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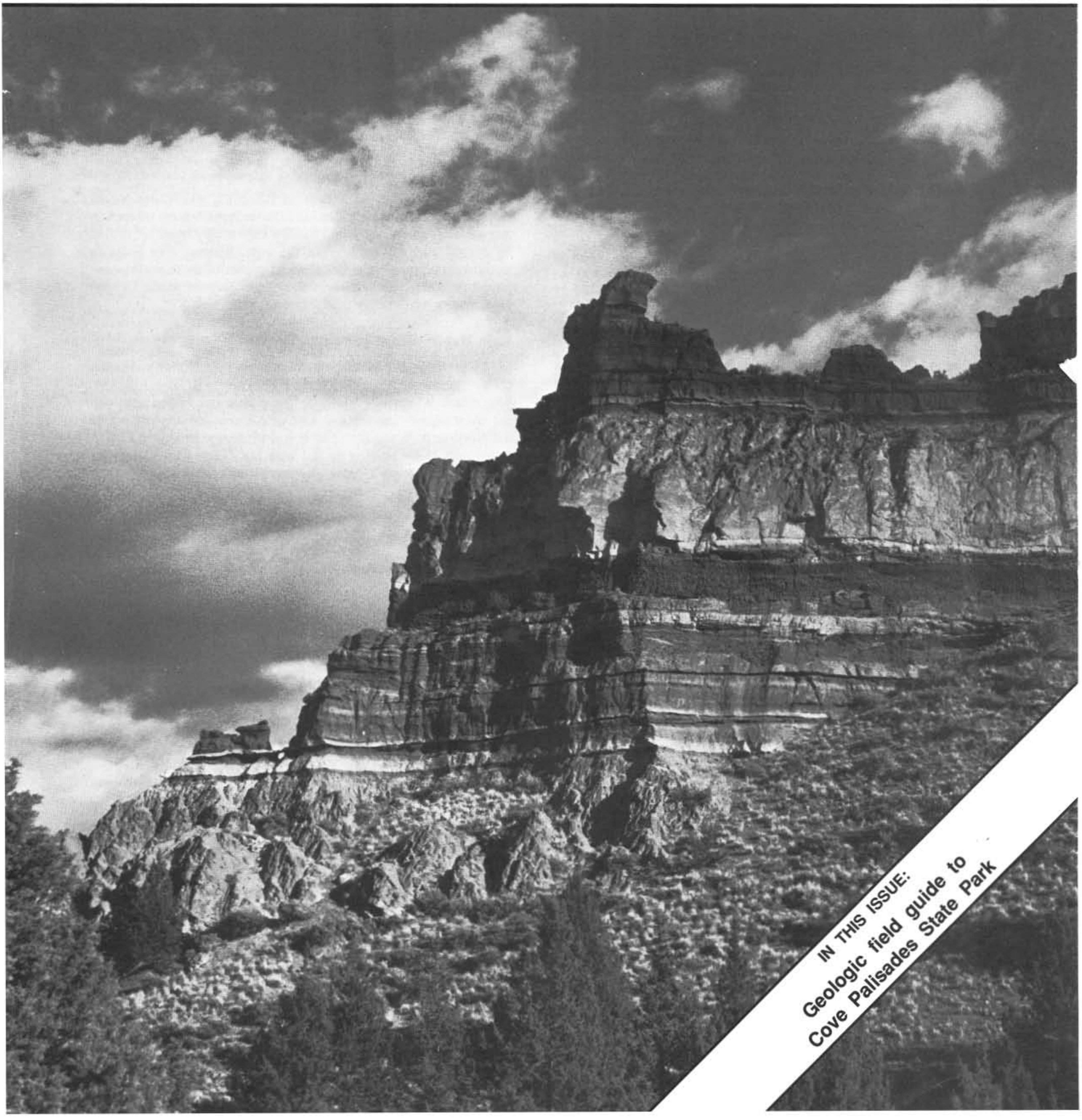

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Cove Palisades State Park

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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*, 6th ed., 1978.) 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 DOGAMI.

Cover photo

"The Ship" at Cove Palisades State Park. Coarse sandstones and two ignimbrites are well displayed in this erosional remnant. The upper white ignimbrite is the Cove ignimbrite unit. The lower rough unit, just above the grass on the left, is the Jackson Buttes ignimbrite. The article beginning on the next page describes the geology of Cove Palisades State Park and is followed by a field trip guide to the area.

OIL AND GAS NEWS

Summary of 1989 drilling at Mist Gas Field

ARCO has finished drilling a seven-well program at Mist, completing three wells as gas producers and plugging four wells. The three new gas producers are the CER 41-16-64, CC 34-28-65, and CER 13-1-55 wells, drilled to depths of 2,105 ft, 2,240 ft, and 1,480 ft, respectively. The four abandoned wells are the CER 24-18-64, CC 34-8-75, Hamlin 33-17-65, and OR 34-25-66 wells, drilled to depths of 1,810 ft, 2,706 ft, 3,150 ft, and 2,452 ft, respectively.

DY Oil has drilled a six-well program at Mist, completing the Neverstill 33-30 as a gas producer. Total depth was 2,225 ft. The remaining five wells were plugged. These are the Burris CC-24-8, CER 23-22-64, Forest Cav 13-6, Lane CC-24-5, and Lane CC-24-5-A wells, drilled to depths of 2,684 ft, 2,680 ft, 1,796 ft, 1,473 ft, and 1,126 ft, respectively.

Rulemaking

Draft rules are being written on HB 2089, which was passed by the legislature this year. The bill calls for ground-water protection and surface reclamation when shallow exploratory holes are drilled by the oil and gas industry in the state. Seismic shot holes or shallow stratigraphic test holes are examples of these shallow exploratory holes. For details, contact Dan Wermiel at the Oregon Department of Geology and Mineral Industries.

Kyle Huber Award presented by NWPA

At its November meeting, the Northwest Petroleum Association (NWPA) presented the 1989 Kyle Huber Award to Duane Leavitt. The award is annually given to the persons or companies with the most significant achievement in oil and gas exploration in the Northwest during the year. It was presented to Duane Leavitt as a result of the drilling he did with DY Oil at Mist Gas Field, including a successful new gas completion.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth(ft)
434	ARCO Columbia Co. 13-3-55 36-009-00263	SW¼ sec. 3 T. 5 N., R. 5 W. Columbia County	Permitted; 1,655.
435	ARCO Columbia Co. 13-4-54 36-009-00264	SW¼ sec. 4 T. 5 N., R. 4 W. Columbia County	Permitted; 2,025.
436	ARCO CER 13-1-55 36-009-00265	SW¼ sec. 1 T. 5 N., R. 5 W. Columbia County	Permitted; 1,645.
437	ARCO OR 34-25-66 36-007-00022	SE¼ sec. 25 T. 6 N., R. 6 W. Clatsop County	Permitted; 2,280.
438	ONGD OR State 32-26 36-067-00004	NE¼ sec. 26 T. 1 S., R. 4 W. Washington County	Permitted; 2,000.
439	DY Oil Lane CC-24-5-A 36-009-00266	SE¼ sec. 5 T. 5 N., R. 5 W. Columbia County	Permitted; 2,000.

□

A field guide to the geology of Cove Palisades State Park and the Deschutes Basin in central Oregon

by Ellen Morris Bishop, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331, and Gary A. Smith, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131

INTRODUCTION

The Deschutes River rises from unpretentious rivulets in the emerald meadows flanking Mount Bachelor. It meanders across the flat floor of the High Cascades and Newberry's lava plains. Then, fueled by melted snows and driven by 2,000 ft (600 m) of fall, it plunges northward, an awakened goliath, a river with a mission (Figure 1).

If it were not for the modern Deschutes River, we would know little of the basin that lies between the High Cascades and the venerable Blue Mountains. But because of the river, the rolling, juniper-clad expanse of west-central Oregon has become a storybook instead of remaining a mystery.

From Redmond to Gateway, the walls of the spectacular canyon of the Deschutes River reveal a basin periodically inundated by lava, swept by floods, and buried beneath volcanic ash. The river persistently cut its channel while eruptions and floods clogged its path to the sea. The Deschutes is a geologist's river. And one of the best places to witness its work is in the canyons of Cove Palisades State Park.

This relatively nontechnical guide to the geology of Cove Palisades State Park and the Deschutes Basin is based upon the work of coauthor Gary Smith, along with that of Richard Conrey, Gene Yogodzinski, Edward Taylor, and others who are cited herein. It updates and expands previously published

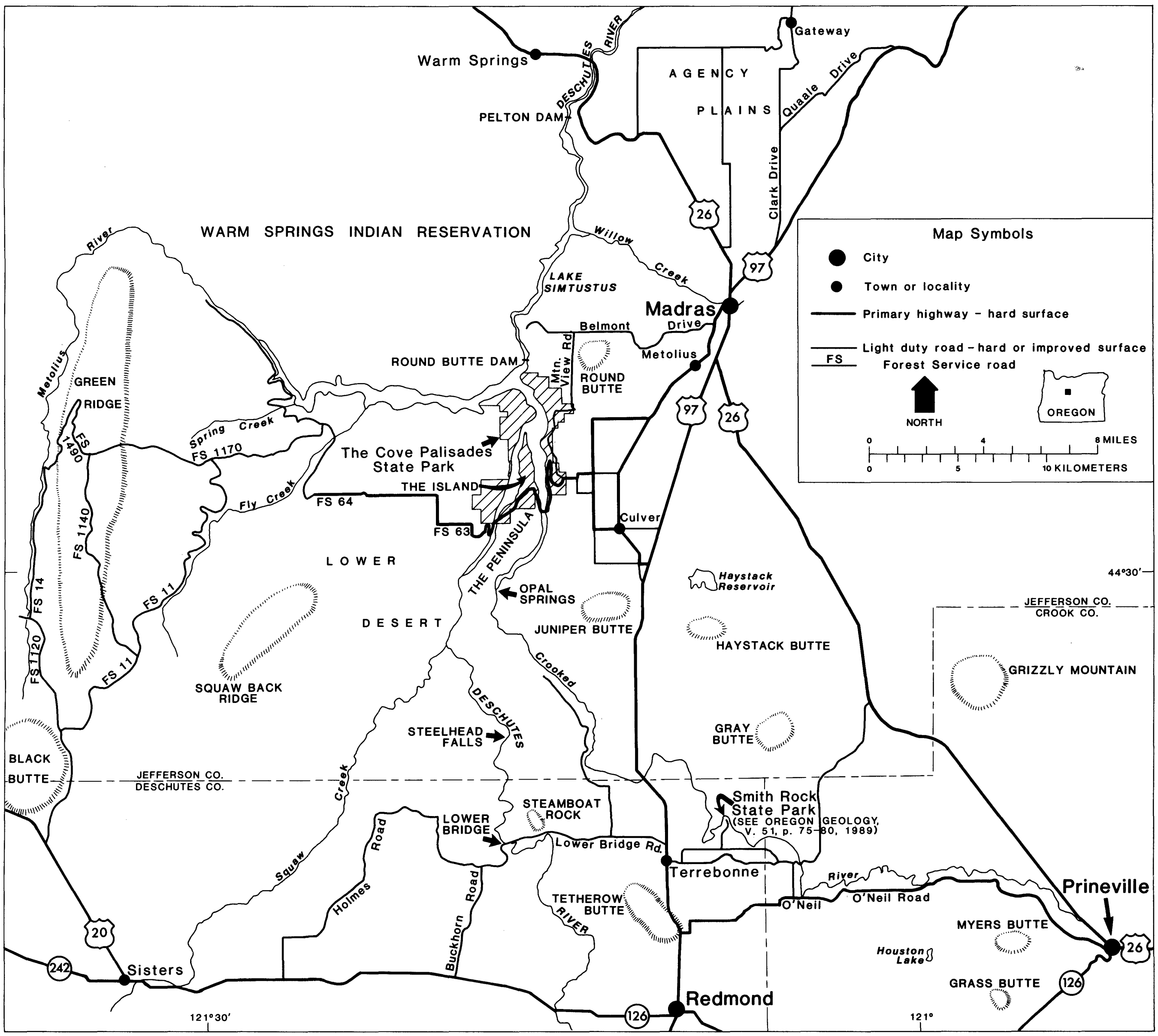

Figure 1. Map showing the geography of the Deschutes Basin.

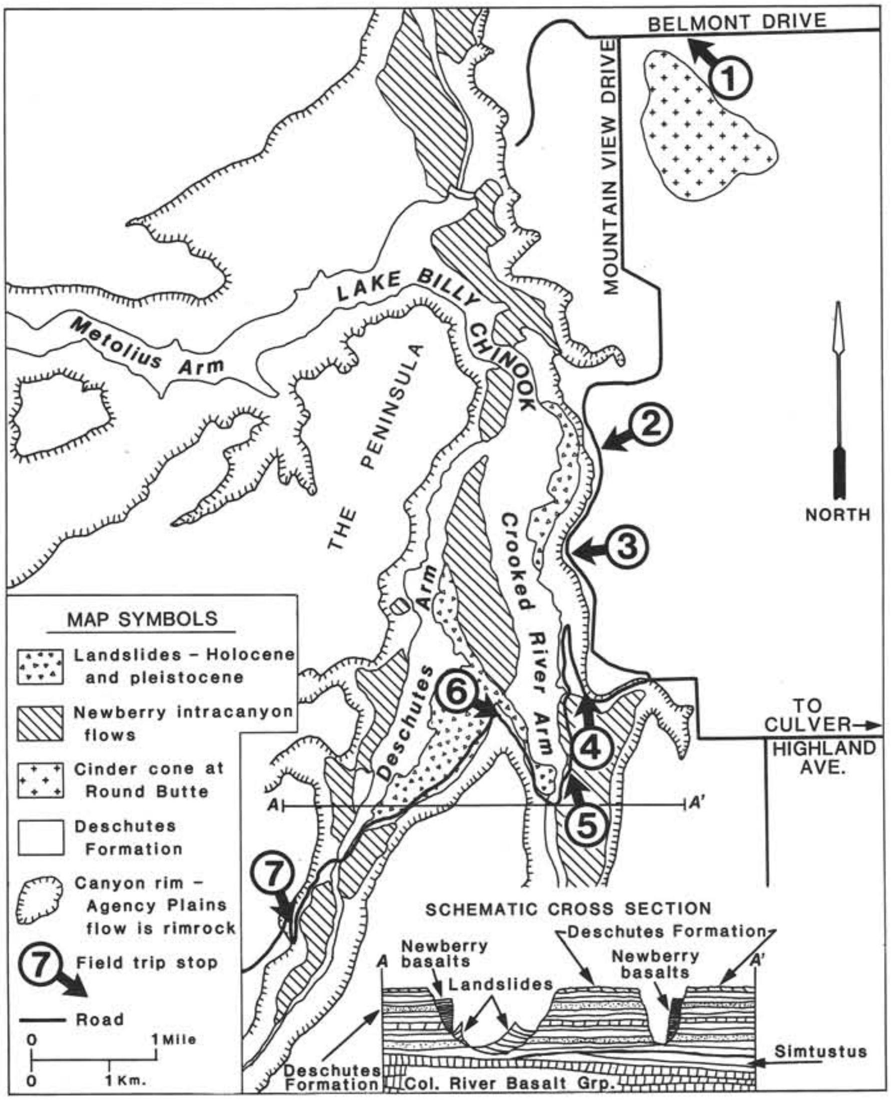

Figure 2. Map showing the geology of Cove Palisades State Park. Revised from Peterson and Groh (1970).

field guides (Peterson and Groh, 1970; Taylor and Smith, 1987). Most of the material printed in the regular format is for the lay reader who wants to learn about the area and its fascinating geology. However, additional and more technical information has been added in brackets for readers who want to learn more about the geologic details.

PRE-MIOCENE GEOLOGY OF THE DESCHUTES BASIN

The Deschutes Basin lies between the west-plunging nose of the Blue Mountains and the north-south Cascade arc (Figure 2). Its volcaniclastic rocks and flows cover approximately 1,900 mi^2 (5,000 km^2), extending approximately from Tumalo (9 mi [15 km] north of Bend) to Gateway (12 mi [20 km] north of Madras) in a crescent-shaped band approximately 15 mi (25 km) wide.

The nature of the basement beneath the Deschutes Basin is unknown. Feldspar-rich anorthosite clasts recovered from a Deschutes Formation basalt suggests that an accreted Precambrian greenstone terrane may underlie the Cascades, the Deschutes Basin, or both (Conrey, 1985).

Two Tertiary volcanic formations appear to extend from the Blue Mountains westward toward the Cascades beneath the Deschutes Basin. The Eocene Clarno Formation (52-40 million years [m.y.]) (Vance, 1988) consists primarily of calc-alkaline andesites, basaltic andesites, and minor rhyolitic domes, along with debris-flow deposits and other products of a stratovolcano terrane (Bishop, 1989b). These volcanic rocks extend from near Baker City in eastern Oregon along the axis of the Blue Mountain anticline to the east edge of the Deschutes Basin and in the Mutton Mountains.

The John Day Formation of Oligocene and early Miocene age is also present in the Deschutes Basin, principally as isolated buttes and highlands that punctuate the landscape. These include Juniper Butte, Powell Buttes, Cline Butte, Forked Horn Butte, and possibly Gray Butte.

Rhyolitic flows and ignimbrites of Oligocene age that are often correlated with the John Day volcanic rocks (Robinson, 1975) are exposed in Haystack Butte and Juniper Butte (Figure 3). Powell Butte, east of Redmond, is Oligocene in age and possibly a source of John Day tuffs. Cline Butte, to the west, is of similar composition and may be of similar age.

The best studied of these is Smith Rock and the Gray Butte complex just west of Terrebonne (Figure 4) (Obermiller, 1987; Bishop, 1989a). This bimodal volcanic center is associated with a thin veneer of olivine basalts dated at 18 m.y. (Obermiller, 1987) and a variety of younger rhyolitic volcanic rocks, ranging from the rhyolite of Gray Butte (12 m.y.) to the now-eroded tuff cone of Smith Rock (11.5 m.y.) (Obermiller, 1987). The age of the Gray Butte complex is uncertain. Stratigraphy (Smith, 1986a,b,c) and fossil evidence (Ashwill, 1983) indicate an Oligocene to early Miocene age and probable correlation with Powell Buttes and similar centers. Mapping by Robinson (1975) shows them to be older than the Columbia River basalts. However, studies indicate radiometric ages of

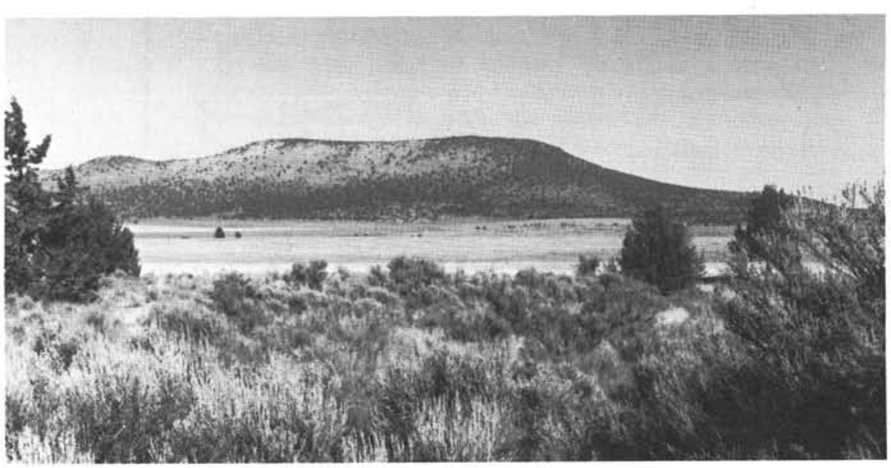

Figure 3. Juniper Butte is an inlier of the Clarno and John Day Formations.

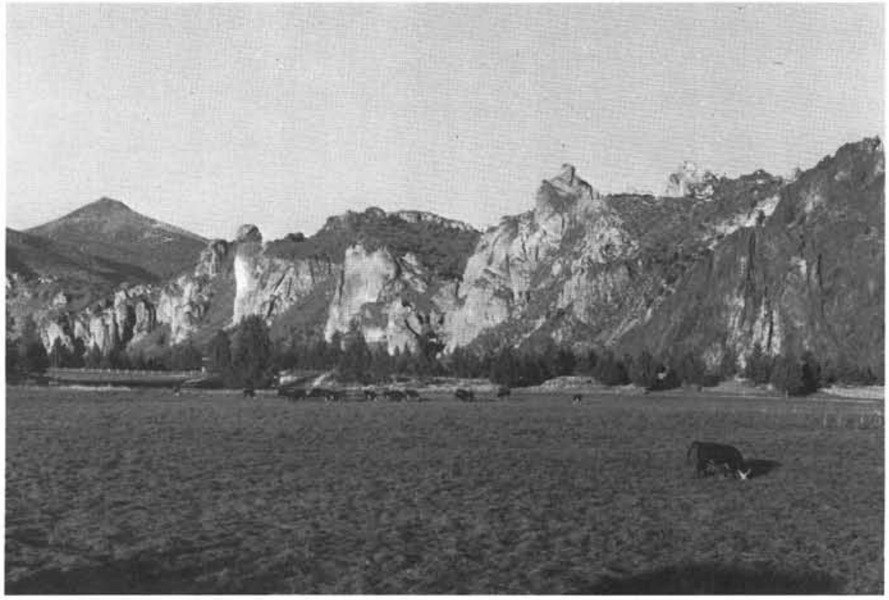

Figure 4. The Gray Butte complex from the west. High peak (left) is Gray Butte. Cliffs and outcrops to the right are Smith Rock. This eruptive center produced rhyolite and tuffs during a pause in the deposition of sediments into the Deschutes Basin.

12 m.y. for Gray Butte and 11.5 m.y. for the tuff of Smith Rock, suggesting a late Miocene age for these rocks (Obermiller, 1987).

SIMTUSTUS FORMATION

The story told by the colorful layers of rock in the canyon of the Deschutes River began about 15 m.y. ago at the time the basalts of the Columbia River Basalt Group were erupted in eastern Oregon, eastern Washington, and western Idaho. Basalt flows of the Prineville chemical type (high Ba and P_2O_5) (Uppuluri, 1974), which are part of the Columbia River Basalt Group, filled much of the channel of the river north of Willowdale (Smith, 1986a,b,c). The waters of the Deschutes slowed. Instead of rapidly downcutting, the river began to deposit more than it carried away, becoming a builder, an "aggrading" stream.

Our evidence comes from a sedimentary rock unit, the Simtustus Formation, that was deposited at the same time that Prineville-type Columbia River basalt flowed into the area from vents far to the south and east. The Simtustus Formation is a sequence of tan and gray, poorly consolidated gravels, sands, and silts exposed along Highway 97, 6 mi (10 km) northeast of Madras along grades into the small community of Gateway and also in the Deschutes River canyon along Lake Simtustus itself.

The Simtustus Formation extends over an area of at least 100 mi^2 (about 250 km^2) and is composed of volcaniclastic rocks conformable upon and interbedded with the Columbia River Basalt Group in the Deschutes Basin (Smith, 1986a). Its type section was defined from composite exposures on the east rim of Lake Simtustus. The formation varies from 3 to 200 ft (1 to 65 m) in thickness and is composed principally of tuffaceous sandstones, pebble conglomerates, debris-flow breccia, and rhyodacite ash-flow tuff.

[Sandstones and conglomerates of the Simtustus Formation]

[Cross-bedded volcaniclastic sandstones with subordinate mudstones are the most abundant rocks of the Simtustus Formation (Figure 5). They often become finer grained upward through a series of sandstone beds (fining-upward sequences). These poorly consolidated rocks represent point-bar, channel, and flood-plain deposits of a meandering river (Smith, 1986a).]

[Massive, tan-colored, fine-grained sandstones containing mudstones and layers of pumice clasts are less common than the coarse, cross-bedded sandstones. Graded bedding, where large clasts are on the bottom of a bed and grain size becomes smaller upward in the same bed, is common. In the Simtustus Formation, conglomerates generally consist of pebbles and cobbles set in a matrix of sand or mud (matrix-supported conglomerates) (Smith, 1986a) (Figure 6).]

[Depositional environment]

[The Simtustus Formation represents channel, overbank, and flood-plain deposition by a north-flowing river. Overall, this ancestral Deschutes River system aggraded, meaning that it deposited more than it eroded. This change of conditions was probably brought about by drainage disruption and filling in of the topography by flows of the Columbia River Basalt Group.]

[Age of the Simtustus Formation]

[The Simtustus Formation has been assigned a middle Miocene age (12 to 15.5 m.y.), based upon the middle Miocene Pelton flora reported by Ashwill (1983) and isotopic ages of the intercalated Columbia River basalts. The Simtustus Formation is separated from the Deschutes Formation by a subtle angular unconformity, indicating that the Simtustus was uplifted and eroded slightly before the Deschutes Formation was deposited on top of it (Smith, 1986a). Thus, there is approximately a 5-m.y. hiatus in deposition between the end of Simtustus deposition and the earliest deposition of the Deschutes Formation.]

Figure 5. Cross-bedded, coarse-grained sandstones of the Simtustus Formation are exposed in a roadcut southeast of Gateway. Photo is about 10 ft (3 m) across.

Figure 6. Matrix-supported, fine-grained sandstone and conglomerate of the Simtustus Formation is exposed at the base of the Gateway Grade.

THE DESCHUTES FORMATION

About 8 m.y. ago, the activity of volcanoes in the Cascades began to influence the basin of the Deschutes River. An increasing amount of volcanic debris clogged the drainage of the river, transforming the Deschutes again into a depositing, aggrading system.

Most of the multicolored sands and volcanic flows that now form the layer-cake walls of the canyon of the Deschutes River were deposited from about 8 until about 4 m.y ago (Figure 7).

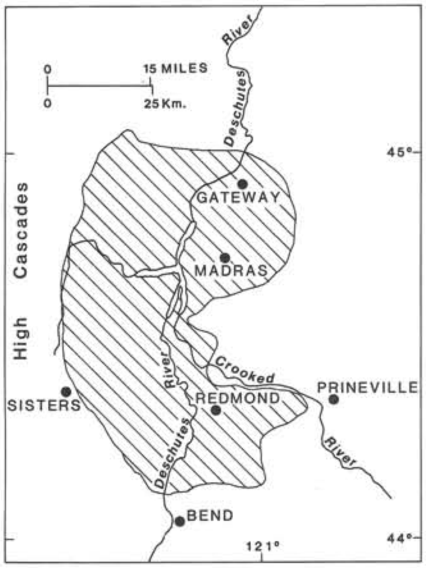

Figure 7. Map showing the distribution of the Deschutes Formation. After Smith (1986a).

These rocks are now known as the Deschutes Formation. Basalt flows, ash-flow tuffs called "ignimbrites" (hot ash and gas that consolidate into a sometimes-hard, sometimes-crumbly layer of pumice), as well as flood-generated torrents of sand and gravel, all contributed to the river's burden—and the geologic record left as the river's storybook (Figure 8). The formation has a maximum thickness of 2,300 ft (700 m).

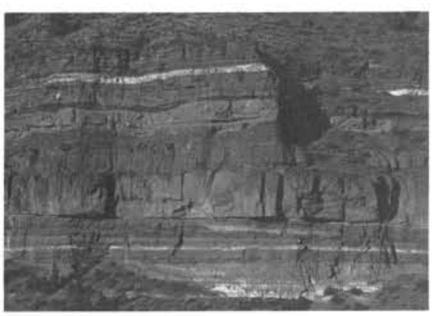

Figure 8. Interbedded sandstones, debris flows, ignimbrites, and basalts are typical of the mixed stratigraphy of the Deschutes Formation. This 100-ft (30-m)-high exposure along the Deschutes River is on the east side of Steelhead Falls.

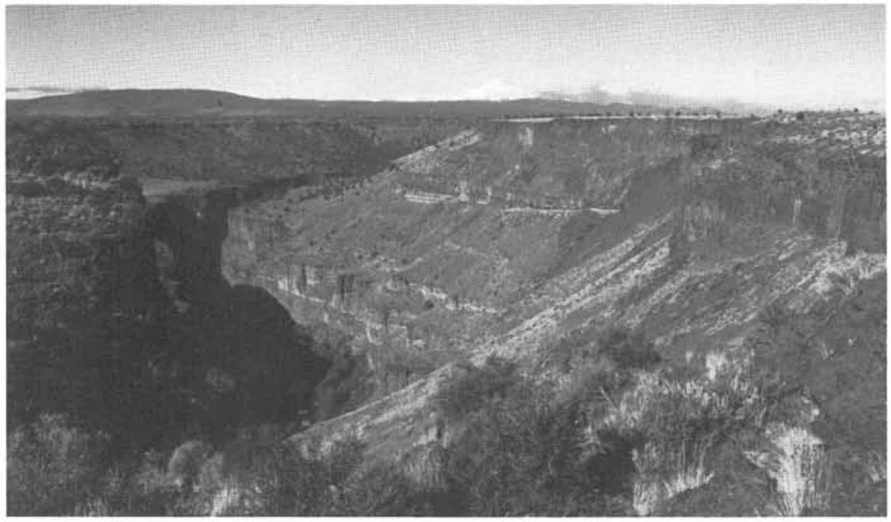

Figure 9. Narrow canyon of the Crooked River near Opal Springs west of Culver is incised through the Deschutes Formation. Squaw Back Ridge, a 2.9-m.y.-old shield volcano forms a bump on the skyline to the left. Green Ridge is the low, dark feature beneath Mount Jefferson in the far background.

Most volcanic sources for the Deschutes Formation were located in the Cascade Range, although subordinate amounts of lava and ash were extruded from vents in the central and eastern parts of the basin. In general, the volcanic rocks (both flows and ignimbrites) thicken and become more abundant westward, forming virtually the entire section at Green Ridge (Conrey, 1985) and the eastern buttress of Mount Jefferson (Yogodzinski, 1986) (Figure 9). Ignimbrites are well preserved and most common in the center of the basin. Sediments increase in thickness and are finer grained eastward through the Deschutes Formation.

BASALTS OF THE DESCHUTES FORMATION

Many of the hard, black basalt flows now exposed in the walls of the Deschutes River canyon were erupted from the eastern edge of the Cascades from low-lying, gently-sloping basaltic shield volcanoes east of where Mount Jefferson was to appear some 7 m.y. later (Figure 9). Others were erupted from vents within the Deschutes Basin, most notably from Tetherow Butte and Round Butte. More rarely, vents developed in the east part of the basin, where, 6.4 m.y. ago, they spread from shield volcanoes near Grizzly northward along Willow and Hay Creeks.

[Cascade diktytaxitic basalts]

[The most abundant basalts within the Deschutes Formation flowed eastward from the nascent Cascades, including the low-lying vents of Green Ridge. Most are olivine basalts with diktytaxitic textures, containing numerous small vesicles that are rimmed with microscopic crystals (Figure 10). These basalts produced distinctive features such as pipe vesicles (Figure 11) when flows encountered water or damp ground.]

[Geochemically, most Deschutes Formation basalts are high-alumina olivine tholeiites with no distinctive geochemical hallmark of their tectonic setting. They are similar to some High Cascade basalts, containing about 16.5 weight percent Al_2O_3, with SiO_2 varying between 49 and 52 weight percent (Table 1) (Smith, 1986a).]

[Deschutes Basin porphyritic basalts]

[Basalts with textures other than diktytaxitic comprise almost half the basalts of the Deschutes Basin. A few occur near the top of Green Ridge (Conrey, 1985). Voluminous lavas that contain visible crystals of pyroxene and plagioclase were erupted from Tetherow Butte. Olivine-bearing basalts are characteristic of Round Butte. The porphyritic basalts are slightly alkaline in character, with lower silica and higher titanium and zirconium contents than the diktytaxitic lavas that were erupted from the Cascades (Table 1) (Conrey, 1985; Smith, 1986a).]

[The basalts erupted from Tetherow Butte are the most evolved of the Deschutes Basin lavas. They are also enriched in Ba, K, Rb, Sr, Zr, and Y compared to the diktytaxitic basalts that were erupted from the eastern Cascades (Smith, 1986a).]

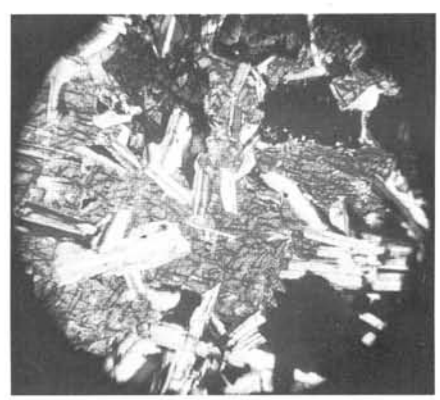

Figure 10. Photomicrograph of diktytaxitic basalt. Note rectangular, lathlike plagioclase crystals protruding into cavities. Photo courtesy of Marvin Beeson.

Figure 11. Pipe vesicles in the Big Canyon Flow, Grandview Grade, Cove Palisades State Park.

Figure 12. Pelton basalt, the oldest diktytaxitic basalt in the Deschutes Formation. This view is at the crest of Clark Drive near Gateway.

DISTINCTIVE BASALTS OF THE DESCHUTES FORMATION

Because of texture, areal extent, stratigraphic location, or exposure, some basalt flows of the Deschutes Formation are distinctive and are useful as marker beds. Several of these flows are described below. Their geochemistry is summarized in Table 1.

Pelton basalts

The oldest known flows in the Deschutes Formation are the Pelton basalts, dated at 7.6 m.y. They extend northward from Lake Billy Chinook and Round Butte Dam to Pelton Dam and Gateway. They are well exposed and perhaps most accessible at the crest of Clark Drive leading down into the community of Gateway (Figure 12). To the south, near Round Butte Dam, as many as eight flows have been reported in this unit (Jay, 1982). The Pelton basalt is a diktytaxitic olivine basalt with comparatively low alumina content (15.7 weight percent). This geochemical fingerprint, coupled with the marked thinning of the unit to the north, suggests a source in the southeastern Deschutes Basin, where similar basalts are more abundant.

Table 1. *Geochemistry of Deschutes Formation basalts. All values are in weight percent.*

	Diktytaxitic basalts			Phenocrystic basalts		
	J203	**OC2**	**D299**	**RB46**	**SF143**	**RB39**
SiO_2	50.3	50.5	51.1	50.9	52.2	52.4
TiO_2	1.8	1.6	1.0	2.6	2.7	1.8
Al_2O_3	16.1	16.3	17.0	14.6	13.7	16.8
FeO	11.5	9.9	8.0	14.0	14.0	9.2
MnO	0.2	0.2	0.2	0.3	0.2	0.2
MgO	7.5	8.2	8.0	4.6	5.1	5.9
CaO	9.5	11.1	10.8	8.6	7.5	8.8
Na_2O	2.4	2.6	2.3	3.1	3.7	2.1
K_2O	0.4	0.3	0.2	0.6	0.7	1.0
P_2O_5	0.4	0.3	0.2	0.6	0.5	0.4
TOTAL	100.0	100.8	98.7	100.2	100.3	98.6
Ba	402	na	91	467	484	456
Rb	22	na	9	19	22	19
Sr	320	na	337	372	386	805
Zr	113	na	89	157	155	213
Ni	112	na	110	22	38	140

J203=Pelton basalt; OC2=Opal Springs basalt; D299=Fly Lake flow; RB46=Agency Plains flow, Tetherow Butte basalt; RB39=Round Butte.. Analyses adapted from Smith, 1986a.

Tetherow Butte basalts

Radiometrically dated at 5.31 m.y. (Smith, 1986c), these extensive and voluminous porphyritic basalts that were erupted from Tetherow Butte near Terrebonne flowed northward almost to Gateway. There are two distinctive flows and an abundance of more locally derived eruptive products. Tetherow Butte is a 3-mi (5-km)-long complex of red and black cinder cones southwest of Terrebonne (Figure 13). The original height of these cones may have approached 660 ft (200 m).

The most extensive flow from this complex is named the Agency Plains flow (Figure

Figure 13. Pahoehoe flow structures in the Tetherow Butte flows. Tetherow Butte, southwest of Terrebonne, was the source of basalts that flowed approximately 36 mi (60 km) northward to Agency Plains.

Figure 14. Gateway valley, looking northward to the Deschutes. Agency Plains basalt forms the rimrock to left; the older Pelton basalt forms rim to right.

14) (Smith, 1986a). It can be traced from Tetherow Butte northward past Madras and covers most of the flat farmland known as Agency Plains between Madras and Gateway. This flow, which varies in thickness from 7 to 165 ft (2 to 50 m), forms part of the east rimrock at Cove Palisades and occurs along much of the central Deschutes River canyon.

A slightly younger flow, named the Crooked River flow (Smith, 1986a), extends northward to Opal Springs, where its flow front forms a 7-ft (2-m)-high escarpment on the canyon rim. Low spatter mounds are aligned on the top of this flow, perhaps tracing an ancestral Crooked River drainage (Smith, 1986a,b,c).

Round Butte basalts

The last basaltic lavas erupted in the Deschutes Basin were extruded 3.97 m.y. ago from Round Butte, 5 mi (8 km) southwest of Madras (Smith, 1986c) (Figure 15). One flow can be traced northward toward Agency Plains; the lowest of four flows that extend westward toward Round Butte Dam displays pillow structures and peperites where it entered the channel of the ancestral Deschutes River (Smith, 1986a). Other flows of undetermined thickness apron the remainder of the butte.

OTHER FLOW ROCKS OF THE DESCHUTES FORMATION

Basaltic andesite, andesite, dacite, and rhyolite lavas are subordinate in volume and breadth of distribution to the basalts of the Deschutes Formation. None of these units have been distinguished by name. They increase dramatically in abundance westward toward Green Ridge and Mount Jefferson. Notable occurrences are along Green Ridge (all lithologies), at Pipp Spring on the Warm Springs Indian Reservation (basaltic andesite), and a distinctive, columnar-jointed basaltic andesite just below the rim on the Crooked River grade near the entrance to Cove Palisades State Park (Figure 16) (Smith, 1986a).

These seemingly more evolved rocks are apparently unrelated to the abundant diktytaxitic basalts of the Deschutes Formation. They cannot be derived from diktytaxitic basalts by simple fractionation. They may have come from a different source (Smith, 1986a) or have been produced by the mixing of a silica-rich (rhyolite) magma with a basalt (Conrey, 1985).

Figure 16. Deschutes Formation basaltic andesite in the roadcut near the east entrance to Cove Palisades State Park displays well-defined columnar jointing. The rounded base of this flow and the gravels beneath it suggest that the flow followed a small

Figure 15. Round Butte is a cinder cone perched atop the shield volcano that erupted the youngest flows of the Deschutes Formation. Note ancient landslide in middle ground.

IGNIMBRITES OF THE DESCHUTES FORMATION

In addition to producing basalts, the vents of the ancestral Cascades erupted hot, frothy clouds of ash (called "ignimbrites") into the Deschutes Basin. Red and pink, salmon, white, or gray, the colored layers in the canyon walls are mostly ignimbrites. These porous, silica-rich ash units are abundant in the Deschutes Formation. Ignimbrites are known by a number of other names, including "ash-flow tuff" and "welded tuff." All apply to a hot, laterally-ejected, ground-hugging cloud of ash and gas that may travel at velocities of up to 75 mph (120 km/hr) and may consist of several pulses of ash that are deposited in the same area and that cool as a single unit.

The ignimbrites of the Deschutes Formation are commonly 7 to 33 ft (2 to 10 m) thick. Most were extruded from shallow magma chambers beneath now-buried vents in the Cascades. They are interbedded with the lava flows and sedimentary units of the Deschutes Formation. There is no apparent systematic variation in their abundance or composition upward through the section.

Ignimbrite textures

There is a tremendous variety of texture, content, and consolidation in the ignimbrite units of the Deschutes Formation. They may contain a variety of components, including pumice clasts, rock clasts, and pebbles or cobbles of underlying units. They may be densely welded into a glassy, columnar-jointed, flow-like mass, if the unit was deposited at temperatures high enough to allow molten ash to stick together. Such units may contain flattened, elongate and glassy clasts, termed "fiamme," that result from the collapse and quick cooling of frothy, molten pumice clasts (Figure 17).

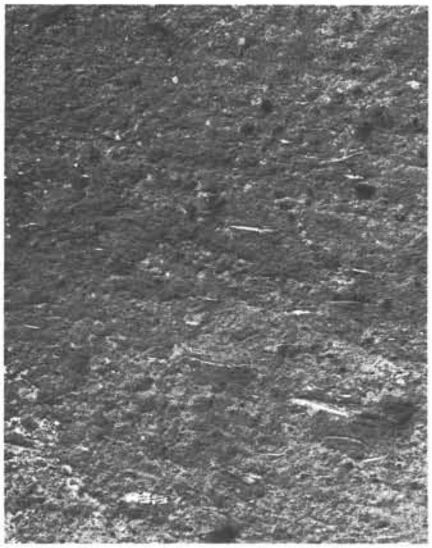

Figure 17. The thin white clasts in this ignimbrite are flattened pumice clasts called "fiamme." Their presence indicates that the ash flow was deposited at relatively high temperatures. (This photo is of the Rattlesnake ignimbrite and was taken east of Dayville, Oregon. The Rattlesnake ignimbrite is a widespread ash-flow tuff that is contemporaneous with the Deschutes Formation and is found over an area from south of Burns to the Deschutes Basin.)

These textures usually develop in the centers of large ash-flow sheets that cover hundreds of square miles, rather than in smaller ignimbrites covering tens of square miles that seem to be common in the Deschutes Formation. Ignimbrites like those of the Deschutes Formation are more characteristically dusty, fragile, and crumbly masses of tuff, small in volume, that came to rest far from their vent. They may at first resemble mudflow deposits. However, examination will reveal that many clasts are pumice, usually of only one or possibly two different compositions (Figure 18).

Ignimbrite stratigraphy

There is a stratigraphy to most ignimbrites, a sort of anatomical classification

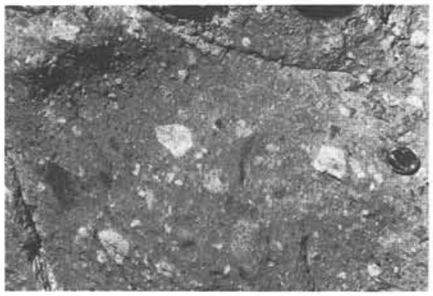

Figure 18. Mixed basalt and rhyodacite clasts in an unnamed ignimbrite at Cove Palisades State Park.

scheme. There are three parts to most ignimbrites of the Deschutes Basin (Figure 19): (1) A thinly laminated, poorly consolidated layer of ash or pumice at the base of the ignimbrite caused by the initial contact of the base of the unit with the cold ground. This unit is formed into thin beds (laminations) by the powerful initial surge of the rapidly moving ignimbrite. (2) The bulk of the ash flow is a matrix-supported, poorly sorted pyroclastic conglomerate, usually containing pumice clasts. This is the thickest portion of the ash flow. The bottom portion of this layer may be graded, from large clasts just above layer 1, upward to finer material. Above this normal grading, pumice clasts may be reversely graded. (3) The tops of some ignimbrites are veneered by layers of ash, presumably the last dregs of the ash cloud to settle.

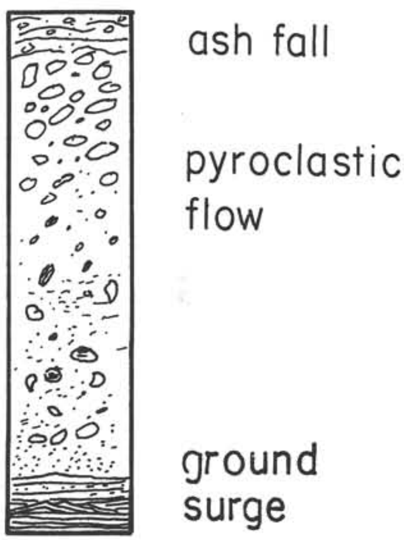

Figure 19. An ignimbrite section, typical of those in the Deschutes Formation. After Sparks and others (1973).

[Composition and petrology of Deschutes Formation ignimbrites]

[The ignimbrites of the Deschutes Formation are mostly dacitic to rhyolitic in composition (Table 2), with silica contents ranging from about 62 to 72 weight percent. Only one unit of basaltic andesite composition was reported by Smith (1986a).]

[Some ignimbrites contain two or more varieties of pumice clasts—probably the result of mixing two different magmas just prior to ignimbrite eruption (Conrey, 1985) or eruption from a zoned magma chamber (Smith, 1986a).]

[Modeling has shown that these dacitic to rhyolitic ash flows were not derived from the olivine basalts by fractionation. Rather, most had a separate source or underwent a mixing process to arrive at their erupted compositions (Conrey, 1985; Smith, 1986a).]

Table 2. *Geochemistry of Deschutes Basin ignimbrites. All values are in weight percent.*

	SJ19	RB10	RB27
SiO_2	71.6	70.4	62.4
TiO_2	0.5	0.5	1.3
Al_2O_3	15.7	15.7	17.0
FeO	3.4	3.0	5.8
MgO	2.0	0.8	2.1
CaO	2.4	1.6	4.3
Na_2O	2.1	4.3	4.7
K_2O	2.5	4.0	1.6
TOTAL	100.1	100.4	99.1

SJ19=Chinook ignimbrite; RB10=Cove ignimbrite; RB27=Peninsula ignimbrite. All analyses adapted from Smith, 1986a.

DISTINCTIVE IGNIMBRITE UNITS IN THE DESCHUTES FORMATION

Of the hundreds of ignimbrites within the Deschutes Formation, several merit more detailed description because they are well exposed, contain characteristic features, and/or are useful as stratigraphic markers. Although none of the units described below have been radiometrically dated, they are discussed in order of age, from oldest to youngest.

Jackson Buttes ignimbrite

The lower, pink-colored slope of "The Ship" at Cove Palisades State Park is composed of a poorly welded unit known as the Jackson Buttes ignimbrite (cover photo). It is named for its exposure at Jackson Buttes on the Warm Springs Indian Reservation. It is as much as 76 ft (23 m) thick, and, in some locations, displays columnar jointing. The pinkish to light-orange color of this unit is due to alteration by escaping gases during its deposition and consolidation.

Cove ignimbrite

At Cove Palisades State Park, the Cove ignimbrite is a white tuff that forms the prow of "The Ship" and is also found in the roadcuts along the access roads (Figure 20). It is unwelded and contains scattered white to light-gray pumice clasts up to 0.8 in. (2 cm) in diameter. This unit, which has a very

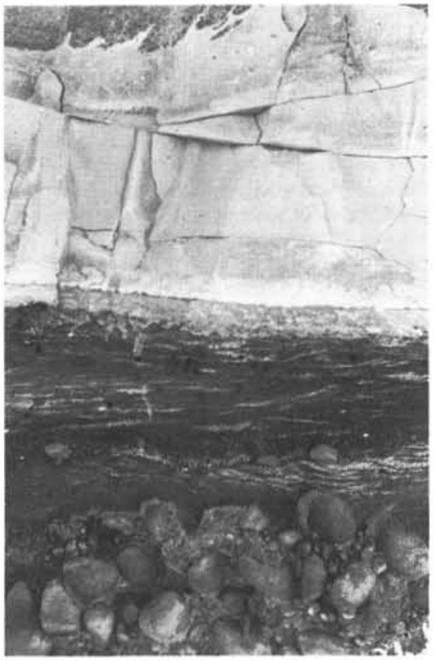

Figure 20. The Cove ignimbrite, about 2 ft (0.6 m) in thickness here, is exposed in roadcut on the Crooked River grade. Note flat, layered bottom above conglomerate and sandstone. Uneven top suggests that a debris flow covered the ignimbrite here before it was well consolidated.

limited distribution, is exposed only over about 5 mi (8 km) of the Deschutes River canyon.

Fly Creek ignimbrite

This unit is distinctive because it is the most mafic of ignimbrites analyzed from the Deschutes Basin (approximately 53 weight percent silica) (Conrey and Dill analyses, *in* Smith, 1986a) and is also one of the most densely welded ignimbrites in the basin, a fact consistent with its probable higher temperature of eruption and large lateral distribution (more than 68 mi^2 [175 km^2]) (Smith, 1986a). In Cove Palisades State Park, this unit is about 33 ft (10 m) thick and unwelded, light orange in color, with gray to light-orange pumice clasts. Its clasts are of at least two different compositions: rhyodacite and basaltic to basaltic-andesite pumice. The Fly Creek ignimbrite thickens dramatically westward, where it becomes densely welded and glassy in exposures along Fly Creek.

SEDIMENTARY UNITS OF THE DESCHUTES FORMATION

Records of floods and braided river channels are present in the poorly consolidated conglomerates and sandstones exposed along the canyon of the Deschutes River. Some deposits, such as the Tetherow debris flow near Tetherow Crossing on the Deschutes, contain enormous boulders up to 40 ft (12 m) in diameter, indicating sudden, catastrophic avalanches of debris unleashed from now-eroded Cascade volcanoes. Others, more common and less dramatic, are the remains of turbulent floods of gravels and sand.

[Sedimentary environments]

[The poorly cemented sedimentary rocks of the Deschutes Formation consist generally of clast-supported conglomerates and volcaniclastic sandstones. They may be subdivided into five facies associations, or sedimentary environments (Smith, 1986b).]

[River-channel deposits]

[Clast-supported conglomerates, with pebbles and cobbles that rest upon one another, rather than lying in a matrix of mud and sand, are deposits of an active river channel (Figure 21). Clasts are usually rounded pebbles and cobbles laid like shingles parallel and facing upstream in a pattern called "imbrication." Sandstone interbeds may represent channel bars or smaller channels abandoned after periods of high discharge (Smith, 1986a). Such conglomerates are abundant, thick, and striking in the Deschutes Formation (Figure 22).]

[Flood-plain deposits]

[Massive or laminated fine-grained sandstones and siltstones are characteristic of flood-plain deposits. These rocks are comparatively rare in the Deschutes Formation. Where present, they commonly contain fossil floras (including *Planus*, *Populus*, *Acer*, and *Salix*) (Ashwill, 1983). Diatomite and diatomaceous mudstone deposits, usually less than 3 ft (1 m) thick, indicate the presence of marshes and small, acidic lakes.]

[Sheet-flood deposits]

[Thinly bedded sandstone and pebble conglomerates 2 to 10 in. (5 to 25 cm) thick that may display limited, low-angle cross-bedding are typical of deposition by slow streams in broad, shallow, braided channels (Figure 23). Such deposits are common in the Deschutes Formation.]

[Hyperconcentrated flood-flow deposits]

[Normally graded, clast-supported conglomerates or coarse sandstones are typical of fluid, turbulent mudflows or flood deposits. These types of sedimentary processes have been named "hyperconcentrated flood flows" (Smith, 1986b).

Figure 21. Imbricated, clast-supported cobble conglomerates of the Deschutes Formation represent river-channel deposits.

Figure 22. This thick section of river-channel conglomerates fines upward and is overlain by sands of smaller channels and flood-plain deposits. Such a sequence suggests that an active river cut a channel here, then migrated or meandered laterally, leaving flood-plain deposits on top of its old channel.

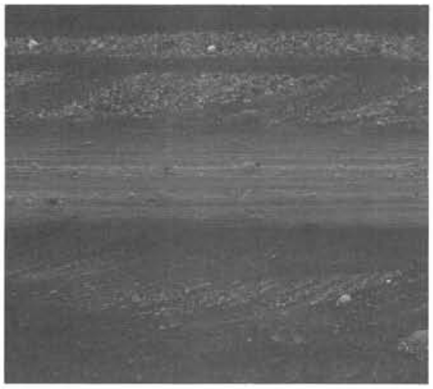

Figure 23. Sheet-flood deposits in the dark sands of the Deschutes Formation display low-angle cross-bedding and matrix-supported pebble conglomerates.

They develop when a high discharge of water carries a sediment load intermediate between a debris flow and normal stream flow. Such a "hyperconcentrated flood flow" would contain between 40 and 80 weight percent as sediment and the remainder as fluid (water). Such flows would be turbulent, and grain-on-grain support would be important for the transportation and continued suspension of particles. These flows are more fluid than debris flows or lahars. They are abundant in the Deschutes Formation.]

[Two principal types of sediments result from hyperconcentrated flood flows. The first is a clast-supported, normally graded conglomerate (Figure 24). These rocks may grade upward into horizontal bedding. The second, in lower velocity flows, is a thinly bedded, coarse sandstone that displays a wide range of clast size (poor sorting) and usually grades continuously into the beds below and above.]

[Debris-flow deposits]

[Unsorted, usually very coarse-grained, matrix-supported deposits that were transported at high rock/water ratios are termed "debris flows" (Figure 25). This term encompasses fluvial, mudflow-type deposits as well as flows more closely linked to volcanism (lahars).

Some of these units within the Deschutes Formation, such as the Tetherow debris flow, are spectacular, containing clasts more than 6 ft (1.8 m) in diameter. Many grade laterally into finer grained rocks. Debris-flow deposits are increasingly rare toward the east in the Deschutes Formation.]

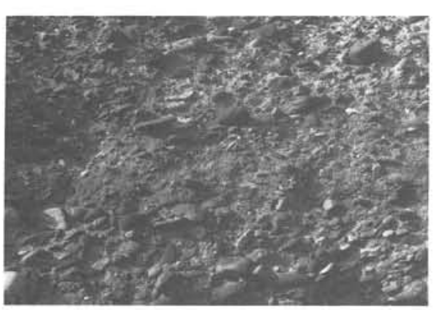

Figure 24. Hyperconcentrated flow, clast-supported, normally-graded conglomerate, Deschutes Formation, Cove Palisades State Park.

Figure 25. Debris-flow deposit, Deschutes Formation, near Steelhead Falls.

PLIOCENE VOLCANISM IN THE DESCHUTES BASIN

What stopped this deposition and returned the Deschutes to its canyon-cutting glory was, literally, the downfall of the Cascades. For reasons not fully understood, about 4 m.y. ago, the volcanoes of Oregon began to subside into a downfaulted structure called the High Cascade graben (Figure 26). Eruptive activity remained vigorous, although perhaps not as explosive as before. However, because the rising east wall of the graben formed a barrier to eastward transport of volcanic debris, products of the late Pliocene eruptions were trapped in the graben and never reached the Deschutes drainage.

Because little of the river's energy was needed to carry debris erupted from these sinking volcanoes, the Deschutes could now go to work downcutting and exposing its history.

Several volcanic centers to the southeast—most notably Grass Butte near Prineville—erupted diktytaxitic basalts that flowed mostly westward into the Deschutes Basin. Basalts from these low shield volcanoes form the rimrock at Terrebonne and much of the high, rock-strewn plateau between Redmond, Terrebonne, Powell Butte, and Prineville. The age of these flows is 3.4 m.y. (Smith, 1986a). Pleistocene basalts also cover much of the area between Redmond and Prineville.

East of the High Cascade graben, relatively small quantities of basalts were erupted, forming low shield volcanoes or cinder cones. Squawback Ridge and Little Squaw Back, east of Green Ridge, are 2.9-m.y.-old shield volcanoes built by these eruptions.

Two million years ago, the Deschutes River drained northward along a channel similar in location to the canyons we see today. The course of the old river cut through a semiarid plain, incising a canyon through the volcanic layer cake. By 2 m.y. ago, the canyons were nearly as deep as we see them today.

PLEISTOCENE INTRACANYON BASALTS

Intracanyon basalt flows from Newberry volcano and the rising Cascades flowed through and filled the Deschutes, Metolius, and Crooked River channels from 1.6 million to less than 700,000 years ago.

The most voluminous of these intracanyon flows, dated at about 1.2 m.y., came from the vicinity of Newberry volcano and followed the Crooked River canyon from O'Neil northward to the present location of Round Butte Dam (Smith, 1986a). At least 15 of these intracanyon flows were erupted in rapid succession. They form the distinctive intracanyon bench that extends along the Crooked River from the approximate location of Smith Rock State Park northward through Cove Palisades State Park (Figure 27). These basalts also form "The Island," a stark, flat-

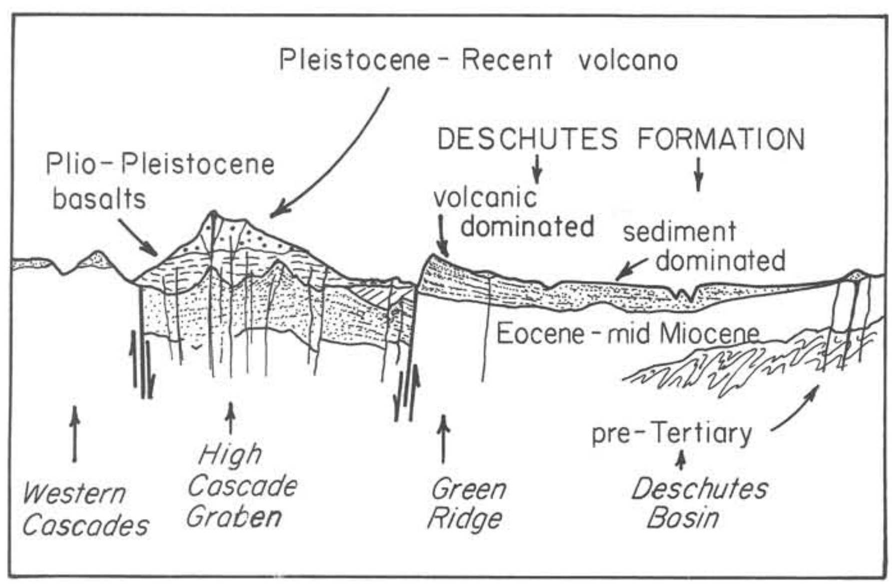

Figure 26. Schematic cross-section of the Cascades and the Deschutes Basin. After Smith (1986a) and Taylor and Smith (1987).

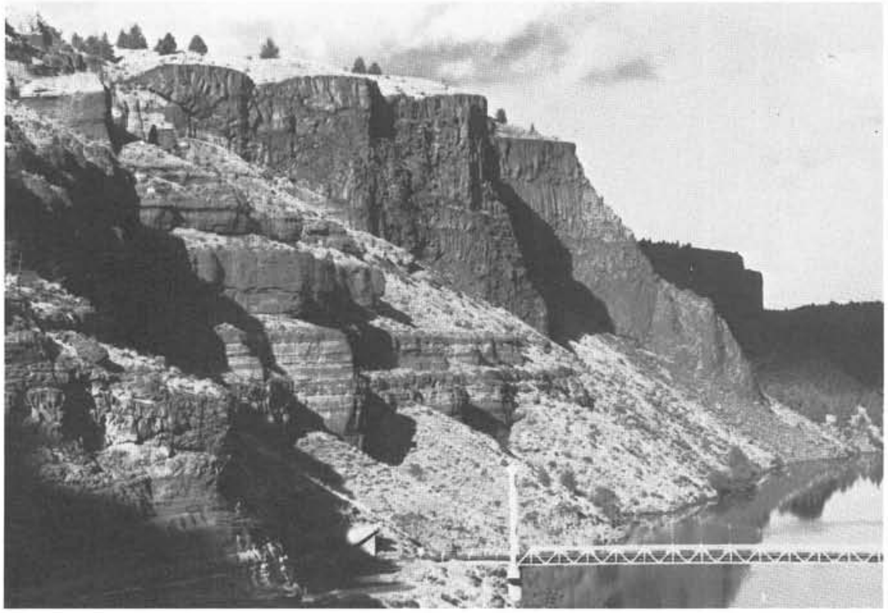

Figure 27. Intracanyon basalts from Newberry volcano lap onto and overlie the horizontal beds of the Deschutes Formation in Cove Palisades State Park. The contact between the two units cuts diagonally from near the top left of the photo down toward the lower right. View is on the west side of the Deschutes Arm of Lake Billy Chinook.

topped basalt ridge that rises abruptly from Lake Billy Chinook, separating the Deschutes from the Crooked River in Cove Palisades State Park.

The extreme thickness of the Newberry basalts at Cove Palisades suggests that they may have ponded in that area of the canyon, perhaps due to the solidification of a basalt dam somewhere downriver. Such ponding might also account for the fact that basalts flowed from Cove Palisades more than 2.5 mi (4 km) up the Deschutes River canyon.

The Newberry basalts are distinctive, cliff-forming rocks in Cove Palisades State Park and elsewhere along their exposure in the canyons. They were evidently extruded rapidly; multiple flows form single cooling units. These abrupt cliffs provide excellent displays of columnar jointing, with lower colonnades of regular, parallel columns, and upper entablatures composed of tiers of curving and discontinuous columns or sequences of colonnade-entablature-colonnade (Figure 28).

The difference in structure of these two portions of a basalt flow has been correlated with differences in cooling history (Long and Wood, 1986). Colonnade columns form during slow, steady-paced, downward cooling. The more wildly creative entablature structures result from local variations in cooling rate and direction.

CONCLUSION

The Deschutes Basin is a record book of more than 15 m.y. and 2,800 ft (900 m) of volcanic deposition and erosion. Among the noteworthy observations that can be made about this area are the persistence of a river system in the same valley for a long time, the large volumes of lava and ash erupted into the Deschutes Basin during the late Miocene and early Pliocene, and the variety of sand and gravel deposits laid down in this filling basin.

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*(Continued on page 16, **References**)*

Figure 28. Intracanyon bench of Newberry basalts in the Deschutes River canyon near Steelhead Falls.

Field trip guide to Cove Palisades State Park and the Deschutes Basin

by Ellen Morris Bishop, Department of Geosciences, Oregon State University

INTRODUCTION

This field trip guide is designed to help the user examine and understand the varied rocks of Cove Palisades State Park. Interesting side trips may also be taken to other areas in the Deschutes Basin that are shown on the map (Figure 1).

One of the most spectacular and accessible cross-sections of the Deschutes Formation is exposed in Cove Palisades State Park. Therefore, this field trip guide focuses on the single road that descends into the canyon at Cove Palisades, where the Deschutes Formation and intracanyon Newberry basalts are well exposed. Several large landslides, and one much smaller, very recent one, are also present in the canyon.

This field trip may be easily negotiated in a single day. The history and facilities of Cove Palisades Park are detailed elsewhere in this guide. Because the park has well-developed campgrounds and a small store, it may readily be used as an overnight stop on a longer tour of Pacific Northwest geology.

COVE PALISADES STATE PARK FIELD TRIP GUIDE

Mile 0.0. Begin field trip at City Hall located at the intersection of D and 6th Streets in downtown Madras. Follow D street west across Highway 97 to the old Culver Highway. Bear left (south) toward Culver. At mile 1, turn right (west) onto Belmont Drive. This road continues west for 8 mi to Round Butte Dam. At mile 3, Belmont Drive winds across Dry Canyon. The flows that form the rim of Dry Canyon are Agency Plains diktytaxitic basalts of the Deschutes Formation. They originated at Tetherow Butte, some 20 mi to the south, about million years ago. Trough-banded volcaniclastic sandstones of the Deschutes Formation representing channel fills are visible in the roadcut below the rim on the small canyon's west side. As you continue to climb, you are venturing onto the apron of basalts and cinders produced by Round Butte, the youngest of the Deschutes Formation eruptive centers.

STOP 1. Mile 3.8. Round Butte basalt and scenic views.

A low roadcut on the left (south) side of the road exposes the porphyritic basalts of Round Butte. These rocks have been dated at 3.9 million years (m.y.) (Smith, 1986a). Note the dark color and relatively smooth feel of these rocks. Their textures and compositions distinguish them from the more voluminous, vesicle-rich diktytaxitic flows that emanated from the Cascades.

The view from this location, as well as from the remainder of Belmont Drive, is inspiring. To the north, the Deschutes River canyon holds Lake Simtustus. Columbia River basalts, overlain by the sedimentary rocks of the Simtustus Formation, are visible in the lower canyon walls. The Deschutes Basin sweeps westward to Green Ridge, with the deep canyon of the Metolius River incised through it. The peaks of the High Cascades rise beyond Green Ridge. Mount Hood, Olallie Butte, Mount Jefferson, and Three Fingered Jack are visible from the north shoulder of Round Butte.

Continue west along Belmont Drive. At mile 6, turn left (south) onto Mountain View Drive. At the junction with Round Butte Drive, turn right (west) toward Cove Palisade State Park.

Mile 9.5: Park entrance.

STOP 2. Mile 10. View of Cove Palisades State Park.

Stop at the first parking area on the right past the park entrance. Peer carefully over the low wall at the edge of the parking lot. About 650 ft below, at the bottom of a sheer cliff of Deschutes

History and facilities of Cove Palisades State Park

(revised slightly from Peterson and Groh, 1970)

The Madras area of Jefferson County was initially settled about a century ago, and favorite fishing locations and places for relaxation were soon discovered in the deep canyons to the west. One of these places was on the banks of the Crooked River about 2 mi above its junction with the Deschutes River. This secluded spot, sheltered by canyon walls, came to be known as "The Cove."

Public and private development through the years improved the accessibility of The Cove, first with roads from Madras and later with bridges across the Crooked and Deschutes Rivers and a road connecting Grandview and Sisters to the west. A small hydroelectric plant was built at The Cove in 1912 and was enlarged in 1923 to provide power for the communities of Madras, Prineville, and Redmond. Even a peach orchard was established at The Cove, because the climate was quite mild at the bottom of the canyon.

In the late 1930's and early 1940's, the Oregon Highway Commission, which had recognized the recreational potential of the area, acquired through purchase and lease agreement from public and private holders some 7,000 acres of this canyon region. After World War II, trails and camping facilities were built, and the area was officially named "Cove Palisades State Park."

All of this began to change, though, for in 1960, the construction of Round Butte Dam began on the Deschutes River, just below the mouth of the Metolius River. This rock-fill dam has raised the water level nearly 400 ft above the bottom of the canyon. The old Cove Palisades State Park and the adjacent hydroelectric plant are now under 200 ft of water.

Through agreement with the State Parks and Recreation Division, Portland General Electric Company, owner of the dam, provided for a move of park facilities to a location about a mile to the southwest on the Deschutes River side of "The Peninsula." After the dam was completed. the reservoir created a three-armed body of water that is named Lake Billy Chinook for the Warm Springs Indian guide who accompanied Captain John C. Fremont in his early-day exploration of Oregon. The maps in Figures 1 and 2 show the extent of Lake Billy Chinook.

The present facilities of Cove Palisades State Park include a main overnight camping area near "The Ship" and a smaller area at the top of Crooked River grade. There are 272 campsites available, 87 with full trailer hookup, 91 with electricity, and 94 improved tent sites. The park is open year-round, with campgrounds open from mid-April until the end of October. Day-use areas provide parking, boat launching, picnicking, and swimming areas. A marina concession, open from mid-April until mid-October, offers boat rental, a restaurant, and a store. Further information about the facilities and reservations for group camping at Cove Palisades State Park may be obtained from the park offices, phone (503) 546-3412.

Formation rocks, is the Crooked River Arm of Lake Billy Chinook. The lumpy mass to the south between the cliff bottom and the lake, the location of the Cove Palisades Marina, is a landslide, probably late Pleistocene in age, as are the small peninsulas that jut into the water upstream and hummocky east slope of "The Island"—the flat-topped ridge of Newberry intracanyon basalt that separates the two rivers.

Continue south on Mountain View Drive about 1.5 mi to the third viewpoint.

STOP 3. Mile 11 (approximately). View of the canyons of the Deschutes and Crooked Rivers.

This viewpoint is almost directly above the Cove Palisades marina and east of "The Island." Both landslides that were viewed obliquely from Stop 2 can be observed again here.

This stop affords an excellent perspective of the Newberry intracanyon flows in the Crooked River canyon directly to the south. You can also see the intracanyon flows backed up into the Deschutes River canyon by the ponding of basalt flows at Cove Palisades.

Across the Crooked River arm and slightly to the south, at the narrow point that joins "The Island" with "The Peninsula," stands a sculptured, banded erosional remnant of the Deschutes Formation known as "The Ship." It consists of dark sandstone beds and two light-colored ignimbrite layers and will be examined much closer at Stop 6.

The arid country across the lake to the west is known as the "Lower Desert." This country was homesteaded in the early 1900's during a decade of abnormally high annual rainfall. Several communities, including Grandview and Geneva, sprang up.

However, by 1920, the abundant grass and potential for agriculture that was nourished by the unusual 10 to 15 in. of annual rainfall had literally dried up. Ranches could not survive on the thin soils above Deschutes Formation flows and the still-younger basalts from Squaw Back Ridge. All that is left now of the small farms and communities is a well-manicured cemetery at Grandview and a few wooden skeletons of dreams.

Continue south on Mountain View Drive to the "T" junction with Cove Palisades Drive. At this junction (mile 12), turn right (west) on Cove Palisades Drive. Continue half a mile past the entrance to Cove Palisades State Park. Drive just past the first campground entrance (Loop E) and pull off into large turnout on the left.

Warning: The road through Cove Palisades State Park is narrow and heavily traveled by recreational vehicles and trailers, especially during summer months. Be alert for traffic at all times while examining roadcuts in Cove Palisades State Park. Be sure your vehicle is parked completely off the roadway at any time that you stop in this area.

STOP 4. Mile 14. Crooked River Arm grade.

It is recommended that you walk down this grade in order to leisurely examine the variety of Deschutes Formation rocks exposed here. Drivers may wish to wait at this turnout until the group has reassembled at the bottom of the grade, as there is no good parking area at the bottom of this hill.

This extensive roadcut exposes a sequence of alternating sandstones, conglomerates, lapillistones, and ignimbrites that are typical of the Deschutes Formation. Two volcanic flows are present. The rimrock at the top of the grade (at the park entrance sign) is the Agency Plains flow from Tetherow Butte, a basalt of the Deschutes Formation that originated approximately 20 mi to the south. Like the Round Butte basalt, this flow is not diktytaxitic, and is a different chemical type than the Cascade diktytaxitic basalts of the Deschutes Formation. (See text above for details.)

Below this rimrock basalt and separated from it by coarse sandstones and a thick, white tuffaceous bed is a basaltic andesite that displays excellent columnar jointing. This flow is a channel-filling unit of probably limited extent and unknown origin.

Sandstones are mostly volcaniclastic sheet-flow and hyperconcentrated debris-flow deposits. Conglomerates are of either river channel or hyperconcentrated debris flow origin. (See text of accompanying paper for fuller discussion of these units.)

Two ignimbrites are exposed in this section and are the same units present in "The Ship." The first is a fairly well-consolidated, light-pink unit containing both light (rhyolite) and dark (andesite?) pumice. It is well exposed in roadcuts about 75 vertical ft below the rim. The second is the Cove ignimbrite, a white to gray, dense unit that overlies a conglomerate and cross-bedded sandstones about halfway down the grade. This ignimbrite displays classical planer bedding (base-surge deposits) at its base, becomes less consolidated upward, and in places is eroded by the overlying channel-fill deposits.

Overall, the story told by this section of the Deschutes Formation is that of a broad plain, with a braided river system running northward across it, distributing the intense load of volcanic debris shed into the basin. Stream channels (seen in outcrop as concave-upward, bedded, and often gravel-filled exposures that usually cut downward into underlying beds) are common here. Old soil horizons (paleosols) can be identified by the presence of carbon-stained cavities that were once the roots of trees and grasses of a wetter climate.

Fossils are comparatively rare in the Deschutes Formation, perhaps because the depositional system was fairly energetic and washed most plant and animal remains away. Tattered plant leaves are the most abundant and include sycamore and ash (Ashwill, 1983). The presence of some diatom-rich sedimentary layers attests to scattered, shallow lakes. Fossil salmon occur in some channel deposits (Cavender and Miller, 1973).

If you look south, over the bank from the roadway about 100 yd past the turn-out, you can see an excellent exposure of the contact between the layer-cake Deschutes Formation and the younger intracanyon Newberry basalt.

From the base of the grade, continue south about three-quarters of a mile on Cove Palisades Road. Watch for the large turnout on the right (west) side of the road below the Newberry basalts.

STOP 5. Mile 16. Newberry intracanyon basalts; recent and old landslides.

This stop offers a good view of the intracanyon Newberry basalts. Note the complex patterns of jointing. The lower, straight columns, which are called the "colonnade," form by slow, steady cooling. The curved, irregular columns above them are called the "entablature." Their feathery patterns develop because the presence of water within the basalt flow(s) causes the lava to cool and solidify at irregular rates and in diverse directions. The Newberry basalts here are composed of multiple flows that formed one or two cooling units. Their exceptional thickness is the result of ponding behind a basalt dam downstream. As a result, basalt lava that flowed down the Crooked River drainage was backed up almost 4 mi into the Deschutes River canyon.

Two landslides are apparent across the lake from this viewpoint. The oldest, probably of Pleistocene age, forms a peninsula that juts into the lake. Its rock layers slant northward, toward the viewer. It may have occurred when the Crooked River, swelled by glacial meltwaters, undercut the Newberry basalt flow.

The second landslide occurred in the wet winter of 1988. It is visible above the roadway across the lake. Most of the mass that moved in this slide is talus and colluvium and was not attached to the underlying bed rock. Continue across bridge, up the grade, and past Group Camping Area to the left. Proceed around curve and pull into large turnout on left (south) side of the road.

Figure 29. Petroglyph on a boulder that was moved to the base of "The Ship" near the headquarters of Cove Palisades State Park.

STOP 6. Mile 19. "The Ship" and Indian petroglyph (Figure 29).

The high, ragged promontory above the parking area is known as "The Ship." The thick, light-colored layers in this exposure of the Deschutes Formation are ignimbrites. The lower unit is the best consolidated and most extensive and is named the Cove ignimbrite. Dark layers are sandstones and conglomerates. The columnar basalts to the north are the Newberry intracanyon flows of "The Island."

Between "The Ship" and "The Island" lies the hummocky terrain of a large landslide. This slide extends southward along the Deschutes Arm and creates almost 2 mi^2 of relatively flat areas on which campground, day-use, launch areas, and the park headquarters are developed. Like the old landslide noted at the previous stop, this is most likely Pleistocene in age. The landmass is stable now and is thus a safe place for development and camping.

Continue southwest, past campgrounds and launch areas, to the Deschutes Arm bridge. Cross the bridge and park in the turnout to the right.

STOP 7. Mile 20. The Deschutes Arm grade.

Again, it is recommended that you take the time to walk up this grade and examine the details of the Deschutes Formation. (Less hardy souls may wish to drive up and walk down.)

The Deschutes Arm grade exhibits a number of features that contrast with those apparent on the Crooked River Arm grade. The rimrock here is diktytaxitic basalt of the Canadian Bench flow of the Lower Desert basalt—flows of the Deschutes Formation that originated in the Cascades. Several coarse debris flows are present near the top of the grade, and, in general, the sediment is slightly coarser. The Cove ignimbrite, as well as a pinkish-gray ash flow slightly higher in the section, can be examined along this grade.

At the switchback, a close view of the contact between intracanyon flows and the underlying Deschutes Formation reveals a reddish baked zone.

Perhaps one of the most interesting features of this grade is the diktytaxitic basalt exposed in a roadcut about 200 yd below the switchback curve. There are three thin flows of this basalt. All display an excellent set of pipe vesicles.

These unusual, and here, classical, features are slender, cylindrical cavities extending upward from the base of a lava flow. They commonly have a top that is bent at a right angle, indicating the direction that the lava was moving at the time it cooled. They are formed by water vapor that is trapped beneath a lava flow and streams upward into the moving lava as steam. The inside of most pipe vesicles is glassy.

From the top of this grade, the adventurous may wish to take Forest Service Road 64 to Forest Service Road 63, to the Gateway Cemetery, a distance of about 4 mi. Those of a less historical bent may end the Cove Palisades Field Trip here.

GLOSSARY

Anorthosite: A plutonic igneous rock composed almost entirely of plagioclase feldspar. These rocks are rare now but formed significant portions of the earth's early continents and island arcs from 2.4 to 1.2 billion years ago.

Clast-supported: A sedimentary rock fabric in which larger clasts form the supporting framework, and finer grained particles simply fill the limited amount of space between large cobbles or pebbles.

Dacite: A volcanic rock intermediate in composition between rhyolite and andesite.

Diktytaxitic: A texture in volcanic rocks characterized by small, irregular vesicles (holes), bounded and often lined with small crystals of plagioclase feldspar. Most commonly found in basalts, a diktytaxitic texture imparts a rough, sharp feeling to a fresh surface.

Graded bedding: A type of sedimentary bedding showing gradual change in particle size, normally from coarse at the bottom to fine at the top. In reverse bedding, the coarse particles are at the top.

Ignimbrite: A volcanic (volcaniclastic) rock formed by deposition of a hot cloud of ash and gas ejected laterally from a volcano.

Matrix-supported: A sedimentary rock in which larger clasts rest passively in a matrix of finer grained material.

Normally graded: See "Graded bedding."

Peperite: Explosive intrusions of magma into wet sediment, producing a mixed and chaotic rock containing angular fragments of volcanic rock, glass, clays, and sediment.

Phenocryst: A crystal that is visible to the naked, unaided eye, usually within a fine-grained, volcanic rock.

Porphyritic: An igneous rock texture, usually in volcanic rocks, wherein two different-sized populations of crystals occur in the rock, or where larger crystals are set in a fine-grained groundmass.

Pyroclastic rocks: Fragments produced by direct and commonly explosive volcanic action.

Reversely graded: See "Graded bedding."

Rhyodacite: A volcanic rock intermediate in composition between rhyolite and dacite.

Stratovolcano: A volcano composed of alternating lava and ash or cinders and other pyroclastic material. Most large volcanic cones, including Mount Hood and Mount Jefferson, are stratovolcanoes.

Tholeiite: A high-silica basalt, usually containing abundant pyroxene.

Volcanic arc: An arcuate chain of volcanoes above a subduction zone.

Volcaniclastic rocks: Fragmental rocks composed predominantly of reworked or eroded volcanic material.

Xenolith: An inclusion of an exotic or foreign rock in an igneous rock, rather like a raisin in a pudding.

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Fear in a handful of numbers*

by Dennis Overbye. Copyright 1989 The Time Inc. Magazine Company. Reprinted by permission.

Everybody talks about the weather, goes the saying (often wrongly attributed to Mark Twain), *but nobody does anything about it*. The word from scientists is that whoever said this was wrong. All of us, as we go about the mundane business of existence, are helping change the weather and every other aspect of life on this fair planet: Los Angelenos whipping their sunny basin into a brown blur on the way to work every morning; South Americans burning and cutting their way through the rain forest in search of a better life; a billion Chinese, their smokestacks belching black coal smoke, marching toward the 21st century and a rendezvous with modernization.

On the flanks of Mauna Loa in Hawaii, an instrument that records the concentration of carbon dioxide dumped into the atmosphere as a result of all this activity traces a wobbly rising line that gets steeper and steeper with time. Sometime in the next 50 years, say climatologists, all that carbon dioxide, trapping the sun's heat like a greenhouse, could begin to smother the planet, raising temperatures, turning farmland to desert, swelling oceans anywhere from four feet to 20 feet. Goodbye Venice, goodbye Bangladesh. Goodbye to millions of species of animals, insects, and plants that haven't already succumbed to acid rain, ultraviolet radiation leaking through the damaged ozone layer, spreading toxic wastes, or bulldozers.

A species that can change its planet's chemistry just by day-to-day coming and going has, I suppose, achieved a kind of coming-of-age. We could celebrate or tremble. What do we do when it is not war that is killing us but progress? When it is not the actions of a deranged dictator threatening the world but the ordinary business of ordinary people? When there are no bombs dropping, nobody screaming, nothing to fear but a line on a graph or a handful of numbers on a computer printout? Dare we change the world on the basis of a wobbly line on a graph? We can change the world, and those numbers, slowly, painfully—we can ration, recycle, carpool, tax, and use the World Bank to bend underdeveloped nations to our will. But the problem is neither the world nor those numbers. The problem is ourselves.

In our relations with nature, we've been playing a deadly game of cowboys and Indians. We all started as Indians. Many primitive cultures—and the indigenous peoples still clinging today to their pockets of underdevelopment—regarded the earth and all its creatures as alive. Nature was a whistling wind tunnel of spirits. With the rise of a scientific, clockwork cosmos and of missionary Christianity, with its message of man's dominion and relentless animus against paganism, nature was metaphorically transformed. It became dead meat.

The West was won, Los Angeles and the 20th century were built, by the cowboy mind. To the cowboy, nature was a vast wilderness waiting to be tamed. The land was a stage, a backdrop against which he could pursue his individual destiny. The story of the world was the story of a man, usually a white man, and its features took their meaning from their relationship to him. A mountain was a place to test one's manhood; an Asian jungle with its rich life and cultures was merely a setting for an ideological battle. The natives are there to be "liberated." By these standards even Communists are cowboys.

The cowboys won—everywhere nature is being tamed—but victory over nature is a kind of suicide. The rules change when there is only one political party allowed in a country or there is only one company selling oil or shoes. So too when a species becomes numerous and powerful enough to gain the illusion of mastery. What we have now is a sort of biological equivalent to a black hole, wherein a star becomes so massive and dense that it bends space and time totally around itself and then pays the ultimate price of domination by disappearing.

Modern science, a cowboy achievement, paradoxically favors the Indian view of life. Nature is alive. The barest Antarctic rock is crawling with microbes. Viruses float on the dust. Bacteria help digest our food for us. According to modern evolutionary biology, our very cells are cities of formerly independent organisms. On the molecular level, the distinction between self and nonself disappears in a blur of semipermeable membranes. Nature goes on within and without us. It wafts through us like a breeze through a screened porch. On the biological level, the world is a seamless continuum of energy and information passing back and forth, a vast complicated network of exchange. Speech, food, posture, infection, respiration, scent are but a few pathways of communication. Most of those circuits are still a mystery, a labyrinth we have barely begun to acknowledge or explore.

The great anthropologist and philosopher Gregory Bateson pointed out 20 years ago that this myriad of feedback circuits resemble the mathematical models of thinking being developed for the new science of artificial intelligence. A forest or a coral reef or a whole planet, then, with its checks and balances and feedback loops and delicate adjustments always striving for light and equilibrium, is like *a mind*. In this way of thinking, pollution is literal insanity (Bateson was also a psychologist). To dump toxic waste in a swamp, say, is like trying to repress a bad thought or like hitting your wife every night and assuming that because she doesn't fight back, you can abuse her with impunity—30 years later she sets your bed on fire.

Some of these circuits are long and slow, so that consequences may take years or generations to manifest themselves. That helps sustain the cowboy myth that nature is a neutral, unchanging backdrop. Moreover, evolution seems to have wired our brains to respond to rapid changes, the snap of a twig or a movement in the alley, and to ignore slow ones. When these consequences do start to show up, we don't notice them. Anyone who has ever been amazed by an old photograph of himself or herself can attest to the merciful ignorance of slow change, that is, aging—*Where did those clothes and that strange haircut come from? Was I really that skinny?*

We weren't born with the ability to taste carbon dioxide or see the ozone layer, but science and technology have evolved to fill the gap to help us measure what we cannot feel or taste or see. We have old numbers with which, like old photographs, we can gauge the ravages of time and our own folly. In that sense, the "technological fix" that is often wishfully fantasized—cold fusion, anyone?—has already appeared. The genius of technology has already saved us, as surely as the Ghost of Christmas Future saved Scrooge by rattling the miser's tight soul until it cracked. A satellite photograph is technology, and so are the differential equations spinning inside a Cray supercomputer. There is technology in the wobbly rising trace on a piece of graph paper. There is technology in a handful of numbers.

The trick is to become more like Indians without losing the best parts of cowboy culture—rationalism and the spirit of inquiry. We need more science now, not less. How can we stretch our nerves around those numbers and make them as real and as ominous

*This thought-provoking essay was originally published in the October 9, 1989, issue of *Time* magazine (page 119) and is reprinted here, with permission of the publishers, in the hope that it will be of interest to you, our readers. We hope to make other additions to *Oregon Geology* in future issues. Please let us have your ideas on changes you would like to see in the magazine. We welcome your ideas.

as our cholesterol readings? Repeat them each night on the evening news? We need feedback, as if we were the audience in a giant public radio fund-raising drive hitting the phones and making pledges. Like expert pilots navigating through a foggy night, we need the faith to fly the planet collectively by our instruments and not by the seat of our pants. In the West we need the faith and courage to admit the bitter truth, that our prosperity is based as much on cheap energy as on free markets. A long-postponed part of the payment for that energy and prosperity is coming due if we want to have any hope of dissuading the Chinese and the rest of the Third World from emulating us and swaddling the planet with fumes and wastes.

What if the spirit doesn't hit? We can't afford to wait if we want to survive. While we are waiting for this sea change of attitude, we could pretend—a notion that sounds more whimsical than it is. Scientists have found that certain actions have a feedback effect on the actor. Smilers actually feel happier; debaters become enamored of their own arguments; a good salesman sells himself first. You become what you pretend to be. We can pretend to be unselfish and connected to the earth. We can pretend that 30-ft-long, black-tinted-glass, air-conditioned limos are unfashionable because we know that real men don't need air conditioning. We can pretend that we believe it is wrong to loot the earth for the benefit of a single generation of a single species. We can pretend to care about our children's world.

The air has been poisoned before, 3 billion years ago, when the blue-green algae began manufacturing oxygen. That was the first ecological crisis. Life survived then. Life will not vanish now, but this may be the last chance for humans to go along gracefully. □

Agency welcomes Tom Wiley and Frank Hladky to Grants Pass Field Office

Thomas J. Wiley, formerly of the U.S. Geological Survey (USGS), and Frank R. Hladky, formerly of private industry, have joined the Oregon Department of Geology and Mineral Industries (DOGAMI) as professional staff for the Grants Pass Field Office located in southwestern Oregon.

