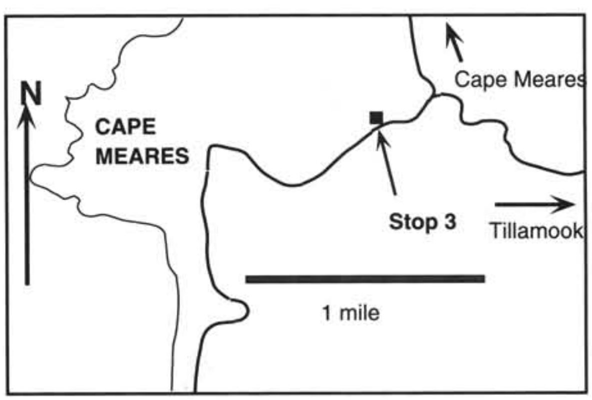

Figure 18. Location of Stop 3.

Figure 19. Overview of Tillamook Bay, view to the north, showing bay spit.

The major historic spit breach (1952) at the south end of the Tillamook Bay spit (Figure 20) left no geologic evidence of submergence or catastrophic flooding in adjacent marshes. The lack of marsh response to this historic spit breach is significant in view of the size of the breach prior to artificial closure by the U.S. Army Corps of Engineers in 1956. Based on these observations and similar ones in Alsea Bay (Peterson and Darienzo, 1992), we conclude that prehistoric spit breaches are unlikely candidates for the mechanism(s) of episodic marsh termination and burial recorded in the larger Cascadia tidal basins.

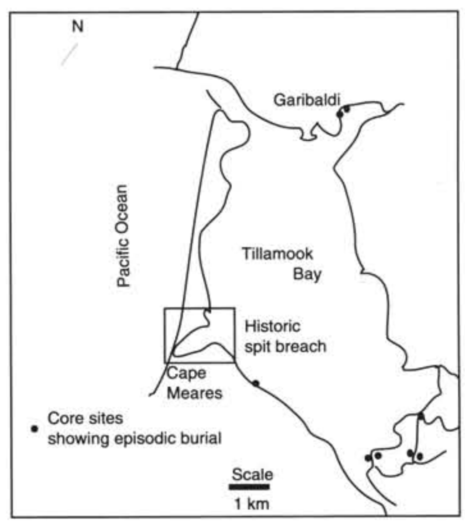

Figure 20. Map of Tillamook Bay, including marsh core sites recording prehistoric subsidence events. Core sites at Garibaldi show thin tsunami deposits over prehistoric buried peats. The historic breach of the southern end of the Tillamook Bay spit is shown (box). Adjacent marsh sites show no evidence of submergence from the spit breach.

Stop 4. Cape Meares beach

Location (Figure 21): Beach access in the Cape Meares village. Park off the roadway, and please do not block the residents' driveways. Walk out onto the beach and head south ⅓ to 1 mi along the sea cliffs.

Features: Late Pleistocene peats, liquefaction, and colluvium in marine (bay) terrace deposits (Figure 22).

Site description: At least three buried peat horizons can be traced in late Pleistocene estuarine deposits in the sea cliffs south of the town of Cape Meares. The buried peats generally show sharp upper contacts with bay muds, indicating abrupt subsidence (Mulder, 1992). Small clastic dikes and abundant muddy-flow features demonstrate sediment liquefaction. Are these liquefaction features of coseismic origin, or were they produced by debris-flow loading? Toward the southern end of the exposed Pleistocene section, the bay deposits are buried under colluvium derived from the Cape Meares ridge.

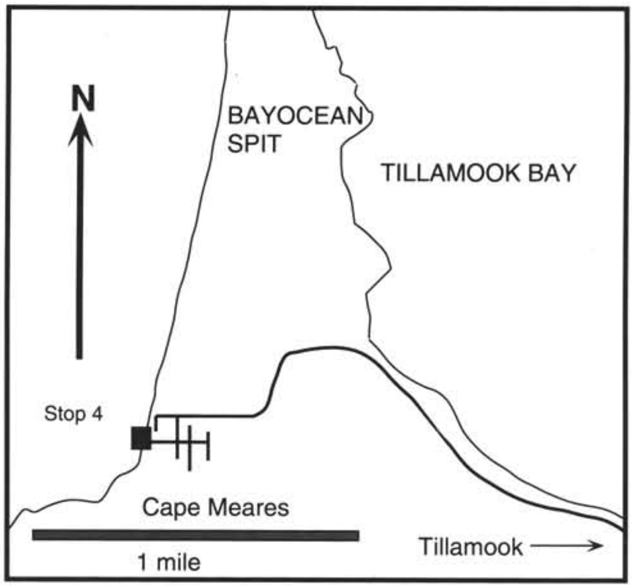

Figure 21. Location of Stop 4.

Stop 5. Short Sands, Cove Beach, Arch Cape, Arcadia, Indian Beach

Location (Figure 23): Low terrace sea cliffs along Highway 101, between the Cape Falcon (south) and Tillamook Head (north) headlands.

Features: Evidence of episodically buried peaty horizons in late Pleistocene terrace deposits from Cape Falcon to Tillamook Head.

Site description: Unlike the present coastline, the late Pleistocene coast of northern Oregon had extensive barrier lagoons. These lagoons have left records of episodically buried peaty horizons at many sites (Mulder, 1992) that are not associated with fault-controlled river valleys or faults mapped offshore (Goldfinger and others, 1992). For example, episodically buried peaty horizons in late Pleistocene barrier lagoon deposits are found at many sites between Cape Falcon and Tillamook Head. Although outcrop exposure is not continuous, there is no evidence to suggest that the buried peat horizons are restricted to local structures (faults or fold axes). Furthermore, long-term vertical deformation of the lowest late Pleistocene terrace surface (assumed 80 ka in age) in this area is negligible, e.g., about 10 m (33 ft) elevation change over the distance of 10 km (6 mi) (Mulder, 1992). The late Pleistocene subsidence events recorded here, as in other sites of the northernmost Oregon coast, appear to be located in the zone of elastic deformation, landward of the locked zone.

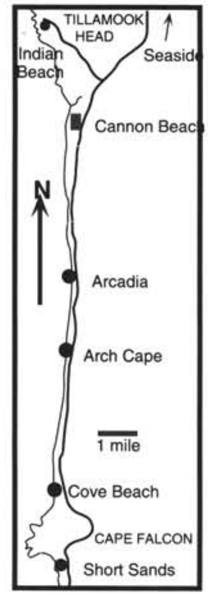

Figure 23. Locations of Stop 5.

Stop 6. Cannon Beach

Location (Figure 24): Ecola wetlands adjacent to Ecola Creek near downtown Cannon Beach. Park near the public rest rooms adjacent to the city park and walk out onto the marsh between the roadways and the waste water treatment ponds.

Features: Examine cores and shallow pits (1 m [3 ft] depth) in wetlands for evidence of the last two prehistoric events of tsunami overtopping of the Cannon Beach barrier spit.

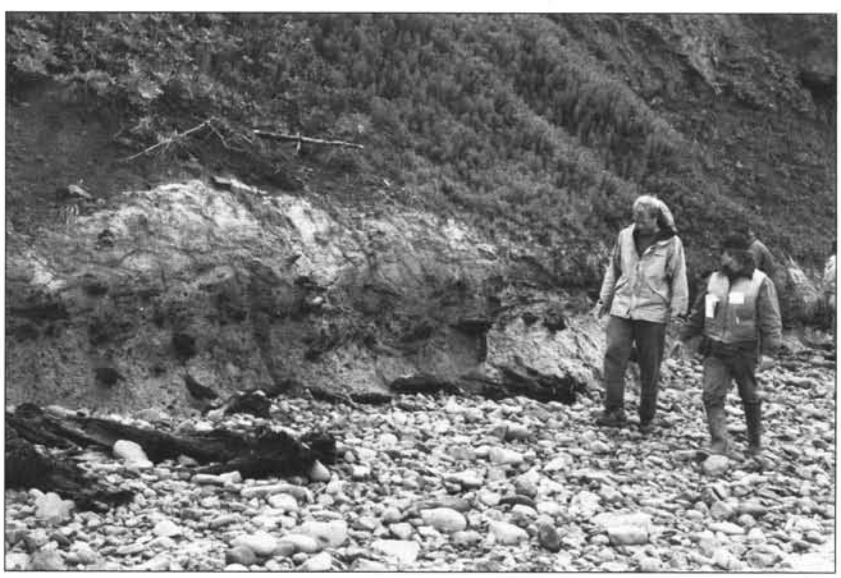

Figure 22. Photograph of bay terrace deposits exposed in sea cliffs south of the village of Cape Meares.

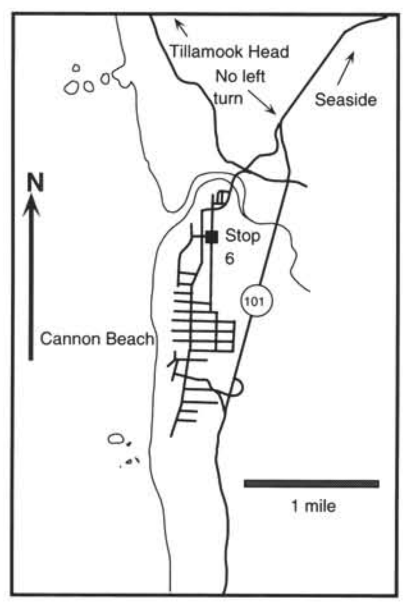

Figure 24. Location of Stop 6.

Site description: The Ecola Creek wetland area behind downtown Cannon Beach (Figure 25) is the first site to yield unequivocal geologic evidence of Cascadia tsunami runup heights at the ocean shoreline (Gallaway and others, 1992). As many as eight buried peats and/or tsunami deposits are recorded in about 3,000 radiocarbon years of deposition in the Ecola Creek wetlands (Figure 26). The uppermost buried peat (younger than 380±60 RCYBP) is associated with a tsunami, whereas the second youngest tsunami (younger than about 1,000 years in age) is located within a peat, i.e., no subsidence.

Figure 25. Photograph of Friends of the Pleistocene field trip participants in the Ecola Creek wetlands, facing towards the source of the prehistoric tsunami sands (downtown Cannon Beach area) that blanketed the wetlands.

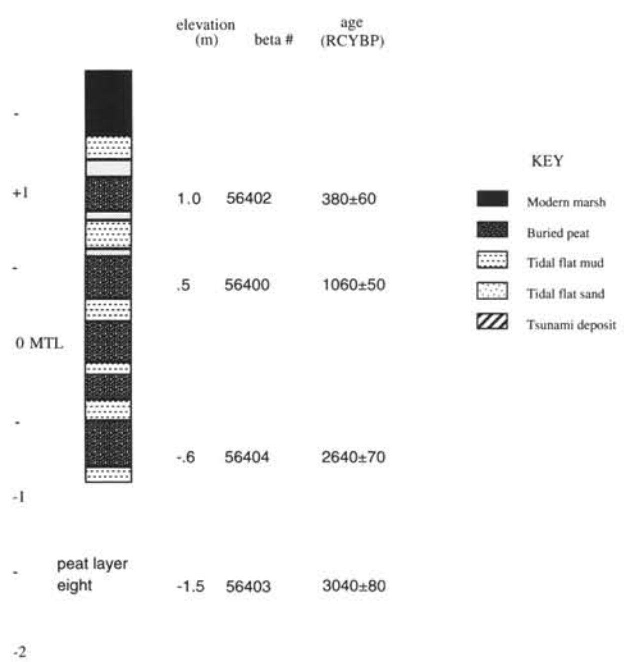

Figure 26. Core log of buried peats from core site northeast of Ecola Creek bend. This log shows thin tsunami sands at the top of uppermost buried peat (38±060 RCYBP) and on the top and bottom of a debris-flow deposit (less than 1,200±60 RCYBP, assumed less than 1,000 RCYBP by correlation to other cores [Gallaway and others, 1992]). A total of eight buried peats are found at this core site (oldest is 3,040±80 RCYBP). The top five peats/tsunami layers (shown in this figure) might be correlative with the last five regional dislocation events (Figure 9). Beta number is radiocarbon laboratory sample number.

We interpret these tsunami deposits to represent Events 1 and 2 of the five CSZ subsidence events mentioned above. Tsunami-deposit isopach maps indicate that these paleotsunamis entered the wetlands both via the Ecola Creek mouth and by overtopping the southern end of the Cannon Beach spit (Figure 27). Backshore-foredune transitions in the Cannon Beach spit and in many other spits of the Cascadia margin exceed + 5 m (16 ft) MSL (Petit, 1991), yielding CSZ tsunami runup heights of at least 6 m (20 ft) above MSL at Cannon Beach (Figure 28).

The prehistoric CSZ tsunami Event 2 is of particular interest for two reasons. This Cascadia tsunami appears to have propagated well beyond the area of corresponding coastal subsidence in central Oregon (Darienzo, 1991). In addition, it bounds a debris-flow deposit in the northwest corner of the Ecola Creek wetlands (Gallaway and others, 1992). To our knowledge, this is the first debris flow to be tied directly to a megathrust dislocation event in the Cascadia margin. Two and possibly three sand layers from the Event 2 tsunami are associated with the deposition of the debris flow on the wetland surface adjacent to a ravine (Figure 25). The separation of the tsunami layers by the debris-flow sediments confirms multiple wave trains of the Event 2 tsunami. Multiple trains of tsunami waves (two to three) for the Event 2 tsunami are also implied by alternating sand and organic detritus layers at other Ecola Creek wetland sites.

Unlike the prehistoric Cascadia tsunamis, the significant flooding from the historic 1964 Alaskan tsunami was limited to the Ecola Creek mouth area. The preexisting Ecola Creek bridge at the north end of Cannon Beach was removed from its footings and carried about 150 m (500 ft) up the Ecola Creek channel by that tsunami (Terry Swagert, Cannon Beach resident, personal communication, 1992). No historic tsunami deposits have been identified in the Ecola

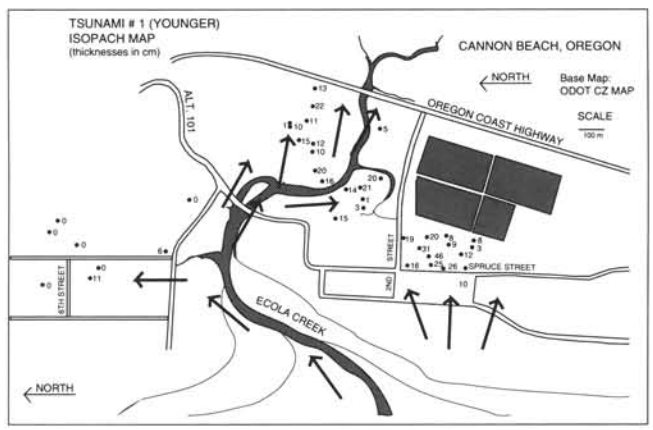

Figure 27. Isopach map of youngest prehistoric tsunami (300 Cal. Year BP) deposit thickness at Cannon Beach. Maximum deposit thickness at south end of Cannon Beach spit indicates spit overtopping as well as surge propagation up the Ecola Creek channel. Arrows show direction of tsunami movement.

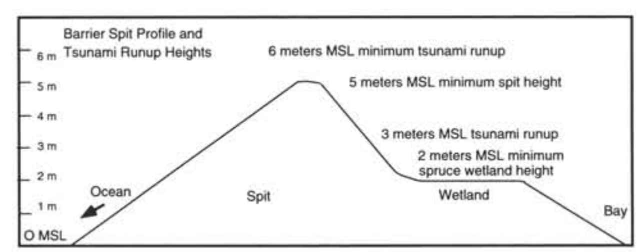

Figure 28. Generalized diagram of tsunami overtopping spit of assumed elevation (+5 m MSL). Estimated minimum runup height of CSZ tsunamis at Cannon Beach ocean shoreline is +6 m MSL (Gallaway and others, 1992).

Creek wetlands except for small remnants of the destroyed bridge that were found immediately adjacent to the Ecola Creek channel. The wetland areas of tsunami inundation and deposition for the last two prehistoric Cascadia tsunamis are at least ten times larger than that for the 1964 Alaskan tsunami in the Ecola Creek wetlands.

Stop 7. Seaside overview at Tillamook Head

Location (Figure 29): Take the beach access route off Highway 101 at the south end of Seaside to drive west to the Tillamook Head overlook. Park along the roadway or hike out to the sea cliff above the Seaside cove for a broad overview of the south end of the Clatsop spit area.

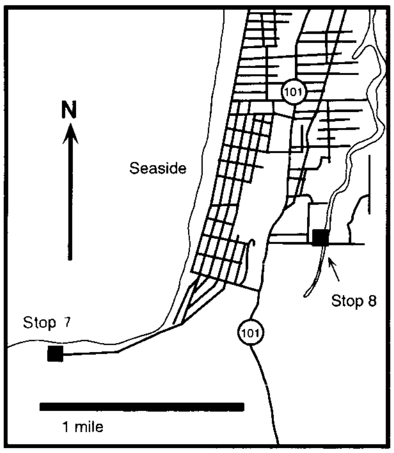

Figure 29. Locations of Stops 7 and 8.

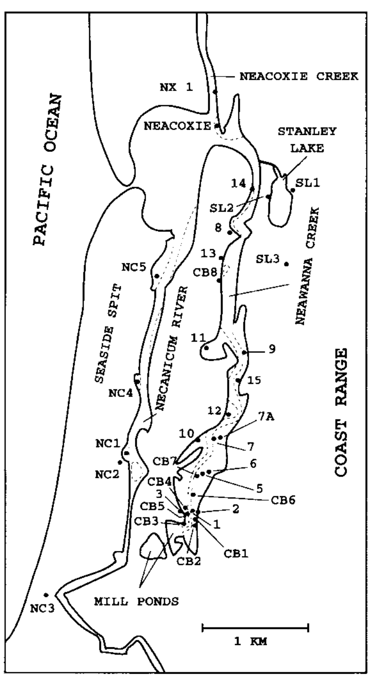

Figure 30. General map of Seaside area, showing location of cores taken and cutbanks (CB) examined.

Features: Beach cobble ridges, Necanicum and Neawanna River morphology, and probable historic tsunami deposits in Necanicum River.

Site description: The Seaside area is developed on Clatsop Spit, which extends south to Tillamook Head and north to the Columbia River. Gravel beach ridges and dunes prograded westward, due to diminished rates of eustatic sea-level rise during late Holocene time (Rankin, 1983). The source of the gravels, which range up to cobble size, is the Tillamook Head basalt. Gravel beach ridges are separated by small, linear valleys that contain the Necanicum River, Neawanna Creek, and Stanley Lake wetlands (Figure 30).

The marshes of the Necanicum River valley contain two distinct sand layers sandwiched between rooted muds within 1 m (3 ft) depth (Figure 31) (Darienzo and others, 1993). The sands can be traced over 2 km (1.2 mi) from core site NC2 to NC5 (Figure 30). Radiocarbon dates and historic artifacts indicate that the anomalous sand layers are historic. Neither layer is associated with abruptly buried peats, further distinguishing them from prehistoric Cascadia tsunamis. However, historic tsunamis are known to have surged into Necanicum Bay. Walls of water 3 m (10 ft) high and 1.2 m (4 ft) high, respectively, are reported to have traveled up the Necanicum River as a result of tsunamis produced by the 1964 and 1946 Alaskan and Aleutian earthquakes. Sand from the 1964 tsunami was deposited on the Highway 101 bridge, where it crosses the Neawanna Creek (Neal Maine, Seaside Public Schools, personal communication, 1992). There is no evidence that the historic Alaskan tsunamis left any sandy deposits in the Neawanna Creek wetlands behind Seaside.

The young Necanicum River valley has no prehistoric marsh deposits; thus we have no record of paleotsunami inundation along Seaside's ocean frontage areas. However, geologic evidence of prehistoric tsunami inundation landward of Seaside is well preserved in the Neawanna and Stanley Lake wetlands (see Stop 8 below).

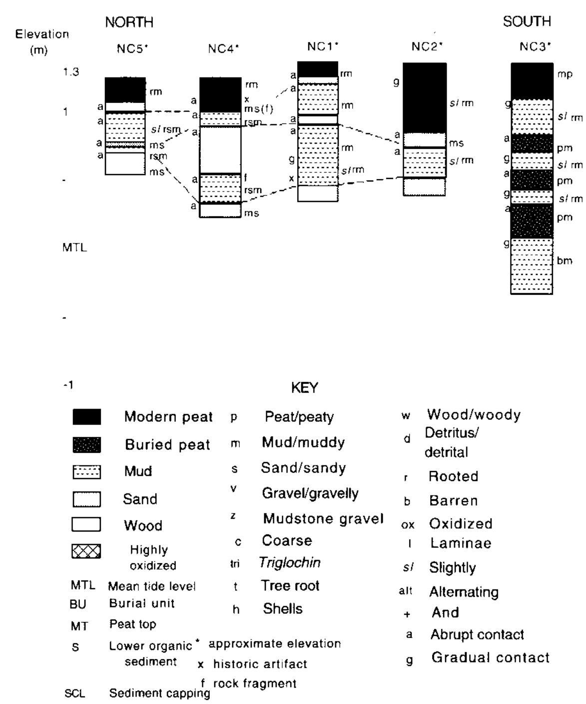

Figure 31. Stratigraphy of historic sand layers (probable 1946 and 1964 Alaskan tsunami deposits) in Necanicum River.

Stop 8. Neawanna cutbank

Location (Figure 29): At the south end of Seaside, turn off Highway 101 to travel east on S Ave. about ⅓ mi to the bridge crossing over Neawanna Creek. Park and walk north, out onto the marsh, or along the cutbank on the east side of the Neawanna tidal creek. **Requires low tide.**

Features: Coseismically buried peats, tsunami-deposited sand, and debris-flow deposits.

Site description: The upper reaches of the Neawanna tidal channel contain evidence for six coseismic burial events in the last 2,200 RCYBP. The coseismic subsidence events are denoted by abruptly buried peats, tsunami sands, and some debris-flow deposits (Darienzo, 1991) (Figure 32). Tree roots protruding from peaty horizons in the cutbanks indicate that some of the paleowetlands here were forested prior to coseismic subsidence and burial.

The debris-flow deposits overlying the buried peats are characterized by chaotic structure and poorly sorted clay and gravel. The gravel contains rounded mudstone fragments that are easily crushed between the fingers. One debris-flow deposit (20–30 cm [8–12 in.] thick) can be traced in the cutbank over a distance of 80 m (260 ft) between core sites CB5 and CB6, where it gives way to sand at CB6 (Figure 30). Debris-flow deposits are not found downstream of core site 7, confirming an upland/upstream source. Additional work is needed to constrain the relative timing of the debris-flow deposits with respect to tsunami inundation. However, beach sand is mixed in with some of the muddy gravel deposits, suggesting the potential for codeposition from tsunami and debris-flow sources.

The sandy tsunami deposits in the Neawanna core sites pinch out (from 26 to 0 cm [100 in.] thickness) with distance down the tidal

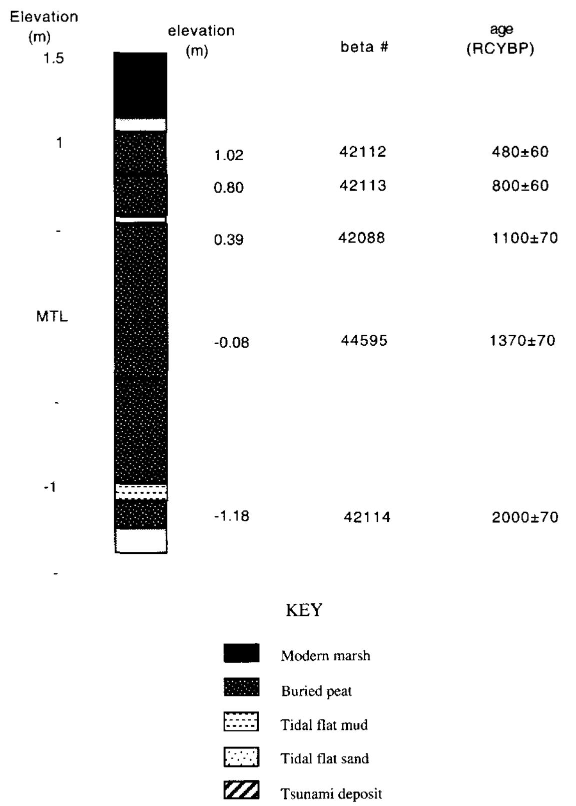

Figure 32. Stratigraphy and radiocarbon ages of buried peats from core site 2 along the upper reaches of the Neawanna. Beta number is radiocarbon laboratory sample number.

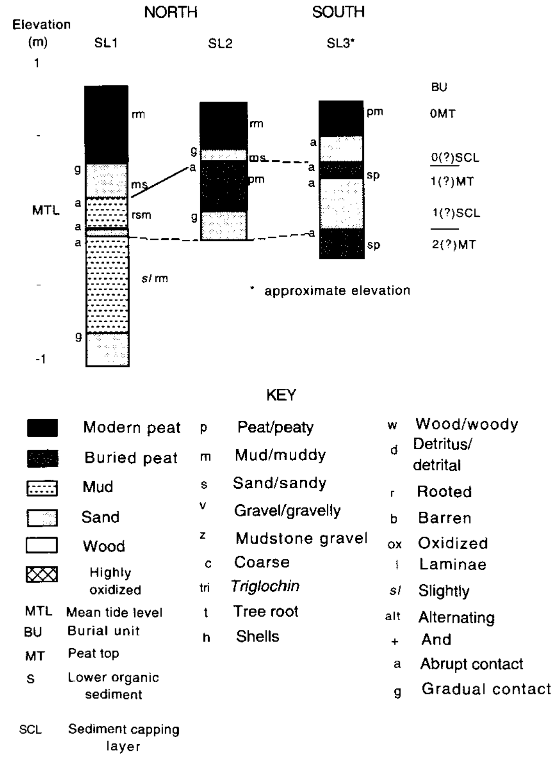

Figure 33. Stratigraphy of representative cores in the Stanley Lake area.

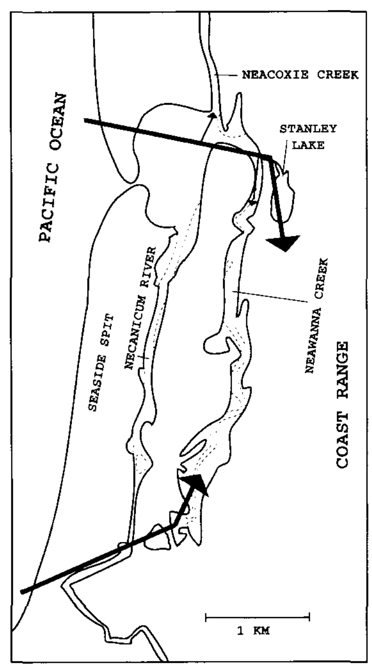

Figure 34. Arrows show probable directions of movement of the tsunami surges for the last two Cascadia earthquakes. The thicker arrows depict the main surge corridors and the thinner arrows other possible corridors.

channel (to the north). A northward propagation of the tsunami surge here is also supported by the sand mineralogy, indicating a beach sand supply from the west, as opposed to a river sand supply from upstream or downstream. The beach sands are discriminated from river sands on the basis of heavy mineralogy and relative grain rounding (Darienzo and others, 1993). The paleotsunamis that deposited beach sands in marshes of the upper Neawanna tidal channel are interpreted to have surged through or over the spit at the south end of Seaside.

However, even thicker paleotsunami deposits are found in the Stanley Lake area, northeast of Seaside (Figure 33). The sand layers range from 4 to 68 cm (1.5–27 in.) in thickness and contain from 75 to 100 percent beach sand components. The uppermost sand layer(s) in Stanley Lake was (were) deposited within the last 800 years RCYBP, suggesting deposition from one or both of the last two Cascadia tsunamis. The lack of an intervening peat might reflect scouring by the last paleotsunami (CSZ Event 1), but this hypothesis will require AMS radiocarbon dating for confirmation. The mineralogy and thickness of the tsunami sands here indicate that the tsunami surges breached the ridge between the Necanicum bay mouth and the Stanley Lake valley before dissipating with distance south along the Stanley Lake valley. At the south end of the Stanley Lake valley, the CSZ Event 1 and Event 2 tsunamis are separated by a peaty horizon. The patterns of Cascadia tsunami propagation in the Seaside area are complex (Figure 34), with surges crossing gravel ridges at low points and dissipating in intervening lowland valleys between the gravel ridges.

Stop 9. Youngs Bay, Columbia River

Location (Figure 35): Drive north toward Warrenton, but head east on Oregon Coast Highway 101 alternate (old Hwy 101) toward Astoria. Park at the west end of the bridge and walk north out on a dike road to view tidal creek cutbanks in the northeast corner of the small marsh.

Features: Marsh cutbank and/or shallow cores show evidence of two paleotsunami deposits about 10 km (6 mi) upriver of the Columbia River mouth.

Site description: This marsh site is located at the west side of Youngs Bay, between Warrenton and Astoria, in the lower Columbia River estuary. There has been much speculation about Cascadia tsunami runup in the Columbia River. The 1964 Alaskan tsunami is reported to have nearly topped dikes along the Warrenton shoreline that were 3 m (10 ft) high. The two paleotsunami deposits recorded at this site clearly indicate sufficient tsunami runup to overtop high marsh settings some 15 km (9 mi) from the mouth. However, the Columbia River tidal inlet has been substantially altered in historic time. Numerical tsunami modeling will likely be required to evaluate the importance of historic inlet changes in controlling potential runups of future Cascadia tsunamis.

A general core log for the shallow marsh stratigraphy at this site is shown in Figure 36. The upper tsunami layer is associated with

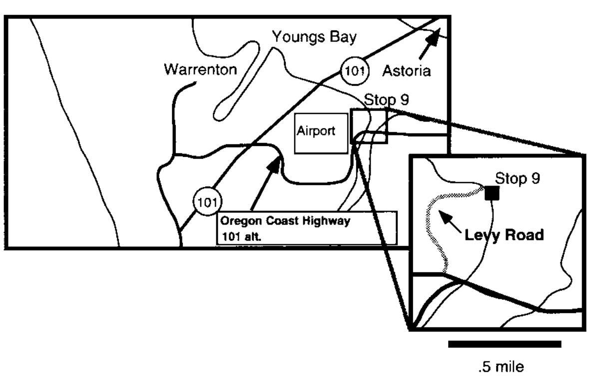

Figure 35. Location of Stop 9.

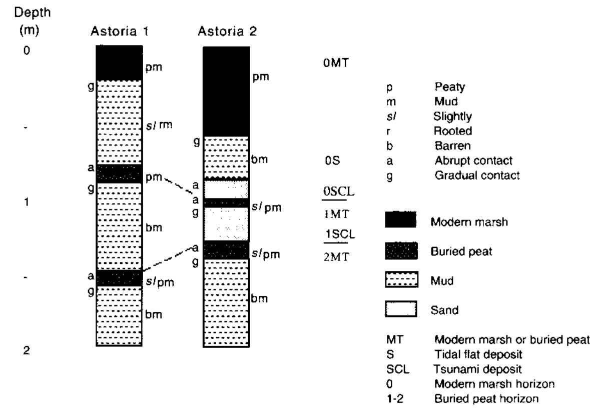

Figure 36. Stratigraphy of last two Cascadia tsunamis (Events 1 and 2) in Youngs Bay-Warrenton area of lower Columbia River.

marsh burial and is presumed to be CSZ Event 1, at about 300 years ago. The lower tsunami layer is not associated with coastal subsidence and is tentatively correlated with CSZ Event 2. These deposits have yet to be radiocarbon dated. It is interesting to note that at this site the tsunami layer associated with local subsidence is thinner than the tsunami layer not associated with local coastal subsidence. This site possibly extends the propagation distance of the CSZ tsunami Event 2 at least 100 km (62 mi) beyond the area of observed coastal subsidence in central Oregon (Peterson and Darienzo, 1992).

Stop 10. Nestucca Bay marsh

Location (Figure 37): Highway 101 bridge area over Nestucca River as it enters Nestucca River valley between Woods and Pacific City. The prehistoric wetlands are now pasture lands. River banks have been diked, so marsh stratigraphic examination requires coring or shallow pits in the pastures. **Permission for access to the pasture lands is required from the owners.**

Features: Coseismically buried peats and tsunami-deposited sands. This site has the largest number of buried peats (12) reported to date for the central Cascadia margin.

Site description: Nestucca Bay is fed by the Nestucca and Little Nestucca Rivers and is separated from the Pacific Ocean by a long sand spit (Figures 1 and 38). There are very few natural marshes in the area due to the extensive diking of wetlands for grazing of dairy cattle. Nevertheless, coseismically buried peats were identified beneath pasture soils along both rivers (Figure 38) (Darienzo, 1991). The strongest evidence for coseismic peat burial with tsunami deposition is at the Nestucca Duck sites, which record CSZ Event 1, about 300 years in age (Figure 38). However, thin tsunami layers (1 cm [0.4 in.] thick) that are associated with several buried peat horizons have been traced upriver to the Hurliman 4 site and to sites along the lower reaches of the little Nestucca channel (Figure 38).

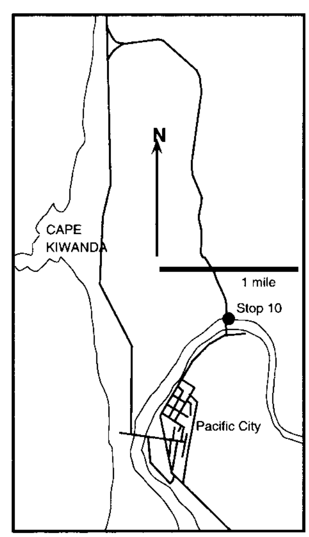

Figure 37. Location of Stop 10.

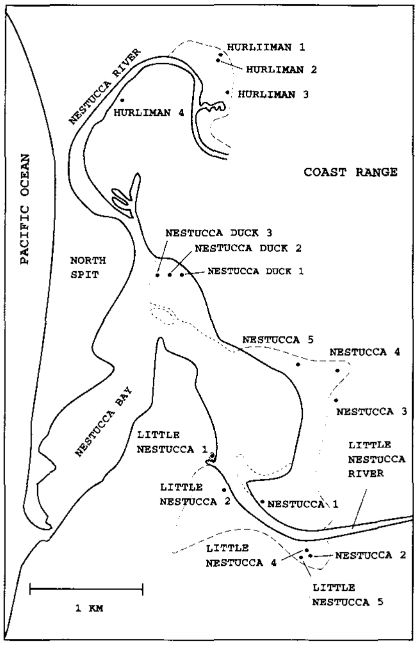

Figure 38. General map of Nestucca Bay with core site locations. The areas outlined with the wide dashed lines are pasture land and short dashed lines tidal marshes.

The deepest paleoseismological core taken in the Pacific Northwest was from the Hurliman 2 core site (Figure 39). Some 12 burial events were identified in 13 m (43 ft) of core depth at that site. The deepest buried peat yielded a radiocarbon age of approximately 5,700 RCYBP. The average recurrence interval of the upper six burial events is similar to that calculated for the lower six burial events, i.e., about 400–500 years. The average long-term recurrence interval for this central Cascadia site (12 buried peats in 5,700 years) is somewhat shorter than that estimated from offshore turbidites, i.e., 500–600 years, based on 13 turbidites in the last 6,700 years) (Adams, 1990).

Stop 11. Neskowin

Location (Figure 40): Walk the beach south of Neskowin in winter for evidence of standing forest stumps in the surf zone. **Requires low tide.**

Features: Late Holocene forest developed on wave-cut platform that is now in the surf zone.

Site description: A forest of tree stumps (more than 100 in number) is occasionally exposed in the surf zone immediately south of the town of Neskowin (Figure 41). This forest likely corresponds to one of several buried wetland horizons in the Neskowin River valley behind the beach. A radiocarbon age of one standing stump in the forest is approximately 2,000 RCYBP (C.D. Peterson and B. Paul, unpublished data, 1990). This forest is located on a Holocene wave-cut platform that was initially cut below sea level. It then emerged above sea level to grow the forest, then submerged below sea level, where it now stands in the surf zone. Abrupt subsidence and burial by beach sands are thought to have preserved the forest in its present sea-level position. The recognition of similar surf zone forests on the Oregon coast (1983–1985) helped focus the attention of some of these authors on late Holocene sea-level changes in the central Cascadia margin.

The Oregon coast consists of segments of sandy beaches, called littoral cells, that are separated by headlands or other barriers. Movement of sand up and down the coast is generally confined to each cell, with the headlands or other barriers inhibiting transport of sand from

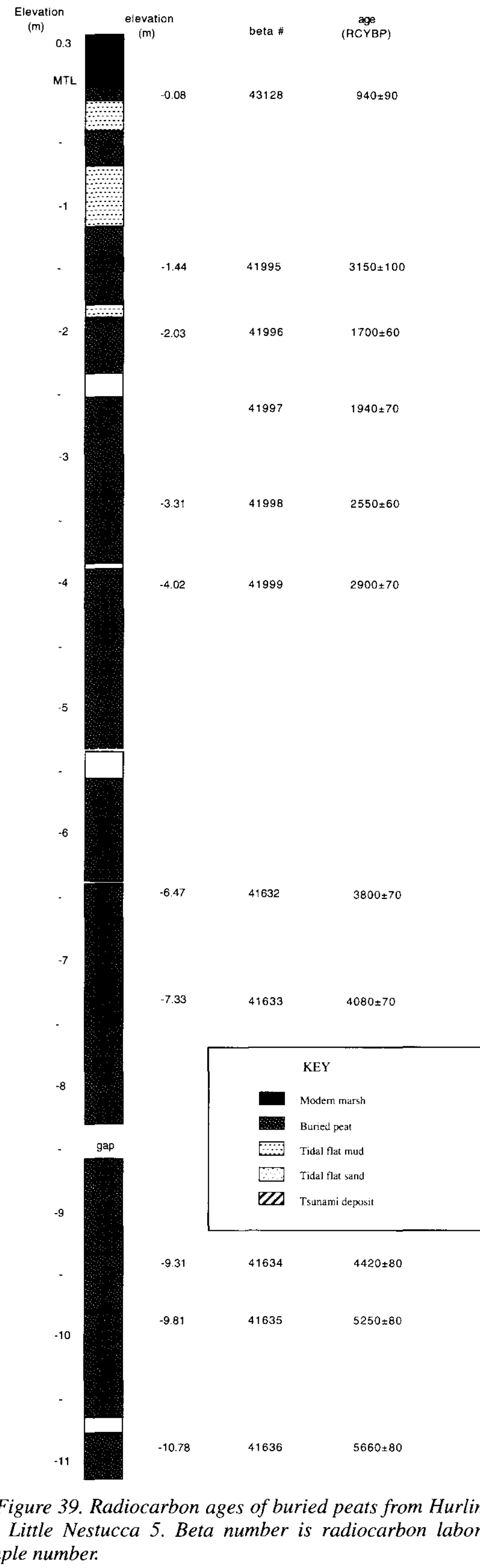

Figure 39. Radiocarbon ages of buried peats from Hurliman 2 and Little Nestucca 5. Beta number is radiocarbon laboratory sample number.

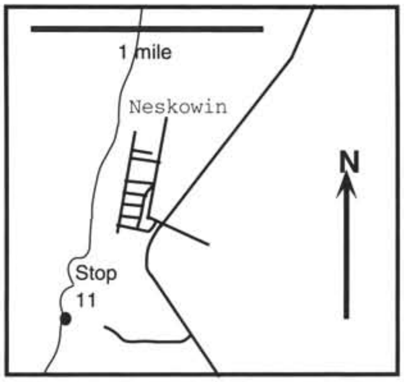

Figure 40. Location of Stop 11.

Figure 41. Photograph of large stumps developed on late Holocene wave-cut platform now in the surf zone. Age of one tree is about 2,000 RCYBP.

one cell to another. Progradational beaches north of Neskowin contrast sharply with widespread shoreline retreat in the Lincoln City cell to the south. The two cells differ in sand supply, even though the adjacent cells are similar in size, river drainage-basin area, and predicted rate of uplift (Goldfinger and others, 1992). We hypothesize that sand is excavated from bluffs in the Lincoln City cell and bypassed around Cascade Head to supply the Neskowin-Pacific City cell. Such a process could be accelerated during periods of beach and sea cliff erosion following coseismic subsidence.

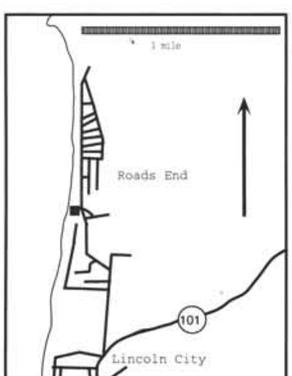

Figure 42. Location of Stop 12.

Stop 12. Roads End Beach Wayside

Location (Figure 42): At the north end of Lincoln City find Roads End intersection with Highway 101 (McDonalds Restaurant on opposite side of intersection). Take road north to the Roads End Beach Wayside parking lot. Walk down the path to the beach and head south 300 ft to view the late Pleistocene sea cliffs.

Features: Coseismic liquefaction features (convolute bedding) in late Pleistocene marine-terrace deposits.

Site description: The late Pleistocene terraces (assumed 80 ka in age) contain highly convoluted heavy-mineral layers that were originally deposited in planar foreshore beds (Figure 43). These convoluted beds are associated with clastic dikes, sills, and vent-collapse structures in many of the Oregon marine terrace deposits (Peterson and Madin, 1992). The tops of the convoluted beds at this site are eroded, proving the liquefaction to have occurred during the period of marine terrace deposition and not during the subsequent 80,000 years (Figure 44). Higher up in the section, some transitional backshore to eolian dune sands show a second liquefaction event. Some sites in the Lincoln City terraces show as many as three distinct liquefaction events that occurred during the period of deposition, near the end of that marine transgression.

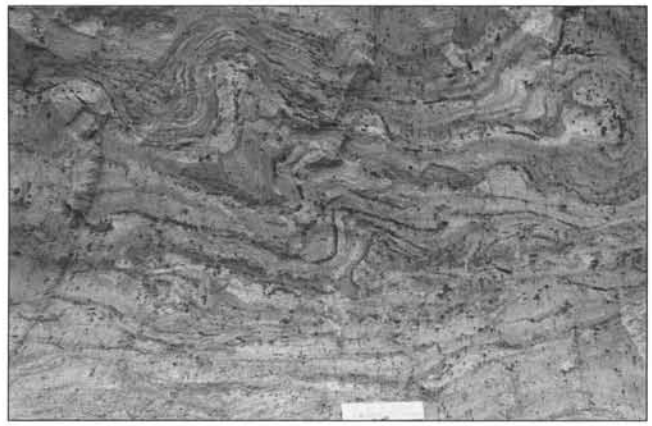

Figure 43. Photograph of highly convoluted beds in marine terrace deposits.

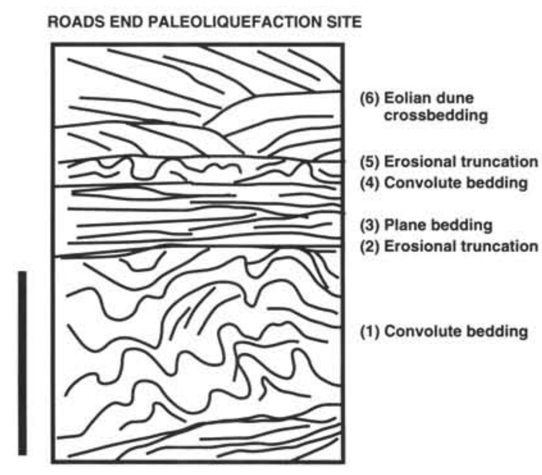

Figure 44. Convoluted foreshore deposits (liquefaction) are truncated by overlying planar beds. A second liquefaction event is represented by smaller scale convolute beds in overlying dune deposits. Liquefaction in dune deposits generally corresponds to permeability caps under interdune pond sediments. High pore pressure allowed localized liquefaction above the water table.

Stop 13. Salishan Spit, Siletz Bay

Location (Figure 45): Stop at the office of Salishan Lease Holders, Inc., on the west side of Highway 101, opposite Salishan Lodge. With permission, drive out to the Siletz Bay spit. Park at the north end of the Golf course and walk east on a dirt access road to about half the length of the fairway. Leave the road and walk north 300 ft through trees and/or brush to wetland areas.

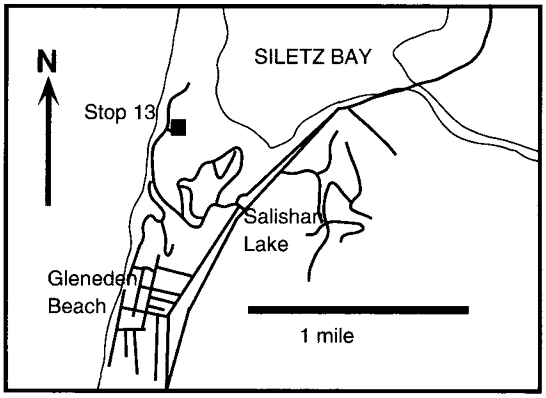

Figure 45. Location of Stop 13.

Features: Coseismically buried peats and tsunami-deposited sands.

Site description: Siletz Bay is separated from the Pacific Ocean by a spit that now contains an artificially stabilized foredune and numerous residences (Figures 1 and 46). Six coseismically buried peats with overlying tsunami deposits up to 25 cm (10 in.) thick are identified in marsh deposits along the spit and across the bay in the Millport Slough area (Darienzo, 1991) (Figures 46 and 47). The Salishan House site at the southern end of the spit contains particularly well-developed buried peats and overlying tsunami sands.

This is an example of one of our tsunami sensitive sites. The tsunami sands on the spit are derived directly from the beach (spit overtopping) except for the fifth buried peat, which shows a significant river sand component. Since the bay deposits adjacent to the spit are predominantly of river sand mineralogy (Peterson and others, 1984), a tsunami that propagated up the bay would deposit a mixed (beach/river) sand mineralogy. The overtopping of the spit by three of the last four paleotsunamis substantiates estimates of tsunami runup (+ 6 m [20 ft] MSL) predicted from the Cannon Beach sites discussed above. Additional work is needed here to establish the age of the topmost tsunami layer, which is contaminated by young roots descending from the modern wetlands.

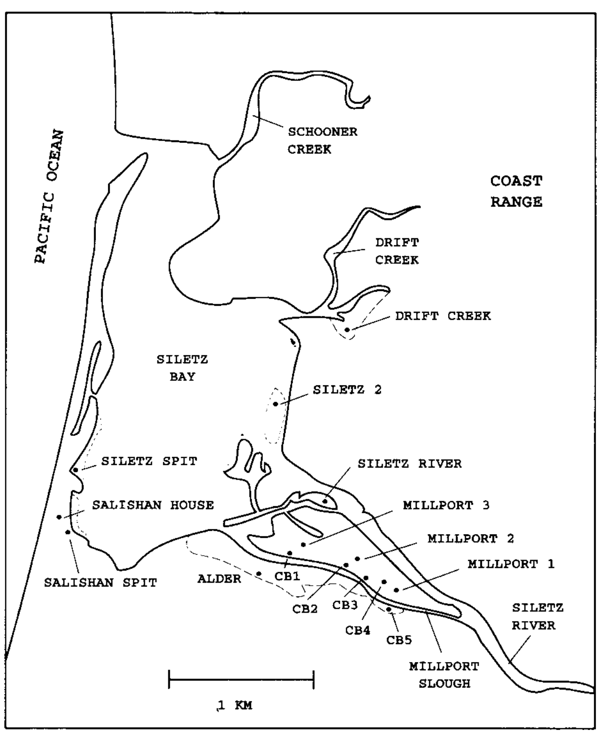

Figure 46. General map of Siletz Bay showing core site locations. Dashed lines show cored marsh areas.

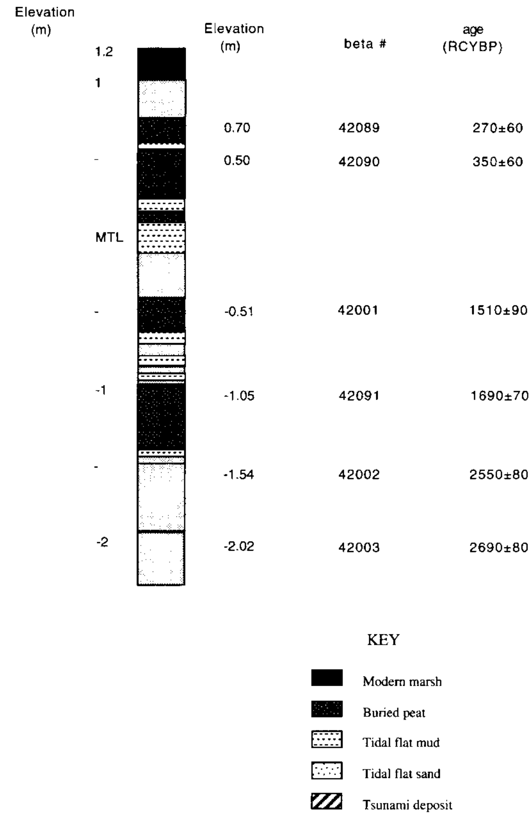

Figure 47. Radiocarbon ages of buried peats from Salishan House. Beta number is radiocarbon laboratory sample number.

Stop 14. Millport Slough, Siltez Bay

Location (Figure 48): Turn east off Highway 101 at Alder Road, immediately north of Salishan Lodge. Take the road to a small bridge over a tidal channel (Millport Slough). Explore cutbanks southeast of the Millport Slough bridge to find one to three buried wetland horizons. **Requires low tide.**

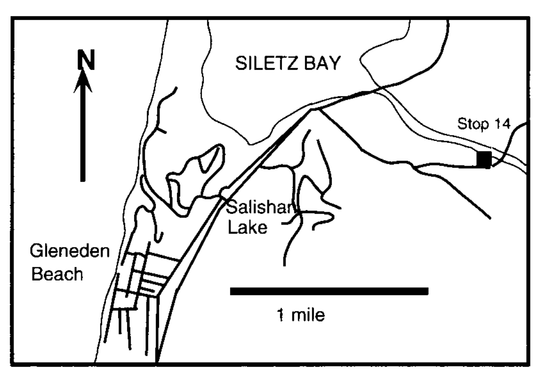

Figure 48. Location of Stop 14.

Features: Several buried wetlands in tidal creek cutbanks; additional buried peats and tsunami deposits in deeper cores.

Site description: This distal marsh site (Figure 46) is located well upriver of the bay mouth and ocean shoreline. It shows evidence of multiple uplift and subsidence cycles (Figure 49). Sufficient sediment supply during aseismic uplift cycles permitted the development of forested wetlands prior to subsequent subsidence events. Tsunami layers directly overlying buried peats are thin and discontinuous this far up the bay, but they do occur locally above the fourth, fifth, and seventh buried peats (Figure 49).