Tom Wiley finished a Bachelor of Science degree in 1979 at Humboldt State University in northern California. He received his Master's degree in geology from Stanford University in 1983. As a USGS geologist, his principal duties included conducting geologic mapping and other field studies focused on the understanding of sedimentary basins and basement terranes in western North America. This background is particularly appropriate for the Grants Pass Field Office geologist. Tom's work included studies of the geology in and around western Oregon as part of regional syntheses of tectonics and petroleum potential. He compiled the geology of the Pacific Ocean floor west of Oregon for a new geologic map published by the Geological Society of America and worked in Tertiary basins of the Franciscan terrane of California. In addition, he has participated in field studies in Alaska, the People's Republic of China, and Tibet.

Tom recently assisted in organizing and coordinating the Third Circumpacific Tectonostratigraphic Terrane Conference held in 1985 in Sydney, Australia, and was North American Coordinator for the Fourth Circumpacific Tectonostratigraphic Terrane Conference held in 1988 in Nanjing, People's Republic of China. Tom Wiley has numerous publications to his credit.

Thomas J. Wiley.

Frank R. Hladky.

Also joining DOGAMI as a project geologist is Frank Hladky, a recent employee of Newmont Exploration, Ltd. Frank's experience in recent years included that of research associate at Idaho State University, during which time he performed a geologic assessment of tribal lands in southern Idaho that are administered by the U.S. Bureau of Indian Affairs. The project resulted in several significant maps and other reports, either published by or in press at the USGS.

Frank received his Bachelor of Science degree in geology from the University of Oregon in 1982 and his Master of Science degree in geology from Idaho State University in 1986. His most recent exploration for Newmont included regional and strategic analyses of the Carlin Trend for the purpose of gold exploration in the western United States. His primary areas of interest include structure, deformational events, stratigraphy, and timing and mechanisms of ore emplacement. Frank also has numerous geologic publications to his credit.

DOGAMI is pleased to continue its many years of effort in the Grants Pass area on behalf of the citizens and interests of Oregon and is especially pleased to add to its staff two highly qualified professional geologists in Tom Wiley and Frank Hladky. □

McMurray rejoins DOGAMI

Gregory McMurray rejoined the staff of the Oregon Department of Geology and Mineral Industries (DOGAMI) as Marine Minerals Program Coordinator on November 13, 1989.

McMurray had served in this position between September 1984 and January 1989 as coordinator for the State/Federal Gorda Ridge Technical Task Force and will now continue in a similar function for the State/Federal Oregon Placer Minerals Task Force. His duties will concentrate on providing management and technical support for non-Department scientific working groups that study the various aspects of offshore mineral exploration and development.

A biological oceanographer, McMurray received his Bachelor's degree in zoology from Ohio University, his Master's degree in biology (limnology) from the University of Akron, and his Doctor's degree in oceanography from Oregon State University. As a senior oceanographer at VTN Oregon, Inc., he was project manager and principal investigator for physical, chemical, and biological oceanographic studies of the Pacific Coast estuaries and fjords. He has also served with the U.S. Geological Survey, studying the phytoplankton ecology of San Francisco Bay and the lower Sacramento River. During 1989, following his first term with DOGAMI, McMurray was Deputy Director for the National Coastal Resources Institute at Newport, Oregon, and, later, a consultant to Exxon for environmental studies of the Prince William Sound oil spill in Alaska.

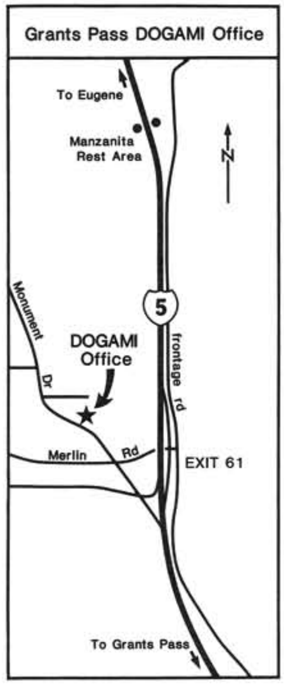
Gregory McMurray.

McMurray is author and coauthor of numerous papers and reports based on his oceanographic studies in Alaska, California, and Oregon. He is the editor of the recent Springer-Verlag publication containing results of studies of the Gorda Ridge Task Force. (See page 21 of this issue.) □

DOGAMI reopens Grants Pass Field Office in new location

The Oregon Department of Geology and Mineral Industries (DOGAMI) is pleased to announce the reopening of its field office in Grants Pass with responsibilities for southwestern Oregon, an area that encompasses not only the Klamath Mountains but also part of the Coast Range and part of the Cascade Range and that extends into the Basin and Range province. Closure of the office appeared imminent, owing to successive budget cuts, but public and legislative interest enabled the Agency to reopen the office at its new facilities in joint quarters with the State Forestry Department at 5375 Monument Drive, Grants Pass.

Major missions of the Agency include the ongoing collection of meaningful geologic data for the public good, education of the public and government in geologic matters, regulation of such geologic activities as oil and gas and geothermal exploration and production, mineral exploration and mining, and, finally, participation in the development of public policy on resource-oriented issues.



Sketch map showing new location of DOGAMI Grants Pass Field Office.

Within this context, the activities of the Grants Pass Field Office will be extremely important in southwestern Oregon, an area of intense geologic interest and policy issues. Primary work load for the office will be oriented toward geologic data collection and mapping plus information dissemination to a broad audience, including private industry, government agencies, and the public in general.

The new location of the DOGAMI Grants Pass Field Office is at the same address as the State Forestry Department: 5375 Monument Drive, Grants Pass, OR 97526. The location is approximately 3 mi north of Grants Pass and just west of Interstate Highway I-5 (see sketch map).

After the retirement of former Grants Pass Field Office geologists Norm Peterson, five years ago, and Len Ramp, approximately a year ago, the office has now been restaffed with new geologists identified in a nationwide recruiting effort that took eight months to complete. Running the office will be Tom Wiley, formerly of the U.S. Geological Survey. Working in close harmony with him will be Frank Hladky, who comes to the Agency from private enterprise.

During the winter months, the Agency will be addressing policy issues and broad geologic riddles in southwestern Oregon in a systematic approach to identifying at least one broad, multi-year project into which to place its efforts. Emphasis will be on identifying a project of value to the people of southwestern Oregon, with promise of attracting supplemental efforts from Federal agencies, possibly including the U.S. Geological Survey, and private industry. It is the Agency's belief that, in terms of project design, a partnership effort in a broad area over a reasonable period of time yields the greatest long-term payoffs for Oregon. We welcome Tom Wiley and Frank Hladkey into the Agency and look forward to many years of productive work with them. □

BOOK REVIEW

by Ralph S. Mason, former State Geologist of Oregon

William A. Rockie, Seventy Years a Geographer in the West. Written by W.A. Rockie, compiled and updated by John D. Rockie, edited by Larry W. Price. Published 1989 by Department of Geography, Portland State University, P.O. Box 751, Portland, Oregon 97207. 70 p., $11.95.

All autobiographies should be viewed with a certain amount of circumspection by a reviewer. Fact and fiction, unvarnished truths, adventures and misadventures lie like mine fields along their paths. Here is an account, put together by the author over a period of many years but never completed before his death. It was eventually augmented with the help of some of William Rockie's professional friends at the Department of Geography at Portland State University, and the combined material was then compiled by his son John. To complicate matters even more, the reviewer knew the author for nearly forty years, both professionally and as a good friend and neighbor.

Unavoidably, there are gaps in the telling, but the message comes through loud and clear. Here was a man who participated in the earliest beginnings of the soil conservation movement and then pushed and prodded the fledgling movement for the next half century. If nothing else, this account provides an almost complete history of the growing awareness of the need for soil conservation in this country—and odd places scattered around the world as well.

If anything, Rockie understates many of his multitudinous activities and observations. His transect of the Sahara from Algiers to Lagos, Nigeria, is a case in point. One interesting anecdote he related upon his return from this project is not in his book: During a lunch stop in the desert, Rockie removed a square foot of wind-polished pebbles that formed the lag blanket. Steadily, the wind blew away the unprotected sand, and a miniature "blowout" formed even as he watched. On another occasion he told of riding a small landslide in the Matanuska Valley, Alaska, down a slope of only two degrees—revamping for all time old ideas about the "angle of repose." One wonders how many other similar observations Rockie might have included if he could have completed his book himself. A latter-day Boswell could certainly have embellished the text with a wealth of informal material.

Interestingly, mention is made that, at the oasis of Tamanrasset in Algeria, Rockie inventoried a small portion of the irrigated area and counted 26 different species among a total of 2,294 trees—in an area previously reported to have but one "spiky gnarled willow." Fact is often more interesting than fiction! □

NEF publishes poster on mining

The National Energy Foundation (NEF) has announced the publication of an educational poster entitled "From Mountains to Metal. The Story of Rocks, Minerals, and the Mining Industry."

The colored poster is approximately 2 x 3 ft large and depicts in drawings explained by text eight steps from exploration for minerals to reclamation of mined sites. The back of the poster is filled with large-print text, tables, and graphic illustrations presenting "Helpful Information to Teach about Rocks, Minerals, and the Mining Industry."

The poster is available from the National Energy Foundation, 5160 Wiley Post Way, Suite 200, Salt Lake City, Utah 84116, phone (801) 539-1406. The price of the poster is $2.50, and various discounts are offered for orders of 100 copies or more. For shipping and handling, a minimum of $3 or 10 percent of the order amount is charged.

—NEF news release

DOGAMI releases limestone report and Adrian quadrangle map

New report on limestone in Oregon

A comprehensive report on limestone in Oregon, its formation, industrial uses, and occurrences, has been released by the Oregon Department of Geology and Mineral Industries (DOGAMI). The report is intended to serve as a basis for further study and exploration and for the continued development of limestone as an industrial-mineral resource in Oregon's economy.

Limestone Deposits in Oregon, by DOGAMI geologist Howard C. Brooks and with an appendix by DOGAMI geochemist Gary L. Baxter, has been published as DOGAMI Special Paper 19.

The report consists of a 72-page text with numerous illustrations, especially location maps and analytical tables, and two separate plates. Plate 1 presents locations and analytical data for nearly 300 samples collected and analyzed for this report. Plate 2 contains a map of limestone deposits and areas in Oregon keyed to the discussion in the text.

Oregon's approximately 40-million-ton output of crushed and ground limestone has been used mainly in the production of about 18.5 million tons of cement. Other major uses of Oregon's limestone have been the production of industrial and agricultural lime; fillers, extenders, and mineral pigments for such products as plastics, paint, rubber, floor coverings, adhesives, and paper; surface coatings for paper manufacture; and refining agents for sugar production.

The limestone has come mainly from metamorphosed high-calcium deposits of Palozoic and Mesozoic age in the Blue Mountains and Klamath Mountains and from low-grade deposits of Tertiary age in the Coast Range. Eastern Oregon has local occurrences of lacustrine carbonate beds and small travertine deposits.

New geologic quadrangle map for Adrian area

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new geologic map that describes in detail the geology and mineral potential of a portion of the Owyhee region in eastern Oregon near the city of Adrian. Geothermal energy is the only minral resource known to exist, but potential for natural gas and, to a lesser extent, gold or uranium has also been identified.

Geology and Mineral Resources Map of the Adrian Quadrangle, Malheur County, Oregon, and Canyon and Owyhee Counties, Idaho, by DOGAMI geologist Mark L. Ferns, has been released in DOGAMI's Geological Map Series as map GMS-56. The publication, resulting from an ongoing study of southeastern Oregon areas with a potential for mineral resources, was prepared in cooperation with the U.S. Geological Survey (USGS) and the Idaho Geological Survey and partially funded by the COGEOMAP program of the USGS.

The Adrian 7½' Quadrangle covers approximately 48 square miles along the Owyhee River around the river's Big Bend area south of Adrian. The two-color map of the quadrangle (scale 1:24,000) identifies eight rock units, the oldest of which are approximately 15 million years old. Geologic structure is described both on the map and in the accompanying geologic cross section. The approximately 27- by 38-inch map sheet also includes a discussion of the quadrangle's mineral resource potential and a table showing trace-element analyses of rock samples.

The two new releases are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5528. The price for Special Paper 19 is $8, for map GMS-56 $4. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

MINERAL EXPLORATION ACTIVITY

Major metal-exploration activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	QM Chevron Resources, Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources, Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

Exploration rule making

The Technical Advisory Committee organized to make recommendations on exploration permit rule making relative to House Bill 2088 has met twice and will meet next in Salem on January 10, 1990. It is expected that three public hearings and a two-week comment period will be used to receive public comment on draft rules. The hearings will likely be scheduled for March or April. Anyone wishing to be on the draft rule mailing list should contact Doris Brown at the Oregon Department of Geology and Mineral Industries (DOGAMI) Mined Land Reclamation, 1534 Queen Avenue SE, Albany, OR 97321, phone (503) 967-2039.

Bond ceiling rule making

The Technical Advisory Committee organized to make recommendations on rule making relative to bond ceilings (Senate Bill 354) has met twice and will meet again January 9, 1990. The track for rule making is similar to that for the above-mentioned exploration rule making process, and again three public hearings and a two-week comment period will be used to receive public input. Anyone wishing to receive draft rules should contact Doris Brown at the address or telephone number above.

Status changes

Atlas Precious Metals has submitted a plan of operations to the U.S. Bureau of Land Management (BLM). An Environmental Impact Statement for the site will be required by BLM. The Atlas project coordinating committee met on December 19, 1989, to discuss NEPA compliance and agency permitting schedules.

Formosa Exploration, Inc., has submitted its baseline studies and operating plan for the Silver Peak Mine to DOGAMI and the Department of Environmental Quality.

All readers who have questions or comments should contact Gary Lynch or Allen Throop at the MLR office in Albany, phone (503) 967-2039. □

DOGAMI receives funding for earthquake hazard mitigation

On November 15, 1989, the Oregon Department of Geology and Mineral Industries (DOGAMI) requested $489,285 from the State Emergency Board to support earthquake hazard mitigation. On December 15, 1989, the Emergency Board allocated $230,000 of State General Fund to DOGAMI for earthquake hazard mitigation. The allocation includes funds for an earthquake engineer and for subcontracted studies and support for a seismic network.

Recent findings by researchers working on Oregon and Washington coastal marshes indicate that the Northwest may be vulnerable to damage from great subduction-zone earthquakes. The action by the Emergency Board is in response to this newly recognized threat.

DOGAMI has assembled an advisory panel to assist in deciding on priorities for the State program and provide ongoing advice regarding information needs. □

Gorda Ridge subject of new book

A book entitled *Gorda Ridge: A Seafloor Spreading Center in the United States' Exclusive Economic Zone* has been released by Springer-Verlag New York, Inc. It contains the proceedings of the Gorda Ridge Symposium, conducted in Portland, Oregon, during May 1987 under the sponsorship of the joint state/federal Gorda Ridge Technical Task Force and was edited by Greg McMurray of the staff of the Oregon Department of Geology and Mineral Industries. The Gorda Ridge Task Force was active in directing and coordinating research on Gorda Ridge from 1984 through 1988.

The new volume presents a summary of recent advances in seafloor research related to mineral exploration on the ridge, which is the only seafloor-spreading center within the 200-nautical-mile-wide Exclusive Economic Zone of the United States. The book includes sections on the results of Gorda Ridge mineral exploration, on the newest technologies for mineral exploration and sampling on the seafloor, on the evolving field of hydrothermal-vent biology and ecology, and on the exploration of sediment-hosted sulfide deposits discovered in the southern segment of Gorda Ridge. The book is of interest to researchers in marine geology and biology as well as to those involved in ocean-policy development and environmental issues.

Cost of the new book is $89. More information may be obtained from the publisher by writing Springer-Verlag New York, Inc., P.O. Box 2485, Seacaucus, NJ 07096-2491. □

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.

STRATIGRAPHY AND SEDIMENTARY PETROLOGY OF THE MASCALL FORMATION, EASTERN OREGON, by John L. Kuiper (M.S., Oregon State University, 1988), 153 p.

The type section of the Mascall Formation, which is located in the John Day Valley, is interpreted to represent a sequence of paleosols. These fossil soils were formed on a flood plain during the middle Miocene. The measured thickness of this section is 1,340 ft, and although the top of the section is truncated by an erosion surface, the original thickness was probably not much more than 2,000 ft. Sediment accumulation rates were high in the vicinity of the type section, with deposits being predominantly of the overbank type. Minimum sediment accumulation time at the type section is thought to have been several hundred thousand years.

A concretionary horizon that occurs within the type section is determined to represent a significant temporal hiatus. Because of the absence of caliche in this layer and elsewhere in the type section and because of the occurrence of moisture-loving plants, a wet, temperate climate during the middle Miocene (Barstovian) is envisioned for the type section.

The flood-plain sediments of the type section are predominantly composed of ash that was produced by nearby silicic volcanism. This ash was mostly washed in from the surrounding highlands, but on occasion the flood plain was blanketed by air-fall debris. Scanning electron microscopy demonstrates that this ash is of the type erupted by Plinian- and Peléan-type volcanoes. The ash has been mostly altered to clay minerals, and SEM, TEM, and XRD analyses show these clays to consist principally of smectite (Ca, Mg) with lesser amounts of kaolin and tubular halloysite.

Deposits west of Picture Gorge are predominantly of flood-plain origin; however, a limited lacustrine sequence also occurs. East of the type section, the flood-plain deposits tend to become coarser and reflect main-channel deposition.

Farther to the east, near the mouth of Fields Creek, a 300-ft-thick lacustrine sequence occurs, representing a shallow eutrophic lake that was at least 3.5 mi in east-west dimension.

Mascall deposits of the Paulina Basin also were formed in a flood-plain environment. The area was characterized by slow sediment accumulation rates, and river meandering resulted in deposition of large tabular sandstone bodies. Meander-loop cutoff probably occurred often, and as a result the flood plain was probably dotted with oxbow lakes. Volcanoes were active nearby and on occasion covered the flood plain with pyroclastic debris.

The Mascall Formation is believed to have been deposited only in the structural and topographic lows of the time. Present occurrences of Mascall rocks in the John Day Valley, Paulina Basin, and Fox Basin and Miocene rocks in the Bear Valley and Unity Basin that may or may not be Mascall are not the remnants of a huge alluvial fan. Rather, all of these structural lows were filled with sediment and pyroclastic material from their respective adjacent highlands.

Pumices ranging from white to black in color, representing a zoned eruption, were collected from Mascall deposits in the John Day Valley. Chemical analysis of these pumices precludes magma mixing as a means of producing the zoned eruption. It is not known whether crystal fractionation or assimilation of wall-rock material represents the mechanism involved. High K_2O values in the Mascall pumice show the magma had a continental source.

THE STRATIGRAPHY AND DEPOSITIONAL SETTING OF THE SPENCER FORMATION, WEST-CENTRAL WILLAMETTE VALLEY, OREGON; A SURFACE-SUBSURFACE ANALYSIS, by Linda J. Baker (M.S., Oregon State University, 1988), 171 p.

The upper Eocene Spencer Formation crops out in the low hills on the western edge of the central Willamette Valley, Oregon. Surface exposures in eastern Benton and southeastern Polk Counties and oil and gas well records and cuttings in Polk, Marion, and Linn Counties were studied to determine Spencer stratigraphy, regional lithologic variations, and depositional environment. Methods used include study of outcrops, petrography, texture, and well cuttings, as well as correlation of well logs and microfossil data. The distribution of the underlying lower upper Eocene Yamhill Formation is also briefly considered.

The Yamhill Formation consists of the Miller sandstone member enclosed between mudstones. The lower and middle Yamhill units record shoaling from bathyal to marginal marine depths, and they are overlain by bathyal upper Yamhill mudstones. The Miller sandstone is lens shaped, trends parallel to the Corvallis fault, and reaches a maximum thickness of approximately 2,000 ft on the east side of the fault. The Miller sandstone grades westward into bathyal mudstones and eastward into volcanic tuffs and flows. Thinning of the Miller sandstone and upper Yamhill mudstone along the Corvallis fault suggests movement during early late Eocene. The absence of Yamhill strata along the outcrop belt to the southwest may be related to this tectonic activity. Alternatively, Yamhill strata may have been misidentified as Tyee Formation or Spencer Formation.

The Spencer Formation was deposited in a tectonically active forearc basin during a transgression that was interrupted by several short-term regressional/progradational events. The Spencer is stratigraphically divided (informally) into a lower sandstone-rich member and an upper mudstone member; it is also divided geographically (informally) into northwestern, east-central, and southern provinces. The lower member is 700 ft thick in the northwestern and southern areas and thickens to 1,400 ft in the east-central area. As compared to the north and south areas, sandstones in the east-central area are coarser (fine to medium versus very fine to fine), the sandstone-to-siltstone ratio is higher, and volcanic interbeds are more common. Deposition is thought to have been at inner-shelf and shoreface depths, grading eastward into nonmarine. In the northwestern area, abundant hummocky cross-bedding of arkosic to arkosic-lithic lower Spencer sandstones suggests deposition on a storm-wave-dominated shelf. Periods of shoaling to shoreface depths are indicated. In the south, sandstones are markedly more volcanic-rich (dominantly arkosic litharenites), contain more fossils, and are more highly bioturbated. Shelf-storm deposits in the south are normally graded with a basal lag of coarse volcanic grains and fossils. Besides a more proximal volcanic source, a shoal/barrier within the southern part of the basin may have caused the different sediment character. Deposition was probably at middle- to inner-shelf depths at the outcrop belt. It may have deepened slightly eastward before shoaling to nonmarine in the easternmost part of the study area. Volcanism was active nearby on the eastern and southeastern margins of the basin. Small volcanic centers within the basin may have created highs and acted as localized volcanic sources.

As transgression continued, upper Spencer mudstones were deposited at middle to upper bathyal depths. Volcanic activity increased on the eastern edge of the basin. Mudstones grade eastward and upward into tuffs and flows of the eastern Willamette volcanic facies. □

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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, a file copy on 5-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 6th ed., 1978.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the 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

Workers install wellhead at the DY Oil well Neverstill 33-30 in the Mist Gas Field, northwestern Oregon. See related summary report on oil and gas exploration and development in Oregon for 1989, beginning on page 43.

OIL AND GAS NEWS

Mist Gas Field report revised

The Mist Gas Field Report published by the Oregon Department of Geology and Mineral Industries (DOGAMI) has been revised and is now available with all 1989 activity and changes included. This report includes the Mist Gas Field Map, which was revised to include the seven wells ARCO and the six wells DY Oil drilled during the year. The location, status, and depth of all wells are indicated on the map. The report also includes production figures for the wells at Mist from the initial production in 1979 through the end of 1989. Included are well names, revenue generated, pressures, annual and cumulative production, and other data. The Mist Gas Field Report, Open-File Report 0-90-1, sells for $7.

Rulemaking continues

Draft rules to implement House Bill 2089 (1989 Legislature) are now available for review. These are to provide for ground-water protection and surface reclamation when shallow exploratory holes, such as seismic shot holes, are drilled by the oil and gas industry in Oregon. Administrative rules relating to oil and gas exploration and development in Oregon are also being reviewed at this time. These were last revised in November 1985, and revisions to these rules may be proposed. Public hearings for them and for House Bill 2089 rules will be scheduled for some time during February or March. Contact Dan Wermiel for details. □

New maps and reports released by DOGAMI

Geologic maps for southeastern Oregon

Two new geologic maps released by the Oregon Department of Geology and Mineral Industries (DOGAMI) describe the geology and mineral potential of the Double Mountain and Grassy Mountain areas in southeastern Oregon. These areas are currently the focus of intensive exploration for gold but show potential also for other mineral resources, such as feldspathic sands, limestone, bentonite clay, diatomaceous earth, perlite, natural gas, and geothermal energy.

DOGAMI geologists M.L. Ferns and L. Ramp produced both DOGAMI map GMS-57, *Geology and Mineral Resources Map of the Grassy Mountain Quadrangle, Malheur County, Oregon*, and DOGAMI map GMS-58, *Geology and Mineral Resources Map of the Double Mountain Quadrangle, Malheur County, Oregon.*

Both of the maps are two-color maps at a scale of 1:24,000. They show rock units and geologic structure on a topographic base and identify the locations of samples collected for analysis, fossils, and, in the case of GMS-58, gas-exploration wells. The price of each map is $4.

The two publications were prepared in cooperation with the U.S. Geological Survey (USGS) and were partially funded by the COGEOMAP program of the USGS.

The Grassy Mountain 7½-minute Quadrangle covers approximately 48 mi^2 south of Vale, Oregon. The map of the quadrangle, GMS-57, consists of two plates: The first plate contains the geologic map, two geologic cross sections, and a discussion of the mineral resources of the quadrangle; the second plate contains two tables of sample analyses.

The Double Mountain 7½-minute Quadrangle is the immediately adjacent quadrangle to the north. The map covering this quadrangle, GMS-58, consists of one plate that includes the geologic map, analytical tables, two geologic cross sections, and a discussion of the mineral-resource potential of the quadrangle.

*(Continued on page 36, **Reports**)*

Maps: the Earth on canvas

by Evelyn M. VandenDolder, Arizona Geological Survey

This paper first appeared in the Winter 1987 issue of *Fieldnotes* (v. 17, no. 4), published by the Arizona Bureau of Geology and Mineral Technology. Since that date, the name of the publication has been changed to *Arizona Geology*, and the name of the state agency has been changed to the Arizona Geological Survey, located at 845 N. Park Avenue, #100, Tucson, Arizona 85719, phone (602) 882-4795. The content of the original paper was modified to include information about Oregon instead of Arizona. It was also updated and expanded slightly by Glenn Ireland, State of Oregon Resident Cartographer, whose assistance is gratefully acknowledged. *—Editors*

INTRODUCTION

Amelia Earhart, the plucky aviator whose 1937 round-the-world flight ended in disaster, may have been the victim of a mapmaker's mistake. Earhart's flight plan gave the wrong coordinates for Howland Island, the South Pacific sandbar that was only 2 miles (mi) long and that she and navigator Fred Noonan were trying to reach when they vanished. The faulty flight plan, which was based on inaccurate government charts, put Howland Island 7 mi to the northwest of its actual location. Earhart's flight plan listed the coordinates for the tiny island as latitude (lat) 0°49' N., longitude (long) 176°43' W., whereas the actual coordinates are lat 0°48' N., long 176°38' W. (Barker, 1986). Some investigators who searched for the possible causes for Earhart's disappearance believed that she and Noonan were on course and would have reached Howland Island if they had been given the correct coordinates. The first chart to list accurate coordinates was published four to five months after Earhart and Noonan vanished. It is therefore likely that the mapping mistake was discovered during the search for Earhart.

Earhart's story illustrates the importance of accuracy in maps and translates a seemingly inconsequential error on paper into the language of human tragedy. Accurate, detailed maps have enabled humans to chart not only their courses across vast oceans but also the progress of their civilizations. The following article gives an abbreviated history of cartography, the art and the science of mapmaking; explains scale, coordinate systems, and projections; illustrates how remote-sensing techniques aid mapmaking; describes various specialized maps and how they are used; and lists several sources of maps of Oregon.

HISTORY OF MAPMAKING

Maps are as old as human culture. The detail and accuracy of mapmaking have, in turn, both reflected and enhanced the advancement of civilization. From prehistoric hunters, who probably drew crude maps in the dirt, to Renaissance navigators, who explored and mapped the oceans and continents, to today's cartographers, who use satellite images, mapmaking has had a long and exciting history.

Figure 1. Today's cartographic instruments range from the compass, which was invented during the 11th or 12th century, to sophisticated computer systems that can increase the speed, accuracy, and quality of all mapmaking efforts. Drawing by Peter F. Corrao, Arizona Geological Survey.

As human culture evolved from a nomadic, hunting existence to a more settled, agrarian lifestyle, land ownership and determination of property lines became more important. The oldest known map, dated about 2500 B.C., is a small clay tablet that shows a man's estate nestled amid mountains and rivers in Mesopotamia (Chamberlain, 1950; Raisz, 1962). The Egyptians measured and mapped their countryside for property taxes to fuel their thriving civilization. These early peoples believed that Earth was flat, and their maps reflected this concept.

Ancient Greek culture emphasized logic, reason, and scientific thought, nurturing interest in the world as well as the mind. The Greeks conceived the idea of a spherical Earth. About 400 B.C., Aristotle offered evidence as proof: the shape of Earth's shadow on the Moon during an eclipse (Chamberlain, 1950). Eratosthenes (276-194 B.C.), mathematician and philosopher, estimated the size of Earth based on observations of shadows and a knowledge of geometry. Despite his crude methods (by modern standards), his estimate of Earth's circumference of 28,000 mi was only 12 percent larger than its actual size (about 24,900 mi; Chamberlain, 1950). His map, which showed parts of Europe, Africa, and Asia, was the first to include parallels and meridians. The early Greeks also defined the poles, the equator, and tropics and developed several projections that are still used today.

Medieval cartographers, seeking a more simplistic view of the world to mirror their religious beliefs, chose more symmetrical, "divinely perfect" outlines for Europe, Africa, and Asia rather than the more accurate, irregular coastlines of earlier maps. In the late 13th century, however, the use of the compass burgeoned, as did the production of highly accurate maps known as "portolan charts," which were used with minor modifications for more than three centuries. Portolan charts were based on systematic compass surveys. Most charts included 16 or 32 compass roses with radiating rhumb lines (lines that show the compass directions), a design sometimes used on current maps as decoration (Raisz, 1962).

The discovery of the Americas effected a renaissance in cartography. As the number of trade routes increased, so did the need for more detailed maps. New discoveries from explorations modified humans' view of the world. The first map to include America, published in 1500, showed it as part of Asia (Raisz, 1962). It was not until after Magellan's voyage from 1519 to 1522 that maps accurately depicted the immensity of the Pacific Ocean. The invention of the engraving and printing processes during this period enabled wider and more timely distribution of new maps. The highest quality maps produced during the late 16th and 17th centuries were compiled by Dutch and Flemish mapmaking masters, such as Mercator, Ortelius, and Janszoon (Raisz, 1962).

The 18th century, known as the Age of Reason, brought a concomitant age of map accuracy. Instruments to measure latitude and longitude became more sophisticated. Triangulation and topographic mapping of France during this time, sponsored by the Cassini family, spurred interest in similar national surveys during the following century (Raisz, 1962). Cartographers of the 19th century also diversified and specialized their products, creating geologic, economic, and transportation maps, among others. With the founding of the U.S. Geological Survey (USGS) in 1879, the systematic mapping of the United States became an organized effort.

In our own century, the advent of remote-sensing techniques such as aerial photography and satellite imagery has enabled the cartographers to create a "bird's-eye" view of the world and its features. Digital scanning systems and laser plotters have dramatically increased the accuracy and detail of modern maps (Figure 1). Technological advances and increasingly sophisticated instruments continue to enhance the quality and accuracy of human attempts at sketching the face of Earth.

SCALE

Scale defines the relationship between a distance shown on a map and the corresponding actual distance on the ground. Scale may be expressed in three ways (Zumberge and Rutford, 1983):

1. As a graph, line, or bar divided into units that represent ground distances.

2. In words that state the relationship between map distance and ground distance; for example, "1 inch (in.) equals 1 mile (mi)" means that 1 in. on the map corresponds to 1 mi on the ground.

3. As a fraction or fixed ratio between linear efforts in measurements on the map (the numerator) and corresponding distances on the ground (the denominator). For example, a scale of $\frac{1}{63,360}$ (or 1:63,360) means that one unit of measurement on the map (for example, 1 in.) represents 63,360 of the *same* units on the ground. In this example, 1 in. on the map corresponds to 1 mi on the ground (1 in. [map] = 63,360 in. [ground] = 5,280 feet [ft] [ground] = 1 mi [ground]). The first number (map distance) given in the ratio is always 1; the second number (ground distance) varies, but the *larger* the second number, the *smaller* the scale.

Many areas have been mapped several times, but at different scales. One should choose a map with a scale appropriate for its intended use. For instance, a large-scale map shows more detail but less area; therefore, an urban planner might choose a 1:600-scale map that shows power and water lines, house lots, streets, etc. A small-scale map, on the other hand, shows less detail but encompasses a wider area. A geologist who is interested in the general geologic history of Oregon might choose a 1:500,000-scale geologic map of the state that shows major rock formations and geologic features. An exploration geologist looking for gold, however, would prefer a larger scale, such as 1:24,000, that would enable him or her to see more precisely the location of specific rock units or structures on the ground.

Large-scale topographic maps (see section titled "Types of Maps") of 1:24,000 show natural and manmade features such as important buildings, campgrounds, caves, ski lifts, watermills, bridges, and private roads. Intermediate-scale topographic maps scaled 1:50,000 and 1:100,000 usually omit these

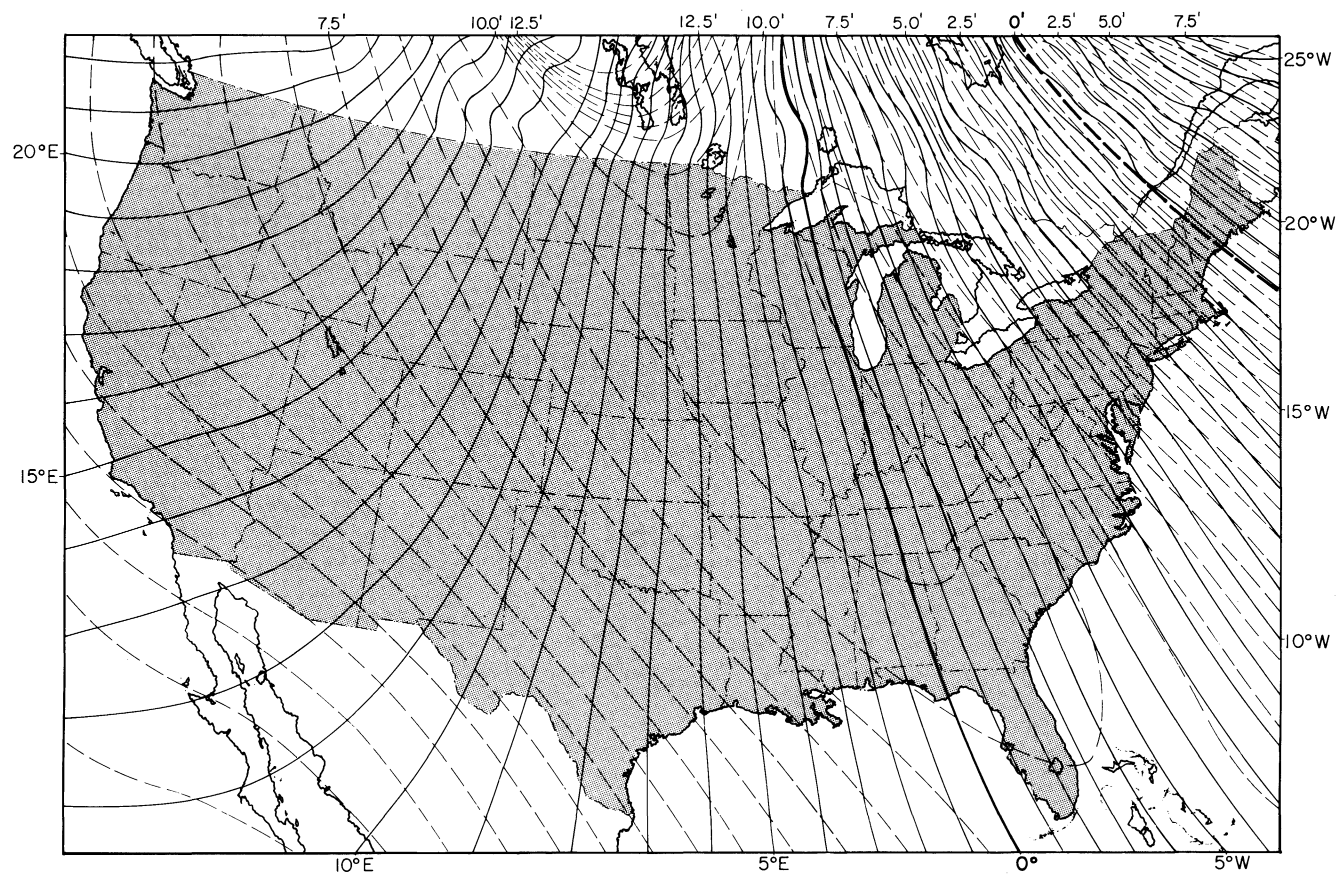

Figure 2. Magnetic declination, also known as compass variation, is the angle between true (geographic) north and the direction in which the magnetic compass points (magnetic north). Its value at the beginning of 1980 is indicated in this chart by isogonic lines, or lines of equal declination. Values along the top of the chart refer to dashed lines. Values along the sides and bottom of the chart refer to solid lines. Solid lines indicate the number of degrees between magnetic north and true north, with magnetic north east of true north at locations that are west of the 0° line (labeled on the bottom of the chart) and west of true north for locations that are east of the 0° line. Dashed lines indicate change in minutes per year in the direction of magnetic north, with change to more eastward direction east of 0° line (labeled on the top of the chart) and change to more westward direction west of 0° line. From Fabiano and Peddie, 1980.

features. Small-scale topographic maps of scale 1:250,000 and smaller (i.e., scales with a larger denominator) show only major features such as national and State parks, Indian reservations, airports, major roads, and railroads (U.S. Geological Survey, 1981b).

COORDINATE SYSTEMS

"Finding oneself" is not easy in this world, whether it be in the psychological or geographical sphere. Ever since the first map was compiled, cartographers have searched for an accurate system to locate points on the globe. Some map users, such as navigators, need a means to track their progress across oceans; others, such as land owners and government officials, need a method to establish property lines; still others, such as geologists, need a way to identify localities of outcrops, minerals, etc., so that future researchers can find and study them.

In the United States, three coordinate systems are generally used: (1) geographic coordinates (latitude and longitude); (2) Public Land Survey (PLS), also called the "Land Office Grid" or "township and range"; and (3) Universal Transverse Mercator (UTM) grid. A fourth system—State Plane Coordinates—is used extensively by state and local governments, in large-scale mapping, and in engineering and property surveys. Each of these systems is explained in the sections that follow.

LATITUDE AND LONGITUDE

Cartographers have arbitrarily divided the Earth's surface into a system of reference coordinates that are termed "latitude" and "longitude" and are based on a series of imaginary lines called "parallels" and "meridians," respectively, drawn on the surface.

If one imagines Earth as a globe with an axis through the North and South Poles, the meridians of longitude would be circles around the globe that pass through both poles. A meridian is labeled according to its distance, measured in degrees, east or west of the zero meridian, which was established in 1884 by international agreement as the meridian that passes through Greenwich, England, near London. Before this time, many countries used meridians that passed through their own capital cities as the 0° meridian for their own maps (Chamberlain, 1950). The zero meridian is also called the "Greenwich" or "prime" meridian. Because the globe encompasses 360°, the 180° west meridian (long 180° W.) and the 180° east meridian (long 180° E.) represent the same imaginary line known as the "International Date Line." Although this line mostly follows the 180° meridian, there is some variation to prevent separating land masses, such as the Aleutian Islands, into time zones with different days.

Midway between the North and South Poles, the Equator, an imaginary line that circles Earth, divides it in half into the Northern and Southern Hemispheres. Imaginary lines drawn concentrically around the poles and parallel to the Equator are called "parallels of latitude." They are labeled according to their distances, measured in degrees, north and south of the Equator. The Equator is 0° latitude (lat 0°), the North Pole is 90° north latitude (lat 90° N.), and the South Pole is 90° south latitude (lat 90° S.). Parallels of latitude, as their name states, always parallel each other; meridians of longitude, however, converge at the poles.

Each degree used to measure latitude and longitude may be divided for more precise location into 60 minutes, represented by the minute symbol ('). Each minute, in turn, may be subdivided into 60 seconds, identified by the second symbol ("). For example, the coordinates of the Portland office of the Oregon Department of Geology and Mineral Industries are lat 45°30'50" N., long 122°40'43" W.

Because the circumference of the Earth is about 24,900 statute (land) miles (21,600 nautical miles), each degree of latitude measures about 69.2 statute miles (60 nautical mi), each minute measures about 1.15 statue miles (1 nautical mi), and each second measures about 101 ft (Chamberlain, 1950). Distances represented by degrees of longitude vary depending upon the latitude. At both the North and South Poles, for example, one could walk through 360° of longitude by walking in a circle around the pole. At the Equator, such a walk would be a considerable undertaking, indeed! At the latitude of Portland, one second of latitude equals 71 ft. One second of longitude equals the same as at the Equator—101 ft.

Time zones are related to meridians because of Earth's rotation. A full rotation of Earth on its axis (360° of longitude) takes 24 hours, 15° of longitude takes one hour, and 1° takes four minutes.

The latitude-and-longitude system of coordinates is used worldwide. Similar systems have been extrapolated for use in space. Of the three systems discussed in this article, this is the only one that can be determined astronomically and without a map (Merrill, 1986a).

Meridians always run in a true north-south direction. True north, however, is not the same as magnetic north (the direction that the needle in a magnetic compass points), except on the meridian that passes through the magnetic North Pole (Zumberge and Rutford, 1983). This is because of polar wandering; the geomagnetic axis does not coincide with Earth's axis of rotation. The magnetic North Pole is actually at about lat 70° N., which is about 1,250 mi from the geographic (true) North Pole (Strahler, 1981).

The angle in any given location between true north and magnetic north is called the "magnetic" or "compass declination." Declination records have been kept in Paris and London since about 1600 (Strahler, 1981). Local declination and its annual variation are usually shown in the lower margin of most maps published by the USGS. The correction for annual change, however, will be only approximate if the map is more than 20 years old (Compton, 1962). Declination can also be determined from an isogonic chart (Figure 2) or by setting a compass on a level surface and sighting on Polaris, the North Star (Compton, 1962). In Portland, the magnetic declination is 19.64° E., based on the International Geomagnetic Reference Field (Shaul Levi, Geophysics Group, College of Oceanography, Oregon State University, personal communication, 1989).

PUBLIC LAND SURVEY SYSTEM

The Public Land Survey System was instituted in 1785 by the Continental Congress from the recommendation of Thomas Jefferson. The system was instituted to get away from the metes and bounds surveys along creeks, stone walls, and ridges that characterized the surveys of the 13 colonies. The Public Land Survey System is the legal method of describing land in all states except the original colonies and Texas. A Spanish system is used in Texas.

Township and range designations are used to locate property boundaries and describe land areas. The basic unit, called a "section," is a square-shaped area 1 mi long and 1 mi wide. One standard section contains 640 acres. A standard township is 6 mi on each side and contains 36 sections, or 23,040 acres. When the sections and townships were surveyed, each section was intended to encompass an exact square mile of land. Surveying errors, however, created irregularities in the shapes of many sections and townships in the United States (Zumberge and Rutford, 1983).

Township-range divisions are based on a grid of perpendicular lines. Township lines are numbered every 6 mi north and south from an initial point. Range lines are numbered every 6 mi east and west from the initial point. Instead of the Equator and zero meridian, reference lines for township designations are specific east/west and north/south lines called the "base line" and "principal meridian," respectively (Zumberge and Rutford, 1983). A township is located by giving its position north or south of the base line and east or west of the principal meridian. The notation "T. 4 S., R. 2 W." indicates township four south, range two west. Many base lines and principal meridians are used in the United States, so township and range coordinates are never very large. In Oregon and Washington, the townships are measured from the Willamette Base Line (about lat 45°31'11" N.) and Willamette Principal Meridian (about long 122°44'34" W.), which originate at the Willamette Stone in the West Hills of Portland (see USGS Portland, Oreg.-

Wash., 7½-minute series [topographic] map). Southeast Stark Street in Portland follows the Willamette Base Line. West of Portland, the Willamette Base Line goes through Hillsboro as SE Baseline Street.

As with degrees of latitude and longitude, sections may be further divided to locate features more precisely: into halves (e.g., the north half [N½] or east half [E½] and then into quarters (e.g., the northwest one-quarter [NW¼] or southeast one-quarter [SE¼]). Quarter sections, in turn, may be subdivided into halves or quarters. In Figure 3, the 40 acres shown in the extreme southeast corner of section 24 are designated by this notation: SE¼SE¼ sec. 24, T. 1 S., R. 2 W. Property and land exchanges are often described in these terms.

Because the township, range, and section coordinate system is a flat grid made of perpendicular lines in 1-mi segments, there has to be something built into the grid to make it fit over the curved surface of the earth. Correction meridians and parallels are established every four townships (24 mi) from the initial point. These Guide Meridians and Standard Parallels adjust the alignment of the north-south lines to correct for the convergence of the lines toward the pole. Imagine two lines, 6 mi apart, running true north for 24 mi. In 24 mi, these two lines will be 5.96 mi apart because of convergence. At the 24-mi mark along the principal meridian, a standard parallel is established. The township lines are readjusted from 5.96 to 6 mi apart, and another 24-mi block is surveyed north from the standard parallel.

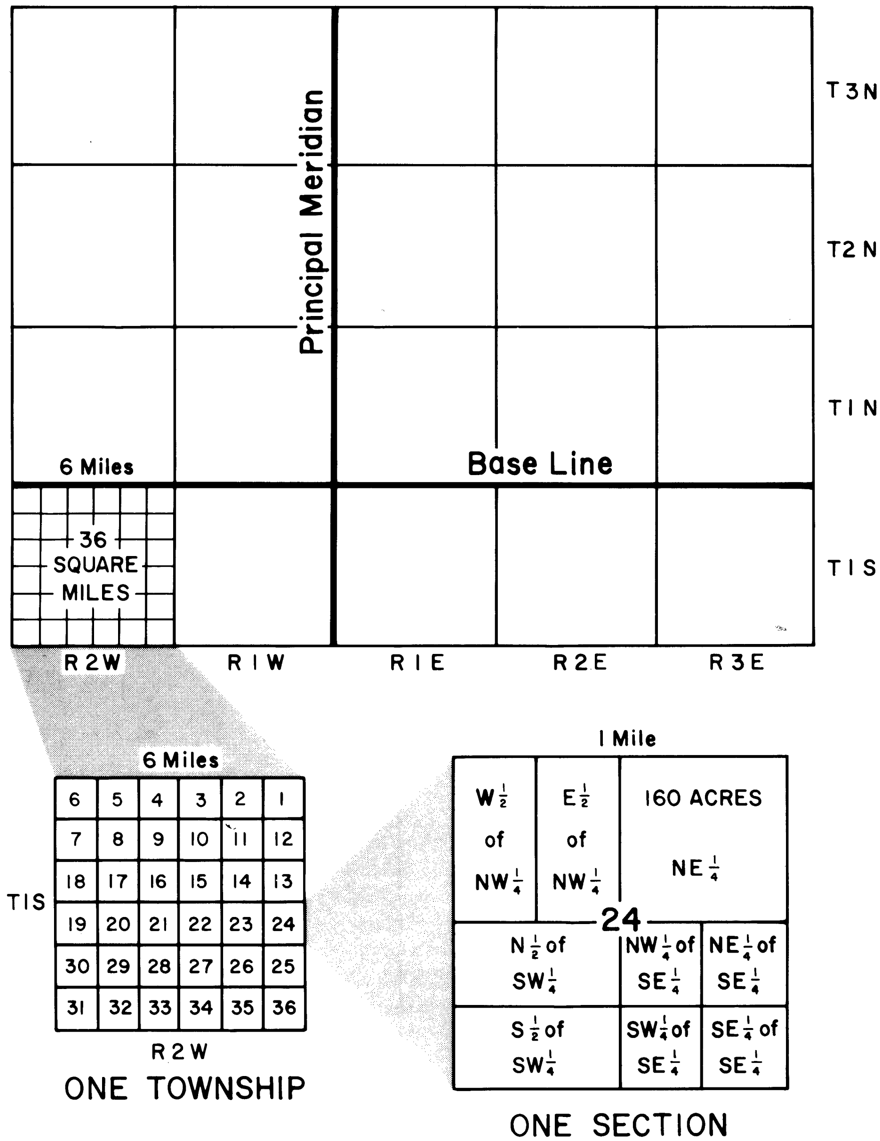

Figure 3. Township and range land divisions used in the United States and some parts of Canada. From Zumberge and Rutford, 1983.

UTM GRID

The Universal Transverse Mercator (UTM) grid was adopted by the U.S. Army in 1947 to assign rectangular coordinates on military maps of the world (Snyder, 1987). Although the original UTM grid used only numerals as coordinates, the U.S. Army simplified it by substituting letters for several numbers. In military parlance, the UTM is called the "Military Grid System." In scientific jargon, it is simply called the "UTM" (U.S. Department of the Army, 1969, 1983; Hines, 1986; Merrill, 1986b).

The UTM divides Earth from west to east into 60 numbered zones, each of which encompasses 6° of longitude. Beginning at the 180° meridian (the International Date Line), zones are numbered 1 to 60 consecutively from west to east (Merrill, 1986a). For example, zone 1 extends from long 180° W. to long 174° W. From south to north, the UTM divides Earth into 20 lettered subzones, each of which encompasses 8° of latitude, except for zone X, which extends 12° (Merrill, 1986a; Snyder, 1987). These zones are lettered C to X consecutively from south to north. (The letters I and O are not used to avoid confusing them with numbers.) Numbered and lettered grid zones extend only from lat 80° S. to lat 84° N. The polar regions beyond these parallels are assigned coordinates on the Universal Polar Stereographic (UPS) grid (Snyder, 1987), which will not be discussed in this article. The State of Oregon lies in UTM grid zones 10T and 11T, which cover a rectangular area from long 126° W. to 114° W. and from lat 40° N. to 48° N.

Each grid zone may be further divided into grid squares that measure 100,000 meters (m) (109,361 yards [yd]) on a side; these are given double-letter designations. In turn, grid squares may be subdivided with finer numerical grids that enable one to locate an area 10 m by 10 m (11 yd by 11 yd) on most current maps (Merrill, 1986a).

The USGS began adding UTM grid lines to its 7½-minute quadrangle maps in 1957. Most 15-minute quadrangle maps do not include them. State base maps, new maps, and reprinted quadrangle maps, however, include UTM grid lines or tick marks (Merrill, 1986a). The UTM grid is significant to digital cartography in that it is widely used to encode map data for eventual computer handling.

STATE PLANE COORDINATE SYSTEM

The National Geodetic Survey, in coordination with each state legislature, has designed and mandated a projection system that will "fit" each state with a minimum of distortion. Property and engineering surveys are required by state law to show the State Plane Coordinates of the monuments and control points on the plats and maps. Most states are too large for one projection to cover the entire state without exceeding the distortion lines. When a state is divided into two or more State Plane Coordinate projection zones, the boundaries of the zones are divided along county boundaries. This is so that a county survey will always be in only one zone. The State Plane Coordinate system is designed so that there can be some overlap from one zone to another without exceeding the accuracy standards of the zone in which most of the survey is taking place.

Oregon's State Plane Coordinate System is based on the Lambert Projection with two zones, a North Zone and a South Zone. This projection was chosen because Oregon is wider in an east-west direction and the Lambert Projection "fits" better in an east-west direction with minimum distortion. Idaho has a system based on the Transverse Mercator Projection because the state is longer in a north-south direction. Idaho has three zones: East, Central, and West.

USGS 7½-minute quadrangle maps show the State Plane Coordinate System ticks every 10,000 ft in black along the edges of the quadrangle. Ticks with complete numbers are located on the southwest and northeast corners of USGS maps. Other tick marks along the edge are unnumbered. Quadrangles with more than one state will identify each of the state's plane coordinate zone ticks.

In an unending quest for perfect accuracy, scientists continue to develop new location systems or modify old ones and debate the usefulness, precision, and accuracy of each (Hines, 1986; Merrill, 1986a,b, 1987; Nelson, 1987).

MAP PROJECTIONS

Earth is a sphere, actually a spheroid because it bulges slightly at the Equator and flattens at the poles. The most accurate map of Earth is a globe because, on it, scale is constant, and geographical relationships are true. Since a globe is cumbersome and impractical on a large scale, cartographers have developed ways to convert the three-dimensional spherical image to a two-dimensional flat image. A map projection is a systematic method of transferring the grid system of parallels and meridians from globe to paper using mathematical calculations to alleviate distortion (Chamberlain, 1950).

As the word "projection" implies, areas of the globe are projected onto another surface and then transferred to paper. This intermediate surface can be a cylinder, cone, or plane. The shape of the surface, the line of contact or point of tangency between the surface and the globe, and the point on Earth that is chosen as the center or starting point determine the type of the projection (Figures 4 and 5).

There is no best projection to portray the world. A cartographer determines which projection to use based on the characteristics deemed most important, such as area, shape, scale, or direction. Hundreds of projections have been developed throughout the history of cartography, but only a few dozen are used to produce most of today's maps. Some of the more common or useful projections are briefly described below. Snyder (1987) has written an excellent book on projections that includes both historical and descriptive text for the layperson and mathematical calculations for the professional cartographer.

CYLINDERS

Perhaps the best known and most easily drawn projection was developed by the Flemish cartographer Gerardus Mercator (1512-1594). The Mercator projection is drawn by wrapping a cylinder around the globe, with both surfaces touching along the Equator; meridians are then projected from the center of the globe (Snyder, 1987; Figures 4a and 5a). Mercator developed this projection to aid navigation. This is the only projection on which all points are shown at their true compass courses from one another; if a ship's direction remains constant with respect to north, the sailing route between two points is a straight line. Since 1910, this has been the standard projection used on the nautical charts of the U.S. Coast and Geodetic Survey, now called the National Ocean Service (Snyder, 1987). Areas in the polar regions, however, are greatly distorted with this projection. Greenland appears to be larger than South America, yet it is only one-eighth the size of the continent (Snyder, 1987; Figure 5a). Because most world maps in elementary and high school textbooks are drawn with the Mercator projection, students could be confused about relative sizes of land masses. This projection is best used on maps of equatorial regions and has been used to map those areas on Earth, Mars, Mercury, Venus, the Moon, and the satellites of Jupiter and Saturn (Snyder, 1987).

Variations of the Mercator projection have been developed to handle special cartographic needs. In the Transverse Mercator projection, the cylinder and globe touch along a meridian instead of along the Equator (Figures 4b and 5b). Areas along the central meridian remain true to scale, no matter how far north or south of the Equator they are. This projection is used for areas in which the north-south dimension is greater than the east-west dimension. It is also the base for the USGS 1:250,000-scale maps (1° x 2° quadrangles) and some 7½- and 15-minute quadrangles (Snyder, 1987). In the Oblique Mercator projection, the cylinder touches the globe along a circle path specifically chosen to alleviate distortion in the mapped areas (Figures 4c and 5c). The USGS has further modified this to obtain the Space Oblique Mercator projection, which is used for continuous mapping of Landsat satellite images (Snyder, 1987).

CONES

Cylindrical projections are used mostly for maps of the world or narrow areas along the Equator, a meridian, or an oblique circle. Conic projections, on the other hand, are used to map areas in the middle latitudes that extend in mostly an east-west direction.

A regular conic projection is drawn by setting a cone on top of the globe, with the cone apex and globe axis aligned. The cone and globe touch along a specific latitude (standard parallel). Meridians are drawn from the apex to points at which corresponding meridians on

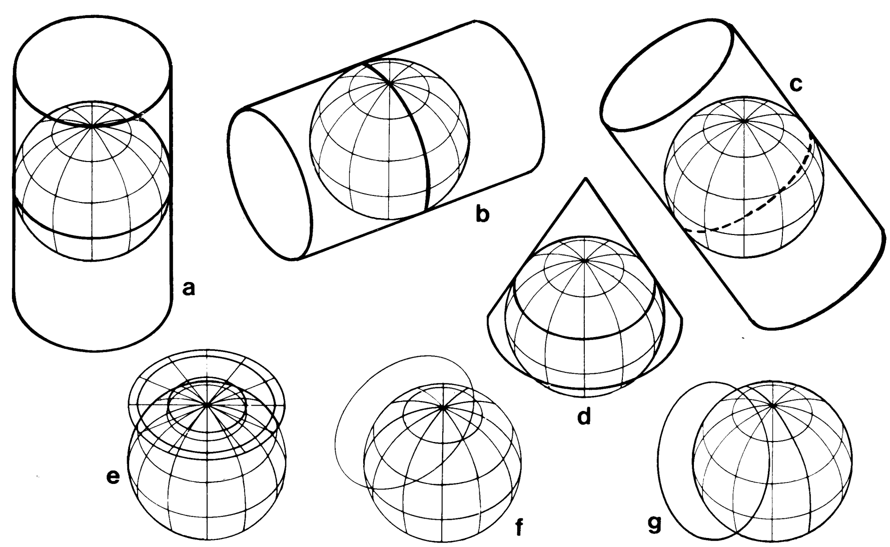

Figure 4. Projection of the globe onto three surfaces: (a) regular cylindrical (surfaces touch along Equator); (b) transverse cylindrical (surfaces touch along meridian); (c) oblique cylindrical (surfaces touch along circle path); (d) regular conic (surfaces touch along parallel); (e) planar or azimuthal, polar aspect (surfaces touch at pole); (f) planar or azimuthal, oblique aspect (surfaces touch at point between pole and Equator); and (g) planar or azimuthal, equatorial aspect (surfaces touch at Equator). From Snyder, 1987.

the globe intersect the standard parallel (Figure 4d). The cone is then cut along one meridian and unrolled (Snyder, 1987).

The simplest conic projection is the Equidistant or Simple Conic, which shows true scale along all meridians and one or two standard parallels (Figure 5d). It is the basic form developed about 150 A.D. by the Greek astronomer and geographer Claudius Ptolemy. This projection is the one most often used in atlases for maps of small countries (Snyder, 1987).

Variations of the simple conic projection include the Polyconic, which is mathematically based on an infinite number of cones tangent to an infinite number of parallels (Snyder, 1987). This projection was developed by Swiss-born Ferdinand Rudolph Hassler (1770-1843), who became first superintendent of the U.S. Coast Survey, precursor of the U.S. Coast and Geodetic Survey. Because of Hassler's promotion, the Polyconic projection was used on large-scale maps of the United States, such as USGS 7½- and 15-minute topographic quadrangles, until the 1950's. Quadrangle maps drawn with the Polyconic projection at the same scale and based on the same central meridian will fit exactly from north to south or east to west; however, they cannot be mosaicked in both directions without distortion (Snyder, 1987).

The Lambert Conformal Conic projection was developed by the Alsatian mathematician and cartographer Johann Heinrich Lambert (1728-1777). On this projection, local shapes, scale, and angles remain accurate, but area does not. It is used for mapping large countries and smaller regions with an east-west orientation such as the United States, North Carolina, Long Island, and Oregon (Snyder, 1987). It has been used on USGS 7½-minute quadrangle maps of Oregon prepared since the 1960's and is also the projection used for the USGS 1:500,000-scale State base-map series.

PLANES

Azimuthal (or zenithal) projections are drawn on a plane that touches the globe at one of the poles, the Equator, or some point between these. The center of the projection determines its aspect: polar, equatorial, or oblique (Figures 4e,f,g; 5e,f,g). The direction or azimuth from the center to every other point of the map is shown accurately. Because this projection has one standard point or center, it is used mostly to portray circular regions such as Antarctica, rather than areas that extend mostly in one direction (Snyder, 1987). On polar aspects, meridians are shown as straight lines that radiate at true angles from the center (pole), like the spokes on a wheel; the latitude lines appear as concentric circles around the pole (Figure 5e).

Except for the polar aspect, azimuthal projections are more difficult to draw than the cylindrical or conic versions. Azimuthal projections, however, portray Earth's roundness and unity, features that are less apparent in the other two projections.

The Stereographic projection is the most widely used azimuthal projection. Hipparchus, the Greek astronomer and the father of trigonometry (2nd century B.C.), is credited with its invention, although it was probably known already to the Egyptians. The Stereographic projection was used only for maps of the heavens until the early 1500's (Snyder, 1987). This projection can depict only one hemisphere at a time. Its polar aspect is used extensively for maps of Antarctica and the polar regions of other planets and satellites (Figure 5e).

The Orthographic projection is probably the best known of the azimuthal projections. Because the perspective is from an infinite distance, maps drawn with this projection appear as they would from outer space, with a three-dimensional effect (Figure 5f). Its development, too, is credited to Hipparchus, who used it for astronomical calculations. The Orthographic projection became popular during World War II, as world leaders tried to emphasize the global aspects of the conflict (Snyder, 1987). It is seldom used in atlases today, except for pictorial views of the globe, because only one hemisphere can be shown at one time, and distortion near the outer edges is severe.

The Azimuthal Equidistant projection shows distances and directions correctly from one point (point of tangency) on Earth's surface and any other point on the map (Figure 5g). Maps based on this projection usually show less than one hemisphere. The Egyptians probably used the polar aspect for star charts. Navigators have used it to chart coastlines based on distances and directions obtained at sea. This projection is used today in maps of the polar regions and continents and in world maps for radio and seismic use. The polar aspect is also used as the emblem of the United Nations.

REMOTE SENSING

Before the invention of the airplane, mapmaking was a down-to-earth profession based on observations made on land or sea. With the advent of aviation, cameras could record what only birds and balloonists had seen previously. Remote-sensing techniques, such as aerial photography and satellite imagery, are used by scientists, engineers, and cartographers to determine land features, to study seasonal changes in vegetation and wildlife habitats, and to evaluate damage caused by geologic hazards such as floods, landslides, and active volcanoes.

Vegetational differences are reflected in the shades and patterns that appear in black-and-white aerial photographs. Heavy vegetation such as forests are medium to dark

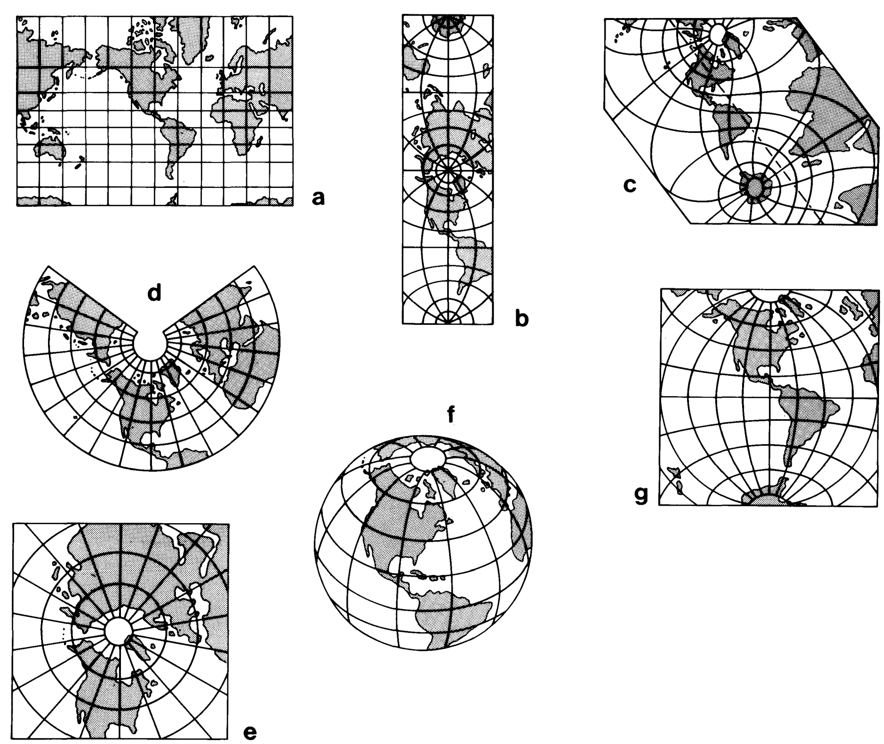

Figure 5. Selected map projections: (a) Mercator (regular cylindrical); (b) Transverse Mercator (transverse cylindrical); (c) Oblique Mercator (oblique cylindrical); (d) Simple Conic (regular conic); (e) Stereographic (planar or azimuthal, polar aspect); (f) Orthographic (planar or azimuthal, polar aspect); and (g) Azimuthal Equidistant (planar or azimuthal, equatorial aspect). From Snyder, 1987.

gray in color, whereas grasslands are light gray. Cultivated fields are usually rectangular in shape. Shades also give clues to soil and rock type. Clays that retain moisture, for example, appear darker than dry sand. Because the type of vegetation commonly reflects the bedrock on which it grows, vegetational variations can also be used to determine rock type (Zumberge and Rutford, 1983).

Photointerpretation can be enhanced by viewing aerial photos stereoscopically. Two photos of the same area taken from slightly different positions can be overlapped through the use of a stereoscope to show the relief of the land. Each eye sees only one of the photos, but the brain combines the two images to produce a three-dimensional view (Zumberge and Rutford, 1983).

False-color images are created by satellites that record infrared radiation from Earth. The measured differences are computer-enhanced to produce a picture in which the colors are not true to life; for example, green vegetation may show as red, and water may appear black (Zumberge and Rutford, 1983). Color variations result from differences in vegetation, soil, moisture, and rock types. False-color images created by Earth Resource Technology Satellites (Landsat) are byproducts of the U.S. space program. Each Landsat satellite circles the globe 14 times a day, scans a particular area of Earth more than 40 times a year, and creates images, each of which covers 115 mi^2 (U.S. Geological Survey, 1981a). The frequency and amount of coverage make satellite imagery especially useful in studying Earth's surface. Satellite images, however, cannot show the detail that aerial photographs can because they are taken farther from Earth's surface and thus, at a smaller scale. Because the satellites pass over the same point every nine days, comparative studies can be conducted on such topics as vegetation or human habitation.

TYPES OF MAPS

A map is a graphic representation of part of Earth's surface. Some types, such as road maps, show the distribution of features and manmade structures in two-dimensional form. Other types, such as topographic maps, illustrate the three-dimensional nature of Earth's features on a two-dimensional surface. Because geologic structures are three-dimensional, the latter type of map is more useful to geologists.

There are basically four types of maps: planimetric, topographic, thematic, and photoimage maps (U.S. Geological Survey, undated[b]). Planimetric maps show natural features, such as rivers and lakes, and cultural features, such as roads, railroads, towns, and land boundaries, but do not show relief features, such as hills or valleys. The latter may be labeled, however. A land map is a planimetric map. Topographic maps show both features and surface elevations. Photoimage maps, such as the orthophotoquads and orthophotomaps, are derived from aerial photographs that have been corrected to eliminate distortions due to perspective or camera tilt. These maps are related to standard coordinate systems but show photographic details that do not usually appear on conventional maps. Thematic maps show information about a specific theme or topic such as geology, rainfall, population, soil (pedology), or vegetation. Thematic maps include geologic maps, which show the position, structure, and composition of rock units and surficial materials and the nature of boundaries between rock types, such as faults and depositional contacts; geophysical maps, which show variations in the geophysical properties, such as gravity or magnetism (Figure 2); hydrologic maps, which show information about water resources; pedologic maps, which show distribution and character of soils,; and land-use maps, which indicate the areas that are used for agricultural, recreational, wilderness, urban, or other purposes (U.S. Geological Survey, undated[b]).

Because of their usefulness to the professional geologist and because they are often confused by the layperson, topographic and geologic maps are described in the following sections.

TOPOGRAPHIC MAPS

Every geologic process leaves a mark on Earth's surface. Wind and water erosion, glaciation, and volcanism leave their respective signatures as characteristic landforms. Unlike other maps, a topographic map shows these three-dimensional imprints, as well as cultural features. Relief (mountains, hills, valleys, and plains), bodies of water (lakes, ponds, rivers, canals, and swamps) and cultural features (roads, railroads, towns, land boundaries, etc.) are depicted on topographic maps.

On a topographic map, relief is shown through the use of contour lines, imaginary lines on Earth's surface that connect points of equal elevation above or below sea level (Figure 6a). A contour interval, the difference in elevation between two adjacent contour lines, is generally a constant value chosen according to the ground slope and map scale. Two contour intervals may be shown on a single map to show relief features more precisely. Contour intervals on different maps may range from 5 to 1,000 ft (Zumberge and Rutford, 1983). Widely spaced contours indicate flat areas or areas with a gentle slope, while closely spaced contours indicate steep terrain such as mountains or cliffs. When contour lines cross stream-filled valleys or canyons that are shown on a map, they bend upstream; the contour resembles the letter "V" with the apex pointing upstream (Zumberge and Rutford, 1983). Index contours, on which elevations are labeled, are usually every fifth contour line and are drawn with heavier lines than other contours. Spot elevations may be given for specific locations such as mountain summits, road intersections, or lakes. Bench marks indicate points at which the land elevations have been precisely determined by surveying techniques and are marked by brass plates that are permanently fixed in the ground. These can be found on the tops of remote mountains as well as on the sidewalks of major cities. Each bench mark is shown on a topographic map by the letters "BM," followed by a cross and the measured elevation.

A shaded relief map is darkened to simulate the effect that sunlight and shadow would have on terrain. The pattern of light and dark accentuates the shape of physical features and creates a three-dimensional effect. Slope maps create this same effect through the use of different colors and color shades to indicate steepness and slope (U.S. Geological Survey, undated[b]).

A topographic map covers a specific quadrangle, an area that is outlined by parallels of latitude (the northern and southern boundaries of the map) and meridians of longitude (the eastern and western boundaries of the map). Standard quadrangle maps are bounded by 7½ minutes each of latitude and longitude (7½-minute quadrangle), by 15 minutes each of latitude and longitude (15-minute quadrangle), by 30 minutes of longitude and 60 minutes of latitude (30-by-60-minute quadrangle), or by 1° of latitude and 2° of longitude (1° by 2° quadrangle; Table 1). The USGS has been producing standard topographic maps for 7½- and 15-minute quadrangles in the United States since the 1880's. Although the actual area shown on a quadrangle map is a trapezoid, the map appears to be rectangular because the meridians converge toward the pole by such a small amount for each map that the eye has trouble detecting the difference.

Government agencies and private industries use topographic maps as bases for more specialized maps, such as geologic, land-use, soil, and road maps. Specialized data are superimposed directly on the topographic base sheet. Topographic maps are also used by planning agencies to aid in selecting sites for highways, airports, industrial plants, pipelines, powerlines, communication facilities, and recreational areas (U.S. Geological Survey, 1983). These maps are especially important in assessing and managing natural resources. They can also serve as practical guides for any camping, hiking, fishing, or hunting trip.

GEOLOGIC MAPS

Just as a person's face may reflect his or her character, the face of Earth may reveal what lies beneath its surface. A geologic map shows how Earth would appear if materials, such as vegetation, were stripped away (U.S. Geological Survey, 1982). These maps use standard symbols, patterns, and colors to depict the types and relative ages of rocks and surficial materials and the surface and subsurface associations or rock units (Figure 6b).

A geologic map is not easy to create. It requires countless hours of fieldwork, keen observation skills, an ability to think three-dimensionally, and at times, X-ray vision. The first step includes studying areas where rocks are visible and can be identified in outcrops, such as ledges, fault scarps, and streambanks, or in excavations, such as roadcuts, mines, and wells. In areas where the bedrock is covered, geologists may be able to infer the underlying rocks by studying surficial materials, vegetation, landforms, and regional structure. Techniques for determining age are unique to each rock type. The age of each rock or surficial unit is identified from fossils or bits of other rocks included within it, from radiometric dating, or from its position relative to other units. (Barring an episode of geologic upheaval, a sedimentary or volcanic rock unit is always younger than the one below it, a natural law that geologists call the "law of superposition.") Geologists also study aerial photographs and preexisting maps to fill in missing data and to corroborate field observations (U.S. Geological Survey, 1982).

The geologist records the locations, types, and ages of the rock units and surficial materials by using various colors or patterns on a topographic base map. Standard patterns have been adopted to distinguish among rock types. The basic rock units shown on a geologic map are called "formations." A formation is usually named after a geographic feature (mountain, canyon, town, etc.) near the area where the unit was first identified and/or described. Using special symbols, the geologist records other significant observations on the map such as faults, folds, contacts between rock units, and the strike and dip of formations (respectively, the direction of a horizontal line within a unit and the angle that the unit slopes in outcrop).

The reliability of a geologic map depends on the number of observations made in the field and the competence of the geologist. If there are few outcrops, little contrast between rock types, and a history of complicated geologic events, geologists can produce many plausible interpretations and make several credible geologic maps of the same area (U.S. Geological Survey, 1982).

Geologic maps can be used to locate mineral or energy deposits because specific rock types or structures (e.g., faults) are often associated with specific deposits. They can also be used to locate sources of ground water or construction materials (sand and gravel, flagstone, etc.), to determine the suitability of areas for agriculture or urban development, or to identify potential geological hazards. Geologic maps provide an enormous amount of information needed for deciphering Earth's long and complex geologic history.

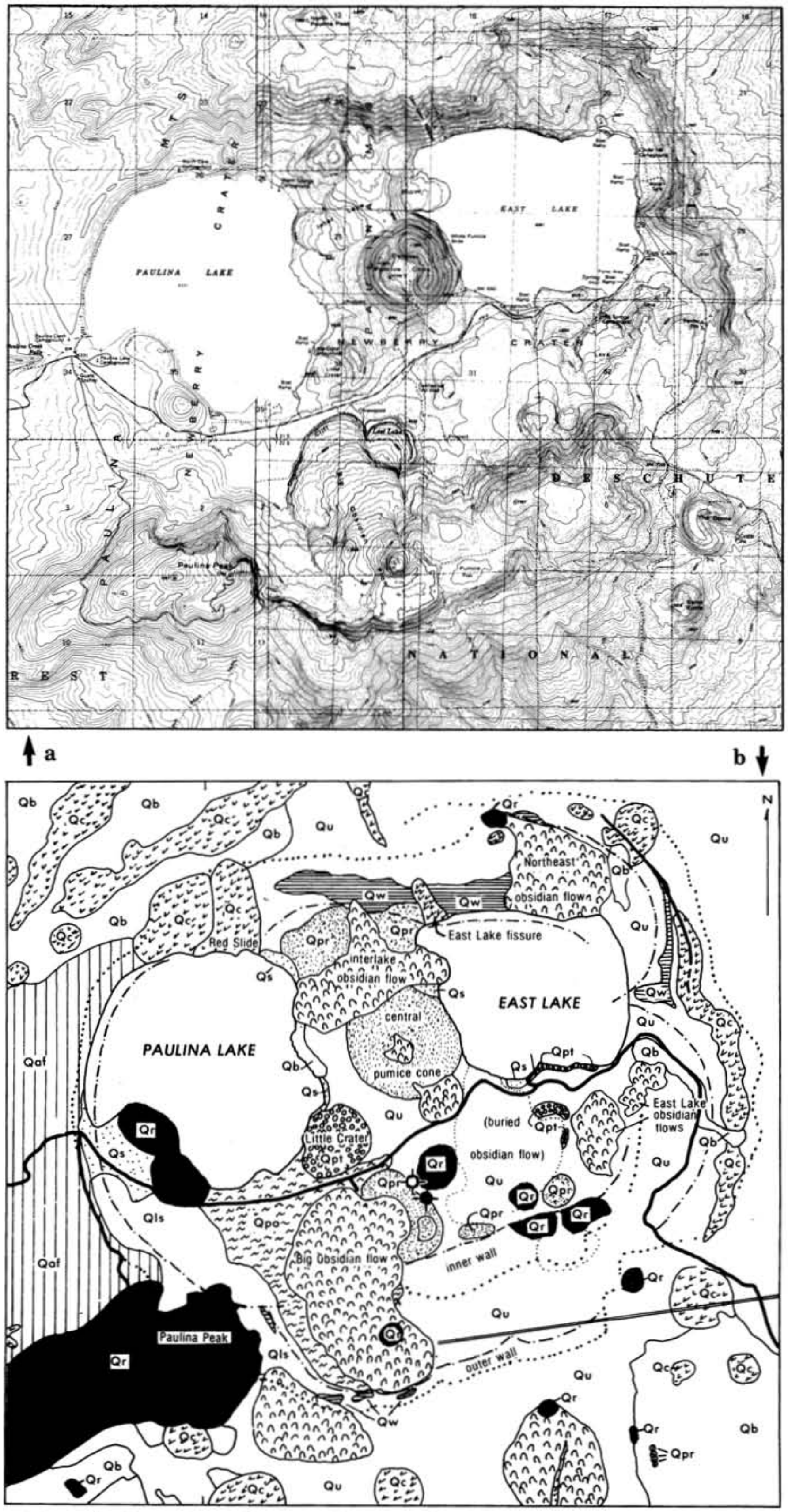

Figure 6. Comparison of topographic (a) and geologic (b) maps drawn at the same scale for the same region, the Newberry caldera in central Oregon. Note contour lines in (a) that indicate topographic relief and patterns in (b) that symbolize rock types.

WHERE TO OBTAIN MAPS

(Single copies of a limited number of brochures describing Oregon maps and aerial photography are available at no cost from the Portland office of the Oregon Department of Geology and Mineral Industries [see address and phone number on the inside front cover]. Produced in 1988 by the Oregon Mapping Committee of the State Map Advisory Council, the brochure is entitled "Oregon: Maps and Aerial Photography Information Guide," and it is a comprehensive listing of State, Federal, regional, and local map- and aerial photography-producing agencies in Oregon. The guide provides complete information on where to obtain the full range of maps available in Oregon. Most of the information about Oregon maps and aerial photographs presented below is taken from this brochure; the rest of the information is from the author of the original paper.—*Editor*)

Table 1. *Map scales and corresponding areas on the ground. From U.S. Geological Survey, 1981b*

Scale	One inch on map represents	One centimeter on map represents	Standard quadrangle size (lat x long)	Quadrangle area (square miles)
1:24,000	2,000 feet	240 meters	7½ x 7½ minute	49 to 70
1:62,500	nearly 1 mile	625 meters	15 x 15 minute	197 to 282
1:250,000	nearly 4 miles	2½ kilometers	1° x 2° or 1° x 3°*	4,580 to 8,669
1:1,000,000	nearly 16 miles	10 kilometers	4° x 6°	73,734 to 102,759

* 1° x 3° is the standard size for quadrangle maps of Alaska.

An excellent source of information for map users is the book *Maps for America* (Thompson, 1987), published as a special volume by the USGS. This book presents the story of maps and mapping with the aim to provide a basis for an understanding of map content. The richly illustrated book originally commemorated the Survey's 100th anniversary in 1979 and is now available in its expanded, third edition from the Government Printing Office and its bookstores at a price of $25.

The Earth Science Information Center (ESIC) of the USGS provides a nationwide information service for cartographic data of the United States, including maps, charts, aerial photographs, satellite images, and map data in digital form obtained by more than 30 Federal agencies. For information on Oregon, contact either the headquarters (Earth Science Information Center, U.S. Geological Survey, 507 National Center, Reston, VA 22092, phone 1-800 USA MAPS) or the Western Branch Office (Western Mapping Center-ESIC, U.S. Geological Survey, Mail Stop 532, 345 Middlefield Road, Menlo Park, CA 94025, phone [415] 329-4309).

The USGS has placed on microfilm virtually all of the topographic maps of the United States that it has published since 1884. These are available from the ESIC offices. Printed versions of USGS maps of Oregon (topographic, geologic, land-use, etc.) may be obtained from the Western Distribution Branch, Box 25286, Federal Center, Bldg. 41, Denver, CO 80225, phone (303) 236-7477.

Aerial photographs and Landsat images may be obtained from the USGS ESIC Menlo Park, California, office or the USGS Earth Resources Observation System (EROS) Data Center. Contact User Services Section, EROS Data Center, Sioux Falls, SD 57198, phone (605) 594-6151.

Another source of aerial photos is the U.S. Department of Agriculture (USDA). The Agricultural Stabilization and Conservation Service (ASCS) maintains an extensive file of aerial photographs. For more information, contact: Aerial Photography Office, ASCS-USDA, 2222 West 2300 South, Post Office Box 30010, Salt Lake City, UT 84130, phone (801) 524-5856. The Soil Conservation Service produces pedologic maps and soil-survey reports, which include aerial photos and describe the geology, properties, and management of soils within the survey area. In Oregon, contact the USDA Soil Conservation Service, Federal Building, 1220 SW Third Avenue, Portland, OR 97204, phone (503) 221-1794.

The USDA Forest Service prepares and distributes recreational, base, regional, and other specialized maps and survey data as well as aerial photos. For information, contact them at P.O. Box 3623, Portland, OR 97208, phone (503) 326-2877 (for recreation maps) and 326-4165 (for special map products).

The U.S. Bureau of Land Management (BLM) compiles and distributes maps that show land status, mineral status, Federal and State lands, and private properties. BLM also maintains land records and provides aerial photographs. For information, contact the Oregon State Office, 825 NE Multnomah St., P.O. Box 2965, Portland, OR 97208, phone (503) 231-6281 for maps and 231-6885 for photos.

The National Ocean Service provides aeronautical and nautical charts that are sold by authorized dealers. Catalogs are available upon request from National Ocean Service, Pacific Marine Center N/MOPX4, 1801 Fairview Avenue East, Seattle, WA 98102, phone (206) 442-7657.

The Oregon Department of Forestry produces maps showing forest protection units and land management and orthophotomaps and township aerial photomaps as well as high-altitude aerial photographs of portions of eastern and western Oregon and low-altitude aerial photographs of State Forest lands. For information, contact Graphic Services, 2600 State Street, Salem, OR 97310, phone (503) 378-2504.

The Oregon Department of Geology and Mineral Industries produces and sells geologic, mineral-resource, geologic-hazard, geothermal, geophysical, rock-resource, and regional oil and gas maps and also sells USGS topographic maps. For the Department's address and phone number, see the inside front cover of this magazine.

The Oregon Historical Society has over 10,000 historical maps of the Pacific Northwest covering exploration, topography, and social development. For information, contact Map Library, 1230 SW Park Avenue, Portland, OR 97205, phone (503) 222-1741. In addition, old maps may be examined in public and university libraries. They may also be obtained from the National Archives (Publication Sales Branch, National Archives, 8th and Pennsylvania Avenue NW, Washington, D.C. 20408) or from the Library of Congress (Geography and Map Division, Library of Congress, Washington, D.C. 20540).

The Oregon Department of Land Conservation and Development has numerous types of planning and land use maps for reference only. For information, contact them at 1175 Court Street NE, Salem, OR 97310, phone (503) 373-0050.

The Oregon State Library has a collection of Federal, State, and private and local agency maps. It also is ESIC affiliate office and a depository for U.S. government maps. These maps are for reference only. For information, contact them at the State Library Building, Salem, OR 97310, phone (503) 378-4368.

The University of Oregon has a large collection of maps from Federal, State, private and local agencies. The library is an ESIC affiliate office and is a depository for U.S. government maps. For information, contact the Map Library, 165 Condon Hall, Eugene, OR 97403, phone (503) 686-3051.

The Oregon Department of Revenue sells assessor's tax maps as well as U.S. Public Land Survey plats and timber ownership and tax district maps. For information, contact the Cartographic Unit, 955 Center St., Salem, OR 97310, phone (503) 378-3381.

The Oregon Division of State Lands supplies public ownership maps. For information, contact them at 1600 State Street, Salem, OR 97310, phone (503) 378-3805.

The Oregon Department of Transportation produces planimetric maps that outline roads, distinguish road surfaces (e.g., paved vs. dirt), and show other cultural features. Contact the Distribution Unit, Transportation Building, Room 17, Salem, OR 97310, phone (503) 378-6255 or 378-6254.

The Oregon Water Resources Department produces and sells drainage basin, land use, ground water, geology, and water-right maps.

For information, contact Oregon Water Resources Department, 3850 Portland Road NE, Salem, OR 97310, phone (503) 378-3671 or 378-3741.

Some private companies distribute maps produced by government agencies or commercial firms. These are generally listed in the Yellow Pages of telephone directories under the general heading "Maps."

In addition, the wide variety of maps produced by the National Geographic Society may be obtained by contacting the Society at P.O. Box 2806, Washington, D.C. 20013.

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Earthquake hazard workshop announced

The fourth annual workshop of the National Earthquake Hazards Reduction Program will be entitled *Earthquake Hazards in the Puget Sound and Portland Areas* and held April 17-19, 1990, at the Seattle Sheraton Hotel.

The Washington State Division of Geology and Earth Resources will conduct the workshop in cooperation with the U.S. Geological Survey and the Federal Emergency Management Agency. Topics will include the geologic and seismologic setting in western Washington and Oregon, site effects, lifelines, structural engineering with emphasis on building retrofit, and loss estimation. A field trip will let the participants inspect buildings undergoing retrofit in downtown Seattle.

A poster session is planned to present highly detailed information on any of the workshop's topics. To volunteer a poster or for more information, contact Timothy Walsh or Stephen P. Palmer at the Washington Division of Geology and Earth Resources, Mail Stop PY-12, Olympia, WA 98504, phone (206) 459-6372, FAX (206) 459-6380.

—Washington Division of Geology and Earth Resources release

***(Reports**, continued from page 26)*

Tyee Basin project yields first report

A comprehensive report entitled *Geology and Oil, Gas, and Coal Resources, Southern Tyee Basin, Southern Coast Range, Oregon*, by A.R. and W.A. Niem of Oregon State University and with major contributions by E.M. Baldwin of the University of Oregon, has been released as DOGAMI Open-File Report O-89-3 and sells for $9.

The report is the first publication produced in a five-year study project, begun in mid-1988, to investigate the oil, gas, and coal potential of the Tyee Basin. This is an area of more than 4,000 mi^2 in the southern Oregon Coast Range that is underlain dominantly by Eocene sedimentary rocks. The project is funded by a consortium of public and private supporters, including the Douglas County Industrial Development Board, GCO Minerals Company, the Oregon Department of State Lands, Menasha Corporation, the U.S. Bureau of Land Management, the USDA Forest Service, and Weyerhaeuser Corporation.

The new report consists of (1) a blackline compilation geologic map including all relevant published and unpublished studies; (2) a map showing distribution of oil, gas, and coal geochemical data; (3) a plate containing three cross sections; and (4) a text containing preliminary assessment of the oil, gas, and coal potential of the southern Tyee Basin; a discussion of the stratigraphic problems that exist in the southern Coast Range; and tables of data on source rock and maturation, porosity and permeability, coal analyses, and oil and gas shows in exploration wells as well as in water wells and natural seeps.

Much of the information presented in the report consists of previously confidential research data and is made available here for the first time through the cooperation of several oil companies.

Placer minerals study group reports

Preliminary Feasibility Study: Oregon Placer Minerals presents a preliminary resource and economic evaluation of black sand deposits on beaches, coastal terraces, and the continental shelf offshore along the coast of Oregon. Black sands may contain heavy minerals such as magnetite, chromite, ilmenite, garnet, rutile, gold, and platinum-group metals.

This approximately 180-page report was produced by the joint State-Federal Oregon Placer Minerals Task Force established by the U.S. Secretary of the Interior and the Governor of Oregon in September 1989 and funded by the U.S. Minerals Management Service. It has been published as DOGAMI Open-File Report O-89-12 and sells for $8.

The report includes a summary of placer mineral resource information, an economic evaluation, an environmental review, a market definition, an economic and strategic analysis, and a set of recommendations for future study. In draft form, the report sections were made available for public comment, and responses to public and peer-review comments are summarized in an appendix.

Mist Gas Field map updated

All 1989 exploration and development activity at the Mist Gas Field, Oregon's only producing field, has been incorporated in the 1990 update of the *Mist Gas Field Map*, DOGAMI Open-File Report O-90-1 ($7). For more details, see the "Oil and Gas News" on page 26 of this issue.

All publications mentioned above are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

Mining and exploration in Oregon in 1989

by Howard C. Brooks, Baker City Field Office, Oregon Department of Geology and Mineral Industries

PRODUCTION

The U.S. Bureau of Mines estimate of the value of Oregon's 1989 nonfuel mineral production is $199 million, about 12 percent above the $178 million value for 1988. The increase is largely due to higher output of cement and crushed stone and the resumption of nickel production. More than 95 percent of the value of Oregon's nonfuel mineral production is in the construction materials, sand, gravel, stone, and cement. Other nonmetallic commodities produced in 1989 were limestone, pumice (Figure 1), diatomite, clay, zeolite, and talc. Nickel and gold were the only metals produced in significant quantity. In recent years, the State commonly has ranked first nationally in the production of pumice and fourth in the production of diatomite and is a significant producer of processed natural zeolite.

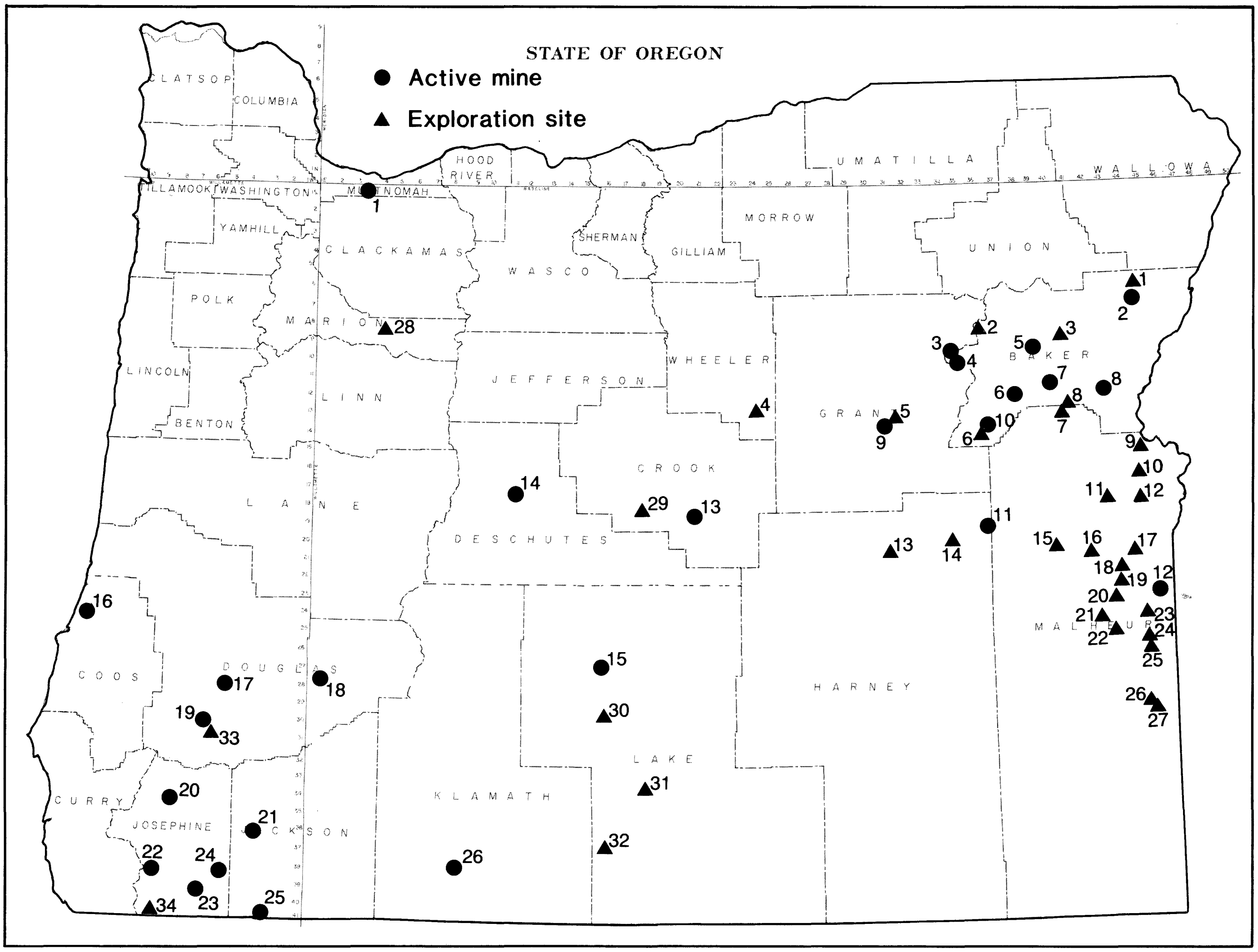
Sand, gravel, and crushed stone for use in construction were produced from pits and quarries throughout the State.

Crushed and screened silica rock was produced for a variety of uses from a quarry in Jackson County by Bristol Silica and Limestone Company (Figure 2, active mine site 21; Figure 3). Silica rock from Quartz Mountain (Figure 2, active mine site 18) in Douglas County was used by Glenbrook Nickel Company in its nickel smelting operation at Riddle.

Table 1. *Summary of mineral production value (in millions of dollars) in Oregon for the last 18 years. Data for 1989 derived from U.S. Bureau of Mines annual preliminary mineral-industry survey and Oregon Department of Geology and Mineral Industries natural-gas statistics*

	ROCK MATERIALS Sand, gravel, stone	METALS AND INDUSTRIAL MINERALS Cement, nickel, pumice, etc.	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	134	65	4	203

Figure 1. Cascade Pumice Company: part of screening facility (Figure 2, active mine site 14).



EXPLANATION

ACTIVE MINES AND AREAS

1. Columbia Brick and Tile
2. Bonanza Mining(placer gold)
3. Pyx Mine (lode gold)
4. Greenhorn area (placer gold)
5. Elk Creek (placer gold)
6. Pine Creek area (placer gold)
7. Dooley Mountain area (perlite)
8. Ash Grove Cement West (cement and crushed limestone)
9. Canyon City Placers (placer gold)
10. Lower Grandview Mine (lode gold)
11. Eagle-Picher Industries (diatomite)
12. Teague Mineral Products (bentonite and clinoptilolite)
13. Central Oregon Bentonite/Oregon Sun Ranch (bentonite clay)
14. Cascade Pumice/Central Oregon Pumice (pumice)
15. Oil Dry Production (diatomite)
16. CooSand (Silica sand)
17. D and D Ag Lime and Rock (agricultural limestone)
18. Quartz Mountain (silica)
19. Glenbrook Nickel (nickel)
20. Galice area (placer gold)
21. Bristol Silica and Lime (silica)
22. Josephine Creek area (placer gold)
23. Sucker Creek area (placer gold)
24. Campman Calcite (agricultural limestone)
25. Steatite of Southern Oregon (soapstone)
26. Klamath Falls Brick and Tile (brick)

EXPLORATION SITES AND AREAS

1. Cornucopia Mine (gold)
2. Herculean Mine (gold, base metals)
3. Flagstaff Mine (gold)
4. Spanish Gulch (gold)
5. Prairie Diggings (gold)
6. Grouse Creek project (gold, copper)
7. Racey property (gold)
8. Malheur City area (gold)
9. Kerby (gold)
10. Tub Mountain area (gold)
11. Hope Butte (gold)
12. Vale Butte (gold)
13. Idol City area (gold)
14. Drewsey area (gold)
15. Gold Creek area (gold)
16. Harper Basin (gold)
17. Shell Rock Butte (gold)
18. Grassy Mountain (gold)
19. Burnt Mountain area (gold)
20. Dry Creek Buttes area (gold)
21. Quartz Mountain (gold)
22. Red Butte (gold)
23. Katey (gold)
24. Bannock (gold)
25. Mahogany (gold)
26. Hillside (gold)
27. Anderson (gold)
28. Bornite (copper, gold, silver)
29. Bear Creek Butte area (gold)
30. Summer Lake area (gold)
31. Paisley area (gold)
32. Quartz Mountain (gold)
33. Silver Peak (gold, silver, copper)
34. Turner-Albright (copper, zinc, gold)

Figure 2. Mining and mineral exploration sites in Oregon in 1989 (excluding sand and gravel and stone). Active mines are keyed to Table 2; exploration sites and areas are keyed to Table 3.

1. Columbia Brick Works

Sec. 14, T. 1 S., R. 3 E., Multnomah County. Plant produces facing brick using clay from a company-owned pit nearby.

2. Bonanza Mining Company—placer gold

Sec. 3, T. 7 S., R. 45 E., Baker County. Largest mine in Oregon, located on Pine Creek about 3 mi below the old Cornucopia gold mine. Employed 26 people in 1989. Gravel depth varies from 20 to 70 ft; values are concentrated near bedrock. Washing plant handles 60 yd per hour and operates eight months per year, six days per week, three shifts per day. The pit operates two 10-hour shifts per day. Backfilling and reclamation in one part of the pit are concurrent with stripping and mining in another part.

3. Pyx Mine—lode gold

Sec. 1, T. 10 S., R. 35 E., Grant County. Small operation in early summer; ore milled in a small gravity separation plant in Sumpter.

4. Greenhorn area—placer gold

Tps. 9, 10 S., Rs. 35, 35½ E., Baker and Grant Counties. Several small, seasonal operations, including parts of Snow Creek, upper North Fork of Burnt River, Parkerville, and Winterville areas.

5. Elk Creek—placer gold

Tps. 9, 10 S., R. 39 E., Baker County. Several small, seasonal operations.

6. Pine Creek area—placer gold

T. 12 S., R. 38 E., Baker County. Small seasonal operations including Goldwater, Inc., which has been active for several years.

7. Dooley Mountain area—perlite

Tps. 11, 12 S., R. 40 E., Baker County. Mined and used by Supreme Perlite Company to produce expanded perlite at a facility in Portland.

8. Ash Grove Cement West, Inc.—cement and crushed limestone

Sec. 11, T. 12 S., R. 43 E., Baker County. Annual sales were about 500,000 tons of cement and 220,000 tons of crushed limestone valued at over $25 million. Employs 105 people. The crushed limestone is shipped to sugar refiners in Oregon and Idaho for use in the process of extracting sugar from sugar beets. Markets in place for capacity production in 1990.

9. Canyon City Placers—placer gold

Sec. 6, T. 14 S., R. 32 E., Grant County. Washing plant and dragline operation by Cammtex International, Inc.

10. Lower Grandview Mine—lode gold

Sec. 6, T. 14 S., R. 37 E., Baker County. Small, seasonal underground mine; new ownership in 1989.

11. Eagle-Picher Industries, Inc.—diatomite

Processing plant is 7 mi west of Vale in sec. 6, T. 19 S., R. 44 E., Malheur County; open-pit mine sites are 70 mi west of plant in Tps. 19, 20 S., Rs. 35, 36 E., Harney and Malheur Counties. Products are used as filter aids in clarifying fluids including water, beverages, juices, syrups, edible oils, fuels, and pharmaceuticals. Total employment (mining, trucking, processing) about 50 people.

12. Teague Mineral Products—bentonite and clinoptilolite

Plant is in sec. 8, T. 23 S., R. 46 E.; mines are in secs. 28, 29, T. 23 S., R. 46 E., Malheur County, Oregon, and nearby in Idaho. The bentonite is used chiefly as soil sealant for waste disposal sites, ditches, and ponds, for drilling mud and absorbent, and as binder for cattle food pellets. Uses of the clinoptilolite include pet litter, odor control products, fungicide carrier, and ammonia absorbent. The plant includes five mills, which allows for production of a full range of sized products from coarse granules to micronized powders. Research in the uses of bentonite and zeolite is being continued.

13. Central Oregon Bentonite Company/Oregon Sun Ranch, Inc.—bentonite clay

Both in sec. 4, T. 19 S., R. 21 E., Crook County. Small production from adjacent properties near Camp Creek.

14. Cascade Pumice Company/Central Oregon Pumice Company—pumice

Tps. 17, 18 S., R. 11 E., Deschutes County. Combined annual production about 200,000 tons. The major use is lightweight aggregate in poured concrete and in concrete blocks.

15. Oil-Dri Production Company—diatomite

Secs. 14, 21, 23, T. 27 S., R. 16 E., Lake County. Product is packaged and sold to several different companies for resale, mainly as pet litter.

16. CooSand Corporation—silica sand

Sec. 34, T. 24 S., R. 13 W., Coos County. Uses of product include glass manufacture (Owens Corning in Portland), construction, sand blasting, and railroad traction.

17. D and D Ag Lime and Rock Company—agricultural limestone

Sec. 20, T. 28 S., R. 5 W., Douglas County. Small producer of ground limestone from quarries operated before 1935 by Oregon Portland Cement Company.

18. Quartz Mountain—silica

Sec. 2, T. 28 S., R. 1 E., Douglas County. Produced silica for the Glenbrook Nickel Company operation of the nickel smelter at Riddle.

19. Glenbrook Nickel Company—nickel

Secs. 28, 29, T. 30 S., R. 6 W., Douglas County. Company reactivated former Hanna Nickel Company smelter to process 6-million-ton stockpile of lateritic material grading 0.7 percent nickel left at the site when Hanna closed the smelter in January 1987. The Company has not decided whether to reopen the Nickel Mountain Mine; the equipment was removed when the mine closed.

20. Galice area—placer gold

Tps. 34, 35 S., R. 8 W., Josephine County. Small, seasonal operations.

21. Bristol Silica and Limestone Company—silica

Sec. 30, T. 36 S., R. 3 W., Jackson County. Crushed and screened silica rock sold for a variety of uses including poultry grit, sand blasting, and decorative stone. Small amounts of dolomite have been sold from an occurrence on the margin of the silica quarry.

22. Josephine Creek area—placer gold

Tps. 38, 39 S., R. 9 W., Josephine County. Several small, seasonal operations.

23. Sucker Creek area—placer gold

Tps. 39, 40 S., Rs. 6, 7 W., Josephine County. Several small, seasonal operations.

24. Campman Calcite Company—agricultural limestone

Sec. 31, T. 38 S., R. 5 W., Josephine County. Company mined, crushed, and ground limestone from the Jones Marble Quarry for agricultural use mainly in southwestern Oregon.

25. Steatite of Southern Oregon—soapstone

Secs. 10, 11, T. 41 S., R. 3 W., Jackson County. Block soapstone sold mainly for carving.

26. Klamath Falls Brick and Tile Company

Sec. 19, T. 38 S., R. 9 E., Klamath County. Plant produces a variety of facing and paving bricks using clays from pits in several western Oregon counties and northern California.

Cement was produced only by Ash Grove Cement West, Inc. The plant and quarries (Figure 2, active mine site 8) are near Durkee in Baker County. Small amounts of limestone were produced for agricultural use by Campman Calcite Company at the Jones Marble quarry (Figure 2, active mine site 24) in Josephine County and by D and D Ag Lime and Rock Company from a quarry (Figure 2, active mine site 17) in Douglas County.

Diatomite was produced by Eagle Picher Industries (Figure 2, active mine site 11) for use as filter aid and by Oil-Dri Production Company (Figure 2, active mine site 15) for use as pet litter.

Pumice was produced by Cascade Pumice Company and Central Oregon Pumice Company (Figure 2, active mine site 14) from several quarries near Bend in Deschutes County. Combined annual output has averaged about 200,000 tons for several years.

Bentonite clay and zeolite were produced by Teague Mineral Products Company from its plant (Figure 2, active mine site 12) 2 mi

Figure 3. Bristol Silica and Limestone Company: silica qarry and primary crusher. Dolomite occurs along the upper left edge of the quarry (Figure 2, active mine site 21).

south of Adrian in Malheur County. Bentonite also was produced by two small operations (Figure 2, active mine site 13), Central Oregon Bentonite Company and Oregon Sun Ranch, Inc., in Crook County.

Clay was produced by Ash Grove Cement West, Inc., for use in making cement. Clay for brick making and engineering applications was produced in several western counties. Two brick plants were operated, one in Multnomah County by Columbia Brick Works, Inc. (Figure 2, active mine site 1), the other in Klamath County by Klamath Falls Brick and Tile Company (Figure 2, active mine site 26).

Carving-grade talc was produced by Steatite of Southern Oregon (Figure 2, active mine site 25).

The nickel plant (Figure 2, active mine site 19) near Riddle was reactivated by Glenbrook Nickel Company.

Gold production was dominated by the Bonanza Mining Company, placer operation (Figure 2, active mine site 2). Some gold was produced at the Lower Grandview lode mine (Figure 2, active mine site 10) and at several dozen small, intermittently operated placer mines in northeastern and southwestern parts of the State (Figure 4).

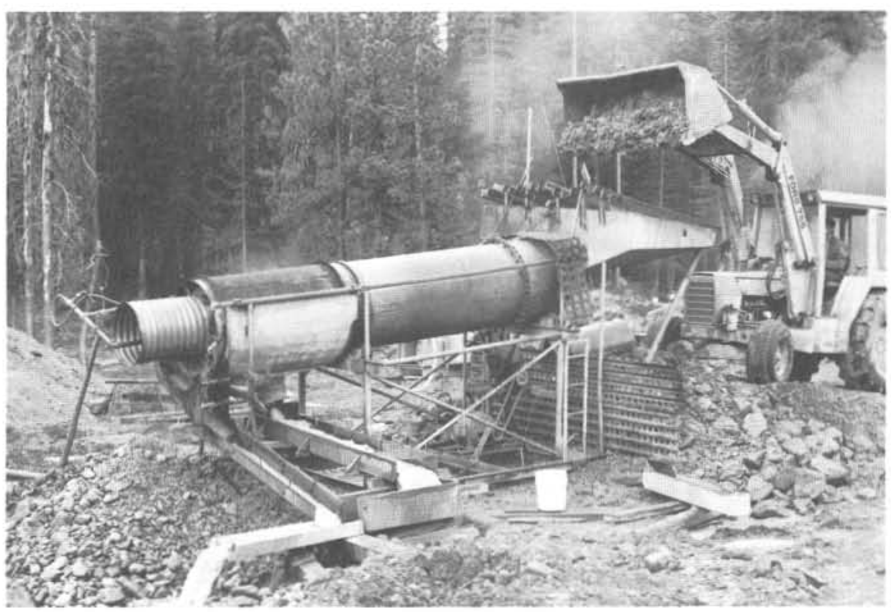


Figure 4. Trommel and sluice washing plant: Ray Tracy placer mine on Snow Creek in the Greenhorn area (Figure 2, active mine site 4).

Table 3. *Exploration sites in Oregon, 1989*

1. Cornucopia Mine—gold
Sec. 27, T. 6 S., R. 45 E., Baker County. Small underground exploration-drilling program by owners, UNC Corporation.

2. Herculean Mine—gold and base metals
Sec. 22, T. 8 S., R. 36 E., Baker County. Small exploration and development program by Cable Cove Mining Company.

3. Flagstaff Mine—gold
Sec. 6, T. 9 S., R. 41 E., Baker County. Drilling program by Hecla Mining Company.

4. Spanish Gulch—gold
Secs. 12, 13, T. 13 S., R. 24 E., and secs. 7, 18, T. 13 S., R. 25 E., Wheeler County. Small drilling program by ASARCO.

5. Prairie Diggings prospect—gold
Sec. 33, T. 13 S., R. 32 E., Grant County. Drilling program by Goldsearch Resources, Inc.

6. Grouse Creek prospect—copper, silver
Secs. 24, 25, T. 14 S., R. 36 E., Baker County. Drilling program continued by Golconda Resources, Ltd.

7. Racey property—gold
Secs. 19, 20, 21, T. 13 S., R. 41 E., Malheur County. Continued drilling by Ican Minerals, Ltd., and, late in the year, by Ican and Billiton Minerals U.S.A., Inc., joint venture.

8. Malheur City area—gold
Tps. 12, 13 S., Rs. 40, 41 E., Baker County. Land acquisition, surface exploration, and some drilling by Earth Search Sciences, Inc., and Beaver Resources joint venture.

9. Kerby—gold
Secs. 22, 27, T. 15 S., R. 45 E., Baker County. Drilling continued by Malheur Mining Company. Feasibility and base-line environmental studies underway.

10. Tub Mountain area—gold
Secs. 4, 5, 6, 7, 8, T. 17 S., R. 45 E., Malheur County. Malheur Mining, Atlas Precious Metals, and Euro-Nevada Mining Corporation, Inc., have claim groups in the area. Malheur Mining's group was leased to Echo Bay. Some drilling on all three properties.

11. Hope Butte—gold
Sec. 21, T. 17 S., R. 43 E., Malheur County. Chevron continued drilling.

12. Vale Butte—gold
Secs. 28, 29, T. 18. S., R. 45 E., Malheur County. Under evaluation by Atlas Precious Metals Company.

13. Idol City area—gold
Tps. 20, 21 S., R. 32 E., Harney County. Drilling by Newmont Mining Company.

14. Drewsey area—gold
Tps. 20, 21 S., Rs. 34, 35 E., Harney County. Exploration and evaluation programs by Cyprus Gold Exploration Company, Battle Mountain Gold Corporation, Reserve Industries, Corona Gold Corporation, and others. Cyprus drilled several holes at the Red Butte prospect in sec. 35, T. 20 S., R. 35 E., and later dropped the claims.

15. Gold Creek area—gold
Secs. 3, 4, T. 2 S., R. 40 E., Malheur County. Geochemical sampling and geophysical surveying by Manville Corporation.

16. Harper Basin—gold
Secs. 22, 23, T. 21 S., R. 42 E., Malheur County. Exploration drilling by American Copper and Nickel Company and Atlas Precious Metals Company on adjoining properties.

17. Shell Rock Butte—gold
Sec. 18, T. 21 S., R. 45 E., Malheur County. Small drilling program by ASARCO, Inc., on property owned by Western Epithermal; lease dropped later. Small drilling program by Atlas Precious Metals Company on its own property.

18. Grassy Mountain—gold
Sec. 8, T. 22 S., R. 44 E., Malheur County. Atlas Precious Metals Company continued drilling, began base-line environmental studies, and submitted operating plan and permit application to the U.S. Bureau of Land Management. Announced reserves total 1.2 million oz of gold in ore averaging 0.065 oz gold per ton.

19. Burnt Mountain area—gold
Secs. 4, 5, 6, 7, 8, 9, T. 23 S., R. 44 E., Malheur County. Land acquisition and sampling by Noranda Exploration, Inc.

20. Dry Creek Buttes area—gold
Tps. 23, 24 S., Rs. 43, 44 E., Malheur County. Rotary drilling by Noranda Exploration, Inc., on the Lavery claims. Manville, ASARCO, and Noranda hold large claim blocks in nearby areas.

21. Quartz Mountain—gold
Sec. 6, T. 25 S., R. 43 E., Malheur County. Chevron drilled one hole for water and set up a prefab camp in preparation for an extensive exploration program in 1990.

22. Red Butte—gold
Secs. 26, 27, 34, 35, T. 25 S., R. 43 E., Malheur County. Hand sampling program by Chevron. Prospect is in a Wilderness Study Area.

23. Katey—gold
Tps. 24, 25 S., R. 45 E., Malheur County. Small rotary drill program and soil and rock-chip sampling by ASARCO.

24. Bannock—gold
Sec. 11, T. 26 S., R. 45 E., Malheur County. Small drilling program by Manville.

25. Mahogany—gold
Secs. 25, 26, T. 26 S., R. 46 E., Malheur County. Small drilling program by Chevron.

26. Hillside—gold
Secs. 26, 27, 34, T. 29 S., R. 45 E., Malheur County. Surface sampling and geophysical surveys by Manville Corporation.

27. Anderson property—gold
Sec. 35, T. 29 S., R. 45 E., Malheur County. Surface sampling and small drilling program by Nerco Exploration Company.

28. Bornite—copper, gold, silver
Sec. 36, T. 8 S., R. 4 E., Marion County. Plexus Resources Corporation obtained development rights. Company reports that drilling by AMOCO and others in late 1970's and early 1980's indicates reserves of 3.1 million tons averaging 2.49 percent copper, 0.023 oz per ton gold, and 0.067 oz per ton silver.

29. Bear Creek Butte area—gold
Tps. 18, 19 S., R. 18 E., Crook County. Drilling program continued by Freeport-McMoRan Gold Company.

30. Summer Lake area—gold
Sec. 14, T. 30 S., R. 16 E., Lake County. Small drilling program by N.A. Degerstrom, Inc.

31. Paisley area—gold
T. 34 S., Rs. 18, 19 E., Lake County. Surface investigation by N.A. Degerstrom, Inc.

32. Quartz Mountain—gold
Secs. 26, 27, 34, 35, T. 37 S., R. 16 E., Lake County. Pegasus Gold, Inc., joint-ventured with Quartz Mountain Gold Corporation, agreed to continue exploration, conduct feasibility studies, and develop a mine plan. A feasibility study completed in August 1989 delineates proven and probable reserves of 9.8 million tons for the combined Crone Hill and Quartz Butte deposits, with an average grade of 0.045 oz per ton gold. Drilling by Quartz Mountain Gold Corporation indicates reserves of 64 million tons averaging 0.025 oz gold per ton. More than 625 holes aggregating about 250,000 ft have been drilled on the 9,700-acre property.

33. Silver Peak Mine—gold, silver, copper
Sec. 23, T. 31 S., R. 6 W., Douglas County. Drilling continued by Formosa Mining Company.

34. Turner-Albright—copper, zinc, gold
Secs. 15, 16, T. 41 S., R. 9 W., Josephine County. Savanna Resources, Ltd., and Aur Resources, Ltd., agreed to joint venture; Aur to spend $2.5 million on exploration. Company reports that drilling indicated reserves of 3.3 million tons averaging 1.46 percent copper, 3.3 percent zinc, and 0.11 oz gold per ton.

Figure 5. Drilling at the Hope Butte prospect by Chevron Resources Corporation (Figure 2, exploration site 11).

Figure 6. Chalcedony vein exposed on Gold Creek prospect (Figure 2, exploration site 15) of Manville Corporation.

Figure 7. Mineralized hydrothermal breccia exposed on the east side of Red Butte (Figure 2, exploration site 22).

EXPLORATION

The southeastern Oregon gold rush accelerated following the announcement in late 1988 of a discovery in the Grassy Mountain area. Atlas Precious Metals continued drilling its Grassy Mountain site (Figure 2, exploration site 18) through most of 1989 and announced an increase in geologic reserves to 1.2 million oz of gold in ore averaging 0.065 oz per ton. Feasibility studies and collection of baseline environmental and water-quality data are underway. An operating plan was submitted to the Bureau of Land Management in November. Extensive drilling was also done at the Hope Butte (Figure 2, exploration site 11; Figure 5) and Kerby prospects (Figure 2, exploration site 9). Evaluation of the results is in progress.

Exploration activity still is concentrated in northern Malheur County but is spreading to other areas. Nearly 8,000 claims were located in Malheur County in 1989, bringing the total number of claims in the county to more than 21,000. Exploration drilling was done on at least 16 different properties in the state. Figure 2 shows the location of properties where extensive surface sampling or drilling has been done.

All but two of the deposits in Malheur County are in rocks of Miocene or Pliocene age. The northern two deposits (Figure 2, exploration sites 7 and 8) are partly hosted in an altered quartz diorite porphyry. The mineralization may be Tertiary in age. Most of the other Malheur County deposits are sediment hosted; some of them occur in silicic volcanic rocks. Associated basalt is locally mineralized.

The deposits typically are of epithermal origin (Figures 6 and 7). Hot-spring sinter are associated with several of them. Silicification and argillic alteration of the host rocks is common. Anomalous levels of arsenic are also common and may or may not be associated with gold. Chevron geologist David Bush reported that mineralization at Quartz Mountain and Hope Butte has been dated at 17.8 and 3.9 million years, respectively (personal communication, October 1989). The dates are based on multiple radiometric analyses of adularia.

Geologic mapping of the Boise 1° x 2° quadrangle (scale 1:250,000) in central Malheur County continued. The mapping involved workers from the Oregon Department of Geology and Mineral Industries (DOGAMI), the U.S. Geological Survey, and Portland State University. Geologic maps of the Graveyard Point, Owyhee Dam, and Adrian quadrangles were released in 1989 by DOGAMI. Similar geologic maps of the Double Mountain and Grassy Mountain quadrangles were released in early 1990. □

Oil and gas exploration and development in Oregon, 1989

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

ABSTRACT

Oil and gas lease activity declined in 1989. Five U.S. Bureau of Land Management lease sales were held, with no leases purchased. There were filings for 99,351 federal acres. The total of federal acres under lease was 463,528 acres at year's end. No state or county lease sales were held during the year.

Thirteen wells were drilled in the Mist Gas Field and vicinity, of which seven were drilled by ARCO and six by DY Oil. Three ARCO wells and one DY Oil well were successful gas completions. The field had 18 gas producers and seven gas wells awaiting pipeline connection at year's end. A total of 2.6 billion cubic feet (Bcf) of gas was produced during 1989, with a value of $3.5 million. ARCO also drilled an unsuccessful Astoria Basin test in Clatsop County.

The Mist natural gas storage project became fully operational on November 1, 1989. The redesign of the Miller Station was completed during the year.

Northwest Natural Gas Company has constructed a 49-mi natural-gas pipeline from Mist Gas Field to Portland, providing a pipeline loop through the field.

The Department of Geology and Mineral Industries continued the study of the Tyee Basin in Douglas and Coos Counties and will publish the first phase of maps and reports during the year.

Rulemaking is now underway to implement House Bill 2089 and to revise the oil and gas exploration and development rules in Oregon.

LEASING ACTIVITY

There was a decline in leasing activity during 1989. Leasing activity included five public land lease sales by the U.S. Bureau of Land Management (BLM) plus over-the-counter filings of BLM property. No leases were purchased at any of the lease sales. There were filings for 30 parcels totaling 99,351 acres located in Wheeler, Crook, and Wasco Counties. F and F Georesources filed for two of the parcels in Wheeler County, and D.M. Yates filed for the remainder. A total of 183 parcels consisting of 463,528 acres were under lease at year's end. This is a decline from the 876,138 acres in 397 parcels under lease at the end of 1988. The total rental income during 1989 was about $519,000, a decline from the $1,139,000 during the previous year.

At the end of 1989, active State of Oregon leases numbered 58, totaling 73,428 acres. Total rental income was $73,428 for the year.

No state or county lease sales were held during 1989.

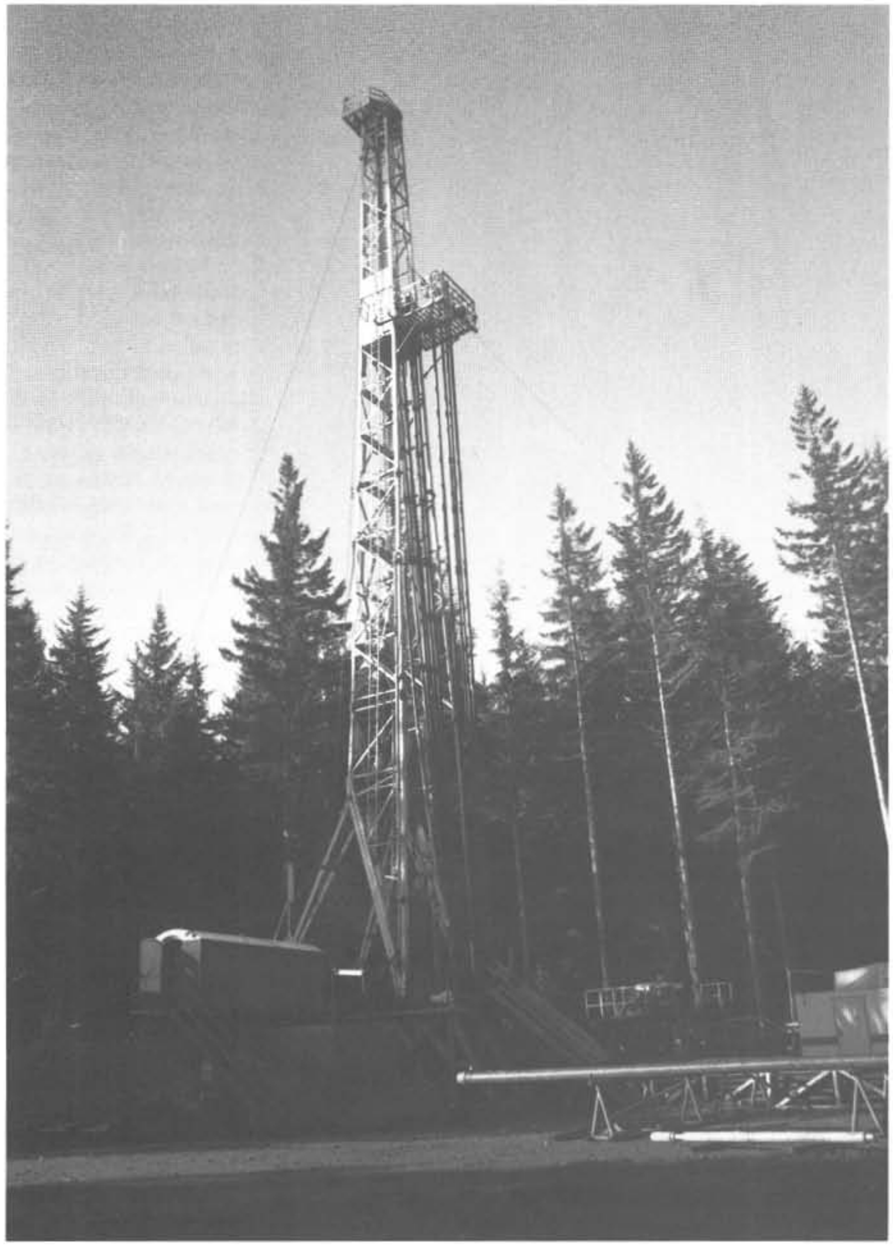


Figure 1. ARCO well OR 21-33-86, the deepest well drilled in Oregon during 1989, was a wildcat test in the Astoria Basin in Clatsop County.

DRILLING

A total of 14 exploratory oil and gas wells was drilled in the state in 1989. This is the same number of exploratory oil and gas wells that were drilled during 1988 but is an overall decrease in total wells because during 1988, in addition, five gas-storage wells were drilled and three redrills undertaken. All but one of the wells were drilled in the Mist Gas Field area, a pattern that has continued since the field was discovered in 1979. The other well was a wildcat well drilled by ARCO in the Astoria Basin of northwestern Oregon. This well, the OR 21-33-86 (Figure 1), was located about 12 mi northwest of Mist Gas Field in Clatsop County near the town of Westport. The well was drilled to a total depth of 5,896 ft, making it the deepest well drilled in Oregon during 1989, and it was plugged and abandoned as a dry hole.

Figure 2. Preparations to perforate for a flow test at the DY Oil well Neverstill 33-30, the only gas producer at Mist Gas Field not operated by ARCO.

At Mist Gas Field, two operators were active during the year. As has been the case for the past several years, ARCO Oil and Gas Company was the most active operator, drilling seven exploratory wells. Of these, three were successful gas completions, and four were dry holes. DY Oil drilled six exploratory wells at Mist, one of which was a successful gas completion (Figure 2), and the rest were dry holes.

Total drilling footage for the year was 33,823 ft, a decrease from the 61,523 ft drilled during 1988. The average depth per well was 2,416 ft, a small decline from the 2,797 ft per well drilled during the previous year.

During 1989, the Oregon Department of Geology and Mineral Industries (DOGAMI) issued 19 permits to drill (Table 1), while 13 permits were canceled during the year (Table 2).

DISCOVERIES AND GAS PRODUCTION

Mist Gas Field saw four new producers, a decrease from the seven producers drilled during 1988. ARCO Oil and Gas Company is the operator of three of the discovery wells, which are the CER 13-1-55, CER 41-16-64, and CC 34-28-65. With the successful completion of the Neverstill 33-30 well, DY Oil became the only other gas producer at Mist. There were 18 producers at year's end, up from 14 producers at the end of 1988. In addition, seven gas wells were awaiting pipeline connection. Eight additional wells are shut-in former producers. One of these, the CC 44-21, has been converted by ARCO Oil and Gas Company to a water-disposal well. This will add an additional water-disposal well at the field to supplement the CC 13-1, which is currently the only well used for this purpose.

Gas production for the year totaled 2.5 Bcf. This is a decline from the 4.0 Bcf produced during 1988. Part of the decline is

Table 1. *Oil and gas permits and drilling activity in Oregon, 1989*

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD = total depth PTD = proposed TD RD = redrill
418	ARCO Oregon 21-33-86 36-007-00020	NW¼ sec. 33 T. 8 N., R. 6 W. Clatsop County	Abandoned, dry hole; TD: 5,985.
420	ARCO Col. Co. 34-28-65 36-009-00249	SW¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,240.
421	ARCO Col. Co. 42-32-74 36-009-00250	NE¼ sec. 32 T. 7 N., R. 4 W. Columbia County	Permit issued; PTD: 1,750.
422	ARCO CER 24-18-64 36-009-00251	SW¼ sec. 18 T. 6 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 1,810.
423	ARCO CER 41-16-64 36-009-00252	NE¼ sec. 16 T. 6 N., R. 4 W. Columbia County	Completed, gas; TD: 2,105.
424	ARCO Hamlin 33-17-65 36-009-00253	SE¼ sec. 17 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 3,150.
425	DY Oil CER 23-22-64 36-009-00254	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 2,680.
426	Leadco CC-Jackson 23-17 36-009-00255	SW¼ sec. 17 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 2,500.
427	DY Oil Neverstill 33-30 36-009-00256	SE¼ sec. 30 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,225.
428	DY Oil Forest Cav 13-6 36-009-00257	SW¼ sec. 6 T. 5 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,796.
429	DY Oil Burris CC 24-8 36-009-00258	SW¼ sec. 8 T. 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 2,684.
430	DY Oil Lane CC-24-5 36-009-00259	SW¼ sec. 5 T. 5 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,473.
432	ARCO Col. Co. 34-8-75 36-009-00261	SE¼ sec. 8 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,706.
434	ARCO Col. Co. 13-3-55 36-009-00263	SW¼ sec. 3 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD: 1,655.
435	ARCO Col. Co. 13-4-55 36-009-00264	SW¼ sec. 4 T. 5 N., R. 4 W. Columbia County	Permit issued; PTD: 2,025.
436	ARCO CER 13-1-55 36-009-00265	SW¼ sec. 1 T. 5 N., R. 5 W. Columbia County	Completed, gas; TD: 1,645.
437	ARCO OR 34-25-66 36-007-00022	SE¼ sec. 25 T. 6 N., R. 6 W. Clatsop County	Abandoned, dry hole; TD: 2,452.
438	ONGD Oregon State 32-26 36-067-00004	NE¼ sec. 26 T. 1 S., R. 4 W. Washington County	Permit issued; PTD: 2,000.
439	DY Oil Lane CC-24-5-A 36-009-00266	SE ¼ sec. 5 T. 5 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,126.

Table 2. *Canceled and denied permits, withdrawn applications, 1989*

Permit no.	Operator, well, API number	Location	Issue date	Cancellation date	Reason
378	ARCO Longview Fibre 23-33-65 36-009-00215	SW¼ sec. 33 T. 6 N., R. 5 W. Columbia County	3-9-87	3-9-89	Permit canceled; expired.
379	ARCO Col. Co. 11-7-65 36-009-00216	NW¼ sec. 7 T. 6 N., R. 5 W. Columbia County	2-19-87	2-21-89	Permit canceled; expired.
381	ARCO Col. Co. 23-18-65 36-009-00218	SW¼ sec. 18 T. 6 N., R. 5 W. Columbia County	2-19-87	2-21-89	Permit canceled; expired.
382	ARCO Col. Co. 32-26-65 36-009-00219	NE¼ sec. 26 T. 6 N., R. 5 W. Columbia County	2-19-87	2-21-89	Permit canceled; expired.
384	ARCO Col. Co. 24-26-65 36-009-00221	SW¼ sec. 26 T. 6 N., R. 5 W. Columbia County	2-19-87	2-21-89	Permit canceled; expired.
385	ARCO Col. Co. 22-27-65 36-009-00222	NW¼ sec. 27 T. 6 N., R. 5 W. Columbia County	2-19-87	2-21-89	Permit canceled; expired.
389	Leadco CC-Jackson 23-17 36-009-00226	SW¼ sec. 17 T. 5 N., R. 4 W. Columbia County	7-1-87	7-1-89	Permit canceled; expired.
390	ARCO CFI 31-1-65 36-009-00227	NE¼ sec. 1 T. 6 N., R. 5 W. Columbia County	5-21-87	5-21-89	Permit canceled; expired.
411	ARCO Hamlin 33-17-65 36-009-00245	SE¼ sec. 17 T. 6 N., R. 5 W. Columbia County	7-5-88	4-4-89	Permit canceled; per permittee's request.
413	ARCO Col. Co. 22-17-75 36-009-00247	NW¼ sec. 17 T. 7 N., R. 5 W. Columbia County	9-26-88	9-26-89	Permit canceled; expired.
419	ARCO Oregon 13-33-86 36-007-00021	SW¼ sec. 33 T. 8 N., R. 6 W. Clatsop County	11-16-88	11-16-89	Permit canceled; expired.
431	Northwest Fuel Dev. Hammerberg 32-14-65 36-009-00260	NE¼ sec. 14 T. 6 N., R. 5 W. Columbia County	7-7-89	11-8-89	Permit canceled; per permittee's request.
433	ARCO Meridian 34-31-65 36-009-00262	SE¼ sec. 31 T. 6 N., R. 5 W. Columbia County	—	—	Application withdrawn.

attributable to the shutdown of pipeline for construction and maintenance at Mist Gas Field. The cumulative field production as of the end of 1989 was about 38.4 Bcf. The total value of the gas produced for the year was $3.5 million, a decrease from the $6.4 million during 1988. Gas prices ranged from 14 cents to 15 cents per therm, a decrease from the range of 14 cents to 20 cents per therm during 1988.

GAS STORAGE

During the year, Northwest Natural Gas Company completed its redesign of the Miller Station at Mist Gas Field, including installation of two new compressors. This completed construction at the natural gas storage project, which became fully operational on November 1, 1989. Natural gas was injected into the Bruer and Flora Pools, each having three injection-withdrawal wells. Natural gas was withdrawn from these pools starting in December 1989.

OTHER ACTIVITIES

During 1989, Northwest Natural Gas completed construction of the Mist South feeder gas pipeline. This 49-mi pipeline connects the natural gas storage project at Mist Gas Field to the Portland area via a 16-in. pipeline (see *Oregon Geology,* v. 51, no. 5).

DOGAMI continues the study of the oil and gas potential of the Tyee Basin, located primarily in Douglas and Coos Counties in southwestern Oregon. The first phase of the study is now completed and includes production of a regional geologic map and cross sections and a source-rock report of the area. These will be published and available for purchase from DOGAMI. The study is intended to investigate those characteristics needed to generate and trap gas and oil, namely, source rock, stratigraphy, and structural framework. The study, which is being funded by landowners in the study area and by county, state, and federal agencies, will publish surface geologic maps and a fence diagram of the Tyee Basin using surface and subsurface well control during 1989.

The Northwest Petroleum Association remained active during 1989, with about 125 members at year's end. At monthly meetings, papers related to the oil and gas industry are presented. For 1990, plans are to hold the annual field symposium during September in Roseburg, Oregon, including a field trip to observe the structure and stratigraphy of the Tyee Basin.

Offshore oil and gas exploration is still many years away in the region, but planning is underway at the state and federal levels. The Oregon Ocean Resources Management Task Force, established by the 1987 Legislature, has continued to hold meetings and workshops to gather input regarding planning for new uses of the ocean, primarily mineral development. The Task Force will issue an interim report during early 1990. The general consensus from the public has been that existing uses such as fishing and tourism should be preserved, whereas oil and gas exploration or mining should be prevented. A final plan is scheduled for release in July 1990.

The U.S. Minerals Management Service plans to hold an April 1992 oil and gas lease sale for the Outer Continental Shelf off Oregon and Washington. Planning continues for the sale despite opposition from the State of Oregon, which feels this sale should be delayed or possibly canceled, pending completion of detailed studies of the affects of this activity. Industry interest will be gathered this year, which may ultimately determine whether there will be a 1992 offering.

During 1989, DOGAMI published its Oil and Gas Investigation 15 , entitled *Hydrocarbon Exploration and Occurrences in Oregon.* This publication lists all known oil and gas occurrences in Oregon in wells and on the surface such as oil and gas seeps. Its cost is $7. As a companion to OGI-15, DOGAMI published Open-File Report 0-89-10, *Bibliography of Oil and Gas Exploration in Oregon, 1896-1989.* This provides a comprehensive listing of references relevant to oil and gas exploration in Oregon. The cost is $5. DOGAMI also has recently revised the Mist Gas Field Report, described in the "Oil and Gas News" (p. 26 of this issue).

DOGAMI has continued the development of rules to implement House Bill 2089 and to revise administrative rules relating to oil and gas exploration and development in Oregon. This work is scheduled for completion during 1990. □

MINERAL EXPLORATION ACTIVITY

Major metal-exploration activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	QM Chevron Resources, Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources, Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

Exploration and bond ceiling rule making

Advisory Committees organized to make recommendations on exploration permits (HB 2088) and bond ceilings for some metal mines (SB 354) likely will have concluded their work by the time you read this. For a copy of either set of draft rules and a schedule of rulemaking hearings, contact Doris Brown at the Oregon Department of Geology and Mineral Industries (DOGAMI) Mined Land Reclamation Office, 1534 Queen Avenue SE, Albany, OR 97321, phone (503) 967-2039.

Mining issues forum

In order to bring together all groups concerned with mining in Oregon, DOGAMI and others will sponsor a forum to review potential beneficial and negative impacts from large-scale mining in Oregon. Representatives of a wide range of interests, including mining companies, environmental groups, state and local elected officials, and regulatory agencies will be invited to participate.

Additional information will be presented in this column in the May and July issues of *Oregon Geology.*

Status changes

Pegasus Gold is taking over the property currently permitted to Wavecrest Resources at Quartz Mountain and Angel Camp in Lake County. A project coordinating committee meeting was held with Pegasus and the regulatory agencies on February 22 to review the adequacy of the baseline data collected to date.

The operating plan of Formosa Exploration, Inc., was approved for completeness in December by DOGAMI. Final approval of the permit by DOGAMI is possible this spring. The Water Pollution Control Facility Permit issued by the Department of Environmental Quality has been drafted. Contact Jerry Turnbaugh, phone (503) 229-5374, for further information.

An initial project coordinating committee meeting for Chevron's Hope Butte property was held in February.

All readers who have questions or comments should contact Gary Lynch or Allen Throop at the MLR office in Albany, phone (503) 967-2039. □

Capitol display celebrates 25th anniversary of State Rock

The display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem currently houses an exhibit that celebrates the 25th anniversary of the adoption of the Thunderegg as Oregon's State Rock. The exhibit, which will remain until May 15, 1990, was provided by the Far West Lapidary and Gem Society of North Bend/Coos Bay and arranged by Bert Sanne and Cecelia Haines.

The display features a framed copy of Senate Joint Resolution 18, adopted March 29, 1965, and signed by Governor Mark O. Hatfield. Ten color photographs encased in lucite present the theories of the Thunderegg's origin. *—OCRMC news release*

Corrections

The rush to meet deadlines and the complexity of the Department's new desktop publishing system resulted in errors in the January 1990 issue of *Oregon Geology.* We apologize for any inconvenience this may have caused.

1. Figure 16 caption, p. 8, last sentence should have the words "stream channel" added at the end.
2. Figure 20 caption, p. 10, should read "Reworked airfall deposit exposed in roadcut on the Crooked River grade."
3. Figure 23 caption, p. 11, should read "Dark, cross-bedded sands are interspersed with laminated sheet-flood deposits in the Deschutes Formation near Round Butte."
4. Figure 24 caption, p. 11, delete the words "Hyperconcentrated flow."
5. Figure 25 caption, p. 11, change first three words to "Extremely coarse conglomerates."
6. Complete sentences 7 and 8 in "Cove Palisades State Park Field Trip Guide" on p. 13 should read "Flows exposed at the rim of Dry Canyon are Round Butte flows."
7. Stop 4, p. 14, paragraph 5, sentence 2, delete "both" and "and dark (andesite?)." Sentence 4, same paragraph, should be changed to two sentences that read "The second is the light-colored Cove ignimbrite. A white to gray reworked tuff unit overlies a conglomerate and cross-bedded sandstone about halfway down the grade."
8. Stop 5, p. 14, paragraph 1, next to last sentence should be changed to read "Their exceptional thickness may be the result of ponding behind a basalt dam downstream, although there is no direct evidence of this other than their thickness and behavior in places as a single cooling unit."
9. Stop 6, p. 15, paragraph 1, sentence 3, change "lower unit" to "upper unit." □

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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, a file copy on 5-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 6th ed., 1978.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the 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

Bayocean peninsula, the sand spit at Tillamook Bay, projects 4 mi northward from Cape Meares. A dike along the bay was built to close a mile-long gap eroded during a storm in 1952. Article beginning on page 57 discusses archaeological finds from the bay area as possible evidence of periodic breaching of the spit in the past, not just by storms but by wave erosion from earthquake-related tsunamis or bay seiching.

OIL AND GAS NEWS

Rules being finalized

Public hearings were held during April regarding the implementation of House Bill 2089 (1989 Legislature). These will provide for ground-water protection and surface reclamation when shallow exploratory holes, such as seismic shot holes, are drilled by the oil and gas industry in Oregon. Public hearings were also held during April on the revisions to administrative rules for oil and gas exploration and development in Oregon. Copies of these rules should be available during July. for details, contact Dan Wermiel at the Oregon Department of Geology and Mineral Industries (DOGAMI), phone (503)-229-5580.

Report on Tyee Basin oil, gas, and coal resources released

The first publication produced in the five-year Tyee Basin study project has been released by the Department (see description in the March issue of *Oregon Geology*, p. 36). The project was begun in mid-1988 and is funded by a consortium of public and private supporters. The Tyee Basin, an area of more than 4,000 mi^2 in the southern Oregon Coast Range, is underlain dominantly by Eocene sedimentary rocks.

Much of the information presented in the report consists of previously confidential research data and is made available here for the first time through the cooperation of several oil companies.

The report has been released as DOGAMI Open-File Report O-89-3 (price $9) and is entitled *Geology and Oil, Gas, and Coal Resources, Southern Tyee Basin, Southern Coast Range, Oregon*. It was produced by A.R. and W.A. Niem of Oregon State University, with major contributions by E.M. Baldwin of the University of Oregon.

NWPA Field Symposium scheduled

The Northwest Petroleum Association has scheduled its 1990 Annual Field Symposium for September 30, October 1, 2, and 3, 1990, in Roseburg, Oregon. The symposium will include one day of talks relating to energy development, primarily oil and gas, in the Pacific Northwest. Two days of field trips will be held to observe the strata of the Tyee Basin and Coos Basin areas. For details, contact the NWPA, P.O. Box 6679, Portland, OR 97228-6679. □

Papers on industrial minerals published

Papers presented at the 25th Forum on the Geology of Industrial Minerals have been published by the Oregon Department of Geology and Mineral Industries (DOGAMI). The Forum was held in spring 1989 in Portland, Oregon, and was attended by about 120 industrial mineral specialists from all parts of the United States, Canada, and Great Britain.

The new publication is entitled *Industrial Rocks and Minerals of the Pacific Northwest. Proceedings of the 25th Forum on the Geology of Industrial Minerals, April 30 to May 2, 1989, Portland, Oregon*, and has been released as DOGAMI Special Paper 23.

In addition to the 16 technical papers presented at the Forum, the 100-page publication contains the chronology of the Forums that have been held annually since 1965 in 22 different states of the U.S. and in Toronto, Ontario, and a list of the participants at the 25th Forum.

Six of the technical papers present surveys of occurrences and production of various industrial minerals in the Pacific Northwest

*(Continued on page 70, **Proceedings**)*

Geothermal exploration in Oregon, 1989

by George R. Priest, Oregon Department of Geology and Mineral Industries

INTRODUCTION

Geothermal exploration activity increased somewhat in 1989 relative to 1988. Drilling occurred on the flanks of Mount Mazama near Crater Lake National Park, at Santiam Pass, in the Alvord Desert, and in the Western Cascades. The amount of leased land and lease revenues declined sharply on federal lands. The total amount of federal land leased for geothermal resources has declined steadily since the peak in 1983.

DRILLING ACTIVITY AND RESULTS

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued from 1970-1989. Figure 2 shows the same information for geothermal prospect wells. Tables 1 and 2 list the Oregon Department of Geology and Mineral Industries (DOGAMI) permits for geothermal drilling that were active in 1989. Six new permits were issued, three for prospect holes and three for geothermal wells. Eight holes were drilled. Four shallow (< 152 m) temperature-gradient holes drilled by the U.S. Geological Survey (USGS) in the northern part of the Western Cascades had temperature gradients typical of background values for the area. A well drilled to a depth of 450 m in the Alvord Desert produced 1,211 liters per minute of 152 °C water in a 22-hour flow test (press release by Anadarko Petroleum Corporation). A temperature-gradient hole drilled by California Energy Company (CEC) near the east boundary of Crater Lake National Park reached a temperature of 129 °C at 1,068 m depth (Daily Journal of Commerce

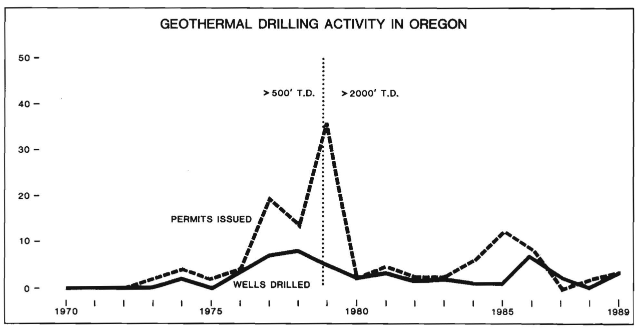

Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 610 m.

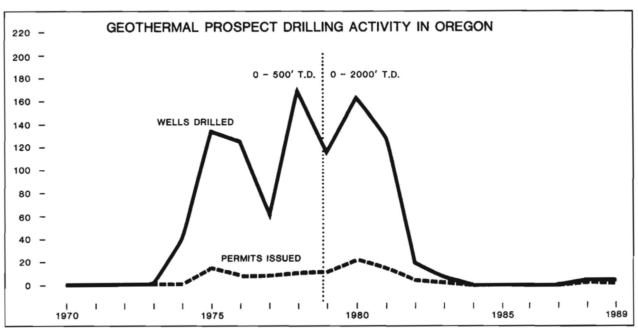

Figure 2. Geothermal prospect well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth of less than 610 m.

Table 1. *Active permits for geothermal drilling in 1989*

Permit no.	Operator, well API number	Location	Status, proposed total depth (m)
116	Calif. Energy Co. MZI-11A (deepening) 36-035-90014-80	SW¼ sec. 10 T. 31 S., R. 7½ E. Klamath County	Suspended; confidential.
117	Calif. Energy Co. MZII-1 (deepening) 36-035-90015-80	SE¼ sec. 13 T. 32 S., R. 6 E. Klamath County	Suspended; confidential.
118	GEO* N-1 36-017-90013	SW¼ sec. 25 T. 22 S., R. 12 E. Deschutes County	Suspended; 1,387.
124	Thermal Power Co. CTGH-1 36-047-90002	SE¼ sec. 28 T. 8 S., R. 8 W. Marion County	Plugged; 1,463.
125	GEO* N-2 36-017-90018	SW¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Suspended; confidential.
126	GEO* N-3 36-017-90019	NE¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Suspended; 1,219.
131	GEO* N-4 36-017-90023	NE¼ sec. 35 T. 21 S., R. 13 E. Deschutes County	Suspended; confidential.
132	GEO* N-5 36-017-90024	NE¼ sec. 8 T. 22 S., R. 12 E. Deschutes County	Suspended; confidential.
135	GEO* NC88-29 36-017-90027	SE¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Canceled.
136	GEO* NC54-5 36-017-90028	NE¼ sec. 5 T. 22 S., R. 12 E. Deschutes County	Canceled.
137	DOGAMI Cache Creek No. 1 36-017-90029	NW¼ sec. 1 T. 14 S., R. 8 E. Deschutes County	Canceled.
138	GEO* NC54-5 36-017-90030	NE¼ sec. 5 T. 22 S., R. 12 E. Deschutes County	Permit; 3,048.
139	Oxbow Power Corp. 77-24 36-031-90001	SE¼ sec. 24 T. 13 S., R. 7½ E. Jefferson County	Suspended; 141.
140	Calif. Energy Co. MZI-9 36-035-90017	SW¼ sec. 9 T. 31 S., R. 7½ E. Klamath County	Canceled.
141	Calif. Energy Co. MZI-11 36-009-90018	SW¼ sec. 11 T. 31 S., R. 7½ E. Klamath County	Withdrawn by applicant.
142	Calif. Energy Co. MZI-11B 36-035-90019	SW¼ sec. 14 T. 31 S., R. 7½ E. Klamath County	Suspended; confidential.
143	Calif. Energy Co. CE-BH-4 36-017-90031	SW¼ sec. 27 T. 16 S., R. 9 E. Deschutes County	Permitted; 1,676.

* GEO-Newberry Crater, Inc.

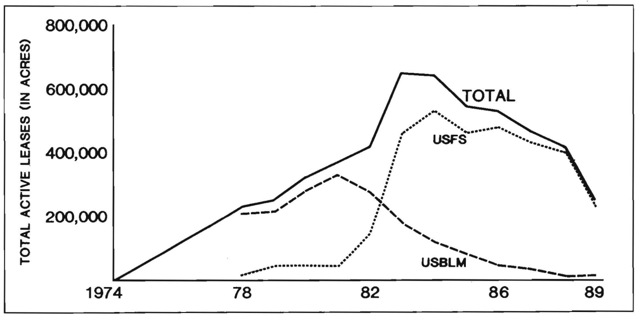

Figure 3. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December 1989.

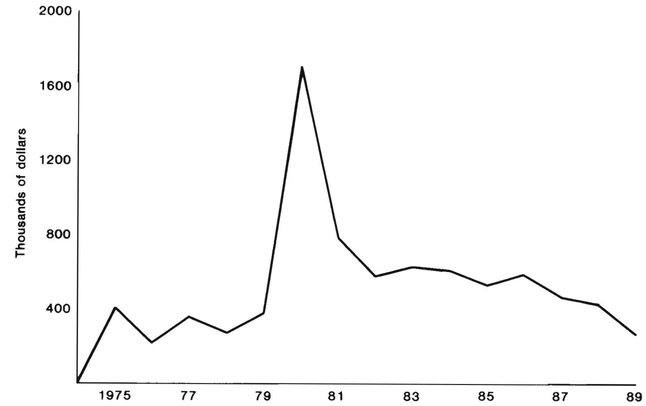

Figure 4. Federal income from geothermal leases in Oregon from the inception of leasing in 1974 through December 1989.

article, March 15, 1990). CEC also deepened a nearby hole, but the results are confidential. The Oxbow Power Corporation, working cooperatively with DOGAMI, rotary-drilled to 141 m near Santiam Pass. The Santiam Pass hole is scheduled to be diamond-cored to approximately 900 m in July of 1990.

LEASING

The consolidation of land holdings continued in 1989 as the total leased acreage of federal lands decreased by about 40 percent (Table 3; Figure 3). This decrease in leased lands was almost entirely caused by a decline in USDA Forest Service (USFS) leases (Table 3). U.S. Bureau of Land Management (USBLM) leases also suffered declines, but so little USBLM land is leased that it contributed little to the total. This decrease marks the sixth straight year of decline since the 1983 peak in total leased acreage.

Part of the reason for the steep decline in leased lands is a shift from leasing on the flanks of Newberry volcano to areas in the High Cascades. Lease applications for approximately 85,000 acres in the High Cascades, principally in the Bend highlands and Santiam Pass area, are currently being processed with the USFS (Robert Fujimoto, personal communication, 1990).

Figure 4 is a graph of the annual total monies received by the federal government from geothermal leasing in Oregon from 1974, when leasing was initiated, to the present. Included in the graph is income from filing fees, rental on competitive and noncompetitive leases, and bonus bids. Income from geothermal leasing peaked in 1980 at $1,701,189 and has declined steadily since then to its present level of about $268,000.

KNOWN GEOTHERMAL RESOURCE AREA (KGRA) SALES

No KGRA lands were offered for bid in 1989. Some KGRA lands at Newberry volcano will probably be incorporated into a proposed geological monument (see section on regulatory actions).

Table 2. *Active permits for geothermal prospect drilling in 1989 (holes less than 610 m)*

Permit no.	Operator, well name	Location	Issue date; status
97	Anadarko Petroleum Well 25-22A	Alvord Desert area	Suspended; confidential.
98	USGS	Mount Hood National Forest, two sites	June 1989; drilled to 153 and 70 m.
99	USGS	Willamette National Forest, two sites	June 1989; drilled to 92 and 46 m.

REGULATORY ACTIONS

USFS and USBLM officials met with industry and environmental groups in February 1989 to work out a preliminary boundary for the proposed Newberry Volcanoes National Monument. The area of the monument will reportedly encompass much of the land formerly classified as KGRA. Bills establishing the monument were submitted to the House (HR 3840) and Senate (S 1947) on November 21, 1989. These bills are under review at present.

DIRECT-USE PROJECTS

The direct use of relatively low-temperature geothermal fluids continued in 1989 at about the same level as over the last several years. Most of the activity is centered in Klamath Falls and Vale.

Ashland

Jackson Hot Springs in Ashland, Oregon, is still being operated as a resort.

Klamath Falls

The City continued to wrestle with the problem of defective piping installed in its district heating system. In 1989, the City completed engineering plans for the replacement of the defective pipe connections, and replacement should occur in the near future. Further expansion of the system is planned utilizing the Small Scale Energy Loan Program of the Oregon Department of Energy.

La Grande

The Hot Lake Recreational Vehicle Resort is utilizing 85 °C water from the Hot Lake artesian well to heat a pool and building. The company hopes to eventually use the resource to heat a fish-farming operation and to generate electricity.

Lakeview

In Lakeview, the binary-cycle electrical generating station set up several years ago remains idle. The 300-kilowatt (kw) unit had an output of 250 kw from 105 °C water in a November 18, 1982, test (Geo-Heat Center Quarterly Bulletin, 1982).

Paisley

The Paisley area has one of the best quality but least utilized low-temperature geothermal resources in the State. Thermal wells there reportedly have high flow rates (observations of Gerald L. Black, 1981) and temperatures as high as 111 °C at only 228 m (Oregon Department of Geology and Mineral Industries, 1982). A campground and recreational-vehicle park utilizes hot water for a pool, but no other uses are known.

Vale

In Vale, the successful Oregon Trail Mushroom Company, which commenced full-scale operations in 1986, continues to operate using water from a 107 °C aquifer for heating and cooling. Oregon Trail annually produces 2.3 million kilograms of mushrooms, which are marketed in Spokane, Seattle, Salt Lake City, and the Treasure Valley area in Idaho (Geo-Heat Center Quarterly Bulletin, 1987). Ag-Dryers, a grain-drying facility, also uses the resource.

USGS ACTIVITIES

1989 saw the publication by the U.S. Geological Survey (USGS) of 27 papers discussing the geological, geophysical, and tectonic setting of the Cascade Range, as part of the proceedings of a workshop held in December 1988 (Muffler and others, 1989b). Contributors included earth scientists from the USGS, universities, and the state geological surveys of Oregon and Washington. Many of these papers, as well as other contributions, are soon to be published in a special volume of the *Journal of Geophysical Research.* Pat Muffler and Marianne Guffanti are continuing their assessment of the geothermal potential of the Cascade Range (Muffler and Guffanti, 1989).

Also published in early 1989 was a small-scale (1:500,000) compilation map of the Cascade Range in Oregon, summarizing a decade of work by several contributors (Sherrod and Smith, 1989). In addition, full-color maps showing greater detail are now in press: (1) part of the Cascade Range between Three Sisters and Crater Lake (Sherrod, in preparation) and (2) west half of the Klamath Falls 1° x 2° quadrangle (Sherrod and Pickthorn, in preparation). Eleven new K-Ar age determinations for the Klamath Falls map will soon be published by *Isochron/West* (Pickthorn and Sherrod, in preparation).

Dal Stanley has integrated several east-west magnetotelluric-profile interpretations with regional seismic-refraction modeling (Stanley and others, 1989). This work better defines a high conductive (2 to 20 ohm-meters) zone that occurs at depths of 6 to 20 km and is largely confined within a mid-crustal layer with seismic velocity of 6.4 to 6.6 km/sec. The proposed model suggests that metamorphic zonation and fluids are responsible for superposition of these features.

Steve Ingebritsen and Bob Mariner continued water chemistry and hydrologic modeling of the Breitenbush Hot Springs and McKenzie Pass areas as part of a project to understand the circulation of meteoric and hydrothermal water in the Cascades (Ingebritsen and others, 1989a,b; Mariner and others, 1989).

Charlie Bacon's geologic map of Crater Lake is progressing. His studies will rigorously define the magmatic evolution and events leading to the caldera-forming climactic eruptions in Holocene time (Druitt and Bacon, 1989; Bacon, 1990). Field work included five dives with the portable submersible *Deep Rover*, during which samples were collected from the submerged parts of the caldera walls.

Keith Bargar and Terry Keith continued studies of hydrothermal-alteration mineralogy at Mount Hood, Newberry volcano, and the Clackamas River area. It is evident that low-temperature alteration (not much greater than 100 °C) is present to several kilometers depth in the Western Cascades, with no higher temperature minerals present. High-temperature mineralization is found only in areas adjacent to small plutons and hot springs.

Willie Scott coordinated a field trip in the Mount Bachelor-South Sister-Bend area for the Friends of the Pleistocene Fall 1989 Meeting (Scott and others, 1989). Trip leaders included Andrei Sarna-Wojcicki and Cynthia Gardner of the USGS and Edward Taylor and Brittain Hill of Oregon State University (OSU). Other Oregon Cascade field trips were conducted in association with the Santa Fe, New Mexico, meeting of the International Association of Volcanology and Chemistry of the Earth's Interior (Muffler and others, 1989a; Swanson and others, 1989).

The year 1989 also saw the beginning of a major investigation of Mount Hood, a volcano that heretofore was relatively unstudied despite its obvious hazard potential and proximity to the densely populated area of Portland and vicinity. This project is a cooperative effort between the Geologic and Water-Resources Divisions of the USGS and involves geologists Willie Scott, Tom Pierson, Bob Tilling, and Dave Sherrod. It will focus in part on downstream debris flows and floods, recent eruptive history, and geologic mapping and petrology of Mount Hood and vicinity. Field work by Dave Sherrod was concentrated mainly in the area southeast of Mount Hood, in an effort to finish three 15-minute quadrangles along the crest and east slopes of the range. Willie Scott is working mainly with the pyroclastic flows erupted from Mount Hood during the last 15,000 years.

BONNEVILLE POWER ADMINISTRATION

In its Draft 1990 Resource Program, Bonneville Power Administration (BPA) offered to purchase, in joint ventures with regional utilities, 10 MW of output from each of three geographically diverse geothermal pilot projects in the Northwest. The power contracts will include an option on the next 200 MW to be developed at each site. The main goal of the project is to determine the location, size, and cost of power at three of the largest, most promising sites in the region. Secondary goals are to encourage exploration, to build capability in regulators and developers, and to resolve land use issues that could impede development. If the projects proceed as scheduled, plants could start producing power as early as 1994.

BPA will also work with USFS, USBLM, and state energy offices to produce estimates of economic and land use impacts of geothermal development in areas where exploration is under way or imminent. Programs for public outreach and base-line environmental data collection are also being developed.

BPA has contracted with the Washington State Energy Office (WSEO) to produce a series of guides to the energy facility regulator maze in Idaho, Montana, Oregon, and Washington (WSEO is subcontracting appropriate parts of the project to the other three states). The guides will cover geothermal, hydroelectric, solar, wind, cogeneration, and biomass energy development. The geothermal guide is due in mid-1990 and will be followed by a workshop for developers, planners, and regulators in late 1990.

BPA is also participating, with the University of Hawaii and the Electric Power Research Institute, in a project aimed at improving our ability to use slim holes for reservoir assessment.

Table 3. Geothermal leases in Oregon in 1988

Types of leases	Numbers	Acres
Federal leases in effect:		
Noncompetitive, USFS	153	234,638.54
Noncompetitive, USBLM	1	622.79
KGRA, USFS	1	100.00
KGRA, USBLM	7	16,465.12
Total leases issued:		
Noncompetitive, USFS	357	685,805.79
Noncompetitive, USBLM	266	406,157.79
KGRA, USFS	8	11,924.61
KGRA, USBLM	62	118,307.85
Total leases relinquished:		
Noncompetitive, USFS	204	451,167.25
Noncompetitive, USBLM	265	405,535.00
KGRA, USFS	7	11,824.61
KGR, USBLM	55	101,842.73
Lease applications pending	107	——

If the proposed technology proves to be feasible, then software will be developed to facilitate use. Expected completion date is mid-1991. A follow-on project might be a joint effort with a developer to test the technology in the Northwest.

DOGAMI APPLIED RESEARCH

DOGAMI formulated a scientific drilling program in 1987 (Priest and others, 1987a). Funding to support the program was found in 1989 from contributions of $200,000 by the U.S. Department of Energy (USDOE) and $100,000 by Oxbow Power Corporation (OPC). A hole was rotary-drilled and casing was set to 141 m in 1989 near Santiam Pass (Figures 5 and 6). The hole will be diamond-cored to about 900 m, and temperatures will be measured. It is hoped that the geologic and geophysical data from this hole will help to better understand the geologic history and regional heat flow near the axis of active volcanism in the Cascades. Those interested in participating in the project are encouraged to contact George R. Priest for further information.

In 1988, UNOCAL donated to DOGAMI core from four temperature-gradient holes that is currently available for use in research projects. The holes, drilled in the High Cascades near the South Sister and Mount Jefferson (Figure 5), reached depths ranging from 250 to 610 m. No temperature data from the holes are publicly available, but detailed lithologic logs are being produced as part of DOGAMI's scientific drilling program. The core is stored at Oregon State University, with representative samples available for inspection at DOGAMI.

An abstract in *EOS* (Priest and others, 1989) presents new isotopic age data for the UNOCAL holes. The paper shows that downward displacement on a complex graben structure in the Santiam Pass area is probably greater than or equal to 1.4 km. This amount of displacement is consistent with earlier interpretations of Taylor (1981). High permeability and geothermal fluids could occur in fractures and intergranular pore spaces associated with intra-graben faults and fill.

GEO-HEAT CENTER, OREGON INSTITUTE OF TECHNOLOGY

The Geo-Heat Center at the Oregon Institute of Technology (OIT) specializes in assisting in the development of low-temperature (< 90 °C) and moderate-temperature (90-150 °C) geothermal applications for direct use. The Center is under contract with USDOE to provide geothermal services to state and federal agencies who receive requests from engineering consultants, planners, and developers for development assistance on direct-use projects. The assistance can range from answering technical questions and simple consultations on methods, equipment, and applications to providing feasibility studies. The Geo-Heat Center has published over 70 such feasibility studies, which are available as examples. The project period is slated to run through the end of 1992.

The Geo-Heat Center continues to be involved in the evaluation of the Klamath Falls geothermal aquifer. Its staff plays an active role on the Klamath Falls Geothermal Advisory Committee and continues to publish the *Geo-Heat Center Quarterly Bulletin*, which has been in circulation since 1975.

ACTIVITIES OF OREGON WATER RESOURCES DEPARTMENT

The Oregon Water Resources Department (WRD) low-temperature geothermal program increased monitoring in the Klamath Falls area for aquifer pressure, temperature, and water-quality data in response to the City of Klamath Falls ordinance requiring injection of all geothermal effluent by July 1, 1990. WRD continues to monitor a light but persistent decline in the geothermal aquifer of about 0.3 m per year. Local officials feel that injection will halt this decline in the resource. WRD will continue to monitor to see whether any further steps are needed to stabilize the aquifer.

Jan Koehler recently joined WRD as a staff geologist, after having recently worked for the State Health Division drinking-water program. Jan brings a lot of water-quality control experience to the Department, which should be very useful in the geothermal program.

Senate Bill 237, passed in the last legislative session, requires WRD to develop rules that address several geothermal issues. The Department must adopt a "temperature below which low-temperature geothermal appropriations shall not be protected from thermal interference caused by ground-water appropriations for other purposes." The Department must also define terms such as "thermal interference" and "substantial thermal alterations."

Review of the statewide geothermal well and spring network continues, as WRD attempts to consolidate the net and assign monitoring efforts to the regional offices.

ACTIVITIES OF OREGON DEPARTMENT OF ENERGY

In 1989, the Oregon Department of Energy (ODOE) continued its research work, in cooperation with the Washington State Energy Office, on behalf of BPA. Results of both 1988 and 1989 work were presented to BPA in a July 1989 publication, "Innovative Design of Geothermal Generating Plants." ODOE put together additional case studies of two small independent power projects operating in Oregon. Neither was a geothermal plant, but the work provides BPA with insight necessary to eventually contract with a small geothermal developer.

ODOE provided comments on the Northwest Power Council (NPC) geothermal-issue paper and at a December NPC hearing presented testimony supporting geothermal energy development.

ODOE responds to public inquiries on geothermal energy development from the public, answering over 120 such inquiries in 1989. Since ODOE started keeping track of these inquiries in 1984, the yearly average is about 130 requests.

ODOE continues to certify geothermal tax credits for both homes and businesses in the state. In 1989, 70 residential tax credit applications were reviewed and 59 final certificates issued. The total number of geothermal residential tax credits issued from 1978 through 1989 is 596. Two geothermal business energy tax credit applications were reviewed in 1989. The total number of geothermal business energy tax credits issued from 1980 through 1989 is 40.

ODOE's geothermal specialist also attended the USDOE geothermal program review and the Geothermal Resource Council (GRC) Small (Geothermal) Power Plant meeting, taught a community college course session on geothermal energy at Central Oregon Community College, spoke at the USFS annual Lands and Minerals Conference, and published a paper on financial aspects of geothermal power plants for the annual GRC meeting.

RESEARCH BY OREGON STATE UNIVERSITY

Brittain Hill, a doctoral candidate at OSU, is continuing his work on Quaternary ash flows in the Bend area (Hill, 1985) and the silicic highland west of Bend. He will also be the field supervisor for scientific work on the scientific drill hole at Santiam Pass.

Jack Dymond and Robert Collier of the OSU College of Oceanography continued investigations at Crater Lake during the summer of 1989. Their objective is to determine whether or not hot springs exist on the floor of the lake. They contributed the following summary of their 1989 work.

Laboratory and surface-ship studies were extended during the summer of 1989 with deployment of the single-person submersible *Deep Rover*. The scientists used *Deep Rover* primarily to search out, observe, and sample thermal features in the bottom of the lake. In addition, they deployed in situ experiments to obtain time series measurements of flow rates, composition, and temperatures of the anomalous fluids found in certain parts of the lake. A total of 24 dives were carried out. Of these, five were funded by the

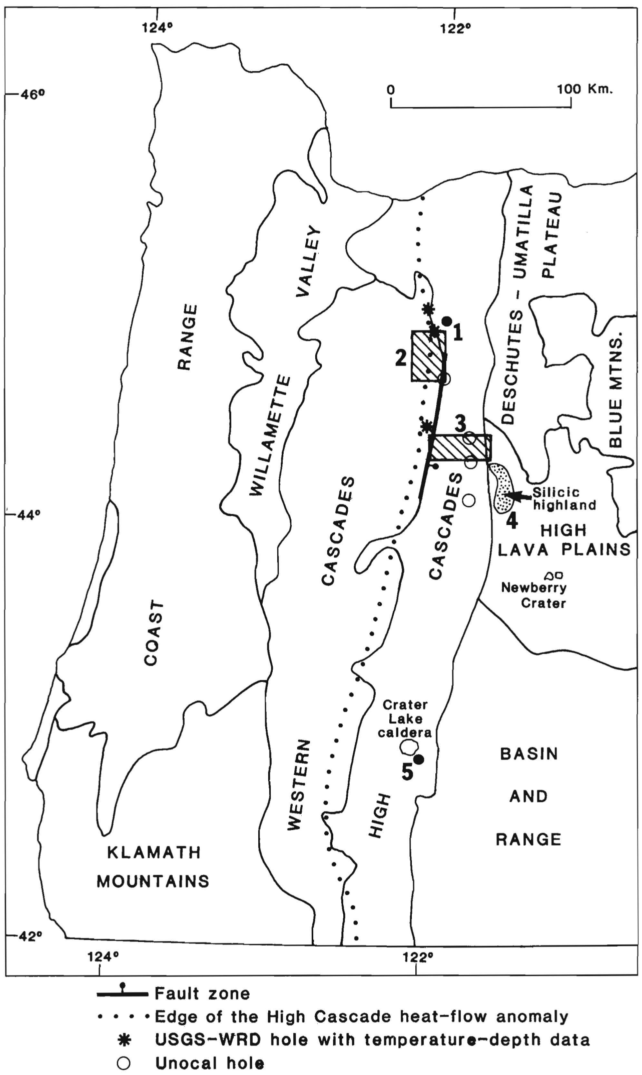

Figure 5. Physiographic provinces of western Oregon (after Dicken, 1950), showing major areas of geothermal activity discussed in text. 1. Location of Thermal Power drill hole CTGH-1. 2. Breitenbush study area. 3. Santiam Pass study area. 4. Silicic highland study area. 5. Location of CEC drill hole MZI-11A. Edge of High Cascade heat-flow anomaly after Black and others (1983).

USGS for observation and sampling of the lake's submarine geologic features. Four dives were funded by the National Geographic Society in order to carry out biological observations of moss and attached algae.

The submersible observations extended the areal coverage provided by the 1987 Remotely Operated Vehicle and the 1988 *Deep Rover* studies. These extended surveys located many additional colonies of chemoautotrophic bacteria. Most of the colonies were located within the southern basin that received major attention in 1988. However, a large area of bacteria coverage was located in the deep waters near Palisade Point. All the bacterial communities were associated with fluids 2-15 °C above the ambient temperatures that are found in the deep lake. These temperature anomalies are greater than those observed previously and, according to Dymond and Collier, exceed the USGS temperature criteria for geothermal waters.

One of the most surprising discoveries of the 1989 studies was the existence of pools of more saline water in the deep lake. These pools have dimensions ranging from a few centimeters to more than 10 m across. The pools are filled with fluids that are more than an order of magnitude more saline than normal lake waters. These waters have ^{222}Rn concentrations more than three orders of magnitude greater than background lake concentrations and have temperature anomalies of 2-6 °C above normal lake waters. Pools in the basin adjacent to the Palisades Point exhibited evidence of inlet and outlet channels in the sediments. These streamlike features may not presently be flowing, but erosional forms suggest that intermittent flow does occur. Bacterial communities of a variety of forms are associated with the pools, including both iron and sulfur oxidizers. The analytical program on the many aqueous and solid samples is currently underway.

RESEARCH BY WASHINGTON STATE UNIVERSITY

Richard Conrey is finishing up a four-year study of the Mount Jefferson area. He found that, for the last 2.5 Ma, about 200 km^2 of the area has been the site of andesitic to rhyodacitic volcanism (Conrey, 1988). He postulates that a granodiorite-tonalite batholith lies at shallow depths beneath the area.

MOUNT MAZAMA (CRATER LAKE) AREA

The reader is referred to Black and Priest (1988) for a detailed history of geothermal development issues at Mount Mazama prior to July 1988.

The National Park Service supported the research by Jack Dymond and Robert Collier of OSU mentioned above (section on Oregon State University).

In 1989, California Energy Company continued drilling on the two sites on the east side of the National Park that were discussed previously (section on drilling activity). In 1986, the MZI-IIA site (Table 1) had been drilled to 413 m, yielding a temperature of 107 °C at 405 m and a temperature gradient of 372 °C/km in the lowest 20 m of the hole (Priest and others, 1987b). Since the temperature at 1,068 m was only 129 °C, the high temperature gradient obviously did not persist at depth. These preliminary temperature data are, however, consistent with entry of thermal water in the upper part of the hole.

ACKNOWLEDGMENTS

This paper could not have been written without the cooperation of numerous individuals in government and industry. Jacki Clark of USBLM provided the federal leasing data. Bob Fujimoto of USFS provided much useful information on regulatory issues. Dennis Olmstead and Dan Wermiel of DOGAMI furnished the data on drilling permits. Alex Sifford of ODOE and Susan Hartford of WRD provided information on their agencies' activities for the year. Gene Culver of OIT provided information on direct use projects around the state. David Sherrod and Terry Keith of USGS supplied accounts of USGS activities in Oregon. Jack Dymond and Bob Collier of Oregon State University provided the summary of their study of Crater Lake. George Darr of BPA contributed the section on his agency's activities.

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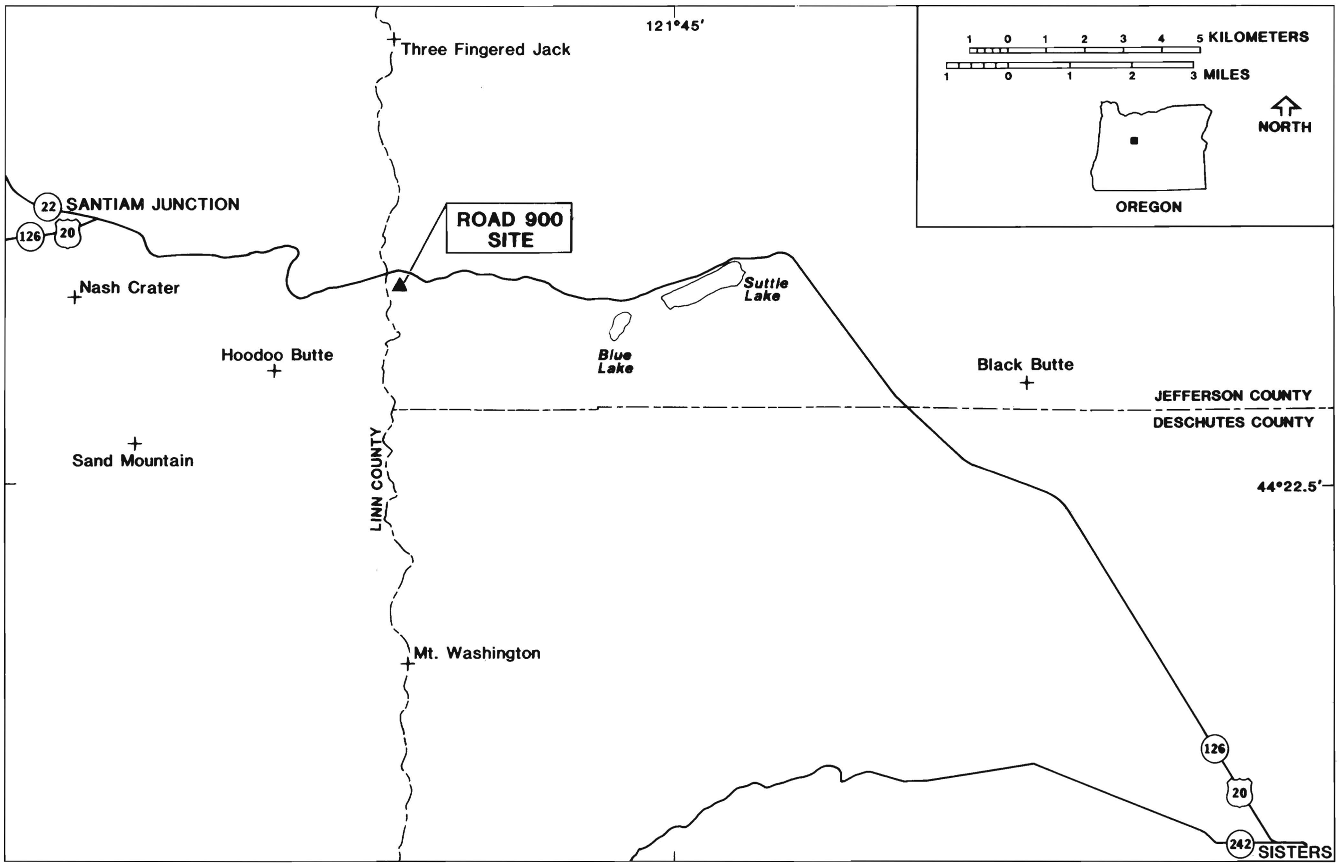

Figure 6. Location of scientific drill site near Santiam Pass, Oregon. Present depth, 141 m; target depth, 914 m.