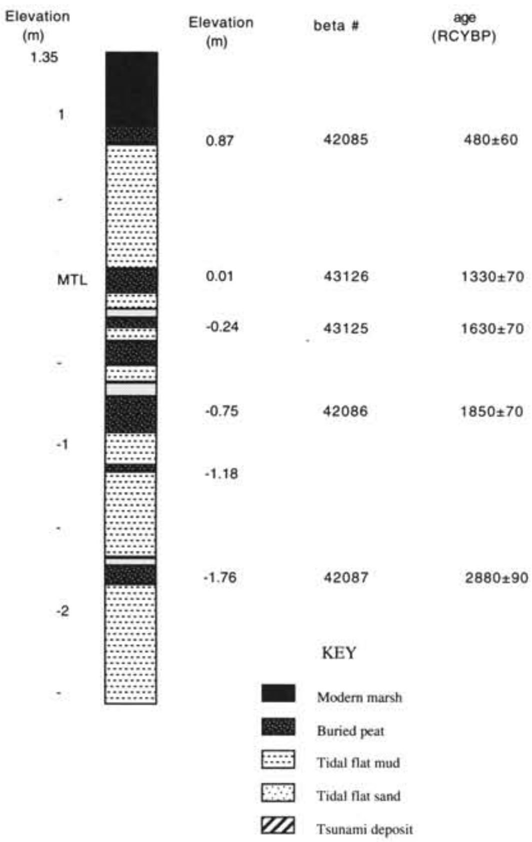

Figure 49. Radiocarbon ages of buried peats from Millport Slough. Beta number is radiocarbon laboratory sample number.

Stops 15 and 16. Gleneden and Lincoln Beaches

Location (Figure 50): Here we describe two separate late Pleistocene liquefaction sites. The Gleneden site is easily accessed from the Gleneden Beach Wayside, about 1 mi west of Highway 101. Walk down the beach access trail and continue north (30–650 ft) to view the sea cliffs. The Lincoln Beach site can be accessed by a long beach walk, or with permission from the Sea and Sand Trailer Park owners. From the Trailer Park, just north of Lincoln Beach, walk north (160 ft) to view the sea cliff deposits.

Features: Coseismic liquefaction features (flames, sills, and dikes) in late Pleistocene marine terrace deposits.

Site description: At the Gleneden Beach Wayside site are well-exposed examples of injection flames and lateral sills in late Pleistocene beach and dune deposits (assumed age 80 ka). The largest flame structure (> 1 m [3 ft] in height) at this site is located under a slight overhang at a distance of about 100–150 m (300–500 ft) north from the beach access path. The smaller clastic sills throughout the outcrop (Figure 51) are representative of liquefaction evidence at many late Pleistocene coastal terrace sites in Oregon and Washington (Peterson and Madin, 1992). The sills are identified by injection terminations of primary bedding at both upper and lower sill contacts (Figure 52).

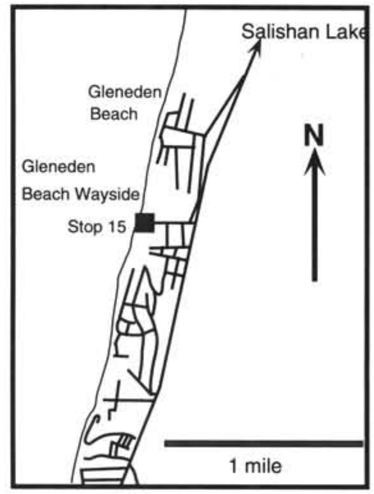

Figure 50. Location of Stop 15; Stop 16, not shown, is located on the beach 2 mi south of Stop 15.

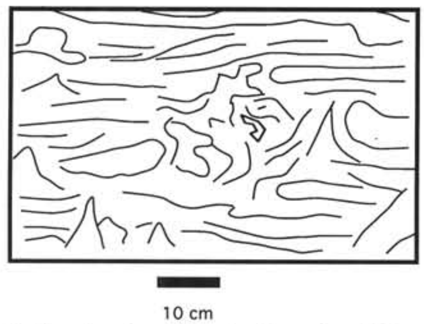

Figure 51. Line drawing of clastic sills and small flame structures in coarse backshore sands from a late Pleistocene marine terrace deposit at the Gleneden Beach site.

Figure 52. Photograph of clastic sills in backshore beach deposits of late Pleistocene marine terrace.

The liquefaction features at the Sea and Sand Trailer Park site include large-scale vertical and horizontal injections that have dismembered horizontal peats in muddy deposits (10–15 m [30–50 ft] outcrop length). These deposits are thought to represent a back-berm lagoonal setting, as evidenced by the basal channel contacts in beach/barrier deposits. The sand injections actually represent two different episodes of coseismic liquefaction. The initial injection event(s) occurred during the period of deposition

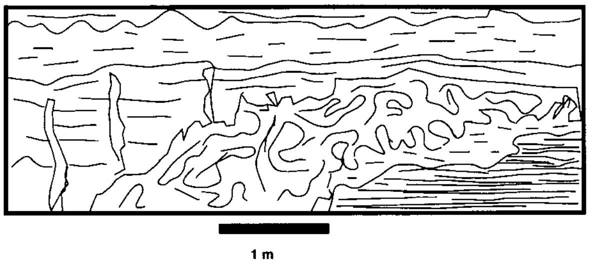

Figure 53. Line drawing of late Pleistocene lagoonal deposits showing two episodes of coseismic liquefaction at Lincoln Beach Trailer Park. Thin peaty layers in the section are dismembered by vertical and horizontal sand injections. These severely disturbed beds underlie an undeformed silty layer (< 0.5–1 m [2–3 ft] thick) that caps the section. Thin vertical cracks are filled with unweathered sand that is much younger (no iron staining) than the weathered lagoonal deposits.

of the section (about 80 ka) followed by subsequent weathering of the deposits. A second set of thin vertical cracks (50-cm [20-in.] spacing) cut the weathered deposits, and these cracks are filled with unweathered sands (possibly Holocene? in age), suggesting a more recent event of injection(s) (Figure 53).

ACKNOWLEDGMENTS

Support for the research that has been conducted at many of these field trip stops has been provided by Oregon Sea Grant College Program, National Earthquake Hazards Reduction Program, National Science Foundation, Oregon Department of Geology and Mineral Industries, Federal Emergency Management Agency, and the Clatsop County Sheriff's Office.

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DOGAMI releases publication updates

Three new releases of the Oregon Department of Geology and Mineral Industries (DOGAMI) represent updates of earlier publications: the annual report and map of the Mist Gas Field, the database of mineral localities, and the directory of mineral producers in the state.

Mist Gas Field Report
Open-File Report O–93–1

The Mist Gas Field Report is now available with all activity and changes for the year 1992. The report includes (1) the Mist Gas Field Map, showing location, status, and depth of all wells, and (2) the listing of production figures from the initial production in 1979 through the end of 1992, showing well names, revenue generated, pressures, annual and cumulative production, and other data. The new Mist Gas Field Report is DOGAMI Open-File Report O–93–1 and sells for $8.

Mineral Information Layer for Oregon (MILOC)
Open-File Report O–93–8

MILOC is a database in dBase III+ format that can be imported into computerized geographic information systems or used with a personal computer as a stand-alone, county-by-county database. For use as a mineral-data layer, each site is located by both latitude/longitude and Universal Transverse Mercator (UTM) coordinates.

The database provides information on nearly 8,000 mineral occurrences, prospects, and mines in Oregon. Records on individual sites include a great variety of data on location, commodity, geology, descriptions of mine workings, and many other subjects. The updated version has been made more user-friendly and, in response to input from users, contains some changes in the structure of the records.

The database comes as a set of two 1.2-megabyte (5¼-inch, high-density) diskettes in MS-DOS format and sells for $25. Owners of the first edition may exchange their original diskettes for the new ones at the reduced price of $15.

Directory of Mineral Producers in Oregon
Open-File Report O–93–9

The *Directory of Mineral Producers* was derived from a Departmental computer listing originally designed for internal use. Its updated version includes approximately 1,000 production sites operated by about 550 mineral producers and includes more exploration companies than the earlier version.

The 56-page directory contains two tables: Table 1 is arranged alphabetically by commodity and operator, covering over 30 commodities—from "Abrasives" to "Zeolite"—and listing producers with addresses and township/range designations of their operating sites. Table 2 is arranged alphabetically by county and commodity, showing in abbreviated form which commodities are produced by whom in a given county. The price for the new directory, Open-File Report O–93–9, is $8.

The new reports are now available over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; and the DOGAMI field offices in Baker City: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and Grants Pass: 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

Position Announcements
Oregon Department of Geology and Mineral Industries

Geotechnical Engineer/Seismic Hazard Geologist/Engineering Geologist

The Oregon Department of Geology and Mineral Industries seeking to hire a geologist, engineering geologist, or geotechnical engineer to participate in seismic hazard studies. The minimum qualifications are a master's degree in geology, engineering geology, geotechnical engineering, or geophysics. Duties will include geologic mapping, geologic computer modeling, shallow seismic reflection profiling and other detailed geophysical surveys, fault trenching, paleoliquefaction studies, design, contracting, and execution of drilling and cone penetrometer programs, and other tasks necessary to identify earthquake sources and map the geologic component of earthquake hazard in western Oregon urban areas. In addition to the minimum educational requirements, applicants should have significant experience in two or more of the specific areas listed above. Excellent written and oral communication skills, particularly with nontechnical audiences and media, are essential. Applicants with significant mathematics, engineering, and computer background will be more competitive. This position will commence in late 1993 or early 1994, and the position is guaranteed through July 30, 1995, with the possibility of continuation beyond that date. Salary is commensurate with experience; negotiations will start at $2,606 per month, with an excellent benefit package. This position will be stationed in Portland, Oregon. Field work in the Willamette Valley and along the Oregon coast will be required. Interested applicants should send a resume and cover letter to Ian Madin, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street # 28, Portland, OR 97232. Resumes will be accepted until October 1, 1993. After that date, necessary application materials and an explanation of the hiring process will be provided to applicants.

Minerals Economist

The Oregon Department of Geology and Mineral Industries is seeking to hire a minerals economist to participate in data collection, data analysis, and communication regarding the economics of mineral production in the state with attention to demand for aggregate and other mineral commodities.

Duties will include developing data and models for mineral production in Oregon, participating in select mineral economic issues in parts of Oregon, completing an annual list of Oregon mineral producers, and developing new reports of selected case studies of mineral production in various parts of the state.

Minimum qualifications include proficiency in statistics, excellent communication skills, excellent interpersonal qualities under a variety of conditions, and training in economics. Experience in mineral economic analysis and computer skills are desirable. Applicants with significant qualifications in these categories will be the most competitive.

This position will begin in early 1994 and is guaranteed through June 1995, with the possibility of continuation beyond that date. Salary is commensurate with experience.

The position is stationed in Portland, Oregon. Travel throughout Oregon will be required.

Interested applicants should send a resume and cover letter to Don Hull, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street # 28, Portland, OR 97232. Resumes will be accepted until November 15, 1993. After that date, necessary application materials and an explanation of the hiring process will be provided to applicants.

Reclamationist

The Oregon Department of Geology and Mineral Industries Mined Land Reclamation program will soon have a position opening for a reclamationist.

The reclamationist conducts field inspections of proposed and active mining operations, produces site compliance reports, calculates reclamation bonds, and participates in technical reviews as part of an interdisciplinary team.

Qualifications for a reclamationist typically include at least a bachelor's degree with a major in environmental, biological, or physical science, or in engineering and at least one year of experience in reclamation, environmental coordination, or engineering. Preference is given for experience in mining.

Anyone sending a resume will receive a formal announcement of the job opening at the time the position officially opens. Expected hiring is January 1994. Starting salary range is $2,606–$2,871 per month plus excellent benefits.

If you are interested, please send a resume and cover letter to Department of Geology and Mineral Industries, Attn: Recruiting, 1536 Queen Avenue SE, Albany, OR 97321.

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Historical earthquakes in and around Portland, Oregon

by Jacqueline D.J. Bott and Ivan G. Wong, Woodward-Clyde Federal Services, 500 12th Street, Suite 100, Oakland, California 94607

ABSTRACT

A reevaluation of all known moderate-sized earthquakes in the Portland area has revealed that at least 17 events of Richter magnitude (M_L) 4 and larger have occurred in historic time; six events have been M_L 5 and greater. These observations indicate that the Portland region is the most seismically active area in Oregon. Based on the historical record, recurrence estimates suggest that a M_L 5.5 and larger earthquake will occur about every 100 to 150 years and a M_L 6 and larger earthquake every 300 to 350 years. A crustal earthquake of M_L 6 or greater could generate a greater level of ground shaking in the Portland metropolitan area than could a moment magnitude (M_W) 8+ event on the Cascadia subduction zone and thus needs to be considered in seismic hazard evaluations of the region.

INTRODUCTION

Fewpeople realize that the region centered on the city of Portland is possibly the most seismically active area within the state of Oregon. The Richter magnitude (M_L; see Table 1) 5.6 Scotts Mills earthquake of March 25, 1993 (Figure 1), which shook most of western Oregon and southwestern Washington, is the largest event known to have occurred in northwestern Oregon and attests to the earthquake potential of the region. The absence of larger events in the historical record, however, has led to the general belief that larger events cannot occur. Recent recognition of the potential for a great earthquake (moment magnitude [M_W] 8+) rupturing the Cascadia subduction zone has also accelerated research into investigating crustal faults, which are the sources of the earthquakes occurring in the Portland region. Seismic monitoring of earthquakes in northern Oregon since 1980 has led to an improved understanding of seismogenic sources and the rate of earthquake occurrence in the region.

In this study, we have reviewed the earthquake history of the Portland region and reevaluated all events of approximate M_L 4 and greater that have occurred since the first recorded earthquake in 1846. Specifically, estimates of the magnitudes of these moderate-sized earthquakes were based on the size of their felt areas (i.e., areas in which the earthquake was reported as having been felt by people)—particularly, of course, those earthquakes that occurred prior to adequate seismographic coverage and thus do not have instrumentally determined values. After these reevaluated events have been incorporated into the historical record, the earthquake recurrence for the Portland region can be estimated. Such information is critical for the estimation of average recurrence intervals of earthquakes larger than the largest ever observed, e.g., M_L 6 and greater, and hence for the assessment of seismic hazards.

EARTHQUAKE DETECTION

How do we learn about earthquake occurrences? Historical earthquake records can generally be divided into records of the pre-instrumental period and the instrumental period. In the absence of adequate seismographic coverage, the detection of earthquakes is generally based on direct observations and felt reports. The results are strongly dependent on population density and distribution, and the study region, typical of much of the western United States, was sparsely populated in the 1800s. Thus the detection of pre-instrumental earthquakes shows varying degrees of completeness.

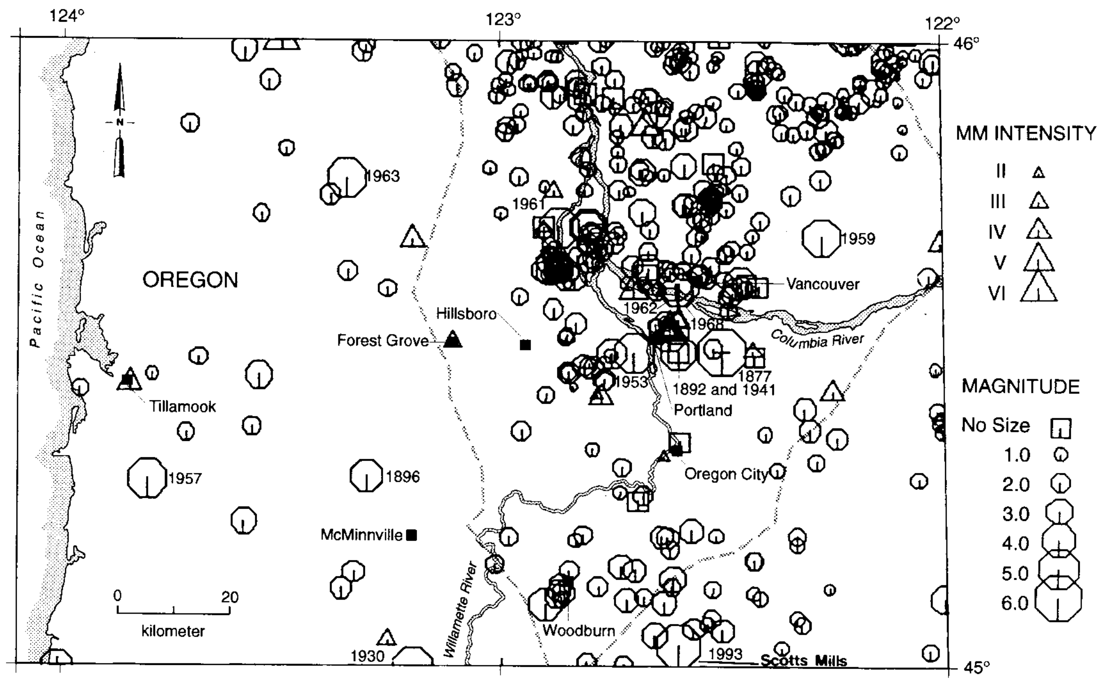


Figure 1. Historical seismicity of northwestern Oregon and portions of southwestern Washington during the period from 1846 to the present. In this study, the Portland region coincides with the Portland fold belt province as defined by Unruh and others (1993), and its boundaries are shown by the dashed line.

Table 1. *Types of earthquake magnitudes*

Symbol	Description
M_L	Richter (local) magnitude
M_S	Magnitude derived from recorded surface waves
m_b	Magnitude derived from recorded body waves
M_D	Magnitude derived from recorded duration of earthquake
M_W	Moment magnitude, derived from seismic moment
M	Unspecified magnitude

An evaluation of the population growth in the Portland region shows gradual increase up to 1940 in all counties except Multnomah (Oregon) and Pierce (Washington). Despite this slow growth, however, many widely distributed towns were established in or near the Willamette Valley and along the Columbia River as early as the 1850s. For example, Portland was first settled in the mid-1840s. Similarly, Salem was established in 1844, Hillsboro in 1845, Forest Grove in 1850, Eugene in 1852, McMinnville in 1853, and Tillamook in 1866 (Figure 1). Newspapers in the region, which are a major source of documentation, began publishing soon after the establishment of the major towns. Based on this relatively early settlement in the region, we estimate that the pre-instrumental historical record is complete for earthquakes of M_L 5 and larger since about 1850.

Although seismograph stations were established as early as 1906 in Seattle and 1944 in Corvallis, adequate seismographic coverage of the Portland region did not begin until 1980, when the University of Washington expanded its regional network into northwestern Oregon. Prior to this time, few stations operated in Oregon. Two of the most important seismograph stations, although at considerable distance from Portland, were the Blue Mountains Observatory in northeastern Oregon and the Longmire station in southwestern Washington. The latter was operated as part of the Worldwide Standardized Seismographic Network in addition to the Corvallis station. Based on this evolution of seismographic coverage, the historical record is complete at small magnitude levels (M_L 2.5 and greater) only since 1980.

SIGNIFICANT EARTHQUAKES

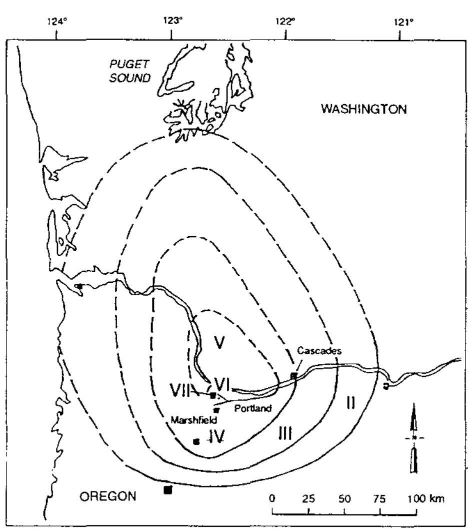
Introduction

In historical times, 17 earthquakes of estimated M_L 4 and greater are known to have occurred within the Portland region (Figure 1). These events, their felt effects and felt areas are described in the following discussion. Available isoseismal maps including ones developed in this study for the earthquakes in 1941, 1961 (August 18, September 17, and November 6), and 1963 were evaluated.

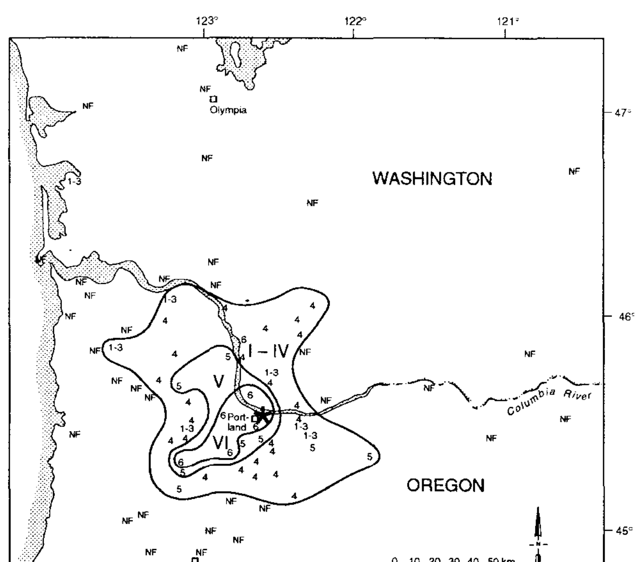
On the basis of several empirical relationships between felt areas of various intensities and M_L developed by Toppozada (1975) for California and western Nevada, we have attempted to estimate the magnitudes of the significant historical earthquakes in the Portland region. We believe that these relationships are applicable to both western Oregon and Washington because the crustal attenuation in both regions appears to be comparable to California. For example, the attenuation factor, Q_0, is about 150 in much of California and approximately 200 in northwestern Oregon and southwestern Washington (Singh and Herrmann, 1983). When we use the well-constrained felt areas of the 1962 Portland and the 1981 Elk Lake earthquakes for calibration, the Toppozada (1975) relationships appear to estimate the actual magnitudes quite well.

1877 earthquake

The earliest known significant historical earthquake in the Portland region occurred on October 12, 1877 (Figure 1). Two events are actually reported for this day, one at about 9 a.m. PST and one at 1:53 p.m. PST (Berg and Baker, 1963). There appears to be some confusion in the various anecdotal sources as to which event had a maximum intensity of Modified Mercalli (MM) VII (see Table 2 for description of MM intensity scale). Research by Thenhaus (1978) uncovered the fact that a smaller event of maximum intensity MM III occurred at 9 a.m. and was probably located near Cascades, Washington, because it was not reported as felt elsewhere. The second earthquake, at 1:53 p.m., occurred near Portland, where it caused chimneys to break (MM VII). It was also felt in a number of towns around Portland (e.g., Marshfield) and as far north as Puget Sound (Figure 2). Based on the isoseismal map developed by Thenhaus (1978), the total felt area is estimated to be 41,250 km^2.



12 October 1877 M_L 4¾



29 December 1941 M_L 4½

Figure 2. Isoseismal maps for the 1877 and 1941 earthquakes. Asterisk indicates instrumentally determined epicenter.

Table 2. *Abridged Modified Mercalli (MM) intensity scale. Equivalent Rossi-Forel (RF) intensities in parentheses.*

I	Not felt except by a few under especially favorable circumstances. (RF I).
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (RF I to II).
III	Felt quite noticeably indoors, especially on upper floor of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (RF III).
IV	Felt indoors by many, outdoors by few during the day. Some awakened at night. Dishes, windows, door disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (RF IV to V).
V	Felt by nearly everyone, many awakened. Some dishes, windows, and other fragile objects broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (RF V to VI).
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (RF VI to VII).
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-Ebuilt ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (RF VIII).
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel wall thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels. Persons driving cars disturbed. (RF VIII + to IX).
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings; with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (RF IX +).
X	Some well-built structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (RF X).
XI	Few, if any, [masonry] structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Averaging the estimated magnitudes from the various felt area relationships indicates that the 1877 earthquake probably was about a M_L 5¼ event (Table 3). For comparison, the M_L 5.5 Portland earthquake of 1962 was felt in Seattle with an intensity of MM IV, whereas the 1877 earthquake was felt only in the southern Puget Sound with an intensity of MM II. The less severe damage reported for the 1877 earthquake supports the conclusion that the 1877 earthquake had a smaller magnitude than the 1962 event.

1892 earthquake

At 8:30 p.m. PST on February 3, 1892, a "severe" earthquake (MM VI) (Townley and Allen, 1939) caused brick buildings to sway and windows to rattle in Portland, terrifying people inside (Holden, 1898) (Figure 1). The motion was reported as lasting 30 seconds and as being the most severe shock ever felt in Portland, although this is puzzling, given the observations of the 1877 event. As far as is known, no major damage occurred. In Astoria, the earthquake lasted 3 seconds, causing houses to shake. It was felt as a light shock as far west as the Yaquina Head lighthouse on the Oregon coast. The earthquake was felt over an area of more than 26,000 km^2 (Coffman and others, 1982), although no known isoseismal map has been developed. Based on this felt area, a poorly constrained value of a M_L 5 is estimated (Table 3).

1896 earthquake

The inhabitants of McMinnville were awakened at 3:17 a.m. PST on April 2, 1896, by an earthquake of maximum intensity MM VI, accompanied by a loud rumbling noise and followed by two or three distinct shocks in rapid succession (Townley and Allen, 1939). The earthquake was felt in Portland at about 3:20 a.m. PST as a single shock of brief duration and was also felt as far south as Salem. The earthquake was felt over an area of about 2,600 km^2 (Coffman and others, 1982) and is thought to have occurred close to McMinnville (Figure 1), which was the location of the greatest felt intensity (Berg and Baker, 1963). We estimate a M_L 4 for this earthquake, because we believe the felt area may be somewhat underestimated (Table 3).

1930 earthquake

On July 19, 1930, at 6:38 p.m. PST, an earthquake of intensity MM V–VI (Coffman and others, 1982) occurred near Perrydale, Oregon, a town about 20 km northwest of Salem (Figure 1). Plaster cracked and windows rattled at McCoy (Neumann and Bodle, 1932), and the roadbed was cracked 0.8 km west of Perrydale. A smaller foreshock occurred in the same area on July 8 at 12:30 p.m. PST but with a maximum intensity of only MM III. Although no felt area has been estimated for the larger earthquake, reports of localized damage indicate a magnitude of at least M_L 4 (Table 3).