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(Continued on page 66, **Geothermal***)*

Paleoseismicity and the archaeological record: Areas of investigation on the northern Oregon coast

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INTRODUCTION

"Then everything got dark; no one could see anything. The men could not go fishing, women were unable to go root digging, nothing could be done. Very soon the water began to rise. Many small things were drowned, small people....That little muskrat came back. He carried that sun....Everywhere there was daylight again, and all the flood went down" (Jacobs and Jacobs, 1959, p. 83-84).

This quotation is from a Nehalem-Tillamook myth recorded in 1934 by anthropologist Elizabeth Jacobs. The storyteller was Clara Pearson, probably the last fluent speaker of the Nehalem language on the northern Oregon coast. According to Mrs. Pearson, this story with its catastrophic flooding belonged to the earliest time period of the Tillamook oral literature. Stories of the myth age were assigned to happenings long before the 19th century.

Although great flood myths are frequently encountered worldwide, can this Nehalem version have originated in an actual event that happened on the northern Oregon coast between 300 and 400 years ago? Recently, geological, dendrochronological, and archaeological evidence has been produced to support the theory that coastal areas of Oregon and Washington have experienced catastrophic earthquake-generated subsidence or tsunami flooding (known popularly as "tidal waves") or both at least twice in the last 1,000 years.

This theory has now been widely reported in both scientific and popular literature. Yeats (1989) writes, "The submergence of archaeological sites indicates that earthquakes affected Native American communities prior to the establishment of a culture that kept written records."

The earthquake-subsidence record evidence for the Oregon and Washington coasts first received widespread public interest following publication of a paper by B.F. Atwater in *Science* in 1987 (Atwater, 1987). Atwater presents the results of a geologic study of the Washington coast, showing that during the last 7,000 years intertidal mud has rapidly buried coastal marshes at least six times. Atwater writes, "Nothing other than rapid tectonic subsidence readily explains the burial of the peat layers." At Willapa Bay, a sand sheet extending 3 km inland and covering a marsh surface is attributed to an earthquake-generated tsunami.

Tsunamis, or seismic sea waves, can take several forms. Seismic sea waves are very low and long, with sea heights of less than 1 m. Moving as shallow-water waves, their velocity and coastal crest height vary greatly due to bottom contours, headland refraction, and other local variables. These multiply or reduce wave height and may result in either a huge cresting wave front or simply an unusually rapid rise in water level. Another variable of a tsunami's local effect on estuaries is the magnitude of the seiching, or shore-to-shore ("bathtub") wave action, that occurs in wave-disruptive bodies of water that are partially enclosed. Bascom (1980) writes, "A Pacific tsunami will usually succeed in exciting all the bays and harbors around its rim. Often these will oscillate for days." Tsunami-generated seiches can occur harmonically, with water-level changes in a bay happening every few minutes and exceeding in height the normal tidal fluctuations. Such events in shallow estuaries could result in significant bank erosion and mud deposition.

The source of the rapid subsidence and earthquake-generated tsunamis is likely to be a megathrust earthquake on the Cascadia Subduction Zone that extends less than 100 km off the coast of Washington and Oregon. Although there is no historic precedent, Heaton and Hartzell (1987) indicate that earthquakes of great magnitude might occur on the Cascadia Subduction Zone, generating ground shaking lasting longer than two minutes and causing tsunamis of significant size. Subduction zone megathrust earthquakes in an analogous situation in Japan have generated local tsunami heights of greater than 6 m. A great subduction megathrust earthquake in Chile in 1960 generated local run-up heights exceeding 20 m.

At Netarts Bay (Figure 1) on the Oregon coast, Peterson and others (1988) have also shown the presence of rapidly buried marshes that they attribute to episodes of abrupt coastal subsidence. Twelve core sites in marsh lands of this bay showed several episodes of marsh burial in the last 3,300 years. Radiocarbon analysis indicates that the most recent events occurred less than 400 years before the present (B.P.). A date of A.D. 1580±60 was obtained from the top of a marsh surface that is overlain by a sediment-capping layer associated with "catastrophic sheet floods over the subsided marsh system" (Peterson and others, 1988). In another, more recent paper, Darienzo and Peterson (1990) present additional data derived from sediment and diatom analyses that further support the presence of tectonic subsidence and tsunami deposition at Netarts Bay.

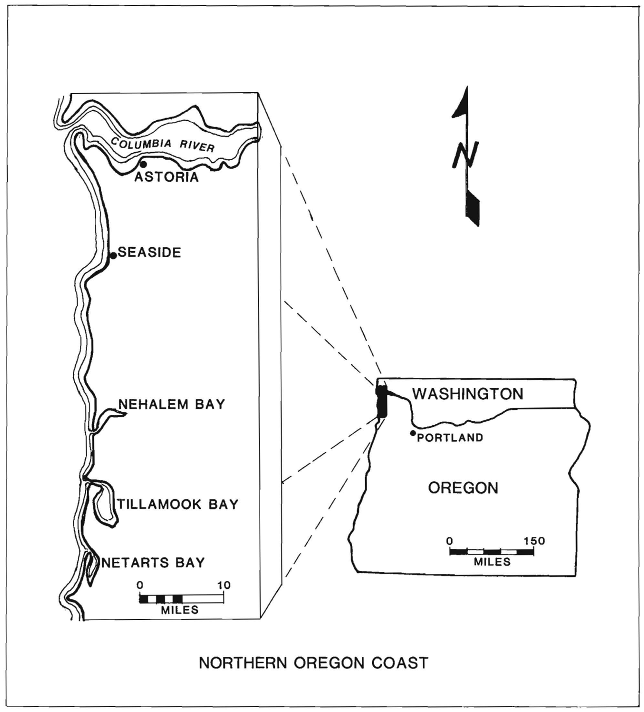

Figure 1. Map of the northern Oregon coast showing locations discussed in the text.

Grant and McLaren (1987) describe a similar buried marsh at the Salmon River estuary, approximately 40 km south of Netarts Bay, with evidence of a landward-directed surge of sandy water that deposited a thin layer of capping sand for at least 2 km along the Salmon River estuary. At Nehalem Bay, Grant found a marsh buried beneath sand and silt that she attributes to an episode of rapid subsidence.

Tree-ring data have also been examined for evidence of sudden coastal landform disruption. Carver and Burke (1987) have found disruptive growth rings in trees on the northern California coast dated at about 300 years B.P. The disruption is attributed to a landslide that could have been earthquake-generated. Dendrochronologist Yamaguchi and others (1989) report that cedar trees along a 60-mi span of the southern Washington coast died about the same time. Yamaguchi also is quoted in the *Oregonian* (Hill, 1989) as stating, "This is the first strong evidence that this subsidence event occurred synchronously up and down the coast." Yamaguchi attributes the death of the cedars to sudden submergence of the tree roots below high tide, with the tree rings indicating that this event occurred close to A.D. 1680.

Estuaries are highly sensitive environments that rapidly reflect subtle microenvironmental changes. This is especially true of those mollusks and fish most likely to be preserved in datable archaeological contexts. With the data from four coastal localities, we are attempting to appraise the archaeological evidence of sudden landform or sea-level changes on the northern Oregon coast as a contribution to the evaluation of earthquake hazards in Oregon.

NETARTS BAY

Netarts Bay has an estuary of 2,300 acres. It is protected behind a sand spit and has no large streams emptying into it. Its long-term stability is shown by the presence of every species of bay clam found in Oregon and, significantly, three that are not found in other Oregon estuaries. Edible shell fish that were found in Netarts Bay include the gaper (*Tresus capax*) and cockle (*Clinocardium nuttallii*). Both of these are easily obtainable in bay sand or sandy mud and were extensively dug and eaten by native peoples. Other less common but edible clams, the butter clam (*Saxidomus giganteus*) and the bent-nose clam (*Macoma nasuta*) are also found in Netarts Bay, where they occur close to the surface in gravelly or sandy mud (Oregon Department of Fish and Wildlife, 1982).

During late prehistoric times, a native village was established on Netarts sand spit, resulting in the deposition of an extensive shell midden (refuse pile) over 2 m deep in places (Archeological Site 35TI1).

The upper levels of the midden are composed of about 50 percent gapers and about 50 percent cockles. Other shellfish including butter clams were also observed but in small numbers. The occupation of this site continued into the historic period, with metallurgical analysis of copper alloy artifacts recovered from a late housepit indicating that the site was still in use during the late 1700's (Steele, written communication, 1985). Two radiocarbon dates of A.D. 1670±150 and A.D. 1800±150 were obtained from a late housepit in which copper artifacts and pre-19th century Chinese ceramics were also found.

This shell midden was excavated in the 1950's by Thomas Newman, who observed that the lowest 35 cm of midden deposits included masses of crushed shell, mammal bones, bone-woodworking tools, and cooking pits. A single radiocarbon date of A.D. 1400±150 was obtained from this lowest (i.e., oldest) midden level. Newman did not report any evidence of abandonment of the site or observe a clear break between the lowest midden and later deposits—which could be interpreted as the result of sudden landform changes—but he writes, "It is quite clear that occupation of this stratum did not take place under conditions existing today. Both sea level and water table must have been substantially lower to permit occupation" (Newman, 1959). He notes that, at the level of the lowest midden, these deposits were inundated by high tide all months of the year. He writes, "If highest tides and fresh-water table were lowered by 1 m, the site as it must have been during occupation would have been barely habitable....A 2-m drop in both sea level and fresh-water table would allow occupation at all times except under the severest conditions."

Thus, from Newman's comments it appears that the evidence of the lowermost shell midden is suggestive of subsidence/sea-level change. However, alternative, nontectonic explanations can also be considered. Northwest coastal villages were often located very close to the upper limit of high tide, and food-processing and cooking activities typically took place on the beaches in front of domiciles. As a result of these practices, cultural materials including shellfish and fire-cracked rocks would likely accumulate where periodic tidal inundation occurred.

If abrupt subsidence did occur at Netarts Bay during the last 500 years and resulted in as great a vertical displacement as Newman's evidence suggests, it must be reconciled with the archaeological record of a continuing shellfish-gathering community at this location both before and after this event. A sudden drop in elevation of 1 m or more should have drastically affected the local mollusk harvest. Probably this elevation change also would have caused the rapid wave erosion of much of the sand spit protecting the relatively small and narrow estuary. Perhaps, because Netarts Bay does not have any significant watercourses emptying into it, the shellfish population of the estuary recovered from the effects of such disruption. This might not have been possible, however, without the sand spit surviving as a protective barrier, a condition that would be consistent with the archaeological evidence for Site 35TI1.

Nevertheless, more recently, Darienzo and Peterson (1990) presented strong, core-derived evidence that a tsunami-generated marsh burial and subsidence of at least 1.3-1.5 m occurred between 300 and 400 years B.P. This magnitude of sea-level change is close to Newman's estimate based on midden depth.

TILLAMOOK BAY

Tillamook Bay is 9 km north of Netarts Bay and is the second largest estuary (14,000 acres) on the Oregon coast. It has approximately seven times the surface area of Netarts Bay and periodically in prehistoric times was significantly larger than today. Five rivers and numerous streams and sloughs empty into the bay. In addition to shellfish, salmon returning to these streams provided an important food resource available to prehistoric inhabitants. The Wilson River site (Site 35TI2) is situated on a low cobble terrace at the point where the Wilson River formerly emptied into Tillamook Bay. Due to silting during the last 120 years, the bay is now about 4 km farther west. This estuary, like all other major Oregon coastal estuaries, has formed behind a protective sand spit that is highly vulnerable to storm action. The spit protecting Tillamook Bay has been breached by storms in historic times and is now protected by a breakwater. However, even if the sand spit did not exist, the Wilson River site would be partially protected from ocean waves by a headland (Pitcher Point) about 6 km to the northwest.

The Wilson River site was chosen for archaeological subsurface investigations in 1989 for several reasons: (1) shellfish remains were visible in the midden deposits and appeared to be interspaced with strata where shellfish were absent; (2) the depth of the site (over 2 m) indicated a long and probably continuous occupation; and (3) the site is situated on a major bay immediately north of Netarts Bay and would presumably have experienced the same marsh burial events documented at Netarts.

The extensive Wilson River site was originally excavated during the 1970's by relic collectors who destroyed approximately 80 percent of the cultural deposits. Fortunately, however, some information derived from these uncontrolled excavations was published by Sauter and Johnson (1974). The excavators noted that the composition of the midden deposits varied both in depth and proximity to the river. The latest occupation was found on high ground farthest away from the river where there were housepits surrounded by a shell midden. This portion of the site appeared to be late prehistoric and historic and was probably the location of the Tillamook Indian community that still existed there in 1852 (Vaughan, 1852). Sauter and Johnson reported that the shell midden associated with this late village included

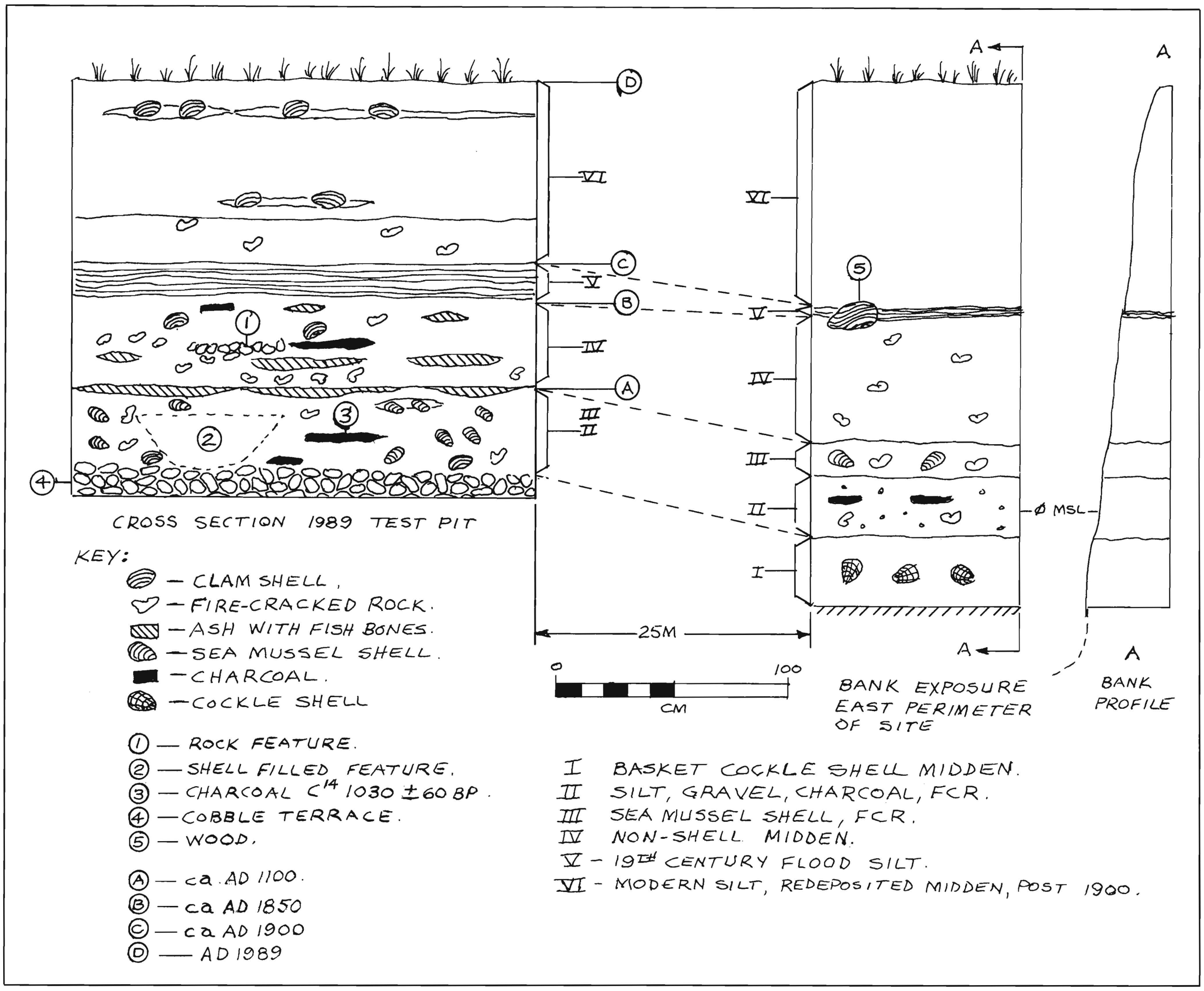

Figure 2. Stratigraphy of Wilson River Site 35TI2, Tillamook Bay. FCR = fire-cracked rock.

the mollusks generally found in Tillamook Bay as well as salmon bones. Artifacts reportedly associated with the occupation included whale bone clubs with carved zoomorphic designs, elk antler digging-stick handles, and awls and wedges made from bone. Beneath this shell midden, the authors reported a nonshell midden that was an "oily, charcoal-filled layer of midden which contained hundreds of bird bones and mammal bones of elk, deer, bear, beaver, sea otter, cougar...whale vertebrae." These deposits also included evidence of extensive flint knapping and the use of flaked-stone arrow points. The lowest midden and that closest to the river was observed to include a "lower shell midden" with a higher frequency of bone tools, harpoons, fishhooks, and toggle points than other areas. Although Sauter and Johnson did not attempt to correlate the differences observed in the site's midden, they noted the resource shifts indicated by the midden composition and suggested that time lapses may have occurred between occupations.

Archaeological investigations were conducted at the Wilson River site in August 1989 by college archaeology classes from Tillamook Bay Community College and Mount Hood Community College. A trench 24 m long and 2 m wide was excavated by arbitrary 10-cm levels to the base of the midden. The area chosen was a narrow strip of previously unexcavated soil located parallel to the Wilson River and adjacent to the area dug over by relic collectors. At the time of the excavation, river bank erosion was exposing cultural material to about the summer high-water line.

In early 1990, bank erosion approximately 25 m upstream from the trench location exposed an in situ shell midden located at an even lower level. In this lower shell midden, a 31-cm-thick stratum of large basket cockles, *Clinocardium nuttallii* (Conrad), was visible (Figure 2). The shells were largely intact and cemented together in a compact silt matrix. This stratum is interpreted as representing the result of dumping the shells into a relatively quiet water rather than as representing a living surface, so that, as such, the exposure does not necessarily indicate subsidence. The cockles indicate the presence of an estuarine environment nearby, although it may not have been identical with that found today. The cockle stratum is overlain by a 23-cm-thick layer of nonshell midden containing fire-cracked rocks and charcoal in a mud matrix containing gravel. No break in the site's use was observed between the cockle stratum and this layer; however, mollusks appear to be entirely absent in the higher layer.

Above the nonshell midden is a 14-cm-thick, dense, blue-appearing deposit of highly fragmented shells of the sea mussel, *Mytilus californianus* (Conrad). This mussel is found in dense beds on intertidal rocks along the open coast and occasionally in sheltered waters north to British Columbia. It has been widely used as a food source by many cultures. Exclusive presence of the sea mussel would indicate an open-coast environment, with a rocky shoreline (either cobbles or larger base rock). Mussels would survive on cobbles that would not be rolled around by the surf in storms, which are largely from the southwest in the Tillamook area. It should be noted that if the Tillamook sand spit were not present, the Wilson River mouth would largely be sheltered by the projection of Pitcher Point, which would block the sea directly west of the river mouth.

We interpret from the presence of sea mussels in such great quantities and the absence of estuarine forms that the Tillamook (Bayocean) sand spit did not exist at the time this level was deposited. During recorded times, the sand spit at Bayocean was developed and deteriorated. At one time, it was breached by the ocean, and if it had not been for the intervention of the U.S. Army Corps of Engineers, Tillamook Bay might have again reverted to open-coast environment. This was not the result of a catastrophic geological incident but a shifting of natural forces.

The mussel stratum abruptly ends and is overlain by a 57-cm-thick nonshell midden. Only minute unidentifiable particles of shells that were possibly the result of vertical transport were observed. We suspect they were moved to this level through activities of earthworms, rodents, trampling, and other human and natural activities and originated in lower and/or higher levels. This

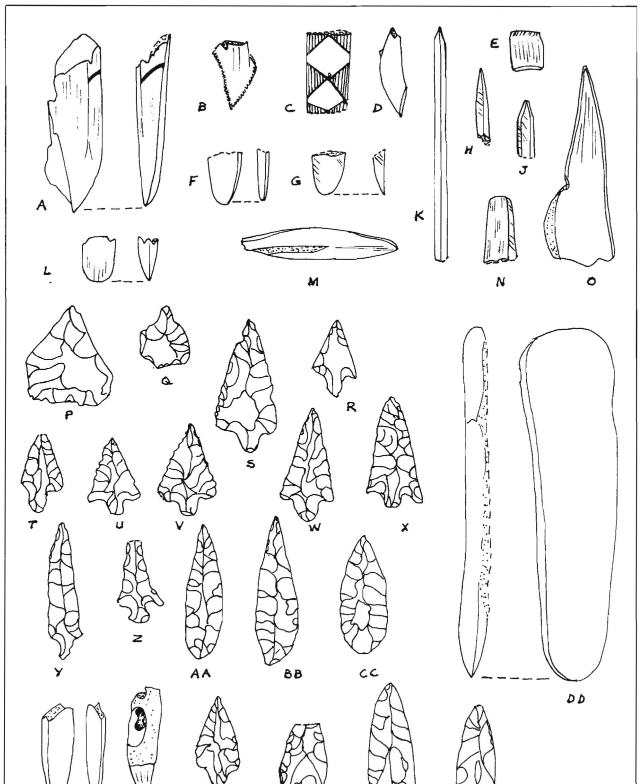

Figure 3. Artifacts of the Wilson River site, A-DD of a nonshell midden, EE-KK of a mussel shell midden. A = bone wedge fragment; B = shark's tooth; C = decorated antler; D = beaver tooth chisel; E = bone bead fragment; F, G, L = tips of antler wedges; H, J = bone points; K = bone needle; M = bone harpoon part; N = base of bone harpoon; O = bone awl; P = flaked stone knife; Q = flaked stone perforator; R-Z = flaked stemmed arrow points; AA-CC = flaked leaf-shaped points; DD = stone adze; EE = tip of bone wedge; FF = sea mammal tooth pendant; GG = flaked stone arrowpoint; HH-KK = flaked lanceolate point. Length of DD is 11.5 cm.

stratum is capped by a series of flood-deposited silts including tree limbs, historic artifacts, and redeposited midden.

Observations of other bank exposures at this site show a white, chalky-appearing shell midden occurring as lenses at the top of the nonshell midden and composed of bay clams and some gastropods. The predominant clam that was observed is the basket cockle, *Clinocardium nuttallii* (Conrad). Also found are the butter clam, *Saxidomus giganteus* (Deshayes); the gaper clam, *Tresus capax* (Gould); and the frilled dogwinkle snail, *Nucella lamellosa* (Gmelin). These are currently found in Tillamook Bay. The basket cockle is abundant and was a major portion of the commercial clam harvest of Tillamook Bay during the first part of this century.

The shell finds in the upper level are consistent with the present estuarine environment of Tillamook Bay. This late, upper shell midden appears to correlate with the uppermost cultural material excavated by Sauter and Johnson and associated with the late prehistoric/historic Tillamook Indian use of the site. By the inception of this occupation, the Tillamook Bay estuary was fully established with the mollusk types found historically near this location.

It is significant to note that there are substantial layers of deposits without shells separating the bay clam/sea mussel/bay clam stratum. A time period would be expected before reestablishment of species in a radically changed ecology. The layers without shells appear to represent such periods of reestablishment. It would also be expected that the bay clam to sea mussel interspace would be less, as sea mussels could be readily introduced from adjoining open coast, while bay clams would need transport of a substantial distance from other estuaries.

The excavated trench provided additional data concerning the site's stratigraphy. The lowest cultural materials consisting of a 30-cm-thick shell midden correspond to the mussel shell layer observed in the bank. In the trench, however, this deposit rests directly on a cobble terrace. Above the mussel shell midden is a nonshell midden 45 cm thick that is capped by flood silts dated to the late 19th century. Above this are mixed and redeposited materials including lenses of shells from the late midden. A radiocarbon date of A.D. 920±60 was obtained from charcoal recovered from the mussel shell midden.

If we consider the above-mentioned data alone, it would appear that a sand spit formed Tillamook Bay around 920 A.D., and the sea mussels were not able to survive. We can further speculate that the nonshell midden represents the subsequent time period in which clam veliger larvae finally arrived in the new bay in sufficient numbers to develop a reproducing population. This would have taken an extended period, for the predominant ocean flow past Tillamook Bay is southerly. To the north, Nehalem Bay, which is a relatively new estuary, contains different species. The Necanicum estuary was probably gone by 920 A.D. Larvae of the butter clam would probably have traveled from somewhere north of the Columbia River, and the gaper clams may have been introduced from Netarts. Cockle clams can survive in the open ocean, where they are possibly washed from estuaries. Such survival populations might have been the first to become introduced, which could account for the abundance of cockles.

Significantly, both the eroded bank exposures and trench stratigraphy do not show a hiatus in the site's occupation despite what appear to be abrupt shifts in resource procurement. The excavations showed that the mussel shell midden and the nonshell midden above it contain very similar artifact assemblages with a high percentage of bone and antler woodworking tools. Both contain significant numbers of sea and land mammal bones and salmon bones. Elk and deer were the dominant mammals hunted during both periods. Duck bones were found only in the nonshell midden, a finding consistent with the assumption that this was the time of bay development. Arrow points from the mussel shell midden are represented by only four examples; three of these are lanceolate; one has a contracting stem. Arrow points from the nonshell midden are more numerous and include both stemmed and leaf-shaped forms (Figure 3). The largest number of arrow points are stemmed forms recovered from the mixed upper deposits, where they were redeposited during the 20th century by leveling and filling of the site.

The midden deposits at the Wilson River site appear to show very significant environmental changes in Tillamook Bay over at least the last 1,000 years. These changes resulted in shifts in the availability of shellfish obtained within the catchment area of the site's inhabitants. Such shifts were apparently not viewed by the prehistoric inhabitants as sufficiently disruptive to bring about abandonment or relocation of the site. Also, they do not necessarily indicate abrupt subsidence at this location. (The inundated materials might be interpreted as the result of prehistoric trash disposal into the Wilson River rather than as changes in sea level.)

Yet, while there is no direct support for earthquake-generated catastrophic change at this locality, the abrupt disappearance in shellfish utilization can be interpreted as indicating that the rapid habitat change resulted from the periodic building and breaching of the sand spit protecting Tillamook Bay. That breaching and disappearing of the sand spit could have been caused by wave erosion from tsunamis and/or bay seiching.

NEHALEM BAY

With a surface area of 4,100 acres, Nehalem Bay is Oregon's fifth largest estuary (Figure 4). This estuary is unusual in that it does not contain the major beds of native shellfish found farther south. The only abundant clam is the softshell, *Mya arenaria* (Linne), found in tidal flats common along the northern and eastern edge of the bay. Although originally thought to have been introduced, its wide range suggests that it may be native. Unlike the other clams found in the estuaries, it has the ability to withstand significant changes in salinity (White, 1976). Because it can survive in low salinity, it is found as far up the Nehalem River as the town of Nehalem. This clam might survive geological changes that would eliminate an estuary or an environment of a very limited estuary. However, its absence in the Nehalem middens suggests that it was recently introduced or was scarce in prehistoric times.

Near the mouth of the Nehalem estuary, we find a relative abundance of native littleneck clams *(Protothaca staminea)*. Although this clam prefers a high salinity and is also found in sheltered coves along the open coast, its limited presence in Nehalem Bay would be consistent with a relatively new or re-established estuary. These clams occur in Nehalem middens with a scattered and limited distribution. Gapers, butterclams, and cockles also occur in Nehalem middens in small numbers, where they are intermingled with barnacles, ocean mussels, limpets, and sea snails. This suggests that they are not a nearby resource but were transported to Nehalem Bay through trade or infrequent visits to adjoining waters. In fact, Nehalem Bay, unlike Oregon's other major estuaries, lacks identified shell middens despite the presence of numerous late prehistoric house sites and a significant native population during the early historic period, probably because of the fragile nature of the protecting sand spit. This sand spit many have broken down at intervals sufficiently frequent to prevent the development of those conditions favorable to clam beds.

The oldest documented archaeological site of the group of sites at Nehalem Bay (Site 35TI4) is fully inundated and consists of a layer of fire-cracked rock overlain by a 35-cm-thick stratum of silt (Figure 5). The upper 10 cm of the silt include waterlogged organic materials containing leaves of willow, *Salix* sp., and red alder, *Alnus rubra.* Also present is moss (*Sphagnum* sp.), a cone of red cedar (*Thica plicata*), and numerous seeds of Sitka spruce (*Picea sitchensis*). Wood fragments and small logs also occur at the top of the silt and include Douglas fir (*Pseudotsuga menziesii*). These plants are found around Nehalem Bay at forested wetland margins located at present no closer than 0.9 km from this site. Fragments of a waterlogged twinned mat woven from Douglas fir root were found at the top of the silt. A portion of the mat has been radiocarbon dated to 380±60 years B.P., with a calibrated range of A.D. 1410-1635 (Woodward, 1986). This date is consistent with the radiocarbon date of 370±60 years B.P., with a calibration range of A.D. 1431-1660, obtained from the top of a buried marsh at Netarts (Peterson and others, 1988). The silt layer is interpreted as having formed in a sheltered tidal marsh that developed behind a prehistoric sand spit. Sand dunes bordering this marsh stabilized and were invaded by a dense growth of Sitka spruce, willows, red alder, and shrubs, creating a spruce swamp/tidal channel habitat. Leaves and other vegetation fell, were washed directly into a body of quiet shallow water, and there covered with silt. This phase ended abruptly between 300 and 400 years ago

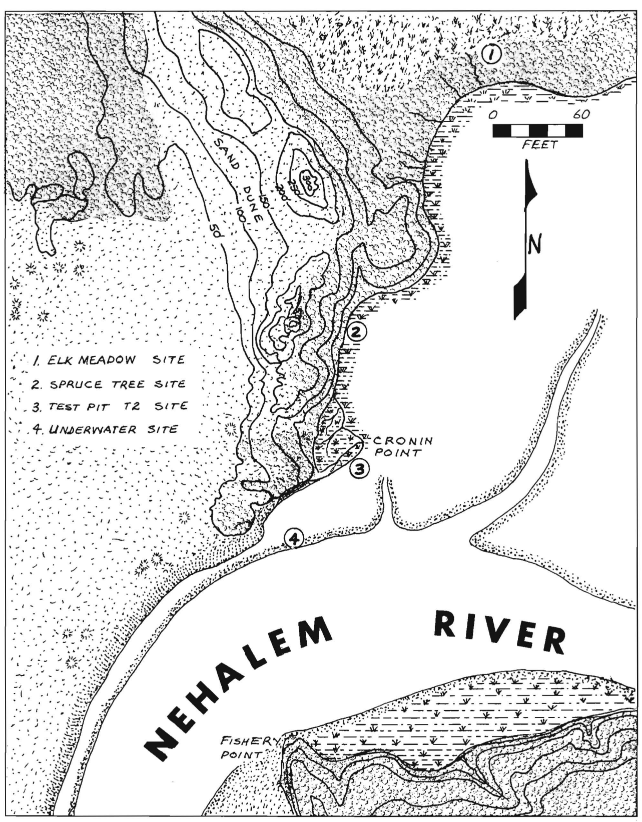

Figure 4. Nehalem Bay redrawn from 1875 map (U.S. Coast Survey Chart, 1875), showing sites discussed in text.

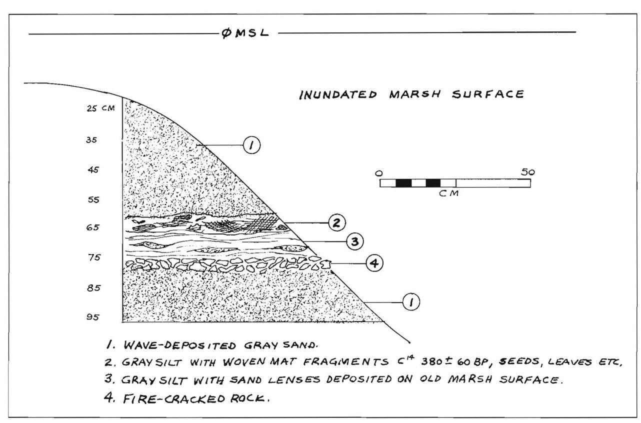

Figure 5. Underwater site, Nehalem Bay. MSL = Mean Sea Level.

with the disappearance of the sand spit and burial of the spruce swamp with wave-transported sand. This was a potentially catastrophic event for any prehistoric community at this location. More recently, channel shifts have cut into the deposits and exposed the edge of the site.

A portion of Nehalem Bay Site 35TI4 is on Cronin Point, which is shown as a tidal marsh in an 1875 geodetic survey of the bay (U.S. Coast Survey Chart, 1875) (Figure 4). At present, a portion of the southern edge of this marsh is experiencing seasonal tidal bank erosion, but other areas are being invaded by wave-deposited alluvium including both sand and cultural material eroded from the bank. These processes occur primarily during the fall and winter. During the spring and summer, silt tends to cover the site, which is largely stabilized by the growth of grasses.

Archaeological testing of this site in 1980 consisted of the excavation of four 1-m by 2-m test pits that were excavated to the summer low-tide water table. Stratigraphic profiles of two of these test pits are shown in Figures 6 and 7. They show evidence of repeated burial of marsh surfaces by wave-deposited sediments. The most recent episode of this process began during the late 19th century and is continuing today. Materials currently moving across the site include a partially sorted deposit consisting primarily of sand, lithic rubble, and mixed cultural materials of all ages. The first author has observed materials, including fist-sized rocks and recent debris, to have been transported at least a meter to the north-northeast by a single intense storm. In 1980, experiments conducted near the site showed that modern ceramic fragments between 1 cm and 5 cm in diameter were transported by incoming tidal action between 2 and 3 m a year in this direction, even without intense storm-tidal action. This rate suggests that much of the fire-cracked rock and artifacts observed at this site originated 200-300 years B.P. and were originally in situ about 550 m southwest of Cronin Point. The rate of littoral transport would, of course, be much more rapid if the Nehalem sand spit did not exist and the location were an open beach. Experiments cited in Bascom (1980) show that some of 600 radioactive pebbles tracked during an experiment on the east coast of England were moved as much as a mile from their original location.

The pattern of frequent episodic marsh burial at Cronin Point during late prehistoric and historic times makes the identification of possible tsunamis difficult because their effects are not easily differentiated from local effects of intense wave action generated by Pacific storms.

At the Spruce Tree site of 35TI4, in situ cultural material occurs beneath a sand dune (Figure 8). At the time this site was occupied, a Sitka spruce swamp existed at this locality,

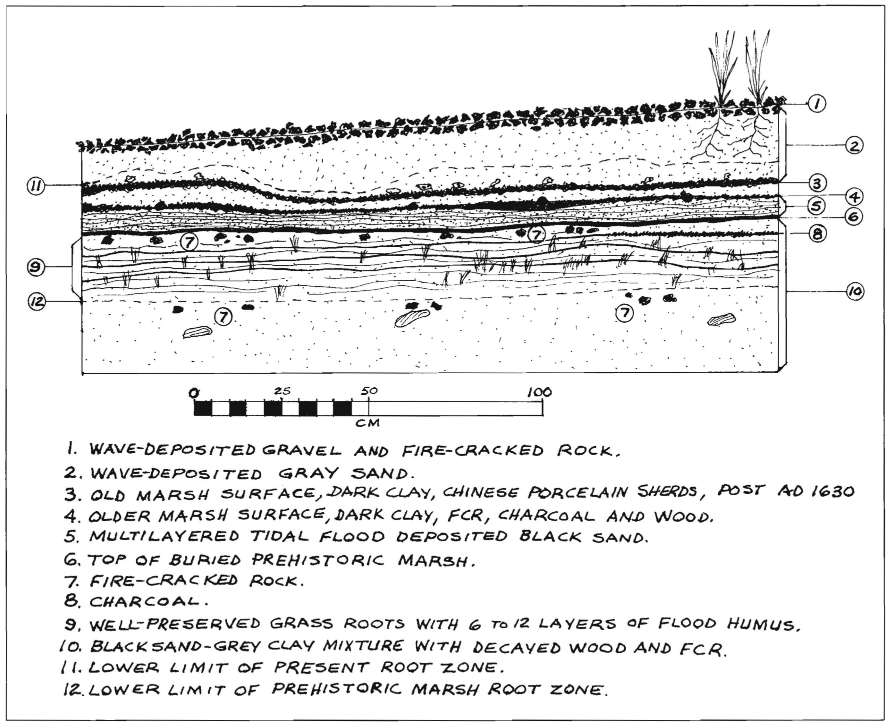

Figure 6. Cronin Point stratigraphy, West Wall Test Pit T2P1, Site 35TI4, Nehalem Bay.

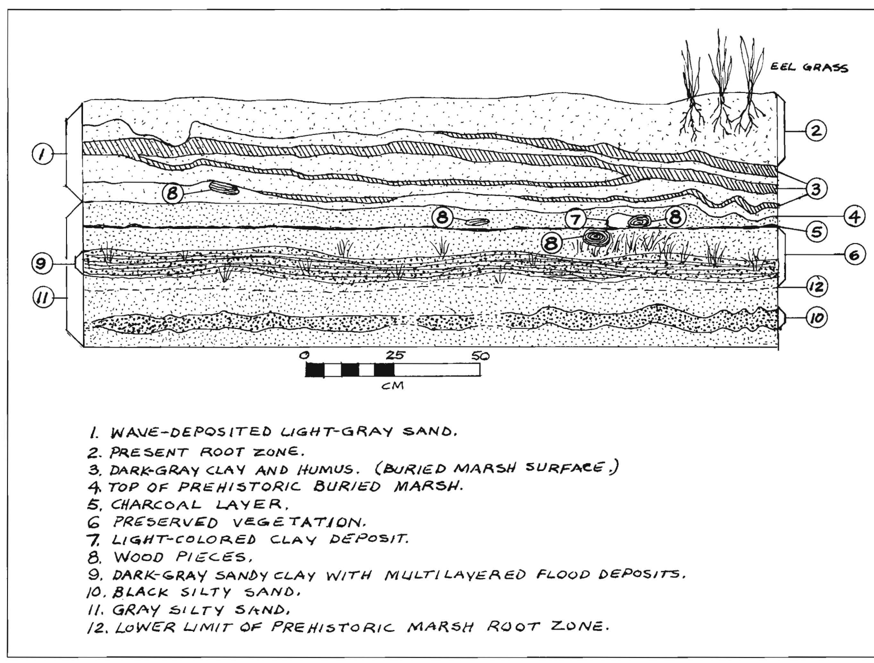

Figure 7. Nehalem Bay stratigraphy, West Wall Test Pit T2P2, Site 35TI4 .

which is now marked by partially inundated roots of these trees. Fire-cracked rock and artifacts occur here on the present marsh surface. A radiocarbon date of 260±40 years B.P. with a calibration of A.D. 1490-1670 has been obtained from charcoal associated with cultural materials (Woodward, 1986).

In 1989, the first author conducted test excavations at the Elk Meadow site of 35TI4 (Figure 9). This site is at the same elevation as the Spruce Tree site on the edge of a sand terrace that extends above sea level at least 2 km north. This site also has inundated spruce tree roots and is shown as forested on the Nehalem Bay survey of 1875. Since 1875, this forest has been replaced by a tidal marsh that has moved north at least 35 m since the site was occupied. The archaeolog-

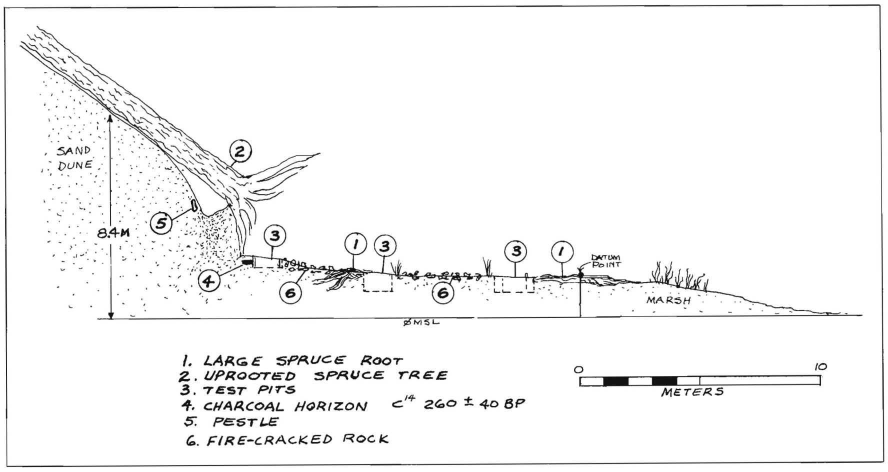

Figure 8. Spruce Tree site, Nehalem Bay.

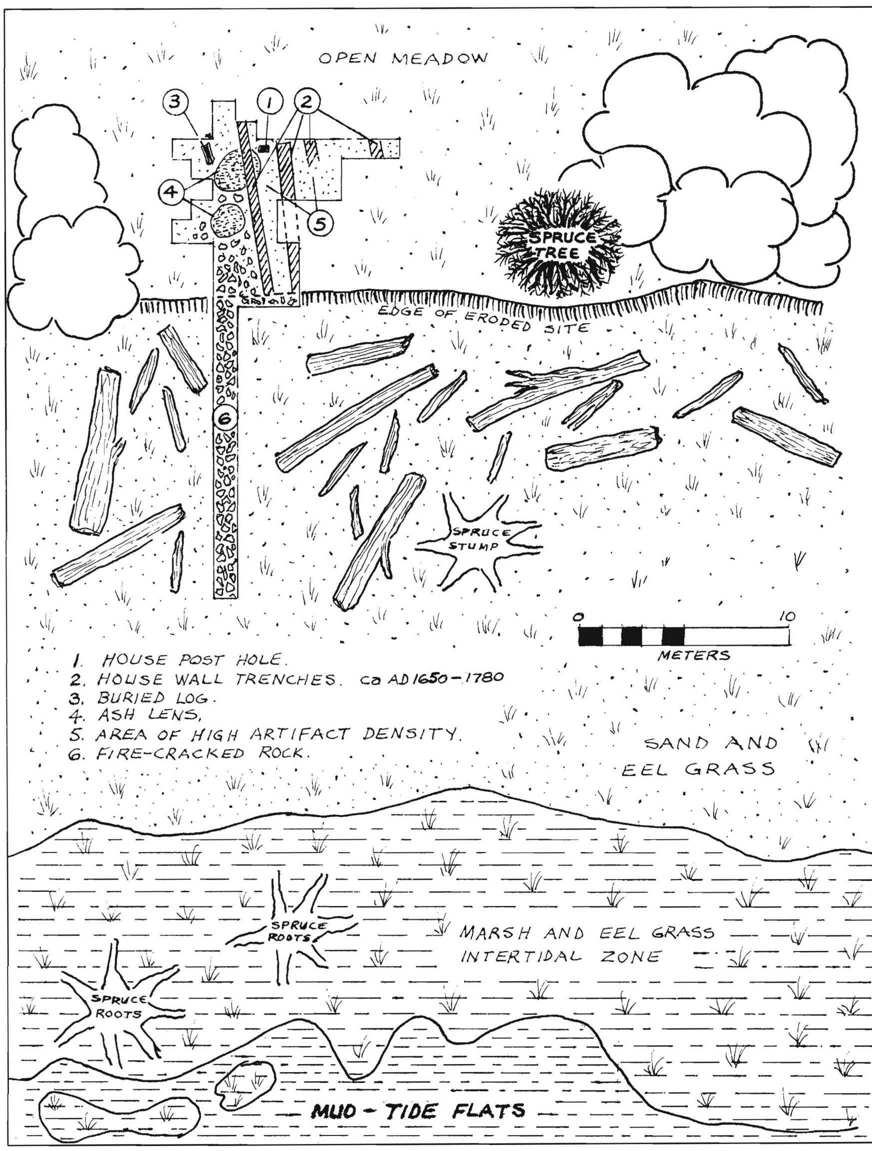

Figure 9. Elk Meadow site, Nehalem Bay.

ical excavations show that a plank(?) house at least 8.5 m long had been constructed fully above ground on the sand sheet. Evidence of food preparation includes a large amount of fire-cracked rock and small fragments of mammal and fish bones. The only bone large enough for identification was identified as from a Roosevelt elk (*Cervus roosevelti*). It is significant that shellfish are entirely absent.

The lithic artifacts recovered from the site include two pestles, eight small arrow points, a stone knife, and 25 hide scrapers (Figures 10, 11, and 12). Beeswax, Chinese ceramics, and iron, lead, and bronze artifacts that were found on the house floor are attributed to a shipwreck (or more) on the Nehalem sand spit (Figures 13 and 14). Absent are glass beads, rolled copper ornaments, or other artifacts associated with the early historic period. This house site, with its primary emphasis on hunting, fishing, cooking, and hide preparation, is dated to ca. A.D. 1650-1780.

The tidal archaeological sites around the Nehalem estuary show that rapid habitat and land-form changes have been ongoing since at least ca. 400 years B.P. Many of these are probably cyclic and associated with the position of the Nehalem River channel and the form of the Nehalem sand spit. At one earlier dated site, however, fully inundated cultural materials were found in association with a wetland pond/Sitka spruce swamp rapidly buried by a massive sand sheet. This burial may be interpreted as evidence of seismic-generated subsidence, a tsunami, or both. Such events would probably have brought about wave erosion of any protecting sand spit and would have exposed Nehalem Bay directly to ocean waves. One result of this could have been the formation of the beach-sand terrace on which the Spruce Tree and Elk Meadow sites are situated.

Geodetic survey maps and photographs made between 1868 (U.S. Coast Survey Chart, 1868) and 1940 show the Nehalem sand spit as a low, narrow, wind-deflated surface almost entirely devoid of vegetation. During the 19th century, the wrecks of possibly two ships were periodically visible on the spit following episodes of wind erosion. The last recorded time that a wreck was visible was 1926. Between 1890 and 1916, one wreck with exposed ribs, a keel, and teak-wood decking was partially stripped of its wood, which was then locally used to make furniture and souvenir walking canes. In 1989, the Quaternary Isotope Laboratory of the University of Washington obtained a radiocarbon date of A.D. 1638±21 (M. Stuiver, personal communication, 1989) from one of these Asian teak-wood (*Tectona grandis*) canes that had been in museum storage. With the age calibration of Stuiver, two age ranges were obtained: A.D. 1517-1593 and A.D. 1620-1639. The Quaternary Isotope Laboratory has also recorded a date of A.D. 1640±20 (M. Stuiver, personal communication, 1990) from a ship's pulley that was made of an Asian wood (*Calophyllum* sp.) (Figure 15). Calibration of this date is A.D. 1519-1589 or A.D. 1622-1639. The pulley was found in 1896 on or near the teak-wood wreck.

The presence of shipwreck debris on the Nehalem spit indicates that the present spit has been in place in some form since at least the early 17th century. The teak-wood wreck lay on its side and is at present buried beneath about 3 m of wind-blown sand. This suggests that at the time of the wrecks, the spit assumed a far lower, more barlike configuration than it now has.

SEASIDE

At Seaside, Clatsop County, a three-site cluster situated on an old beach terrace was excavated by amateur archaeologists in the 1970's (Phebus and Drucker, 1979). Although a complete report is not available, some data concerning these shell middens have been published.

Radiocarbon dates show that the earliest occupation was established on a cobble terrace by at least 600 B.C. This culture, in addition to fishing and the hunting of land and sea mammals, collected bay clams (described as *Schizothaerus nuttallii*, *Saxidomus giganteus*, and *Protothaca staminea*), cockles (*Cardium* sp.), and sea mussels (*Mytilus californianus*). The likely source of the bay shellfish was the now-filled Necanicum estuary.

The site's stable occupation continued with no observed changes in midden composition until site abandonment about 185 B.C. Brief reoccupation is indicated about A.D. 200. A second period of intensive use of the locality occurred between A.D. 245 and 915. The shell middens from this second period lack the estuary shellfish but instead are composed primarily of sea mussels. Sea snails, barnacles, and

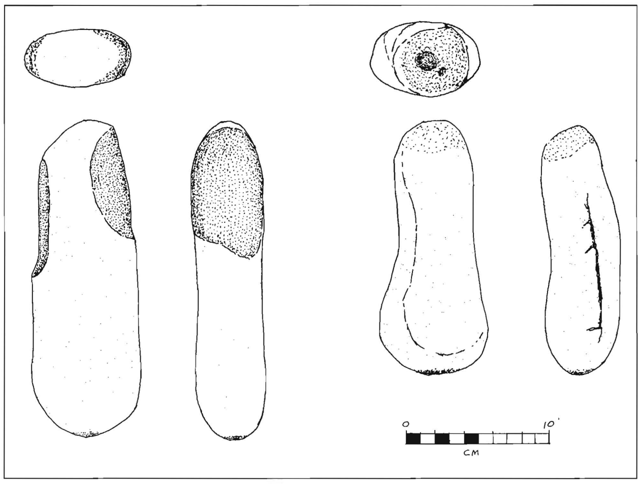

Figure 10. Stone artifacts, Elk Meadow site.

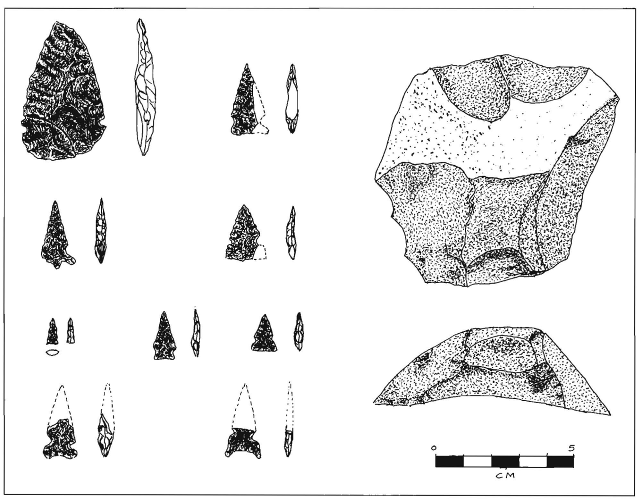

Figure 11. Flaked stone artifacts, Elk Meadow site.

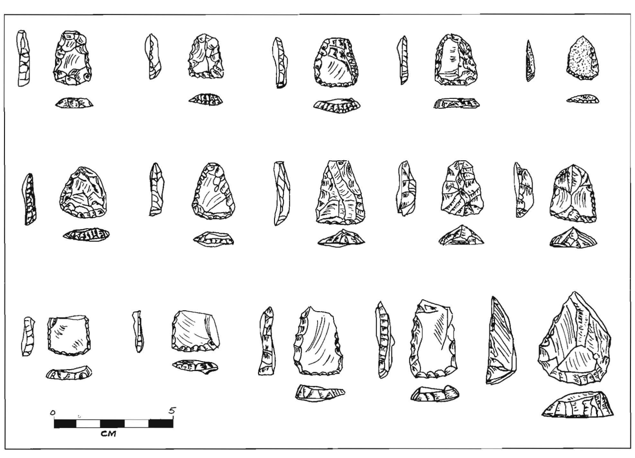

Figure 12. Hide scrapers, Elk Meadow site.

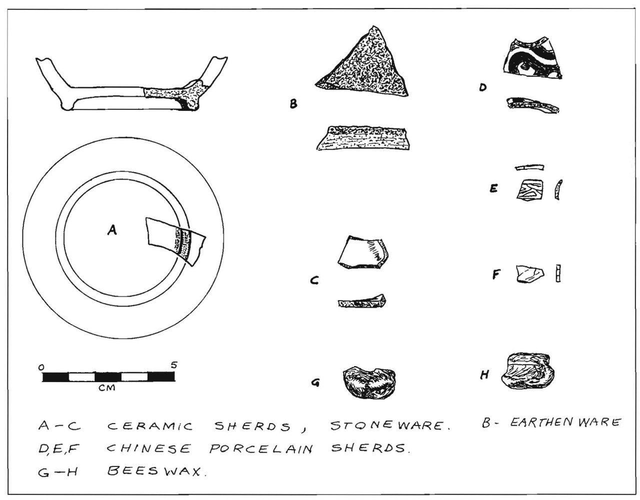

Figure 13. Ceramic and beeswax artifacts, Elk Meadow site.

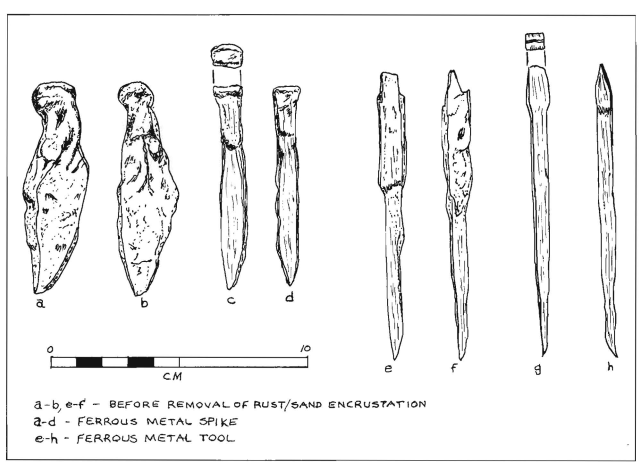

Figure 14. Iron artifacts, Elk Meadow site.

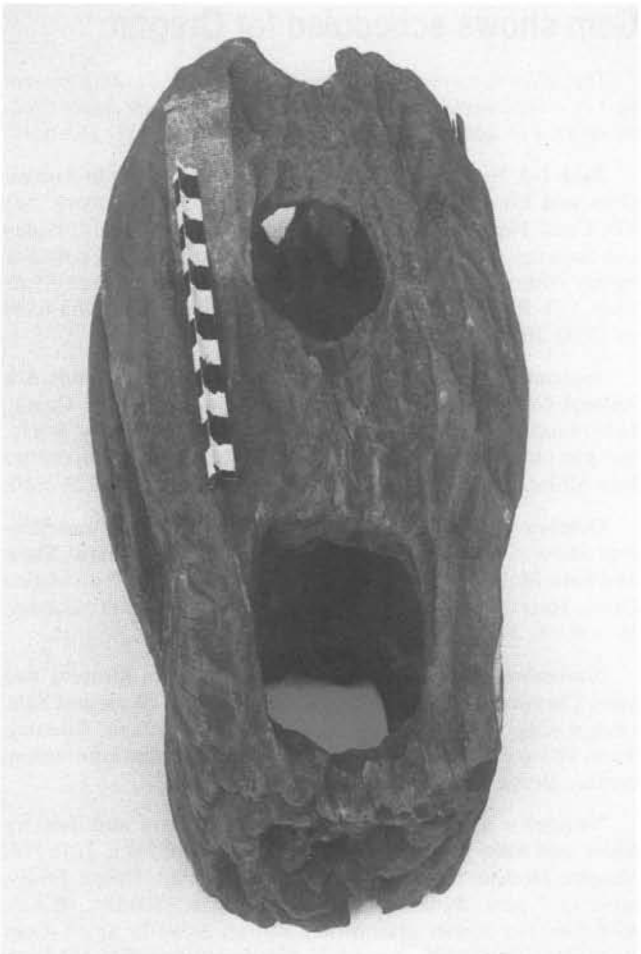

Figure 15. Ship's pulley from prehistoric shipwreck on Nehalem sand spit. Photo courtesy of Wayne Jensen, Jr.

razor clams were also observed, indicating that, at this time, the Necanicum estuary no longer was extant, and an open-beach environment existed similar to that found at Seaside today.

Although artifacts from both the bay-clam and the mussel-collecting cultures exhibit similar bone and stone tool types, there are enough significant differences in house form, artistic expression, and woodworking technology to indicate that the littoral mussel collectors may not have been the direct descendents of the earlier bay clam collectors. There is archaeological evidence that a population replacement occurred between A.D. 200 and 300 and was directly linked to a relatively rapid change in the Necanicum estuary and loss of its major shellfish resources. Phebus and Drucker (1979) conclude that "...the Seaside area, north of Tillamook Head, has undergone some dramatic topographical alterations that must have certainly required some serious economic adjustment on the part of the native population."

CONCLUSIONS

Archaeological sites located near four present or prehistoric estuaries on the northern Oregon coast show evidence of landform/habitat changes associated with sand-spit stability during the last 2,000 years. Shellfish utilization by prehistoric inhabitants is an important indicator of estuary change that may be the result of rapid subsidence, tsunamis, or intense-storm waves. At Netarts, Tillamook, and Nehalem Bays, we find inundated archaeological materials that suggest sea-level changes resulting from subsidence. However, prehistoric human occupation at Netarts and Tillamook Bays appears to have continued without being affected by catastrophic events. One of the archaeological sites on Nehalem Bay shows an episode of rapid microenvironmental changes and sand burial attributed to a tsunami, subsidence, or both. The result of this episode, which likely occurred between 300 and 400 years B.P., may have been catastrophic for any inhabitants of the site.

ACKNOWLEDGMENTS

We wish to express our special appreciation to Sharon Woodward for her assistance with excavation supervision, artifact drawing, and typing of this report. Barbara McCorkle also helped with artifact analysis and drawing, and Wayne Jensen of the Tillamook Pioneer Museum provided important support for archaeological research in Tillamook Bay. C. Dale Snow kindly took time to review the report, and Steve Cragg located funds for radiocarbon dating. Susan Foster and Jack Foster of Mount Hood Community College assisted in identification of faunal remains.

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Number of significant earthquakes down in 1989

Although the magnitude 7.1 Loma Prieta earthquake that struck the Santa Cruz Mountains of California on October 17, 1989, made the United States particularly earthquake sensitive, the world actually had slightly fewer significant earthquakes during 1989 than the average for the past two decades.

Earthquakes are defined as "significant" if they register a magnitude of at least 6.5 or, with a lesser magnitude, cause casualties or considerable damage.

The average number of significant earthquakes per year has been about 60 since record-keeping began in the early 1970's. The 55 significant earthquakes reported during 1989 were also six fewer than the total for the previous year.

In addition, the 526 persons believed to have died in consequence of earthquakes around the globe in 1989 were significantly fewer than the 28,000 or more believed to have perished in earthquakes in 1988. The number is also well below the average of 10,000 deaths per year from earthquakes.

The most deadly earthquake of 1989 was a magnitude 5.3 tremor that shook the Tajik region of the Soviet Union on January 22, triggering landslides that buried several villages and killed an estimated 274 persons.

The second most deadly seismic event was a magnitude 5.7 earthquake in Iran on August 1 that is believed to have killed at least 90 people and injured 15, when their villages were struck by earthquake-induced landslides.

The strongest tremor and the only "great" earthquake (magnitude of 8.0 or larger) recorded was an 8.3-magnitude earthquake on May 23 in the South Pacific near the Macquarie Islands, about midway between Australia and Antarctica. The island region is sparsely populated, and there were no reports of injuries or damage.

The Loma Prieta earthquake in California caused 62 deaths, injuries to more than 3,500 people, and property damage estimated at $5.6 billion. Five others of the world's significant earthquakes occurred in the United States or nearby waters. Only one of these, an August 8 tremor of magnitude 5.3 near Los Gatos, California, caused a death, when a young man became disoriented and jumped from a second-story balcony. The others occurred in Hawaii (June 26, magnitude 6.2), west Los Angeles (January 19, magnitude 5.2), southern Alaska (September 4, magnitude 6.9), and the Andreanof Islands of the Aleutians (October 7, magnitude 6.7).

Among the earthquake reports worldwide for 1989, a few items are particularly noteworthy: The People's Republic of China had five significant earthquakes that caused 37 deaths and considerable damage. At least 30 people were killed when a magnitude 5.9 tremor hit northern Algeria on April 15. Australia, which normally does not experience many damaging earthquakes, recorded at least 11 deaths and considerable damage when a magnitude 5.5 tremor hit Newcastle, near the southeastern coast on December 27. Japan, which recorded only one significant earthquake in 1988, experienced five significant tremors during 1989. All the earthquakes were centered east and south of the island of Honshu. One person was killed in a magnitude 5.5 tremor on February 19.

—*U.S. Geological Survey news release*

Notice to OSU geology graduates

We were asked by the Department of Geosciences of Oregon State University to publish the following notice:

To all Oregon State University Geology alums. If you have never received a Biennial Report, or if your address is wrong on the last report you have received, or if you know of someone who should be on the alum list, please send a current address to Therese Belden, Department of Geosciences, Oregon State University, Wilkinson Hall 102, Corvallis, OR 97331-5506, or call her at (503) 737-1238. □

Gem shows scheduled for Oregon

The following news of upcoming gem shows in Oregon were part of a list compiled by Kay Myers, Oregon Coast Agate Club, Newport. For additional information, call her at (503) 265-6330.

June 1-3, Newport: Oregon Coast Agate Club, 26th Annual Gem and Mineral Show. Oregon National Guard Armory, 541 SW Coast Highway 101. Dealers (no tailgating). Hours: Friday and Saturday, 10 a.m. to 6 p.m.; Sunday, 10 a.m. to 5 p.m. For further information, contact Ethel Baldie, c/o Oregon Coast Agate Club, P.O. Box 293, Newport, OR 97365, phone (503) 265-6330 or (503) 265-6334.

September 1-3, Canby: Willamette Valley Rockhounds, 8th Annual Gem, Mineral, and Jewelry Show. Clackamas County Fairgrounds, Highway 99E. Hours: Saturday and Sunday, 9 a.m. to 6 p.m.; Monday, 9 a.m. to 4 p.m. For further information, contact Jean Miller, Box 136, Molalla, OR 97038, phone (503) 829-2680.

October 19-21, Portland: Portland Regional Gem and Mineral Show Association, 10th Annual Gem and Mineral Show and Sale. Multnomah County Exposition Center, off I-5 on Marine Drive. Hours: Friday and Saturday, 10 a.m. to 7 p.m.; Sunday, 10 a.m. to 5 p.m.

November 10-11, Oregon City: Clackamette Mineral and Gem Corporation, 27th Annual Rock and Gem Show and Sale. Oregon City High School, 11th and Jackson. Hours: Saturday, 9 a.m. to 8 p.m.; Sunday, 10 a.m. to 5 p.m. For further information, contact Bernie Schultz, phone (503) 656-3347.

November 16-18, Portland: Gem Faire Gem and Jewelry Show and Sale. Montgomery Park Exhibition Center, 2701 NW Vaughn. Dealers' inquiries invited (no tailgating). Hours: Friday, noon to 7 p.m.; Saturday, 10 a.m. to 7 p.m.; Sunday, 10 a.m. to 6 p.m. For further information, contact Steve E. Small, Gem Faire, Inc., Box 3296, Reno NV 89505, phone (702) 356-0516 or (503) 265-6330. □

(***Geothermal***, *continued from page 56)*

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The case of the counterclockwise river

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, Portland, Oregon 97207-0751

INTRODUCTION

A tiny creek appears just east of Cochran, a former Southern Pacific Railroad station located at the summit elevation of 1,808 ft in a little-known pass through the northern Coast Range of Oregon. For 6 mi, the creek flows east to the town of Timber, where the valley widens and the creek, gathering water from several tributaries, meanders north for almost 10 mi across narrow flood plains and then turns northeast for 4 mi to Vernonia.

Within slightly incised meanders through a narrower valley, the creek continues from Vernonia north-northeast for 5 mi, then north-northwest for 5 mi, and northwest 4 mi to the town of Mist. There it takes a 6-mi arc to the west and southwest to arrive at Birkenfeld, where it begins a generally southwest-trending and deeply incised meandering course for 25 mi to the mouth of the Salmonberry River, a stream that completes the oval, since only 14 mi upstream to the east, the headwaters of one of its tributaries begin just south of Cochran, within a mile of where our river began!

This is the peculiar 65-mi-long counterclockwise loop made by the Nehalem River around the heart of the northern Coast Range before it turns west-southwest for the last 15 mi through deeply incised meanders to Nehalem Bay and the Pacific Ocean. The width of the Coast Range between Forest Grove and Tillamook Bay is less than 40 mi; the Nehalem River valley is more than 90 mi long.

DISCUSSION

The purpose of this essay is to develop multiple hypotheses, one of which might account for this apparently anomalous course of the Nehalem River, a minor geomorphic puzzle that has intrigued me for more than 40 years, ever since the publication of the first geologic map of the area (Warren and others, 1945). Old-fashioned armchair geomorphic analysis, "reading the contours" of topographic maps, which I have sometimes indulged in since my retirement (Allen, 1975, 1989a,b) can occasionally furnish valuable insights into the geologic history of an area.

I have heard that the course of the Nehalem River caught the attention of interpreters scanning satellite images, looking for "astroblemes," structures produced by the impact of large meteorites or comets. Although this hypothesis (no. 1) can be quickly discarded, another hypothesis (no. 2) is suggested by similar drainage patterns that can form within giant calderas produced by great volcanic explosions.

Structural uplift or doming, as in the Black Hills of South Dakota, is a third more likely explanation (no. 3); its implications will be explored later. Still another hypothesis (no. 4) suggests that the Miocene Nehalem River, originally flowing east into the Columbia, was diverted north and then west by flows of Yakima Basalt filling the ancestral Columbia River valley.

Geographic factors that can be investigated during a study of these hypotheses are statistics on relative rainfall, length and gra-

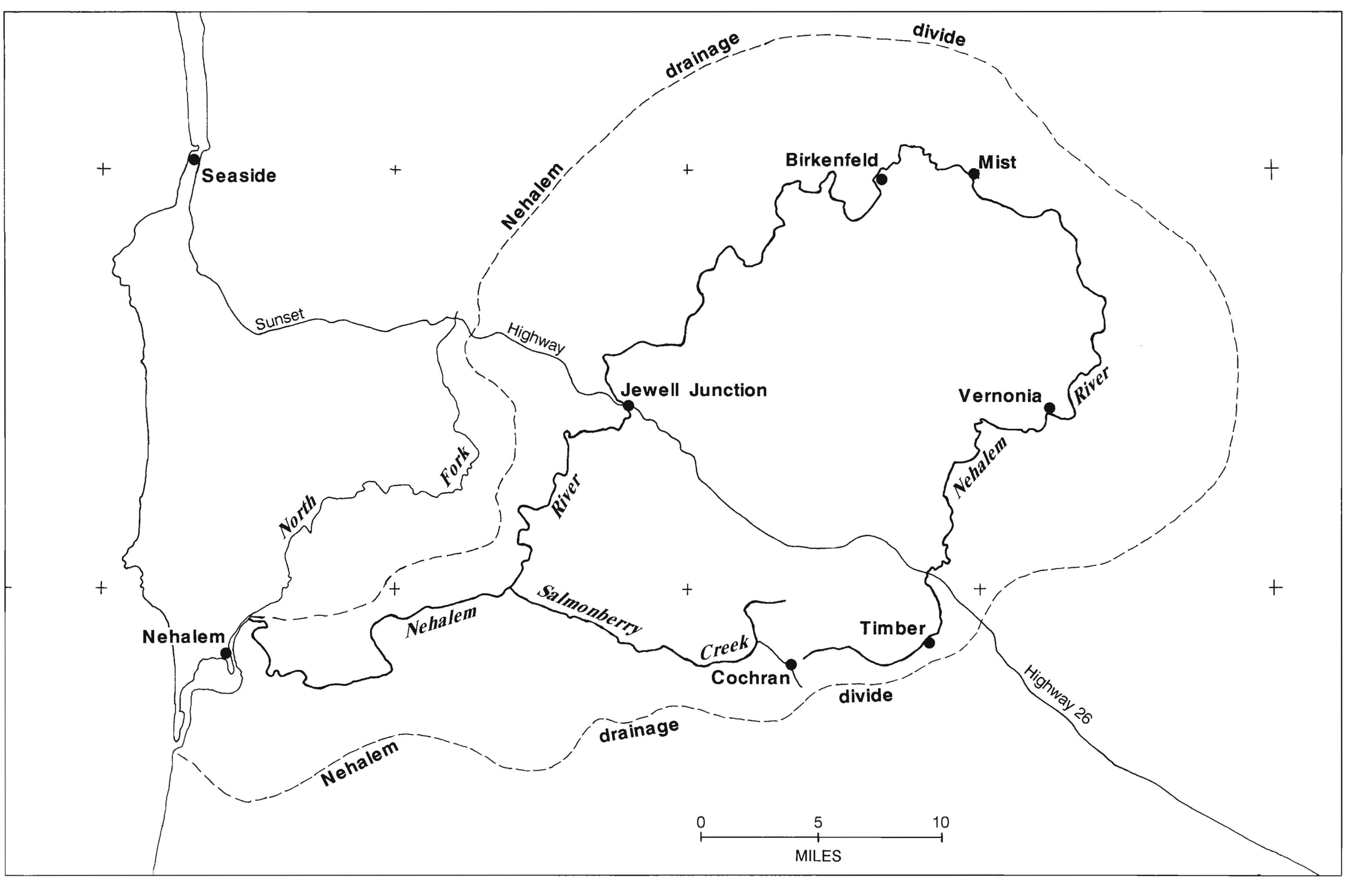

Figure 1. Index map showing counterclockwise course and drainage area of the Nehalem River in northwest Oregon.

dients of stream channels, and changes of drainage divides. Geomorphic features to be studied include presence or absence of meanders (especially when incised), different valley-wall slopes and benches or terraces, upland surfaces of low relief (which used to be called "peneplains"), and barbed tributaries.

Along the Oregon coast, geologic and geomorphic features were studied by Lund (1971, 1972a,b, 1973a,b, 1974a,b, 1975), but within the northern Oregon Coast Range, possibly due to heavy vegetation, the geologic maps of Warren and others (1945), Wells and Peck (1961), and Niem and Niem (1985) are the only ones that have been published, and no geomorphic studies have been made.

Areal geology and bedrock structure ("ground truth") must always be considered whenever geologic maps are available, since bedrock characteristics can affect drainage patterns and result in drainage changes due to differential erosion. Dipping strata can cause lateral migration of valleys. Vertical beds or a fault zone may result in a straight valley course. Tight folding may result in an Appalachian-type trellis pattern, and domal uplift may produce both radial and concentric patterns.

GEOGRAPHY

Careful map measurements on seven 15-minute quadrangles (Birkenfeld, Cathlamet, Enright, Nehalem, Saddle Mountain, Timber, and Vernonia) gave the length of the Nehalem River valley as 88 mi, with a valley gradient of 20 ft per mi (determined by dividing the change in elevation between the start and end of the river, which is 1,808 ft, by the length of the river, which is 88 mi, giving a gradient of approximately 20.5 ft per mi). Repeated, more precise measurements following each meander gave a "channel length" of 121 mi. The average river gradient (1,808 ft divided by 121 mi = 14.9 ft per mi) itself is thus approximately 15 ft per mi.

One tributary of the Salmonberry River rises near Cochran and joins the river, which flows 14 mi westerly to its mouth on the Nehalem at an elevation of 231 ft. The Salmonberry River thus completes the southwest 55° of the 305° Nehalem loop, with a channel gradient of 113 ft per mi (1,808 ft - 231 ft = 1,577 ft divided by 14 mi = 113 ft per mi), 7.53 times that of the Nehalem. The area within this loop is nearly 300 mi^2, while the area within the Nehalem River drainage (excluding the North Fork) is a little more than twice that.

Average annual rainfall in the northern Coast Range is higher than anywhere else in Oregon, being 110 in. at Nehalem near the mouth of the river and 130 in. at Glenora on the Wilson River, 10 mi southwest of Cochran. West of the main drainage divide of the Coast Range, adiabatic/orographic rainfall is greater than to the east, and stream gradients are steeper since they travel a much shorter distance to the sea. Erosion on the west side of the northern Coast Range could well have been more rapid than anywhere else in the state.

GEOMORPHOLOGY

Barbed tributaries in the Coast Range can indicate stream capture of the headwaters of streams flowing east into the Willamette River. Barbed tributaries on both the South and North Forks of the Salmonberry River suggest that at least 8 mi of the Nehalem has been captured and that the North Fork before its capture at a point 1½ mi west of Cochran once formed the headwaters of the Nehalem River.

The result of such stream captures is that the Coast Range drainage divide here lies farther to the east than anywhere else north of Eugene. At its easternmost limit, the divide now lies within 12 mi of the Columbia River; south of the Nehalem drainage basin, the Coast Range divide lies 15 mi farther to the west. At its northern limit, the Nehalem drainage divide lies only 2 mi south of the Columbia River.

Usually a stream will constantly adjust its course so as to run on the most easily eroded bed rock. The location of a stream then is nearly always a result of such differential erosion of the various kinds (stratigraphy) and the folding and fracturing (structure) of the bed rock. Thus the stream may follow a bed of soft shale lying between more resistant sandstone layers, or it may follow a zone of broken rock caused by a fault or sets of closely spaced joints.

Within the Nehalem drainage basin, upland areas of gently rolling surfaces can be observed on several of the quadrangles. These could be interpreted as remnants of a once continuous, late mature or early old-age erosion surface. Elevations on this surface usually lie between 800 and 1,200 ft, with few ridges and prominences rising above them to above 2,000 ft.

The Nehalem drainage divide is marked by several basaltic prominences reaching nearly 3,000 ft or more. Among these are Saddle Mountain, Humbug Mountain, Onion Peak, Pinochle Peak, Rogers Peak, Larch Mountain, and Round Top.

STRATIGRAPHY AND STRUCTURE

The cast of our detective story must include the geologic formations making up the northern Coast Range, whose names and ages are as follows (Baldwin, 1981):

Miocene (5.3 to 23.7 million years):
- Yakima Basalt Subgroup of the Columbia River Basalt Group
- Astoria Formation

Miocene and Oligocene:
- Scappoose Formation

Oligocene (23.7 to 36.6 million years):
- Pittsburg Bluff Formation

Eocene (36.6 to 57.8 million years):
- Keasey Formation
- Goble Volcanics
- Cowlitz Formation
- Yamhill Formation
- Tillamook Volcanics
- Siletz Volcanics

The most important player in this "Case of the Nehalem Loop" is certainly the Keasey Formation, an easily eroded mudstone and shale, with the underlying resistant lavas of the Goble and Tillamook Volcanics and the overlying Pittsburg Bluff sandstones as supporting players and possibly the Yakima Basalt also entering into the plot.

Faulting appears not to have significantly interrupted the contacts of the formations or affected the course of the Nehalem. The relatively straight 25-mi-long, generally east-west course of the Salmonberry and upper Nehalem might suggest this, but such a fracture has not yet been mapped.

CONCLUSIONS

A much simplified history of the main structural feature involving the above formations, as first suggested by Warren and others (1945) and later presented on the state geologic map (Wells and Peck, 1961), indicates that beginning perhaps in late Miocene time, the formations named above began to be arched up into a north-northeast-plunging geanticline.

Millions of years of slow erosion then beveled off this giant fold, reducing it to a surface of low relief, with streams meandering near sea level. Eocene volcanic rocks were exposed in the core of the fold, and outcrops of the later sedimentary formations formed arcuate belts around the plunging north end of the fold. Pliocene and later uplift eventually rejuvenated the streams and incised their meanders into the rising lowlands, etching out valleys in the weaker Keasey Formation.

One resulting deduction (hypothesis no. 3, modified) is that during this second period of uplift and resulting orographically increased rainfall, the Nehalem River captured all the streams that occupied the arcuate belt of Keasey shale during the rapid clockwise headward erosion of most of the upper part of its valley.

For the 45 mi from Timber to Jewell Junction, the Nehalem River follows this Keasey belt, with the exception of a 10-mi stretch north of Vernonia, where its meanders have cut less than a mile into the Pittsburg Bluff Formation. The lower 40 mi of the valley, from Jewell Junction to Nehalem Bay, is mostly carved in resistant Tillamook Volcanics. The river originally meandered across a surface of low relief, now uplifted to 800-1,000 ft, upon which the major drainage pattern was established as the range began to rise.

The lower course of the river became fixed within the underlying volcanic rocks, but the upper course migrated down-dip on the "slip-off" contact at the base of the Keasey shale, moving the Coast Range drainage divide 10 to 15 mi to the north and east.

Still another possible deduction (hypothesis no. 4) proposes that a middle Miocene Nehalem River, which originally flowed east across a topography of low relief, was diverted north and west by flows of Yakima Basalt that filled a former broad valley of the Columbia River, then located 10-20 mi west and south of its present course. Today, numerous erosional remnants of basalt lie less than 10 mi from the Nehalem River along most of its course.

Whichever hypothesis is finally chosen (and the main purpose of this discussion is to spur further investigation), the Nehalem River remains the longest river within the Oregon Coast Range and the only one with 305° of counterclockwise course.

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Hungarian appeals to mineral collectors

We have received a request from a mineral collector in Budapest, Hungary, and we are passing it on, hoping to reach some collectors interested in contacting this person. His letter is printed below, with a few editorial changes needed to clarify the writer's English.
(Editors)

Budapest, October 30, 1989

I am sorry I cannot write to you in my poor English.

I am a Hungarian mineral collector. That is unusual in Hungary, so it's very difficult for me. In Hungary, we have only few people whose profession is mineral collecting.

In early 1989, the Society for Popularization of Scientific Knowledge approached me, because I have a considerable collection, and they want to make a comprehensive exhibit of my collection. I was happy, but I haven't one perfect, good mineral from your country.

If it were possible for you to send me any mineral from the U.S.A., I would be very happy and grateful, and it would be a great help for my exhibit.

I offer to send Hungarian minerals in exchange. Accurate scientific names with precise locality information (e.g., pegmatite deposits, mineralogy of Nb, Ta, Ti, REE minerals, pegmatite phosphates, feldspars, and minerals of the zeolite group).

In Hungary, we hear very rarely about American minerals. So you can send us what you want. We trust you. Any assistance you can give me in locating literature will also be most appreciated.

Sorry for my poor English again, but I am looking forward to hearing from you soon. Should you wish to send us minerals or literature for our collection, please send them to this address:

Gabor Tompai
Geology
Körösi Csoma ut. 5.
9. em. 27.
H-1102 Budapest
Hungary.

Thanks for your kindness!
Yours very sincerely,
Gabor Tompai □

Financial assistance for geologic studies in Washington available

Awards to help defray expenses will be available in the 1991 fiscal year for original geologic mapping and other geologic studies that are useful to the Washington Division of Geology and Earth Resources in compiling the new geologic map of Washington.

Available funds will be approximately $15,000 for fiscal year 1991, and awards wil be made on the basis of proposals submitted. First priority will be given to proposals for work in areas lying within the northwest and southeast quadrants of the new state geologic map that are currently unmapped, poorly mapped, or poorly understood geologically. Proposals are due by June 4, 1990.

For additional information and suggestions, interested persons may consult with Division staff, specifically J. Eric Schuster, Assistant State Geologist, State Geologic Map Program, Division of Geology and Earth Resources, Department of Natural Resources, Mail Stop PY-12, Olympia, WA 98504, phone (206) 459-6372 or SCAN 585-6372; or Keith L. Stoffel, Geologist, Spokane Field Office, Division of Geology and Earth Resources, Department of Natural Resources, Spokane County Agricultural Center, N. 222 Havana, Spokane, WA 99202, phone (509) 456-3255 or SCAN 545-3255. □

MINERAL EXPLORATION ACTIVITY

Major metal-exploration activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	QM Chevron Resources, Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources, Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App
March 1990	Red Jacket Bond Gold	T. 9 S. R. 17 E. Jefferson County	Gold	App

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

Exploration and bond ceiling rule making

Advisory committees organized to make recommendations on exploration permits (HB 2088) and bond ceilings for some metal mines (SB 354) finished their work in April. For a copy of either set of draft rules or a schedule of rulemaking hearings, contact Doris Brown at the Oregon Department of Geology and Mineral Industries (DOGAMI) Mined Land Reclamation Office, 1534 Queen Avenue SE, Albany, OR 97321, phone (503) 967-2039.

Mining issues forum

A steering committee has been established to determine the format, time, and location of the forum. The committee is composed of representatives from environmental groups, mining companies, regulatory agencies, and state and local elected officials. Additional information will be presented in future issues of *Oregon Geology.*

Status changes

The operating-permit application for the Formosa Exploration Silver Peak mine has been determined to be complete and adequate. The permit will be issued upon receipt of the financial security. A summary of the operation and permit is available from the MLR office for comments.

The meeting of the project coordinating committee for the Hope Butte project by Chevron was rescheduled from February to May.

Bond Gold has applied for an exploration permit in Jefferson County.

All readers who have questions or comments about exploration activity should contact Gary Lynch or Allen Throop at the MLR office in Albany, phone (503) 967-2039. □

New field trip guides for Oregon published

Field excursions to volcanic terranes in the western United States, Volume II: Cascades and Intermountain West. Published by New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801, Memoir 47, $17 plus $1.50 for postage and handling.

The geology of some volcanic terranes in Oregon is presented in field trip guides included in this recent publication: (1) a one-day trip from Hood River to Portland via Mount Hood, with optional side trips to Old Maid Flat and Mount Tabor/Boring Lava exposures; and (2) three legs of a Southern Cascades trip leading from Klamath Falls through Klamath Basin to Crater Lake and through the Western Cascades to Medford and Siskiyou Pass.

The field trip guides are part of volume II in a two-volume set, Memoirs 46 and 47 of the New Mexico Bureau of Mines and Mineral Resources. They were published in conjunction with the General Assembly of the International Association of Volcanology and Chemistry of the Earth's Interior held in June 1989 at Santa Fe, New Mexico.

Guidebook for field trip to the Mount Bachelor-South Sister-Bend area, central Oregon High Cascades. Published by U.S. Geological Survey, Open-File Report 89-645, available for $10.25 from U.S. Geological Survey Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225.

This field guide to the central Oregon High Cascades highlights aspects of the volcanic and glacial history in the vicinity of Mount Bachelor (formerly Bachelor Butte), South Sister, and Bend.

The three one-day field excursions were conducted on the occasion of the Fall 1989 Meeting of the Friends of the Pleistocene. Each field trip log begins at Little Fawn Campground, a group campground run by the USDA Forest Service on the south end of Elk Lake near Mount Bachelor. □

(***Proceedings**, continued from page 50)*

states of Oregon, Washington, Idaho, Montana, and the Province of British Columbia, and in Virginia, where the 26th Forum is scheduled to be held in May of this year. Seven papers describe specific commodities such as bentonite, limestone, pozzolans, rare earths, talc, and zeolites. Three papers discuss various methods and problems in laboratory analysis of industrial minerals.

The new publication, DOGAMI Special Paper 23, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. The price is $9. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

		Price √
GMS-4	Oregon gravity maps, onshore and offshore. 1967	3.00
GMS-5	Geologic map, Powers 15-minute Quadrangle, Coos/Curry Counties. 1971	3.00
GMS-6	Preliminary report on geology of part of Snake River canyon. 1974	6.50
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OREGON GEOLOGY

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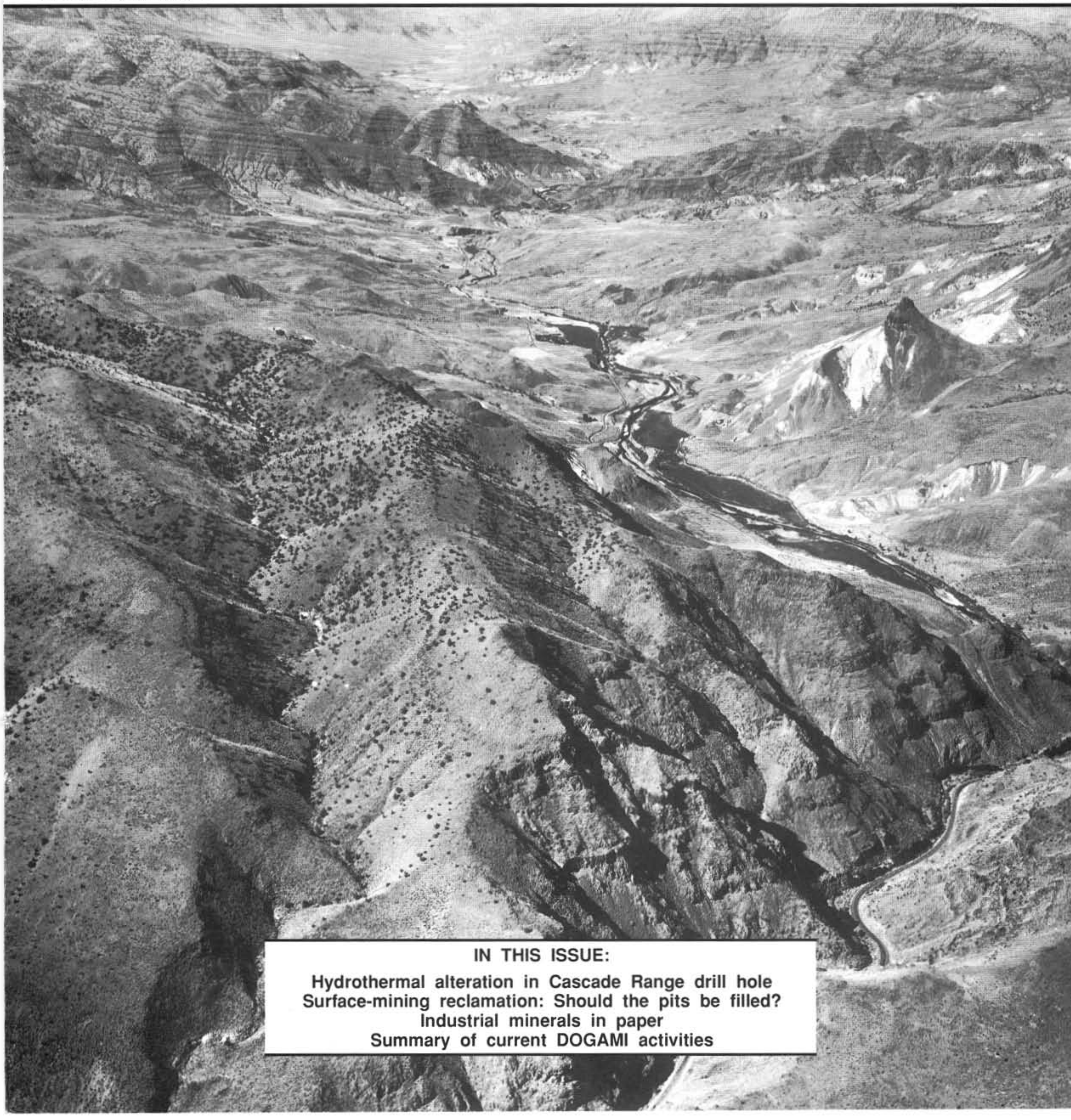

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Surface-mining reclamation: Should the pits be filled?
Industrial minerals in paper
Summary of current DOGAMI activities

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OIL AND GAS NEWS

DY Oil performs workover on gas well

DY Oil has completed workover operations on its well Neverstill 33-30 at Mist Gas Field, Columbia County. Since gas production from the well had declined significantly, the well was reperforated within the Clark and Wilson sandstone reservoir in an attempt to restore commercial production. The well was put back into production during May. This is the only well at the field that is not operated by ARCO Oil and Gas Company.

Rules to be presented for adoption

In June, administrative rules for implementation of Oregon House Bill 2089 were adopted by the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI). These rules provide for ground-water protection and surface reclamation when shallow exploratory holes, such as seismic shot holes, are drilled by the oil and gas industry in Oregon. Copies of these rules will be available in August. For details, contact Dan Wermiel at the DOGAMI office, phone (503) 229-5580. □

DOGAMI Governing Board adds new member

John W. Stephens of Portland has been appointed by Governor Neil Goldschmidt and confirmed by the Oregon Senate for a four-year term as member of the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI). He succeeds Portland lawyer Donald A. Haagensen.

A native of Portland, Stephens is a Stanford graduate and received his law degree from the University of California at Los Angeles. He is a partner in the Portland law firm of Esler, Stephens, and Buckley. During the last six years, he also served on the board of directors of the Northwest Pilot Project, a volunteer social-service agency. Stephens has had a lifelong, even if nonacademic, interest in the geology of Oregon and attended the central Oregon summer camps of the Oregon Museum of Science and Industry at Camp Hancock for several years when he was growing up.

Serving with Stephens on the three-member board are Sidney R. Johnson, current chair, president of Johnson Homes in Baker City, and Ronald K. Culbertson of Myrtle Creek, president of the South Umpqua State Bank in Roseburg. □

Contents

Hydrothermal alteration in geothermal drill hole CTGH-1, High Cascade Range, Oregon

by Keith E. Bargar, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025

ABSTRACT

Geothermal drill hole CTGH-1, located about 14 km northeast of Breitenbush Hot Springs in the High Cascade Range of northwestern Oregon, was drilled to a depth of 1,463 m. The maximum reported temperature at the bottom of the drill hole was 96.4 °C. Continuous drill core from the CTGH-1 drill hole consists of andesitic to basaltic lava flows, tuffs, and volcanic breccia. Red to orange iron-oxide-stained tuffaceous rocks are at least partly altered to smectite. Vesicles, fractures, and open spaces between breccia fragments are partly to completely filled by secondary minerals. Initial alteration mineral deposits consist of iron- and magnesium-rich minerals (hematite, smectite, and celadonite), which were followed by precipitation of potassium-rich minerals (celadonite, wellsite, and phillipsite). Later formed deposits include sodium-rich analcime, clinoptilolite, calcium-rich zeolite minerals (chabazite, erionite, heulandite, scolecite, and thomsonite), silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz), and mordenite. Minor native copper, calcite, apatite(?), and adularia(?) are present in the drill core. The above secondary minerals are compatible with the present low-temperature hydrothermal conditions.

INTRODUCTION

Geothermal drill hole CTGH-1 is located about 14 km northeast of Breitenbush Hot Springs and 6 km northwest of Olallie Butte, at an elevation of 1,170 m, near the Western Cascade-High Cascade boundary in northwestern Oregon (Figure 1). Drilling of the 1,463-m-deep core hole by Thermal Power Company and Chevron Geothermal on a cost-sharing basis with the U.S. Department of Energy began on June 7, 1986, and was completed September 7, 1986 (Conrey and Sherrod, 1988). The hole was rotary-drilled to 161-m depth and then cored to the hole bottom with essentially 100-percent core recovery. The maximum reported temperature at the bottom of the drill hole was 96.4 °C (Blackwell and Steele, 1987) (Figure 2), and the temperature gradient below the ~ 500-m depth was about 80 °C/km (Priest and others, 1987; Blackwell and Baker, 1988).

Drill core from the CTGH-1 drill hole is stored in the University of Utah Research Institute core library in Salt Lake City, Utah. A total of 307 core samples, between depths of 163 m and 1,463 m, consisting of fracture fillings, vug fillings, or representative samples of stratigraphic intervals, was obtained to identify the alteration minerals and to determine the physical and chemical conditions responsible for secondary mineralization of the drill core. Petrographic and binocular microscope, X-ray diffraction, and scanning electron microscope (SEM) (equipped with an X-ray energy dispersive spectrometer—EDS) methods were used in studying the drill core samples.

Lithologic and petrographic descriptions as well as K-Ar ages and chemical analyses of late Tertiary (Pliocene) to Quaternary rocks recovered from the drill hole are given in Sherrod and Conrey (1988) and Conrey and Sherrod (1988). Except for one dacitic interval, drill core from the CTGH-1 drill hole consists predominantly of andesitic to basaltic lava flows, tuffs, and breccias. The more silicic rocks contain some vapor-phase tridymite in addition to primary minerals (quartz, plagioclase, magnetite, and pyroxene). Primary minerals of the mafic rocks are mostly plagioclase, pyroxene, magnetite, olivine, and hornblende (identified in only one sample); α-cristobalite from devitrification occurs in several samples.

Textures of the lava flows vary from massive to vesicular; fracturing ranges from moderate to very intense. Most fractures and vesicles contain at least traces of mineralization, and the majority of open spaces are partly to completely filled by secondary minerals.

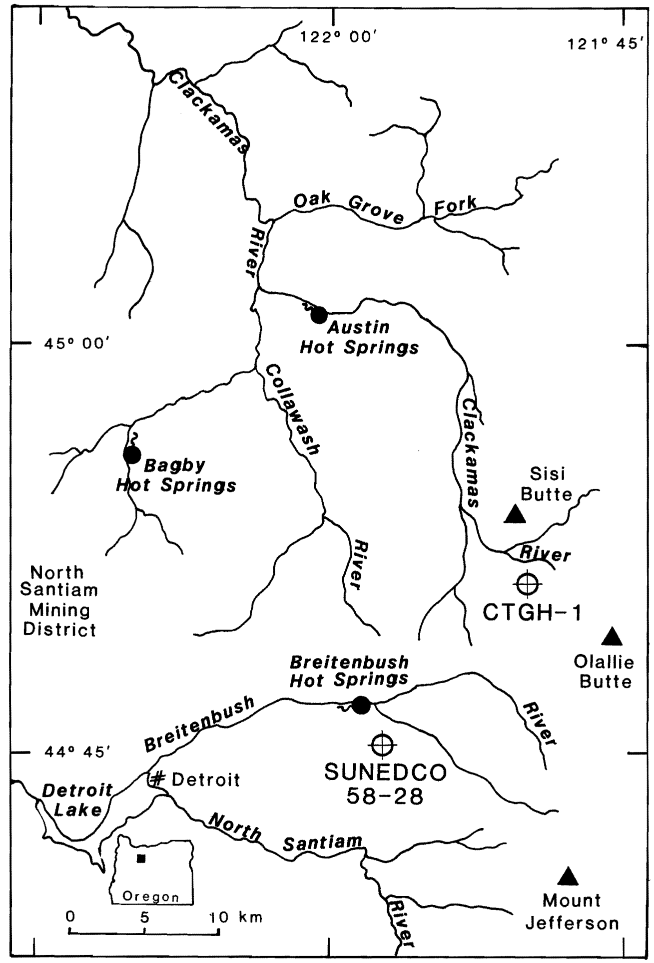

Figure 1. Map showing the location of geothermal drill hole CTGH-1 in northwestern Oregon.

SECONDARY MINERALIZATION

Introduction

From 163- to 622-m depth, the secondary mineralogy consists of smectite, hematite, and scarce zeolites (chabazite, wellsite, and heulandite) (Figure 2). Between depths of 622 m and 885 m, smectite and chabazite are the predominant alteration minerals, although significant analcime and other zeolite minerals (clinoptilolite, heulandite, phillipsite, scolecite, and thomsonite) are present along with minor hematite, calcite, and apatite(?). Below 885-m depth, smectite remains the dominant secondary mineral and is found along with celadonite, zeolite minerals (clinoptilolite, erionite, heulandite, and mordenite), and silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz); less abundant hematite and rare goethite, native copper, and adularia(?) also were identified.

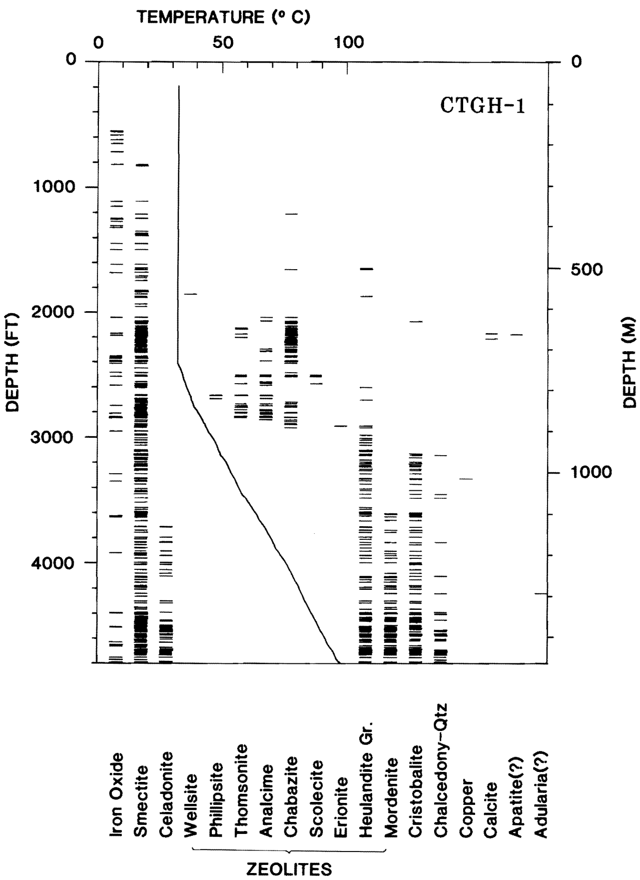

Figure 2. Distribution of secondary minerals with depth in drill hole CTGH-1. Temperature data from Blackwell and Steele (1987).

Hematite

Red-orange-brown iron-oxide stains are scattered throughout the CTGH-1 drill core (Figure 2) in abundances that range from a pervasive brick-red coloring of an entire specimen to microscopic orange-staining. The iron oxide was usually identified as hematite by X-ray diffraction; however, a few samples appear to contain X-ray amorphous iron oxide. Much of the hematite occurs in association with volcanic breccias, highly vesicular basalts, or tuffaceous deposits, where it probably formed by oxidation of primary magnetite during cooling of the volcanic rocks. A few thin red hematite stains on fracture surfaces or vesicle walls in the lower part of the drill hole appear to be closely associated with later secondary mineral fillings. Similarly, soft orange-red goethite coats a fracture surface at 1,456-m depth. The only other secondary iron-oxide mineral identified in the drill core is ilmenite, which occurs as black, metallic, hexagonal crystals that are closely associated with vapor-phase tridymite at 440-m depth.

Smectite

Above 480-m depth, very few samples contain smectite; however, below that depth, smectite occurs in virtually every sampled interval as coating on fracture surfaces, lining of vesicle walls, or complete filling of vesicles; between breccia fragments; and as groundmass alteration (particularly in tuffaceous rocks). In some vesicles, several generations of smectite were deposited earlier than other secondary minerals. Semiquantitative chemical analyses of selected smectite samples, using an EDS on the SEM, are given in Table 1. X-ray diffraction analyses together with the EDS chemical data suggest that smectite in the CTGH-1 drill core consists of randomly distributed deposits of montmorillonite (commonly a Ca- or Na-rich smectite), nontronite (Fe-rich smectite), or saponite (Mg-rich smectite).

Celadonite

Micaceous celadonite (Figure 3) occurs intermittently below 1,130-m depth normally as a soft, blue-green claylike material deposited as horizontal layers (later than green smectite) in cavities and fractures. In a few vesicles, the blue-green clayey layers are sandwiched between horizontal beds of medium- and dark-green smectite. At 1,138-m depth, celadonite formed earlier than a heulandite-group mineral (probably clinoptilolite) and β-cristobalite (Figure 4). Later formed, emerald-green, micaceous celadonite, like that shown in Figure 3, is sprinkled on top of the β-cristobalite. Semiquantitative chemical data for celadonite are given in Table 1.

Zeolite minerals

In the interval from 163 to 622 m, the only secondary minerals other than hematite and smectite are, in rare occurrences, chabazite, heulandite, and wellsite. Wellsite, an intermediate zeolite mineral in the phillipsite-harmotome group, was identified only in vesicles of basaltic rock from 564-m depth, where the mineral formed as randomly oriented, elongate, prismatic crystals, clusters of radiating crystals (Figure 5), or closely spaced elongate crystals deposited

Table 1. *Relative abundance of elements in hydrothermal minerals from the CTGH-1 drill core**

Mineral	Si	Al	Ti	Fe	Mg	Ca	Ba	K	Na
Smectite	1	3	—	2	5	4	—	6	—
Smectite	1	3	—	4	5	2	—	—	—
Smectite	1	4	—	2	5	3	—	6	7
Smectite	1	4	7	2	5	3	—	6	8
Smectite	1	5	—	2	4	3	—	—	—
Smectite	1	2	—	5	—	4	3	—	—
Celadonite	1	4	6	2	5	7	—	3	8
Celadonite	1	5	—	3	4	—	—	2	—
Celadonite	1	4	—	3	5	—	—	2	—
Zeolite minerals									
Wellsite	1	3	—	—	—	5	2	4	—
Wellsite	1	2	—	—	—	5	4	3	—
Wellsite	1	2	—	—	—	5	3	4	—
Wellsite	1	2	—	—	—	5	3	4	—
Phillipsite	1	2	—	—	—	4	—	3	—
Phillipsite	1	2	—	—	—	4	—	3	—
Phillipsite	1	2	—	—	—	4	—	3	—
Phillipsite	1	3	—	—	—	4	—	2	—
Phillipsite	1	2	—	—	—	4	—	3	—
Thomsonite	1	3	—	—	—	2	—	—	—
Analcime	1	2	—	—	—	4	—	—	3
Analcime	1	2	—	—	—	—	—	—	3
Analcime	1	2	—	—	—	5	—	4	3
Chabazite	1	2	—	—	—	3	—	4	—
Scolecite	1	2	—	—	—	3	—	—	4
Scolecite	1	3	—	—	—	2	—	—	—
Scolecite	1	3	—	—	—	2	—	—	—
Scolecite	1	3	—	—	—	2	—	—	—
Erionite	1	2	—	—	—	3	—	4	5
Heulandite	1	2	—	—	—	3	5	4	—
Heulandite	1	2	—	—	—	3	—	4	—
Heulandite	1	2	—	—	—	3	—	4	—
Heulandite	1	3	—	—	—	2	—	4	—
Heulandite	1	2	—	—	—	3	—	4	—
Heulandite	1	3	—	—	—	2	—	4	—
Heulandite	1	3	—	—	—	2	—	4	5
Heulandite	1	2	—	—	—	3	—	4	5
Heulandite	1	2	—	—	—	3	—	4	5
Clinoptilolite	1	3	—	—	—	4	—	2	—
Clinoptilolite	1	2	—	—	—	3	6	4	5
Clinoptilolite	1	2	—	—	—	3	5	4	6
Clinoptilolite	1	2	—	—	—	3	—	4	5
Clinoptilolite	1	2	—	—	—	4	—	3	5
Mordenite	1	2	—	—	—	3	—	—	—

*Based on semiquantitative chemical data obtained from an X-ray energy dispersive spectrometer on the scanning electron microscope (1 = most abundant; — = not detected).

Figure 3. Scanning electron micrograph showing books of euhedral celadonite crystals from 1,133-m depth.

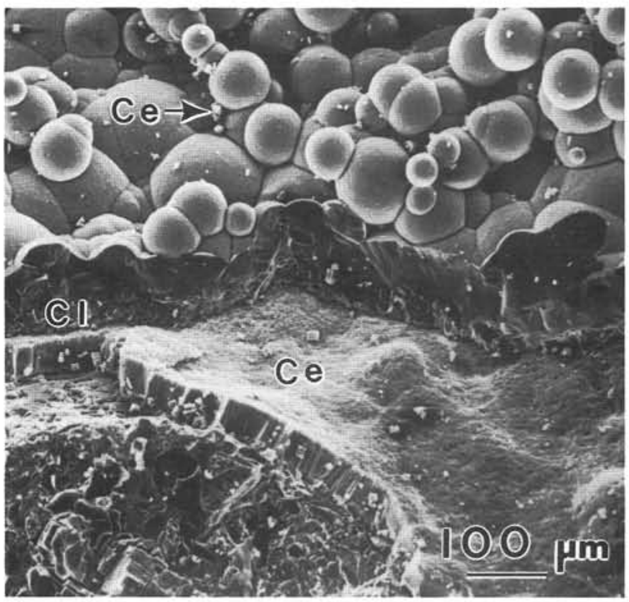

Figure 4. Scanning electron micrograph showing a fracture coating of clayey celadonite (Ce), blocky clinoptilolite (Cl), botryoidal β-cristobalite, and later micaceous celadonite (arrow) at 1,138-m depth.

as overlapping, radiating, hemispherical crystal clusters to produce a botryoidal-appearing vesicle coating. In Figure 5, the wellsite crystals appear to be partly coated by later smectite; however, the majority of the light- to dark-green horizontal smectite layers fill the bottoms of the vesicles and are earlier deposits. Semiquantitative analyses of wellsite (Table 1) show significant Ba and K and a little Ca in addition to Si and Al. X-ray diffraction analyses of the wellsite are similar to phillipsite and harmotome, but the approximately equal proportions of Ba and K suggest that the mineral is wellsite rather than Ba-poor phillipsite or K-poor harmotome (Gottardi and Galli, 1985).

In the interval from 622- to 885-m depth, zeolites occur with orange to green smectite and local iron-oxide staining (mostly hematite, but amorphous iron oxide may be present). These minerals

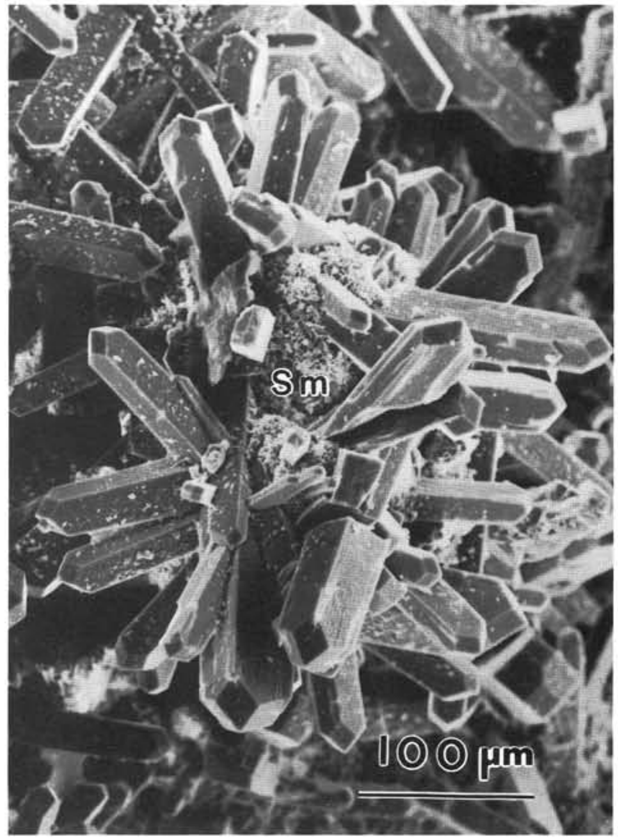

Figure 5. Scanning electron micrograph of a cluster of radiating wellsite prismatic crystals and later smectite (Sm) deposits from 564-m depth.

fill vesicles, fractures, and open spaces between volcanic breccia fragments and are dispersed in altered tuffaceous rocks. Phillipsite, an early-formed zeolite mineral in this drill core, was identified in only three samples (at 811, 812, and 821 m). At 821-m depth, colorless phillipsite crystals (Figure 6) formed in basalt vesicles, whereas, at 812-m depth, the phillipsite pervasively coats open spaces in volcanic breccia, forming clusters of closely spaced elongate crystals that appear partly dissolved. Semiquantitative EDS analyses indicate that both samples have approximately the same chemical composition: Si, Al, and K > Ca (Table 1).

At 812-m depth, phillipsite is associated with later clusters of colorless tabular or lamellar thomsonite crystals. Thomsonite crystals at 764-m depth were deposited as irregularly oriented, tabular clusters (Figure 7), whereas at a depth of 767 m, the tapered, tabular thomsonite crystals form somewhat fan-shaped clusters (Figure 8). Only Si, Al, and Ca were detected in an EDS analysis of thomsonite (Table 1). Fractures and vesicles in highly altered basalt at 663-m depth contain a soft, colorless, botryoidal coating that consists of hemispherical-shaped clusters of closely spaced thomsonite crystals.

The thomsonite crystals at 663-m depth are overlain by later deposits of colorless chabazite crystals. Pseudocubic rhombohedral chabazite (frequently twinned) (Figure 9), deposited in association with earlier smectite in many open spaces, is the predominant zeolite mineral in this interval. A semiquantitative EDS analysis of chabazite from 634-m depth (Table 1) shows the presence of Si, Al, Ca, and very minor K.

Scattered open-space deposits of colorless, trapezohedral analcime crystals are closely associated with chabazite, although the depositional sequence is undetermined; analcime also formed later

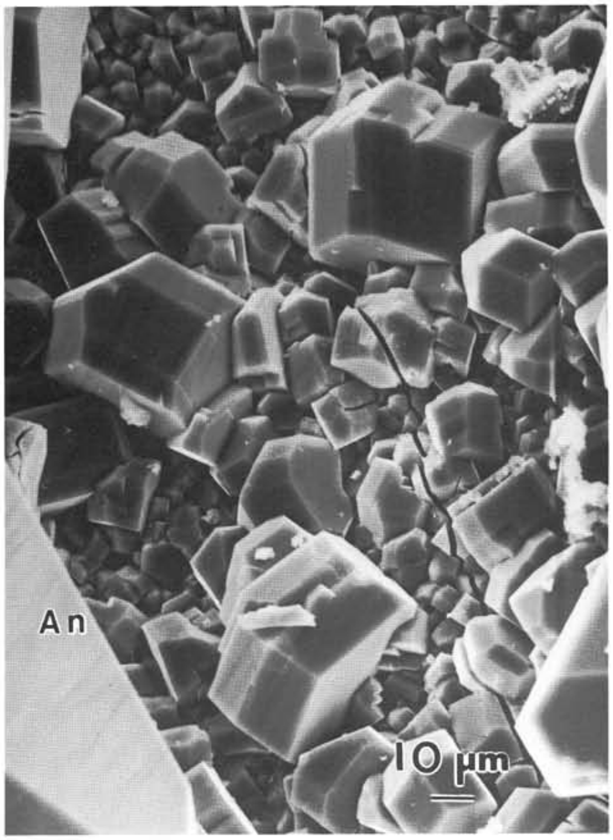

Figure 6. Scanning electron micrograph of a vesicle filling from 821-m depth containing euhedral phillipsite and later analcime (An).

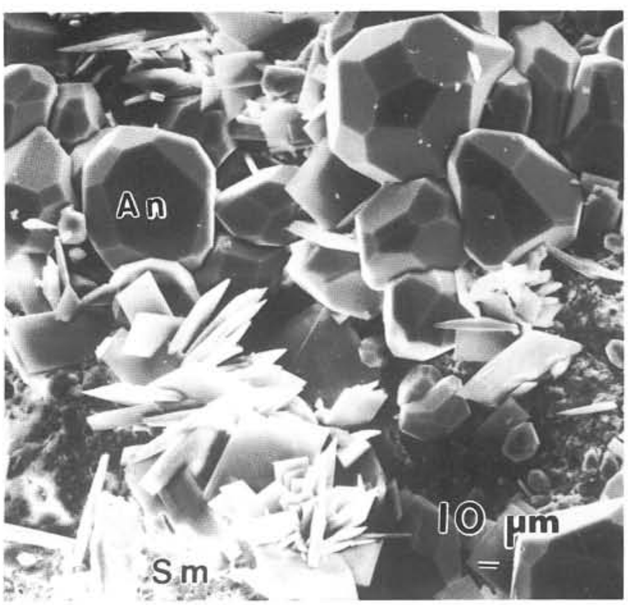

Figure 7. Scanning electron micrograph of a fracture filling from 764-m depth that is lined by smectite (Sm), later tabular thomsonite, and finally trapezohedral analcime (An) crystals.

than thomsonite (Figure 7) and phillipsite (Figure 10). Semiquantitative analyses for analcime show Si, Al, Na, K, and Ca (Table 1). The presence of Ca indicates that the mineral is not a pure analcime end-member of the analcime-wairakite solid solution series and probably should be considered a "calcian" analcime (Gottardi and Galli, 1985).

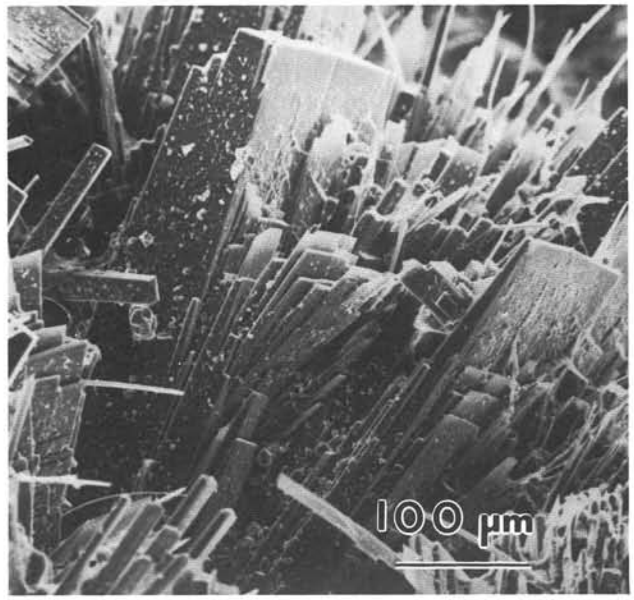

Figure 8. Scanning electron micrograph showing tabular thomsonite and acicular scolecite crystals from a fracture at 767-m depth.

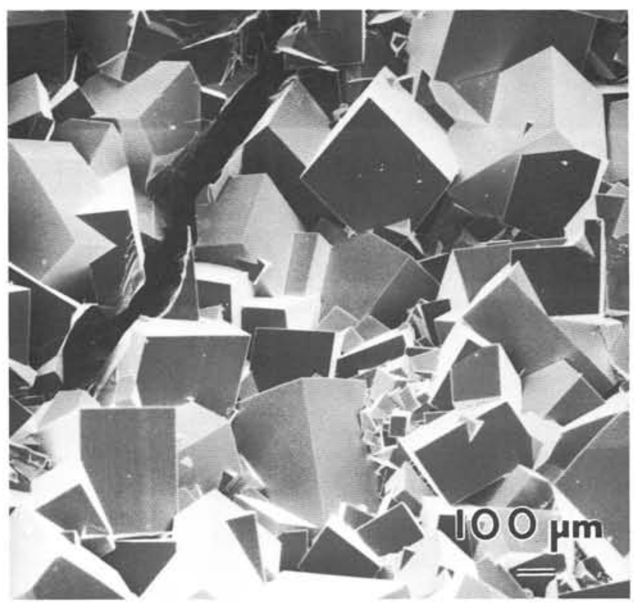

Figure 9. Scanning electron micrograph of euhedral, pseudocubic chabazite crystals lining a fracture at 634-m depth.

Fracture fillings in drill core between 764- and 785-m depth contain radiating clusters of colorless, acicular scolecite crystals that were deposited later than thomsonite (Figure 11), chabazite, and analcime. Semiquantitative analyses by EDS indicate that the chemical constituents of scolecite are Si, Al, Ca, and very minor Na (Table 1).

Below 885-m depth, except for one occurrence of chabazite at 892-m depth, the zeolite minerals discussed above are com-

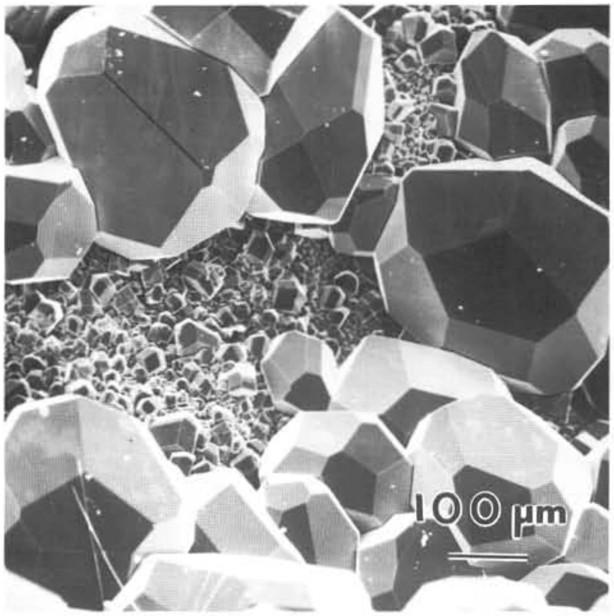

Figure 10. Scanning electron micrograph of a vesicle filling at 821-m depth lined by tiny phillipsite crystals and later large trapezohedral analcime crystals.

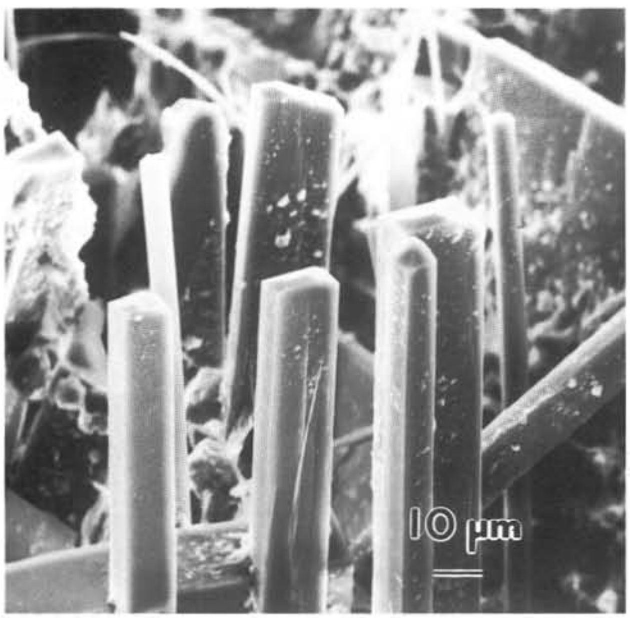

Figure 11. Scanning electron micrograph showing tabular thomsonite and later acicular scolecite crystals that coat fractures at 767-m depth.

pletely absent, and the interval contains heulandite-group zeolites (heulandite and clinoptilolite) along with abundant mordenite and minor erionite. Early-formed reddish hematite staining is sporadically distributed through the interval. Later formed smectite is the dominant open-space filling. At depths greater than 1,130 m, blue-green clayey celadonite fracture and vesicle deposits formed either later than green smectite or are sandwiched between horizontal green smectite layers.

Three samples between the depths of 886 m and 888 m contain columnar bundles of acicular erionite crystals that were deposited

Figure 12. Scanning electron micrograph showing columnar bundles of erionite crystals and later blocky heulandite crystals from 887-m depth.

later than green smectite. In the SEM, these columns occasionally show hexagonal cross sections (Figure 12) and are seen to have formed earlier than associated blocky heulandite crystals at 887-m depth. An EDS analysis of erionite shows the presence of Si, Al, Ca, K, and Na (Table 1).

Heulandite (Ca > Na+K) and clinoptilolite (Na+K > Ca), two heulandite-group zeolite minerals, are both present in the lower part of the CTGH-1 drill core. Clinoptilolite is abundant below 892-m depth but was identified in only one sample above that depth. In drill hole CTGH-1, heulandite-group zeolite minerals, deposited in vesicles and fractures and between breccia fragments, formed later than hematite, smectite, celadonite, and erionite but are earlier than α-cristobalite, β-cristobalite, or mordenite (Figures 13 and 14). Minor smectite appears to be deposited later than some open-space heulandite-group minerals (Figure 15). The crystal morphology of the heulandite-group minerals in drill core CTGH-1 varies from a tabular "tombstonelike" habit shown in Figure 15 to a more blocky morphology as seen in Figures 12, 13, and 14.

White, cottonlike mats of interwoven long, thin, fibrous crystals or small tufts of fibrous mordenite crystals (Figure 14) appear to be the latest mineral deposited in many open spaces below 1,099-m depth in the CTGH-1 drill core. An EDS analysis of mordenite from 1,260-m depth showed the presence of only Ca, Al, and Si.

Silica minerals

Silica minerals (β-cristobalite, α-cristobalite, chalcedony, and quartz) from the CTGH-1 drill hole occur as open-space deposits that formed later than most other minerals except for mordenite (Figure 14) and minor smectite (Figure 16). Between depths of

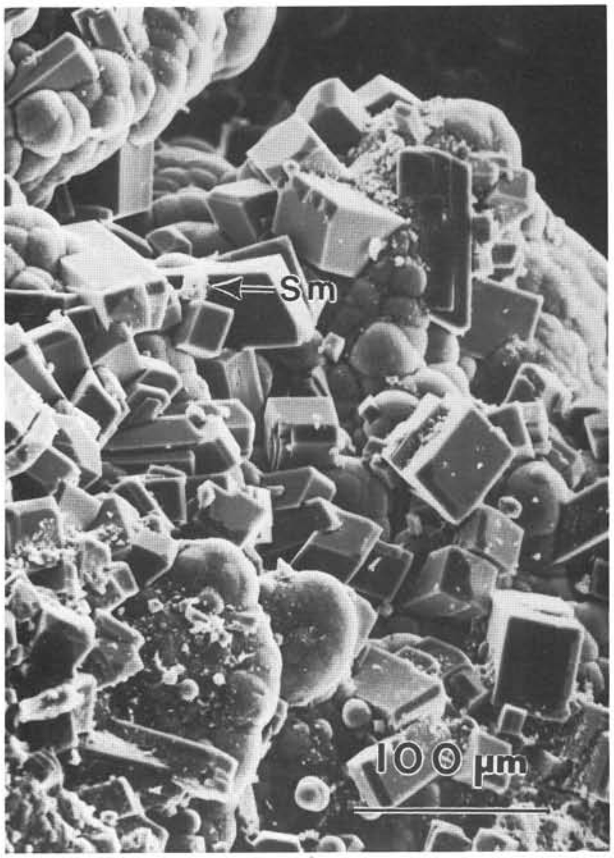

Figure 13. Scanning electron micrograph of a fracture filling at 983-m depth coated by blocky clinoptilolite crystals, later botryoidal β-cristobalite, and late smectite (Sm).

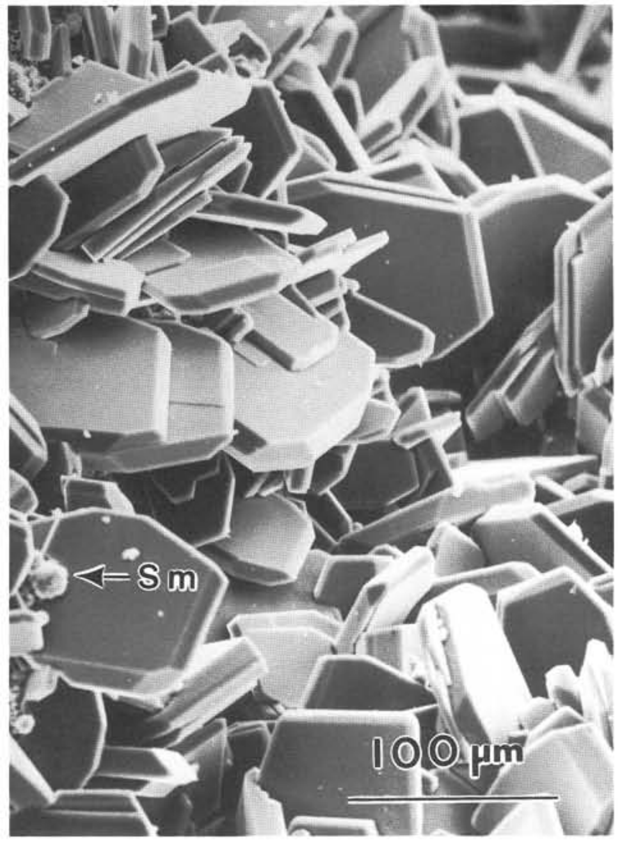

Figure 15. Scanning electron micrograph of tabular, "tombstonelike" clinoptilolite crystals and later smectite (Sm) lining a vesicle at 1,341-m depth.

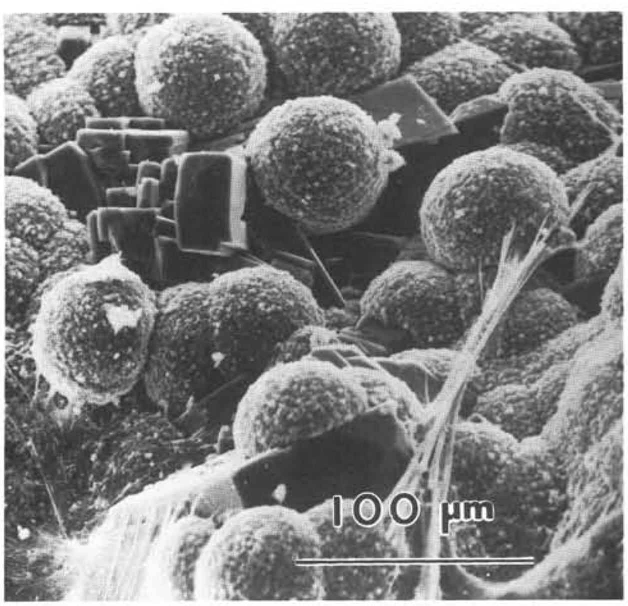

Figure 14. Scanning electron micrograph of a vesicle filling at 1,394-m depth consisting of blocky clinoptilolite, of later botryoidal α-cristobalite crystal clusters, and of still later fibrous mordenite.

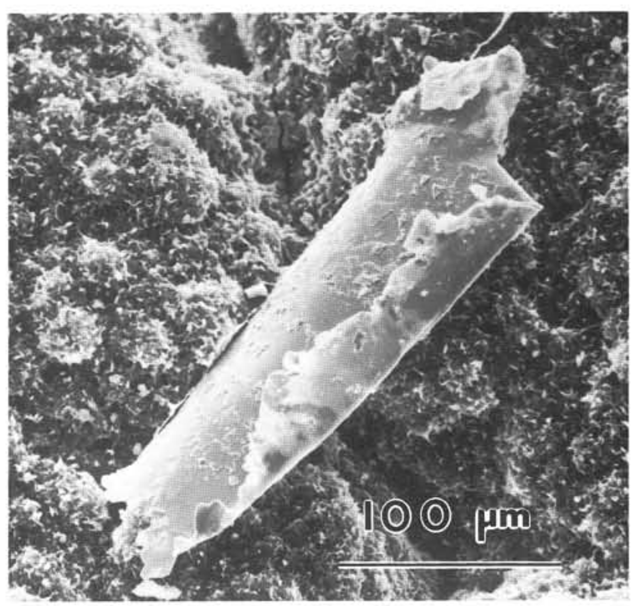

Figure 16. Scanning electron micrograph showing a deposit in an open space from 1,015-m depth consisting of native copper, later botryoidal clusters of β-cristobalite crystals, and still later smectite (fuzzy coating on β-cristobalite).

956 and 1,372 m, colorless, frosted, or bluish, smooth botryoidal silica (Figures 4 and 13) was identified as β-cristobalite in several X-ray diffraction analyses. Deposits of β-cristobalite alternate with similar-appearing botryoidal α-cristobalite between 1,061-m and 1,372-m depth. Below 1,372-m depth, spherical clusters of blocky α-cristobalite crystals (Figure 14) are the predominant silica phase.

Tiny, colorless, euhedral quartz crystals occur in vesicles from seven scattered drill core samples. Many other open-space white, colorless, yellow, or green massive silica deposits consist of cryptocrystalline chalcedony.

Other minerals

The only other secondary minerals in this drill core are calcite, apatite(?), adularia(?), and native copper. The first three minerals were identified only in X-ray diffraction analyses from depths of 663 and 675 m (calcite), 665 m (apatite?), and 1,293 m (adularia?); the modes of occurrence for these three minerals were not observed. Native copper occurs in two samples from near 1,015-m depth as an open-space deposit that appears to be earlier than botryoidal β-cristobalite and white smectite (Figure 16).

CONCLUSIONS

The paragenetic sequence of secondary minerals from drill core CTGH-1 (Figure 17) suggests that rock/water interaction, initially through alteration of basaltic glass and mafic minerals, provided sufficient Fe and Mg (Table 1) to form the earlier deposited secondary minerals. During later mineralization, K, Na, Ca, and Si were more prevalent constituents of the fluids, and the minerals that formed consisted mostly of zeolites and silica minerals.

The secondary mineral assemblage of the CTGH-1 drill core is similar to hydrothermal alteration mineralogy of upper Tertiary rock outcrops exposed in the Breitenbush-Austin Hot Springs area (Keith, 1988). Smectite and most of the zeolite minerals identified in the CTGH-1 drill core are compatible with the present low temperatures measured in the drill hole (Kristmannsdottir and Tomasson, 1978); silica minerals also can form at temperatures below 100 °C (Benson and Teague, 1982). Even though the depth of burial at the bottom of the CTGH-1 drill hole is nearly 1.5 km, the current high heat flow of the area (Blackwell and Baker, 1988) and the nearby hot springs (Figure 1) suggest that low-temperature hydrothermal alteration rather than burial diagenesis is responsible for the formation of alteration minerals in the CTGH-1 drill core. In a recent report on the genesis of zeolites, Gottardi (1989) indicates that hydrothermal environments usually produce euhedral crystals of a large number (six to eight) of zeolite minerals, whereas diagenetic processes result in fewer zeolite species that form smaller (10-20 μm) anhedral crystals. Euhedral crystals of 10 zeolite minerals found in the CTGH-1 drill core uniformly exceed 20 μm and support Gottardi's conclusions.

ACKNOWLEDGMENTS

The author thanks R.O. Oscarson for assistance in obtaining the scanning electron micrographs and M.M. Donato and M.H. Beeson for their critical reviews of this report.

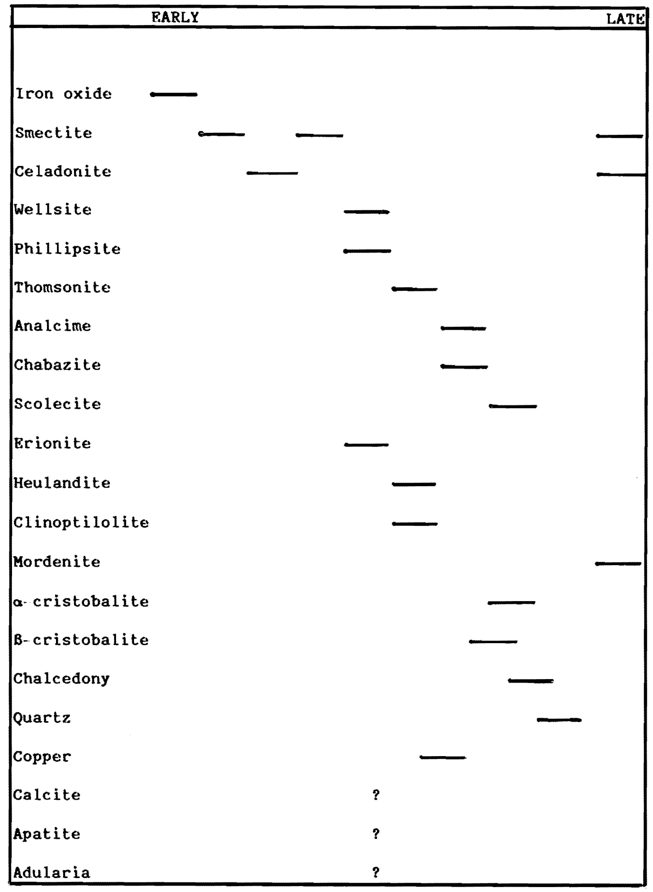

Figure 17. Approximate paragenetic sequence of hydrothermal minerals deposited in drill core from the CTGH-1 drill hole.

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Should the pits be filled?

by Allen Throop, Mined Land Reclamation Program, Albany Office, Oregon Department of Geology and Mineral Industries

INTRODUCTION

What is the best way to use the natural resources of this country? At this time, there is no one answer to this question. Ultimately, the citizens of this country will have to decide. This article is intended to (1) explain some of the major differences between coal- and metal-mining techniques, and (2) show why returning the land to its approximate original contours after mining is acceptable to coal miners but strongly resisted by the metal industry.

The current intense exploration for gold in southeastern Oregon could lead to the development of a major new mine. The prospect of large open-pit mines in Oregon has resulted in the expression of serious valid concerns about environmental protection. The two most frequently asked questions are the following: (1) Will miners be required to fill in the hole when they are through? (2) Why do miners use cyanide? This article attempts to answer the first question. The second question was addressed in the January 1989 issue of *Oregon Geology* ("Cyanide in Mining," v. 51, no. 1, p. 9-11, 20).

The short answer to the question about filling in open pits is that it is economically not feasible and neither federal laws nor any state laws require that land mined for hard-rock metal be returned to pre-mine topography. Coal mines, however, are treated differently; land affected by coal mines must be returned to the approximate original contours. To understand the differences between common practices in the two industries, one needs to review the law and have some knowledge of basic geology and mining techniques.

In 1977, the U.S. Congress passed the Surface Mining Control and Reclamation Act (SMCRA). This law requires that the topography of surface mines be returned to the "approximate original contour" upon completion of mining. Contrary to popular belief, the law does not require the site to be returned to the actual original topography.

The following comparison of a coal mine and a metal mine is presented to demonstrate the differences between the two mining techniques. The two hypothetical examples are simple cases; in reality, each mining site is unique and presents special problems.

COAL-MINING TECHNIQUES

The first example is Breakeven Coal Company's Itsa Mine. The mine is located in the rolling hills of one of the Great Plains states. The coal is in a flat-lying seam that averages a thickness of 100 ft. The minable portion is 2,500 ft wide and 2 mi long. The contact between overlying shale and underlying limestone is sharp. The overburden, which is the material lying between the top of the coal deposit and the surface, ranges from 50 to 300 ft thick, with an average thickness of 150 ft. A cross section through the unmined area is shown in Figure 1a.

Breakeven Company obtains all of its permits and starts mining from the north end of its property. To reach the coal, Breakeven starts out with a drop cut down through the overburden and builds up a hill with the overburden that it has removed. After reaching the coal seam, Breakeven begins mining toward the south. Initially, the overburden is placed on the pile that was started during excavation of the drop cut. However, as soon as the coal is removed, the company starts putting overburden into the mined-out area (Figure 1b). As soon as backfilling begins and material is no longer being added to the original hill, the hill is contoured, covered with topsoil removed from the mine area, and revegetated.

Now a repetitive cycle is begun within the mine. The overburden is removed, slice after slice, carried over to the area from which coal was removed, and dumped into the mined-out area. Often this process is done with a huge dragline, such as the one shown in Figure 2. The rock is literally thrown from one side of the excavation to the other by the highly efficient machine. As the dragline moves along successive strips, loaders and trucks follow along behind, removing coal from the seam. As soon as it is piled up to the desired level, the overburden is contoured, topsoiled, and revegetated. The cycle is repeated until the south end of the mine is reached.

Compliance with the strict definition of "approximate original contour" would mean that overburden from the original drop cut would finally have to be hauled from the north end to the south end and used to fill the final cut. In this case, Breakeven will seek a variance from the rules to create a pond that, if carefully done, can be an important wildlife or recreation asset to the area. Creating the pond saves the company the large amount of money that would be needed to move the overburden from the north end of the mine to the south end.

"Approximate original contour" is achieved by having the hills, valleys, and slopes similar to those that existed prior to mining. However, the actual shape of the mined area can be completely different when compared to the original location of the hills and valleys. Depending on the ratio of the overburden to the coal, the approximate original contour may be above or below the elevation of the pre-mine topography.

Strip mining and restoration of the approximate original contour work well where the valuable mineral is tabular in nature, lies approximately parallel to the original ground surface, and is close enough to the surface for economical mining.

GOLD-MINING TECHNIQUES

Now let's look at Glittering Gold's Justa Mine in the Basin and Range country in one of the Far West states. The ore body is egg shaped and oriented with the point sticking up. However, the edges are irregular, and the amount of gold in the ore gradually tapers off as the depth gets greater. Perhaps the comparison with an egg would be closer to reality if you imagine that the egg shell broke shortly after it was emplaced, and the egg white seeped out into the surrounding rock.

At this mine, ore was found at the surface, so production can begin almost at once (Figure 3a). The miners realize that to get continued production, they must start stripping waste immediately. However, where Breakeven Coal knew that its mine would go down only to 200 ft and the waste could therefore be dumped relatively close to the edge of the mine, Glittering Gold realizes that its final pit edge will be over 1,000 ft away from where the ore crops out. Therefore, the overburden must be carried farther away from the initial excavation.

The sequence of mining is shown in Figures 3b through 3d. The bottom of Justa Mine will not be at the place where there is no more gold. Instead, all else being equal, it will be at the elevation where the cost of removing waste from the pit sides and hauling more ore from the pit bottom can no longer be justified by the grade and amount of ore exposed on the bottom.

A comparison of Figures 1 and 3 shows the major difference between a coal strip mine and the open pit of a metal mine. With good planning, overburden removal finishes at a coal mine when the last coal is removed. Final regrading and topsoiling closely follow the overburden replacement.

On the other hand, the metal mining companies object strenuously to filling in the pit because the job is more costly and

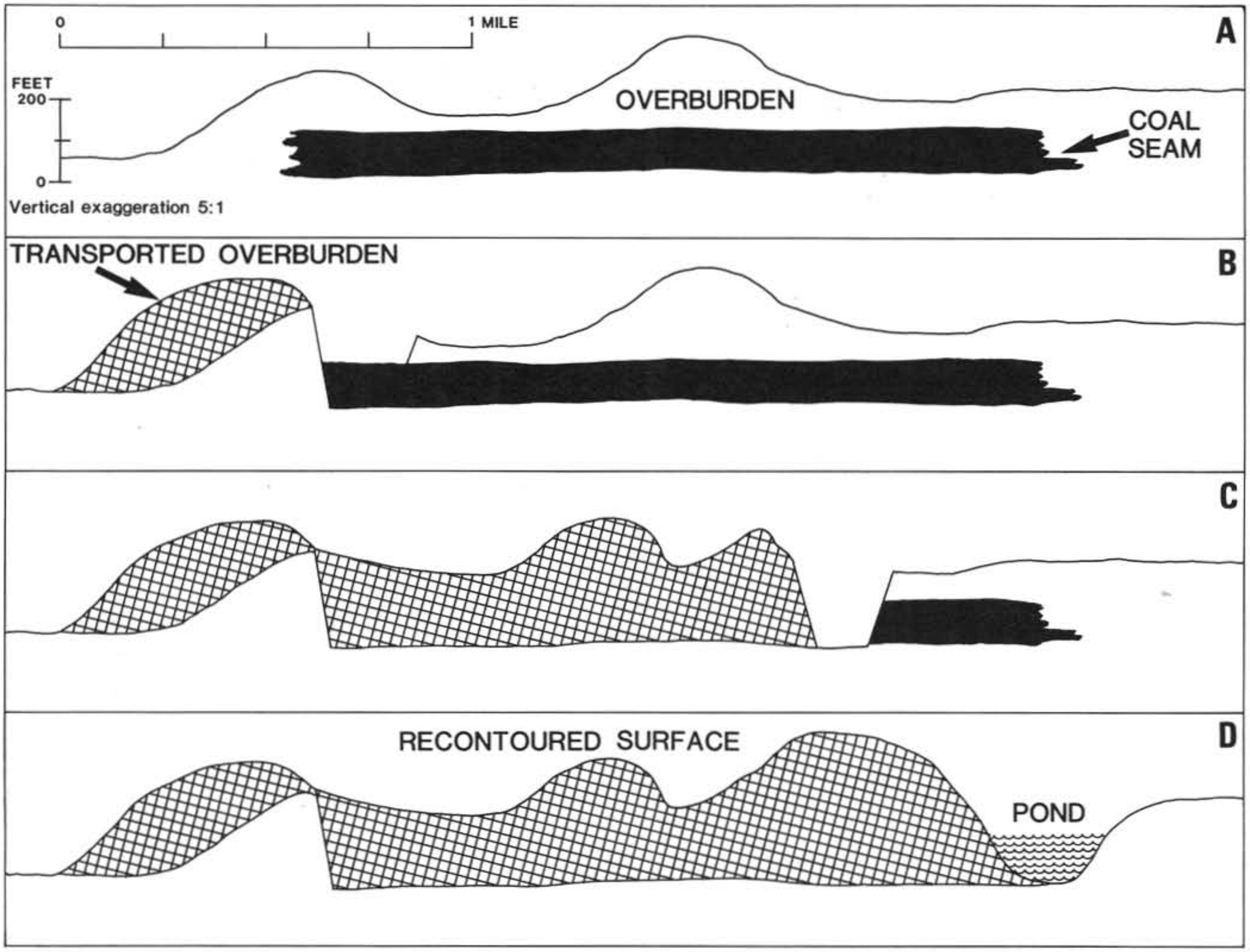

Figure 1. Cross sections of Breakeven's Itsa Mine, a coal mine where a flat-lying coal seam is covered by overburden ranging from 50 to 300 ft in thickness. Note vertical exaggeration. A. Pre-mine cross section, showing the original contour of land before mining begins. B. When the first cut is made, the overburden is built up into a hill until coal is finally exposed for mining. As soon as no new material is to be added to the overburden hill, the hill is contoured, covered with topsoil that was removed from the mine site, and revegetated to make it stable and not prone to landsliding. C. After coal is removed from a portion of the excavation, overburden removed from a different part of the mine is piled into the mined-out area, contoured, topsoiled, and revegetated. This cycle is repeated until the end of the mine is reached. D. The mine after mining has ceased, the land has been restored to the "approximate original contour," and a pond has been created for wildlife or recreational use.

Figure 2. Dragline used to move overburden from above the coal seam to a mined-out portion of the operation. The bucket of the machine is large enough to carry two pickup trucks.

cannot be started until mining is completed. Not only does this mean that it has to be done after income from the mine has stopped coming in, but it is more expensive than in the coal-mine situation because the rock must be loaded into trucks for a second trip and hauled back into the pit. Moving rock by truck rather than by dragline is far more expensive. Double hauling adds immensely to the cost.

Arguments in favor of backfilling an open pit:

1. Aesthetics: An abandoned pit may be aesthetically undesirable to some or unsafe.

2. Acid mine drainage: In some cases where the pit will naturally fill with water, minerals that have the potential to generate large amounts of acid can be controlled by dumping them into water-filled pits. In other cases, acidic waters in the pit bottom could be eliminated by filling in the pit.

Arguments against backfilling:

1. Economy: Post-production backfilling cost is large in terms of both dollars and fuel. Assuming an average backhaul of 1.5 mi (a 3-mi round trip), the hauling cost would be on the order

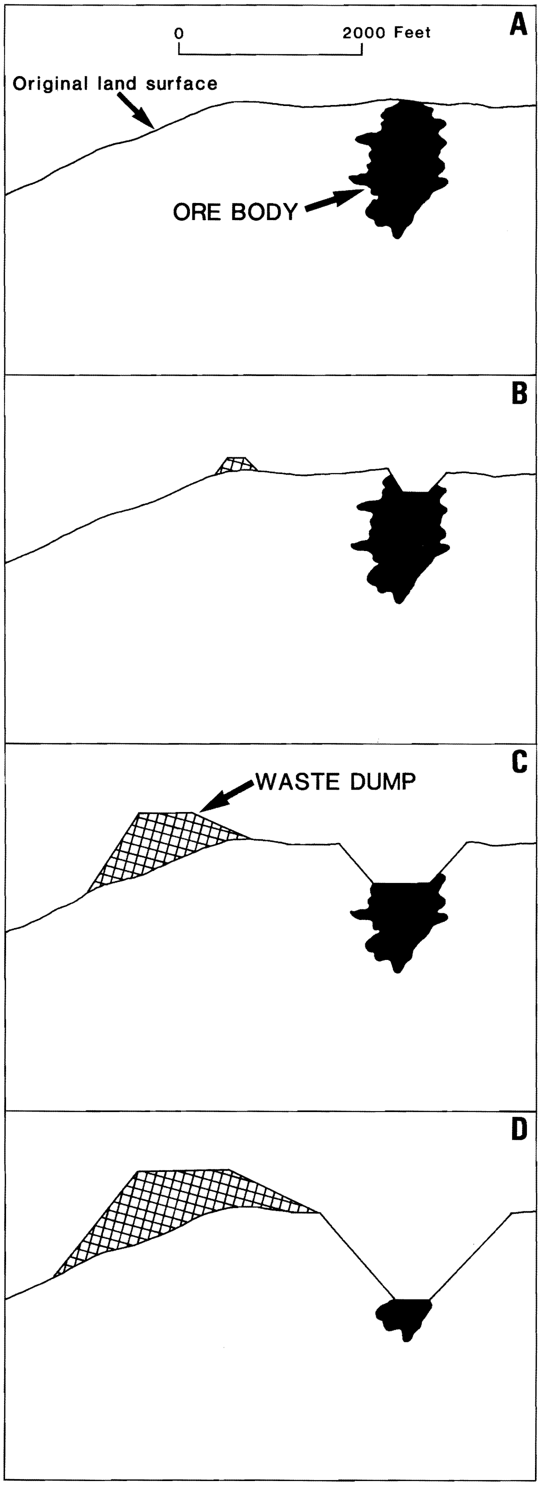

Figure 3. Cross sections of Justa Mine, a western U.S. gold mine developing an egg-shaped ore body. A. Pre-mine topography, showing the location and shape of the ore body. B. First cut into the ore body. Note how far away from the ore body the waste material must be transported, so that later excavations will not undercut the waste dump. C. Mine when about half of the ore body has been removed. Note how it is impossible to begin filling the pit at this stage without covering up some of the remaining ore. D. Mine site after the currently economic ore body has been removed. Waste has been piled some distance from the pit, and the waste pile can be contoured and seeded.

of $37 million, and approximately 1 million gallons of fuel would be consumed for backfilling a pit with 50 million tons of rock. This is the cost only of moving the rock in trucks. Considerable additional expense would be generated in such tasks as loading the trucks, maintaining haul roads, and overseeing the project.

2. Acid mine drainage: Rock with the potential for producing acid could be properly isolated when it is first removed from the pit. Digging the rock up and moving it a second time could increase the potential for causing environmental damage.

3. Stability: Many mines remove the side of a hill rather than excavate a hole in the ground. Final slopes blasted into hard rock are far more stable than loose material dumped back over the side of an excavated hill.

4. Future mining: Metal mines generally shut down because mining has become uneconomic under the price and mining methods of the day. The mineralization at the bottom of the excavation may well be economic again in the future. Is covering this resource wise?

Regardless of whether the pit is backfilled or not, the site cannot be returned to the original contour. During the blasting and milling process, open space is introduced into the rock. The volume of material to be disposed of can be twice as much as the volume of the excavation from which it came. Even if the pit is backfilled, large waste dumps and/or tailings piles would remain.

CONCLUSION

As stated at the beginning of this paper, there is no consensus on the best way to use our natural resources. Each type of mineral extraction offers its own problems. Each ore body is unique. Society has a need for minerals that are produced from the earth, but society also has the responsibility to produce those minerals while minimizing the long-term negative impact on the land. The debate over the best way to produce minerals that are needed to maintain our current standard and pattern of living, to maintain access to potential future resources, and to protect the environment will continue for many years. In order to have a meaningful debate, it is imperative that all parties understand current mining practices. ☐

April fireball lights up Oregon

by Richard N. Pugh, Cleveland High School, Portland

A major fireball event occurred over Oregon on April 13, 1990, at 8:35 p.m. PDT. At that time, the sun had set, but it was not totally dark.

The fireball entered the atmosphere off the Oregon coast near Florence. It was observed to move east-southeast and was last seen breaking up southeast of Christmas Valley.

The fireball was seen from Portland, Oregon, in the north to Christmas Valley, Oregon, in the east and to Redding, California, in the south. Most observers saw an object as bright and large as a full moon. The duration of the event was three to six seconds. The fireball was reported to be round to teardrop shaped and having a yellow to green color. Several observers reported seeing the fireball pulsating and changing colors as it "fell." Most observers saw a yellow to white tail of varying length. Many reports mentioned sparks coming off the fireball, and five reports mentioned disruption or breakup of the object near the end of its path. Two to four fragments were reported.

One report, from Philomath, Oregon, mentioned anomalous sound: A low, moaning/whistling sound was heard at the same time the fireball was seen. No sonic booms were reported.

These sightings have been reported to the Scientific Event Alert Network, Smithsonian Institution. Anyone with any additional information about this event or other fireball sightings should contact Dick Pugh, Cleveland High School, 3400 SE 26th Avenue, Portland, OR 97202, phone (503) 280-5120. ☐

Industrial minerals in paper: A chase for technical superiority*

by Hal McVey, P.O. Box 343, Rough and Ready, California 95975, and Peter Harben, P.O. Box 800, Morris, New York 3808, independent consultants specializing in market evaluations of industrial minerals on an international basis.

INTRODUCTION

Industrial minerals provide substance to the paper industry. They are utilized in substantial volumes in the manufacture of paper as pigments, fillers, and coating agents that contribute properties such as brightness, opacity, light weight, strength, and cost effectiveness. Perhaps more importantly from the suppliers' viewpoint, because most of these minerals have been upgraded by sophisticated processing, there is a commensurately large value-added factor that creates an impressive dollar volume for minerals destined for this end use. Minerals consumed as fillers and extenders in the North American paper market in 1988, for example, were valued at a record $1,000 million. Growth in consumption has been spurred by some of the technological changes discussed below plus a 200-percent increase in pulp prices since 1986. By far the bulk of this 5-million-ton-plus market is accounted for by titanium dioxide, kaolin, calcium carbonate, and talc.

Terminology

A basic conflict of terms emerges the moment that the industrial mineralist meets the paper technologist. What we in industrial minerals call "fillers" or "extenders" are called "pigments" in the paper trade. Since this article is written for *Industrial Minerals,* we will stick with our own terminology. Even so, this subject needs some clarification.

For some time there has been an uneasiness within the industrial minerals industry with the nomenclature "filler" or "extender" minerals. The terms imply that these minerals are just rather low-cost dirt that contributes little else but volume or weight to paper, plastics, paint, rubber, and other manufactured items. This concept is far from the truth, since most of these minerals contribute beneficial properties. For example, in paper they improve the brightness, create opacity or resistance to show-through, cause ink receptivity or ink hold-out, provide glossiness or flatness, act as a pitch-control agent, as scavenger for anionic elements created by the chemicals used in the papermaking process, and, yes, do fill space in the pulp for a very definite reason as discussed below. However, due to the beneficial effects of industrial minerals, the term "functional fillers" seems to have emerged as the best descriptive adjective. We still use the words "filler" and "extender," but they are understood to have a more profound meaning than just space filler.

PAPERMAKING AND INDUSTRIAL MINERALS

The basic ingredient of paper is pulp. The selection of the types of pulp with different technical benefits and different prices is a world in itself and needn't concern us for the purpose of this discussion. We can assume that paper is a network of cellulose fibres with air spaces in between. A goodly portion of these spaces is filled by industrial minerals, wherein they are added at the wet end of the papermaking process. This means that the pulp, certain chemicals, and industrial minerals make up the slurry that is compressed and dried to form paper.

However, the type and quality of mineral used depends on the type of paper being manufactured. For example, tissue-type papers do not contain minerals. Groundwood pulp-type papers that are used to make newsprint, official airline guides, and telephone directories contain little or no filler (more on this later). Papers for magazines like *National Geographic* and *Hustler* or company annual reports contain up to 30 percent by weight of minerals. By way of general interest, the paper people use the term "ash" for the mineral content. This is derived by burning a piece of paper and weighing the residue, which is the ash or mineral content.

Quality and specifications

The paper industry is extremely demanding when it comes to quality and quality control. This is well illustrated in a later section (*USA Today* syndrome). However, the general qualities that are required from minerals in papermaking are as follows:

- Brightness — in most cases the higher the better. However, high brightness reduces opacity. See next item.
- Opacity and/or show-through — this is essentially the ability of paper to not show ink through to the other side of the page so that the reader of a news article does not see the Marlboro man peeking through from the following page.
- Bulk density — generally the lower the better.
- Abrasion characteristics — more correctly, lack of abrasion as would be caused by hard minerals such as silica.
- Particle size — the criteria are built around the 2-micron-size level.
- Particle size distribution — the distribution of the various sizes of the mineral is as important as the maximum and minimum particle sizes. Generally, the really fine particles of less than 0.25 micron are detrimental.
- Retention — a high percentage of the mineral must be retained in the slurry and end up in the paper in order to avoid an obvious loss.
- Rheology and viscosity — rheology is the science of the flow of matter (minerals) under stress. With paper machines traveling up to 4,000 ft/minute, the manner in which the minerals flow is of extreme importance.
- pH — the acidity or basicity of the mineral must be compatible with the process.
- Economy — this is a comparative evaluation. Cost might be determined by the mineral being at a lower cost than the pulp, as a lower cost replacement for titanium dioxide, or a higher cost because it adds something special to the paper and is, therefore, economical to use.

Titanium dioxide

The most highly prized and highly priced pigment used in paper is titanium dioxide made from a rutile, synthetic-rutile, ilmenite, ilmenite-slag, or leucoxene feedstock. The finely divided white powder is extremely white and bright (100 percent on a General Electric Brightness [GEB] scale of 100 percent), and its refractive index of 2.7 is the highest of any pigment used in paper. Thus even at modest concentration levels, titanium dioxide contributes greatly to brightness and opacity. In short, except for its high price, it is the ideal white pigment. In most cases, one of the prime functions of a filler is to reduce the amount of titanium dioxide pigment used in the manufacturing process. Although there has been a certain degree of success, and research is continually trying to increase this substitution, titanium dioxide remains the supreme pigment for papermakers.

Last April the tight TiO_2 market in North America gradually pushed up prices past the $1/pound mark for the first time when SCM Chemicals announced price increases for anatase grades to

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\$1/pound and rutile grades at \$1.02 and \$1.03/pound. Despite these price increases and low stocks, demand for TiO_2 has continued to climb in response to the paper industry's push for whiter, lighter, and more opaque lightweight coated (LWC) and increased production of premium coated free-sheet grades. In 1988 the U.S. paper industry used 290,000 short tons of titanium dioxide, that is 27 percent of the total consumption. For the paper industry this represented a 2-percent rise in U.S. consumption over 1987, which was relatively low due to being supply-constrained (consumers continue to be on allocation based on their previous purchasing patterns). Expectations are that this will increase to 3 percent in 1989, given some easing of supplies and the continuation of the trend to better quality paper.

North American producers are all increasing production capacity of titanium dioxide pigment in a frantic effort to keep up with demand. Increases have been achieved through debottlenecking and running plants uncomfortably close to 100-percent capacity. Projects are underway to substantially increase capacity in North America. DuPont, the largest producer, is increasing its U.S. capacity from the current level of about 600,000 short tpa (tons per year—*ed.*) to 750,000 short tpa by 1991. 100,000 tons of this increased capacity will be at its DeLisle, Mississippi, plant. In July, DuPont announced plans to increase the capacity of its Altamira plant from 55,000 tonnes (metric tons —*ed.*) to 79,000 tonnes by the end of 1990. Kerr-McGee recently completed its 21,000-ton expansion at Hamilton, Mississippi, which brings capacity to 106,000 short tpa. Kemira Inc.'s 50-percent expansion of its Savannah, Georgia, plant to 110,000 short tpa is about complete, and SCM has completed a modest expansion at Ashtabula, Ohio. NL Chemicals is building a 90,000 short tpa plant at Lake Charles, Louisiana, which will be completed by 1991. Therefore, over the period 1988-1991, more than 300,000 short tons of capacity will be added to U.S. plants. In Canada, NL Chem Canada and Tioxide Canada will add 40,000 and 11,000 short tons of capacity by the end of 1990 to bring the national capacity to 137,000 short tons.

As mentioned previously, titanium dioxide's price tag has traditionally encouraged the replacement by other minerals—mainly kaolin, calcium carbonate, and talc—and one of the major objectives of industrial minerals companies and others is to find that almost-perfect replacement for TiO_2 pigment. To date, none have succeeded, although technological advances and compromises have helped to score some successes. For example, in some grades of uncoated paper up to 50 percent of the titanium dioxide can be replaced by fillers such as calcined kaolin, precipitated silica, or precipitated calcium carbonate, whereas in paper grades where opacity is essential, replacement is less than 15 percent.

Kaolin leads

As might be expected, the paper companies use that mineral or combination of minerals most readily available that fulfills a technical need and is competitively priced. There is a great deal of effort to develop new formulations based on what might be called a mineral cocktail, and substitution is always a strong possibility. In North America, kaolin clay is, and will remain, by far the largest tonnage industrial mineral used in papermaking. In 1988, around 4.5 million short tons of various types of kaolin was used, with its nearest rival, calcium carbonate, at less than 1 million short tons.

The general trend in kaolins has been toward greater sophistication and quality. First there was air-floated, then water-washed, followed by delaminated and calcined kaolin. Although water-washed has been the backbone of the kaolin industry with around 3 million short tons produced each year, it can be said that the quality of a No. 2 Filler produced in 1989 would be vastly superior to a No. 2 Filler produced in 1979. This improvement would be reflected in better consistency and improved particle size distribution. The same improvement would be noticeable in other grades.

Delaminated kaolin is what it sounds like, the laminated kaolin as it occurs in nature is broken down into thinner platelets to improve the brightness and opacity. Calcined kaolin gives a high brightness and lower bulk density; however, the high brightness is detrimental in that it reduces opacity.

Of course each of these improvements is made at a cost—air-floated clay would sell for about \$50/ton, water-washed for something less than twice that amount at \$100/ton, delaminated for over twice that amount with a price in the range of \$250/ton, and calcined for about eight times the cost of the air-floated at \$400/ton. Nevertheless, they all serve a purpose at their level of cost, or they would not be used.

The 5-percent growth in demand for calcined, delaminated, and premium coating grades in 1988 was powered by the strength of lightweight and premium coated paper market. Overall, North American producers shipped 7.5 percent more coated paper in 1988 compared with 1987, and mills operated at over 95 percent of capacity. In 1989, a further increase of 4 percent in consumption is expected, and capacity utilization will be near to 96 percent. This sustained growth in kaolin demand (despite replacement at some free-sheet mills by calcium carbonate) has been evident for several years and has kept prices firm. The buoyancy of the market has encouraged the main producers—Engelhard, ECC America, Georgia Kaolin, J.M. Huber, Nord Kaolin, and Thiele Kaolin—to expand production by 700,000 short tpa, and they are planning to introduce new products.

Another trend in kaolin is to try and locate deposits and develop mines closer to the point of use. This has been particularly noticeable in Canada and more especially in western Canada and the Pacific Northwest states of the U.S.A. In the latter case, the existing rail freight rates of \$75-85/ton from Georgia is a significant cost that would be greatly reduced for a western producer. Three kaolin projects have been considered in Canada, one each in Ontario, Saskatchewan, and British Columbia. The two in Ontario and Saskatchewan are secondary deposits consisting of kaolin and silica sand that would be separated into those respective industrial mineral products. The deposit in British Columbia is a primary deposit that would not have the associated silica sand. None of these three is an imminent producer, but the search for a local source is ever present.

Some of the technical innovations by the kaolin producers in Georgia are of interest. One is the production of a "high-bulking pigment" that is accomplished through processing techniques. Ultrafine kaolin of less than 0.25 micron is optically inefficient, and therefore it is advantageous to stick these together to form larger particles (80-90 percent less than 2 microns). This creates a product with more air space, and the light bounces off these particles rather than passing through, thus creating superior opacity and hiding power. This technique can be used on both filler and coating clays.

One problem with mineral fillers is that they tend to weaken the sheet of paper. Taking the technique a step further, producers are now adding chemicals which increase the retention of the kaolin causing it to stick to the fibre. This results in a strong sheet of paper and still provides the benefits of the mineral—it is known as "high-bulking, high-strength pigment or filler." If the level of loading can be increased from 10 percent to 15 percent or even 18 percent using the newer kaolin at a lesser cost than fibre, then a savings is made on production costs combined with an improvement in quality.

USA Today syndrome

There is still another step which is based on what may be called the *USA Today* syndrome. Paper companies are constantly hunting a lighter weight paper that has greater opacity and less show-through. Quality expectations were heightened still further in the case of *USA Today*, a newspaper launched seven years ago, which has grown to a circulation of over 5 million, making it the third largest daily in the U.S.A. A major characteristic of the paper is the use of 4-color, high-quality printing for both advertising and editorial. This trend is being followed by others; for example, the *Los Angeles Times* and the *New York Times* are installing color press lines, and color printing is forecast to increase 20 percent annually. All this puts great demand on the supply of very high quality and brighter newsprint that has light weight plus opacity.

In addition to some standard tests such as ink absorption, the *USA Today* newsprint sheet is tested by a process that measures three-dimensional light color components on scales of black to white, green to red, and blue to yellow. In addition, the quality must be consistent for each of the 30 printing locations across North America. It was recently revealed that just eight newsprint mills in North America are able to meet *USA Today*'s quality standards, but many more are trying. The role of the mineral would appear critical in achieving the brightness, light weight, and opacity required for color printing on newsprint.

For the sake of discussion we can say that certain newsprint has a brightness of 55 percent, but that this is not bright enough. The paper company can use chemicals to bleach its pulp to a 65-percent brightness, but this causes two problems—as the brightness goes up the opacity goes down, and there is an increased effluent problem from the chemicals used as bleaching agents. Therefore, this is only partially acceptable. Another approach is to use a low bulk density clay with a high brightness. Calcined kaolin fits this requirement with a brightness of over 90 percent GEB, but, as usual, the high brightness also means lower opacity. In addition, calcined kaolin reduces the strength of the paper, so that the loading factor is limited to a maximum of 5 percent, and at more than $400/ton FOB, calcined kaolin is uneconomical over 3 percent.

The trend now is to create a mineral additive, consisting of kaolin and other minerals, that will agglomerate the ultrafines, be lightweight, and allow the brightness to be controlled from the 60's to 90's. In this way, there is no need to add a 90-percent-GEB clay to a 60-percent-GEB newsprint and thereby reduce the opacity. In other words, the mineral will be tailored to fit the specific need. In this case, the clay will sell for about one-half of the cost of the pulp or about one-third of the cost of titanium dioxide.

Calcium carbonate or PCC

The other large-tonnage mineral besides kaolin used in the paper industry has been "natural calcium carbonate," a term used for high-brightness, high-quality limestone or marble. There is no specified level when limestone or marble becomes calcium carbonate in the industrial minerals parlance, but a brightness of 80-85 percent GEB is a good dividing line. The North American paper industry consumes around 750,000 short tpa of this material, with a growth rate of around 15 percent per year. Several technological trends have allowed this growth to take place.

The pH or acid/base environment of making paper has an effect on the product. The Egyptians invented the papermaking process and used a basic or alkaline environment for production. Some of the papyrus produced is still extant today. However, in the industrialized era the production process was gradually changed so that an acidic method became dominant. In the past 20 years or so, papermaking based on the alkaline side has been gaining favor once again, most especially in Europe and more recently in North America. It is now estimated that almost 30 percent of the North American production of printing and writing paper (excluding newsprint) is alkaline. This is expected to exceed 45 percent by 1992.

A major drawback with paper produced in an acidic environment is that it is subject to rapid deterioration, as can be seen in the yellow pages that crumble after being on the shelf for just a few decades. This negative archival effect is highly detrimental. In the mill, the alkaline process has technical and economic advantages, particularly in the production of coated fine grades of paper. The pros and cons of the process and the conversion is a subject by itself. The main advantage from an industrial minerals viewpoint (and the paper company's) is the ability to load or fill the sheet with more minerals, including calcium carbonate, thereby replacing expensive pulp while at the same time maintaining paper strength. Some mills have experienced as much as a 10-percent increase in the loading factor which can be as high as 30 percent by weight (50 percent plus has been achieved in the laboratory).

Calcium carbonate is a good filler in paper, has many of the proper characteristics, including brightness, is more universally available than kaolin and is therefore commonly cheaper. However, a carbonate utilized in an acidic environment would create one of the great bubble baths of all time. However, with the advent of "alkaline sizing" it is possible to use calcium carbonate, and suppliers developed suitable grades with tighter size distributions, less abrasiveness, and containing less dispersant. The use of calcium carbonate by no means eliminates kaolin on a technical basis, but it does discourage its use in paper mills remote from a kaolin source.

With the coming of the alkaline sizing process to papermaking, several producers of calcium carbonate expanded production to meet the expected increase in demand. There was a spate of takeovers that rationalized the North American fine-ground calcium carbonate industry down to five major producers—Pfizer, Georgia Marble, Omya Inc., ECC America, and J.M. Huber—plus several minor producers. In addition, companies commenced exploration programs for high-brightness natural calcium carbonate deposits throughout North America. Although only one new high-quality calcium carbonate mine has been developed (in Washington State), expansions have created somewhat of an oversupply situation due to a lower than expected growth in the conversion to alkaline papermaking and the dramatic success of its synthetic equivalent (PCC).

Carbon dioxide (CO_2) is a by-product of the paper mills, and lime (CaO) can be brought to the paper mill from any nearby source. The CO_2 gas is bubbled through the lime to create a precipitated calcium carbonate with high brightness and good uniformity of size. The process can be regulated to produce different sizes and, thereby, different particle size distribution. There is invariably a substantial cost saving in transportation over fine-ground calcium carbonate as well as security of supply. For the most part, however, delivered prices are comparable.

The popularity of this concept has been such that ten satellite plants are currently in operation in North America, with five more starting up this year for a total capacity of 600,000 short tpa. The company spearheading the development of these so-called satellite plants is Pfizer, Inc., which will have a minimum of 11 plants operating by the end of the year, along with one each from Steel Brothers, Champion, Olin, and Finch Pruyn.

This 0.5-0.6 million short tons of PCC, used almost exclusively as a filler, largely detracts from the ultrafine ground calcium carbonate and kaolin. Nevertheless, both these products are essential filler minerals. In fact, recent technical studies are illustrating that a combination of PCC and kaolin can provide greater opacity, higher ash levels per unit of filler in the sheet, and moderate brightness. A study carried out by the State University of New York at Syracuse on mills in Wisconsin and Virginia illustrated that a combination of fillers reduced costs (despite the freight costs of the clay) for the same quality paper.

Talc

Talc is widely used in paper mills as a means of controlling the content of pitch contained in the wood pulp. Something in the range of 150,000 short tpa is used in North America for this purpose. As noted earlier, the Finnish and to a certain extent Scandinavian mills use talc as a functional filler, since the local material is of high quality and is more readily available than high-grade kaolin or calcium carbonate.

Some North America paper mills are now considering the utilization of talc as a function filler. This trend is being led by the Scandinavians with interests in North America and requiring a high-brightness talc of 93-94 percent GEB. At least one Canadian talc producer is on the verge of producing such a grade consistently and is optimistic about the reception in the marketplace.

Table 1. *Summary of North American paper*

	Production (1,000 short tons)			Operating rate
	1986	1987	1988	(percent)
Newsprint	5,630	5,842	5,971	99.3
Uncoated g'wood	1,540	1,485	1,617	86.7
Coated paper	6,263	6,860	7,410	96.9
Uncoated free-sheet	10,410	10,977	11,379	96.6
Bristols	990	1,044	1,130	98.0
Thin paper	247	251	221	71.5
Cotton paper	152	163	162	82.2
Kraft/industrial	5,117	5,072	5,207	92.0
Tissue	5,095	5,301	5,488	95.1
Total paper	35,444	36,994	38,585	95.8
Percent increase	4.3	4.4	4.5	—

Table 2. *Major North American new coated-paper expansions*

Company	Location	Capacity (1,000 tpa)	Startup date
Blandin Paper Co.	Grand Rapids, Minn.	220 CGW	1989
Champion Papers Consolidated	Bucksport, Maine	33 CGW	1989
Papers Inc.	Stevens Point, Wis.	60 CGW*	1989
Internatl. Paper Co.	Corinth, N.Y.	100 CF	1989
Champion Papers	Sartell, Minn.	—CGW	1989
Repap Enterprises Inc.	Newcastle, N.B.	200-260 CGW/CF	1989
Fraser Paper Ltd.	Madawaska, Maine	—CGW	1990
Westvaco Corp.	Wickliffe, Ky.	100 CF	1990
Champion Papers	Quinnesec, Mich.	265 CF*	1990
Scott Paper Co.	Skowhegan, Maine	215 CF*	1990
Scott Paper Co.	Muskegon, Mich.	30 CF	1990
Proposed			
Blandin Paper Co.	Grand Rapids, Minn.	250 CGW	n.a.
Boise Cascade Corp.	Rumford, Maine	—CGW*	1991
Bowater Southern	Calhoun, Tenn.	250 CGW*	n.a.
Fraser Paper Ltd.	Madawaska, Maine	—CGW*	n.a.
GNN/MD Papier	Millinocket, Maine	—CGW*	n.a.
James River Corp.	St. Francisville, La.	—CGW*	n.a.
Mead Corp.	Escanaba, Mich.	—CGW*	n.a.
Pentair Inc.	Niagara, Wis.	92 CGW	n.a.
Internatl. Paper Co.	n.a.	—CF	n.a.
Repap Enterprises Inc.	The Pas, Man.	—CF	n.a.

*New machines. CGW = coated groundwood; CF = coated free-sheet. Source: *Pulp and Paper Week.*

Other possibilities

The filler business is a battleground for substitution. R-and-D departments of suppliers are constantly striving to improve their products and secure additional markets, while the equivalent departments in consuming companies attempt to replace existing fillers with cheaper and/or technically superior varieties.

For example, Japan presently uses around 100,000 tpa of zeolites as a filler in paper. It is generally conceded that this usage would not be so high if high-quality kaolin clays were available domestically. However, despite the lack of high brightness, there are some benefits to the use of zeolites in papermaking. One major kaolin producer has experimented with clinoptilolite and has issued a patent for increasing the brightness to the mid-90's GEB. The initial target was believed to be carbonless carbon paper, but there is now a possibility of using higher brightness clino as a functional filler in newsprint-type paper. This is due to its ion-exchange capacity and possibly molecular-sieve attributes as a scavenger for deleterious chemicals used in the paper-production process. At least one U.S. producer of zeolites is investigating this end use.

There is some substitution potential from outside the mineral industry. For example, Rohm and Haas has been marketing its Ropaque OP-84 as a substitute for TiO_2 in paper coating since 1984. This is a hard, nonfilm-forming styrene/acrylic copolymer latex sphere with a core of water. As the coating dries, the water diffuses out of the core leaving a hollow, air-filled, lightweight sphere with a specific gravity of 0.81 (90 percent lighter than TiO_2). The resultant sphere has excellent light-scattering properties in that light is refracted four times—as it strikes the particle, enters the hollow sphere, strikes the other side of the interior surface, and exits the particle. In addition, the average inner diameter of 0.3 micron is about half the wavelength of light and is ideal for light scattering, and the sphere improves the spacing characteristics of the TiO_2 particles, which tend to pack or crowd. According to the manufacturer, the sphere provides lightweight and other coated paper with:

- Higher levels of gloss
- Greater smoothness for improved print properties
- Higher bulk without loss of gloss
- Lower coating weights without reducing coating thickness
- Improved gloss while maintaining opacity and brightness

Once again, the aim is to achieve high opacity while maintaining brightness and light weight and keeping costs in check. Research will continue to experiment with minerals, chemicals, and "other" materials to satisfy the ever-changing needs of the paper manufacturers.