1941 earthquake

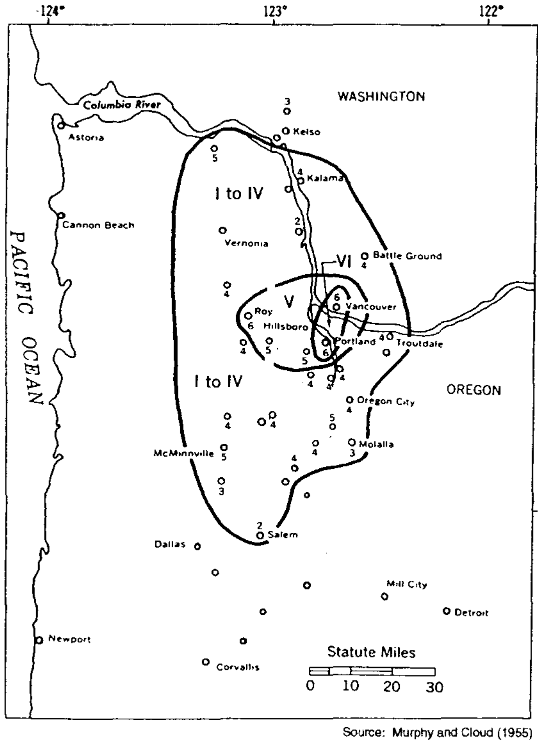
A strong earthquake was felt by most residents of Portland on December 29, 1941, at 10:37 a.m. PST (Figure 2). Small objects were displaced, and some trees and bushes were shaken (Neumann, 1943). Display windows shattered, and plaster cracked in Hillsboro and Sherwood. The earthquake caused chimneys to crack, vases to overturn, trees to shake and a school bell to ring in Yamhill, frightening many people (Neumann, 1943). Intensity MM VI effects were also felt in Vancouver and Woodland, Washington, where plaster cracked, vases overturned, and small objects moved. The felt area is estimated to be about 9,000 km^2, although this value is not well constrained. The epicenter is assigned to the Portland area, the location of the maximum intensity (Figure 1). Based on the size of the felt area, the earthquake appears to be about M_L 4½ (Table 3).

1953 earthquake

Coffman and others (1982) report that an earthquake of intensity MM VI occurred in northwest Oregon on December 15, 1953, and was felt over an area of about 8,000 km^2 (Figures 1 and 3). Slight damage was sustained in Portland and Roy, Oregon, and in Vancouver, Washington. The earthquake occurred sometime just before 8:32 p.m. PST on December 15, the time the earthquake was instrumentally recorded in Corvallis. In Portland, it was generally felt, frightening many people, cracking plaster, and causing objects and dishes to fall (Murphy and Cloud, 1955). Murphy and Cloud (1955) report one cracked chimney, slight damage to a tile fireplace, and cracks at the juncture between a one-story building and the abutting apartments. The location of this event is well constrained by the isoseismal map (Figure 3), which shows the maximum intensity within a small zone between Vancouver and Portland. Calculations of magnitude from the felt area suggest this earthquake to be about M_L 4½ (Table 3).

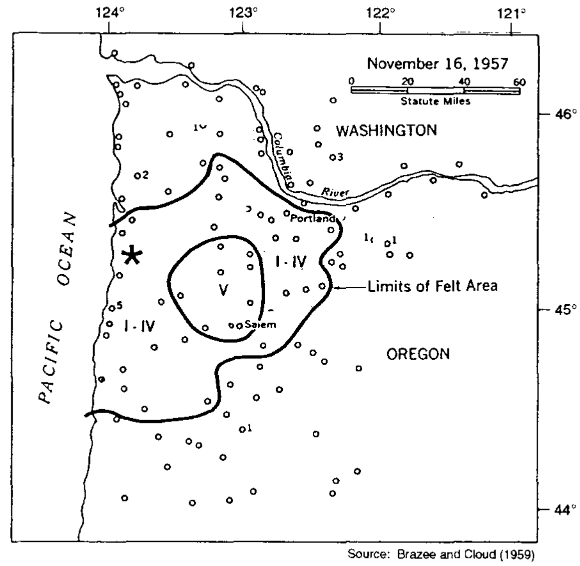
1957 earthquake

On November 16, 1957, at 10:00 p.m. PST, an earthquake shook the area just northwest of Salem (Brazee and Cloud, 1959) (Figure 4). The instrumental (i.e., instrumentally determined) location reported in Coffman and others (1982) lies about 80 km northwest of Salem, 60 km further west than the felt epicenter would suggest (Figure 1). This large discrepancy may be due to a



15 December 1953 M_L 4½

Figure 3. Isoseismal map for the 1953 earthquake.



16 November 1957 M_L 4½

Figure 4. Isoseismal maps for the 1957 earthquake. Asterisk indicates instrumentally determined epicenter.

bias in the population distribution or site-response effects in the Willamette Valley area around Salem. Similarly, strong ground shaking occurred in the Salem area in the recent Scotts Mills earthquake, as typified by the damage to the State Capitol building, although the epicenter lay about 32 km to the east. Most people in Salem were frightened by the 1957 earthquake, where the highest intensity is reported (MM VI) (Figure 4). However, only slight damage, consisting of cracked walls and plaster, was reported in the western part of Salem (Brazee and Cloud, 1959). Momentary power outages were reported, including a television blackout. Some people felt a single sharp, blast-like jolt, while others said the vibrations lasted for several seconds. The magnitude, based on the felt area of 13,600 km^2 assumed for this event (Figure 4), is estimated to be about M_L 4½ (Table 3).

August 18, 1961, earthquake

At 8:46 p.m. PST, on August 18, 1961, a maximum intensity MM VI earthquake was felt in and around the towns of Lebanon and Albany south of Salem (cover illustration). This earthquake was felt over an area of 18,300 km^2 from southwest Lane County in Oregon to Cowlitz County in Washington. The instrumental location is approximately 40 km northeast of the location of the maximum intensity (cover illustration), where chimneys toppled, windows broke, traffic lights and signs fell, and plaster cracked. The instrumental (i.e., instrumentally determined) magnitude assigned to this earthquake is M 4.5 (unspecified magnitude scale) by Cal Tech in Pasadena, California, and a coda duration magnitude (M_D) 3.9 as measured at the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993). The available data show a large felt area trending north-south, but the east-west extent is difficult to constrain. The magnitude of the event from limited felt information suggests a M_L 4½ (Table 3).

September 15/17, 1961, earthquakes

Two moderate earthquakes occurred on September 15 and 17, 1962, approximately in the same vicinity near Siouxon Peak in southwestern Washington. The maximum intensities and felt areas are MM VI and 22,000 km^2, and MM VI and 24,300 km^2, respectively (cover illustration and Table 3). The first event occurred at 7:25 p.m. PST near Cougar, Washington, in Gifford Pinchot National Forest. The event was felt by and frightened many people, and the shock lasted 20 seconds. Small objects were overturned, and hanging objects swung east-west (Lander and Cloud, 1963). Several aftershocks that were felt followed the first event.

The September 17 earthquake, the larger of the two events, occurred at 7:56 a.m. PST. Instrumental magnitudes for the two principal earthquakes on September 15 and 17 are M_L 4.8 and M_L 5.1, respectively, determined from the Wood-Anderson seismograph operated by the University of California at Berkeley (UCB) in Arcata, California (Grant and Weaver, 1986) (Table 3). The epicenter of the larger event was southeast of Cougar (cover illustration), where the shaking lasted 20 seconds, and most observers felt it and heard moderate earthquake noises. A house shifted 2.5 cm on its foundations in North Bonneville, Washington. In Stevenson, Washington, there was slight damage to chimneys, cement foundations cracked, a woodstove moved 15 cm, and plate glass "rippled like a flag" (Lander and Cloud, 1963). In Latourell, Oregon, some cracks were found in a heavy cement basement foundation. Booming noises were heard at Yale Dam and Washougal, Washington. Grant and Weaver (1986) suggest that this earthquake occurred within the Mount St. Helens seismic zone.

November 6, 1961, earthquake

At 5:29 p.m. PST on November 6, 1961, an earthquake was widely felt over an area of 23,000 km^2 in northwest Oregon and southwest Washington (cover illustration). There is some uncertainty in the instrumental location of this earthquake. However, an aftershock of maximum intensity MM V on November 7 at 1:30 p.m. was felt principally in the Portland area, where china clinked, pictures tilted, and a television set slid across the floor. The location of the aftershock suggests that the main shock may have occurred closer to Portland than the instrumental locations would indicate (cover illustration and Figure 1).

During the main shock, minor cracking of plaster appeared to be the principal damage (Lander and Cloud, 1963). Some people reported that this event was the sharpest shock felt in Portland since the body-wave magnitude (m_b) 7.1 earthquake of April 13, 1949, that was centered around Olympia, caused $25 million in damage, and killed eight people. The 1961 earthquake caused a brick chimney to fall, plaster to crack, interior lights to break, door frames to jam, and a water fountain in Portland to spring a leak (Lander and Cloud, 1963). Groceries were thrown from shelves in a grocery store, and windows rippled. People reported noises from several directions. In nearby Glenwood, Washington County, the earthquake was felt by all in the community. Concrete foundation blocks broke, loud rumbling noises like a truck passing by were heard, and a porch roof under repair fell down (Lander and Cloud, 1963).

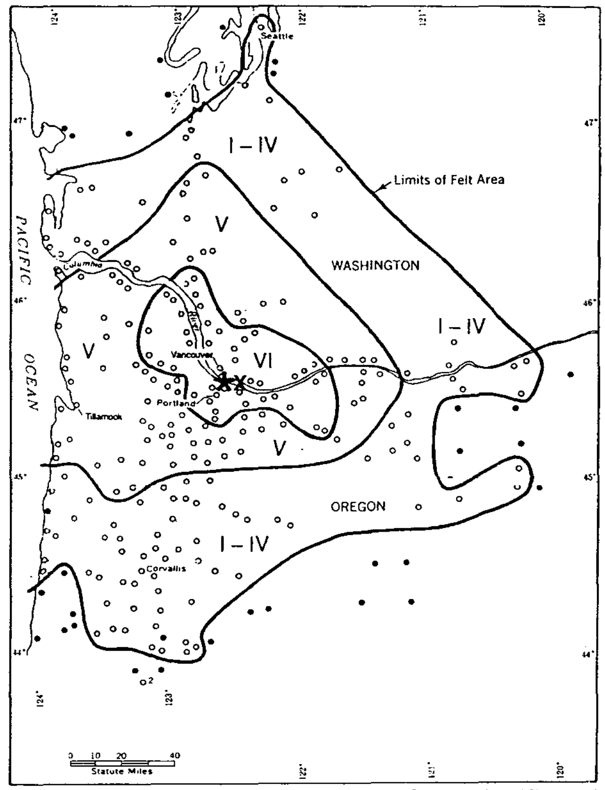
A magnitude of M_D 4.5 has been estimated from the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993); however, Grant and Weaver (1986) note that Longmire magnitudes tend to overestimate the actual value by several tenths of a magnitude unit. Based on the felt area, we estimate a M_L 5 for the 1961 event (Table 3).

1962 earthquake

Until the recent Scotts Mills earthquake, the largest event in historical times in the Portland region occurred at 7:36 p.m. PST on November 5, 1962, with a maximum intensity of MM VII (Coffman and others, 1982) (Figure 1). Numerous chimneys cracked or fell down, windows broke, and plaster cracked in Portland (Dehlinger and Berg, 1962). Six light fixtures fell in a grocery store, and the newsroom located on the fourth floor of the *Journal* Building sustained cracks (Lander and Cloud, 1964). No damage to utilities occurred, but the upsurge of telephone use after the earthquake caused a temporary disruption of service in some areas. A crack 7 m long and 4 cm wide appeared on a road between Tillamook and Oceanside, Oregon (Lander and Cloud, 1964). In Vancouver, Washington, a large chandelier fell, and a jail elevator was put out of service. Numerous aftershocks occurred, but none were large enough to be felt in Portland.

The magnitude of this earthquake has been variously estimated as M 4¾ (UCB-Berkeley, probably M_L), M_L 5 (Dehlinger and others, 1963), M_L 5½ (UCB-Arcata), and more recently as M_D 4.9 and M_L 5.2 (Yelin, 1990) and M_W 5.2 (Yelin and Patton, 1991) (Table 3). It was felt over a wide area (estimated as 52,400 km^2 from Coffman and others [1982] and 70,000 km^2 in this study) (Figure 5). Our magnitude estimate based on the felt area is M_L 5½ (Table 3). Peak ground accelerations of 0.076 *g* (vertical) and 0.103 *g and 0.096 g (horizontal) were measured at a the U.S. Coast and Geodetic Survey strong motion seismograph in the former State Office Building in downtown Portland (Dehlinger and others, 1963). Dehlinger and others (1963) located this event at a depth of 15–20 km, although this value is not well constrained.*

In a more recent study of earthquakes in the Portland area, Yelin and Patton (1991) relocated this event to 15 km northeast of downtown Portland, just east of the original epicentral location of Dehlinger and others (1963), and to a depth of 16 km (Figure 5).



Source: Lander and Cloud (1964)

5 November 1962 M_L 5.5

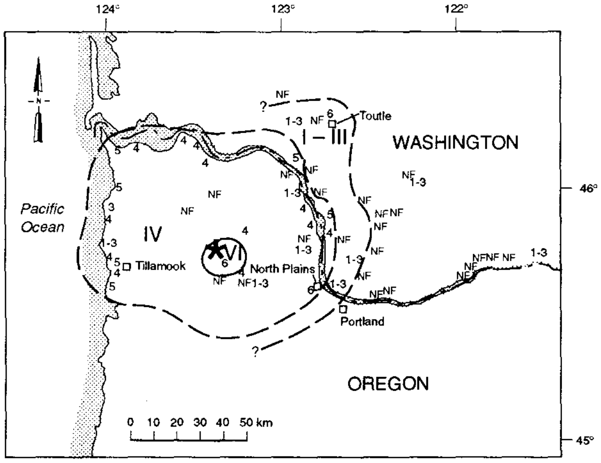
Figure 5. Isoseismal map for the 1962 earthquake. Asterisk indicates instrumentally determined epicenter.

1963 earthquake

At 6:36 p.m. PST on December 26, 1963, an earthquake was felt with a maximum intensity of MM VI in northwestern Oregon (von Hake and Cloud, 1965). This earthquake was felt over an area of only 10,700 km^2 (Figure 6), and damage was slight. Plaster cracked in a few places, and books and pictures fell in North Plains and Timber, Oregon, and Toutle, Washington. In Tillamook, Oregon, a car swayed and went to the opposite side of the highway before being controlled. The isoseismal map for this earthquake (Figure 6) is not well constrained due to differing intensity reports in closely spaced locations—possibly an indication that varied site conditions played a major role in ground motions. The instrumental location, however, agrees well with the area of maximum intensities northwest of Portland (Figures 1 and 6). A magnitude of M_D 4.1 (Longmire) and m_b 4.5 (NOAA) have been instrumentally determined (Table 3). The calculated magnitude from the felt area is M_L 4½.

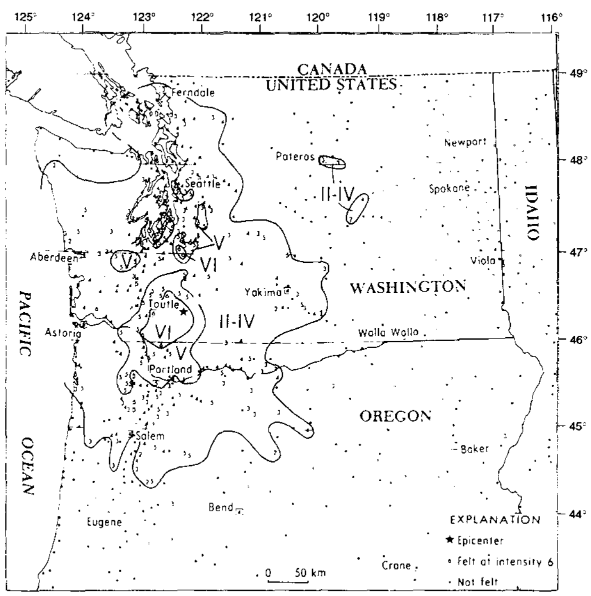
1981 earthquake

The 1981 Elk Lake, Washington, earthquake, the largest known earthquake associated with the St. Helens seismic zone, occurred at 10:09 p.m. PST on February 13, 1981. The earthquake, with magnitudes m_b 5.1, M_S (surface-wave magnitude) 4.8, M_L 5.5, and M_D 5.2 (Stover, 1984), was felt over an area of 104,000 km^2 (Figure 7 and Table 3). Maximum intensities of MM VI were felt around the epicentral region. Damage was reported as foundation and plaster cracks, overturned furniture, broken glasses and dishes, and a few cracked windows. In Ariel, the sidewalk cracked and in Graham, seiches (earthquake-generated waves) occurred in lakes and swimming pools, and chimneys were cracked (Stover, 1984). In Kidd Valley, pottery was broken and 300 maps fell to the floor in the Antique Shed store (Stover, 1984). The main shock was preceded nine months earlier by a swarm of earthquakes that occurred over a two-month period (Grant and others, 1984). The locations of about 1,000 aftershocks delineate a north-northwest-trending, right-lateral, strike-slip fault zone, 6 km long, 3 km wide, and extending from 5 to 12 km in depth (Grant and others, 1984). At least six aftershocks of M_L 2.9 to 3.6 were felt in Kidd Valley, 13 km east of Toutle, that night and the following day. The largest aftershock was felt as far south as Vancouver.



27 December 1963 M_D 5.0

Figure 6. Isoseismal map for the 1963 earthquake. Asterisk indicates instrumentally determined epicenter.



13 February 1981 M_L 5.5

Figure 7. Isoseismal map for the 1981 earthquake.

Other significant earthquakes

Portland has been the site of several smaller earthquakes of interest. One earthquake occurred on January 27, 1968, at 12:28 a.m. PST, in the Portland area. This was the first large event since the damaging November 5, 1962, earthquake (Heinrichs and Pietrafesa, 1968). Heinrichs and Pietrafesa (1968) estimate the magnitude to be M_L 3.7 and the depth of focus to be at 20 to 24 km. Their epicenter places this earthquake south of the Columbia River in the eastern Portland area (Figure 1).

Another earthquake occurred on May 13, 1968, at 10:52 a.m. PST, and its epicenter is located between northeast Portland and the Columbia River. The instrumentally determined value of M_L 3.8 for the event is from the Blue Mountains Observatory. The focal depth is thought to be around 4–12 km (Couch and others, 1968), although it is not well constrained due to lack of adequate seismographic coverage. A maximum intensity of MM IV was felt in Portland. The earthquake caused windows to rattle and hanging objects to swing, but no damage was reported. This earthquake occurred in the vicinity of the November 5, 1962, and the January 27, 1968, events (Figure 1).

Other moderate-sized earthquakes in the Portland region include the following:

- A MM V on August 4, 1959, 21 km northeast of Portland (Figure 1), which was felt over an area of 1,570 km^2. In Portland, the event caused swaying motion, and a few objects were displaced (Eppley and Cloud, 1961). Based on the felt area, the magnitude for this earthquake, estimated to be M_L 4.7 by the Canadian seismographic network, appears to be significantly overestimated.
- A m_b 4.6 event on March 7, 1963, which occurred west of Salem but was felt from Portland to Eugene (von Hake and Cloud, 1965). Damage was limited to slightly cracked plaster and broken dishes in Salem.
- A M_D 3.5 (Longmire) earthquake on January 26, 1964, near Merrill Lake, Washington (von Hake and Cloud, 1966). The event was felt over an area of 5,000 km^2 but only made windows and dishes rattle.
- A M_D 4.1 (Longmire) (MM V) event on October 1, 1964, 9 km east of Cougar (von Hake and Cloud, 1966). Many people were awakened in Portland, and windows and doors rattled.
- A m_b 4.3 (MM V) event on November 30, 1968, in Lewis County, Washington, that was felt over an area of 2,600 km^2 (Coffman and Cloud, 1970).

EARTHQUAKE RECURRENCE

The recurrence or frequency of occurrence for earthquakes in a given magnitude range in a specific region can be estimated on the basis of the Gutenberg-Richter relationship developed for that region. We have estimated this relationship for the Portland region, using our revised historical earthquake record and following the maximum-likelihood procedure developed by Weichert (1980). The earthquake record was corrected for incompleteness, and dependent events (foreshocks and aftershocks) were deleted. All event magnitudes were converted to equivalent M_L values.

Assuming the usual form of the Gutenberg-Richter relationship of $\log N = a - bM$, the recurrence parameters of b and a of 0.84±0.07 and 2.55, respectively, were estimated for the Portland region. This recurrence results in a return period for earthquakes of M_L 6 and greater of about 325 years, with the uncertainty in this value being at least several decades. For M_L 5.5 and greater, the return period of 100 to 150 years is consistent with the occurrence of the 1962 Portland and 1993 Scotts Mills earthquakes in the 150-year historical period. For M_L 6.5 and greater earthquakes, the return period is estimated to be approximately 800–900 years.

CONCLUSIONS

In the relatively brief historical record for northwestern Oregon and southwestern Washington, a large number of moderate-sized earthquakes up to M_L 5.6 have shaken the Portland region and sometimes caused damage. In view of the tectonic and geologic setting of the Portland region astride the Cascadia subduction zone, however, the occurrence of earthquakes as large as M_L 6½ or larger, which have not been experienced in historic times, also seems quite possible. The historical record suggests that such events may occur in the Portland region every few hundred years. It would seem prudent that residents as well as the engineering community and government agencies take the proper steps to mitigate the hazards that will be posed by such probably damaging earthquakes.

Table 3. *Significant historical earthquakes in the Portland region, showing areas for three MM intensity zones ($A_{I\text{-}V\text{-}VI}$), magnitudes calculated from each area (M_{A_I}, etc.), average (M_{ave}), and best estimate (M_{FA}) magnitudes. Recording source abbreviations: UCB = University of California-Berkeley; UW = University of Washington; NOAA = National Oceanic and Atmospheric Administration*

Earthquake	Maximum intensity	A_I (km^2)	A_V (km^2)	A_{VI} (km^2)	M_{A_I}	M_{A_V}	$M_{A_{VI}}$	M_{ave}	M_{FA}	Instrumental magnitude (recording station or source)
October 12, 1877	VII	41,250	2,875	125	5.2	4.6	4.3	4.7	5¼	—
February 3, 1892	V-VI	26,000	—	—	4.9	—	—	—	5	—
April 2, 1896	V	2,600	—	—	3.3	—	—	—	4	—
July 19, 1930	V-VI	—	—	—	—	—	—	—	4	—
December 29, 1941	VI	9,300*	2,143	803	4.2	4.5	5.0	4.6	4½	—
December 15, 1953	VI	10,000	1,782	341	4.3	4.4	4.7	4.5	4½	—
November 16, 1957	VI	13,600	2,476	—	4.5	4.6	—	4.55	4½	—
August 18, 1961	VI	18,300	—	—	4.6	—	—	4.6	4½	M 4.5 (Pasadena); M_D 3.9 (Longmire).
September 15, 1961	VI	22,000	3,213	—	4.8	4.7	—	4.75	4¾	M_L 4.8 (UCB-Arcata).
September 17, 1961	VI	24,300	5,125	—	4.8	4.9	—	4.85	5	M_L 5.1 (UCB-Arcata).
November 6, 1961	VI	23,000	5,656	919	4.8	5.0	5.1	5.0	5	M_D 4.5 (Longmire).
November 5, 1962	VII	70,000	29,403	6,790	5.4	5.7	5.8	5.6	5½	M_W 5.2 (Yelin and Patton, 1991); M_L 5.0 (Dehlinger and others, 1963); M_L 5.5 (UCB-Arcata).
December 26, 1963	VI	10,700	—	—	4.3	—	—	4.65	4½	M_D 4.1 (Longmire); m_b 4.5 (NOAA).
February 14, 1981	VI	104,000	15,800	1,900	5.8	5.4	5.3	5.5	5½	M_L 5.5, M_D 5.2 (UW); M_S 4.8 , m_b 5.1 (Stover, 1984).

*Felt area estimate not well constrained

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To our readers

Because of the length of the articles, this issue has been expanded from the usual 24 pages to 28 pages. As a result, we shall publish one of our later issues with 20 pages. —*ed.*

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and

Modeled Strong Ground Shaking in the Portland Metropolitan Area

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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

Damage caused by the Klamath Falls earthquakes of September 20, 1993. This bridge on Oregon Highway 140 across Howard Bay shows left-lateral displacement across joints in the bridge deck, probably as a result of slumping and settling that caused the bridge deck to rotate. Report on the earthquake begins on next page.

OIL AND GAS NEWS

Drilling at Mist Gas Field

Nahama and Weagant Energy Co. of Bakersfield, California, continues the multiple-well drilling program at Mist Gas Field in Columbia County. Of the first six wells for the year, two have been completed as gas producers, one is suspended, and three are plugged and abandoned. A seventh well, LF 31-36-65, was drilled to a total depth of 3,987 ft and is suspended. Next, the well CC 24-19-65 reached a total depth of 3,044 ft, was plugged and redrilled to a total depth of 2,882 ft, and is now suspended. The last well drilled to date, LF 43-32-65, reached a total depth of 1,909 ft and is suspended.

Northwest Petroleum Association symposium

The NWPA held its 10th annual symposium in Bend during September. Some 70 people were in attendance, heard speakers, and attended a poster session dealing with energy issues in the Northwest. A field trip for this meeting went to the Newberry Volcanic Monument. For more information, including the monthly luncheon program, contact the NWPA, P.O. Box 6679, Portland, OR 97228.

Carbon Energy commences drilling

Carbon Energy International of Kent, Washington, has commenced drilling operations on the Coos County Forest 7-1 well, SE¼ sec. 7, T. 27 S., R. 13 W., Coos County, Oregon. The proposed total depth for this well is 4,250 ft. It is located in the Coos Basin about 10 mi south of Coos Bay. The wildcat well is being drilled for coal-bed methane gas, which may be generated and trapped within coal beds, and this method of extracting methane gas is known as coal degasification. Carbon Energy has one other drilling permit for the WNS-Menasha 32-1 well, SW¼ sec. 32, T. 26 S., R. 13 W., with a proposed total depth of 1,600 ft.

Natural gas pipeline to serve Northwest and California

Pacific Gas Transmission Company will soon complete construction of a 42-in. natural-gas pipeline that stretches over 805 mi from Canada to California, crossing Oregon approximately parallel to State Highway 97, through Biggs, Bend, and Klamath Falls. The $1.7 billion project will increase supply capacity by approximately 900 million cubic feet per day, about 16 percent of it for the Oregon market. Statistics show that during the last ten years Oregon's consumption of natural gas has more than doubled. Much of the pipeline crosses lands managed by the U.S. Bureau of Land Management (BLM), so BLM's Prineville District has taken the lead in ensuring minimal environmental impact and proper restoration of the land disturbed by the pipeline and its construction.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
494	Nahama and Weagant Hemeon 13-14-65 36-009-00316	SW¼ sec. 14 T. 6 N., R. 5 W. Columbia County	Permit issued; 2,800.
495	Nahama and Weagant Johnston 11-30-65 36-009-00317	NW¼ sec. 30 T. 6 N., R. 5 W. Columbia County	Permit issued; 2,700.
496	Nahama and Weagant LF 21-32-75 36-009-00318	NW¼ sec. 32 T. 7 N., R. 5 W. Columbia County	Permit issued; 2,500.
497	Nahama and Weagant Libel 32-15-65 36-009-00319	NE¼ sec. 15 T. 6 N., R. 5 W. Columbia County	Permit issued; 2,800.

□

Klamath Falls earthquakes, September 20, 1993—including the strongest quake ever measured in Oregon

by Thomas J. Wiley[1], David R. Sherrod[2], David K. Keefer[3], Anthony Qamar[4], Robert L. Schuster[5], James W. Dewey[5], Matthew A. Mabey[6], Gerald L. Black[6], and Ray E. Wells[3]

INTRODUCTION

Earthquakes struck the Klamath Falls area on Monday night, September 20, 1993, resulting in two deaths and extensive damage. The quakes were felt as far away as Coos Bay to the west, Eugene to the north, Lakeview to the east, and Chico, California, to the south.

A foreshock recorded at 8:16 p.m. had a Richter magnitude of 3.9. The first of two main shocks, measuring 5.9 on the Richter scale, rumbled through Klamath Falls at 8:28 p.m. Following 16 smaller jolts with magnitudes between 2.2 and 3.8, the largest quake struck at 10:45 p.m. This earthquake, measuring 6.0 on the Richter scale, is the largest to hit Oregon since the 1873 Port Orford/Crescent City earthquake (Jacobson, 1986). Oregon has been shaken by stronger quakes, but those quakes originated beneath the Pacific Ocean west of Port Orford.

NATURE OF THE EARTHQUAKES

The epicenters of the Klamath Falls earthquakes clustered around an area near lat 42°20′N. and long 122°05′W. (T. 37 S., R. 2 W.), within the Mountain Lakes Wilderness, 26 km (16 mi) west-northwest of Klamath Falls, in Klamath County, Oregon (Figures 1 and 2). The magnitude 5.9 main shock that occurred at 8:28 p.m. was located at lat 42°18.94′N. and long 122°03.30′W. at a depth of approximately 12 km (7.5 mi). The magnitude 6.0 main shock that occurred at 10:45 p.m. was located about 6 km (3.7 mi) farther to the northwest (lat 42°21.31′N., long 122°06.61′W.) and at a depth of approximately 12 km (7.5 mi). More than400 aftershocks with magnitudes greater than 1.5 had been recorded by October 12 (Figure 3); the 10 largest had magnitudes ranging from 3.0 to 4.3. Hypocentral depths range from 0–12 km (0–7.5 mi), with the best located aftershocks occurring at depths of 5–12 km (3–7.5 mi).

Initially, individual earthquake hypocenters were poorly located due to a lack of permanent seismographs in the area. However, 20 portable seismographs were rapidly deployed by teams from Oregon State University, U.S. Geological Survey, and University of Oregon.

The first records obtained from portable seismographs showed aftershocks occurring at a rate of one per minute on September 21, most of them too small to be detected except by the portable seismographs. By the end of September, this rate had fallen off dramatically.

During the first week of October, the U.S. Geological Survey installed four permanent seismographs in the epicentral region. Data from these instruments are now telemetered to the University of Washington (UW), where they are recorded as part of the UW seismic network. The UW is now able to precisely locate aftershocks as small as magnitude 0.3.

Analysis of the shock waves was used to determine the orientation of the fault plane and the direction of slip in what is known as a fault-plane solution. One fault-plane solution for the magnitude 6.0 main shock at 10:45 p.m. is shown on Figure 4 and is interpreted to represent a northwest- to north-northwest-striking (N. 38° W.), east-dipping (56°) normal fault with a very small component of left-lateral motion.

Hypocenter ("hypo" = "under") is the point within the Earth where the earthquake actually originates.
Epicenter ("epi" = "upon") is the point on the Earth's surface that lies directly above the hypocenter.

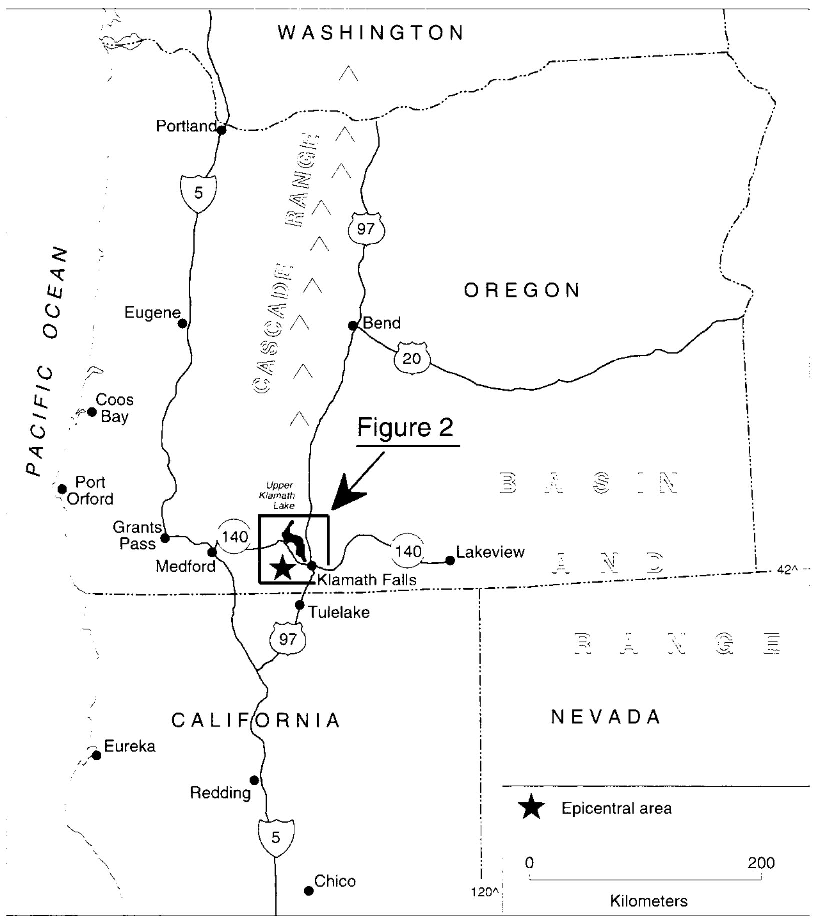

Figure 1. Location map.

[1] *Oregon Department of Geology and Mineral Industries, Grants Pass, Oregon.*
[2] *U.S. Geological Survey, Vancouver, Washington.*
[3] *U.S. Geological Survey, Menlo Park, California.*
[4] *University of Washington, Seattle, Washington.*
[5] *U.S. Geological Survey, Golden, Colorado.*
[6] *Oregon Department of Geology and Mineral Industries, Portland, Oregon.*

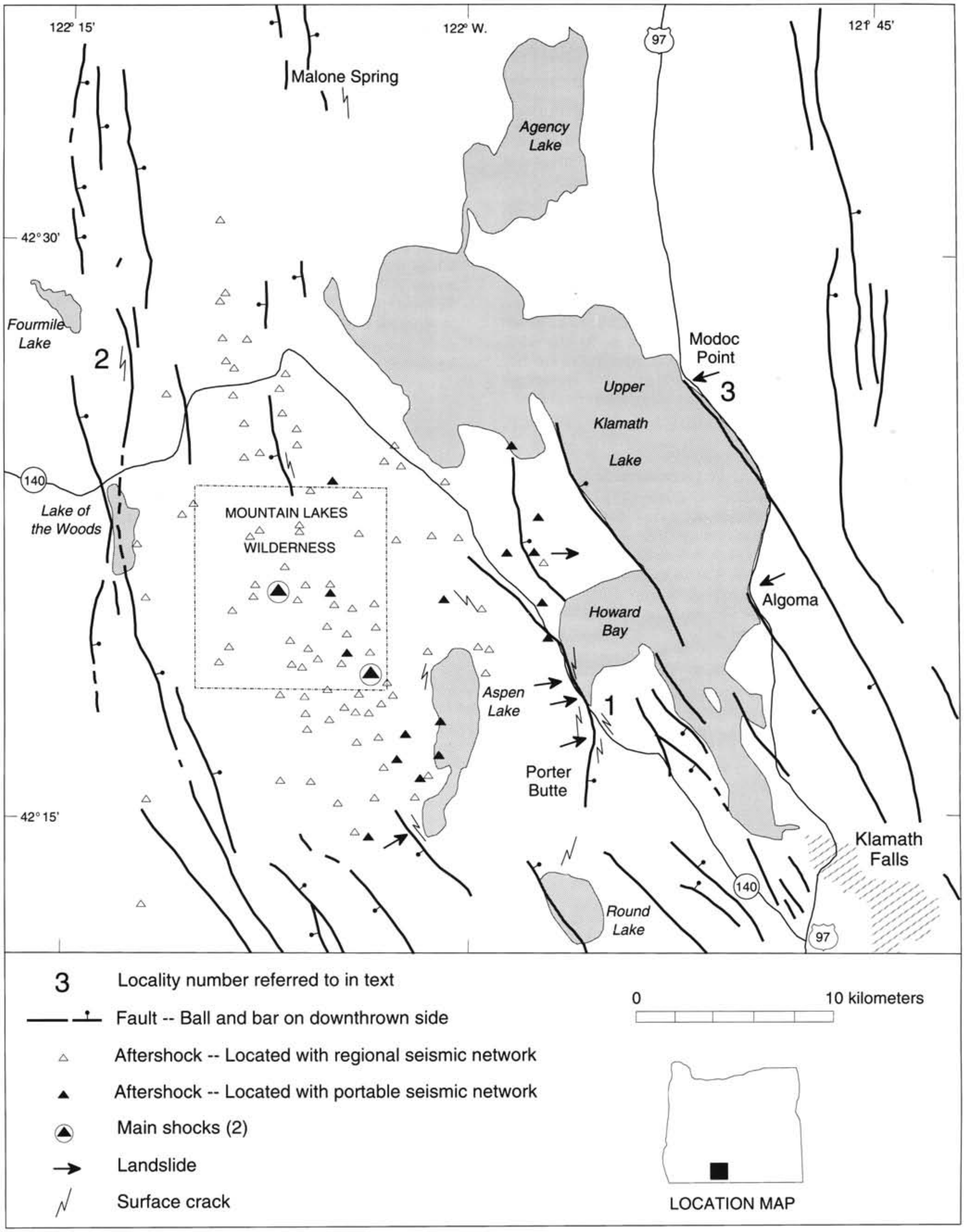

Figure 2. Map showing location of the two main shocks, aftershocks, surface deformation, mapped faults, and localities discussed in text.

SURFACE DEFORMATION

After the earthquake, a search for newly formed fault scarps, newly formed ground cracks, new and reactivated landslides, liquefaction, and related effects was conducted through aerial observation from a small, fixed-wing aircraft and traverses by automobile and on foot. The aerial search was carried out to epicentral distances of about 40 km (25 mi), whereas automobile and foot traverses extended more than 135 km (84 mi) from the epicenter. Neither newly formed ground rupture nor evidence of liquefaction was found. Ground cracks and landslides were the only surface geologic effects that could reliably be attributed to the Klamath Falls earthquakes.

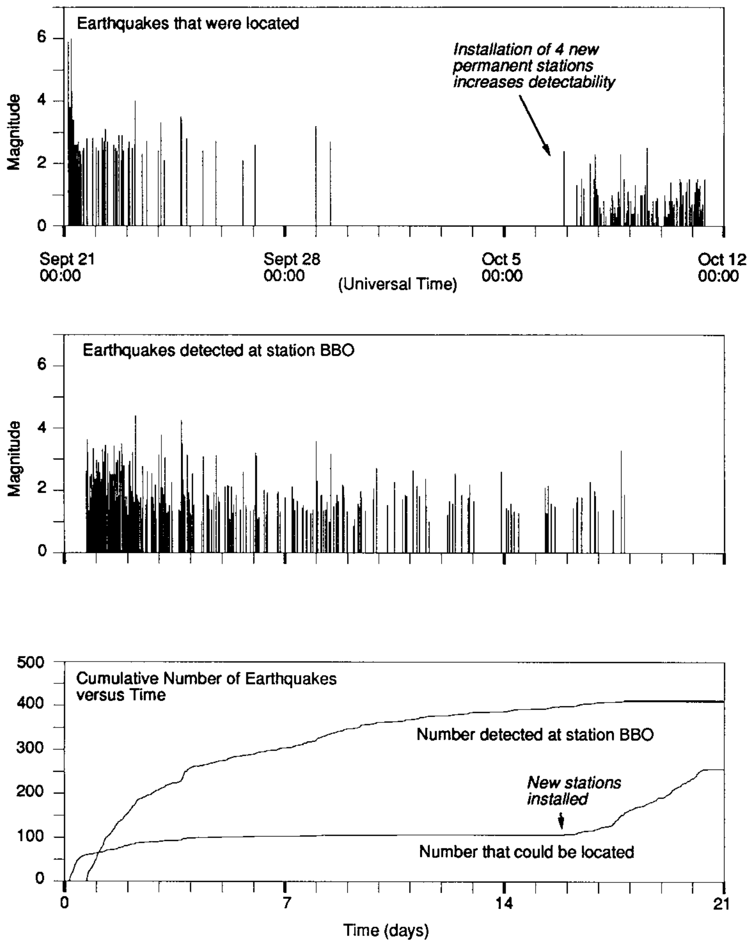

Figure 3. Plots showing earthquake magnitude versus time during first three weeks of earthquake activity. (a) Earthquakes located by University of Washington (UW) seismic network. (b) Earthquakes detected by closest permanent seismograph at station BBO (see Figure 11). (c) Total number of located and detected events. With the addition of the new stations now being recorded at UW, 780 earthquakes had been located by October 22.

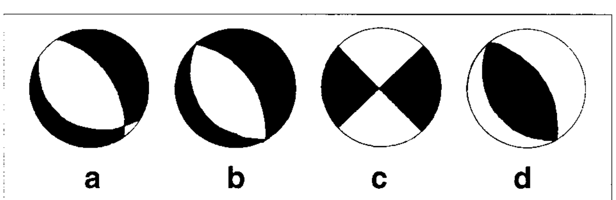

Figure 4. (a) Fault-plane solution for magnitude (M_C) 6.0 main shock at 10:45 p.m. on September 20, 1993 (lower hemisphere stereographic plot). The two planes defined by the boundaries between black (compression) and white (dilation) zones indicate fault orientations that could have produced this earthquake. The N. 38° W. plane dipping 56° NE. parallels many of the known faults in area. (b) Idealized normal-fault solution. (c) Idealized strike-slip-fault solution. (d) Idealized thrust-fault solution.

Ground cracks

Newly formed cracks were typically confined to artificial fill, chiefly in roadways where cinders and crushed rock had been used to elevate roads 30–60 cm (1–2 ft) above the surrounding ground. Newly formed or enlarged cracks were located as far west as Fourmile Lake, as far north as Malone Spring, as far south as Round Lake, and as far east as Howard Bay (Figure 2). Cracking was sparse near the main shock epicenters. Most cracking occurred in an area 3–8 km (2–5 mi) southwest of the epicenters, between Aspen Lake, Howard Bay, and Round Lake. A north-south linear zone with the greatest density of ground cracking, rock fall, and slumping extended from Round Lake to the Highway 140 bridge over the southern end of Howard Bay (Locality 1, Figure 2) and north along Highway 140 where it follows the west shore of Howard Bay. This zone corresponds with a previously mapped north-striking fault whose escarpment forms the east slope of Porter Butte and the west side of Howard Bay. Cracks generally trended north to northwest. Most cracks were only 3–6 m (10–20 ft) in length, but a few were more than 100 m (330 ft) long. Cracks cutting asphalt pavement and bed rock south of Howard Bay are believed to be related to compaction of underlying fill and to landsliding, respectively. Vertical displacements as large as 50 cm (1.6 ft) were found, but only where sliding or slumping was believed to have occurred.

One crack could be traced beyond road fill and into regolith. That crack was one of five or six found along a 30-m (100-ft) stretch of logging road north of Round Lake. Cracks in this set had irregular trends for lengths of 30–60 cm (1–2 ft) and overall trends of N. 5° W., N. 10° W., and N. 15° E., and opened as much as 1 cm (0.4 in.). Slip vectors were east-west (N. 86° W., N. 82° E., and N. 76° W.), as determined by aligning paired features such as gravel clasts and voids or embayments and protrusions.

Gaping cracks wide enough to insert a hand to the wrist characterized the embankment of Highway 140 along and south of Howard Bay. These cracks were related to spreading and slumping of road fill during and since the shaking events. Cracks along the centers of two gravel roads occurred in areas with thick fill and were similarly thought to result from lateral movement. Cracks were also found associated with culvert crossings.

Several cracks in a truck-turnaround pad constructed on the edge of a cinder cone north of Round Lake had a small component of normal separation, but the downdropped side coincided with the approximate outer (downslope) flank of the cinder quarry, and the downdip separation probably resulted from gravity failure. These cracks, which trended between N. 5° E. and N. 10° W., had opened about 2.5 cm (1 in.). One measured slip direction had a plunge of 15° on trend S. 76° E.

Figure 5. Rock-fall boulder from steep ridge bordering Oregon Highway 140 west of Howard Bay (Locality 1, Figure 2). Boulder fell from near-vertical slope partly visible in background and came to rest on highway shoulder.

29 km (18 mi) west of the 10:45 p.m. epicenter. These landslides were small (typically involving only a few cubic meters of material) and occurred from cuts that evidently had a history of spotty instability. One additional rock slide caused minor damage to railroad tracks near Algoma (Figure 2), according to a report in the Klamath Falls Herald and News (September 21, 1993, p. 1).

The Oregon Highway 140 bridge across Howard Bay, 17 km (11 mi) east-southeast of the 10:45 p.m. epicenter (Locality 1, Figure 2), was damaged by slumping and settlement at the north abutment and settlement of the south abutment. At the south abutment, the approach fill settled approximately 10 cm (4 in.). Left-lateral displacements totaling approximately 17 cm (7 in.) occurred across joints in the bridge deck, probably due to slumping and settling that caused the bridge deck to rotate counterclockwise. South of the bridge, the highway is built on a fill causeway at the edge of the marsh. For a distance of several hundred meters, the fill along the west shoulder of this causeway slumped into the marsh, opening cracks 5–10 cm (2–4 in.) wide (Figure 8).

The U.S. Forest Service reported a northwest-trending crack 8 m (26 ft) long that had opened as much as 5 cm (2 in.) and was located below water level in the marsh east of Malone Spring (Figure 2). Cracks were reported in fill along Cascade Canal, where it traverses the east slope of Rye Spur southeast of Fourmile Lake (Locality 2, Figure 2).

Landslides

The Klamath Falls earthquakes caused landslides throughout an area of about 420 km^2 (162 mi^2) surrounding the epicenter. Most landslides were rock falls or rock slides from road cuts, quarries, and steep bluff faces; these landslides occurred as far as 29 km (18 mi) from the epicenter of the strongest shock at 10:45 p.m.

The most numerous earthquake-induced rock falls were found along the east- to southeast-facing flank of a ridge immediately south and west of Howard Bay, 17 km (11 mi) east-southeast of the 10:45 p.m. epicenter (Locality 1, Figure 2). This ridge, which is 250 m (820 ft) high, has slopes exceeding 45° in some places. Basalt lava flows crop out in the upper part, and the lower slopes are mantled by boulder-rich colluvium and talus. Several dozen boulders, some as large as 4 m (13 ft) across, broke loose and fell or rolled down the slope during the earthquake. A few boulders came to rest on the shoulder and roadway of Oregon Highway 140 (Locality 1, Figure 2; Figure 5). One of these boulders was struck by an 18-wheeled truck, which then veered off the highway and into more boulders at the base of the cliff. Many more boulders came to rest on the unpaved road that climbs the southeastern side of the ridge.

The largest observed rock slide originated on a steep road cut on the east side of U.S. Highway 97, at a point 3 km (1.8 mi) south of the town of Modoc Point and 23 km (14 mi) from the 10:45 p.m. epicenter (Locality 3, Figure 2; Figures 6 and 7). This rock slide, which contained an estimated 300 m^3 (10,600 ft^3) of material, broke loose from a 60° slope composed of heterogeneous volcanic rock that is locally weakly cemented, intensely fractured, or both. The rock slide moved downslope about 100 m (330 ft); most of the material was contained behind a roadside barrier consisting of concrete sections surmounted by a steel fence, but one large boulder, 3.5 m (11.5 ft) in maximum dimension, crashed through the barrier onto the highway. The boulder hit a southbound vehicle, killing the driver.

Other rock falls and rock slides from road cuts were observed adjacent to Oregon Highway 140 as far as 17 km (11 mi) east and

Figure 6. Rock slide from Modoc Rim, 2.9 km (1.8 mi) south of the town of Modoc Point and adjacent to U.S. Highway 97 (Locality 3, Figure 2). Note breach in roadside barrier and impact marks in highway pavement caused by large boulder that hit southbound vehicle and came to rest on road. The boulder was pushed off the road before the photograph was taken and is visible just behind the right side of the breach.

Figure 7. Close-up of large boulder from the Modoc Rim rock slide (Figure 6) that breached barrier along U.S. Highway 97.

Several slumps in fill also occurred along the gravel road below the ridge immediately west of the bridge (Figure 9). These slumps were characterized by crescent-shaped open cracks that were concave downslope in plan view. The largest cracks were more than 100 m (330 ft) long and 30 cm (12 in.) wide. Several such slumps occurred in the quarry and the quarry road on the southeast-facing slope of the ridge, and at least two slumps occurred lower on the road, adjacent to a canal.

The types and areal limits of landslides (Figure 10) caused by the Klamath Falls earthquakes are typical for earthquakes of this magnitude. The area throughout which landslides occurred (Figure 10a), the maximum epicentral distances for rock slides and rock falls (Figure 10b), and the maximum epicentral distances for rotational slumps (Figure 10c) are comparable to similar data from other historical earthquakes. In addition, rock falls, rock slides, and slumps of fill material are among the most common types of landslides in other historical earthquakes of comparable magnitude (Keefer, 1984).

Figure 8. Linear cracks in the causeway fill south of Howard Bay bridge on Oregon Highway 140. These cracks were caused by slumping of fill in a westward direction, toward the right edge of the photograph.

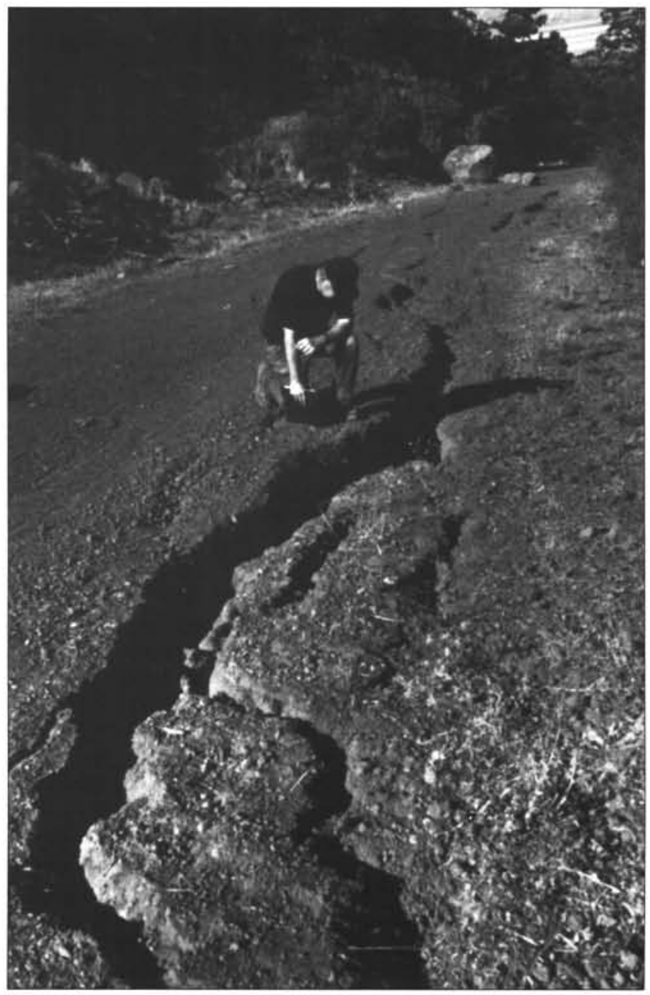

Figure 9. Crescent-shaped cracks associated with rotational slump in fill. Slumps involved unpaved road in quarry at Locality 1 on Figure 2. Boulders on road from earthquake-induced rock falls are visible in background.