OUTLOOK FOR NORTH AMERICAN PAPER

During the latter part of the Reagan administration, paper like many other manufacturing industries enjoyed bumper years. The growth has continued in the first months of the Bush administration, and the pundits are cautiously optimistic that growth will continue. The paper industry appears to be confident, with capital spending reaching a record $11,500 million in 1989. There is the ever-present talk of a "mild recession soon," but in the meantime capacity utilization is expected to remain above 95 percent and overall production to grow at 3 percent or better.

There is some variation in the fortunes of the various grades as illustrated in Tables 1 and 2. However, the grade most relevant to industrial minerals, coated paper, continues to grow apace. Consumption, mainly in commercial printing such as magazines, advertising inserts, and catalogues, increased over 8 percent in 1988, and industry analysts forecast a 4-percent increase in 1989. All this is good news for the mineral industry, and proves that subscribers to *Industrial Minerals* are supporting their own industry! ☐

DOGAMI works in many fields: Current activities summarized

Contributed by DOGAMI staff members; compiled and edited by Klaus Neuendorf

INTRODUCTION

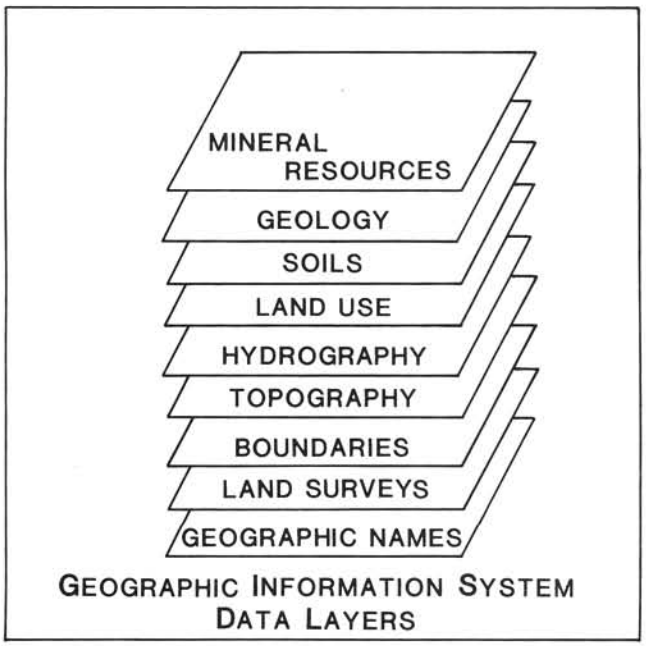
The following is a summary of current activities of the Oregon Department of Geology and Mineral Industries (DOGAMI), both in its main office in Portland and in its field offices in Albany, Baker City, and Grants Pass.

The Portland office serves as a base for most of the Department's major projects and programs. The Albany office is not a geologic field office in the strict sense but the base of the Department's Mined Land Reclamation Program, which has a mostly regulatory function.

PORTLAND

Statewide programs

Economic geology—Jerry Gray is continuing his work on the development of a mineral-resource database. This project includes cooperation with several federal and state natural-resource agencies. Ultimately, it will create a "mineral-data layer" to fit with other portions of Oregon's Geographic Information System (GIS) and a county-by-county mineral database for universal applications by industry, federal, state, and local governments.



Schematic diagram showing typical data layers in a Geographic Information System (GIS).

Ron Geitgey conducts statewide assessments of industrial minerals with attention to resources and markets. After completion of assessments of talc, bentonite, limestone, and silica by various staff members, Ron is currently focusing on pumice. Other industrial-mineral commodities will follow.

Earthquake hazard assessment—George Priest and Ian Madin are working on the development of a geologic database for assessing earthquake risks in Oregon.

A federal grant from the National Earthquake Hazard Reduction Program is funding production of maps of the geology of the Portland metropolitan area, especially areas with significant risk from earthquake shaking. This grant is also funding coordination with other groups and communication of the results to the public. Oregon Senate Bill 955, passed in the last legislative session, directs the Department to take the lead in coordinating assessment and mitigation of a wide range of natural hazards, including earthquakes. The Department recently received $230,000 from the State Emergency Board to set up a permanent seismic hazard assessment program for the state. This program includes the creation of geologic maps and of databases for soil geology and ground response.

Water-resource planning—Dan Wermiel coordinates the Department's participation in statewide water-resource planning and policy development. Currently, this work is focused on the creation of a geologic framework for the planning efforts.

Statewide regulatory activities

Energy minerals—Dennis Olmstead and Dan Wermiel perform the Department's regulatory task for energy minerals. The development of energy minerals, which include oil, natural gas, and geothermal resources, requires regulation to ensure conservation of resources, protection of the correlative rights of mineral owners, and the protection of the safety and environment of Oregonians.

Because geology plays a significant role in the formation of energy mineral resources and in the design and operation of wells that explore for these resources, geologic expertise is an integral part of the regulatory procedure. Thus, the Department has legislative authority to regulate oil, natural-gas, and geothermal exploration and production activities in Oregon. It has exercised this authority since 1949.

Dennis Olmstead checking pressure gauge at a disposal well in Mist Gas Field.

Geothermal exploration drill site of Anadarko Petroleum Company in the Alvord Desert, Harney County.

Regulatory activities include (1) technical evaluation of drilling, production, and well-abandonment programs, and (2) numerous field inspections of well sites before, during, and after drilling. Technical evaluations ensure proper engineering design of the drilling project and protect the correlative rights of mineral owners. Site visits include pre-drilling inspections, testing of blowout-prevention equipment, and inspections of well-plugging procedures and of proper site reclamation. Specialized inspections are also performed for such activities as the plugging of seismic shotholes.

A system of permits and bonds is used to ensure conformance with applicable laws and regulations so that the exploration for and production of energy mineral resources is conducted in a responsible manner. The permit includes technical details of the proposed drilling program, such as the casing program to protect ground-water resources. Close coordination with federal, state, and county agencies is designed to address various environmental and land-use concerns.

Currently, the only natural-gas field in the Pacific Northwest is located in Columbia County, Oregon. The Mist Gas Field, discovered in 1979, has been the most active drilling area in Oregon, averaging 14 wells per year. The recent completion of a natural gas storage project at the gas field requires additional regulation. Other wells are drilled each year throughout the State, requiring further regulatory activity.

Geothermal drilling operations are also regulated. Over the past few years, geothermal drilling has primarily been at the Newberry volcano area in Deschutes County, the Winema National Forest in Klamath County, the Alvord Desert in Harney County, and the Santiam Pass in Jefferson County. The Department's regulatory activities include the technical evaluation of the proposed drilling programs, field inspections during the drilling of the wells, and reclamation site inspections.

The records and cuttings from oil, gas, and geothermal wells are kept by the Department, and, after expiration of a confidentiality period, made available to the public. The Department maintains a warehouse to keep the cuttings, while the well records are located at the agency's main office. The records, which are used for research into the subsurface geology of the state, are continuously interpreted and reinterpreted. These data are integrated with existing data to appraise the state's potential for energy minerals as well as other mineral resources.

Regulatory activities also include legislative work and rule-making. Currently, this includes work on rules for the implementation of new laws, such as the new law regulating seismic shotholes. The law protects ground-water resources that may be affected by shallow oil and exploration holes and regulates reclamation of the affected land surface. Another current project is work on a revision of existing drilling rules.

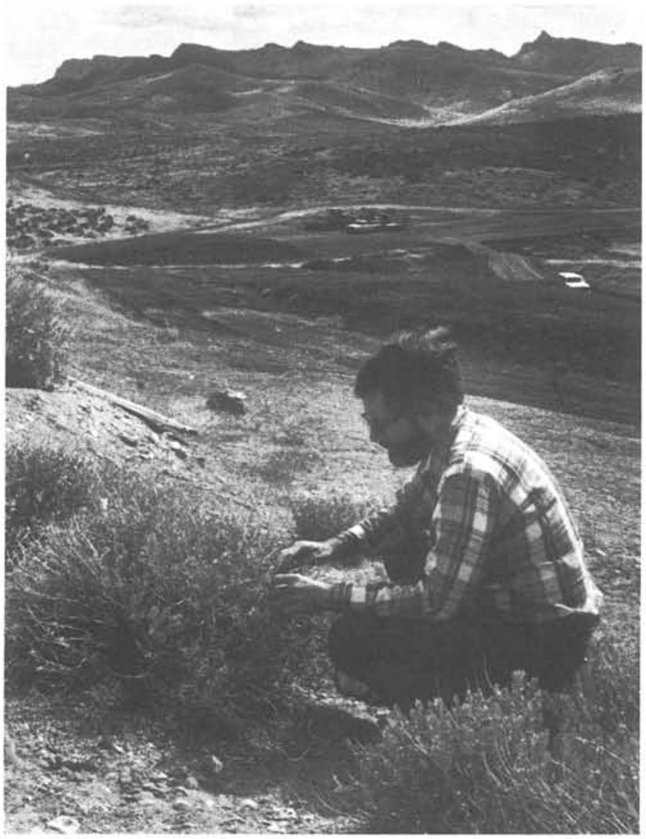
Mined land reclamation—The Mined Land Reclamation Program (MLR) operates from its base in Albany. Supervisor Gary Lynch and staff members Allen Throop, Frank Schnitzer, and Doris Brown (and soon-to-be-added new staff) regulate Oregon's surface-mining activities. This work includes statewide regulation of mining-related exploration, mine design, and subsequent land reclamation, both for aggregate and nonaggregate minerals. In cooperation with other regulatory agencies, MLR works toward protecting the environment and providing beneficial second use of the land.

Other programs

Placer Minerals Task Force—State Geologist Donald Hull co-chairs and staff member Greg McMurray coordinates the Oregon Placer Minerals Technical Task Force, a state/federal body established by the Governor of Oregon and the U.S. Secretary of the Interior. The Task Force recently produced a report summarizing the known black-sand resource in Oregon, its extent and quality, its economics, and the environmental aspects of mining such a resource.

The placer sands, found primarily off the coast of southern Oregon, contain chromium, titanium, gold, platinum, and zirconium. These minerals are economically important, and in some cases the metals are strategic. Production of such minerals has occurred onshore in Oregon in the past. During mineral shortages of World War II, the coastal terraces of southwestern Oregon and the mouth of the Columbia River were explored for chromium and titanium.

Additional basic research is needed to characterize the placer-minerals resource. The recommendation section of the Task Force's recent



Allen Throop of the Mined Land Reclamation Program is examining regrowth of sage planted on a reclaimed portion of a bentonite mine in Malheur County.

report proposes a sample-collection program for 1990 to accomplish this. The proposal includes a two-week oceanographic cruise off Cape Blanco and the Rogue River to collect vibracores and biological samples characteristic of the placer sands. The cruise is scheduled for September.

Offshore resources—Dennis Olmstead oversees completion of key onshore/offshore transects in areas of prime hydrocarbon potential. This program is a contribution to the federal/state processes to estimate resource potential.

Together, Olmstead and John Beaulieu also work on contributions to state policy development with regard to offshore resources.

Santiam Pass scientific drilling project—George Priest is overseeing the cooperative project of drilling a 1-km-deep hole at Santiam Pass in the Cascades for scientific study. A 914-m diamond-core hole to be completed this summer will explore the geologic history of the High Cascades and establish how much heat is flowing out near the crest of the range. The project is expected to yield important geophysical and geologic data and, possibly, aid in the development of a geophysical transect.

This project is part of a wider scientific drilling initiative started by the Department about four years ago to stimulate exploration of large-scale earth processes that have produced mountain ranges, volcanic eruptions, earthquakes, mineral deposits, and geothermal energy in the state.

Tyee Basin assessment—The Tyee Basin project is a five-year study of the hydrocarbon potential of a portion of the southwest Oregon Coast Range. The project was begun in July 1988 and will run through July 1993. The project manager is Gerald Black; his supervisor is George Priest, the Regional Geologist of northwest Oregon. A Steering Committee composed of major donors and landholders in the area provides overall direction.

The study area is an irregularly shaped region that occupies the axis of the Coast Range from a latitude of Glendale on the south to just south of Eugene on the north.

The Tyee Basin project was started in order to stimulate hydrocarbon exploration in the region. There has been long-standing

Charter research vessel Aloha, *to be used as platform during oceanographic cruise of the Oregon Placer Minerals Technical Task Force in September.*

View looking north from Tyee escarpment into Flournoy Valley, Douglas County, the area of the Tyee Basin assessment project. White Tail Ridge in middle distance is composed of deltaic-facies sedimentary rocks capped by continental-shelf-facies sandstones.

interest in the oil and gas potential of the southern Coast Range, and there has been significant drilling there since the early 1900's. This drilling activity includes the Mobil Sutherlin No. 1 well, which is, at 13,177 ft, the deepest hole ever drilled in the state. As recently as 1985, Amoco Production Company drilled two holes to depths of 4,428 and 11,330 ft in the axis of the Coast Range northwest of Sutherlin. At the present time, however, there are no active exploration programs by any of the major oil companies, no lands are under oil and gas leases, and no new wells are contemplated.

DOGAMI believes that the Coast Range in southwestern Oregon has the potential to produce commercial quantities of hydrocarbons and therefore put together a consortium of private and public donors to finance a modest exploration program. Contributors to the study include federal institutions (U.S. Bureau of Land Management and USDA Forest Service), private corporations (Weyerhaeuser, GCO Mineral Company, Menasha Corporation, and the Douglas County Industrial Development Board), and state agencies (DOGAMI and the Division of State Lands). Approximately $110,000 of State Lottery funds are also supporting the work during the present biennium.

To attract the oil companies back into the area, it is necessary to know why they left in the first place. The main reasons were that they did not see good source rock potential, did not see evidence that the area was thermally mature enough to produce oil and gas, did not find particularly good reservoir rocks, and did not understand the stratigraphic framework of the region.

DOGAMI's goals, then, are to provide more source-rock, thermal-maturation, and porosity and permeability data and to improve the quality of the mapping in the basin so that industry understands the geology.

During the first year of the project, the Steering Committee laid out a specific agenda designed to accomplish its long term goals. The specific items on the agenda include:

- 1. Publish a compilation geologic map of the entire Tyee Basin. The map would include every available source of geologic data for the region.
- 2. Compile and publish all available geochemical data.
- 3. Complete a three-dimensional fence diagram. The purpose of this diagram is to tie surface geologic data to subsurface well and geophysical data.
- 4. Conduct detailed geologic mapping to solve specific stratigraphic problems and search for potential reservoir rocks.

A subcontract to accomplish items one and two above was awarded to Alan and Wendy Niem of Oregon State University. The compilation map and accompanying geochemical data were published in March 1990 as DOGAMI Open-File Report O-89-3. The map is a major contribution to the understanding of the geology of southwestern Oregon. The Niems managed to obtain permission to release a large quantity of formerly proprietary oil company data that are included on the map. The Niems are also completing the fence diagram.

Gerald Black completed the field work on a detailed map of the Reston 7½-minute Quadrangle in 1989. In 1990, Black will start mapping in the Camas Valley 7½-minute Quadrangle. By the end of the project, a detailed mapping transect across the southern Coast Range at a scale of 1:24,000 will have been completed.

Technical support

Laboratory—Field studies must be integrated with a variety of analytical techniques for identification, analysis, and age determination of minerals and rocks. Geochemist Gary Baxter and technician Chuck Radasch provide chemical, physical, and mineralogical testing and analyses of samples as needed by all staff geologists in their projects.

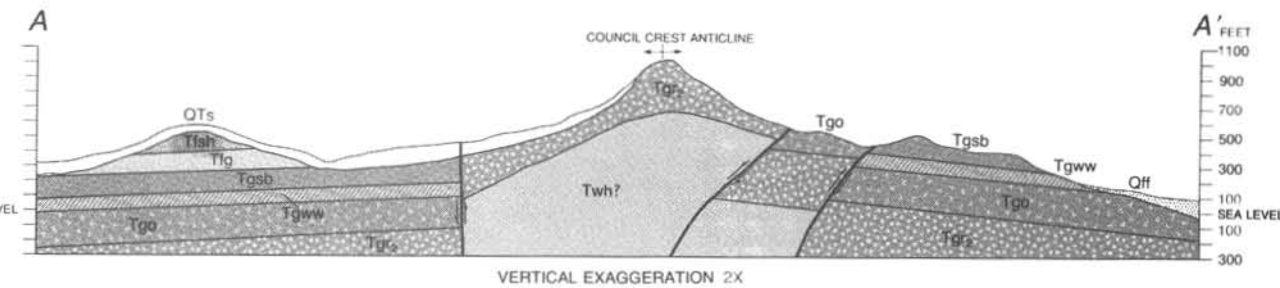
REGIONAL ACTIVITIES

In the Department offices in Portland, Baker City, and Grants Pass, one geologist is identified as Regional Geologist. In addition to regular duties and project work, the Regional Geologist serves the public in matters concerning regional geologic issues and assists local government by contributing to geologic data needs and periodic reviews of county land-use plans.

Northwest (Portland)—As Regional Geologist, George Priest is currently collaborating with Ian Madin to conduct geologic mapping in the Portland area. This mapping is focused mainly on the ongoing studies for earthquake hazard assessment.

In response to new evidence in earthquake research indicating that the "Big One" looms in Oregon's future, DOGAMI is working on an earthquake hazard assessment program for Oregon. Ian Madin

GEOLOGIC CROSS SECTION



A black-and-white version of one of the three colored cross sections included in the first geologic map published in 1989 in connection with the ongoing studies for earthquake hazard assessment in the Portland metropolitan area (DOGAMI map GMS-59). The diagram shows a southwest-northeast-trending section of the area just south of downtown Portland and includes several previously unrecognized faults.

is currently preparing basic geology maps for the Portland metropolitan area in an attempt to locate areas in which soil conditions may increase or reduce earthquake damage. This mapping program also seeks to identify faults in the area and determine whether they are active and capable of generating significant earthquakes.

To date, numerous faults have been located, at least one of which has been active during the last half-million years. The earthquake hazard geology maps for Portland have been released (see page 94). For the rest of 1990, mapping will continue in Clark County, Washington, where a potentially active fault has been recently identified by U.S. Geological Survey seismologists, and in the Damascus area (Clackamas County, southeast of Portland), where more active faults are expected to be present.

Future plans include work on evidence of prehistoric earthquake activity along the coast of Oregon and mapping earthquake hazard geology for the Willamette Valley urban areas. In addition to carrying out research on earthquake hazards, Ian Madin and George Priest are beginning a new program of contracted earthquake hazard assessment using funds recently supplied by the Legislative Emergency Board. This new program also includes the hiring of a geotechnical earthquake engineering specialist.

George Priest also supervises geological and geophysical studies throughout northwestern Oregon.

Southwest (Grants Pass)—In October 1989, the Grants Pass Field Office was restaffed and moved to a new location at 5375 Monument Drive. New geologists are Tom Wiley, Regional Geologist, and Frank Hladky, Resident Geologist. Kathleen Murphy is currently filling the position of office specialist.

In order to select a research program for the office, Wiley and Hladkey reviewed geologic, mining, hazard, and land-use data for southwestern Oregon. Project ideas that resulted from this review were discussed with scientists and planners in industry, academia, and government agencies.

The field office staff decided to undertake a multi-year project of mineral-resource assessment and geologic mapping of the area covered by the east-central portion of the Medford 1° by 2° quadrangle. This area covers parts of Jackson and Douglas Counties and includes the cities of Ashland and Medford. It encompasses the southern part of the Western Cascades and parts of the High Cascades and Klamath Mountains. Mineral resources that may occur in the area include aggregate, asbestos, bentonite, clay, copper, decorative rock, diatomite, dolomite, gold, iron, lead, limestone, manganese, mercury, natural gas, nickel, pumice, silica, silver, soapstone, talc, zeolite, and zinc.

Much of the project area is experiencing rapid population growth. In this situation, the detailed geologic maps that result from this project will, above all, provide land-use planners with improved mineral-resource and geologic-hazard inventories. Mapping will proceed by 7½-minute quadrangles, beginning with the Boswell Mountain Quadrangle north of Medford.

Southern Bear Creek valley in the area of the initial mapping and assessment project of the Grants Pass staff. View shows Eocene and Oligocene volcanic rock in the distance and Eocene sedimentary rock capped with Tertiary intrusive rock in the middle foreground.

East (Baker City)—Geologists Howard Brooks and Mark Ferns and office specialist Janet Durflinger serve the eastern part of Oregon in the Baker City Field Office.

The geologic studies in the area are currently focused on the Boise Sheet mapping project, an ongoing cooperative effort of DOGAMI, the USGS, and Portland State University (PSU) to map the Oregon part of the Boise 1° by 2° Quadrangle in the Owyhee region in southeastern Oregon. DOGAMI interest in the region began in 1982, when the Department made a geochemical survey of Wilderness Study Areas (WSAs) for the U.S. Bureau of Land Management. USGS personnel began mapping selected WSAs in 1984; DOGAMI mapping began in 1987; PSU's involvement started with the establishment of annual field camps in the same year.

Succor Creek, Owyhee Mountains, southeastern Oregon. This is part of the area to be covered by the geologic map of the Boise 1° by 2° Quadrangle, the major current concern of the Baker City Field Office. Photo courtesy Oregon State Highway Division.

The major goal of the project is to provide geologic maps that are usable for mineral-resource investigations and land use planning. The recent discoveries of gold in several parts of the region, including some WSAs, underscores the need for detailed geologic maps—not only to assist in identifying and evaluating mineral resources for future public needs but also to aid in the resolution of land use conflicts.

The mapping effort has yielded a number of 7½-minute quadrangle maps (scale 1:24,000): To date, 12 have been completed and published; others are in various stages of completion. A geologic map of the entire area will be compiled and published at a scale of 1:100,000 after the mapping has been completed. □

MINERAL EXPLORATION ACTIVITY

MAJOR METAL-EXPLORATION ACTIVITY

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	Jessie Page Chevron Resources, Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
May 1989	Hope Butte Chevron Resources, Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App
June 1990	Racey Billiton Minerals USA	T. 13 S. R. 41 E. Malheur County	Gold	Expl
June 1990	Grouse Mountain Bond Gold Exploration, Inc.	T. 23 S. Rs. 1, 2 E. Lane County	Gold	Expl
June 1990	Freeze Western Mining Corporation	T. 23 S. R. 42 E. Malheur County	Gold	Expl

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

EXPLORATION AND BOND CEILING RULES

The rules covering exploration activity that exceeds one total acre of disturbance or on which a drill hole greater that 50 ft deep is drilled are scheduled to be be presented for adoption at the July 9 meeting of the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI). Companies that fall under the new rules must contact the Mined Land Reclamation Program (MLR) office immediately at the location given below.

Rules governing an increased bond ceiling for some metal mines are also scheduled for adoption at the meeting of the Board.

MINING ISSUES FORUM

A one-day meeting to discuss numerous aspects of the impact of large-scale gold mining in Oregon is scheduled for September 8, 1990, in Bend. Speakers from the industry, environmental groups, elected officials, and regulatory agencies will present a wide range of views and opinions on the subject. More information is available from the MLR office.

STATUS CHANGES

Applications for exploration permits were received from Billiton Minerals, Bond Gold, and Western Mining Corporation, and permits will likely be issued in June.

The Bond Gold application of March 1990 for the Red Jacket site in Jefferson County was withdrawn.

Formosa Exploration, Inc., has received an operating permit for its Silver Peak site, which is therefore no longer listed above.

The Chevron Resources exploration site formerly called "QM" has been renamed "Jessie Page."

All readers who have questions or comments about exploration activities in Oregon should contact Gary Lynch or Allen Throop at the MLR office, 1534 SE Queen Avenue, Albany, Oregon 97321, phone (503) 967-2939. □

DOGAMI publications released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two new publications:

Released June 4, 1990: ***Earthquake-Hazard Geology Maps of the Portland Metropolitan area, Oregon***, by staff geologist Ian Madin. DOGAMI Open-File Report O-90-2, 21 p., 8 maps (scale 1:24,000), price $9.

The maps are one-color diazo paper reproductions, approximately 25 by 30 in. Each map covers one of the following 7½-minute quadrangles: Beaverton, Gladstone, Hillsboro, Linnton, Lake Oswego, Mount Tabor, Portland, and Scholls. These maps are a product of an ongoing earthquake-hazard assessment that is being carried out by DOGAMI with funding from the National Earthquake Hazards Reduction Program. The maps provide a fundamental geologic base for future detailed studies of variations in earthquake hazard due to local geologic conditions. They also contain information about known or suspected faults in the Portland area and can be used for a crude assessment of relative earthquake hazard.

Released June 22, 1990: ***Geology and Mineral Resources Map of the Mitchell Butte Quadrangle, Malheur County, Oregon***, by M.L. Ferns, DOGAMI, and K.M. Urbanczyk, Washington State University. DOGAMI Geological Map Series GMS-61, 1 map (scale 1:24,000), price $4.

The Mitchell Butte 7½-minute Quadrangle is located north of Owyhee Dam and south of the city of Vale. The two-color map of the quadrangle describes surficial and bedrock geologic units and geologic structure both on the map and in two geologic cross sections. The approximately 27- by 38-in. map sheet also contains brief discussions of the quadrangle's mineral-resource potential and its ground-water resources and shows results of rock-sample analyses in two tables. While gold is the main potential mineral resource of the area, both natural-gas and geothermal-energy resources may occur.

This publication represents another step in the Boise Sheet mapping project, an ongoing study of southeastern Oregon areas with a potential for mineral resources. A description of the project is given in the summary of current DOGAMI activities on page 93 (Baker City Field Office) in this issue.

For ordering information, see page 96 of this issue.□

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

		Price	√
GMS-4	Oregon gravity maps, onshore and offshore. 1967	3.00	
GMS-5	Geologic map, Powers 15-minute Quadrangle, Coos/Curry Counties. 1971	3.00	
GMS-6	Preliminary report on geology of part of Snake River canyon. 1974	6.50	
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GMS-14	Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00	
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Geologic map of Oregon east of 121st meridan (U.S. Geological Survey Map I-902). 1977 (blackline copy only)	6.10	___
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Landforms of Oregon (relief map, 17x12 in.)	1.00	___
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Northwest Oregon, Correlation Section 24. Bruer and others, 1984 (published by AAPG)	5.00	___
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Back issues of *Ore Bin/Oregon Geology*, 1939-April 1988	1.00	___
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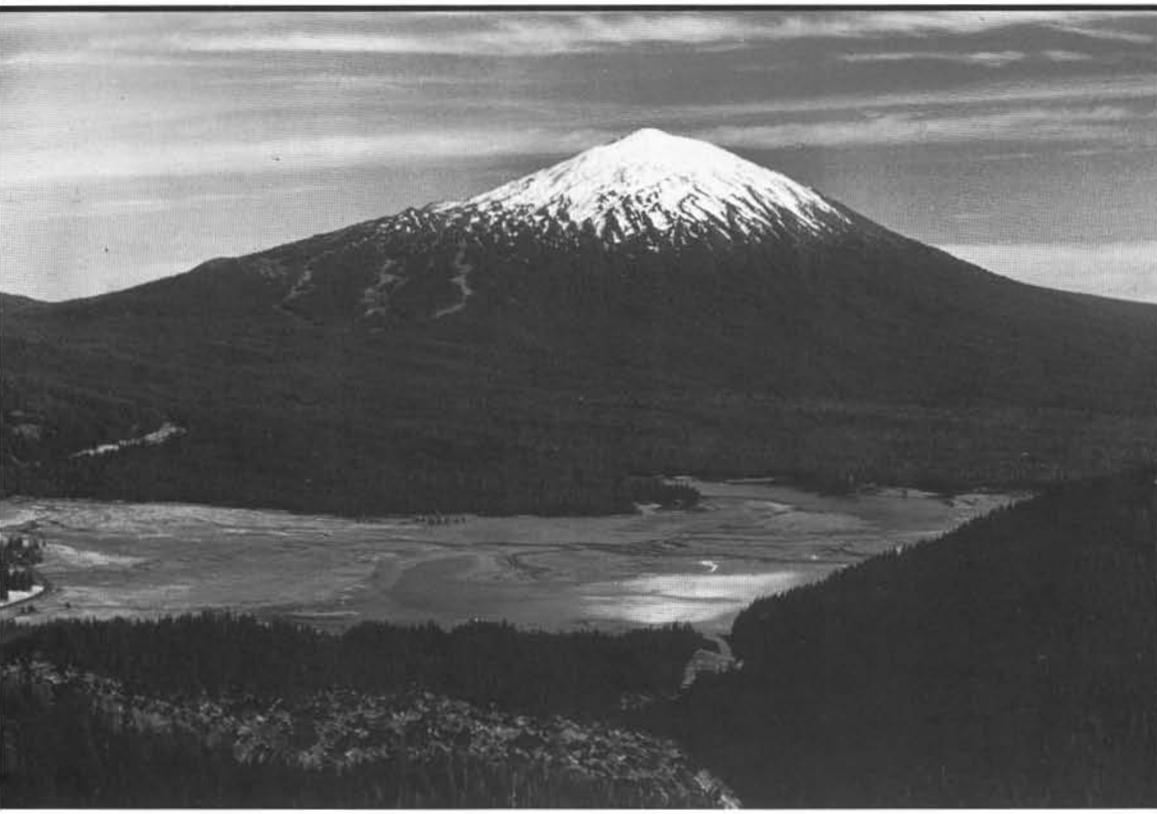
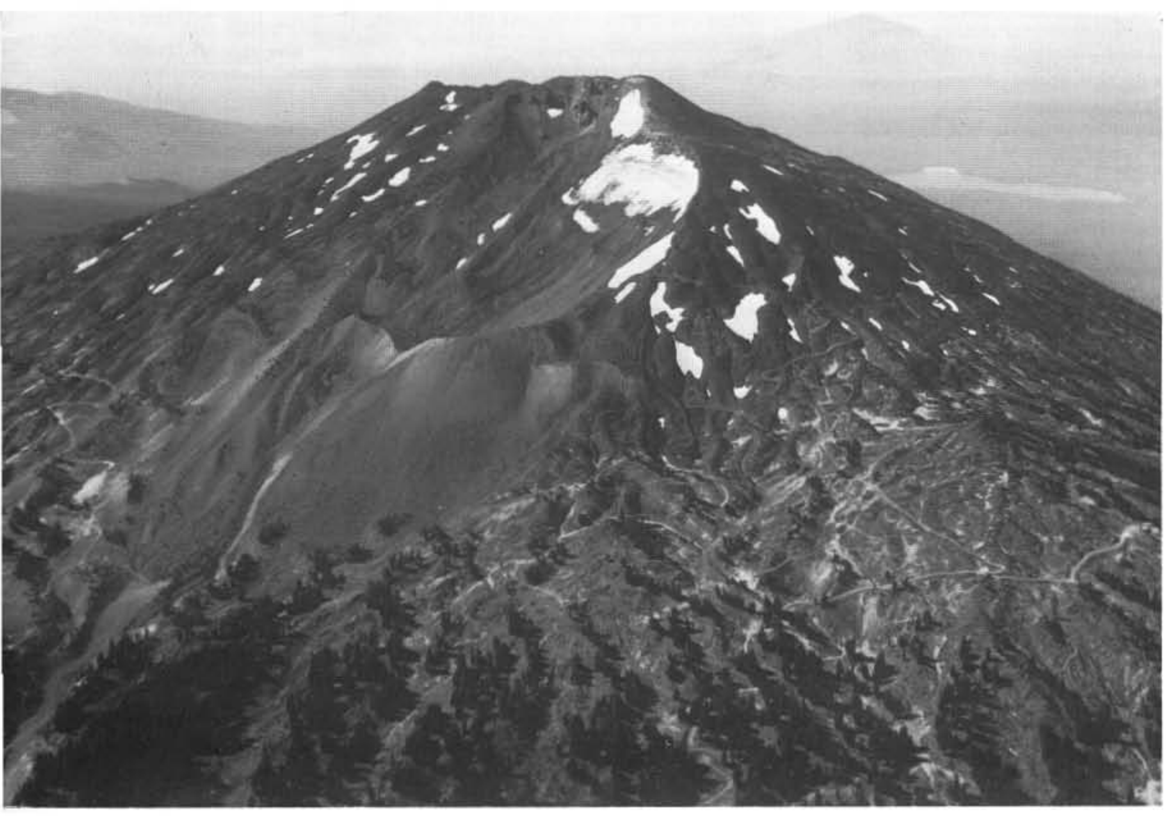


Mount Bachelor—formerly Bachelor Butte



TWO-PART ARTICLE:

Field trip guide to the central Oregon High Cascades

IN THIS ISSUE:

Part 1: Mount Bachelor-South Sister area

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Information for contributors

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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*, 6th ed., 1978.) 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 photos

Mount Bachelor (formerly Bachelor Butte), a major focal point in the field trip guide beginning on page 99.

Top photo shows view of west side of Mount Bachelor from south flank of South Sister, one of whose 2,000-year-old rhyodacite domes is in right foreground. Sparks Lake in middle distance; Cascade Lakes Highway visible along left edge. Mount Bachelor is composed of a steeper summit cone lying on a broad shield. Ski trails are on lava flows that issued from vent marked by small knob on north flank near snow line.

Bottom photo shows aerial view of upper north flank of Mount Bachelor. Visible features include moraines of early and late neoglacial ages, moraines of late glacial age, and lava flows of the mountain that predate and postdate late glacial moraines. Young vents are visible just above tree line. Photos by Lyn Topinka (top) and William E. Scott (bottom), U.S. Geological Survey.

OIL AND GAS NEWS

Rules to be presented for adoption

In November of this year, revised administrative rules relating to oil and gas exploration and development in Oregon will be presented to the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI) for possible adoption. Copies of these rules are available. For details, interested parties should contact Dan Wermiel at the DOGAMI office in Portland, phone (503) 229-5580.

NWPA Field Symposium scheduled

The Northwest Petroleum Association (NWPA) will hold its 1990 Annual Field Symposium September 30 to October 3 in Roseburg, Oregon. The symposium will include one day of talks relating to energy development, primarily oil and gas, in the Pacific Northwest. Two days of field trips will be held to observe the strata of the Tyee Basin and Coos Basin areas. For details of the symposium, contact NWPA, P.O. Box 6679, Portland, Oregon 97228-6679. □

DOGAMI publications released

Oregon's resource potential for oil and gas near and off the northern coast and potential for silica and industrial sand are the subjects of two new publications released by the Oregon Department of Geology and Mineral Industries (DOGAMI):

Released August 17, 1990: ***Onshore-offshore geologic cross section from the Mist Gas Field, northern Oregon Coast Range, to the northwest Oregon continental shelf and slope,*** by A.R. Niem, P.D. Snavely, Jr., and W.A. Niem. DOGAMI Oil and Gas Investigation 17, 46 p., 1 plate (transect), $9.

The publication consists of a 36- by 76-inch ozalid sheet and a 46-page explanatory text. In addition to the geologic cross section and corresponding geologic strip map, the cross-section sheet shows several magnetic, gravity, and seismic-reflection profiles.

This is one of several geologic cross sections that have been or will be constructed in a cooperative effort among the U.S. Geological Survey, Oregon State University, oil companies, geologic consultants, and DOGAMI with funding from the U.S. Minerals Management Service.

The report consists of data and interpretation from offshore seismic-reflection profiles and onshore geological and geophysical studies, meeting at Tillamook Head, northwestern Oregon. The contents will serve to better explain the stratigraphic and tectonic framework and to evaluate the oil and gas potential of the northern Oregon continental margin.

Onshore interpretation is based on seismic profiles, field mapping, well logs, and microfossil age determinations. It extends geographically to the Mist Gas Field in Columbia County. Offshore seismic data are correlated with subsurface units encountered in deep exploratory wells drilled on the continental shelf in the 1960's.

Offshore stratigraphic units consist of (1) a 3,000- to 4,000-m-thick sequence of Tertiary sedimentary, volcanic, and intrusive rocks of the deep marginal Astoria Basin; (2) the upper(?) Oligocene to middle Miocene accretionary complex and slope basin units beneath the upper continental slope; and (3) thrust faulted and folded Pleistocene and Pliocene abyssal plain, slope, and submarine fan sediments. Onshore units include the Eocene Tillamook Volcanics overlain by a 2,500-m-thick forearc sequence of upper Eocene to middle Miocene marine mudstone, sandstone, and minor con-

*(Continued on page 118, **DOGAMI publications**)*

Field trip guide to the central Oregon High Cascades
Part 1: Mount Bachelor-South Sister area

by William E. Scott and Cynthia A. Gardner, David A. Johnston Cascades Volcano Observatory, U.S. Geological Survey, 5400 MacArthur Boulevard, Vancouver, Washington 98661.

This field trip guide was created for the September 1988 meeting of the Friends of the Pleistocene, which was held in the Mount Bachelor area. It was released in a slightly different form and with additional material as U.S. Geological Survey (USGS) Open-File Report 89-645 (Scott and others, 1989). The entire volume was edited by William E. Scott, Cynthia A. Gardner, and Andrei M. Sarna-Wojcicki, all of the USGS. Individual sections of the report by Scott; Gardner; Lundstrom and Scott; Scott and Gardner; Hill; Hill and Taylor; and Sarna-Wojcicki, Meyer, Nakata, Scott, Hill, Slate, and Russell are cited in the references. The complete report may be purchased from USGS, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, Colorado 80225, phone (303) 236-7476, for $10.25.

This first part of the field trip combines the first two days of the original trip and is accompanied by one connected paper by Scott. Part 2 of the central High Cascades field trip guide (the original third day of the field trip) will be published in the next issue of *Oregon Geology* and will continue with a guide to the ash-flow tuffs in the Bend area by Hill and Scott and a paper by Hill and Taylor. All references will be combined at the end of the second part in the next issue.

The mileage in this guide differs slightly from that in the open-file report, because this trip starts in a different location, and the first two days of field trip guides by Scott and Gardner have been combined here into one field trip. Readers may choose to run the trip in a different order, depending on where they are staying. There are several campgrounds near various portions of the trip. Readers are urged to obtain the USDA Forest Service map of the Deschutes National Forest or USGS topographic maps of the area before following the guide, because some features mentioned in the log are not easily found on the maps used for the guide. Also because some of the side roads are not paved, reasonable caution should be taken in following the road log.

INTRODUCTION

This field excursion to the central Oregon High Cascades highlights aspects of the Quaternary volcanic and glacial history in the vicinity of Mount Bachelor (formerly Bachelor Butte) and South Sister (Figure 1).

Regional geologic setting

The High Cascades of Oregon are a north-trending belt of upper Miocene to Quaternary volcanic rocks that were erupted on the east margin of the upper Eocene to Miocene Western Cascades volcanic province (Figure 2) (Taylor, 1981; Priest and others, 1983). Upper Pliocene and Quaternary rocks of the High Cascades form a broad platform of chiefly basalt and basaltic andesite volcanoes that fill a structurally subsided zone in the older rocks of the High Cascades (Taylor, 1981; Hughes and Taylor, 1986; Smith and others, 1987). Each of four major Quaternary volcanic centers along this platform (Mount Hood, Mount Jefferson, Three Sisters-Broken Top, and Crater Lake caldera [Mount Mazama]) have erupted lava flows and pyroclastic material that range in composition from basalt to dacite; except for Mount Hood, they have also erupted rhyolite. Newberry volcano, which lies east of the High Cascades, is also a compositionally diverse Quaternary volcanic center (MacLeod and others, 1981).

The Three Sisters-Broken Top area is a long-lived center of basaltic to rhyolitic volcanism (Taylor, 1981; Hill and Taylor, 1989). The clustering of large composite cones sets the area apart from others in the High Cascades, although the Mount Mazama area prior to the formation of Crater Lake caldera was also a cluster of composite cones (Bacon, 1983).

The ages of most volcanoes in the Three Sisters area are not precisely known. North Sister, a basaltic andesite pyroclastic and lava cone that rests on a shield volcano, is the oldest of the Three Sisters (Taylor, 1981) and postdates (Taylor, 1987) the approximately 0.3-million-year-old (Ma) (Sarna-Wojcicki and others, 1989) Shevlin Park Tuff of Taylor (1981). Middle Sister is intermediate in age between North and South Sister and, like South Sister, is compositionally diverse. Broken Top volcano is also younger than the Shevlin Park Tuff (Hill and Taylor, 1989) and is older than South Sister, but its age relation to Middle and North Sister is not known. The relative degree of erosion of Broken Top suggests an age probably equal to or greater than that of North Sister. Broken Top is a complex composite cone of dominantly basaltic andesite that intermittently erupted andesite, dacite, and rhyolite as lava flows, pyroclastic flows, and pyroclastic falls (Crowe and Nolf, 1977; Taylor, 1978). Cayuse Crater, which is located between Broken Top and the Cascade Lakes Highway, and two nearby vents on the southwest flank of Broken Top (Figures 3 and 4) erupted during earliest Holocene or latest Pleistocene time, but these events were probably unrelated to the long-inactive Broken Top system.

South Sister is the youngest composite volcano of the Three Sisters-Broken Top center and has erupted lavas ranging from basaltic andesite through rhyolite (Taylor, 1981; Wozniak, 1982; Clark, 1983). Although not dated directly, most, if not all, of South Sister is probably of late Pleistocene age. This subjective judgment is based on the relatively little-eroded profile of the volcano and the reasonably good preservation of lava-flow levees and other features, especially on the south and west flanks. The cone of basaltic andesite that forms the summit of South Sister is probably of latest Pleistocene age (Wozniak and Taylor, 1981; Scott, 1987); its crater is still closed and is filled with 60 m (Driedger and Kennard, 1986) of ice and snow. Le Conte Crater (Figure 4), a basaltic andesite scoria cone on the south flank, is between about 15,000 and 6,850 years old. The youngest eruptions recognized on the volcano occurred at a series of vents on the south and northeast flanks that erupted rhyolite tephra and lava flows and domes between about 2,200 and 2,000 years before the present (yr B.P.) (Figures 4 and 5) (Taylor, 1978; Wozniak, 1982; Clark, 1983; Scott, 1987; Taylor and others, 1987).

Mount Bachelor volcanic chain

The Mount Bachelor volcanic chain provides one example of the type and scale of eruptive activity that has produced most of the High Cascades platform, which consists chiefly of scoria cones and lava flows, shield volcanoes, and a few steep-sided cones of basalt and basaltic andesite. The chain is 25 km long;

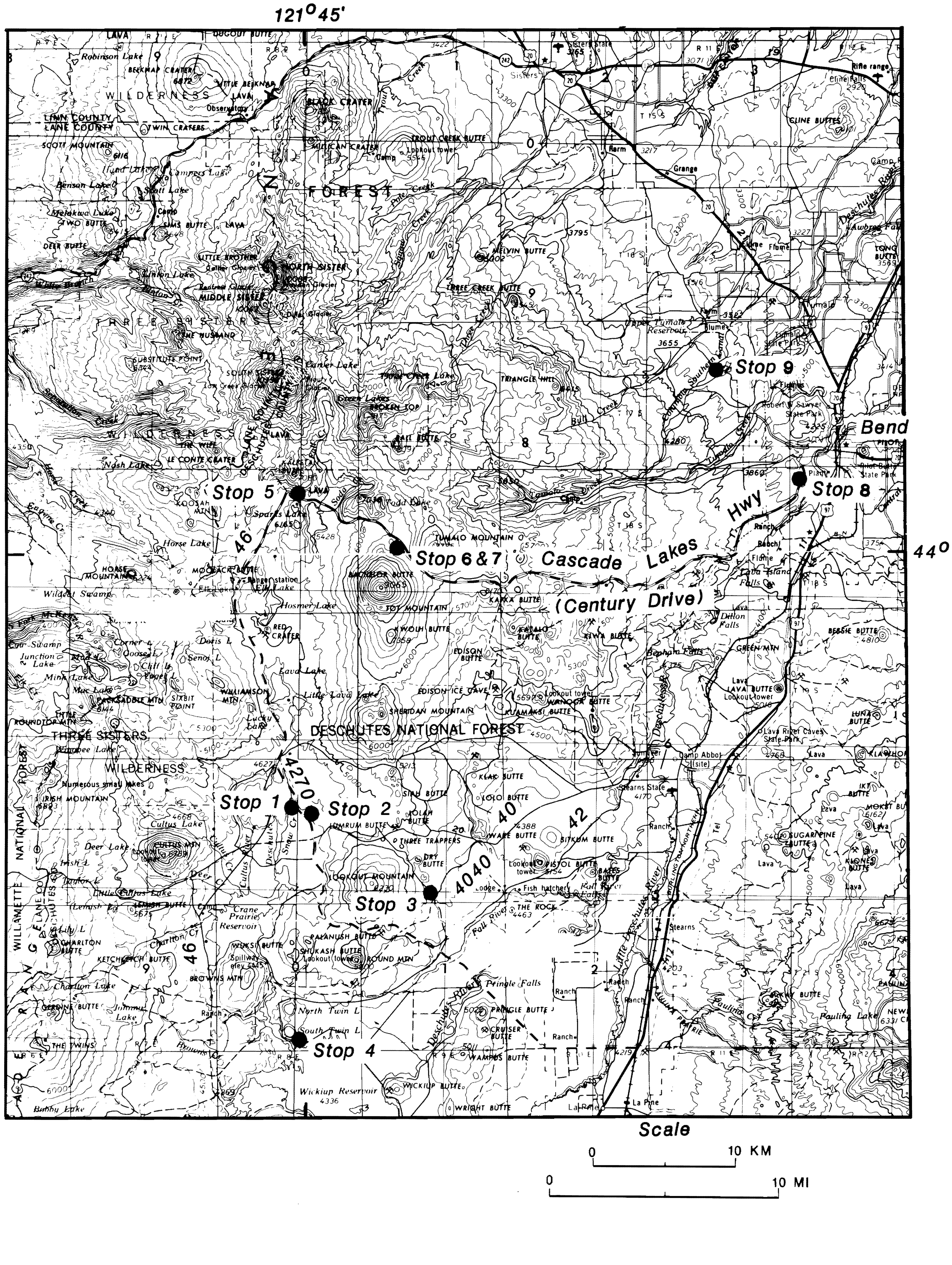


Figure 1. Map of field-trip area. Base map uses former name of Mount Bachelor, "Bachelor Butte." Selected USDA Forest Service roads are identified by 4-digit numerals.

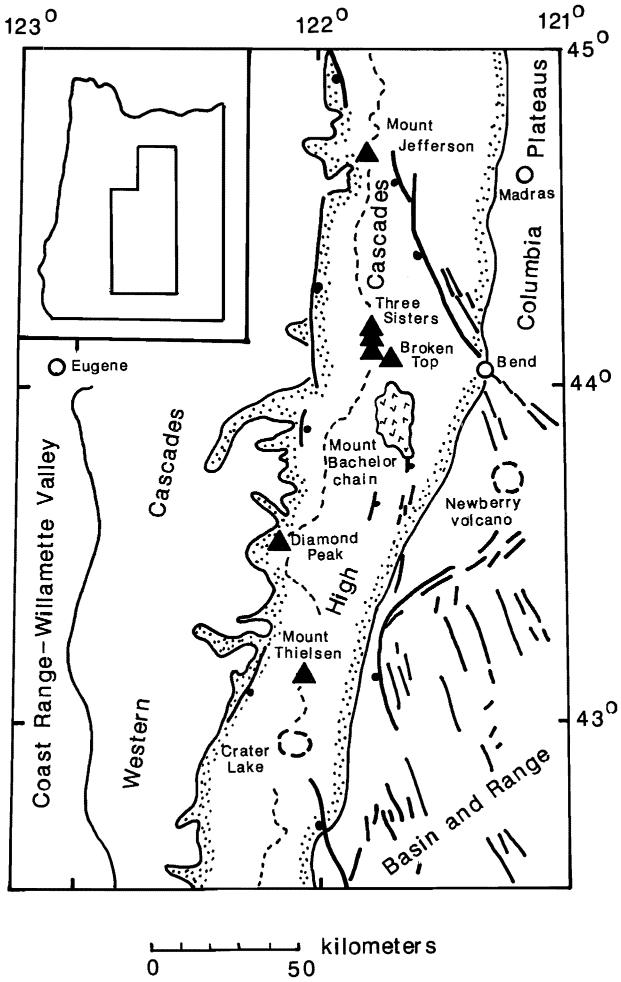


Figure 2. Geologic setting of the Three Sisters-Mount Bachelor area within the upper Miocene to Holocene High Cascades (stippled border). The Western Cascades are composed of upper Eocene to middle Miocene volcanic and volcaniclastic rocks. The parts of the Columbia Plateau and Basin and Range physiographic provinces shown on the map are composed dominantly of Tertiary volcanic and sedimentary rocks; Quaternary volcanic rocks cover most of the area near Newberry volcano. Heavy line = fault; where shown, bar and ball on downthrown side; dashed line = crest of Cascade Range. Broken circle = caldera; triangle = major volcano. Figure compiled from Hammond (1979), Priest and others (1983), and Sherrod (1986).

its lava flows cover 250 km^2 and constitute a total volume of 30-50 km^3 (Scott and Gardner, 1990).

Many vents in the field-trip area, including those of the Mount Bachelor volcanic chain and the Holocene rhyolite lava flows and domes on South Sister, define NNW-NNE-trending alignments (Figure 6) (E.M. Taylor and N.S. MacLeod, written communication, 1981, *in* Bacon, 1985; Hughes and Taylor, 1986; Scott, 1987). Normal-slip faults in the region, including one at the south end of the Bachelor chain, also have this orientation (Figures 2, 3, and 6) (Venkatakrishnan and others, 1980; Kienle and others, 1981). These alignments are oriented parallel to the north-south direction of maximum horizontal compressive stress that affects the region (Zoback and Zoback, 1980).

ROAD LOG

This trip (Figure 1) consists of a drive on the Cascade Lakes Highway and adjacent side roads and a closer examination of Mount Bachelor (formerly Bachelor Butte), including either a chairlift ride or hike to the summit for an overview, a trip down to mid-mountain, and a hiking tour of features that relate to the eruptive history of Mount Bachelor and to late Pleistocene and Holocene glaciation. Other stops focus on (1) the stratigraphic relations among some of the oldest recognized lava flows of the Mount Bachelor volcanic chain and end moraines and outwash fans of the Suttle Lake advance of late Wisconsin age, (2) the southernmost vents of the Mount Bachelor volcanic chain and the fault that extends south from them, (3) hydrovolcanic deposits and landforms in the Wuksi Butte-Twin Lakes chain that lies west of the south end of the Mount Bachelor volcanic chain, and (4) rhyolite tephra and lava flows from vents on the south flank of South Sister volcano. The geologic map (Figure 3) shows most of the major geologic features that are mentioned in the road log.

The trip starts at the southern junction of the Cascade Lakes Highway and the Hosmer Lake-East Elk Lake road (no. 4625). Look for sign "Hosmer Lake-East Elk Lake." There are several campgrounds in this area. If you are starting in Bend, use the instructions in the following section to reach the starting point. Numbers at beginnings of paragraphs give cumulative miles.

From Bend to field trip starting point (by mileage points)

0.0——Junction Highway 97 and Division Street. This is the exit to the Bachelor ski area and Cascade Lakes Highway. Follow exit on Division Street.

0.8——Revere-Division Street intersection. Continue on Division, which is the "Thru Route."

1.9——Turn right on NW Colorado Boulevard.

3.4——Intersection of NW Colorado Boulevard with Century Drive. Turn left on Century Drive. This is the start of the Cascade Lakes Highway (Road 46).

19.9——Junction with road to Sun River. Stay on Road 46.

22.4——Entrance to Sunrise Lodge, Mount Bachelor ski area. Continue on Road 46. (You will be returning here for Stop 7 later in the trip.)

23.0——Entrance to West Village of Mount Bachelor ski area. Continue on Road 46. (This is Stop 6 later in the trip.)

28.8——Devils Lake on left. (This is Stop 5 later in the trip).

33.3——Intersection with road to Sunset View.

34.4——Turnout on left. View of Elk Lake.

36.2——Intersection of Road 46 with 4625, which is the marked turnoff to Hosmer Lake (note sign "Hosmer Lake-East Elk Lake"). This is the start of the field trip. Reset mileage to 0.0. **Mileage points and traveling directions are printed in boldface.**

FIELD TRIP START

0.0——Intersection of Cascade Lakes Highway (Road 46) and Road 4625 near margin of Red Crater lava flow. The side road is a loop going past two campgrounds. This starting point is at the southernmost intersection with the highway where the large sign "Hosmer Lake-East Elk Lake " occurs. Go south on Cascade Lakes Highway.

0.7——Glacial striae and grooves on lava flows indicate direction of ice flow was to southeast, essentially parallel to road.

2.3——View on left of shield volcano of Sheridan Mountain (or Sheridan shield volcano; unit mb1, Figure 3) of the Mount Bachelor volcanic chain.

2.8——Junction with road to Lava Lake; continue south on Cascade Lakes Highway. Ahead, road cuts expose till overlying lava flows. For the next several miles, the highway traverses a belt of lateral and terminal moraines that record the apparently gradual retreat of the upper Deschutes glacier from its maximum advance of Suttle Lake age.

3.0——Meadow on left occupies a valley between two moraines that has been partly filled with sediment as a result of a locally raised base level caused by lava flows of the Sheridan shield volcano. Basal

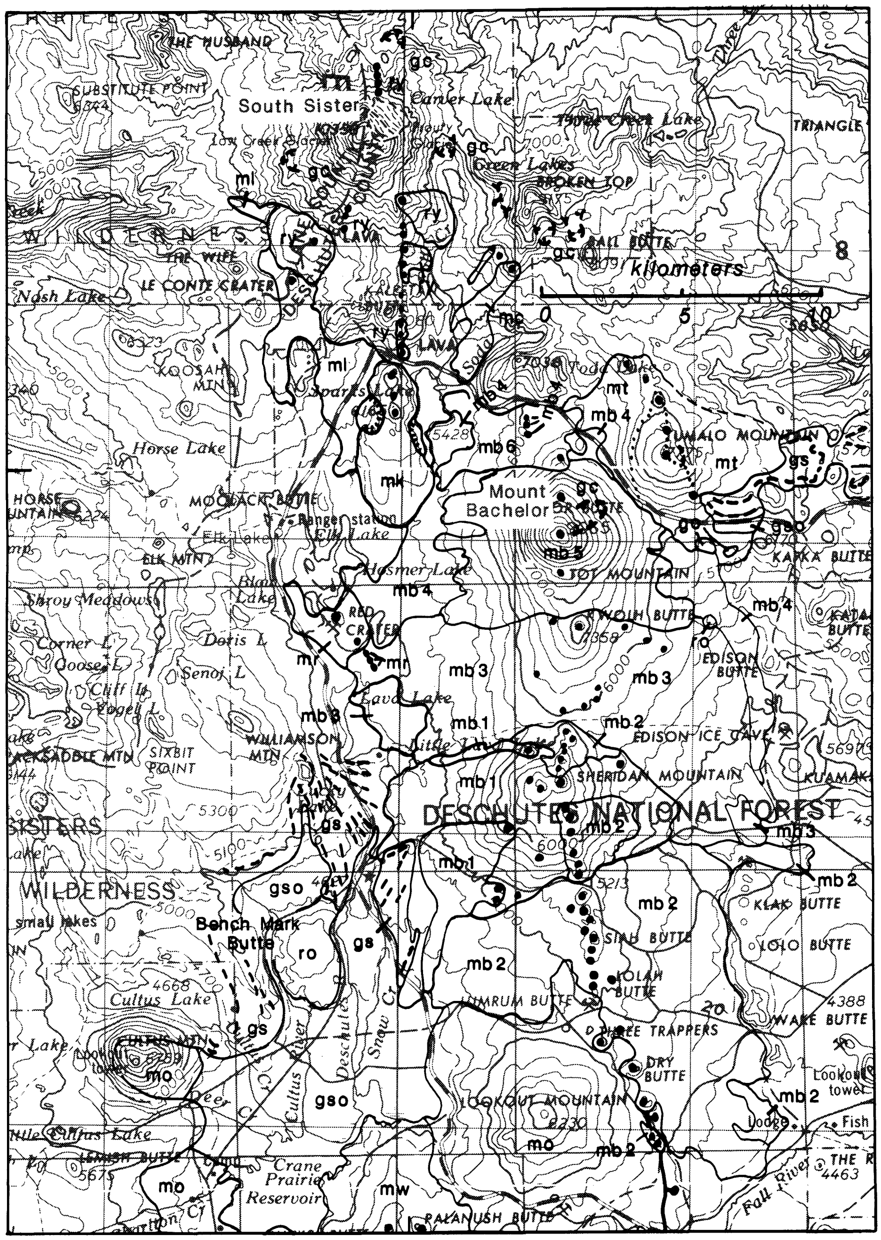


Figure 3. Generalized geologic map of the Mount Bachelor volcanic chain.

EXPLANATION

Glacial deposits

Neoglaciation

gln late neoglacial drift
gen early neoglacial drift

Cabot Creek glaciation of Scott (1977)

gc Canyon Creek drift
gs Suttle Lake drift

go older drift

Volcanic rocks and deposits

ry rhyolite lava flows and tephra of Rock Mesa and Devils Hill eruptive episodes

ro rhyolite lava flows of pre-Suttle Lake age

Mount Bachelor volcanic chain

mb6 lava flows and tephra of Egan cone
mb5 lava flows and tephra of Mount Bachelor summit cone
mb4 lava flows and tephra of Bachelor shield volcano
mb3 lava flows and tephra of Kwolh shield volcano
mb2 lava flows and tephra of Siah chain of vents
mb1 lava flows and tephra of Sheridan shield volcano

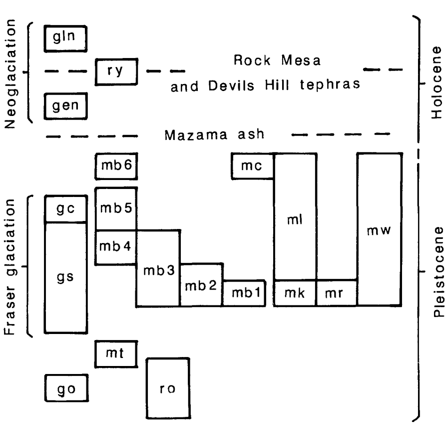
mc lava flow and tephra of Cayuse Crater
ml lava flow and tephra of Le Conte Crater
mw lava flow and tephra of Wuksi, Shukash, and Palanush Buttes
mk lava flows, tephra, and hyaloclastite of Katsuk and Talapus Buttes
mr lava flows and tephra of Red Crater chain of vents

mt lava flows and tephra of Tumalo Mountain
mo undifferentiated mafic lava flows and tephra of pre-Suttle Lake age

Symbols

• vent
- - - - moraine crest
…… approximate glacial limit on Tumalo Mountain

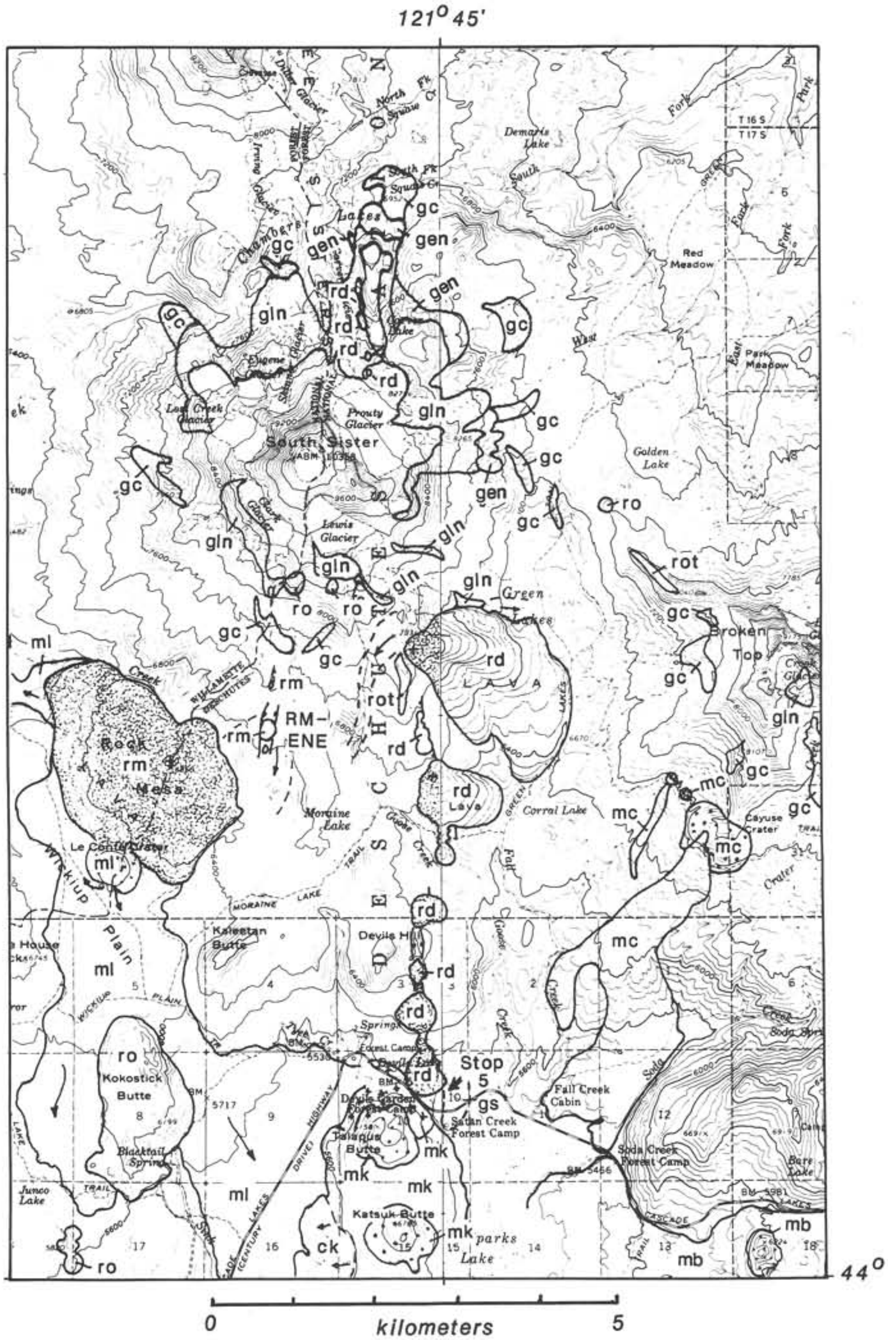
CORRELATION OF MAP UNITS



organic material in a 3.5-m-long core from the center of the meadow has an age of 12,200 ± 150 yr B.P. (W-5210); the base of a 40-cm-thick layer of Mazama ash is at 2.4 m; tephra of the Rock Mesa and Devils Hill(?) episodes is at a depth of about 25 cm. The core bottomed in gravel and sand that contains reworked scoriaceous ash that probably originated as tephra from the Mount Bachelor volcanic chain. The radiocarbon age provides only a minimum limiting age for deglaciation and eruptions of the Mount Bachelor volcanic chain because (1) deposition of organic matter did not begin until after emplacement of the lava flows, (2) the thickness of material sampled to obtain enough organic matter for dating must have accumulated over a period at least as long as several centuries, and (3) younger organic matter is probably contaminating the dated material.

5.5——Junction with Road 4270; turn left and cross Deschutes River, passing Deschutes Bridge Guard Station and Campground. The well-vegetated and stable river banks result from the river experiencing only small variations in discharge through the year owing to its being fed mostly by springs. Road ahead traverses flat surface of outwash fan of Suttle Lake age of Deschutes River.

6.6——Cross Snow Creek, which is fed from springs that rise at the snout of a lava flow from the Sheridan shield volcano that occupies a narrow valley between two moraines. Road ahead climbs low scarp onto till.



Left:

Figure 4. Map showing selected geologic features around South Sister and Stop 5. Glacial deposits: gln = late neoglacial till; gen = early neoglacial till; gc = till of Canyon Creek age; gs = till of Suttle Lake age (shown only near Stop 5). Mafic lava flows, scoria deposits (stippled), and hydrovolcanic deposits (crosses): mc = Cayuse Crater; mb = Mount Bachelor volcanic chain; ml = Le Conte Crater; and mk = Talapus and Katsuk Buttes. Unit ck is large landslide that originated on west side of Talapus-Katsuk plateau. Silicic volcanic rocks: rd = Devils Hill eruptive episode; rm = Rock Mesa eruptive episode (unit at about 7,200-ft altitude northeast of Rock Mesa includes only tephra vents, no lava flows or domes are present); ro = rhyolite and dacite lava flows and domes of pre-Suttle Lake age (numerous units around South and Middle Sister are omitted but include Devils Hill and Kaleetan Butte); rot = thick rhyolite tephra deposits of pre-Suttle Lake age on ridge tops (includes a mantle of Holocene tephra). Dashed lines near units rd and rm show approximate extents of pyroclastic flows. Thick tephra deposits associated with the eruptions of units rd and rm are not shown but surround most of the vents. Crosses on units rd and rm show locations of vents for large lava flows. Mapping taken or modified from Taylor (1978), Taylor and others (1987), Wozniak (1982), Clark (1983), Scott (1987), and Scott (unpublished mapping).

Below:

Figure 5. Aerial view of area south of South Sister and Stop 5. Sparks Lake is at lower right, Katsuk Butte at lower left, part of South Sister at upper left, and in left of center are some features of the Devils Hill chain of vents and flows.

7.2——Low road cuts in till.

7.6——Margin of lava flow of Sheridan shield. **Park on side of road.**

STOP 1—LAVA FLOW OF SHERIDAN SHIELD VOLCANO

This basaltic andesite lava flow (53.3 percent SiO_2) was erupted from the Sheridan shield volcano (Figure 7) based on (1) its geometric relation with overlying flows that form the main part of the shield, and (2) its chemical composition and paleomagnetic direction (Gardner, 1989a,b,c), which are similar to those of other lava flows of the shield. North of the stop, the lava flow is divided into at least two lobes that are separated by left-lateral moraines of the upper Deschutes valley glacier. In a few localities, the base

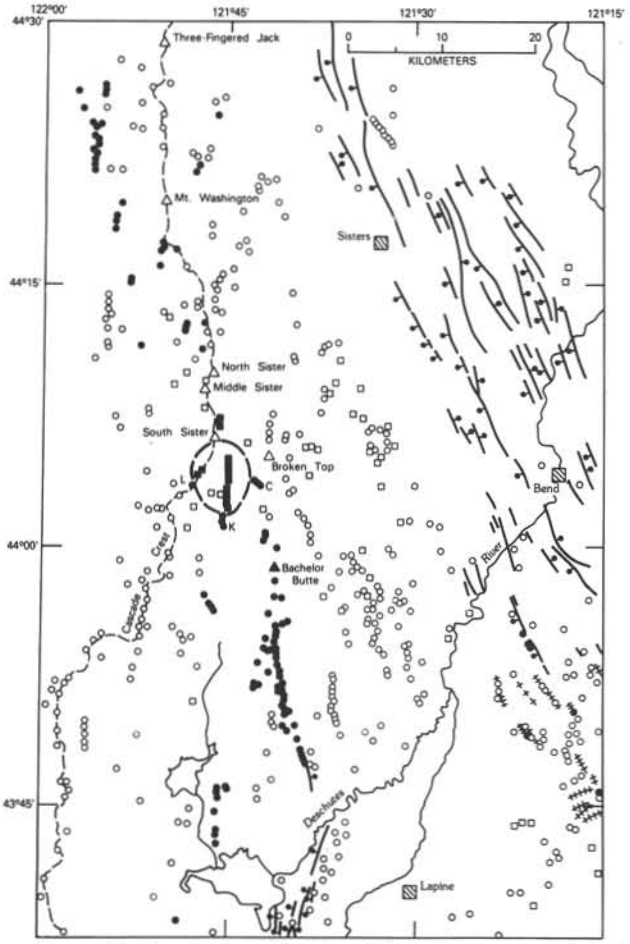


Figure 6. Compilation of vents of Quaternary age and faults in the Three Sisters area (Scott, 1987). Triangles are stratovolcanoes; circles are vents of mafic (basalt and basaltic andesite), mostly monogenetic volcanoes; squares are vents of silicic (dacite and rhyolite) lava domes and flows. Numerous silicic vents on the flanks of South and Middle Sister are not shown. Solid symbols represent vents of latest Quaternary (< 15,000 yr) age; open symbols are vents of pre-latest Quaternary age. L = Le Conte Crater; K = Katsuk and Talapus Buttes; C = Cayuse Crater. Heavy lines are faults; bar and ball on downthrown side. Crossed lines are fissures. The dashed circle represents the maximum extent of a hypothesized magma chamber south of South Sister (Scott, 1987).

of the flow is exposed above unweathered till, suggesting that the flow closely followed deglaciation.

In some places the margin of the flow is partly buried by outwash gravel, indicating that the drainage basin was producing coarse-grained outwash and therefore was probably still significantly glacierized. The lava flow is locally overlain by silty sand that probably originated as loess and eolian sand deflated from till and outwash surfaces. This relation suggests also that glacial conditions still prevailed in the area following the eruption of the lava flow and that active, unvegetated outwash surfaces existed along the Deschutes to provide a source of the eolian sediment. A soil formed in the mantle of eolian sediment and flow rubble is buried by Mazama ash and a scattering of young South Sister tephra.

Continue southeast on Road 4270.

8.0——Road descends margin of lava flow of Stop 1 onto outwash surface. **Junction with Road 4278. Turn left onto Road 4278 and park near Lodgepole Quarry.**

Figure 7. View to the south from Mount Bachelor. Tot Mountain is at lower right, Kwolh Butte at middle left, and Sheridan Mountain at right of center.

STOP 2—OUTWASH OF SUTTLE LAKE ADVANCE

Outwash gravel in this quarry was transported from the north and contains clasts of silicic lava from the Three Sisters-Broken Top area. The outwash gravel exposed in a quarry near Deschutes Bridge in the center of the end-moraine belt and till of both right- and left-lateral moraines within several kilometers of the center lack these silicic clasts. This distribution of erratics indicates that the west and the central portion of the glacier consisted of ice from the east slope of the Cascades south of Three Sisters, which is composed mostly of basalt and basaltic andesite. Silicic clasts are abundant only in the far eastern part of the moraine and outwash belt. The relation of the outwash in this quarry to left-lateral moraines of the upper Deschutes glacier suggests that the streams that deposited the outwash probably occupied an ice-marginal position against a pre-Mount Bachelor volcanic chain upland area to the east.

The area north, west, and east of the quarry is now covered by lava flows from the Sheridan shield volcano (unit mb1) and from the Siah chain of vents (unit mb2). The steep-fronted lava flow directly north of the pit is from one of several scoria cones on the west flank of the Sheridan shield that were erupted after the shield was formed (episode Ib of Figure 8). The lava flows are lithologically distinct in both hand specimen and chemistry from lavas of the shield and also have a different paleomagnetic direction, suggesting that a significant period of time elapsed between the formation of the shield and the eruptions of the cones (Gardner, 1989a,b,c).

The low margin of the lava flow of Stop 1 west of the quarry suggests that the margin is partly buried by outwash. If so, the distribution of the lava flow and the pre-Mount Bachelor volcanic chain topography must have allowed meltwater streams to continue flowing east of the lava flow and to transport outwash through this reach.

A soil and surface lag of stones formed in the outwash is buried by about 50 cm of Mazama ash. The soil is formed in gravel and silty sand that is probably loess mixed with gravel. The soil is oxidized to a depth of 55 cm and consists of a Bw and oxidized C horizons. The outwash is gray and contains well-rounded pebble and cobble gravel in a sandy matrix.

Return to Road 4270 and turn left (southeast). The road continues on outwash; flow fronts of lavas of the Siah chain (unit mb2) lie in the forest to the left of the road.

9.2——Junction with paved Road 40; turn left (east) on 40. The road climbs the north flank of Lookout Mountain, a normally magnetically polarized shield volcano of middle(?) Pleistocene age.

9.6——View to left of margin of lava flow of Siah chain.

10.5——Slow down for view to left of scoria cones of Siah chain, Sheridan shield, Mount Bachelor summit above

Sheridan, and South Sister. Note scoria cones on Sheridan's summit and flanks.

Caution! The upcoming junction is easy to miss.

12.1——Junction with Road 4240; turn right on 4240.

12.8——On left are the Three Trappers. Two of the scoria cones belong to the Siah chain, and one older cone is probably related to Lookout Mountain.

13.8——Dry Butte, another cone of the Siah chain, is on the left. Scoria of Dry Butte is exposed in road cuts.

14.7——Quarry on left is informally named "South Dry Butte," the southernmost scoria cone of the Mount Bachelor volcanic chain. The vents to the south are small fissures that erupted mostly spatter.

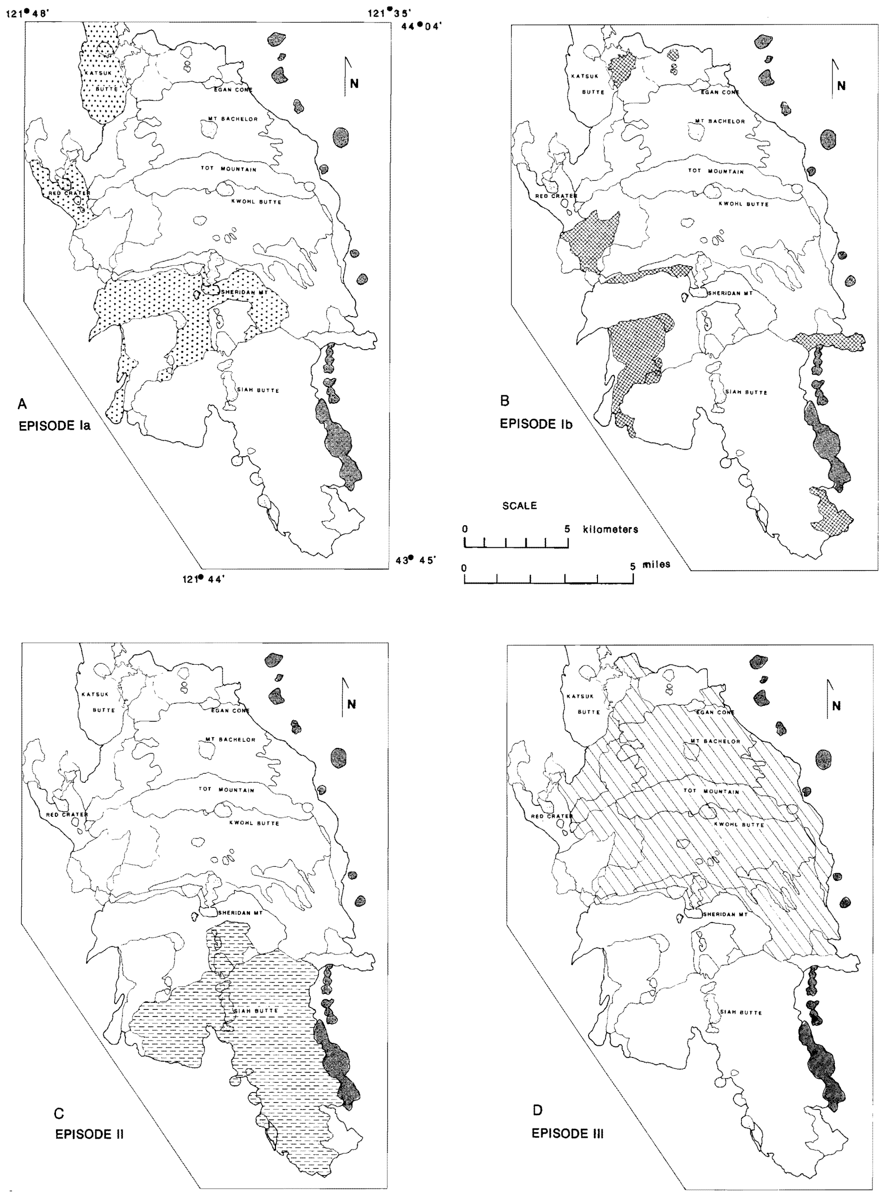
15.0——Road curves to right and crosses low spatter-rimmed pits that are difficult to see through the trees.

15.3——Road crosses fault scarp that is oblique to the trend of the Mount Bachelor volcanic chain.

15.6——Junction with Road 4040 and south end of the Mount Bachelor volcanic chain. **Park along side of Road 4240.**

STOP 3—TWO VENTS AT THE SOUTH END OF THE MOUNT BACHELOR VOLCANIC CHAIN

The southernmost vents of the Mount Bachelor volcanic chain (Figures 3 and 9) lie just west of the road junction and are the only vents along the chain other than vents in the Katsuk area at the north end that show evidence of magma having interacted with ground water. The vents are marked by elongate craters about 100 m long, 50-75 m wide, and about 15-20 m deep. These vents are also the lowest in altitude of any in the Mount Bachelor volcanic chain and lie about 2 km north of and 30 m higher than the top of the sedimentary fill in the La Pine basin. This



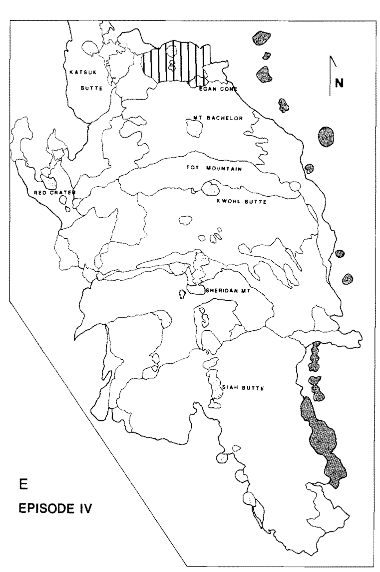


Figure 8. Maps (a-e) showing the development of the Mount Bachelor volcanic chain (MBVC) based on paleomagnetic directions. Chain of vents shown in dark screen along east edge of maps pre-dates the MBVC; pyroclastic cones of MBVC have light stipple. Episodes are discussed in detail by Gardner (1989a,b) and are summarized here. Eruptive activity along the chain was not continuous but occurred as discrete pulses from localized segments of the chain. Lava flows of episode Ia include porphyritic basaltic andesite lava flows from vents along the Sheridan Mountain shield and the basaltic flows of Red Crater and Katsuk Butte. Lava flows from Sheridan Mountain are stratigraphically the oldest lava flows exposed along the MBVC. Stratigraphically younger lava flows on the west flank of the Sheridan shield belong to a later eruptive phase of episode I and are designated Ib. Episode Ib also includes two basalt lava flows from the eastern margin of the Siah chain of cinder cones. Basalt lava flows from numerous vents coalesced to form the Siah chain of cones during episode II. Eruptive activity shifted northward to the Mount Bachelor-Kwolh Butte area during episode III. Lava flows from Mount Bachelor and Kwolh Butte stratigraphically overlie lava flows from the Sheridan and Siah areas. The last eruptive episode, episode IV, corresponds to the emplacement of Egan cone and associated basaltic lava flows on the north side of Mount Bachelor.

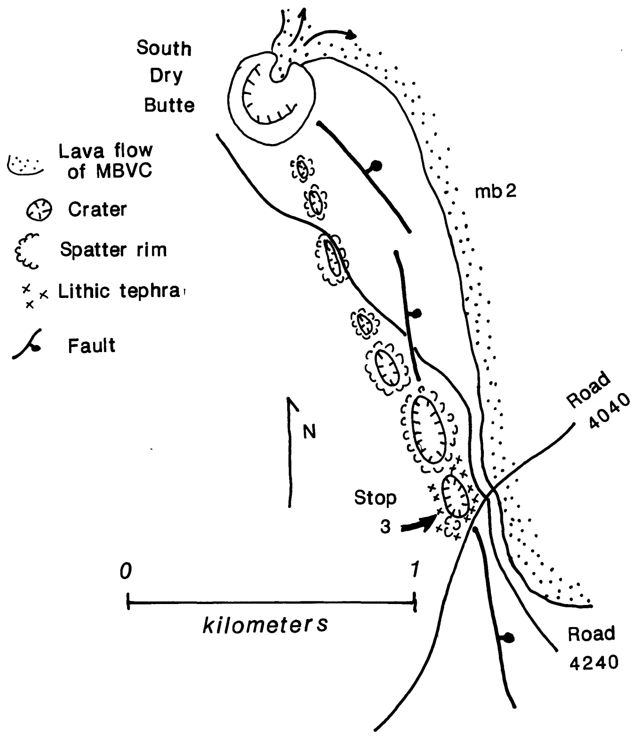


Figure 9. Sketch map of the south end of the Mount Bachelor volcanic chain near Stop 3.

basin lies between the High Cascades and Newberry volcano and may contain a sedimentary fill as thick as 1 km (Couch and Foote, 1985). The ground-water table in the La Pine basin was probably higher than that along many other parts of the Mount Bachelor volcanic chain, and therefore the chance for rising magma to interact with ground water was also greater. Of course, similar evidence in other parts of the Mount Bachelor volcanic chain may be buried by a thick cover of scoria and lava flows.

A shallow quarry and cuts along Road 4040 expose loose to moderately indurated lithic tephra. The tephra is composed of gray lapilli and ash that is much less scoriaceous than the tephra found elsewhere along the Mount Bachelor volcanic chain. Although not as glassy as the hyaloclastite of Katsuk and Talapus Buttes that will be seen at Stop 5, the density of the tephra and its contrast with the later agglutinate spatter suggests some quenching of magma occurred at depth, probably as a result of interaction with ground water. The deposit also contains large (> 1 m) dense, angular blocks of a diktytaxitic basalt lava flow that crops out on the flanks of Lookout Mountain and also in the southern vent. The lithic tephra has a local distribution; there is none in road cuts along Road 4040 just a few tens of meters west of the vent. Presumably the deposit was once there but has since been eroded.

The lithic tephra is overlain by agglutinate spatter and thin basalt lava flows (49.8 percent SiO_2) that were erupted from the southwest corner of the southern vent and from much of the northern pit. An oxidized zone occurs along the contact of the spatter and lithic tephra in the part of the quarry adjacent to the southeast corner of the northern vent but is thought to be related to oxidation by shallow ground water moving along the base of the spatter rather than to soil formation. No such zone occurs in the road cuts, where thin lava flows directly overlie the lithic tephra. However, a lag of coarse rubble on the lithic tephra and below the spatter in the quarry suggests that there may be some time break between deposition of the two units.

The paleomagnetic direction obtained from the thin lava flows in the Road 4040 cuts is identical with others from the Siah chain and suggests that eruptions of the southernmost vent were broadly synchronous with those that formed large scoria cones and numerous lava flows along other parts of the Siah chain.

A fault trends south of the Mount Bachelor volcanic chain and can be seen south of Road 4040 and west of Road 4240. The fault forms an asymmetric graben with a 2- to 4-m-high scarp on the west and a 1-m-high antithetic scarp on the east. The fault can be traced south for several kilometers as a discontinuous zone of scarps and flexures. Scarps are locally vertical and as high as 5 m, and some have up to 2-m-wide open cracks at their base. Rocks of the Mount Bachelor volcanic chain are apparently not offset by the fault. One possibility in light of historical Hawaiian rift eruptions (Pollard and others, 1983) is that at least some displacement on the fault occurred just before the initiation of eruptions along the southern end of the chain as a feeder dike neared the surface.

Continue south on Road 4240. Margins of lava flows of the Mount Bachelor volcanic chain are visible on left; the fault veers west of the road. The road is on lava flows of Lookout Mountain.

17.4——Junction with paved Road 42 at Fall River Guard Station; turn right (west) on Road 42.

19.3——Views to right of Round Mountain, a 350-m-high scoria cone on the south flank of Lookout Mountain shield volcano. No other scoria cones in the area come close to the size of Round Mountain.

24.8——Junction with paved Road 4260 to Twin Lakes and Wickiup Reservoir; turn left onto 4260.

26.7——Twin Lakes Resort; view of South Twin Lake.

27.3——Turn into small parking area on right side of road.

STOP 4—SOUTH TWIN LAKE TUFF RING

Hike cross-country through the forest, up over a ridge and down to South Twin Lake, which occupies a tuff ring (Figure 10). As there is no trail, you may find it easier to look at the lake at Twin Lakes Resort.

South Twin Lake is at the south end of a 7-km-long, north-trending chain of vents, the Wuksi Butte-Twin Lakes chain (WBTLC, Figure 10), which erupted olivine basalt during latest Pleistocene time. The north end of the WBTLC is offset about 8 km west of the south end of the Mount Bachelor volcanic chain in an en-echelon pattern. The WBTLC eruptions may have been contemporaneous with some of the early eruptions of the Mount Bachelor volcanic chain. The northern vents of the WBTLC are marked by scoria cones surrounded by broad aprons of lava flows; hydroclastic deposits are exposed locally but make up a small volume of the surface deposits. The southern vents produced only hydroclastic deposits and are marked by three tuff rings about 1 km in diameter and one about 0.5 km in diameter. The rings have steep inner walls and gently sloping outer flanks. The rings are composed of fall and base-surge deposits that were generated by numerous explosions as basaltic magma interacted with shallow ground water in the western part of the Shukash-La Pine basin.

Hike back to the parking area and head to the exposures along the shore of Wickiup Reservoir, which here occupies a narrow valley of the Deschutes River.

The shoreline exposures reveal about 1.5 m of indurated tuff at a distance of about 200 m from the shore of South Twin Lake. Plane-parallel and wavy bedded and low-angle, cross-stratified tuff (Figure 11) shows evidence of transport outward from the crater by base surges. The tuff overlies fluvial pebble gravel and sand, which, in turn, lie unconformably on strongly deformed fine-grained sediments and diatomite of the basin-fill sequence, visible only when the reservoir water level is low.