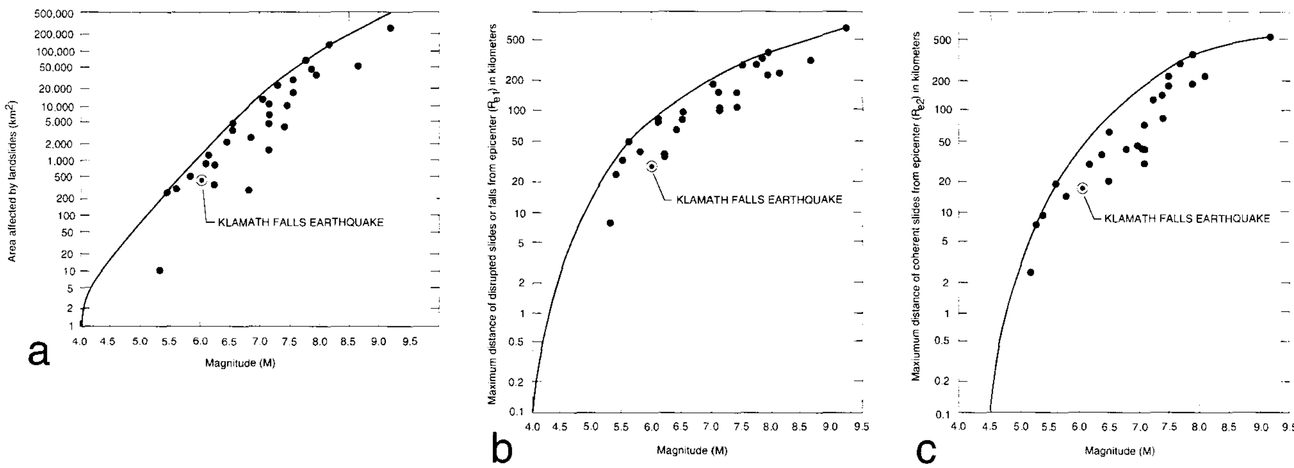

Figure 10. Plots comparing landslides caused by Klamath Falls earthquakes with landslides caused by other historical earthquakes (solid dots). Data on historical earthquakes and solid line denoting upper limit are from Keefer (1984). (a) Area affected by landslides. (b) Maximum epicentral distance of rock falls and rock slides (disrupted slides and falls). (c) Maximum epicentral distance of slumps (coherent slides).

EFFECTS ON SURFACE AND GROUND WATER

No changes in surface water have been reported as of October 11. A rancher with a water gauge on Upper Klamath Lake (Locality 1, Figure 2) reported that the lake level on September 21 and September 24 (after the main shocks) was identical to that measured on September 20 (prior to the earthquakes).

Several residents who rely on ground-water systems near the epicenter reported wells with cloudy or dirty water—"the color of chocolate milk"—that cleared on continued pumping. Piping for several wells was damaged.

Water district employees for the City of Klamath Falls reported that well levels in the urban geothermal system rose 2 ft (60 cm) in the first 36 hours after the quakes and had risen another foot by October 6. This contrasts with a typical year in which water levels decline in late September and early October. In a geothermal system monitored by the Oregon Institute of Technology, water levels reportedly fell 1–7 ft (30–220 cm) before stabilizing on the third day after the earthquake.

One continuously monitored well near Grants Pass, 100 km (60 mi) west of the epicenter, recorded a 35-cm (14-in.) drop in static level following the earthquake and never recovered.

RELATION OF EARTHQUAKES TO NEARBY FAULTS

Dramatic north- to northwest-trending fault-line scarps are the dominant topographic feature throughout the Klamath Falls area (Figure 2; Smith and others, 1982; Hawkins and others, 1989; Sherrod and Pickthorn, 1992). These scarps and the associated system of Basin and Range normal faults trend into the High Cascades volcanic arc in the epicentral area. Fault-plane solutions (Figure 4) suggest that the two main shocks occurred on a northwest- to north-northwest-striking, east-dipping normal fault or several faults. The surface projection of such a fault would lie east of the Lake of the Woods fault zone (Hawkins and others, 1989), assuming a 60° dip and a hypocentral depth of 12 km (8 mi). Aftershocks located by the portable seismic net define two north-trending bands of epicenters (Figure 2): The western band corresponds with the main shock epicenters as located by the regional seismic net. The eastern zone underlies the western shore of Upper Klamath Lake and is coincident with the north-trending zone characterized by the greatest amount of ground cracking and landsliding. Better definition of the fault or faults responsible for these earthquakes must await velocity modeling and thorough analysis of aftershocks recorded by portable seismographs.

INTENSITY AND DAMAGE

The Klamath Falls earthquakes caused two deaths and damaged more than 1,000 buildings. One person died when a car was struck by a boulder on U.S. Highway 97 near Modoc Point (Locality 3, Figure 2). The second fatality was the result of a heart attack.

Damage assessments reported by the Oregon Emergency Management Division (OEM) and the Federal Emergency Management Agency (FEMA) showed that residential, commercial, nonprofit, and government buildings and facilities suffered an estimated total dollar loss of more than $7.5 million (Table 1). The Klamath County Courthouse (built in 1924) and Courthouse Addition suffered the greatest damage, with a combined dollar loss of $3.14 million. Many unreinforced masonry buildings in the city of Klamath Falls were severely damaged. FEMA lists two residences as destroyed. Well-built wood-framed houses that were bolted to their foundations and commercial buildings constructed to modern building codes generally suffered little or no damage. The few modern structures that sustained damage may indicate areas where local conditions, building geometry, or building conditions resulted in more severe damage. Damage to buildings was reported from Tulelake, California, to Modoc Point, north of Upper Klamath Lake (Figure 11, Mercalli zones VI and VII).

Table 2 shows a comparison with the Scotts Mills earthquake of March 25, 1993, demonstrating how a smaller earthquake can be more damaging if it is centered beneath a more populous area. See the May issue of *Oregon Geology* (Madin and others, 1993).

An intensity questionnaire published in several Oregon newspapers resulted in intensity reports from the public that have yet to be compiled. Readers with observations from personal experience or who sustained damage to their homes are urged to fill out and send in the form at the end of this article (page 135).

HISTORICAL AND EXPECTED FUTURE EARTHQUAKES

During the last 50 years, at least 12 earthquakes have occurred within 33 km (20 mi) of Klamath Falls. Seven of these were larger than magnitude 3 and were large enough to be felt (Jacobson, 1986). Evidence from this historic record, combined with geologic evidence for large numbers of large earthquakes in the prehistoric past, suggests that one or more earthquakes capable of damage (magnitude 4–6) hit south-central Oregon every few decades. Earthquakes as large as magnitude 7 have probably occurred (Hawkins and others, 1989).

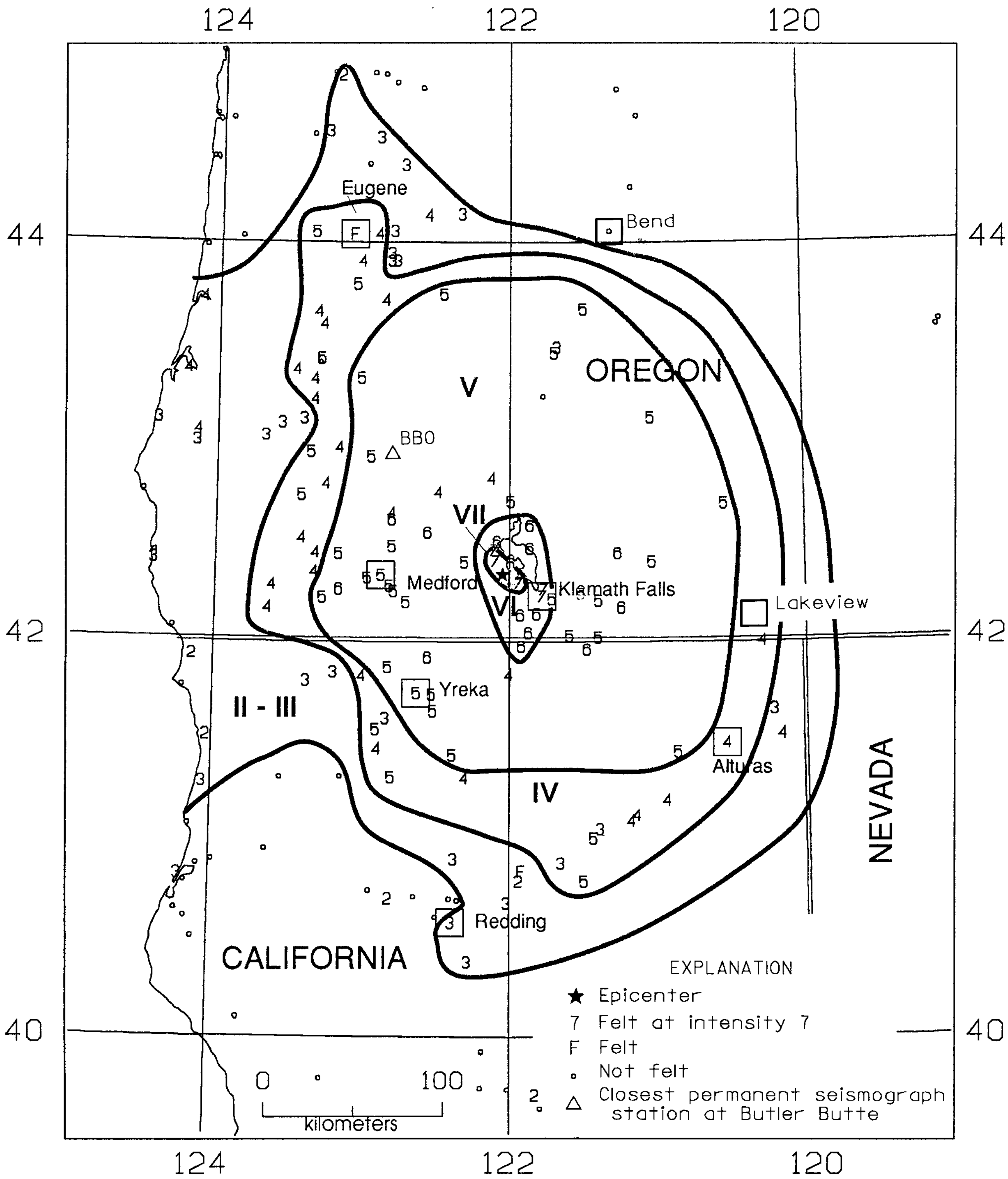

Figure 11. Preliminary Modified Mercalli intensity map for the September 20, 1993, Klamath Falls earthquakes. Explanation of intensities (Roman numerals) in Table 3.

Table 1. *Damage and cost estimates by FEMA*

Klamath County Public Facilities

Klamath County Courthouse	$1,720,000
Klamath County Courthouse, New Addition	$1,420,000
Klamath County Library	$5,000
Klamath County Schools	$26,000
Klamath County	$727,000
Klamath Falls City Schools	$113,000
City of Klamath Falls	$151,000
Klamath Tribes Medical Office	$3,500
Klamath Tribes Chiloquin Hatchery	$44,000
Klamath Tribes Algae Building	$3,000
Merle West Medical Center	$5,000
Oregon Department of Transportation	$15,000
Estimated total dollar loss	$4,232,500

Individual assistance damage estimates in Klamath County

Number of residences		
Destroyed	2	
With major damage	20	
With minor damage	142	
Affected habitable	777	
Total	941	
Estimated dollar loss		$1,140,000
Number of businesses		
Destroyed	0	
With major damage	25	
With minor damage	76	
Total	101	
Estimated dollar loss		$1,963,000
Number of others—non-profit		
Destroyed	0	
With major damage	2	
With minor damage	7	
Total	9	
Estimated dollar loss		$258,000
Total—residences and businesses		
Number	1,051	
Estimated total dollar loss		$3,361,000

Table 2. *Comparison between Klamath Falls earthquakes and Scotts Mills earthquake. Note that area in which the Scotts Mills earthquake was felt was limited by the Pacific Ocean and might have been 20 percent larger if the earthquake had occurred inland.*

	Klamath Falls	Scotts Mills
Magnitude	6.0 and 5.9	5.6
Depth	18 and 20 km	18 km
Maximum intensity	VII	VII
Area felt (km2)	131,000	134,000
Fatalities	2	0
Damage (millions of dollars)	~7.5	~12.6
Buildings destroyed	2	0
Landslides	out to 29 km	no
Ground cracks	yes	no

Table 3. *Excerpts[1] from Modified Mercalli intensity scale of Wood and Neumann (1931) as used in Figure 11*

Intensity	Description
II–III	Observations range from "felt by a few persons at rest" to "felt quite noticeably."
IV	Felt indoors by many, outdoors by few. Dishes, windows rattle; walls creak; standing cars rock noticeably.
V	Felt by nearly everyone, many awakened. Some dishes and windows broken; cracked plaster in a few places; unstable objects overturned; trees, poles, and other tall objects disturbed.
VI	Felt by all, many people run outdoors; some moderately heavy furniture moved.
VII	Everybody runs outdoors; damage negligible in buildings of good design and construction, considerable in poorly built or badly designed structures; some chimneys broken; noticed by persons driving cars.

[1] More complete versions of this scale have been published lately in, e.g., *Oregon Geology* (Sept. 1993, p. 118, and Jan. 1989, p. 17–18; *California Geology* (Sept. 1991, p. 203); and in the U.S. Geological Survey free pamphlet *The Severity of an Earthquake.*

The Klamath Falls earthquake sequence was a multiple event, with two main shocks that probably ruptured different parts of a fault at different times. Aftershocks since then have followed a commonly observed decline curve, decreasing dramatically in both number and magnitude.

This behavior contrasts with earthquake swarms, which are characterized by numerous temblors of similar magnitude and no recognizable main shock. Historic earthquake swarms in the region produced magnitude 4–5 earthquakes that continued for a month or more. For example, earthquake swarms struck 70 km (44 mi) south of Klamath Falls in the 1978 Stephens Pass, California, earthquakes (Bennett and others, 1979) and 160 km (100 mi) to the east in the 1968 Warner Valley earthquakes (Couch and Johnson, 1968).

However, since earthquakes are unpredictable, there is still a chance that significant aftershocks may strike the Klamath Falls area in the months ahead.

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EARTHQUAKE QUESTIONNAIRE

The Oregon Department of Geology and Mineral Industries (DOGAMI) needs the help of the public to accurately determine the effects of the September 20, 1993, Klamath Falls earthquakes. If you live in southern or southwest Oregon, northern California, or northern Nevada, please take the time to read this questionnaire and answer the questions as fully as possible. We need information from as many residents of the earthquake area as possible, **even if you did not feel any effects**. This information may allow us to predict which areas might experience the greatest damage in future large earthquakes. Send to **Klamath Falls Earthquake Survey, DOGAMI, 800 NE Oregon St. #28, Portland, OR 97232.** Thank you for your help!

Where were you in the earthquake(s)? Please describe your location, either by a street address or nearest cross streets. Include the name of the town, or distance and direction from the nearest town if you were out in the country.

Were you in the open, in a car, in a building? If you were in a building, list which floor you were on and how many floors the building has.

What effects did you feel? Describe the sensation. Was it barely felt, strongly felt, hard to stand?

What effects did you observe to surrounding objects, buildings, or ground? (Rocking cars, dishes rattling on shelves, furniture or machinery shifting, rocks falling, road moving, changes in water levels in wells, cracking of the ground or roads, rapid ejection of water from ground, etc.).

□

Reader survey results tallied

We of the Oregon Department of Geology and Mineral Industries (DOGAMI) thank the 183 readers who took the time to answer the questionnaire that appeared in the July 1993 issue of *Oregon Geology*. The responses, which represent approximately 11 percent of the distributed copies of any issue of *Oregon Geology*, were tallied by DOGAMI volunteers Martha Carlson, Emma Geitgey, Rosemary Kenney, Margaret Steere, and Phyllis Thorne. Jean Pendergrass, DOGAMI secretary, tabulated the numerous written comments.

Here are some of the things we learned about the readers who responded to the survey. Approximately 17 percent of them are women; the rest are men. The average age falls into the 46–64 age category. Sixty-one percent of the responders are Oregonians, with 25 percent of those living in the Portland area. Washington is home for 13 percent of the other responders, while California, Texas, Idaho, Colorado, Alaska, and Minnesota and then the other states, in that order, are the home states for almost all of the rest. Of the remainder, 3 percent come from Canada. The farthest response came from Germany.

Twelve percent of the responders are high school graduates; 19 percent attended college, and 39 percent are college graduates. Twenty percent have done some graduate work, and 50 percent have advanced degrees. The largest single category of occupation is professional geologist, followed by prospector, scientist, government employee, educator—plus a variety of other occupations including librarians, physicians, carpenters, tree farmers, secretaries, and train dispatchers. Half of the responders live in households with an annual income of $50,000 and over.

The responders are physically active in the out-of-doors in their leisure time: Camping, hiking, amateur geology, rockhounding, travel, and photography are some of the favorite activities. Reading is about 2½ times as popular as watching TV.

Most of the responders take *Oregon Geology* because they are interested in geology and want to keep up in current activities in geology. Favorite topics include geology of specific areas, volcanoes, earthquakes, plate tectonics, mineral/fossil/gemstone areas, geologic hazards, meteorites, mineralogy, and mining history. Field trip guides, announcements of new publications, and book reviews are liked by many. About 64 percent are satisfied with the magazine as it is now, and another 29 percent are somewhat satisfied. Only 2 percent are somewhat dissatisfied, and none are totally dissatisfied. Reasons for dissatisfaction with *Oregon Geology* include "too technical," "not timely enough," "printed too infrequently," and "technical terms not defined." Most of you like the subject matter of *Oregon Geology*, because suggestions for improvement included the addition of more of all kind of things—more general interest material, more paleontology, more amateur geology information, more gemstones and rockhounding, more pages, more field trip guides, more detailed locations of drilling locations, and more information on current geologic research in the state.

About 54 percent like to receive *Oregon Geology* every two months; 38 percent would like it every month, and 8 percent prefer receiving it every three months. Fifty-nine percent would be willing to pay more for a subscription to get the magazine every month, with 2 percent willing to raise the annual subscription to $9, 15 percent to $10, 23 percent to $12, 3 percent to $14, 25 percent to $15, 11 percent to $16, and 20 percent to $18. Sixteen percent would not be willing to pay more for monthly publication. Twenty-five percent answered the "depends" category, giving such comments as "content is most important, and I would pay more if additional papers are not just fluff," "if quality and volume are retained," and "depends on content" (several times).

Thirty-nine percent don't care if advertising is added to the magazine, and 36 percent think it is a good idea. The 25 percent who think it is a bad idea added such statements as "I like it as it is," "bad idea unless selective," bad idea unless there is no alternative," and "I don't like it, but if it helps keep cost down I'd put up with it."

The question of adding color had responders fairly evenly divided, with 37 percent willing to pay more for color, 39 percent unwilling, and 24 percent saying "depends," offering such comments as "instead, make color photos available to buy", or "if you want color, there would be a tendency to have a beauty standard instead of selecting accurate pictures." The raised annual subscription prices selected by those who would be willing to pay for color range through 3 percent for $9, 7 percent for $10, 3 percent for $11, 26 percent for $12, 3 percent for $14, 20 percent for $15, 6 percent for $16, and 32 percent for $18.

Twenty-six percent were interested in including other topics in *Oregon Geology*, 51 percent said "no," and 23 percent said "depends," adding comments such as "keep it related to earth sciences," "add education," "no, you'd be in competition with too many other recreation rags," "would dilute the publication with side issues," "include programs or aids for education," "don't make it a travel magazine," "maintain scientific credibility," and "there are plenty of magazines that deal with hiking but few that deal with Oregon geology." Many of the responders correctly pointed out that we had included some geologic topics in the list of other possible topics but went on to select paleontology, history, archaeology, geography, natural hazards, and the Oregon coast as some of the most preferred topics for articles.

Forty-six percent of the responders responded favorably to expanding the focus of the magazine to the entire Pacific Northwest, while 54 percent said "no," adding such comments as "OK when the geologic topics cross state boundaries," "it might water down *Oregon Geology*," "we already subscribe to *Washington Geology* and *California Geology*, "might be too much," "interesting idea because Idaho doesn't have a magazine and articles about Idaho might be printed here," and "OK, but keep main focus on Oregon."

Finally, the responders added many helpful comments and ideas at the end of the questionnaire. Clearly, many of you care a lot both about geology and about the magazine and have all kinds of ideas on how to improve *Oregon Geology*. Rest assured we are taking your suggestions to heart and will do all we can to implement them. Because of your willingness to communicate with us, we now know more about you and what you think and want from us. We will do the best with the resources we have. Any changes that we make will always be in your best interests. Thank you again from all of us at DOGAMI. □

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.

Hydraulic control of grain size distributions and differential transport rates of bedload gravels in Oak Creek, Oregon, by Shyuer-Ming Shih (M.S., Oregon State University, 1989), 74 p.

Grain-size distributions of gravels transported as bedload in Oak Creek, Oregon, show systematic variations with changing flow discharges. At low discharges the gravel distributions are nearly symmetrical and Gaussian. As discharges increase, the distributions become more skewed and follow the ideal Rosin distribution. The patterns of variations are established by goodness-of-fit comparisons between the measured and theoretical distributions, and by Q-mode factor analysis. Two end members are obtained in factor analysis, respectively having almost perfect Gaussian and Rosin distributions, and the percentages of the two end members within individual samples vary systematically with discharge.

Transformation from the Gaussian to a Rosin distribution with increasing discharge may be explained by processes of selective entrainment of grains from a bed of mixed sizes. Samples of bed material in Oak Creek follow the Rosin distribution. At high discharges, the transported bedload approaches the grain sizes of that bed-material source and mimics its Rosin distribution. Random-selection processes must be more important to grain entrainment at lower discharges, so that the resulting Gaussian distributions of transported bedload reflect similar distributions of bed stresses exerted by the stream flow.

The results from Oak Creek demonstrate that competence of the flow is reflected in the entire distribution of transported gravel sizes. A sequence of layers of fluvial gravels, modern or ancient, might show systematic variations between coarse Rosin and finer-grained Gaussian distributions, and these could be used to infer frequencies of various discharges and establish a relationship to the source sediment.

A differential bedload transport function is formulated utilizing the dependence of two parameters in the Rosin distribution on the flow stress. The total transport rate, which is also a function of the flow stress, is apportioned within the Rosin grain-size distribution to yield the fractional transport rates. The derived bedload function has the advantage of yielding smooth, continuous frequency distributions of transport rates for the grain-size fractions, in contrast to the discrete transport functions which predict rates for specified sieve fractions. A group of differential transport frequency curves can be constructed that reflects a particular stream's bedload transport characteristics. Successful reproduction of the measured fractional transport rates and bedload grain-size distributions by this approach demonstrates its potential in flow-competence estimates, evaluations of differential transport rates of size factions, and in investigations of downstream changes in bed material grain-size distributions.

Stratigraphy and sedimentology of the late Eocene Bateman Formation, southern Oregon Coast Range, by David G. Weatherby (M.S., University of Oregon, 1991), 161 p.

During the Eocene epoch, a thick sequence of sedimentary and interbedded volcanic rocks was deposited in a fore-arc basin in the central southern Oregon Coast Range, southwest of Elkton, Oregon. Eocene sedimentary formations representing deep-sea-fan, shelf, marginal-marine, and nonmarine environments provide a record of the filling of the basin. The late Eocene Bateman Formation is the stratigraphically highest formation in the central southern Coast Range and represents final deposition in a prograding delta complex.

Sedimentary facies representing deltaic distributary channel, interdistributary swamp and marsh, delta-front, and prodelta environments are present in the Bateman Formation. Deposition of the Bateman Formation on a prograding delta is inferred from the presence of several small- and large-scale, upward-coarsening sequences in which prodelta sediments are overlain by delta-front and distributary-channel sediments. Small-scale upward-fining sequences composed of distributary swamp and marsh sediments represent meandering of distributary channels. Paleocurrent data indicate that delta progradation was to the north-northwest. Lateral facies relationships show that marine delta-front and prodelta sediments are generally more common in the direction of delta progradation, whereas nonmarine distributary-channel and interdistributary swamp and marsh sediments are less common in the direction of sediment transport.

Petrographic analysis of sandstone composition indicates that Bateman sandstones were derived dominantly from an andesitic volcanic arc with minor input from metamorphic, plutonic, and sedimentary sources. Paleocurrent data suggest that the source was located to the southeast, probably in the Western Cascades and the northern Klamath Mountains. □

Strong ground shaking in the Portland, Oregon, metropolitan area: Evaluating the effects of local crustal and Cascadia subduction zone earthquakes and near-surface geology

by Ivan G. Wong, Woodward-Clyde Federal Services, 500 12th Street, Suite 100, Oakland, CA 94607; Walter J. Silva, Pacific Engineering and Analysis, 311 Pomona Avenue, El Cerrito, CA 94530; and Ian P. Madin, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, Portland, OR 97232

ABSTRACT

In its 150-year existence, the Portland metropolitan area has gone relatively unscathed by damaging earthquakes. However, an increasing amount of geologic and seismologic data indicate that crustal earthquakes in the Portland region larger than Richter magnitude (M_L) 6 and Cascadia subduction zone earthquakes of moment magnitude (M_W) 8 or greater will occur in the future. If either were the case, strong ground shaking generated by these events would have a major impact on the Portland area. In this study, we have estimated deterministically site-specific ground motions at four sites located in Portland using a state-of-the-art stochastic methodology. The events modeled were crustal earthquakes of M_W 6 and M_W 6.5 at source-to-site distances of 5, 10, and 15 km and a M_W 8.5 Cascadia subduction earthquake at a distance of about 120 km. In all cases, ground motions will be significant and damaging. The severity of such ground shaking in the Portland metropolitan area will be controlled in large part by the nature of the unconsolidated sediments at each specific location.