The age of the tuff and other eruptive products of the WBTLC are not well constrained. Its lava flows east of Crane Prairie Reservoir are overlain by loess and ash in which a well-de-

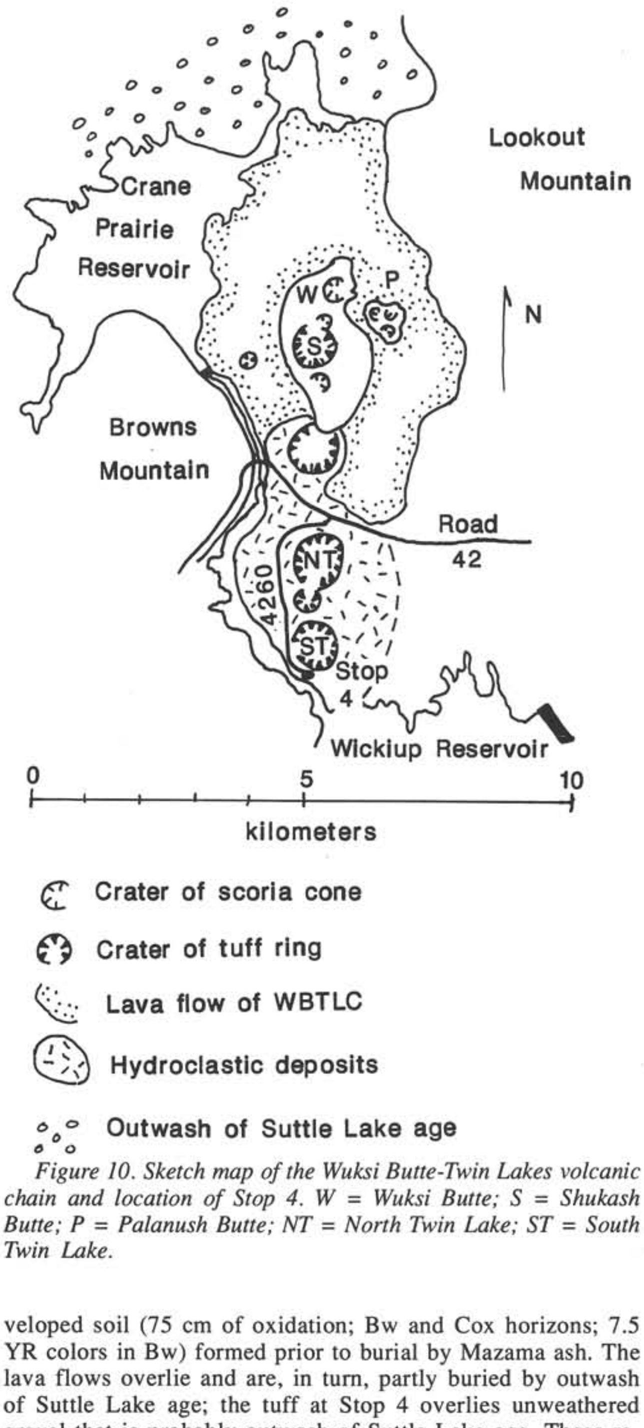


Figure 10. Sketch map of the Wuksi Butte-Twin Lakes volcanic chain and location of Stop 4. W = Wuksi Butte; S = Shukash Butte; P = Palanush Butte; NT = North Twin Lake; ST = South Twin Lake.

veloped soil (75 cm of oxidation; Bw and Cox horizons; 7.5 YR colors in Bw) formed prior to burial by Mazama ash. The lava flows overlie and are, in turn, partly buried by outwash of Suttle Lake age; the tuff at Stop 4 overlies unweathered gravel that is probably outwash of Suttle Lake age. These relations suggest that the WBTLC, as most of the Mount Bachelor volcanic chain, dates from the later part of the Suttle Lake advance and is considerably older than Mazama ash.

Return to cars and head north on Road 4260 to Road 42.

29.8——Junction with Road 42; turn left (west) on 42.

31.1——Browns Mountain Crossing of the Deschutes River. Above this point the Deschutes flows through a narrow valley between an old shield volcano, Browns Mountain, on the west and the latest Pleistocene lava flows and tuffs of the WBTLC on the east.

31.2——Road to Crane Prairie Dam. Road cuts ahead are in weathered lava flows of Browns Mountain. Rounded boulders are the result of incipient spheroidal weathering.

33.7——On left, margin of a young-appearing lava flow from The Twins, a large shield volcano on the crest of the High Cascades. These lava flows are buried by moraines of Suttle Lake age 4 km west of here, so they must be older than 20,000 years.

34.3——Junction with Cascade Lakes Highway (Road 46); turn right (north). Road cuts ahead are in the lava flows discussed at mile 33.7; note the locally well-preserved rubbly flow top beneath a mantle of eolian sediment and tephra.

35.0——Views ahead to Cultus Mountain, Middle and South Sister, Broken Top, and Mount Bachelor.

35.7——Road cuts expose Mazama ash over a well-developed soil formed in pebble gravel and sand. Gravel overlies well-bedded sand and silt. Significance of these sediments is not known, but they are definitely older than the Suttle Lake advance.

35.9——Lava-flow margin at north edge of meadow. Road ahead crosses late Pleistocene lava flows from vents along the Cascade crest. Numerous springs issue from the ends of these flows.

38.0——On right, turnoff to Osprey Observation Site.

38.6——Road is on outwash of Suttle Lake age, which floors much of the Crane Prairie basin. Cultus Mountain, on left, had major ice tongues of the High Cascades ice cap of Suttle Lake age terminating on both its southeast and northeast flanks; their moraines dam Little Cultus and Cultus Lakes.

41.5——Cross Cultus River, another spring-fed stream, which heads at the base of Bench Mark Butte.

41.9——Junction with Road 40; continue north on Cascade Lakes Highway.

43.1——Road cuts here, and for the next 1.5 mi, expose glassy dacite (65.7 percent SiO_2, one analysis) of Bench Mark Butte, which marks an isolated occurrence of dacite in an area that is covered mostly by basalt and basaltic andesite. The flow contains numerous mafic inclusions. The butte is up to 120 m thick, flat-topped, and composed of numerous steep-sided lobes. Its age is not well known, but till of end moraines and outwash of Suttle Lake age lap onto its north and west flanks. Its well-preserved morphology suggests a late Pleistocene age.

44.7——Road cuts in till of Suttle Lake age that marks the outermost moraine of the upper Deschutes valley glacier. Numerous other moraines are passed in the next 3 mi.

45.5——Junction with Road 4270 at Deschutes Bridge; continue north, traveling in part over areas covered earlier in the trip.

51.0——Junction with Hosmer Lake-East Elk Lake road. Continue north. Road follows east margin of lava flow of Red Crater that dams Elk Lake. Red Crater is the northernmost and largest of the 2.5-km-long chain of postglacial scoria cones

51.9——Road cut on right exposes a thin layer of 2,000-year B.P. pumice lapilli from the Rock Mesa vent on South Sister,

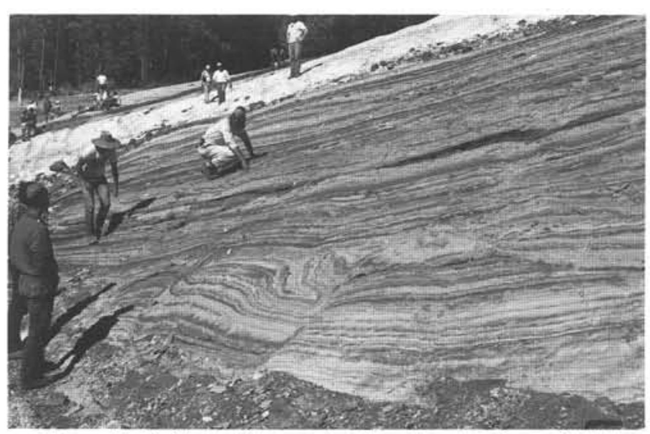


Figure 11. Bedded tuff exposed at Stop 4 on the shore of Wickiup Reservoir in late summer when the water level is low.

Mazama ash, as much as 50 cm of scoria of Red Crater, and till of Suttle Lake age. Lack of significant weathering of the till below the scoria indicates that the eruption of Red Crater occurred not long after deglaciation.

52.7——Turnout on right; view east across Elk Lake to the three major volcanoes of the Mount Bachelor chain (Mount Bachelor, Kwolh Butte, and Sheridan Mountain) and Red Crater.

53.9——Intersection with road to Sunset View. Road cuts expose till of Suttle Lake age. This is a good location at which to observe the degree of soil development in till of Suttle Lake age. The depth of the soil is exaggerated here by a mantle of Mazama ash that is mixed into the top of the till; weathering rinds on stones from the B horizon are < 0.2 mm thick, which is typical for till of Suttle Lake age.

56.3——West margin of postglacial basaltic andesite lava flow from Le Conte Crater, a scoria cone just south of South Sister. The lava flow is older than Mazama ash and may be similar in age to parts of the Mount Bachelor chain. Note the thickening and coarsening blanket of Rock Mesa and Devils Hill tephra. Views of Broken Top ahead.

56.9——On right through trees are Talapus and Katsuk Buttes, scoria cones that rise above a steep-sided plateau, the upper part of which is composed of thin basalt lava flows. This plateau owes its peculiar shape to having been erupted against glacier ice. View ahead to Devils Hill, a glaciated rhyolite dome. The south end of the Holocene Devils Hill chain of vents lies on the east flank of Devils Hill. The rugged, blocky surface of the Holocene rhyolite lava domes and flows contrasts markedly with the glacially smoothed and rounded form of Devils Hill.

58.4——On right, Devils Lake, which is dammed by the lava flow from Le Conte Crater. Road cuts on left are in hyaloclastite formed by the initial eruptions that built Talapus and Katsuk Buttes and the surrounding basalt plateau. **Park here in turnout on right side of road.**

STOP 5—DEVILS LAKE, TALAPUS AND KATSUK BUTTES, AND DEVILS HILL CHAIN OF DOMES

This stop focuses on two topics: (1) The formation of Talapus and Katsuk Buttes, and (2) the rhyolite tephra and lava flows and domes of the late Holocene Rock Mesa and Devils Hill eruptive episodes of South Sister. Figure 4 shows the relations among key geologic units in the area around Stop 5.

Talapus and Katsuk Buttes

Katsuk and Talapus Buttes (Figure 12) are two scoria cones that sit atop a gently south-sloping plateau composed of thin (1-3 m) basalt lava flows. The flows display breccia, locally ropy surfaces, tumuli, and other well-preserved flow-top features. They have obviously not been glaciated, and the reconstruction of the upper Deschutes glacier shown in Figure 13 indicates that, had the plateau been present, it would have been overridden by ice about 200-300 m thick. The cones and flows are typical of those along the Mount Bachelor volcanic chain, except that they terminate in a steep slope that ranges in height from 25 to 110 m (higher slopes probably occurred near the north end, but they have been partly buried by the lava flow of Le Conte Crater on the west and sediments of Sparks Lake basin on the east). Another atypical feature are the hydrovolcanic deposits (hyaloclastite, in part palagonitized) (Figure 14) that are exposed in the lower slopes at the north end of the plateau and in road cuts both east and west of the young rhyolite flow. Till and erratics are locally present on the slopes underlain by hyaloclastite (Taylor, 1978).

Figure 12. Katsuk and Talapus Buttes from Mount Bachelor.

These features imply the following origin: (1) Initial hydrovolcanic eruptions probably occurred in a lake melted into the receding glacier of Suttle Lake age; the glassy hyaloclastite resulted from the rapid quenching of basaltic lava in the water-filled vent followed by explosions that ejected the debris into the lake and onto the surrounding ice or till. The hyaloclastite consists of light-olive-gray to gray, poorly to well-bedded lapilli-and-ash tuff that contains scattered large clasts of juvenile basalt and accidental fragments. The upper part of the tuff in most exposures has been palagonitized and is orange-brown. In all localities, the tuff is pervasively faulted and deformed, probably as a result of syn- and post-depositional mass movements and subsidence caused by melting of underlying glacier ice. (2) As the lake filled with hyaloclastite or drained by opening of channels through the ice margin, water was excluded from the vent, and normal subaerial Strombolian eruptions ensued. The scoria cones of Talapus and Katsuk Buttes were then constructed. Subsequently, lava flows issuing from vents between and at the base of the cones filled the depression that remained in the glacier. Thus the thin flows "sky out" at the steep plateau margins against a now-vanished buttress and form a surface that may have coincided roughly with the surface of the glacier.

A glacier having the slope and thickness of the lava plateau would have had a basal shear stress of about 0.3 bars, which is less than the typical values of basal shear stress (0.5-1.5 bars). Such a low value of basal shear stress suggests that the glacier through which the eruptions occurred was thin and perhaps stagnant. Alternatively, the lava-flow surface may provide only a minimum estimate of ice thickness, and the glacier may have been somewhat thicker. The glacier was probably not greatly thicker than the plateau, in light of the lack of evidence of ice reforming over the plateau following the eruptions. Till and erratic clasts are found only along the base of the north end of the plateau and in road cuts immediately to the east, in which till overlies faulted, bedded hyaloclastite.

Slump blocks composed of the plateau-capping basalt flows lie along the central portions of both the east and west margins of the plateau. Slumping of the steep plateau margin occurred after deglaciation and was perhaps facilitated by underlying bodies of palagonitized hyaloclastite and/or sediments.

The paleomagnetic direction of lava flows at the plateau rim is similar to that of lava flows from the Red Crater area and of the earliest recognized lava flows of the Sheridan shield (episode Ia; Figure 8), which suggests that they could all be coeval.

Holocene rhyolite eruptions of South Sister

Two tephra units erupted from vents on the flank of South Sister between 2,300 and 2,000 years B.P. (Scott, 1987) are exposed at Stop 5 (Figure 15) and are best viewed in road cuts below the talus of the young rhyolite lava flow or in road cuts east of the flow. The tephras lie on a soil formed in Mazama ash and hydrovolcanic deposits of the Katsuk-Talapus area. The lower tephra is about 10 cm thick and consists of a basal lapilli and coarse ash bed about 3-4 cm thick and an upper light-gray to brownish-gray ash deposit that contains a conspicuous brick-

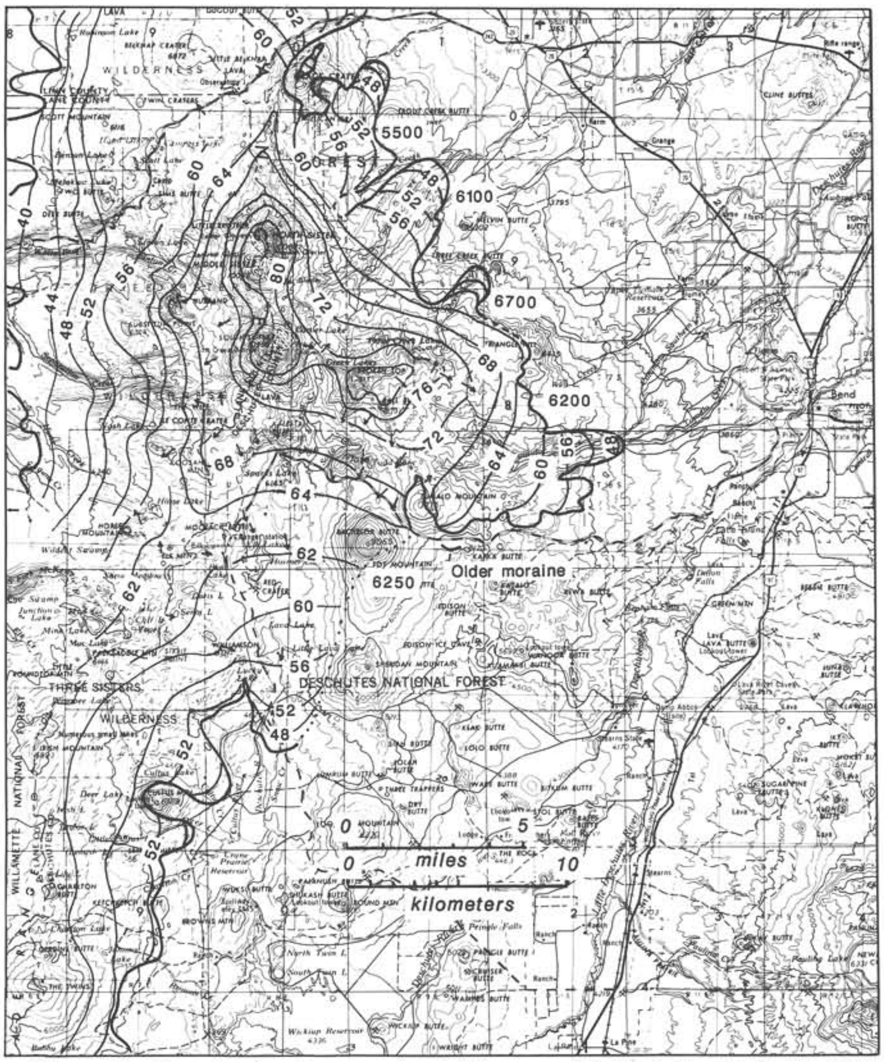


Figure 13. Map showing the reconstructed ice cap of Suttle Lake age in the Three Sisters-Broken Top area. Arrows indicate ice-flow direction as determined from geologic evidence. Contours on the glacier surface are in feet; contour interval is 400 ft, except in the upper Deschutes valley, where a supplementary 6,200-ft contour is shown. ELA (in feet) for several lobes is given by underlined numerals. Older moraine east of Mount Bachelor predates the Suttle Lake advance but is older than Tumalo Mountain.

red marker bed of fine ash about 0.5-1.0 cm thick. The upper tephra is about 65 cm thick and is much coarser grained than the lower unit; individual pumice bombs are as large as 20-30 cm. Lithic fragments are commonly more than 20 cm in diameter in the upper tephra, and several 50-cm-diameter blocks of dacite and rhyolite occur in the layer in nearby road cuts. A significant component of the tephra is juvenile, subpumiceous to glassy, light-gray to black rhyolite; many of the larger clasts display glassy, breadcrusted surfaces. Evidence of reworking, slight weathering, and the accumulation of thin peat between the two tephra layers, which is not well-displayed in the exposures at Stop 5, suggests that they were erupted at least 100 years apart, but no more than a few centuries (Scott, 1987).

The coarse grain size of the upper tephra indicates that it was erupted from nearby vents at the south end of the Holocene Devils Hill chain of vents (Devils Hill itself is a Pleistocene rhyolite dome that lies just west of the south end of the chain) (Figure 4). Lithic fragments of the Pleistocene rhyolite are abundant in the upper tephra layer.

The lower unit with its brick-red marker bed and underlying lapilli can be traced northwestward, thickening and coarsening, to an inferred graben that contains several small domes and lies 1.2 km east of Rock Mesa (RM-ENE, Figures 4 and 16). Thick rims of tephra along the graben indicate that it was a major tephra vent, even though it subsequently produced only small lava domes. This vent also erupted several small pyroclastic flows. A few small elongate craters and open cracks form a 400-m-long chain of vents beginning just a few hundred meters north of the graben. These vented a small amount of tephra, largely after tephra eruptions at RM-ENE had ceased.

Tephra presumably erupted from the vent that subsequently was the source of the Rock

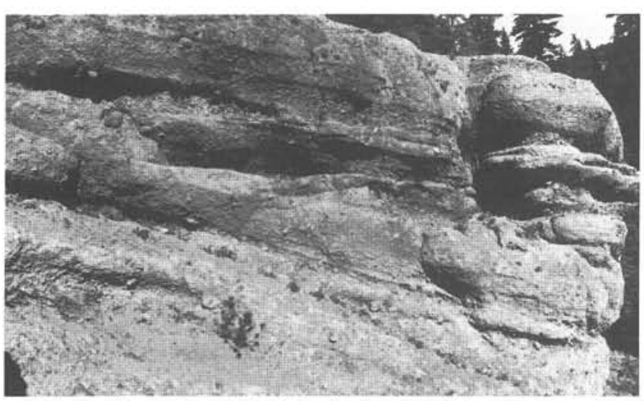
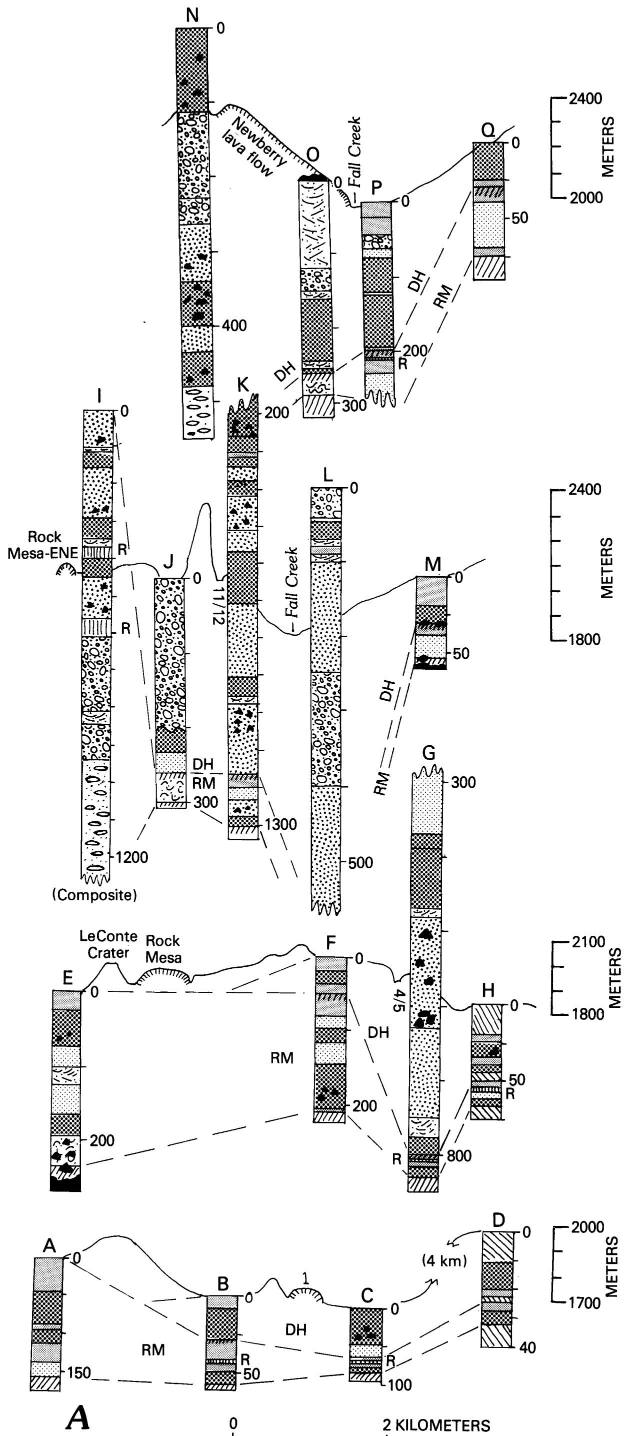
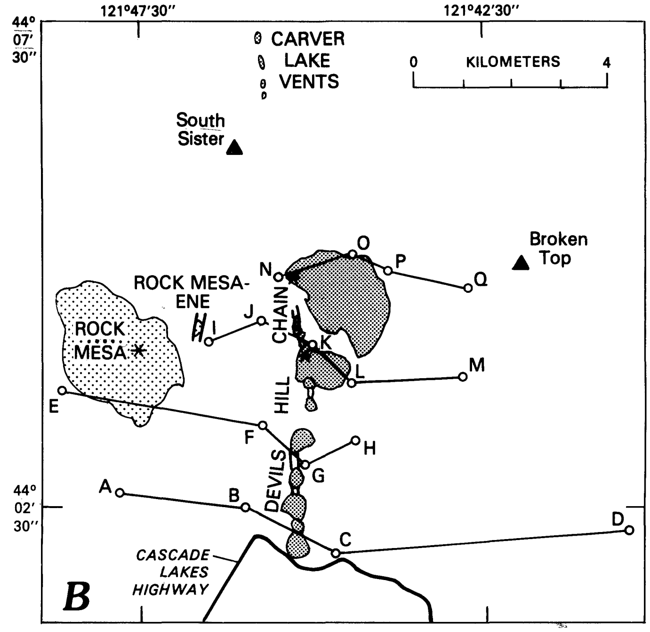


Figure 14. Palagonitized hyaloclastite of Katsuk Butte as it is exposed along the road at Stop 5. This glassy hyaloclastite was produced when, during an eruption, basaltic lava flowed into meltwater from a receding glacier of Suttle Lake age.

Figure 15. Two Holocene tephras described at Stop 5.





Left and above:

Figure 16. Stratigraphic sections of fragmental deposits of the Rock Mesa (RM) and Devils Hill (DH) eruptive episodes (A) and index map (B) to locations of sections. Units are generalized, especially on longer sections. Most tephra-fall deposits are composed of a few to many beds. The altitude scales (in meters) refer to the topographic profiles; the tops of many sections are shown above the topographic profiles in order to save space on the figure. Note that the thickness scales (in centimeters) differ among sections. On sections K and G, the tops of the upper units are not shown. Section L is shown on the east side of Fall Creek, although it lies on the west side. Surface soils are not shown. The base of the Newberry lava flow is shown on section O. Figure from Scott (1987).

Mesa lava flow overlies the tephra of RM-ENE and forms a south-trending lobe (Figure 17), which is the source of much of the scattered pumice on the ground surface seen at earlier stops. The tephras from the Rock Mesa and RM-ENE vents are chemically identical but can be distinguished in proximal areas by their assemblages of accidental lithic fragments. The lithics of the RM-ENE tephra are dominantly andesite, dacite, and rhyolite, whereas the tephra from the Rock Mesa vent contains a conspicuous proportion of basalt and basaltic andesite.

The tephra units exposed at Stop 5 can be traced over several hundred square kilometers to the north and east (Figure 17). The pumiceous character of the tephra-fall deposits of the Rock Mesa and Devils Hill episodes, their pattern of dispersal (restricted largely to within 30 km of vents), and their associated pyroclastic-flow and surge deposits indicate the sub-Plinian nature (Walker, 1973, 1981) of these eruptions.

The rhyolite lava flow that overlies the tephras marks the south end of the Devils Hill chain of lava flows and domes that extends north in several segments for 5.5 km to an altitude of almost 8,000 ft on the southeast flank of South Sister (Figure 4). Following a gap of several kilometers, the chain continues as a 1.2-km-long segment of small domes on the northeast flank. Several lines of evidence developed at Medicine Lake volcano and the Mono and Inyo volcanoes (Bailey and others, 1983; Fink and Pollard, 1983; Miller, 1985; Eichelberger and others, 1985) suggest that eruptions along the chain were fed by dikes or segments of a single dike

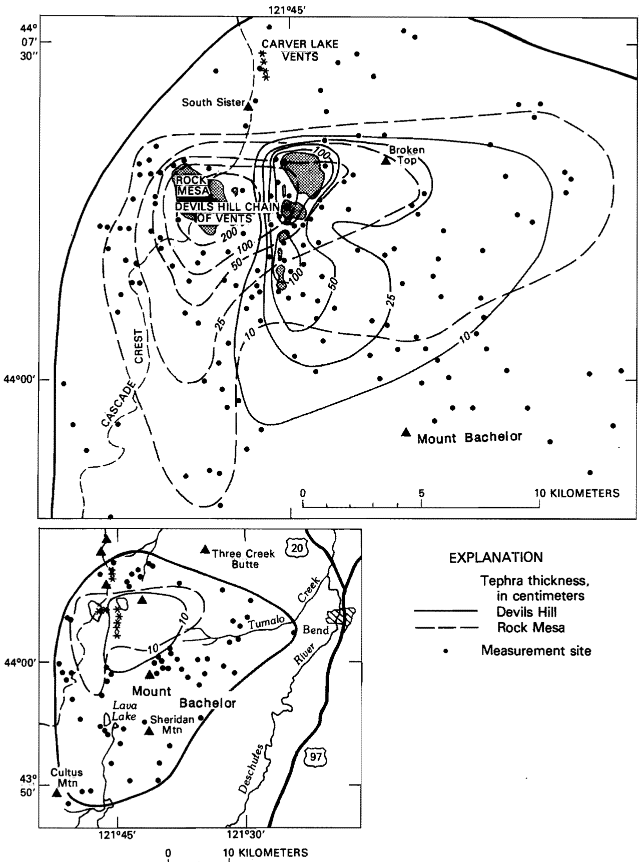


Figure 17. Isopachs of tephra-fall deposits erupted during the Rock Mesa and Devils Hill episodes. Where scale permits, lava flows and domes are outlined; others are located by asterisks. The heavy solid line delineates the approximate outer limit of tephra of both episodes except in the west and southwest, where only tephra of the Rock Mesa episode is present. Modified from Scott (1987).

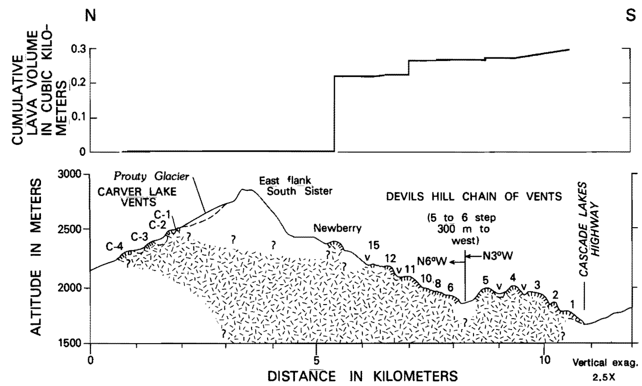


Figure 18. Vertical section along the trend of the Devils Hill chain of vents (1-Newberry) and Carver Lake vents (C-1 to C-4) showing inferred extent of feeder dike (patterned; lower sketch) and the cumulative volume of lava erupted from vents or groups of vents (upper graph). The vents from 6 to C-4 are projected onto a section oriented N. 6 ° W., even though the strike of individual segments ranges up to N. 13 ° W. V's show locations of grabens not filled by lavas. Queries indicate great uncertainty in estimating the extent of the inferred dike. The volume erupted from each vent is shown by a vertical line, except where small volumes from closely spaced vents are represented by a gently sloping line. Tephra volume is not included, as it represents only about 5 percent of the total volume of erupted magma. Based on the tephra's distribution (Figure 17), subequal amounts were erupted from the 1-5 and the 6-Newberry vent areas, and an insignificant volume was erupted from the C-1 to C-4 vent areas. Figure from Scott (1987).

(Figure 18) (Scott, 1987). These include: (1) Structural features, such as aligned vents, grabens, cracks, and linear fractures over vents of flows and domes parallel to vent alignments, occur; (2) tephra and lava erupted from numerous vents along the Devils Hill chain is of remarkably similar chemical composition (all samples are indistinguishable within analytical uncertainty), which suggests that eruptions were fed from a single source; and (3) eruptions along the chain were nearly synchronous, as shown by the tephra erupted from numerous vents forming a single depositional sequence without evidence of substantial interruptions.

During eruptions of the chain, the inferred feeder dikes were locally enlarged, probably by brecciation and erosion (e.g., Delaney and Pollard, 1981), and these areas emerged as principal conduits. Therefore, the dikes did not supply magma uniformly to vents, especially during the lava-extrusion stage that followed the tephra eruptions. The cumulative-volume curve of Figure 18 shows that several of the higher-altitude vents on the southeast flank of South Sister were the source of most of the erupted material.

Return to cars and continue on Cascade Lakes Highway.

58.6——On right, hyaloclastite at base of Talapus Butte. On left, southernmost rhyolite lava flow of 2,000 year B.P. Devils Hill chain of vents. Chain extends 10 km from here to northeast flank of South Sister (Figures 3 and 4). Rhyolite flow overlies tephra of the Devils Hill eruptive episode, tephra of the Rock Mesa eruptive episode, Mazama ash, and hyaloclastite of Talapus and Katsuk Buttes. In road cuts immediately to east, till of Suttle Lake age overlies the hyaloclastite.

59.6——View of Mount Bachelor to east. Note prominent vent on north flank skyline (lodge lies just south of vent) that is the source for an apron of lava flows (covered with ski trails) that were erupted following formation of the upper part of Mount Bachelor. View to left of Broken Top volcano and postglacial (> 9,500, < 12,000 yr B.P.) Cayuse Crater (red scoria cone; Figures 3 and 4) that are visible just above trees at edge of meadow.

60.2——Road cuts through the end of the basalt lava flow from Cayuse Crater. Immediately past the Cayuse flow is Soda Creek. On October 7, 1966, a flood and debris flow originating from the moraine-dammed lake of the glacier on the east flank of Broken Top descended the channel and piled debris on the road (Nolf, 1969). Fine-grained flood sediment covered about 35-45 percent of Sparks Lake meadow south of the road. Lava flow south of the highway and east of Soda Creek is one of several lava flows that form the youngest unit of the Mount Bachelor volcanic chain and that dam Sparks Lake. They were erupted from Egan cone (informal name), a scoria cone on the north flank of Mount Bachelor (unit mbb, Figure 3). Their stratigraphic relation to the Cayuse flow is unknown, as the flows are not in contact; however, several lines of evidence suggest that the Egan flows are younger (see Stop 6). Road ahead rises onto flank of Todd Lake volcano (Taylor, 1978), a glaciated dacite volcano that predates Broken Top volcano.

62.2——On right, margin of basaltic andesite lava flows from Egan cone. On left, unweathered or only slightly weathered till of Suttle Lake age is overlain by basaltic scoria from the northernmost vents of the Mount Bachelor volcanic chain that lie south of highway. Mazama ash and tephra of the Rock Mesa and Devils Hill eruptive episodes overlie the scoria.

63.5——On left, glaciated outcrops of basaltic andesite lava flow from a cone of the Tumalo Mountain chain that is locally overlain by scoria of Bachelor chain, Mazama ash, and tephra of the Rock Mesa and Devils Hill eruptive episodes. Tumalo Mountain is the shield volcano ahead on the left. On the right is a glaciated scoria cone. Ahead is Dutchman Flat, a basin that is closed on the south by lava flows of the Bachelor shield volcano. The upper part of the basin fill is composed mostly of fluvial gray sand, minor silt, and fine gravel; much of the sediment is reworked tephra.

64.2——Turn right at entrance road to West Village of Mount Bachelor Ski Area; at next intersection bear right. Egan cone, composed of red scoria, is visible ahead.

65.0——Park in the southwest corner of the parking area.

STOP 6—MAZAMA ASH

A shallow excavation in the southwest part of the West Village parking lot contains a good exposure of Mazama ash, which serves as a valuable stratigraphic marker in the central High Cascades. The age of Mazama ash is $6,845 \pm 50$ ^{14}C years B.P. (Bacon, 1983; about 7,700 calendar years ago). The ash (Figure 19) lies on unweathered or slightly weathered scoria from nearby Egan cone, the youngest vent of the Mount Bachelor volcanic chain. This lack of substantial weathering suggests that the tephra eruptions of Egan cone are only slightly older than Mazama ash. Mostly reworked Rock Mesa and Devils Hill tephra lies above Mazama ash.

The original thickness of Mazama ash at this site is about 38 cm. The in-place fall deposit is buried by about 70 cm of reworked Mazama ash and scoriaceous ash of Egan cone. The position of this site at the base of a slope probably ensured rapid burial of the fall deposit by reworked material.

Mazama ash exposed here is composed of two distinct units. The lower unit is fine- to medium-grained, light-gray to white ash, and contains abundant ferromagnesian minerals and lithic fragments. It is also conspicuously laminated. The upper unit is thicker, coarser grained, and distinctly more yellow than the lower unit. The upper unit ranges from medium to coarse ash at its base to coarse ash and fine lapilli in its upper part. This sequence is typical of Mazama ash in azimuths north-northeast of Crater Lake.

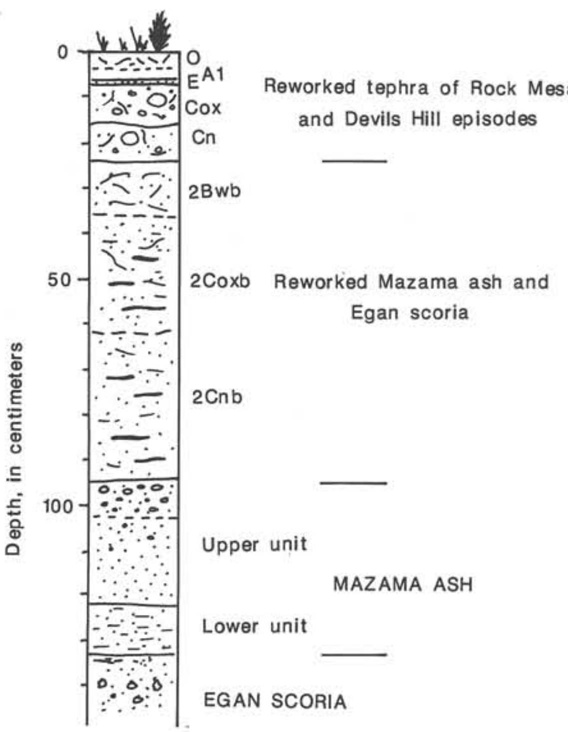


Figure 19. Stratigraphic section of Mazama ash exposed at Stop 6 in excavation at West Village parking lot. Letter and number symbols to right of column are horizon designations of surface and buried soils.

Mazama ash serves as an important stratigraphic marker in central Oregon; its thickness and character make it readily identifiable in the field. Determining the relation of a deposit or surface to Mazama ash is a fundamental task, and, although obvious at this stop, the relation is not always so clear. The deposit of thick reworked ash seen here indicates that the ash has been thinned or removed entirely from other places. The problem of reworking is especially significant at high altitudes where slope processes occur at high rates, as we shall see on the upper slopes of Mount Bachelor.

Return to Cascade Lakes Highway.

65.9——Cascade Lakes Highway. Turn right. Good view of Broken Top and the Three Sisters to northwest.

66.4——Turn right into entrance road to Sunrise Lodge; follow road 0.4 mi. to parking lot.

STOP 7—MOUNT BACHELOR

(As of 1990, the chair lift was operating for scenic rides between June 30 and September 3 from 10 a.m. to 4:00 p.m. Check each year for dates and times of operation.)

Ride Sunrise Chairlift (Figure 20) to mid-mountain. Lift towers are numbered with metal tabs on the cross bar.

Figure 20. Dave and Jenda Sherrod, participants of the 1988 Friends of the Pleistocene meeting in Bend, riding the chairlift up Mount Bachelor.

Base——Sunrise Lodge and the base of the lift are on an outwash fan that heads at the only significant stream channel on Mount Bachelor (Figure 21). The channel originates in the cirque on the northeast flank; the drainage proceeds around the northeast and east margin of Bachelor lava flows as Dutchman Creek. Dutchman Creek is typically dry except during spring and early summer snowmelt periods. During lift and lodge construction, excavations in this area exposed, from top down, 1 m of gravel and sand with no or slight soil development, 4-5 cm of Rock Mesa and Devils Hill tephra, 4 m of gravel and sand, about 40 cm of Mazama ash, and several meters of gravel and sand. At a depth of 7 m, the base of the outwash was not exposed but is assumed to be on Bachelor lava flows.

Tower 5——Approaching head of outwash fan (just past tower 6). Prior to construction and grading, this area contained a sequence of bouldery debris-flow and/or flood levees. The excavation for tower 5 exposed 1.3 m of levee deposit of late neoglacial age that overlies a weakly oxidized soil developed in Rock Mesa and Devils Hill tephras

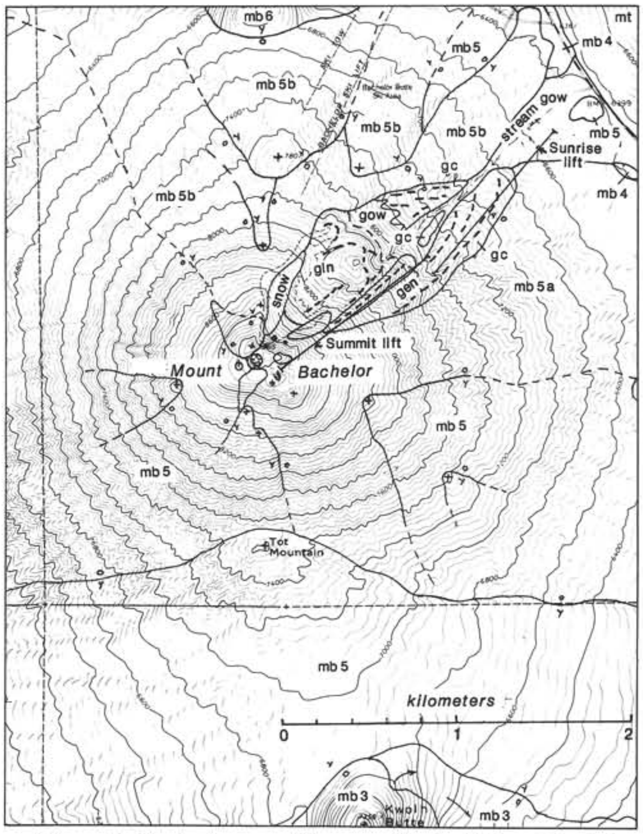


Figure 21. Geologic map of the upper flanks of Mount Bachelor. Unit symbols are the same as in Figure 3 except that the lava flows of the Mount Bachelor summit cone (unit mb5) are locally subdivided into lava flows that predate (unit mb5a) and post-date (unit mb5b) the moraines of Canyon Creek age (gc). mo = lava flows of Tumalo Mountain.

and underlying gravel and sand of probable early neoglacial age. Charcoal fragments on the contact between the buried soil and levee deposit yielded an age of 1,240 ± 70 years B.P. (W-5023). The buried soil consisted of a 2- to 3-cm-thick A1 horizon; a 5-cm-thick patchy E horizon; and a 15-cm-thick, weakly oxidized C horizon.

Towers 7, 8, 9——Basaltic andesite lava flows of Mount Bachelor summit cone.

Tower 10——Distal slope of end moraine of Canyon Creek age that overlies lava flows of summit cone. Remainder of lift line is in drift of Canyon Creek age. Scoria of Egan cone, Mazama ash, and Rock Mesa and Devils Hill tephras locally lie on the till.

Top——The top of the lift is on a thick drift of reworked Mazama ash. **Take Summit Chairlift to top of Mount Bachelor.**

Summit Chairlift

Up to tower 11, the Summit Lift crosses the distal slope of a right-lateral moraine that postdates Mazama ash and is of early neoglacial age. Clasts of Rock Mesa and Devils Hill tephra are scattered on the crest and upper slopes of the moraine but typically do not form a layer. Excavations for the lift towers and power cables formerly exposed till, colluvium derived from till, and Rock Mesa and Devils Hill tephras in beds, lenses, and as scattered clasts in colluvium. Little of the tephra is in place; most has been reworked by wind and slope processes.

Above tower 11, the lift crosses a lava-flow surface eroded by glaciers of Canyon Creek age (and somewhat smoothed by bulldozers); glacial grooves and striae are common on outcrops of dense

Figure 22. Aerial view of the upper northeast flank of Mount Bachelor, showing moraines of early and late neoglacial ages, moraines of late glacial age, and lava flows of Mount Bachelor that predate and postdate late glacial moraines.

rock. Till and drifts of Mazama ash are present locally. The terminal building at the summit is nestled between several vents.

Summit——The summit of Mount Bachelor (Figures 21 and 22) has numerous vents, most of which discharged basaltic andesite lava flows. The summit vents and plugs exposed in the headwall of the cirque are arrayed in a northwest-southeast-trending cluster that forms an elongate summit ridge. The vents are marked mostly by low, blocky domes but also by several shallow collapse craters. Pyroclastic material is scarce, forming only a few remnants of cones of dense scoria that are older than most of the dome vents. The scarcity of pyroclastic material at the summit and on the flanks of the cone indicate that at least the latter summit eruptions were dominantly effusive.

Views from the summit include Newberry volcano to the southeast and the Mount Bachelor volcanic chain to the south. Farther to the south and southwest, numerous shield volcanoes form the bulk of the High Cascades. Some of these shields predate the Brunhes Polarity Chron. Diamond Peak, Mount Thielsen, and Mount Scott (on the east side of Crater Lake) are prominent distant peaks. To the southwest and west, the upper Deschutes River valley contains several lakes dammed by lava flows. The four northern ones (Sparks, Elk, Hosmer, and, except for brief periods, Lava) have no surface outlets; water drains out through the permeable post-glacial lava flows and emerges as springs along the down-valley margins of the flows. Little Lava Lake (and, during high water, Lava Lake) usually forms the head of the Deschutes River. The Three Sisters, Broken Top, and the silicic highland of Taylor (1981) (renamed the Tumalo volcanic center by Hill, 1988, and Hill and Taylor, 1989) east of Broken Top dominate the northern view, with Three-Fingered Jack, Mount Jefferson, Mount Hood, and Mount Adams in the distance.

Return to base of Summit Chairlift.

Mid-mountain

From the base of the Summit Chairlift, hike west to view the moraine sequence of late glacial and neoglacial age and late lava flows of Mount Bachelor that overlie moraines of Canyon Creek age (Figure 21).

Return to cars in parking lot. Return to Cascade Lakes Highway, and turn right (east).

67.2——Cascade Lakes Highway. For next mile on right, lava flows of the Mount Bachelor summit cone and shield are partly buried by outwash of late-glacial and neoglacial age derived from the glacier on the north flank of Mount Bachelor. On left are lava flows of Tumalo Mountain, which predate the maximum of the last glaciation. Thick deposits of reworked Mazama ash and underlying scoria of the Mount Bachelor volcanic chain are exposed locally.

69.5——On the left is bouldery outwash of Suttle Lake age that lies just south of moraines deposited at margin of ice lobe that wrapped around the east side of Tumalo Mountain (Figure 3).

69.7——Junction with road to Sun River; stay on Road 46. Most of the hills on both sides of the road are scoria cones that are much older than Mount Bachelor and Tumalo Mountain; a few of the hills are rhyolite domes related to the Tumalo volcanic center.

72.8——Road follows narrow outwash channel from ice lobe that terminated just north and northwest of highway. Lack of streams today reflects high permeability of fractured volcanic bedrock.

76.9——Road cuts on left expose colluvium that contains a large proportion of matrix. The degree of soil formation is similar to that in till of Suttle Lake age, which suggests that during the last glaciation colluvial transport (solifluction?) was a very active process on these gentle to moderate slopes.

79.3——View to southeast of Newberry volcano, a shield-shaped volcano with a 5-km-wide summit caldera. Newberry is composed of silicic ignimbrites, silicic domes and lava flows, and hundreds of basaltic scoria cones, fissure vents, and related lava flows (MacLeod and others, 1981). Although not high in altitude, the volcano is among the largest (by volume) Quaternary volcanoes in the western conterminous U.S.

80.5——Abandoned quarries in outwash gravel that was transported in channel of mile 72.8. Outwash deposits of both Suttle Lake and pre-Suttle Lake age (on basis of weathering-rind thickness) are present.

85.1——Bend city limits. End of field trip part 1.

Paper connected with field trip

Temporal relations between eruptions of the Mount Bachelor volcanic chain and fluctuations of late Quaternary glaciers

by William E. Scott, U.S. Geological Survey, Cascades Volcano Observatory, Vancouver, Washington

INTRODUCTION

Eruptions of the 25-km-long Mount Bachelor volcanic chain (MBVC) and some other nearby vents (Figure 3) coincided with or closely followed the retreat of late Pleistocene glaciers (Scott and Gardner, 1990). These eruptions were dominantly effusive and covered a 250-km^2 area with lava flows. Owing to limited radiocarbon dating of the volcanic deposits, information about the timing of the eruptions relies heavily on the stratigraphic relation of various volcanic units to glacial deposits. Additional details of the volcanic history have been obtained through stratigraphic relations among the volcanic units, which are defined on the basis of their lithology and source, and especially through the use of secular-variation, paleomagnetic dating techniques (Gardner, 1989a,b). The age constraints derived from these studies suggest that the bulk of the chain was formed during a period of less than 10,000 years, perhaps substantially less.

This short paper discusses the glacial-stratigraphic framework of the central Oregon Cascades, the eruptions of the Mount Bachelor volcanic chain and how they fit into the glacial framework, and the neoglacial deposits on the mountain. The stratigraphic nomenclature used in this report and key radiocarbon ages are given in Table 1.

REGIONAL GLACIAL STRATIGRAPHY

Suttle Lake advance

A mountain ice sheet covered the Oregon High Cascades during the last major glacial advance (Russell, 1905; Crandell, 1965), which is locally called the Suttle Lake advance (Scott, 1977). Although not radiometrically dated, the Suttle Lake advance is broadly equivalent in age to the Evans Creek stade of the Fraser glaciation of Washington (Crandell, 1965; Crandell and Miller, 1974) on the basis of similarities in soil development, weathering-rind thickness, and morphology (Scott, 1977). Although not dated directly in the United States, the Evans Creek stade probably culminated about 18,000-22,000 years before the present (18-22 ka), a conclusion based on radiocarbon ages from British Columbia (Porter and others, 1983).

The maximum extents of glaciers of Suttle Lake age are marked in most valleys by conspicuous belts of end moraines (Figure 3). Valleys are typically free of well-developed moraines between these belts and a younger moraine belt that occupies many valley heads. This distribution of moraines implies that, following their maximum stands, glaciers gradually retreated, with minor stillstands and readvances, leaving a considerable volume of drift in the outer moraine belt. Rates of retreat must have been greater during the time that termini crossed the midsections of valleys, because these areas contain no conspicuous moraines and relatively thin drift. Rates of retreat again slowed (and glaciers may even have readvanced some distance) as ice tongues became restricted to valley heads and built conspicuous moraine belts.

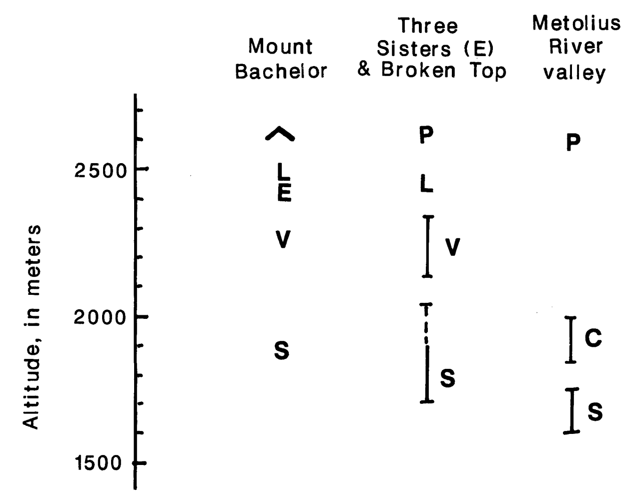


Figure 23. Equilibrium-line altitudes (ELAs) of present-day and reconstructed glaciers in central Oregon. Values for Mount Bachelor and Three Sisters-Broken Top area east (E) of Cascade crest are from Dethier (1980) and this study; values for the Metolius River valley are from Scott (1977). P = present-day glaciers, ^ indicates minimum value; L = glaciers of late neoglacial age; E = glaciers of early neoglacial age; V = valley-head moraines; C = valley-head glaciers of the type Canyon Creek advance; S = glaciers of Suttle Lake age. Bars represent ranges of values that result from ELAs defining surfaces that have substantial gradients.

Table 1. *Stratigraphic framework of selected volcanic and glacial deposits in the Three Sisters-Mount Bachelor area. Parenthetical terms are for correlative events in Washington*

Glacial events		Eruptive products	Age
Neoglaciation	**Late neoglacial advance**		Culminated during mid?-19th century
		Younger lava flows of Belknap Crater	1,400-1,600 B.P.
		Collier Cone tephra and lava flows	1,600 ± 100 B.P.
		Four-in-One Cone tephra and lava flows	1,980 ± 160 B.P.
		Devils Hill tephra and lava flows and domes	ca. 2,000 B.P.
		Rock Mesa tephra and lava flows and domes	2,150 ± 150 B.P.
	Early neoglacial advance		
		Mazama ash	6,845 ± 50 B.P.
		Egan cone tephra and lava flow	6,845-12,500 B.P.
		Cayuse Crater tephra and lava flow	9,500-12,500 B.P.
		Late lava flows (and tephra) of Mount Bachelor summit cone	6,845-12,500 B.P.
Cabot Creek (Fraser) glaciation	**Canyon Creek (Hyak) advance**		11,000-12,500 B.P.
		Mount Bachelor summit cone and shield	2,000-18,000 B.P.
		Shield of Kwolh Butte	12,000-18,000 B.P.
		Siah chain of vents tephra and lava flows	12,000-18,000 B.P.
		Red Crater tephra and lava flows	2,000-18,000 B.P.
		Le Conte Crater tephra and lava flows[a]	6,845-18,000 B.P.
		Katsuk-Talapus hyaloclastite, tephra and lava flows	15,000-18,000 B.P.
		Wuksi-Twin Lakes chain of vents[a]	6,845-18,000 B.P.
		Summit cone of South Sister[b]	> 11,000 B.P.
	Suttle Lake advance (Evans Creek stade)		Culminated 18,000-22,000 B.P.
		South Sister tephras	
		Formation of Tumalo Mountain shield and chain of scoria cones	
		Much(?) of South Sister	
Jack (Hayden) Creek glaciation			75,000 or 140,000 B.P.

[a] Stratigraphic relations to Red Crater, Sheridan, Siah, Kwolh, Mount Bachelor, and Cayuse units uncertain.
[b] Stratigraphic relation to Suttle Lake advance uncertain.

Valley-head moraines and the Canyon Creek advance

The belts of moraines in valley heads cover a broad altitude range and are deposits of glaciers that represent a range of equilibrium-line altitudes (ELAs; Figure 23). The moraines extend up to several kilometers beyond moraines of neoglacial age and record the final activity of late Pleistocene glaciers. Unfortunately, these deposits are not well dated. The only radiometric-age control from central Oregon indicates that moraines on Broken Top, which represent an ELA similar to that of the moraines on Mount Bachelor, predate the scoria of Cayuse Crater, which is older than 9,500 years B.P. (Table 1).

The type Canyon Creek drift (Scott, 1977) is composed of a broad belt of valley-head moraines that lies on the northeast side of Three-Fingered Jack in the Metolius River valley (50 km north of Mount Bachelor). Canyon Creek drift is correlated with Hyak drift (Porter, 1976; Porter and others, 1983) of the Washington Cascades on the basis of similarity of reconstructed glacier ELAs relative to those of present-day glaciers and those of glaciers of Fraser age. The age of the Hyak is between 12.5 and 11 ka (Porter and others, 1983).

Many valley-head-moraine systems in the Three Sisters-Mount Bachelor area have ELAs that are up to several hundred meters higher relative to present-day, neoglacial, and Suttle Lake ELAs than those of Canyon Creek age on Three-Fingered Jack (Figure 23). By assuming that ELAs rose steadily with minor halts and reversals as the last glaciation ended, the moraines on Mount Bachelor could be somewhat younger than the Hyak and type-Canyon Creek moraines. Alternately, some of these differences in late-glacial ELAs may relate to variations of ELA gradients in the region, and the valley-head moraines may all be broadly correlative in age.

One view of late-glacial history is of a time interval of several thousand years during which ELAs were generally rising, glaciers were retreating into valley heads, and glacier termini were becoming more debris laden as their distance from cirque headwall decreased. Conspicuous moraines were built during successive short pauses or readvances. The configuration of valleys was also important in determining the character of the moraine record. For example, on lower-altitude peaks such as Three-Fingered Jack and Mount Washington, the valley-head moraines of Canyon Creek age were deposited by short glaciers largely confined to cirques. In contrast, glaciers with similar ELAs in high-altitude areas like the Three Sisters-Broken Top area would have covered broad upland areas and probably not left much of a depositional record. Not until ELAs had risen to the level at which the glaciers were confined to cirques could conspicuous moraines have been deposited. By that time, glaciers on lower peaks like Mount Washington and Three-Fingered Jack might have been very small or absent, unless, as mentioned above, regional variations in ELA gradients are responsible for some of the observed differences.

Some of the moraines in the Three Sisters-Broken Top area that are older than Mazama ash but lie close to neoglacial moraines may date from the early Holocene (Dethier, 1980) as has been suggested for moraines in the North Cascades of Washington (Beget, 1984; Waitt and others, 1982). However, no compelling evidence has been found to support such an interpretation for the late-glacial moraines discussed here. The relationship of the > 9,500-year-old Cayuse Crater tephra to moraines on Broken Top shows that they and correlative moraines on Mount Bachelor are pre-Holocene in age. In addition, the 25- to 50-m difference in ELAs between the early Holocene and maximum neoglacial glaciers in the North Cascades is less than the > 100-m difference between glaciers of neoglacial and late-glacial age on Broken Top and Mount Bachelor.

Neoglaciation

In the field-trip area, I recognize evidence of two minor glacier advances that postdate the deposition of Mazama ash and informally call them "early" and "late" neoglacial. Evidence for an early neoglacial advance is typically found immediately beyond late neoglacial ice limits. However, many glaciers reached their post-Mazama maxima during late neoglacial time and obliterated any moraine record of early neoglacial advances. Moraines of early neoglacial age are less steeply sloping and more round crested than those of late neoglacial age; they commonly support stands of whitebark pines. Soils are typically poorly developed owing to active erosional processes; however, where best preserved their profiles consist of a 5-cm-thick A1 horizon and a 15- to 25-cm-thick weak color B or oxidized C horizon. The ca. 2-ka Rock Mesa and Devils Hill tephras are found on early neoglacial drifts, and ca. 7-ka Mazama ash is found on surfaces immediately beyond them.

RECONSTRUCTED GLACIERS OF SUTTLE LAKE AGE

During the Suttle Lake advance, a continuous mountain ice cap covered the crest of the Cascade Range in southern and central Oregon, and outlet glaciers flowed down valleys draining both the east and west sides of the range. The highland area around Broken Top provided a broader accumulation area than in other parts of the range, making the ice cap there larger and more complex (Figure 13). In the field-trip area, ice flowed east from the crest of the Cascade Range and south from the Three Sisters-Broken Top area into the upper part of the Deschutes valley to form a large south-flowing glacier that terminated immediately north of Bench Mark Butte (referred to here as the upper Deschutes glacier) (Figures 3 and 13). The eastward extension of the ice cap that occupied the highland east of Broken Top terminated north of the Cascade Lakes Highway and formed a major outlet glacier in the canyon of Tumalo Creek.

A longitudinal profile of the reconstructed upper Deschutes glacier (Figure 24) illustrates several general characteristics of the ice cap. Basal shear stresses of the glacier calculated using the method of Pierce (1979) range from 0.5-1.4 bars (50-140 kPa), which is within the range observed for modern and other reconstructed glaciers (Pierce, 1979; Patterson, 1981). In addition, the lower values occur in areas of compressing (decelerating) flow, and the higher values occur in areas of extending (accelerating) flow, as is typical. The maximum thickness of the glacier, about 1,400 ft (425 m; altitudes of the reconstructed glacier are given in feet to agree with base map), lay near Elk Lake, where the surface slope was small. On the steep upper slopes of South Sister, maximum ice thickness was probably no more than 200 ft (60 m), which is not much greater than the thickness of present-day glaciers (Driedger and Kennard, 1986).

Equilibrium-line altitudes on the ice cap in the Three Sisters-Broken Top area varied greatly (Figure 13), probably largely as a result of differences in precipitation rate. ELAs in the northeastern part of the area near Three Creek Butte were much higher than those farther west. ELAs on the west slope of the High Cascades were more than 1,000 ft (300 m) lower than those on the east side. These patterns probably result from moisture sources lying to the west and southwest and precipitation rates decreasing strongly across the range in a northeasterly direction, which is similar to present conditions.

TEMPORAL RELATIONS OF ERUPTIVE AND GLACIAL EVENTS

Early eruptive history

End moraines of the upper Deschutes glacier of Suttle Lake age form a 7-km-wide belt between Lava Lake and Bench Mark Butte (Figure 3). Lava flows of the Sheridan shield (unit mb1), which include some of the earliest recognized lava flows of the Mount Bachelor volcanic chain, bury much of the east margin of the moraine belt. Therefore, activity along the chain began after about 22-18 ka, the assumed age of the culmination of late Wisconsin alpine glaciation in the Pacific Northwest (Porter and others, 1983). However, it is possible that eruptions began earlier, and their products are buried by younger lava flows.

The following three lines of evidence suggest that some of the earliest eruptions of the Mount Bachelor volcanic chain and eruptions at other vents in the area date from a time after glaciers had retreated from their maximum stands, but while glacial conditions still prevailed in the area.

(1) Lava flows of the Sheridan shield and Siah chain (units mb1 and mb2) on the east side of the outwash-covered basin north

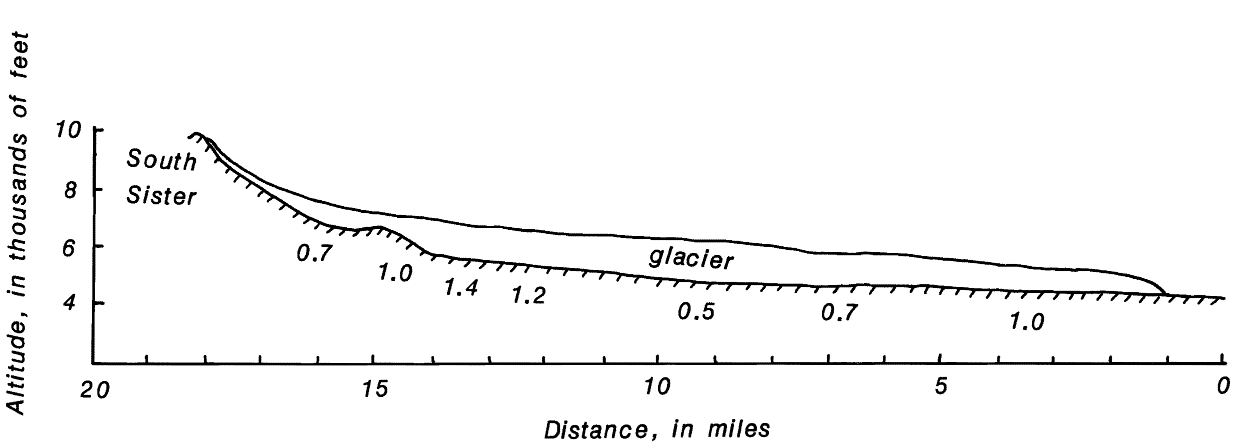


Figure 24. Longitudinal profile of the reconstructed glacier in the upper Deschutes valley. Values along the glacier are basal shear stresses in bars calculated using the method of Pierce (1979).

of Crane Prairie Reservoir, as well as nearby till of the Suttle Lake advance, have thin (< 40 cm) mantles of loess (windblown silt and fine sand). The loess must have been deflated before the end of outwash deposition and before the outwash surfaces became stabilized by vegetation.

(2) As discussed in the road guide (Stop 5), eruptions that formed Katsuk and Talapus Buttes probably began in a lake melted into the retreating glacier that occupied the area around present Sparks Lake.

(3) Scoria erupted from Red Crater (unit mr) directly overlies gray, unweathered till of Suttle Lake age in road cuts along the Cascade Lakes Highway (road log, mi 51.2). The lack of a recognizable weathering profile in the till in a location that appears to be geomorphically stable indicates that the eruptions must have occurred shortly after that site had been deglaciated.

Later eruptive history

Stratigraphic evidence on Mount Bachelor indicates that the eruptive activity along the chain was waning by the end of late-glacial time (Figure 21). The moraines of Canyon Creek age on Mount Bachelor postdate the construction of most of the summit cone, which is among the youngest features of the Mount Bachelor volcanic chain. The left-lateral moraine is overlain by lava flows erupted from vents on the lower north flank of Mount Bachelor (Figure 3); these flows account for only a small fraction of the cone's volume. Some lava flows on the west, south, and east flanks may also postdate the Canyon Creek advance, but these are separated geographically and cannot be related stratigraphically to the moraines.

As discussed in the previous section on glacial history, the moraines of Canyon Creek age on Mount Bachelor may be somewhat younger than those of the type Canyon Creek drift, which is thought to be 12.5-11 ka on the basis of correlations with the Hyak drift of the Washington Cascades. Evidence obtained locally suggests that the moraines of Canyon Creek age on Mount Bachelor are no younger than 9.5 ka, because a correlative moraine on Broken Top is overlain by the > 9.5-ka tephra of Cayuse Crater. Thus, the construction of most of the Mount Bachelor summit cone must have been completed before 9.5 ka and perhaps as early as 12.5 ka.

Stratigraphic evidence indicates that all eruptive activity ended by about 7 ka, because the products of the Mount Bachelor volcanic chain are overlain by Mazama ash, which was erupted from the Crater Lake area 6,850 years B.P. (Bacon, 1983). The original thickness of the ash was about 50 cm at the south end of the chain and about 30-40 cm at the north end (Stop 6). The degree of soil development in scoria of the summit cone and shield volcano of Mount Bachelor (units mb5 and mb4) prior to deposition of Mazama ash suggests that these deposits predate the ash by at least several thousand years. Typically, the soil buried by Mazama ash consists of a cambic B horizon that is 10-20 cm thick and displays weak oxidation extending an additional 10-30 cm into the scoria. In contrast, minimal weathering occurs in the scoria of Egan cone (unit mb6), where it is buried by Mazama ash. This suggests that unit mb6, the youngest of the eruptive products of the Mount Bachelor volcanic chain, may be close in age to Mazama ash. □

Western Mining Council to meet

The Bohemia Mine Owners' Association will host a Northwest Regional meeting of the Western Mining Council on the weekend of October 13-14, 1990, at Our Lady of Perpetual Help School in Cottage Grove, Oregon (13 miles south of Eugene). All interested prospectors and miners are welcome. Preregistration is required; and the registration deadline is September 25.

For more information, write Sue Hallet, 25199 Perkins Road, Veneta, OR 97487, or call (503) 935-1806. □

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.

ELEMENTAL ANALYSIS OF ZIRCON SAMPLES FROM PACIFIC NORTHWEST BEACHES BY INAA, by Bilqees Azim (M.S., Oregon State University, 1989), 111 p.

Fifteen sand samples from beaches along the Pacific North were analyzed for their elemental content by the method of instrumental neutron activation analysis (INAA). A separation technique was employed to separate the zircon (a heavy nonmagnetic mineral with a specific gravity of 4.67) from the rest of the sample. This technique worked fairly well for most of the samples. The zircon content of the heavy nonmagnetic samples was in the range of 58-95 percent, except for two northern California beaches which contained appreciable quantities of rutile. The hafnium content of the heavy nonmagnetic sample was fairly constant. The rare-earth pattern in the heavy nonmagnetic samples was similar to that observed in geological samples.

At present, the Oregon beaches are not economically mineable for zircon.

GEODETIC DEFORMATION OF THE OREGON CASCADIA MARGIN, by Paul Vincent (M.S. University of Oregon, 1989), 86 p.

The purpose of this study is to characterize crustal strain and deformation in western Oregon using high-precision vertical and horizontal geodetic data collected by the National Geodetic Survey. North-south leveling data from surveys between 1930 and 1988 along the Oregon coast were differenced and plotted to show change in benchmark elevations with time; a downward tilt toward the Newport-Tillamook region was found. This is interpreted to be the result of a nonuniform coupling between the subducting Juan de Fuca Plate and the overriding North American Plate. East-west leveling data show landward (down-to-the-east) tilt of the Coast Range which supports earlier findings. Historical triangulation data have been analyzed and show no significant horizontal strain accumulation in the Salem area. A GPS survey of the Columbia River network has recently been completed and is expected to yield additional strain information. □

AMC Mining Convention '90 meets in New Orleans

The American Mining Congress Mining Convention '90 will be held September 23-26 at the Fairmont Hotel in New Orleans. Theme of the Convention is "Challenges in a Changing World."

As featured keynote speaker, U.S. Labor Secretary Elizabeth H. Dole will address labor challenges for the 1990's and beyond. Altogether, 19 sessions will deal with areas of policy and technology concerning the mining industry. □

BLM office moves

The BLM Oregon/Washington State Office has changed its location in Portland from the Lloyd Tower Building to Providence Office Park, two blocks east of the Tri-Met Hollywood Transit Center in Portland's Hollywood District. The new street address is 1300 NE 44th Avenue, while the mailing address remains the same: P.O. Box 2965, Portland, OR 97208.

—BLM News

MINERAL EXPLORATION ACTIVITY

MAJOR METAL-EXPLORATION ACTIVITY

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services, Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	Jessie Page Chevron Resources Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
May 1989	Hope Butte Chevron Resources Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App
June 1990	Racey Billiton Minerals USA	T. 13 S. R. 41 E. Malheur County	Gold	Expl
June 1990	Grouse Mountain Bond Gold Exploration, Inc.	T. 23 S. Rs. 1, 2 E. Lane County	Gold	Expl
June 1990	Freeze Western Mining Corporation	T. 23 S. R. 42 E. Malheur County	Gold	Expl

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

STATUS CHANGES

No status changes in DOGAMI permits were recorded since the last issue of Oregon Geology. Public scoping workshops for an Environmental Impact Statement that is being prepared for the Grassy Mountain project proposed by Atlas Precious Metals, Inc., were held by the Bureau of Land Management in Ontario and Portland on August 21 and 22, respectively.

Numerous new applications for exploration projects are expected in the next few months, as companies comply with the lower thresholds included in House Bill 2088. Many companies active in Oregon are already following the procedures required by the new rules, and no major implementation problems are anticipated.

EXPLORATION AND BOND CEILING RULES

Rules implementing House Bill 2088 regarding exploration were adopted by the Governing Board of the Department of Geology and Mineral Industries (DOGAMI) on July 9. The rules were filed with the Secretary of State on August 3 and became effective on that date. All companies engaged in mineral exploration in Oregon should get in contact with the Department's Mined Land Reclamation (MLR) office in Albany immediately to make sure that their projects are in compliance with the new revised statutes and new rules.

Questions or comments about mineral-exploration permitting should be directed to Gary Lynch or Allen Throop at the MLR office, 1534 SE Queen Street, Albany, Oregon 97321, phone (503) 967-2039. □

Mining companies honored

At the Northwest Mineral Industry Meeting in Portland in May, the Eastern Oregon Mining Association (EOMA), Hecla Mining Company, and THC, Incorporated, received special recognition certificates from the U.S. Bureau of Land Management (BLM) and the USDA Forest Service (USFS) for their demonstrations of good land stewardship in Oregon.

EOMA was named Region 6 Mineral Operator of the Year by the USFS for its voluntary reclamation of two mine sites, the Peerless and Old Crow 80, on Wallowa-Whitman National Forest land. The mines had been abandoned in 1896 with little or no reclamation accomplished.

Hecla Mining Company of Coeur d'Alene, Idaho, and THC, Inc., of Pasco, Wash. were honored by BLM for their cooperation during exploration drilling operations within the Oregon Trail Area of Critical Environmental Concern and the National Historic Oregon Trail Interpretive Center site at Flagstaff Hill near Baker City.

The operators were commended for creating only minimal surface disturbance and for reclaiming the site after completion of the project. The companies also granted easements to BLM so that work on the Interpretive Center could proceeed without interruption, and Hecla volunteered to provide up to $100,000 for the interpretation of modern mining at the Center, if the company should develop an open-pit mine at the site. *—BLM News*

*(**DOGAMI publications,** continued from page 98)*

glomerate. This sequence correlates with the offshore marginal sequence of the Astoria Basin beneath the inner continental shelf.

Released September 4, 1990: *Silica in Oregon,* by staff geologist R.P. Geitgey, Appendix by staff geochemist G.L. Baxter. DOGAMI Special Paper 22, 18 p., 2 plates (1 sample-location index on a 1:1,000,000-scale base map and 1 sheet containing analytic data in tables and histograms), $7.

Silica is produced by three companies in Oregon for various end uses including nickel smelting and production of colored container glass; ferrosilicon; filter bed media; and decorative rock for exposed-aggregate panels, roofing, and landscaping. The new report reviews these operations and surveys other silica occurrences to identify additional sources of silica and industrial sand. Basic chemical, mineralogical, and screen-size data are presented for 45 samples from a variety of geologic environments throughout the state. Nine broad areas where silica occurs are described, and resources of potential commercial interest are identified in Clatsop, Malheur, and Morrow Counties.

Both publications are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

AVAILABLE DEPARTMENT PUBLICATIONS

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		Price	√
GMS-4	Oregon gravity maps, onshore and offshore. 1967	3.00	
GMS-5	Geologic map, Powers 15-minute Quadrangle, Coos/Curry Counties. 1971	3.00	
GMS-6	Preliminary report on geology of part of Snake River canyon. 1974	6.50	
GMS-8	Complete Bouguer gravity anomaly map, central Cascade Mountain Range. 1978	3.00	
GMS-9	Total-field aeromagnetic anomaly map, central Cascade Mountain Range. 1978	3.00	
GMS-10	Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00	
GMS-12	Geologic map of the Oregon part of the Mineral 15-minute Quadrangle, Baker County. 1978	3.00	
GMS-13	Geologic map, Huntington and parts of Olds Ferry 15-minute Quadrangles, Baker and Malheur Counties. 1979	3.00	
GMS-14	Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00	
GMS-15	Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00	
GMS-16	Free-air gravity and complete Bouguer gravity anomaly maps, south Cascades, Oregon. 1981	3.00	
GMS-17	Total-field aeromagnetic anomaly map, southern Cascades, Oregon. 1981	3.00	
GMS-18	Geology of Rickreall/SalemWest/Monmouth/Sidney 7½-minute Quadrangles, Marion/Polk Counties. 1981	5.00	
GMS-19	Geology and gold deposits map, Bourne 7½-minute Quadrangle, Baker County. 1982	5.00	
GMS-20	Geology and geothermal resources, S½ Burns 15-minute Quadrangle, Harney County. 1982	5.00	
GMS-21	Geology and geothermal resources map, Vale East 7½-minute Quadrangle, Malheur County. 1982	5.00	
GMS-22	Geology and mineral resources map, Mount Ireland 7½-minute Quadrangle, Baker/Grant Counties. 1982	5.00	
GMS-23	Geologic map, Sheridan 7½-minute Quadrangle, Polk and Yamhill Counties. 1982	5.00	
GMS-24	Geologic map, Grand Ronde 7½-minute Quadrangle, Polk and Yamhill Counties. 1982	5.00	
GMS-25	Geology and gold deposits map, Granite 7½-minute Quadrangle, Grant County. 1982	5.00	
GMS-26	Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00	
GMS-27	Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1° x 2° Quadrangle. 1982	6.00	
GMS-28	Geology and gold deposits map, Greenhorn 7½-minute Quadrangle, Baker and Grant Counties. 1983	5.00	
GMS-29	Geology and gold deposits map, NE¼ Bates 15-minute Quadrangle, Baker and Grant Counties. 1983	5.00	
GMS-30	Geologic map, SE¼ Pearsoll Peak 15-minute Quadrangle, Curry and Josephine Counties. 1984	6.00	
GMS-31	Geology and gold deposits map, NW¼ Bates 15-minute Quadrangle, Grant County. 1984	5.00	
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GMS-34	Geologic map, Stayton NE 7½-minute Quadrangle, Marion County. 1984	4.00	
GMS-35	Geology and gold deposits map, SW¼ Bates 15-minute Quadrangle, Grant County. 1984	5.00	
GMS-36	Mineral resources map of Oregon. 1984	8.00	
GMS-37	Mineral resources map, offshore Oregon. 1985	6.00	
GMS-38	Geologic map, NW¼ Cave Junction 15-minute Quadrangle, Josephine County. 1986	6.00	
GMS-39	Geologic bibliography and index maps, ocean floor and continental margin off Oregon. 1986	5.00	
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Northwest Oregon, Correlation Section 24. Bruer and others, 1984 (published by AAPG)	5.00	
Oregon rocks and minerals, a description. 1988 (DOGAMI Open-File Report O-88-6; rev. ed. of Miscellaneous Paper 1)	5.00	
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Back issues of *Ore Bin/Oregon Geology*, 1939-April 1988	1.00	
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Color postcard: Oregon State Rock and State Gemstone	.50	

Separate price lists for open-file reports, geothermal energy studies, 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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OREGON GEOLOGY

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Oregon Department of Geology and Mineral Industries

VOLUME 52, NUMBER 6 NOVEMBER 1990

IN THIS ISSUE:
Field trip guide to the central Oregon High Cascades. Part 2: Bend area.
Nonstructural damage in earthquakes.
Potential strong earthquake ground shaking in Portland.

OREGON GEOLOGY

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Main Office: 910 State Office Building, 1400 SW Fifth Ave., Portland 97201, phone (503) 229-5580, FAX (503) 229-5639.

Baker City Field Office: 1831 First Street, Baker City 97814, phone (503) 523-3133. Howard C. Brooks, Resident Geologist.

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

Mined Land Reclamation Program: 1534 Queen Ave. SE, Albany 97321, phone (503) 967-2039. Gary W. Lynch, Supervisor.

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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, a file copy on 5-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 6th ed., 1978.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the 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

Cascade Head, one of the largest headlands along the Oregon coast. The volcanic rocks that make up much of the headland were the subject of one of the papers presented at the 1990 meeting of the Cordilleran Section of the Geological Society of America. See p. 136 for abstracts of several of the papers on Oregon geology that were presented there. Photo courtesy of the Oregon State Parks and Recreation Department.

OIL AND GAS NEWS

NWPA holds symposium, elects new officers and directors

The Northwest Petroleum Association (NWPA) held its annual symposium in Roseburg, Oregon, on September 30 and October 1-3, 1990. The geology of the Tyee and Coos Basins was discussed in both talks and field trips. Officers elected for 1990-91 are Barbara Portwood, president; Lanny Fisk, vice-president; Bill Connelly, treasurer; and Dick Bowen, secretary.

The Directors in office for 1990-91 are Peter Hales, Harry Jamison, Bob Deacon, Bob Fujimoto, Jerry Fish, Delores Yates, and Dennis Olmstead.

Oil and gas studies open to public

The Oregon Department of Geology and Mineral Industries (DOGAMI) maintains a collection of drilling records, well logs, and well samples and makes them available to the public for study. Whenever well samples are subjected to analyses that cause loss of a portion of the sample, DOGAMI receives a copy of the data and results of the study and makes them available to the public. Recently acquired data from such studies include the following:

1. **Analysis of the petroleum hydrocarbon source potential and geochemical characteristics of Clarno Formation strata in the Steele Energy Keys no. 1 well, Wheeler County.** This study, done by Conoco Oil Co., concludes that the Clarno Formation has several zones of shales that are potential source rocks and are composed predominantly of oil-prone terrestrial kerogens.

2. **Subsurface and geochemical stratigraphy of northwestern Oregon,** a Master of Science thesis (1990) by Olga B. Lira, Portland State University. The study is based on analyses of well logs, sample geochemistry, lithology, and paleontology.

3. **Palynologic foraminiferal and nannofossil study of the Standard Oil Kirkpatrick no. 1 well, Gilliam County.** The report, done by Unocal Oil and Gas, concludes that no definitive age can be applied to the strata at the bottom of this well, but it is likely Mesozoic in age.

4. **Stratigraphy and depositional setting of the late Eocene Spencer Formation in the west-central Willamette Valley,** a Master of Science thesis (1988) by Linda Baker, Oregon State University, that analyzes the Spencer Formation using well logs and lithologies, including grain size analysis.

5. **Instrumental neutron activation analysis (INAA) for selected Mist Gas Field wells,** a portion of the studies for a Master of Science thesis, by David Long, Portland State University. The analysis attempts to determine whether the radioactive decay of certain elements may have ionized and released nitrogen from surrounding rocks and from organic matter in the rocks.

6. **Palynologic examination of samples from the Standard Oil Pexco State no. 1, Sunray Bear Creek no. 1, and Texaco no. 17-1 well, Crook County, and Oregon Petroleum Clarno no. 1 well, Wheeler County,** by Unocal Oil and Gas. Ages for various strata in these wells were determined by palynologic correlations.

7. **Radiometric age dating and thermal maturity of strata in the Fenix and Scisson Old Maid Flat well, Clackamas County,** by Shell Oil Company. The report finds that the samples show evidence of rapid heating in the condition of organic matter and in high reflectance readings. Age data indicate a 20.3±1.2-million-year and 20.9±1.1-million-year age for certain strata in this well.

(Continued on page 138, ***Oil and Gas)***

Field trip guide to the central Oregon High Cascades Part 2 (conclusion): Ash-flow tuffs in the Bend area

by Brittain E. Hill, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331-5506, and William E. Scott, David A. Johnston Cascades Volcano Observatory, U.S. Geological Survey, 5400 MacArthur Boulevard, Vancouver, Washington 98661.

This field trip guide was created for the September 1988 meeting of the Friends of the Pleistocene, which was held in the Mount Bachelor area. It was released in a slightly different form and with additional material as U.S. Geological Survey (USGS) Open-File Report 89-645 (Scott and others, 1989). The entire volume was edited by William E. Scott, Cynthia A. Gardner, and Andrei M. Sarna-Wojcicki, all of the USGS. Individual sections of the report by Scott; Gardner; Lundstrom and Scott; Scott and Gardner; Hill; Hill and Taylor; and Sarna-Wojcicki, Meyer, Nakata, Scott, Hill, Slate, and Russell are cited in the references. The complete report may be purchased from USGS, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, Colorado 80225, phone (303) 236-7476, for $10.25.

This second part of the field trip represents the third day of the original trip and is accompanied by one connected paper by Hill and Taylor. Part 1 of the central High Cascades field trip guide (the original first two days of the field trip) was published in the last (September 1990) issue of *Oregon Geology*. The combined references in this issue are for both parts of the field trip guide.

The mileage in this guide differs slightly from that in the open-file report, because the first day of this trip started in a different location, and the first two days of field trip guides by Scott and Gardner were combined into Part 1. Readers may choose to run the trip in a different order, depending on where they are staying. There are several campgrounds near various portions of the trip. Readers are urged to obtain the USDA Forest Service map of the Deschutes National Forest or USGS topographic maps of the area before following the guide, because some features mentioned in the log are not easily found on the maps used for the guide. Also, because some of the side roads are not paved, reasonable caution should be taken in following the road log. *—Editor*

INTRODUCTION

This concluding portion of the field excursion to the central Oregon High Cascades highlights aspects of the ash-flow tuffs in the Bend area. The guide contains brief descriptions of the stops, and some of the key features and interpretations of the stops are discussed further in the paper by Hill and Taylor at the end of the guide. For the map of the field-trip area, see Figure 1, p. 100, in the September 1990 issue of *Oregon Geology*.

ROAD LOG

0.0——Part 1 ended at mile 85.1, the point where Highway 46 (Cascade Lakes Highway/Century Drive) reached the **Bend city limits** from the west. Part 2 will now begin with mile 0.0 at the same point. **Continue into Bend for 1.6 mi.**

1.6——Turn left toward the Bend city baseball fields and Cascade Junior High School. Park in the lot at the baseball fields and walk north across the fields. Head northeast on unpaved roads to abandoned pumice quarry on north side of old Brooks-Scanlon road, which is closed to traffic by line of large boulders. Quarry is on private land.

STOP 8—LAVA ISLAND ASH-FLOW TUFF, TUMALO ASH-FLOW TUFF, AND BEND AIR-FALL PUMICE

This abandoned quarry exposes a 7-m-thick section of Bend Pumice of Taylor (1981) overlain directly by Tumalo Tuff of Taylor (1981) (Figures 1 and 2). The tuff shows lateral and vertical changes in welding and also has a locally well-developed basal layer that contains coarse pumice clasts. Lava Island Tuff of Taylor (1981) lies disconformably on Tumalo Tuff and is thoroughly devitrified. See paper by Hill and Taylor immediately following the field trip guide for information about these units.

Return to intersection with Century Drive (Cascade Lakes Highway).

2.1——Intersection with Century Drive; turn left.

2.4——Intersection with Colorado Avenue; continue on Century Drive.

3.5——Intersection with three-way stop; stop and continue straight ahead (north) on 14th NW St.

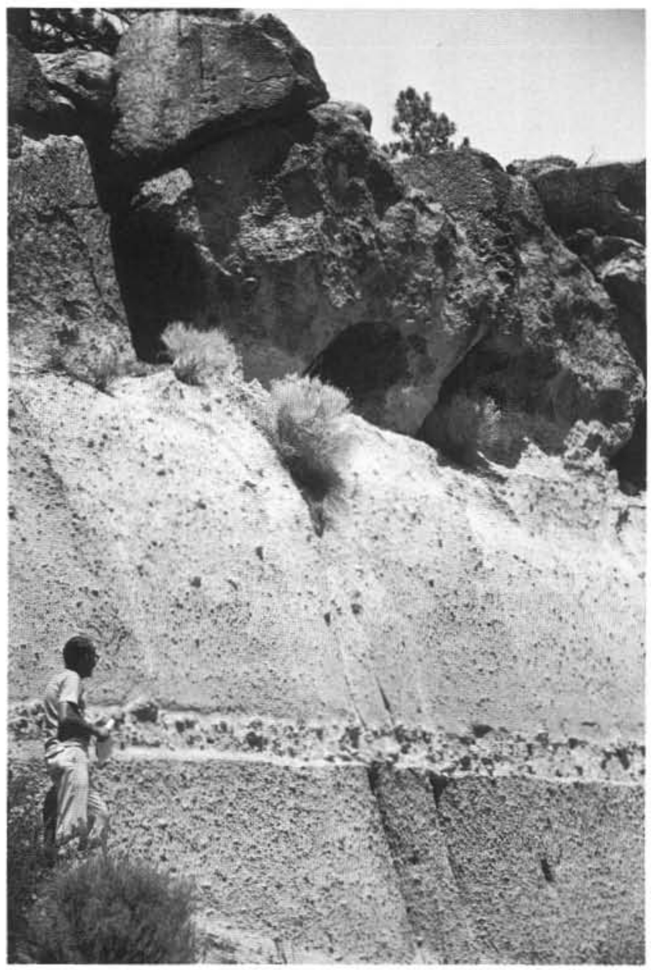

Figure 1. Bend Pumice overlain by Tumalo Tuff at Stop 8.