INTRODUCTION

The Portland metropolitan area and surrounding vicinity have been the most seismically active region in Oregon in historical times. Based on the relatively brief 150-year historic record, six earthquakes of Richter magnitude (M_L) 5 or greater have occurred within the greater Portland area (Bott and Wong, 1993). The recent occurrence of the damaging M_L 5.6 event of March 25, 1993, at Scotts Mills is testimony to the hazards posed by apparently randomly occurring crustal earthquakes. Recent geophysical studies suggest the presence of crustal faults beneath the Portland metropolitan area, which—albeit speculatively—could generate a potentially much more damaging crustal earthquake of M_L 6 or larger. A recent evaluation of earthquake recurrence suggests that a crustal earthquake of M_L 6 or larger should occur somewhere in the Portland region every 300–350 years and an event of M_L 6½ or larger about every 800–900 years (Bott and Wong, 1993). The seismic hazards posed by these earthquakes occurring within the earth's

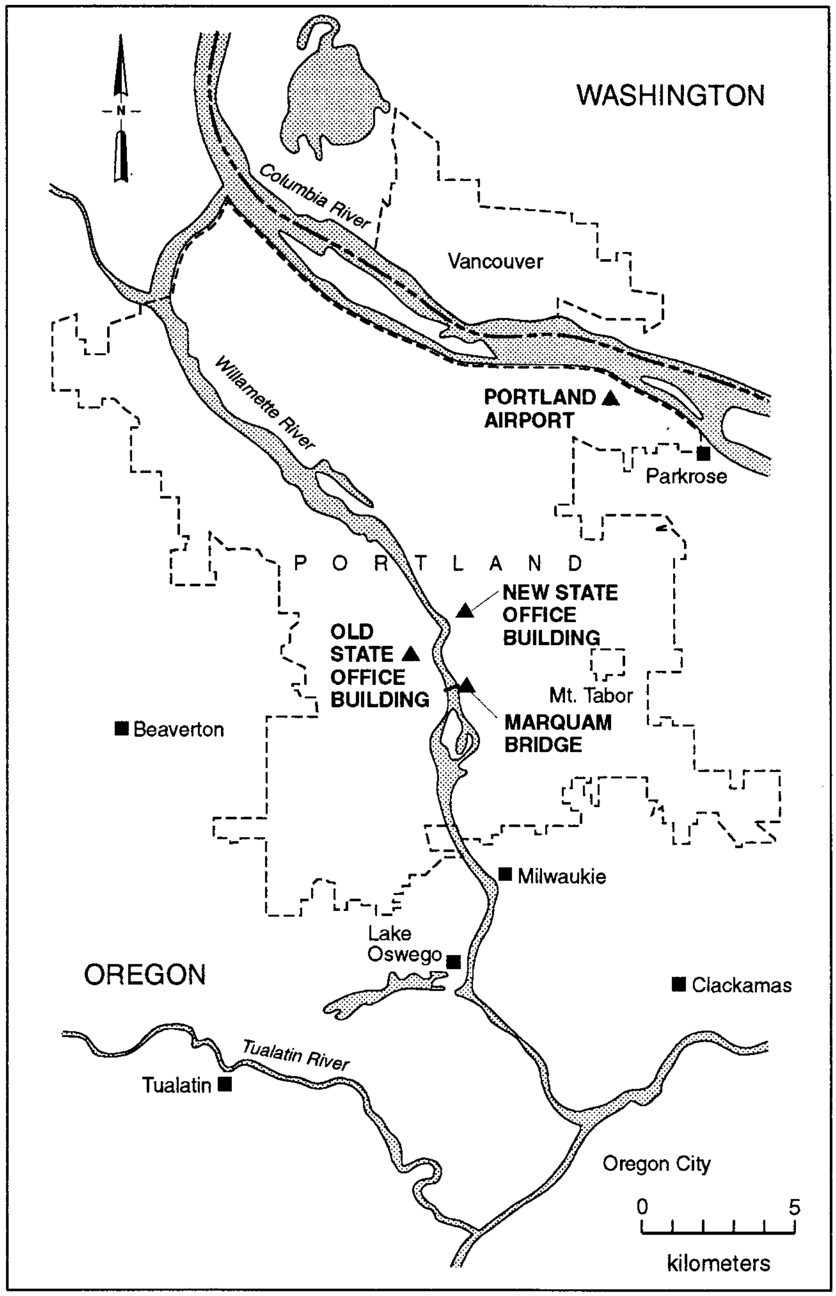

Figure 1. Location of sites (triangles) evaluated in this study.

crust are in addition to the recently recognized threat from a future great earthquake (moment magnitude $M_W \geq 8$) occurring along the interface between the Juan de Fuca and North American plates within the Cascadia subduction zone.

In this study, we have estimated the strong earthquake ground shaking that might be experienced at four sites in the Portland metropolitan area due to (1) moderate to large crustal earthquakes of M_W 6 and 6.5 occurring somewhere beneath the Portland Basin and (2) a M_W 8.5 Cascadia subduction zone earthquake. Our analysis is based on a state-of-the-art methodology that combines the Band-Limited-White-Noise (BLWN) ground-motion model and random vibration theory (RVT). An equivalent-linear site response technique is also employed to accommodate nonlinear soil behavior. This general approach has been previously used in a preliminary assessment of earthquake ground shaking in the Portland area (Wong and others, 1990).

Compared to our earlier study, we have (1) expanded our analyses to four sites and seven hypothetical earthquakes, (2) utilized recently acquired near-surface geologic and shear wave velocity data for the sites, and (3) refined our characterization and approach to modeling the Cascadia subduction zone event. Peak horizontal accelerations and five-percent damped acceleration response spectra have been computed for the following sites (Figure 1): (1) a soft soil site at the east end of the Marquam Bridge in southeast Portland, (2) a deep soft soil site at the Portland airport, (3) the moderately stiff soil site of the old State Office Building in downtown Portland, and (4) the relatively thin soil site of the new State Office Building in northeast Portland. The earthquakes modeled are two crustal earthquakes of M_W 6 and 6.5 at source-to-site distances of 5, 10, and 15 km and the M_W 8.5 Cascadia event at a distance of about 120 km.

It should be noted that our analysis is deterministic with no consideration for the frequency of occurrence of these earthquakes other than they are credible events with some finite probability of occurring. Thus the ground motions estimated in this study, specifically for the crustal earthquakes occurring in the Portland area, should not be used directly for seismic design but as potential scenarios for the greatest ground shaking that might be expected. It is also important that the uncertainties in any ground motion evaluation be fully appreciated given the uncertainties in earthquake source, path, and geologic site parameters that are the basic input into such analyses.

METHODOLOGY

The BLWN-RVT methodology is a stochastic ground motion modeling technique that has been used successfully in recent years to estimate earthquake ground shaking. Because the methodology can incorporate aspects of the source, path, and site that are specifically appropriate for the earthquake region and location to be modeled, it is particularly valuable in areas where few, if any, strong motion records exist. Such is the case for the Portland area. In this study, the crustal earthquakes have been modeled based on a point source representation of the BLWN model. This approach is applicable, given the magnitudes of the events and source-to-site distances being considered. However, because source dimensions will be significant for a great Cascadia subduction zone earthquake relative to its source-to-site distance, the finite fault version of the BLWN-RVT methodology is employed to estimate the ground motions for this event. Details of the point source and finite fault approaches can be found in Silva and others (1992) and Silva and others (1990), respectively.

INPUT PARAMETERS

The earthquake source, propagation path, and site parameters that are required for the site-specific ground motion estimates are described in the following paragraphs.

Earthquake sources

Although the largest known crustal earthquake in the Portland region was the recent 1993 Scotts Mills earthquake, events as large as or larger than M_L 6½ (or M_W 6½) are thought to be possible. Thus, the two crustal earthquakes modeled in this study were M_W 6 and M_W 6.5. The distance defined in the stochastic point source approach is measured from the site of interest to the center of energy release or approximately the center of the potential rupture plane. Source-to-site distances of 5 to 15 km were chosen to evaluate the potential ground shaking that might result from an earthquake occurring on a crustal fault beneath Portland.

Although to date no seismogenic faults have been identified in the Portland area, the relatively high level of crustal seismicity suggests that such faults do exist. Their maximum earthquake generating potential is as yet unknown. Crustal earthquakes in western Oregon tend to occur at depths down to 20–25 km, deeper than do most western U.S. earthquakes. Consequently, the likelihood of a moderate to large earthquake at a source-to-site distance of 5 km is low in the Portland region, unless the event occurs on a fault whose rupture extends up to or close to the earth's surface.

In order to estimate ground motions using the BLWN-RVT point source approach, the stress drop of the modeled earthquake is required. Recently, Youngs and Silva (1992) observed that a stress drop of about 85 bars provides a good fit to recently developed empirical rock attenuation relationships for spectral acceleration based on strong motion data from California. Given the uncertainty of stress drops for Pacific Northwest crustal earthquakes, a value of 100 bars was selected as a reasonable value to use in the point source estimates.

Geologic and seismologic studies conducted over the last five years have led, in the earth science community, to a general acceptance of the view that the Cascadia subduction zone interface has produced large megathrust earthquakes ($M_W \geq 8$) in the prehistoric past and is likely to produce them in the future (e.g., Rogers and others, 1991). The M_W 7.0 Cape Mendocino earthquake of 1992 in northwestern California probably

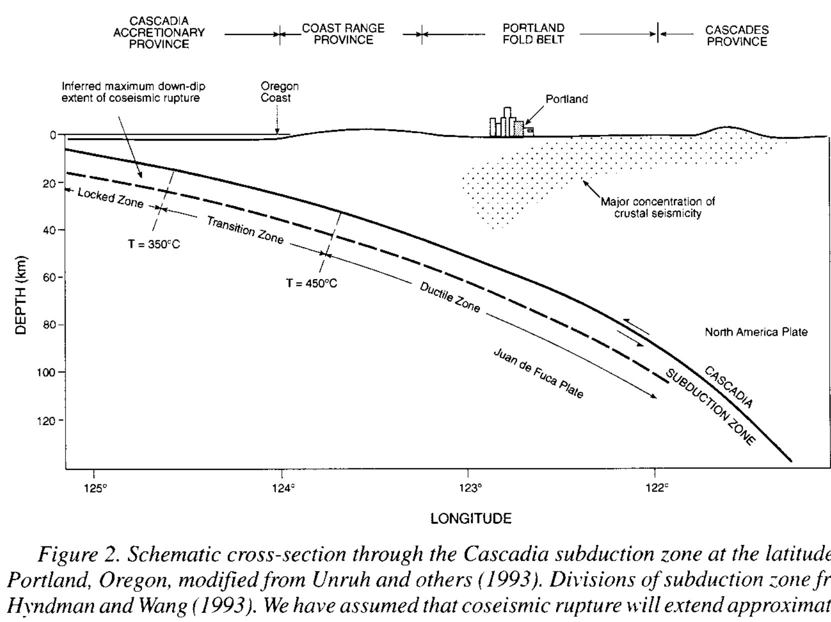

Figure 2. Schematic cross-section through the Cascadia subduction zone at the latitude of Portland, Oregon, modified from Unruh and others (1993). Divisions of subduction zone from Hyndman and Wang (1993). We have assumed that coseismic rupture will extend approximately into the western third of the transition zone.

occurred on the interface and hence demonstrates that the subduction zone, at least at its southern end, is seismogenic (Oppenheimer and others, 1993). The size of the maximum magnitude earthquake that might occur along the interface is, however, the subject of considerable current debate and research. The size of the earthquake is dependent on the length and width of the rupture zone (hence rupture area), which is in turn primarily dependent on the segmented nature and downdip extent of the subducted slab. Current estimates of these rupture parameters are uncertain, given our existing knowledge of the subduction zone. In this study, we have assumed a maximum magnitude of M_W 8.5 as a reasonable value to use at this time.

On the basis of thermal modeling, Hyndman and Wang (1993) defined four down-dip divisions of the Cascadia subduction zone interface (Figure 2, showing zones 2–4): (1) a zone of stable sliding in the unconsolidated and/or clay-rich sediments at the seaward end of the detachment; (2) a locked zone of unstable sliding behavior that allows elastic strain to accumulate; (3) a transition zone in which slip would occur, in part, during earthquake displacement and, in part, during post-seismic slip; and (4) a zone of plastic behavior (ductile) associated with high temperatures. The width of the zone defined by Hyndman and Wang (1993) as locked is about 70 km wide off the coast of Oregon. Adopting their locked zone as the primary site of future rupture, we also conservatively assume that a third of the transition zone will be involved in coseismic rupture. These assumptions result in a rupture width of about 90 km off the coast of Oregon. As derived from an empirical relationship between rupture area and magnitude (Wells and Coppersmith, in preparation), the corresponding rupture length for a M_W 8.5 earthquake would be approximately 300–350 km. Such a length is comparable to other values suggested by investigators who assume a segmented Cascadia subduction zone. Extending the rupture one-third into the transition zone also results in a source-to-site distance from the eastern extent of the rupture to the Portland area of about 120 km. This distance probably has an uncertainty of several tens of kilometers. The depth of the eastern edge of the potential 10° eastward-dipping rupture plane will be approximately 20 km (Figure 2).

In the absence of *a priori* information on the actual slip distribution of a future event, randomized slip distributions were used in the finite fault modeling for the Cascadia subduction zone earthquake. A total of 50 randomized slip models were used. Samples of these models are shown in Figure 3. In order to generate these slip models, the two-dimensional wave-number spectrum of the slip model for the M_W 8 earthquake of 1985 at Michoacan, Mexico, was computed and its phase spectrum randomized.

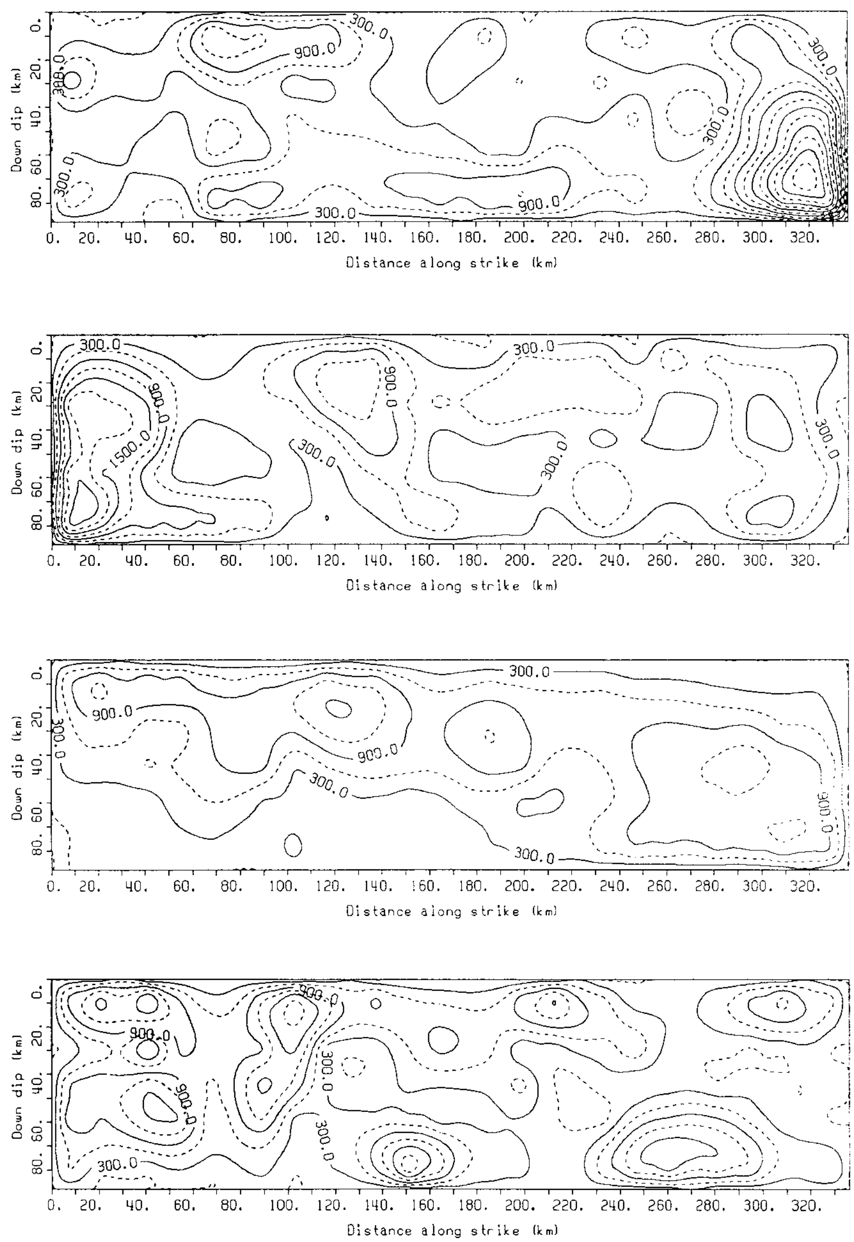

Figure 3. Examples of the 50 randomized slip distribution models used in the estimation of ground motions for the M_W 8.5 Cascadia subduction zone earthquake. Contours represent coseismic slip along the rupture planes in cm. Areas of large slip are called asperities.

Again, in the absence of *a priori* knowledge, points of rupture initiation were randomized along a zone that extends along strike and is located in the lower half of the fault plane toward its eastern edge. Rupture is expected to proceed updip in a Cascadia megathrust earthquake.

Path

To describe the frequency (f)-dependent seismic wave attenuation along the crustal path between source and site (described as $Q[f] = Q_0 f^{\eta}$) for the crustal events, a Q_0 of 200 and η of 0.35 were adopted from Singh and Herrmann (1983), who analyzed the coda waves of recorded local and near-regional earthquakes. These values were determined from the seismograph station located in Corvallis. Given the short source-to-site distances for the crustal events, attenuation has very little effect on the computed ground motions. A shear wave velocity (v_s) of 3.8 km/s and density of 2.8 g/cm^3 were used to characterize the path between the source and the site.

For the Cascadia earthquake, a Q_0 of 273 and η of 0.66 were used to characterize the attenuation of seismic waves along the path from the subduction zone to the site. This attenuation model was adopted from observations of the 1985 Michoacan earthquake (Humphrey and Anderson, 1992).

Sites

All four sites analyzed in this study are located in the alluvium-filled Portland Basin. Near-surface stratigraphy based on borehole data and shear-wave velocities from downhole profiling was provided by DOGAMI (Mabey and Madin, 1992) for the Marquam Bridge and airport sites (Figure 4). The profile for the new State Office Building was slightly revised from the one previously used in Wong and others (1990). Subsurface data for the old State Office Building site are from Shannon and Wilson and Agbabian Associates (1980). The stratigraphy beneath the boreholes is based largely on a few deep exploration boreholes in the Portland Basin and a limited amount of seismic data (Wong and others, 1990). Due to this lack of site-specific data, considerable uncertainties are associated with deeper portions of the geologic profiles, although ground motions of engineering interest in the frequency range of 1 to 10 Hz are controlled largely by the shallow site geology, particularly the unconsolidated sediments.

Occurring within the Portland Basin is the Columbia River basalt (Figure 4), which serves as the top of rock at the four sites in this study despite the relatively high shear-wave velocities for the Troutdale gravel. The basalt is overlain by the Sandy River Mudstone at three of the four sites, by the Troutdale gravel, and then by varying thicknesses of soft, relatively low-velocity alluvial sands and silts. All layers above rock were considered in the equivalent-linear analysis. Three shear modulus reduction curves were used to characterize the dynamic behavior of the unconsolidated sediments at each site: Seed and Idriss (1970) for upper-range sand and mid-range gravel (Troutdale) and Sun and others (1988) for the Sandy River Mudstone. Seed and Idriss (1970) mid-range damping curves for sand and gravel were used for the sands and Troutdale gravels, respectively. A damping curve was developed and used in this study specifically for the mudstone. Modulus reduction and damping curves are a source of uncertainty, since they are based on laboratory measurements of non-site-specific samples.

RESULTS

Earthquake ground shaking on soil sites is influenced by two opposing effects: site amplification and material damping. Amplification by unconsolidated sediments often results in the increase in amplitudes at certain frequencies due to (1) conservation of energy effects as the seismic waves travel from a faster, more rigid material to a slower, softer material; and (2) resonant effects due to constructive interference of multiple reflections. Damping in soils is the dissipation of energy due to a variety of loss mechanisms.

The five-percent damped acceleration response spectra computed in this study for the crustal earthquakes are shown in Figures 5 and 6. The estimated peak horizontal accelerations are summarized in Table 1. For comparison, we have also computed peak horizontal accelerations based on several state-of-the-practice empirical attenuation relationships for crustal earthquakes (Table 2). Inherent in the empirical approach to estimating ground motions is the inability to incorporate site-specific geologic data and hence, site response effects unique to each location.

For the Marquam Bridge site, peak horizontal accelerations range from 0.13 to 0.43 *g*, levels which can result in minor to

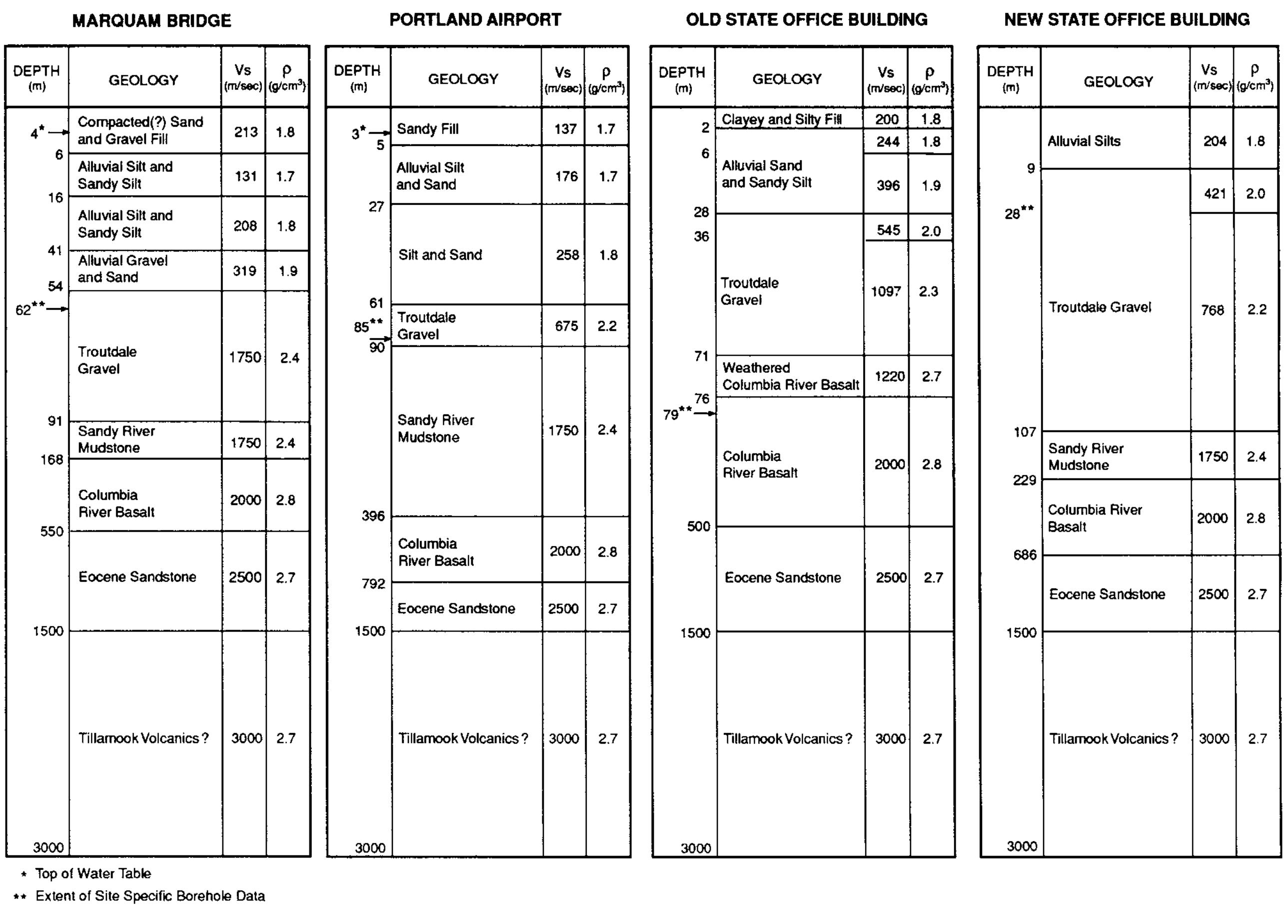

Figure 4. Geologic profiles beneath the four sites analyzed in this study.

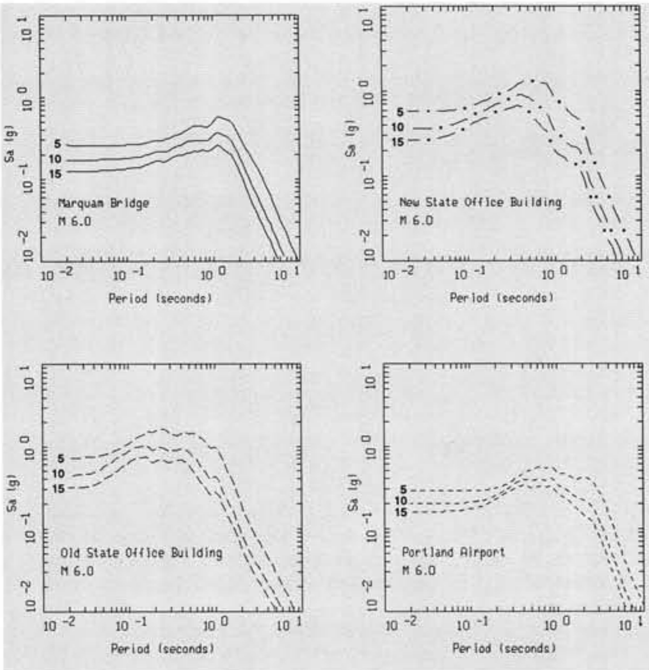

Figure 5. Site-specific five-percent damped median acceleration response spectra for the M_W 6 crustal earthquake at source-to-site distances of 5, 10, and 15 km for the four sites analyzed.

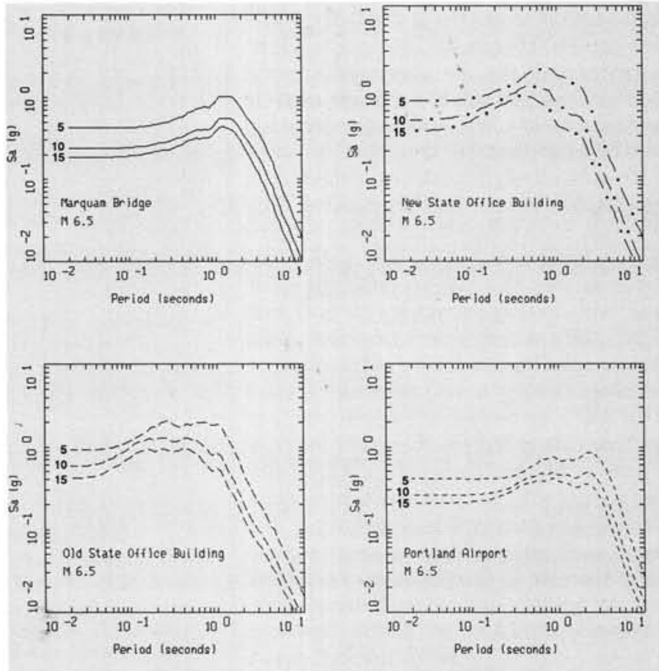

Figure 6. Site-specific five-percent damped median acceleration response spectra for the M_W 6.5 crustal earthquake at source-to-site distances of 5, 10, and 15 km for the four sites analyzed.

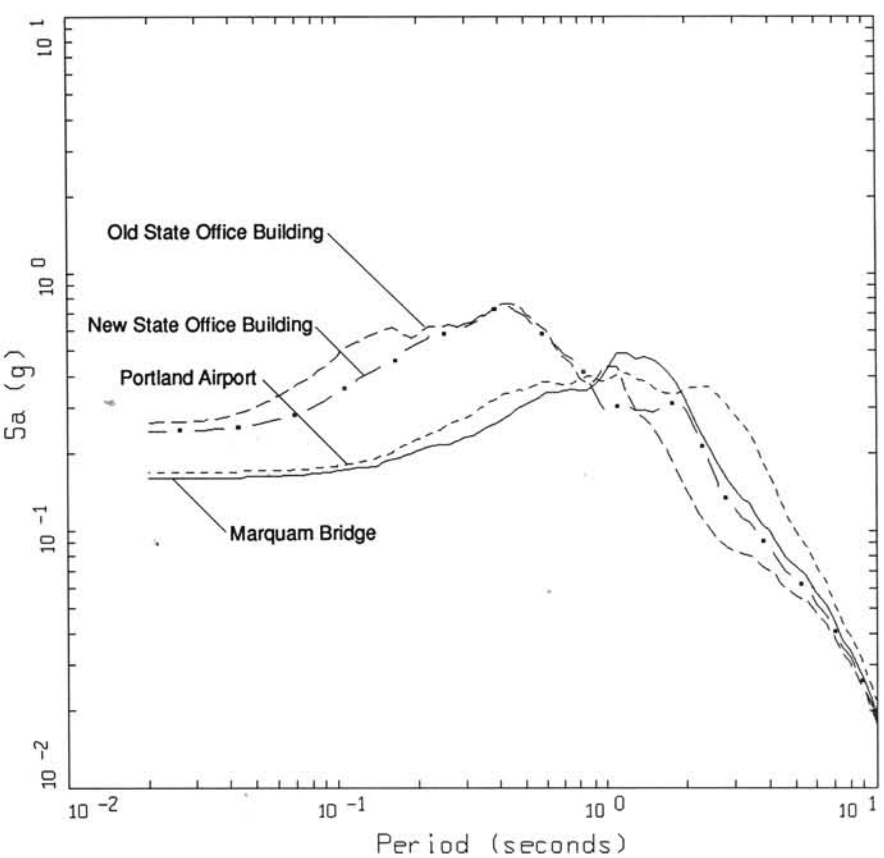

Figure 7. Site-specific five-percent damped median acceleration response spectra for the M_W 8.5 Cascadia subduction zone earthquake for the four sites analyzed, at a source-to-site distance of 120 km.

significant structural damage (Table 1). (Ground acceleration is often expressed in terms of "*g*," or the gravitational acceleration at the earth's surface.) For comparison, ground shaking recorded 50 km away in the Portland area during the recent Scotts Mills earthquake was less than 0.05 *g* (U.S. Geological Survey, 1993).

The strong velocity contrast at the top of the Troutdale gravel beneath the Marquam Bridge site (Figure 4) probably accounts for some site amplification of the ground motions, although this effect appears to be offset by damping in the 54-m-thick low-velocity silts and sands. The low-velocity zone (131 m/s) between the depths of 6 and 16 m (Figure 4) may also act to trap some upgoing energy. In almost all cases, the site-specific stochastic peak horizontal accelerations for the crustal earthquakes are less than typical median empirical values (Tables 1 and 2), attesting to the damping effects of this relatively deep-soil site. The spectral shapes, in particular the resonant peak at a period of 1.5 s, are similar for both the M_W 6 and the M_W 6.5 earthquakes, reflecting the influence of the near-surface site geology (Figures 5 and 6).

The ground motions at the Portland airport reflect the site response of a deep-soil site, although the absence of a low-velocity zone may account for the slightly higher peak horizontal accelerations compared to the Marquam Bridge (Table 1; Figures 5 and 6). Significant short-period damping is probably occurring within the 90-m-thick unconsolidated to poorly consolidated sediments (including the low-velocity Troutdale gravels) (Figure 4). The peak accelerations for this site are comparable to the median empirical values estimated with the relationship of Idriss (1985) for deep-soil sites (Tables 1 and 2).

In contrast, significant site amplification appears to be influencing the ground motions at the old State Office Building site and to a slightly lesser extent at the new State Office Building site. The site-specific stochastic peak horizontal accelerations for both sites significantly exceed typical empirical values (Tables 1 and 2). Beneath the old State Office Building, a strong velocity contrast is located at the boundary between the weathered top of the Troutdale gravel and the rest of the layer (Figure 4). Material damping is not as significant at these sites, due to the thinner nature of the soils and unconsolidated sediments. If a crustal earthquake of M_W 6 or greater were to occur at source-to-site distances of 5–15 km, such as beneath downtown Portland, very strong ground shaking would be experienced (Figures 5 and 6). Given the uncertainties in ground motion estimates, the peak accelerations for the old State Office Building site could exceed 0.6 *g* (Table 1).

Velocity contrasts exist beneath the new State Office Building at boundaries within the Troutdale gravel. The Sandy River Mudstone represents a low-velocity zone within the profile, which probably accounts for the lower peak accelerations and spectral accelerations at short periods, compared to the old State Office Building (Table 1 and Figure 4). The highest spectral accelerations at these two sites occur at periods of 0.1 to 1.0 s (1 to 10 Hz) (Figures 5 and 6), the bandwidth of significant engineering relevance.

Despite the source-to-site distance of 120-km, the M_W 8.5 Cascadia earthquake could generate significant ground shaking in the Portland metropolitan area, particularly at the old and new State Office Building sites (Figure 7 and Table 1). These ground motions, however, must be viewed cautiously, given the large uncertainties surrounding the source-to-site distances to the eastern extent of rupture of a megathrust earthquake and, of course, the maximum magnitude of such an event. The shift in the broad spectral peaks to longer periods for the Portland airport and Marquam Bridge compared to the old and new State Office Buildings reflects the influence of the deep unconsolidated sediments at the former two sites (Figure 7).

An important effect not addressed in this study, especially for the Cascadia earthquake, is the duration of strong ground shaking. Given the extended rupture dimensions of a large megathrust earthquake, duration is a parameter that needs to be considered in seismic design and seismic safety evaluations, particularly for long-period structures, such as tall buildings and bridges, and in areas where soil liquefaction is a potential hazard.

Table 1. *Site-specific stochastic peak horizontal accelerations. MB = Marquam Bridge, NB = new State Office Building, OB = old State Office Building, PA = Portland airport*

			Peak horizontal accelerations			
Earthquake	**Magnitude (M_W)**	**Distance[1] (km)**	**MB (*g*)**	**NB (*g*)**	**OB (*g*)**	**PA (*g*)**
Cascadia	8.5	120	0.16	0.24	0.26	0.17
Crustal	6	5	0.26	0.58	0.72	0.29
		10	0.18	0.36	0.44	0.20
		15	0.13	0.26	0.31	0.16
	6.5	5	0.43	0.78	0.92	0.41
		10	0.24	0.47	0.57	0.26
		15	0.19	0.35	0.41	0.21

[1] Source-to-site

Table 2. *Median empirical peak horizontal accelerations for crustal earthquakes*

				Idriss (1985)	
Magnitude (M_W)	**Distance[1] (km)**	**Campbell (1990) (*g*)**	**Sadigh (1987)[2] (*g*)**	**Stiff[3] (*g*)**	**Deep[4] (*g*)**
6	5	0.37	0.29	0.36	0.31
	10	0.22	0.20	0.25	0.22
	15	0.15	0.14	0.18	0.17
6.5	5	0.43	0.37	0.43	0.36
	10	0.28	0.26	0.30	0.27
	15	0.20	0.20	0.23	0.20

1 Source-to-site

[2] Described in Joyner and Boore (1988)

[3] Stiff-soil sites are underlain by cohesionless soils or stiff clays less than 61 m deep

[4] Deep-soil sites are underlain by more than 76 m of cohesionless soil deposits

SUMMARY

If a crustal earthquake of moderate or larger magnitude (M_W 6) should occur beneath the Portland Basin, significant strong ground shaking is likely. As has been observed in numerous cases worldwide, the amplitudes and frequency content of such ground motions will be strongly influenced by the nature of the soils and unconsolidated sediments beneath a given location in the Portland metropolitan area. Thin-soil sites such as the old and new State Office Buildings can produce severe ground shaking in either a nearby crustal earthquake or a distant large event on the Cascadia subduction zone. Deep-soil sites such as at the Marquam Bridge and the Portland airport, though still capable of experiencing strong shaking, will dampen as well as shift short-period ground motions to longer periods. The range of ground motions observed in this study further emphasizes the need for assessing such hazards on a site-specific basis in the Portland metropolitan area.

ACKNOWLEDGMENTS

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BLM protects "Cenozoic Park" fossils

by John Zancanella; reprinted from BLM News, *September 1993, page 4.*

With the popularity of the movie *Jurassic Park*, interest in fossils is greater than ever before. Few people realize, however, that the Bureau of Land Management is steward to many fossil treasures here in Oregon.

"Fossil remains of dinosaurs like those portrayed in the movie are generally found in the Great Plains and Rocky Mountains regions," explained paleontologist Dr. James Martin. "In Oregon, we have fossils from the Age of Mammals, the Cenozoic Era, which extends back nearly 50 million years."

Martin, from the South Dakota School of Mines and Technology, has been hired by BLM to develop a statewide plan for paleontology, the study of ancient life through the fossil record.

"After conducting research in Oregon for 20 years, I understand that educating people about this resource is as important as working to preserve it," Martin said. "Public responsibility is the key."

In central Oregon, the red, blue-green, and buff-colored sedimentary rocks of the Clarno, John Day, Mascall, and Rattlesnake Formations represent environments that changed from tropical and subtropical forests to a cooler and dryer savanna. The fossils found in these rocks include horses, elephants, rhinoceroses, rodents, cats, dogs, camels, and large piglike animals called oreodonts.

The John Day Formation, visible along the upper John Day River and the surrounding hills, was punctuated by volcanic ash falls that now allow scientists to accurately determine how the plants and animals have changed over time. This formation is significant because its seven- to ten-million-year sequence of fossil-bearing rock is one of the most complete and continuous in the world.

"In fact," Martin explained, "evolutionary changes of the horse were first determined from fossils recovered from the John Day River basin. Erosional and volcanic forces since that time have combined to sculpt and mold these ancient landscapes into the dramatic and wonderful scenes we see today."

In June, the resurgence of excitement about fossils and their importance to scientific study prompted BLM's Oregon/Washington State Director Dean Bibles to visit two Cenozoic fossil sites on BLM-managed lands in central Oregon.

Bibles and Martin toured Logan Butte in BLM's Prineville District and Fossil Lake in BLM's Lakeview District. Ted Fremd, paleontologist with the John Day Fossil Beds National Monument, was also on hand to attest to the importance of the Logan Butte site.

"I was impressed with the wide variety and sheer quantity of the fossil record at these sites," Bibles said. "At the same time, however, I'm disturbed to see so much evidence of unauthorized collection and destruction caused by careless visitors."

Current federal law prohibits the collection of any vertebrate fossils from federal lands without a permit, whereas most invertebrate and plant fossils can be collected by the general public.

"It is essential that we carefully collect and document specimens on public lands, but the process doesn't stop there," explained Martin. "We must preserve fossils for those to come and be able to retrieve them for future study."

Bibles showed enthusiastic support for Dr. Martin's efforts and stated that more education of both BLM staff and the public is needed to protect fossil resources on public lands.

"Fossils are a nonrenewable resource, and vertebrate fossils are the rarest," Bibles said. "We're committed to doing whatever is necessary to ensure that BLM's 'Cenozoic Park' may be studied and enjoyed by future generations." □

DOGAMI PUBLICATIONS

Released September 22, 1993:

Geologic map of the Vale 30 x 60 minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho, by Mark L. Ferns, James G. Evans, and Michael L. Cummings. It is published as map GMS–77. Price is $10. — This has been released together with **Geologic map of the Mahogany Mountain 30 x 60 minute quadrangle, Malheur County, Oregon, and Owyhee County, Idaho,** by Mark L. Ferns, Howard C. Brooks, James G. Evans, and Michael L. Cummings. It is DOGAMI map GMS–78. Price is $10.

A 3,000-mi^2 area of northern and central Malheur County in extreme eastern Oregon is covered by these two geologic maps, the north half by GMS–77 and the south half by GMS–78. Over a period of more than seven years, geologists have mapped, one by one, the 64 7½-minute quadrangles that make up the complete west half (a little more than the Oregon portion) of the Boise 1°x2° quadrangle. The new maps represent a compilation of this work.

Together, they inform the public about the region's geology, which provides the framework for newly discovered gold deposits such as Newmont's Grassy Mountain. They also present information on other geologic resources, among them nonmetallic minerals, geothermal energy, and natural gas, and give a brief assessment of geologic hazards such as landslides and ground-water pollution.

The original mapping work was done at the more detailed scale of 1:24,000, and a portion of it has been published already. The new compilation maps, GMS–77 and GMS–78, are done at the scale of 1:100,000, each including a full-color map sheet approximately 31 by 45 in. in size and a 12-page text with rock descriptions and discussions of the geologic evolution and geologic resources and hazards of the region.

The maps cover parts of two geomorphic provinces, the Owyhee Uplands and the western Snake River Plain. Both provinces are extensional basins, large scars on the earth's surface from two periods of rifting along the Oregon-Idaho border.

The older basin, the Oregon-Idaho Graben, is now partially filled with a variety of volcanic and sedimentary rocks. It extends north-south and began to form shortly after eruption of the voluminous flood basalts of the Columbia River Basalt Group some 15 to 17 million years ago. Large rhyolite calderas and eruptive centers, similar in size to those of modern-day Yellowstone, formed early during the development of the Oregon-Idaho Graben. Gold mineralization was associated with smaller scale calc-alkaline volcanism along the axis of the graben.

The younger basin now forms the northwest-trending western Snake River Plain. It began cutting across the north end of the Oregon-Idaho Graben about 7 million years ago. For a period of about 5 million years, this part of the western Snake River Plain was filled by ancient Lake Idaho (comparable in size to some of the modern-day Great Lakes). The lake was emptied by the Snake River through Hells Canyon about 1.5 million years ago.

Released August 12, 1993:

Pilot erosion rate data study of the central Oregon coast, Lincoln County. Final report to the Federal Emergency Management Agency, by G. R. Priest. I. Saul, and J. Diebenow. The 232-page report includes 30 colored photographs and has been released as Open-File Report O–93–10 for library access only. Photocopies may be obtained at cost.

The pilot study was undertaken to support the Federal Flood Insurance Program. The goal of this program is to explore ways of measuring erosion rates so that bluff and shoreline positions can be predicted accurately up to 60 years in the future and the erosion rates used to set flood insurance rates.

The study area extends along most of the coastline of Lincoln County, between Cascade Head and Seal Rock. The area was chosen as representative of the many coastal environments of Oregon because it includes bluffed beaches, hard-rock headlands, sand spits, and river-mouth beaches. On the basis of geology and geomorphology, the entire length was divided into 32 segments and subsegments, and erosion rates were studied for each of them.

This report is available for inspection in the library of the Portland office of the Oregon Department of Geology and Mineral Industries (see address on page 126 of this issue). Copy services may be obtained from Kinko's at 1605 NE 7th Avenue, Portland, OR 97232, phone 503–284–2129.

Released January 8, 1993:

Neotectonic map of the Oregon continental margin and adjacent abyssal plain, by C. Goldfinger, L.D., Kulm, R.S. Yeats, C. Mitchell, R. Weldon II, C. Peterson, M. Darienzo, W. Grant, and G.R. Priest. Released as Open-File Report O–92–4. Price is $30.

The neotectonic map shows the structure of the continental margin along the Oregon coast and other details that help determine the earthquake hazard potential of the state. Data were contributed by Oregon State University, U.S. Geological Survey, National Oceanic and Atmospheric Administration, and Chevron and Shell Oil Companies. Compilation and publication were supported by the National Earthquake Hazards Reduction Program.

The main map (Plate 1) is a color electrostatic plotted sheet measuring 36 by 45 in. It shows faults and folds along the Oregon continental margin at the Cascadia subduction zone and presents representative sections through salt marshes. A one-color map (Plate 2) shows the track lines for offshore geophysical data. The release also includes a 17-page text with discussions and explanations.

The neotectonic map illustrates how the continental margin has been and is being deformed by underthrusting of the oceanic plate beneath the continental plate. It shows dozens of newly discovered, potentially active submarine faults, some of which may penetrate all the way to the Oregon coast.

The map also shows uplift rates along the coast. This uplift is probably caused by strain that builds up between great subduction-zone earthquakes. The uplift rates, when compared to the rates of global sea-level rise, indicate the parts of the coast that are most vulnerable to gradual coastal flooding and erosion.

Released July 26, 1993:

Schematic fence diagram of the southern Tyee basin, Oregon Coast Range, showing stratigraphic relationships of exploration wells to surface measured sections, by I.-C. Ryu, A.R. Niem, and W.A. Niem, has been published as Oil and Gas Investigation 18. The black-and-white fence diagram is printed on a 36 by 60 in. sheet and is accompanied by a 48-page geologic interpretation. Price is S9.

As part of the final phase of a five-year program to assess the oil, gas, and coal potential of the southern Tyee basin, the fence diagram was constructed from 24 composite measured geologic sections and the stratigraphy of 11 oil and gas exploration wells.

The southern Tyee basin includes and area of approximately 4,800 mi^2 located mainly in Coos, northern Curry, and western Douglas Counties, west of a line marked by Interstate Highway 5 between Cottage Grove and Grants Pass. The southern part of the basin appears to have the greatest oil and gas potential. The mapping work and the resulting fence diagram have produced significant modifications of the stratigraphic nomenclature of the southern Coast Range.

With the exception of Open-File Report O–93–10, the new reports are now available for purchase over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232–2109, phone (503) 731–4444, FAX (503) 731–4066; and 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. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

In memoriam: Norman S. Wagner

"Wag," as he was known to his friends, was born on May 24, 1909, in Wilkes Barre, Pennsylvania. He died October 20, 1993, in St. Elizabeth Hospital in Baker City, Oregon. He will be buried next to his wife Estelle in Oak Hill Memorial Park in San Jose, California.

Wag received bachelor's and master's degrees in geology from Cornell University. In 1936, he was chief assayer for the Idaho Maryland Gold Mine near Donner Pass in California.

In 1942 he started working for the Oregon Department of Geology and Mineral Industries as a resident geologist in charge of the Baker office, one of the department's two field offices. He served in this position until his retirement at the end of 1973. Wag published extensively in his field and received numerous recognitions. He was responsible for extensive pioneer rock location throughout eastern Oregon. He was also interested in the reclamation of dredge tailings in eastern Oregon.

Wag belonged to many professional organizations, including the Society for Mining, Metallurgy, and Exploration, Inc., the American Institute of Mining Engineers, the Northwest Mining Association, and the Idaho Association of Professional Geologists, and he was a charter member of the American Institute of Professional Geologists. Wag was named by the Governor to the Oregon Geographic Names Board.

Wag will be deeply missed by his family and the many friends whose lives were touched and enriched by this truly charming and unique man. □

Russians to play major role at NWMA meeting

For decades, world leaders and people in the mining industry have speculated about the purported endless supply of minerals which lay hidden in the secretive former Soviet Union.

Some of the mystery surrounding Russian mineral resources will be lifted this December in Spokane, Washington, at the 99th annual meeting of the Northwest Mining Association (NWMA).

A half-dozen experts from throughout Russia will share their knowledge of Russian geology and related mineral sciences at the NWMA short course "Global Business Opportunities: Examining the Differences" on November 28–30, 1993, and the NWMA convention "International Mining: Pros and Cons" on November 30 to December 3, 1993.

The Russian experts include Dr. Anatoly A. Siderov and Dr. Leonid M. Parfenov, Russian Academy of Sciences, who will discuss opportunities and problems for joint mining ventures in the Russian Northeast and Northern Siberia at a three-day short course in the Sheraton-Spokane Hotel. The course will also cover business opportunities in Latin America and the Pacific Rim/Asia.

Parfenov, who is chief for the Laboratory on Regional Geology and Tectonics at Yakutsk in Northern Siberia, will also open the NWMA convention as the welcoming luncheon speaker on December 1. This address will be "The Life of a Russian Geologist in Siberia." Before his appointment in Siberia about 10 years ago, he was chief of a similar laboratory at the Institute of Tectonics and Geophysics at Khabarovsk in the central Russia Far East.

Other Russian scientists and scholars will discuss geology and minerals of their country on December 2 and 3.

The convention, one of Spokane's largest, typically draws more than 3,000 attendees from across the globe. Technical sessions are held in the Spokane Convention Center and the Opera House as well as in the Sheraton-Spokane Hotel. A three-day trade show with more than 300 exhibitors is held at the Ag Trade Center Dec. 1–3.

A second short course, Applied Biogeochemical Prospecting in Forested Terrain, will be held Nov. 29–30 at the Sheraton-Spokane. Course instructors are specialists in geology, geochemistry, chemistry, botany, and forestry.

The NWMA membership is made up of individuals and companies of all sizes, representing the small prospector as well as the large corporation.

For information or registration forms for the NWMA annual meeting, call 509/624–1158 or write NWMA, 10 N. Post, Suite 414, Spokane, WA 99201–0772. *—NWMA news release*

IGA announces Geothermal Congress 1995

The International Geothermal Association (IGA) will hold its 1995 World Geothermal Congress May 18–31, 1995, in Florence, Italy. The theme is "Worldwide Utilization of Geothermal Energy." The congress is convened by IGA, co-convened by the Geothermal Resources Council, and sponsored by ENEL, the Italian Electric Power Company.

The Congress will include plenary sessions with invited presentations from various countries that have significant geothermal development, technical sessions, field trips, short courses, exhibits, and a full guest program.

The primary purpose of the 1995 World Geothermal Congress is to provide a forum for international exchange of scientific and technological information on geothermal development during the period 1990–1995. The Congress will generally follow the successful format of the 1975 United Nations International Symposium on Geothermal Energy.

For a circular with further information, interested persons should contact George Fry, Executive Director, International Geothermal Association, LBL 50C, Rms. 106–108, One Cyclotron Road, Berkeley, CA 94720, USA; phone (510) 486-4584, FAX (510) 486-4889. *—IGA news release*

Did you know—?

Russian geologists have made a unique discovery in the northernmost reaches of the Ural Mountains: Searching for mineral resources, they happened upon a cave in which the walls were covered with gigantic crystals of smoky quartz. The biggest specimen had a diameter of 2.2 m (more than 7 ft) and weighs about 1,700 kg (3,750 lb). The crystals are estimated to be 220–260 million years old.

The uniqueness of the find lies in the smoky-transparent color of the megacrystals. Quartz crystals of similar size have been discovered before, in Arkansas, Brazil, or Norway, for instance. But all of these were milky. Quartz crystals form by crystallization of silicon-saturated solutions, under high pressure and at temperatures up to 250°C (approx. 500°F). Clear crystals form when the temperature remains consistently high for a long time; if it fluctuates, microscopic droplets are included, and these disperse light and make the crystal milky. The smoky-brown coloration is the result of inclusion of other elements in the crystal matrix of silica (SiO_2) and is intensified by natural irradiation. A large portion of the smoky quartz that is offered for sale is really artificially irradiated clear quartz.

The newly found megacrystals will most likely end up in museums and private collections. Before they can be sold, however, considerable difficulties in mining them will have to be overcome. The necessary heavy equipment must be flown in and can be used only when temperatures are down to -50°C (-58°F). Only at these temperatures will the deep snow cover on the ground near the cave be frozen hard enough to carry the load of the machines.

—From a note by Arlette Kouwenhoven in Die Zeit, *overseas edition, no. 42 (October 22, 1993), p. 18*

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