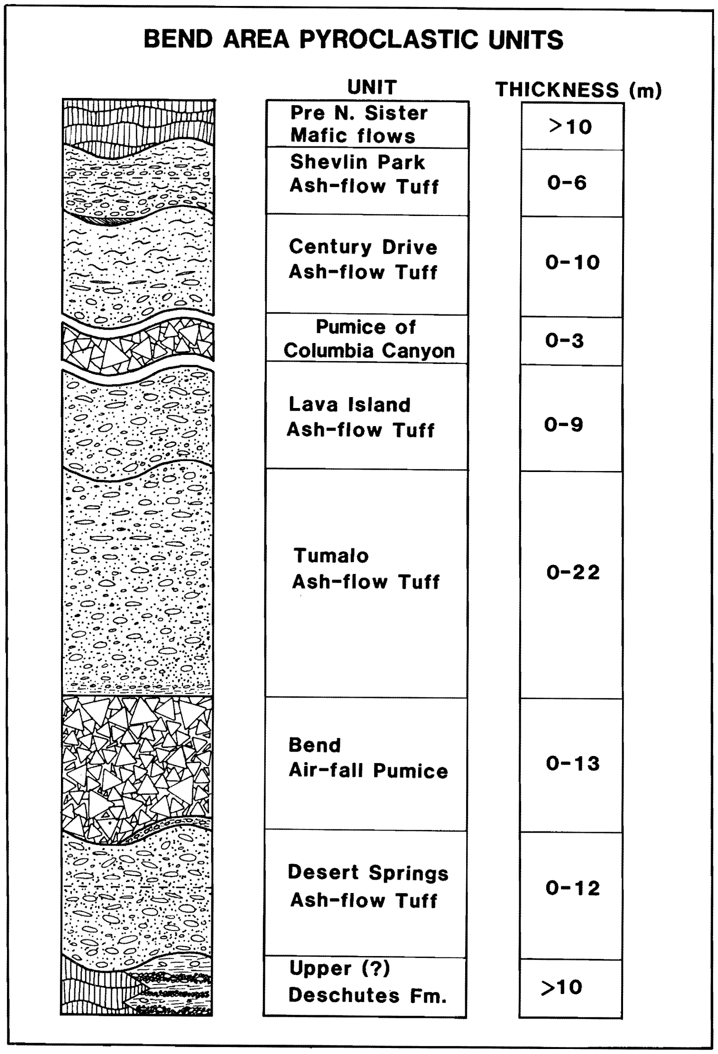

Figure 2. Schematic stratigraphic section of pyroclastic units erupted from the Tumalo Volcanic Center.

3.9——Intersection with NW Newport Ave.; turn left on Newport. Much of the following is taken from Taylor (1981).

4.2——Road to Central Oregon Community College on right. Newport Ave. becomes Shevlin Park-Market Rd. at milepost 0. The road lies in a valley between two early(?) Pleistocene basaltic shield volcanoes (Awbrey and Overturf Buttes) through which four pyroclastic flows passed from west to east.

5.4——Curve to right. Pumice quarries on left reveal Tumalo Tuff overlying Bend Pumice.

5.7——Curve to left. The last 0.5 mi of road has followed the northwest-striking Tumalo fault. Rocks on the southwest side (rangeward) of the fault have been displaced downward. In this vicinity, Desert Springs Tuff of Taylor (1981), Bend Pumice, and Tumalo Tuff have all been faulted; Shevlin Park Tuff of Taylor (1981) has not but has been faulted farther to the southeast.

6.9——Cross Tumalo Creek; entrance to Shevlin Park, which contains many good exposures of Shevlin Park Tuff. Road becomes Johnson Road.

RECOMMENDED SIDE TRIP

Turn left into Shevlin Park. Follow park road 0.6 mi southwest to Red Tuff Gulch on the north side of Tumalo Creek. A 3-m-thick section of Desert Springs Tuff, which contains two flow lobes, crops out here. Moderately welded Tumalo Tuff and Shevlin Park Tuff are exposed about 150 m up the gulch. Reworked pumice lapilli, ash, and obsidian of basal Bend Pumice are well exposed along the park road just to the southwest. Large blocks of welded Tumalo Tuff and Desert Springs Tuff occur in alluvium overlying Bend Pumice.

7.2——Top of grade; turn left on gravel road to Bull Springs Tree Farm. Bear right at first two roads that head off to left.

7.7——First of two roads to right; bear left at both.

8.4——Intersection with the old Brooks-Scanlon road (Road 4606) at abandoned quarry; turn right. Skirt and cross margins of several High Cascade basalt lava flows.

10.0——Road descends and turns sharply to right, crossing shallow canyon. **Pull off either side of road and park in flat area around Columbia Southern Canal.**

STOP 9—TUMALO TUFF, BASALTIC ANDESITE LAVA FLOW, AND SHEVLIN PARK TUFF

At this stop, one can examine outcrops of approximately 0.3-Ma Shevlin Park Tuff (Figure 1) near the canal and in the road cuts and also have a good view of the Tumalo volcanic center, from which the mid-Quaternary pyroclastic-flow deposits and tephras were erupted.

The road cut exposes Tumalo Tuff, which is overlain disconformably by a High Cascade basaltic andesite lava flow from an unknown vent. The tuff has been locally reddened and welded by the heat of the lava flow. The lava flow is overlain by Shevlin Park Tuff, the youngest pyroclastic unit erupted from the Tumalo volcanic center. The Shevlin Park Tuff, which is gray and andesitic in composition, fills a channel cut through the lava flow and Tumalo Tuff.

CAUTION: THE ROAD CUTS ARE TREACHEROUS. THE LAVA FLOW OVERLYING TUMALO TUFF IS LOCALLY UNDERCUT AND CONTAINS LARGE OPEN FRACTURES. DO NOT FURTHER UNDERMINE THE LAVA FLOW. BE CAUTIOUS WHILE EXAMINING THE CONTACT AND BE AWARE OF THE IMPACT OF YOUR ACTIVITIES ON OTHERS AND THEIRS ON YOU. LESS DANGEROUS OUTCROPS OF SHEVLIN PARK TUFF OCCUR ON THE NORTH SIDE OF THE CANYON.

End of field trip. Turn around and head back to Johnson Road.

If you are heading south of Bend, return along trip route to mileage 2.4 (intersection with Colorado Avenue), turn east on Colorado Avenue, and continue to Division Street and U.S. 97.

If you are heading north on U.S. 97 or west on U.S. 20, turn left on Johnson Road as you leave Shevlin Park and continue 4.2 mi to junction with Tumalo Market Road. (At junction, good exposures of Desert Springs Tuff, below road, and Bend Pumice and Tumalo Tuff, in quarries above road, occur 0.4 mi to north along Tumalo Market Road). Turn right on Tumalo Market Road and then immediately turn left (north) and continue about 1 mi to U.S. 20. Late Pleistocene outwash gravels underlie the valley bottom. If you are heading north on U.S. 97, turn right on U.S. 20 and continue to junction with U.S. 97.

Paper connected with field trip

Oregon Central High Cascade pyroclastic units in the vicinity of Bend, Oregon

*by Brittain E. Hill and Edward M. Taylor, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331-5506**

The stops at two Bend sites (see map in field trip guide, Part 1, Figure 1) are to allow you to view several pyroclastic-flow and tephra-fall deposits of mid-Quaternary age (Figure 2). Investigations of these deposits by Taylor (1981), Hill (1985, 1987, 1988), and Hill and Taylor (this paper) have concluded that the units were all erupted from vents in a silicic eruptive center (Tumalo volcanic center) that lay east of present Broken Top volcano (Figure 3). In addition, recent work by Sarna-Wojcicki and others (1989) has provided age constraints on some of these units based on K-Ar dating and tephrostratigraphic correlations. Formerly assumed to be of late Tertiary or early Pleistocene age, the units are now thought to range in age from about 0.65 to 0.3 Ma.

Unlike most areas in the Oregon High Cascade Range, the area west of Bend, Oregon, contains at least five ash-flow tuffs and two major pumice-fall deposits (see field trip guide, Part 1, Figure 16). These pyroclastic units were not erupted from the present stratovolcanoes (Three Sisters, Broken Top) of the Oregon central High Cascades area. Instead, they were erupted from a large silicic vent complex, the Tumalo volcanic center (Hill, 1988), which is located east of Broken Top and west of Bend. The Tumalo volcanic center encompasses the "silicic highland" of Taylor (1978) and forms a 25-km-long, south-trending belt of silicic domes and andesitic cinder cones from Three Creek Butte to Edison Butte. The most significant results of ongoing investigations are that the Tumalo volcanic center produced the largest silicic eruptions in the Oregon central High Cascades less than 0.4 Ma, and that these eruptions preceded the construction of the Three Sisters and Broken Top stratovolcanoes. The purpose of the field trip in the Bend area is to examine some of the features of the pyroclastic units around Bend and to show that these units represent major eruptions from the Tumalo volcanic center.

DESERT SPRINGS TUFF

The Desert Springs Tuff of Taylor (1981) is the oldest of the Pleistocene High Cascade pyroclastic deposits. Where the basal contact is exposed, the Desert Springs overlies the Miocene to upper Pliocene(?) Deschutes Formation (Smith and others, 1987). The Desert Springs contains at least two distinct flow lobes that form one cooling unit. Although complete sections are not exposed, the Desert Springs has an average thickness of about 12 m, with one preserved section 30 m thick. An idealized vertical section contains a poorly welded 2-m-thick basal zone, a 5- to 10-m-thick, pink-to-tan, firmly welded zone of vapor-phase alteration, and an upper poorly welded zone of fresh black glass about 5 m thick. Where preserved, the contact between the flow lobes occurs in the pink welded zone. The Desert Springs Tuff is characterized by black dacitic pumice lapilli and bombs that are up to 0.5 m in diameter and contain up to 15 percent phenocrysts: plagioclase (An_{40}); orthopyroxene ($Wo_3En_{55}Fs_{42}$) and augite ($Wo_{40}En_{38}Fs_{22}$) (both with abundant inclusions of apatite); and titanomaghemite. Outcrops of the Desert Springs Tuff are scattered, but their distribution and westward increase in extent of welding indicate that the tuff was erupted from the Tumalo volcanic center area. The mineralogy and chemistry of the Desert Springs Tuff are also similar to several Tumalo volcanic center domes near Bearwallow Butte.

BEND PUMICE

The Bend Pumice of Taylor (1981) is a rhyodacitic, vitric lapilli-fall tuff that is best exposed along the roads leading to Tumalo State Park. The 2-m-thick basal zone of the Bend Pumice consists of pumice lapilli, ash, and perlitic obsidian and has been locally reworked and mixed with gravel and sand. The basal zone is thought to represent the preliminary stage of a climactic eruption (Hill, 1985). The basal zone is overlain by 3-13 m of air-fall lapilli and ash, which progressively increase in average grain size upsection. Westward increases in average grain size, unit thickness, and size of volcanic rock fragments (Hill, 1985) all indicate that the Bend Pumice was erupted from the Tumalo volcanic center. In addition, the major- and trace-element composition of the Bend Pumice is nearly identical with several of the silicic domes that are preserved in the area of Three Creek Butte and Triangle Hill (Hill, 1987).

The Bend Pumice has been correlated with the Loleta ash bed (Sarna-Wojcicki and others, 1987, 1989), which has an estimated age of 0.35 to 0.39 Ma. K-Ar determinations for plagioclase separates from the overlying Tumalo Tuff yielded an average age of 0.29 ± 0.12 Ma, while obsidian fragments from the basal zone

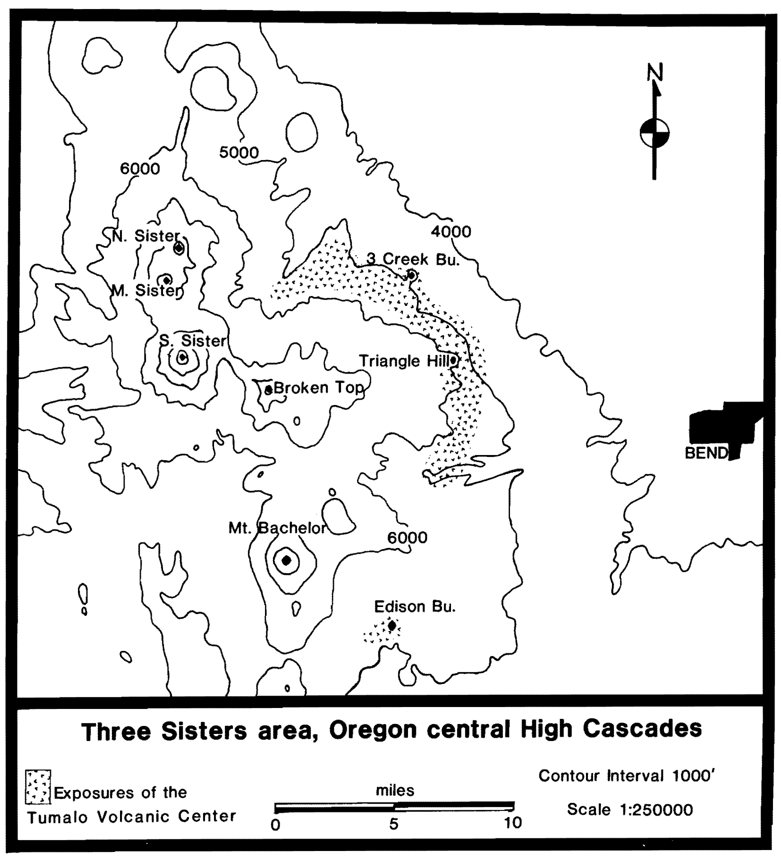

Figure 3. Map showing exposures of the Tumalo Volcanic Center in the Three Sisters area (Brittain Hill, unpublished research, 1990).

*Data tables printed with the original paper (Hill and Taylor, 1989) are not reproduced here.

of the Bend Pumice have an average age of 0.42 ± 0.01 (Sarna-Wojcicki and others, 1989). As the obsidian is interpreted to mark a preliminary stage of the eruption that climaxed with the emplacement of the Bend Pumice and Tumalo Tuff, a best age for the eruption is thought to be about 0.4 Ma, which is at least 0.5 million years younger than previous estimates for this eruption (Armstrong and others, 1975).

TUMALO TUFF

The Tumalo Tuff of Taylor (1981) is a pink-to-tan, rhyodacitic, vitric ash-flow tuff that overlies the Bend Pumice. The absence of a normally graded top to the Bend Pumice and the nonerosive basal contact of the Tumalo Tuff indicate that the Tumalo Tuff was produced through collapse of the Bend Pumice eruption column. The Bend Pumice and overlying Tumalo Tuff represent the eruption of at least 10 km^3 of nearly homogeneous rhyodacitic magma (Hill, 1985).

Both the Bend Pumice and Tumalo Tuff have a distinct mineral assemblage: plagioclase (An_{20}), ferrohypersthene ($Wo_3En_{40}Fs_{57}$), augite ($Wo_{41}En_{41}Fs_{18}$), fresh black hornblende, magnetite, ilmenite, apatite, and zircon. The ferrohypersthenes are the most iron-rich orthopyroxenes that have been observed in the Oregon central High Cascades. Banded pumice, which represents the mingling of rhyodacitic and unrelated dacitic magmas (Hill, 1985), is found in proximal (western) exposures. Although imbrication of pumice clasts in the Tumalo Tuff indicates a northeast direction of flow (Mimura, 1984), the direct association with the Bend Pumice indicates that the Tumalo Tuff was erupted from the Tumalo volcanic center and channeled by northeast-trending drainages (Hill, 1985).

LAVA ISLAND TUFF

The Lava Island Tuff of Taylor (1981) is a purple to gray, intensely devitrified ash-flow tuff that directly overlies the Tumalo Tuff. It is best exposed along the Deschutes River at Meadow Campground (sec. 23, T. 18 S., R. 11 E.). The basal contact with the Tumalo Tuff is sharp and erosive, with no intervening deposits. The Lava Island Tuff closely resembles welded sections of the Tumalo Tuff and has a similar composition and mineralogy except for the fact that the ferrohypersthene is rimmed with iron-rich augite ($Wo_{40}En_{20}Fs_{40}$) and that both pyroxenes contain abundant apatite inclusions. The Lava Island Tuff may thus represent a flow lobe of the Tumalo Tuff that was derived from a deeper, gas-rich part of the magma chamber.

PUMICE OF COLUMBIA CANYON

This informally named dacitic, vitric lapilli-fall tuff occurs underneath the Shevlin Park Tuff in a steep canyon along the Columbia Canal (sec. 17, T. 17 S., R. 11 E.) and overlies several mafic lava flows north of the Tumalo volcanic center. The pumice contains phenocrysts of plagioclase (An_{40}), augite ($Wo_{40}En_{43}Fs_{17}$), hypersthene ($Wo_3En_{63}Fs_{34}$), hornblende, magnetite, ilmenite, and apatite. It has an average grain size (about 1 cm) that is similar to the Bend Pumice at the Columbia Canyon outcrop and contains abundant angular fragments of black obsidian up to 4 cm in diameter, both of which suggest that this unit was erupted from a Tumalo volcanic center vent. While the composition of the pumice of Columbia Canyon is distinctive, it has not been correlated with any other unit in the Oregon central High Cascades. Owing to its limited distribution and obsidian content, the pumice of Columbia Canyon is probably related to a small dome-forming eruption in the Tumalo volcanic center.

CENTURY DRIVE TUFF

The Century Drive Tuff of Taylor (1981) is a variably welded vitric ash-flow tuff containing both rhyodacitic(?) and andesitic pumice. The phenocryst mineralogy of the Century Drive Tuff is plagioclase (An_{35}), augite ($Wo_{41}En_{42}Fs_{17}$), hypersthene ($Wo_2En_{67}Fs_{31}$), olivine (Fo_{71}), and titanomagnetite. It is best exposed along Tumalo Creek west of Shevlin Park, where it forms large, densely welded outcrops. The Century Drive Tuff is restricted to scattered outcrops in the area south and west of Bend, and it appears to be more densely welded in exposures closer to the Tumalo volcanic center, suggesting eruption from one of its vents.

SHEVLIN PARK TUFF

The Shevlin Park Tuff of Taylor (1981) is an andesitic vitric ash-flow tuff that is distributed around a 180° sector east of and centered on Triangle Hill in the Tumalo volcanic center (Hill, 1988). The Shevlin Park Tuff forms one cooling unit and may contain two flow lobes and base-surge deposits in more proximal exposures. The Shevlin Park Tuff contains plagioclase (An_{36}), hypersthene ($Wo_3En_{65}Fs_{32}$), augite ($Wo_{42}En_{43}Fs_{15}$), olivine (Fo_{71}), and titanomagnetite. The distribution of the Shevlin Park Tuff, along with increases in degree of welding and average pumice size, indicates that this unit was erupted from the Tumalo volcanic center. It is probably associated with the Triangle Hill vent complex, which consists of silicic domes and andesitic cinder cones arranged in a roughly circular pattern around Triangle Hill. This complex has a diameter of about 3 km and is centered on a -10 mgal gravity anomaly (Couch and others, 1982). A noteworthy Shevlin Park Tuff outcrop occurs in the upper reaches of the North Fork of Squaw Creek (secs. 29 and 30, T. 16 S., R. 9 E.). At this location, the Shevlin Park Tuff is overlain by a basaltic andesite flow of normal magnetic polarity, which is in turn overlain by the oldest basaltic andesites clearly associated with North Sister (Taylor, 1987). Because North Sister is the oldest stratovolcano of the Three Sisters, this exposure clearly demonstrates that pyroclastic volcanism associated with the Tumalo volcanic center predated construction of the Three Sisters. Basaltic andesite flows from the Tam MacArthur Rim area partly cover the Triangle Hill vent complex, indicating that Tam MacArthur Rim and contemporaneous Broken Top volcanism (Taylor, 1978) postdate Tumalo volcanic center volcanism as well.

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(Continued on page 139, ***Field Trip****)*

Earthquake waves and nonstructural effects

by William M. Elliott, Water Utility Engineer, Portland Water Bureau, 1120 SW Fifth Avenue, Portland, OR 97204

INTRODUCTION

Although earthquakes in Oregon are rare, they nevertheless do occur. Scientific research conducted during the last five to ten years has shown that Oregon's earthquake potential is real. The more frequent shallow earthquakes (magnitude 5-6.5) can occur at any time. Research into the probability of large (magnitude 6.5-7.5) and great (magnitude 8-9) earthquakes is continuing.

This article deals with two concepts: (1) the type of waves that an earthquake generates, and (2) the type of "nonstructural" damage that even moderate earthquakes can cause.

EARTHQUAKE SHAKING

As rocks move within the earth, stresses build up between the masses of material over time. When the strength of the rocks is exceeded or when weak areas such as faults give way and slip, the release of the accumulated strain results in vibrational waves of several types.

Seismologists have identified four wave types that fall into two general wave categories. The two categories are body waves and surface waves. Body waves are of two types: *P* waves and *S* waves. Surface waves are also of two types: Love waves and Rayleigh waves. The ways in which the different wave types produce ground shaking are illustrated in Figure 1.

Body waves of both types travel through the entire mass or "body" of the earth materials in all directions. First to arrive at a given site, the *P* wave is the initial compression wave and travels the fastest. The *S* wave is somewhat slower and resembles an ocean wave arriving on a beach.

Surface waves travel along the surface of the earth with motions slower than either *P* or *S* waves. The third wave to arrive at a site (and the first surface wave) is the Love wave, which is named after the English mathematician A.E.H. Love. This wave is described by Bruce Bolt in his book *Inside the Earth* as follows: "In Love waves, the ground moves from side to side in a horizontal plane but at right angles to the direction of propagation; there is no vertical motion" (Bolt, 1982, p. 44). This rapid side-to-side motion and the attendant reversal of direction are important to the damaging characteristics of Love waves.

The second type of surface waves and the last to arrive at a site are the Rayleigh waves, named for the British mathematician Lord Rayleigh. Again, Bolt's description: "In Rayleigh waves, the particles of rock vibrate both up and down and backward and forward,

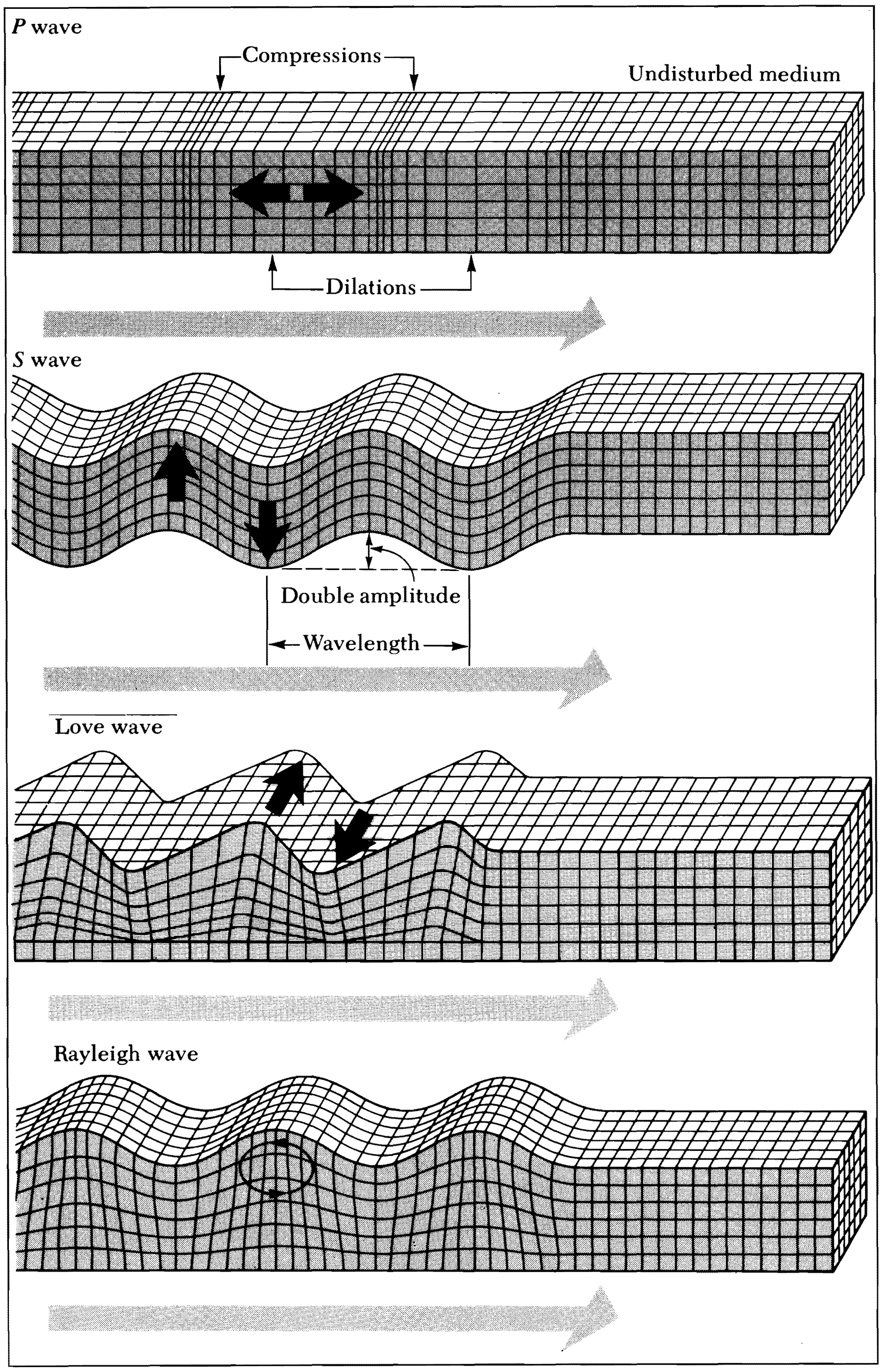

Figure 1. Diagram illustrating characteristics of major types of seismic waves by the types of ground motion they produce. Arrows below the diagrams indicate direction in which the waves are traveling. Arrows on the diagrams indicate ground movement caused by the waves. Sequence from top to bottom also is generally the sequence in which the four waves arrive at a given site. P *waves (compressional) and* S *waves (transverse) are body waves that travel in all directions from the source. Love waves (side-to-side) and Rayleigh waves (up-down and backward-forward) are surface waves that travel around the surface of the earth and are slower than the body waves. Modified from Bolt (1982). Copyright by W.H. Freeman and Company. Reprinted with permission.*

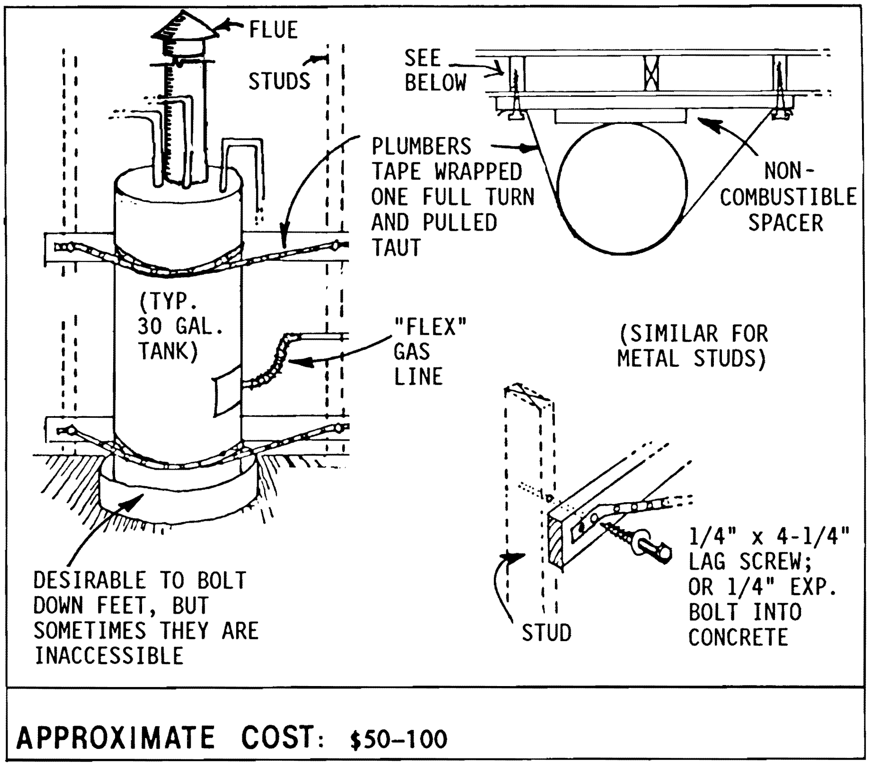

Figure 2. Simple ways to secure a water heater. Strap tank to rigid structure with metal tape, placing noncombustible spacer between tank and wall. Loop tape once all around tank, then attach tape ends to solid structure. Rigid gas pipes connected to the heater should be replaced with flexible gas line.

following in effect an elliptical orbit. However, the elliptical orbit is restricted to a vertical plane pointed in the direction in which the waves are traveling" (Bolt, 1982, p. 44). This rolling motion in a backward direction as the wave travels forward is yet another motion that can cause damage.

In order to distinguish these different wave forms, seismographs that record all the directions of motion (two to record horizontal motion, for example, north-south and east-west, and one to record up-down vertical motion) simultaneously are needed. At present, Oregon is attempting to establish a network of these types of sensitive devices.

The advent of the computer has enabled seismologists to unlock many of the mysteries of the earth and its interior. Readers are directed to other books by Bruce Bolt, such as *Nuclear explosions and earthquakes* (1976) and *Earthquakes* (1988).

GROUND RESPONSE

The vibrations created by an earthquake are not the end of the story. Once these disturbances are generated, they move in the earth as body waves or along the earth's surface as surface waves, decreasing in severity the farther they travel from the source. When these waves arrive at a particular site, the geologic characteristics of that site influence the intensity of the waves. Site geology may cause amplification of the shock (greater shaking than expected) or attenuation (damping or decrease in the shaking intensity). Depending on the site conditions, the ground shaking can trigger landslides, settlement, and slumping, even liquefaction. Liquefaction occurs where fine-grained materials such as sands or silts with adequate moisture can lose their strength temporarily during earthquake shaking. Numerous incidents of damage can be attributed to this phenomenon.

STRUCTURAL VERSUS NONSTRUCTURAL DAMAGE

This article does not discuss the relationships of earthquake damage to structures and buildings. Instead, the attempt made here is to discuss how ground shaking can have a

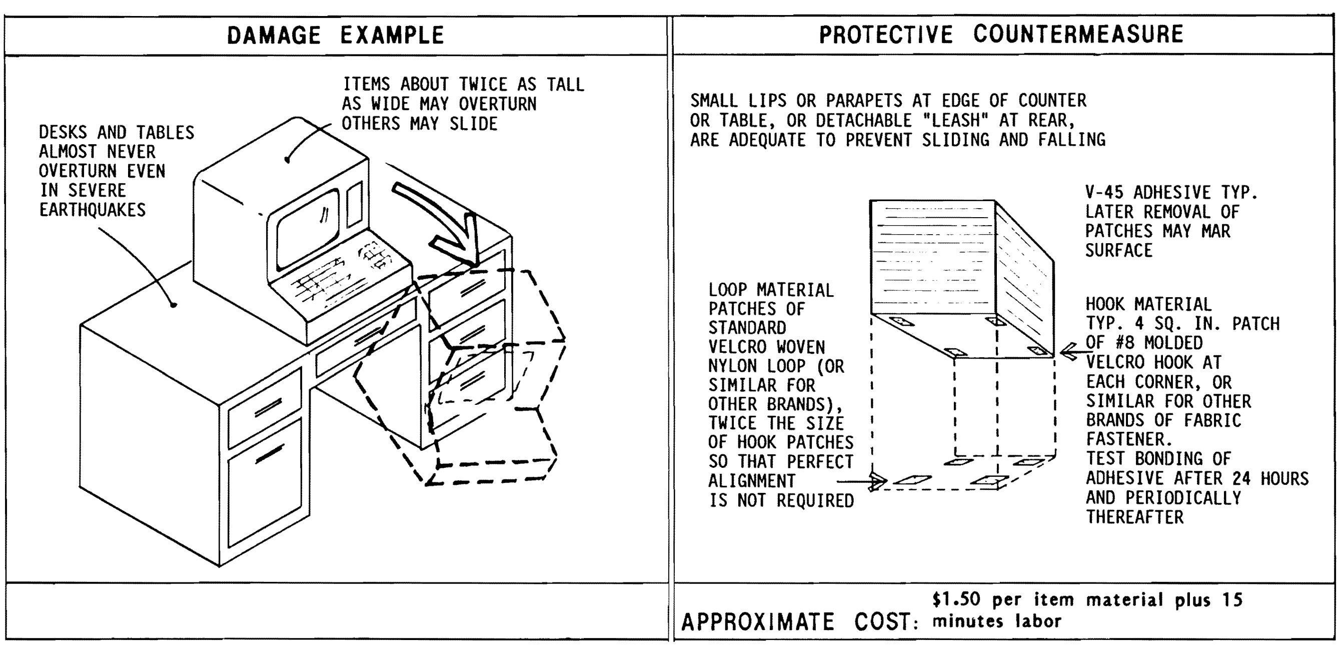

Figure 3. A computer is one of the typical items found on top of desks and tables. While the base may be stable, the equipment itself may topple or slide off. Velcro strips or similar hook-and-pile materials attached to desks can help keep equipment from moving.

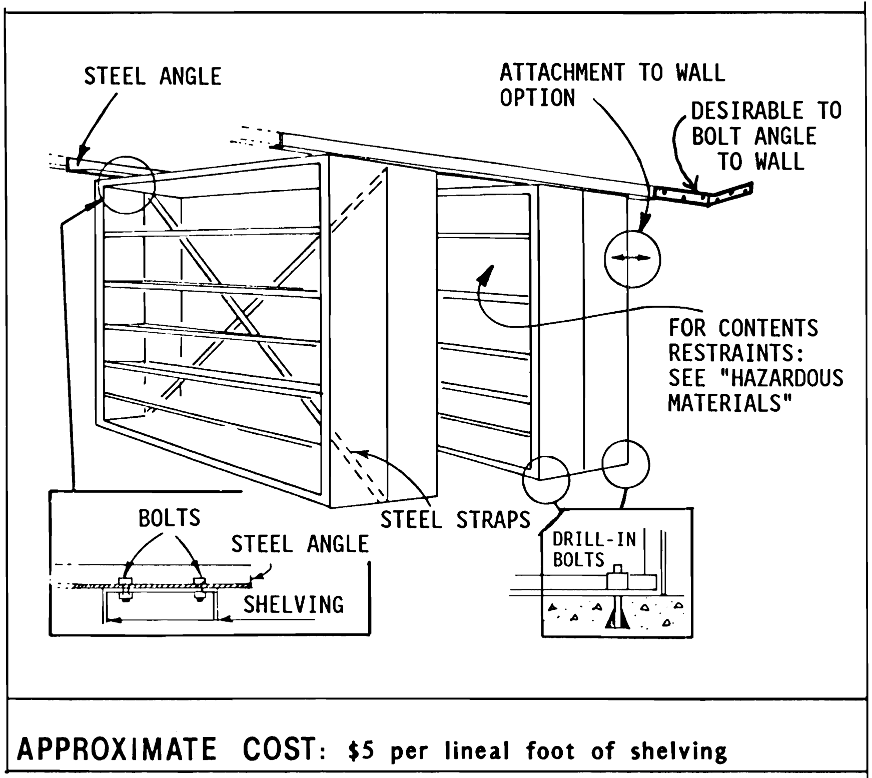

Figure 4. Tall shelving should be stabilized by connecting units rigidly to each other or anchoring them to walls.

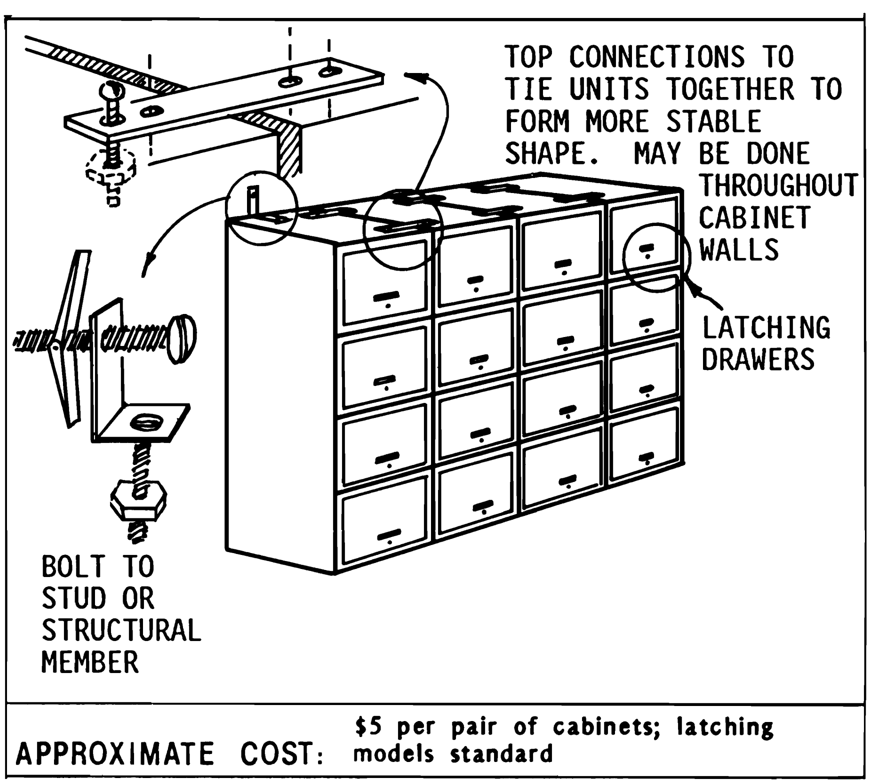

Figure 5. Tall file cabinets can be secured like tall shelves. Their drawers should be equipped with latches.

significant impact on building contents and nonstructural elements. These damages often occur even though the structure itself is not greatly damaged. Nonstructural damage can seriously affect the continued functioning of homes, offices, stores, and factories following an earthquake. Yet, such damage often cannot be anticipated in the planning and building of the structure itself, because it depends on the way in which the occupants furnish and use the structure. Therefore, the hazard of nonstructural damage calls not for the architects, engineers, and other experts but for the common people—all of us—to pay attention to it.

COUNTERMEASURES

Ground shaking and subsequent shaking of a structure affect the nonstructural elements inside, or attached to, that structure mainly in two ways: (1) their uncontrolled movement (swaying, sliding, toppling, falling) and (2) their response to the distortion of the structure to which they are attached (breaking or falling off). Consequently, the degree of danger depends much on how high these items are positioned, or how tall they are, or how well they are secured in their position. Of course, the bigger or heavier they are, the greater may be their vulnerability and danger potential.

When items are fragile, are resting by gravity without restraint, and are not firmly attached, they can break and/or fall and be damaged, cause damage, or injure people.

The following presents some practical examples of nonstructural hazards and inexpensive countermeasures that could be taken to reduce nonstructural earthquake damage. The illustrations are taken with permission from a booklet published by the Bay Area Regional Earthquake Preparedness Project (BAREPP, 1985). BAREPP is a joint project of the California Seismic Safety Commission and the Federal Emergency Management Agency. The included cost estimates are to be considered rough guides and do not include architecture or engineering services that may be needed to perform certain countermeasures.

Homes

A good way to prepare for potential earthquakes is for all of us to take action to safeguard our homes. Simple measures such as securing water heaters and exposed fuel tanks can go a long way toward reducing damage and inconvenience (Figure 2).

Offices

In general, items that are loose and detached (Figure 3), items that are tall and otherwise "tippy" (Figures 4 and 5), and items that are suspended (Figures 6 and 7) are vulnerable and potentially dangerous. Chairs, desks, and tables are comparatively stable, whereas bookcases and file cabinets fall over easily.

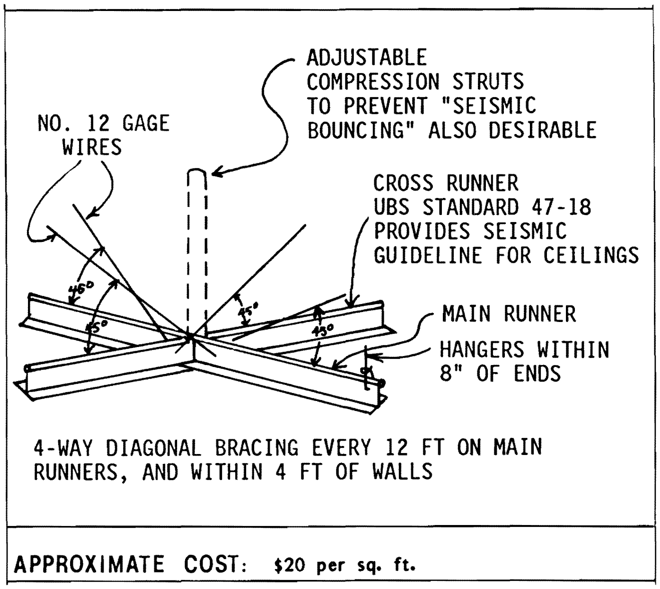

Figure 6. Suspended ceilings, vulnerable from distortion of the support grid and from "bouncing" up and down, can be secured with additional hanging wires and compression struts.

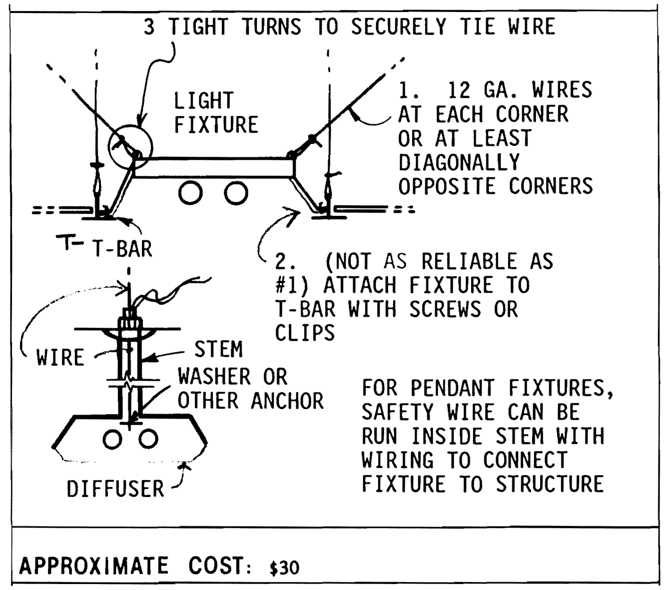

Figure 7. Hanging light fixtures can be made safer with additional wires or anchoring to keep them from swaying and with reinforced suspension to keep them from falling.

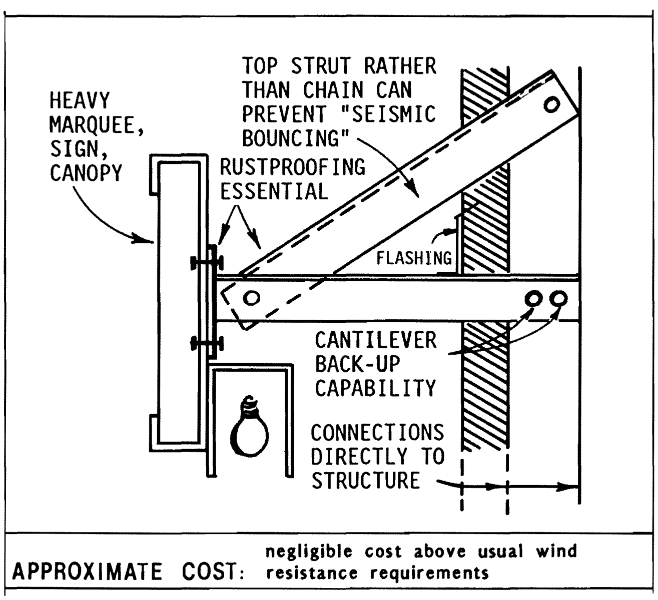

Figure 8. On exterior attachments to a structure, not only strength and rigidity of support but also protection against weakening by rust are important.

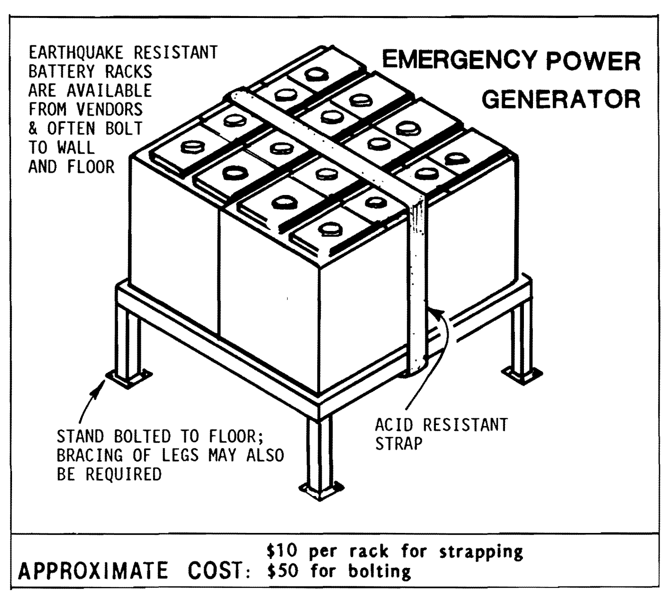

Figure 9. In emergency power equipment, one of the greatest hazards is the sliding of batteries, which may disrupt the entire system. Attach battery racks to floor and strap batteries into racks; add adequate anchorage to generator.

Commercial and industrial

Often stores and factories have significant amounts of glass such as large windows or skylights that present hazards. Addition of tinted solar film, use of laminated glass, or reducing window size are possible countermeasures. Suspended signs or marquees are often quite vulnerable (Figure 8). Shaking can cause items stored on shelves to fall. Simple restraints or similar devices can lessen the risk of these occurrences.

Lights, wires, and equipment can all be vulnerable and dangerous. Those areas where machinery and heavy equipment are used can be made safer by adequate anchoring or bracing of the equipment. Particular care should be taken in securing emergency power supplies (Figure 9).

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(See literature note on page 135.) □

Preliminary assessment of potential strong earthquake ground shaking in the Portland, Oregon, metropolitan area

by Ivan G. Wong and Walter J. Silva, Woodward-Clyde Consultants, Oakland, California 94607, and Ian P. Madin, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97201

ABSTRACT

Strong ground shaking resulting from possible moderate- to large-magnitude earthquakes near the Portland metropolitan area has been estimated deterministically for the soil site of the new State Office Building based on a state-of-the-art ground motion methodology. The earthquakes considered were three crustal events of magnitude (M) 5.5, 6.0, and 6.5 located at an epicentral distance of 10.0 km and a focal depth of 10.0 km and a M 8.0 Cascadia subduction zone event located at a closest distance of 73 km. Region-specific information on crustal structure and seismic attenuation and a detailed but preliminary geologic profile of the site were used in the ground motion estimates. The estimated peak ground accelerations ranged from 0.17 to 0.32 *g* for the crustal earthquakes and 0.20 *g* for the M 8 Cascadia earthquake. Acceleration response spectra estimated for the site for these events were compared with Uniform Building Code (UBC) design spectra; all but the M 5.5 crustal earthquake exceed the currently recommended UBC zone 2B spectrum. This comparison, however, should be viewed in the context of two critical assumptions made in the study: (1) the chosen epicentral distance and focal depth of the crustal earthquakes and (2) the choice of magnitude for the Cascadia event. Existing geologic and seismologic data cannot preclude the possibility of a crustal earthquake occurring closer to Portland nor a subduction zone earthquake significantly larger than M 8. Thus given the extensive unconsolidated sediments in the Willamette Valley and the possible future occurrence of earthquakes of M 6 and larger, strong earthquake ground shaking would appear to pose a potential serious threat to many existing buildings and possibly even to newly constructed buildings in the Portland metropolitan area.

INTRODUCTION

Recent geologic and seismologic studies indicate that the Pacific Northwest may be subjected to a significant level of seismic hazard in contrast to what has been experienced in historic times (Noson and others, 1988; Weaver and Shedlock, 1989; Madin, 1989). This is particularly true for the Portland metropolitan area, which has had only two damaging earthquakes, a M 5+ in October 1877 and a M 5.1 on November 5, 1962. Potential sources of strong earthquake ground shaking in the Pacific Northwest include (Noson and others, 1988; Weaver and Shedlock, 1989) (Figure 1): (1) the possible occurrence of a great earthquake (M ≥8) occurring along the Cascadia subduction zone; (2) a relatively deep intraplate event occurring within the subducted Juan de Fuca plate similar to the 1949 Olympia (M 7.1) and the 1965 Seattle-Tacoma (M 6.5) earthquakes; and (3) a shallow crustal earthquake in the North American plate such as the 1872 North Cascades (M 7.3) and the 1877 and 1962 Portland earthquakes (see Madin [1989] for schematic illustration of potential earthquake sources).

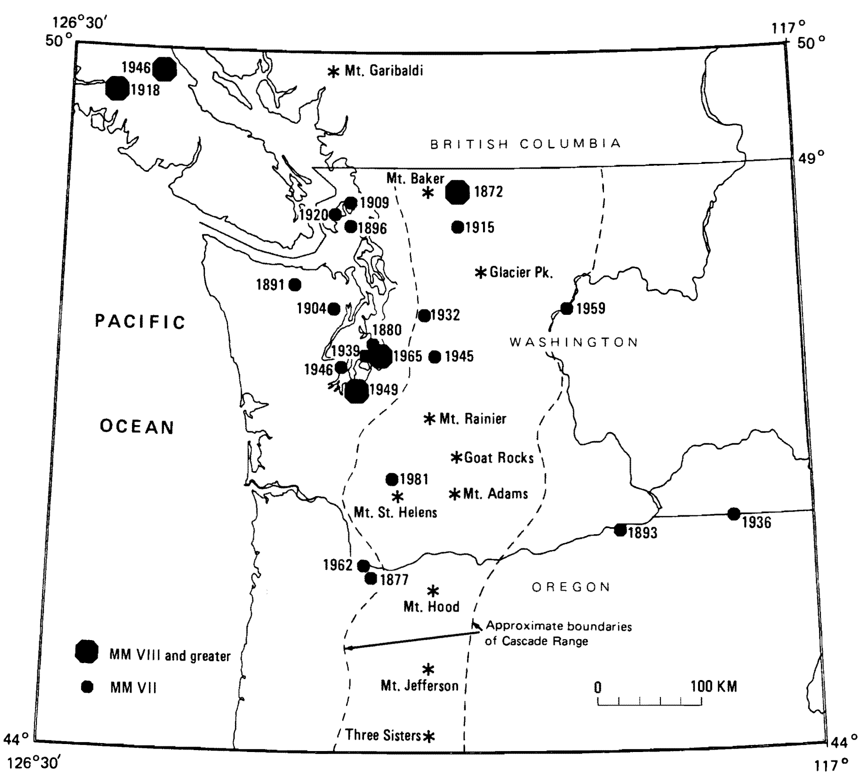

Figure 1. Largest historical earthquakes (Modified Mercalli [MM] VII and greater) of the Pacific Northwest, 1872-1987 (from Noson and others, 1988). Also shown are the principal Cascade volcanoes.

A critical element in the estimation of strong ground motions for the Portland area, as well as other areas in the Pacific Northwest, is to account for the effects of the near-surface geology. It has long been recognized that near-surface unconsolidated sediments and structure can significantly influence, if not dominate, the characteristics of strong ground shaking. Soft cohesionless soils up to 50 m thick are widespread in the Portland metropolitan area (Madin, 1989).

Previous studies of strong ground motion in the Pacific Northwest have focused on either the deep intraplate earthquakes or the Cascadia subduction zone event in the Puget Sound region. Site-specific studies, in particular for a local crustal earthquake in the Portland area, have not been performed to date (Madin, 1989). In the following paper, we describe deterministic estimates of site-specific peak ground accelerations and acceleration response spectra recently determined for the site of the new State Office Building in northeast Portland for four earthquake sources: (1) crustal earthquakes of M (moment magnitude) 5.5, 6.0, and 6.5 located at epicentral distances of 10.0 km from the site and focal depths of 10.0 km; and (2) a Cascadia subduction zone event of M (moment magnitude) 8.0 with the postulated rupture plane located at a closest distance of 73 km. (A response spectrum depicts the peak response of a series of simple harmonic oscillators of different natural periods when subjected to earthquake ground motion. Such a representation has direct engineering relevance because a simple harmonic oscillator with the appropriate natural period can be used as a model for a structure.)

METHODOLOGY

The methodology employed in this study is a state-of-the-art approach combining the Band-Limited-White-Noise (BLWN) earthquake source model with random vibration theory (RVT). This approach has been remarkably successful in predicting the peak ground motions as well as spectral values in different tectonic regimes (Hanks and McGuire, 1981; Boore, 1983; Boore and Atkinson, 1987; Silva and Darragh, 1990). This ground motion model appears to capture well the essential aspects of the earthquake source and one-dimensional rock site effects upon the spectral content of strong ground motions.

The simple BLWN-RVT model also represents a useful analytical tool to approximate site effects on strong ground motion. The effects of unconsolidated sediments upon strong ground motion have been well documented and studied analytically for many years. Results of these studies and other observations have shown that during both small and large earthquakes, surface soil motion can differ in significant and predictable ways from that on adjacent rock outcrops. An additional advantage of the methodology is the ability to address non-linear soil response by using RVT in an equivalent-linear formulation. A detailed description of the methodology is contained in Silva and others (1990).

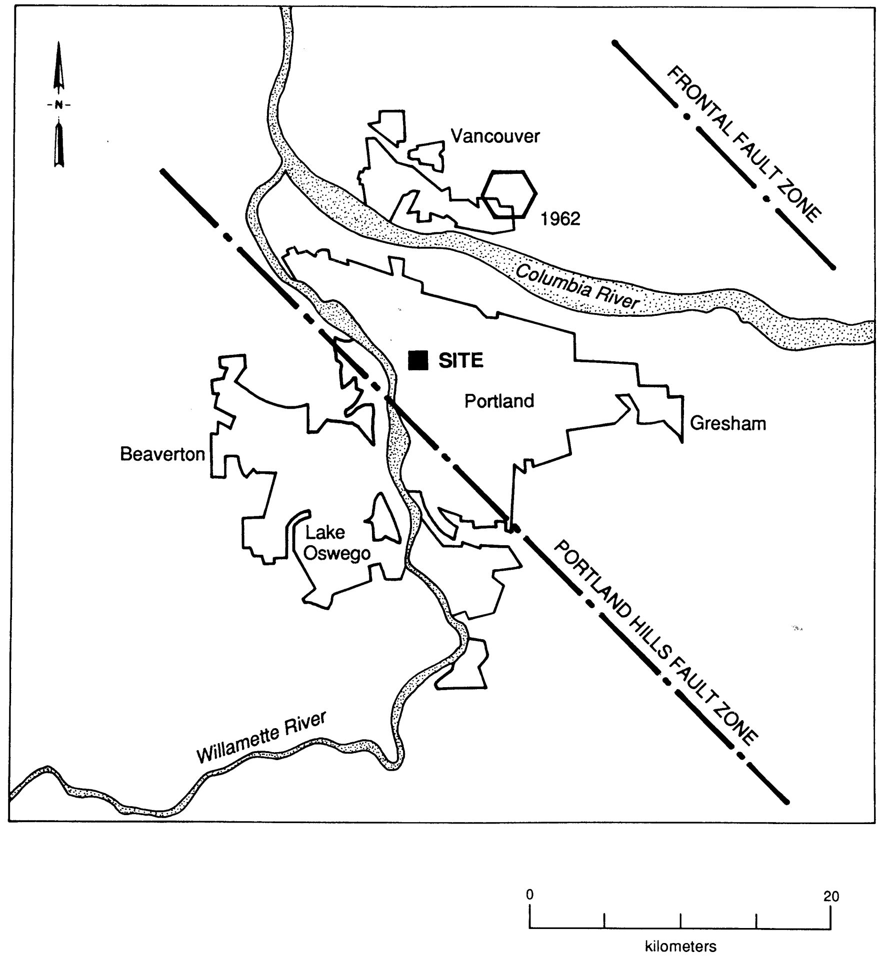

Figure 2. Map of the Portland metropolitan area showing the site of the new State Office Building. Also shown are the Portland Hills and the Frontal fault zones and the epicenter of 1962 earthquake as depicted by Yelin and Patton (1990).

INPUT PARAMETERS

For the estimation of strong ground motions, a characterization of the earthquake source, propagation path, and site geology parameters is required.

Earthquake source

A subduction zone earthquake of M ≥8 or a crustal earthquake of M 5.5 to 6.5 are assumed to dictate seismic design in the Portland area. Considerable uncertainty, however, is associated with the upper-bound value of M 6.5 for the crustal earthquake. Although the largest known earthquake in the Portland area is only approximately M 5+, crustal earthquakes as large as M 7 have occurred in the Pacific Northwest, as evidenced by the 1872 event (Figure 2). Grant and Weaver (1990) have similarly suggested that a M 6.2 to 6.8 is the expected maximum magnitude for an event on the St. Helens zone north of Mount St. Helens. Although the evidence does not exist to conclusively argue for or against the possibility of a M 6.5 earthquake to occur in the Portland metropolitan area, such an event was considered in the strong ground motion estimates to represent a conservative value. Certainly for critical facilities such as hospitals and schools, conservatism should be used both in design and in the seismic safety evaluation of such existing structures.

Although the source locations of such crustal earthquakes are not presently known, an epicentral distance of 10 km was assumed as a reasonable value to use for strong ground motion estimates. Two possible sources in the Portland metropolitan area that may be capable of generating moderate to large earthquakes include the presently aseismic Portland Hills fault zone and the microseismically active Frontal fault zone recently postulated by Yelin and Patton (1990) (Figure 2). The assumed 10-km depth represents the depth to the apparent top of the seismogenic portion of the crust, an assumption based on the distribution of microearthquakes in the Portland area (Yelin and Patton, 1990). The closest distance to the rupture zone is thus calculated at 14.1 km. A stress parameter of 50 bars was assumed for all three crustal earthquakes. This value is typical for western U.S. earthquakes compared to 100 bars for eastern U.S. events (Boore and Atkinson, 1987).

The M 8.0 Cascadia earthquake was assumed to occur at a rupture distance of 73 km, which is based on an epicentral distance of 61 km and a depth of 40 km to the eastern edge of the postulated rupture zone along the interface, as proposed by Somerville and others (1989). A stress parameter of 50 bars was also assumed for the subduction earthquake. Boore (1986) observed that such a value gave a good fit to matching the peak accelerations and velocities of 19 earthquakes ranging from M 6.5 to 9.5, of which the majority were subduction zone earthquakes.

Propagation path

For the propagation path between the crustal earthquakes and the site, a crust characterized by a shear-wave velocity (V_s) of 3.5 km/sec and a density (ρ) of 2.7 g/cm^3 was assumed based on a crustal velocity model for the Cascades (Qamar and others, 1987). To describe the frequency-dependent attenuation in the crust, $Q(f) = Q_o f^\eta$, the coda Q_o of 200 and η of 0.35, based on Singh and Herrmann (1983), were assumed.

The propagation path of the subduction zone earthquake was assigned a V_s of 3.5 km/sec, a ρ of 2.7 g/cm^3, and a constant Q_o of 3,000. The latter value was based on a parametric analysis of the attenuation relationship proposed by Youngs and others (1988) for large subduction zone earthquakes.

Site

The top 28 m of the geologic profile beneath the site was developed based on an exploratory borehole and a downhole V_S survey performed at the site (Figure 3). Layer thicknesses beneath 28 m were estimated on the basis of other available borehole data in the Portland area. V_S values for the lower Troutdale Formation and the Columbia River basalt were based on a downhole V_S survey performed near the existing State Office Building in southwestern Portland. The *P*-wave velocities from a seismic refraction survey (Nazy, 1987) and an assumed Poisson's ratio of 0.30 were used to estimate the V_S for the mudstone. Although considerable uncertainty is involved in such an approach, this value was used in lieu of better information that is currently unavailable. The V_S for the Eocene sediments was based on downhole *P*-wave measurements (also a Poisson's ratio of 0.30) in several deep exploration boreholes in the Portland area (Jack Meyer, Northwest Natural Gas, personal communication, 1990). In general, this geologic profile must be considered to be only a first-order approximation of the actual structure beneath the site because of the possibly large uncertainties in the individual layer velocities as well as in the assumptions that were required on the layer thicknesses (Figure 3).

DEPTH (m)	GEOLOGY	V_S (m/sec)	ρ (g/cm³)	Q_S
	Flood Silts	204	1.84	10
9	Troutdale Formation (cobbly, pebbley, gravel)	421	2.00	10
28		768	2.00	10
107±30	Sandy River Mudstone	817	2.40	15
229 ±46	Columbia River Basalt	1220	2.8	27
686	Eocene Sedimentary Rock	1304	2.70	20

Figure 3. Geologic profile beneath the site of the new State Office Building.

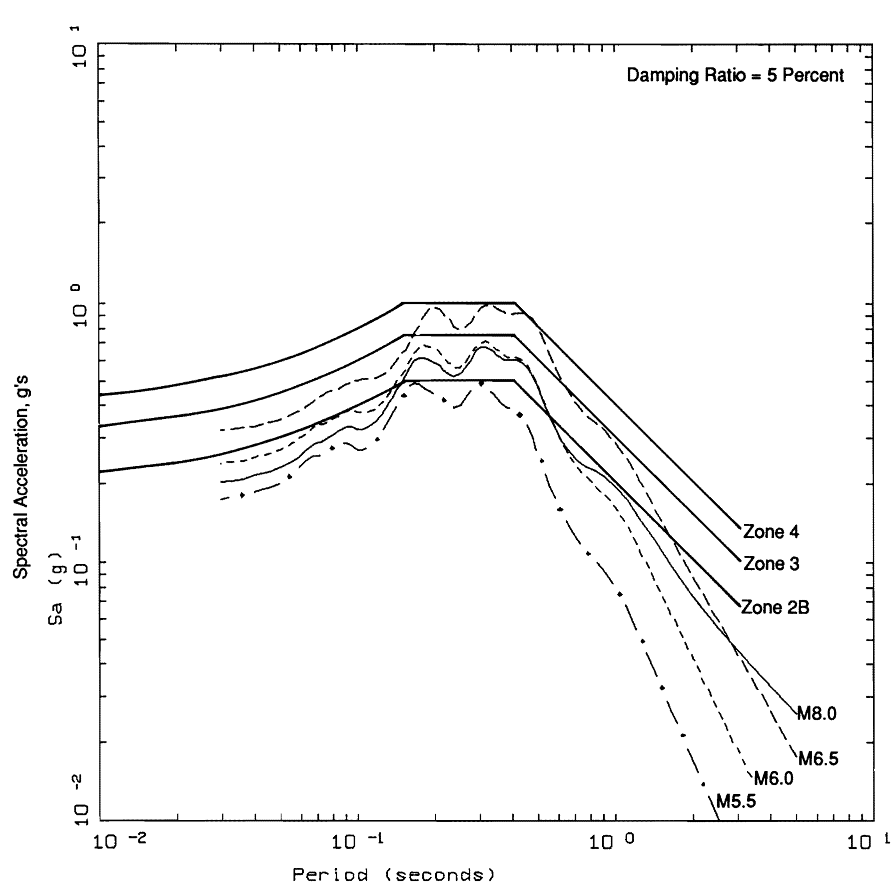

Figure 4. Comparison of the site-specific acceleration response spectra of the four modeled earthquakes and the UBC design response spectra. Zone 2B represents the currently recommended design spectrum for the Portland metropolitan area.

To incorporate the increase in the amplitudes of the seismic waves due to the velocity gradient in the upper crust beneath the geologic profile, Boore's (1986) amplification factors for the western U.S. were also utilized. Estimated densities and shear-wave values of *Q* were also assigned to each layer in the profile. Modulus reduction and damping curves for sand and gravel (Silva and others, 1990) were used to characterize the dynamic properties of the unconsolidated sediments.

RESULTS AND DISCUSSION

The 5 percent damped acceleration response spectra for the site of the new State Office Building, based on the BLWN-RVT methodology, are shown in Figure 4 for the four earthquakes. The spectral shapes are similar for all four events, reflecting the influence of the site geology with only a slight shift to shorter periods (or higher frequencies) as the magnitude decreases due to the corresponding increase in the source corner frequency. The peak horizontal accelerations are 0.17, 0.23, and 0.32 *g* for the M 5.5, 6.0, and 6.5 crustal earthquakes, respectively (Table 1 also lists the peak horizontal velocities). The peak horizontal acceleration for the M 8 Cascadia earthquake is 0.20 *g* at the ground surface and 0.14 *g* for the site without the unconsolidated sediments (equivalent to a rock site) (Table 1). Thus the sediments appear to amplify the ground motions by a factor of 1.4. These strong ground motion estimates probably have a standard error corresponding to a factor of at least 1.5, especially in view of the possible uncertainties in the geologic profile.

A comparison of the Cascadia M 8 and crustal earthquakes shows that the M 6.5 earthquake provides the largest ground motions out to a period of approximately 3.0 sec (Figure 4). The subduction zone event does not become significant in terms of spectral acceleration until a M 6.0 crustal earthquake is being considered at periods greater than 0.50 sec or frequencies less than 2 Hz. However, a significant factor not considered in this study and relevant to engineered structures is the duration of strong ground shaking. The duration of shaking from the Cascadia M 8 event will be significantly longer than the shaking from a crustal M 6.5 earthquake and, hence, potentially far more damaging to certain structures.

Comparison of the site-specific acceleration response spectra with Uniform Building Code (UBC) zones 2B, 3, and 4 design spectra for a type 1 (rock and stiff soils) site is also shown in Figure 4. Three of the four response spectra exceed the currently recommended zone 2B spectrum, and the M 6.5 crustal earthquake spectra exceed the zone 3 spectrum at periods of approximately 0.2 to 0.6 sec. Preliminary acceleration response spectra for the existing State Office Building in southwest Portland and a hypothetical site in the Portland Hills from a M 6.5 crustal earthquake at a distance of 12 km also exceed the UBC zone 2B response spectrum at periods of engineering concern. Although the UBC spectra are probabilistic (based on a 10 percent chance of exceedance in 50 years), and the site-specific response spectra presented here are deterministic (based upon current thoughts on the recurrence of crustal earthquakes and possibly the Cascadia event in the Pacific Northwest), zone 2B appears to underestimate the level of potential strong ground shaking that may affect much of the Portland metropolitan area. This is especially the case since the possibility exists that a crustal earthquake could occur closer to areas in Portland than the assumed 12 to 14 km (Figure 2) and that a Cascadia earthquake could well be larger than M 8 (Noson and others, 1988; Weaver and Shedlock, 1989). Additionally, the UBC does not directly account for the duration of strong ground shaking, which may be significant in a M 8 or greater Cascadia earthquake.

Table 1. *Peak horizontal accelerations and velocities for the site*

Earthquake	Distance (km)	PHA (g)*	PHV (cm/sec)
Crustal M 5.5	14.1	0.17	9.42
Crustal M 6.0	14.1	0.23	15.31
Crustal M 6.5	14.1	0.32	24.26
Cascadia M 8.0	73	0.20	16.01

* g is the acceleration due to gravity at the earth's surface and is equal to 980 cm/sec^2.

CONCLUSIONS

The growing body of geologic and seismologic evidence suggests that a previously unrecognized level of seismic hazard may exist in the Portland metropolitan area. Despite the perceived infrequent occurrence of damaging earthquakes, the present assignment of the UBC zone 2B to the Portland area probably underestimates this hazard. Because of the wide variability in unconsolidated sediments in the Portland metropolitan area, further site-specific estimates of potential strong earthquake ground motions will be required to fully characterize the range of possible ground shaking during future moderate to large earthquakes. Such estimates can eventually lead to maps depicting the relative ground shaking hazard that can be used by government agencies, the engineering and planning communities, and the public at large for hazard mitigation.

ACKNOWLEDGEMENTS

We wish to thank Geotechnical Resources, Inc., and in particular Dave Driscoll, for the support of this study. Tom Yelin, U.S. Geological Survey, kindly provided figures prior to publication. We extend our thanks also to Jack Meyer, Northwest Natural Gas, for his invaluable assistance in developing the geologic profile. The assistance of Doug Wright, Cathy Stark, and Laly Flores-Wong is greatly appreciated. We thank Michael Hagerty, Mark Hemphill-Haley, Bob Green, and especially Bill Joyner for providing critical reviews.

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Correction

With apologies, we must report that some computer goblin gobbled up two numbers in the last issue of *Oregon Geology* (Volume 52, Number 5, September 1990): On page 115, in Table 1 of W.E. Scott's paper in connection with the field trip guide to the central Cascades, the ages given with eruptive products of "Mount Bachelor summit cone and shield" and "Red Crater tephra and lava flows" should both read "12,000-18,000 B.P." We suggest to our readers that they enter this correction in their own copies. □

New geologic maps describe parts of southeastern and southwestern Oregon

New geologic maps that describe in detail the geology and natural-resource potential of portions of the Owyhee region in eastern Oregon and the Coast Range in southwestern Oregon have been released by the Oregon Department of Geology and Mineral Industries (DOGAMI).

Geology and Mineral Resources Map of the Sheaville Quadrangle, Malheur County, Oregon, and Owyhee County, Idaho, by Norman S. MacLeod. DOGAMI Geological Map Series GMS-64, 2 plates (One two-color geologic map, scale 1:24,000, and one sheet containing tables of geochemical data), $4.

Geology and Mineral Resources Map of the Mahogany Gap Quadrangle, Malheur County, Oregon, by Norman S. MacLeod. DOGAMI Geological Map Series GMS-65, one two-color geologic map, scale 1:24,000, $4.

The two 7½-minute quadrangles, located side by side between Lake Owyhee and the Idaho border, cover an area that includes Sheaville and the southeastern flank of Mahogany Mountain. The region has experienced extensive exploration for gold and silver during the last decade. Significant discoveries of gold prospects have been made in areas north of the two quadrangles, and similar geologic conditions extend south into both of the newly mapped quadrangles. Nonmetallic resources identified in the area include zeolites, diatomite, blue agate, and jasper.

The geologic maps show rock units and faults of the area and locations of the samples taken. The descriptive text that is printed on the approximately 40- by 27-inch map sheets includes discussions of geology, structure, and mineral and water resources. Each map also includes geologic cross sections and two tables showing results of whole-rock and trace-element analyses of samples.

Geologic Map of the Reston Quadrangle, Douglas County, Oregon, by DOGAMI geologist G.L. Black, Geological Map Series GMS-68. One two-color geologic map, scale 1:24,000, and a four-page text discussing geologic history and hydrocarbon potential, $5.

This map describes in detail the geology and oil and gas potential of the Reston Quadrangle in the Tyee Basin in southwestern Oregon. The 7½-minute quadrangle covers an area just west of Roseburg in Douglas County and centers on Reston Ridge and the Flournoy Valley. The general geology of the quadrangle, the occurrence of natural gas seeps, and the fact that coal was mined here in the early years of this century suggest that the area might have some source rock potential for oil or gas. In addition to the completed mapping, however, more analytic studies are needed for a more definitive assessment.

The Tyee Basin study project examines the oil, gas, and coal potential of a 4,000-mi^2 area in the southern Coast Range. The project is funded by a consortium of nine corporations or agencies from private industry and federal, state, and county government and has now completed year two of the planned five-year investigation. The new map represents a significant step toward accomplishing a major goal of the project: to resolve some of the stratigraphic problems the area presents.

The map of the Reston Quadrangle shows the distribution of the approximately 50-million-year-old sedimentary rocks that dominate the geology of the area. The area's geology reflects a history of volcanic activity, sedimentary deposition, and sometimes intense deformation and faulting during times when the region was at or near the edge of the continent.

The new maps are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5528. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

Helpful earthquake literature available

In addition to the literature mentioned in W.M. Elliott's article on pages 127-130 of this issue, two new sources provide information on earthquakes and earthquake preparedness and are called to our readers' attention:

1. *Sunset Magazine* has published a "Guide to help you prepare for the next quake" in the 1990 issues of October (p. 163-177) and November (p. 132-137). Obviously, the title addresses Californians in the first place and refers to last year's Loma Prieta earthquake, in which San Francisco was hit hard. But the article quite correctly points out that much of the West has an earthquake history or geologic conditions similar to California.

The October part of the article deals with the question of "How to secure your house and possessions," the November part with "How to secure your family and your neighborhood . . . and what to do during and after a big quake."

The publishers invite you to send requests for reprints in large quantities (100 or more, at a price of 50 to 75 cents each) to Sunset Quake '90 Reprints, Sunset Publishing Corporation, 80 Willow Road, Menlo Park, CA 94025.

2. A 24-page, colorful tabloid was prepared by the U.S. Geological Survey in cooperation with numerous California agencies and such national organizations as the Red Cross, United Way, the Earthquake Engineering Institute, the Federal Emergency Management Agency, and the Applied Technology Council. The title of the brochure says: "The next big earthquake in the Bay area may come sooner than you think. Are you prepared?"

This document was distributed originally in California newspapers, but it is still available to the public and very useful anywhere. It is currently in its second printing, since of the three million copies of the first printing, all that remained was a waiting list with unfilled requests for 200,000 more copies.

The richly illustrated tabloid addresses all major aspects of what one should know about earthquakes and the likelihood of future ones. It gives advice about preparing for the next quake and about measures to reduce the risk of earthquake damage. It also contains extensive assorted lists of materials and addresses for obtaining further information. It is available in English, Spanish, Chinese, and Braille and in recordings for the blind from Earthquakes, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025. □

USGS open-files Oregon quadrangle maps

Preliminary geologic maps of three Oregon 7½-minute quadrangles have been released recently by the U.S. Geological Survey (USGS) as open-file reports.

OFR 90-202: Nestucca Bay Quad., Tillamook Co., $3.25.
OFR 90-312: Dooley Mountain Quad., Baker Co., $7.
OFR 90-413: Neskowin Quad., Lincoln/Tillamook Co., $3.25.

The maps are available from U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. The prices mentioned are for paper copies. □

New Youngquist book available

Mineral Resources and the Destinies of Nations, by Walter Youngquist. Hardcover, 280 p., $17.95. Available through bookstores or from the publisher, National Book Company, P.O. Box 8795, Portland, OR 97207-8795, phone (503) 228-6345.

Youngquist shows how minerals, at all times, have had a decisive influence on the fates of individuals, nations, and civilizations. The author looks at the various hard-mineral and energy-mineral resources and their uses and leads to the resource questions that will shape our future. The book includes a bibliography and an index and should be of particular interest to government and industry planners, economists, sociologists, and political scientists. □

ABSTRACTS OF PAPERS

The following abstracts are of selected papers presented at the 1990 meeting of the Cordilleran Section of the Geological Society of America (GSA) in March in Tucson, Arizona. They were published in the GSA Abstracts with Programs, v. 22, no. 3, p. 16, and are reproduced here with permission. The sequence here is geographical, leading counterclockwise around Oregon, from the southwest to the central coast.

A NEWLY-RECOGNIZED DUCTILE SHEAR ZONE IN THE NORTHEASTERN KLAMATH MOUNTAINS, by M.M. Donato, U.S. Geological Survey, MS 910, 345 Middlefield Road, Menlo Park, California 94025.

A wide and laterally continuous ductile shear zone in southwestern Oregon marks a major lithologic contact between amphibolite-facies metasedimentary rocks of the May Creek Schist (MCS) and structurally underlying amphibolites. Kinematic analysis reveals the sense of movement on the shear zone and provides constraints on the accretionary geometry of the region.

The shear zone trends generally east-west and has been traced approximately 15 km along strike. Its thickness is estimated at two locations as 800 m and 1,500 m. Metaserpentinite bodies within the shear zone were probably tectonically emplaced during deformation. The shear zone was also the locus of intrusion of quartz diorite bodies which display textural evidence of solid-state deformation.

Petrographic criteria, including S-C fabrics and rotated porphyroblasts in semipelitic schists and quartzofeldspathic gneisses, indicate northwestward thrusting (present-day geographic framework) of the metasedimentary rocks over the underlying amphibolites. Quartz petrofabric analyses of 8 of 12 samples within the zone consistently demonstrate top-to-the-northwest sense of shear. Four other samples displayed strong lattice preferred orientation but did not yield shear sense information.

Although the metamorphic age of the MCS and the age of thrusting are poorly constrained, field evidence suggests they predate the nearby undeformed 141-Ma White Rock pluton. Thus the shear zone may be a manifestation of convergence during the Nevadan orogeny, during which an incipient back-arc spreading center (represented by the amphibolites) and its sedimentary cover (MCS) were shortened by faulting.

Geochronologic studies to test this hypothesis are currently under way.

EVOLUTION OF PALEOGENE DEPOSITIONAL SYSTEMS, SOUTHWESTERN OREGON; RESPONSE TO CHANGING FARALLON-NORTH AMERICAN PLATE CONVERGENCE, by P.T. Ryberg, Department of Geology, Union College, Schenectady, New York 12308.

Major changes in sedimentary and structural style occur in Paleogene strata exposed along the southern margin of the Oregon Coast Range. Lithofacies of the early Tertiary Umpqua Group include submarine fan and slope facies (upper Roseburg Formation) which overlie Paleocene basaltic basement (Farallon Plate) rocks to the north. Fan-delta and shallow marine facies (Lookingglass Formation) overlie Franciscan-equivalent strata to the south along the flank of the Klamath Mountains. This depositional system prograded northwestward (actually westward, with paleomagnetic rotation restored) until about 52 Ma. Sandstones and conglomerates of the Roseburg and Lookingglass Formations were derived from recycled orogen and arc-continent collision source rocks in the Klamath Mountains. The structural style and syndepositional deformation of marine slope facies suggest sedimentation in an obliquely convergent subduction complex prior to 52 Ma.

Farallon-North America convergence velocity decreased markedly about 52-50 Ma, ending subduction at this location, as incoming seamounts on the Farallon Plate clogged the trench. In middle Eocene time, a new subduction zone began in a more outboard position. The older, inactive zone accreted to North America and became the site of a rapidly subsiding forearc basin. Flournoy-Tyee sediments comprising a sandy fluvial-deltaic-turbidite ramp depositional system overlapped the old suture and filled the basin from south to north (actually west-northwestward, with paleomagnetic rotation restored), fed by a much larger river system tapping more distal source areas, including the Idaho Batholith. The forearc basin was nearly filled by Narizian time, and the fluvial-deltaic depositional system represented by the coeval Payne Cliffs, Bateman, and Coaledo Formations records the maximum progradation westward across the basin. Coaledo deposition was affected by tectonically induced bathymetry changes offshore, causing local regression-transgression patterns, but these did not greatly affect more proximal fluvial facies. Compositional changes within the upper Coaledo and Payne Cliffs Formations signify the initial transitional onset of western Cascade volcanism by late Eocene time.

HYBRIDIZATION OF ENCLAVES IN THE GRAYBACK PLUTON, KLAMATH MOUNTAINS, SOUTHWEST OREGON, by K. Johnson, C.G. Barnes, M.A. Barnes, and B.L. Schmidt, Department of Geosciences, Texas Tech University, Lubbock, Texas 79409.

Enclave swarms in the Grayback Pluton commonly separate the main body of diorite/quartz diorite from later gabbroic intrusions. The enclaves are lensoid shaped and fine grained and are as much as 2.5 m in length. Two types of enclave are predominant: hypersthene-rich microgabbro and hornblende-quartz microdiorite. The microgabbro consists of plagioclase (>60 percent) with ubiquitous apatite inclusions and abundant pyroxene with minor hornblende rims. The microdiorite contains plagioclase, sparse pyroxene, prismatic hornblende (>50 percent), and interstitial quartz. The host consists of plagioclase (>50 percent), large poikilitic hornblende, minor pyroxene, ± quartz. Individual enclaves are oriented subparallel to the foliation in the host, suggesting a common flow direction. All enclaves display prominent igneous lamination parallel to the enclave/host contact. Field evidence suggests this may, in part, be due to compression acting perpendicular to flow. The compressive stress may have been applied when later gabbroic magmas were intruded nearby.

Enclave/host contacts are sharp, and the enclaves generally lack grain size variation near contacts. Many enclaves are cut by veins of host, some of which are now marked only by stringers of poikilitic hornblende. This suggests that the rest of the vein material was either squeezed out of the vein by local compression or hybridized with the enclave. Some veins of the host diorite contain fragments torn from the enclave during vein formation. Field evidence suggests that chemical interaction between these enclaves and the host magma was accomplished in two ways: (1) diffusion-controlled exchange between veins of host in the enclave, introducing host material into the enclave, and (2) fragmentation of the enclave, introducing enclave material into the host.

LATE MIOCENE VOLCANISM IN THE INLAND PACIFIC NORTHWEST, by D.W. Hyndman, D. Alt, and J.W. Sears, Department of Geology, University of Montana, Missoula, Montana 59812.

Viewed in its entirety, the assemblage of late Miocene basalt and rhyolite in the Pacific Northwest comprises a single volcano of a type and scale hitherto unrecognized. Its development began about 17 million years ago, probably with impact of a large bolide in southeastern Oregon.

Collapse of the initial transient crater opened a basin probably more than 200 km in diameter and many kilometers deep. Pressure relief partial melting in the upper mantle would produce a column of basalt magma with a hydrostatic head proportional to the depth of the basin. The deeper the basin, the deeper partial melting penetrates, and the higher the magma buoyancy will raise the top of the magma column. The crater basin filled with magma to become a lava lake which periodically erupted basalts that flooded nearby lowlands in Oregon, northeastern California, western Idaho, and eastern Washington. Each major eruption would unload the top of the magma column, prompting further pressure relief melting at depth.

Such a deep lava lake would melt crustal rocks and differentiate into coexisting felsic and basaltic components. Basalt plateaus typically contain felsic rocks which include granophyric rhyolites. Felsic magmas erupted as superhot rhyolites in southeastern Oregon and nearby areas of Nevada and southwestern Idaho. Their greater viscosity confined them to the region of the lava lake, thus identifying the site of the impact.

Volcanic activity ended at the impact site after about two million years, but volcanism over the hot spot has since generated the giant rhyolite calderas of the Snake River Plain. Hot-spot volcanism continues in the Yellowstone volcano. Basin and Range volcanism continues to generate basalt and rhyolite in large parts of the region.

STRATIGRAPHY, STRUCTURE, AND MINERALIZATION OF THE DEER BUTTE FORMATION, WEST OF LAKE OWYHEE, MALHEUR COUNTY, OREGON, by M. L. Cummings, Department of Geology, Portland State University, Portland, Oregon 97207.

Felsic volcaniclastic sediments and primary air-fall tuffs are interfingered with basalt palagonite tephra deposits, basalt flows, and rhyolitic flow-dome complexes in the Deer Butte Formation of Miocene age. Geologic mapping in The Elbow, Twin Springs, and Hurley Flat Quadrangles showS formation of successive volcanic-sedimentary basins that become smaller and younger to the east. The volcanic and sedimentary deposits in the older basins were faulted, uplifted, and eroded as successively younger basins were formed. Nonporphyritic to weakly porphyritic rhyolite flows and domes are the oldest deposits in the map area. Xenoliths of rhyolite occur in basalt palagonite tephra deposits for at least 8 km east of rhyolite outcrops, suggesting that rhyolite underlies the volcanic-sedimentary basins.

Hydrothermal systems developed concurrently with faulting and sedimentation. Within two stratigraphic sequences of the Deer Butte Formation, lacustrine sediments that were deposited after extensive basalt hydrovolcanism contain sediments that were altered near the time of deposition. These sediments contain anomalous concentrations of Au, Hg, As, Sb, W, and Mo. As the stratigraphy of the Deer Butte Formation evolved, faulting and uplift of older deposits within the Hurley Flat Quadrangle allowed erosion of hydrothermally altered clasts and transport in east-flowing streams into developing sedimentary basins in the east.

The stratigraphy of the Deer Butte Formation contains a record of sedimentation and volcanism within basins controlled by north-trending fault zones, uplift and erosion within areas of the older basins during the formation of younger basins, and concurrent hydrothermal activity.

SIGNIFICANT DISCOVERIES DURING 1989 INVOLVING DIKES OF COLUMBIA RIVER BASALT IN PRE-TERTIARY ROCKS IN EASTERN OREGON AND WESTERN IDAHO, by W.H. Taubeneck, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331-5506.

The study area includes 6,000 mi^2 (15,540 km^2). Much field work remains.

Four major eruptive axes occur south of an east-west zone (canyon of Powder River along Highway 86 is included) of few dikes at about latitude 44°48′ N. From west in Oregon to east in Idaho, each of the four axes extends northward, passing in turn beyond the Amelia stock for 3.7 km, beyond the Pedro Mountain stock for 3.3 km, beyond the Big Lookout Mountain (BLM) stock for 0.3 km, and beyond the Iron Mountain stock in Idaho for 24 km. Dike distribution in relation to the four stocks, as well as elsewhere in Oregon for the Little Lookout Mountain stock, the Wallowa batholith (WB), and the Bald Mountain batholith, suggests that all axes of dike eruptions were appreciably constrained geographically in longitude by the location of stocks and batholiths.

The highest dike densities are along the four aforementioned eruptive axes rather than in WB as is commonly believed. Some areas contain more than 30 dikes per mi^2. Major sources of Grande Ronde Basalt and Imnaha Basalt are south of latitude 44°48′N. Scores and scores of Grande Ronde feeders are more than 13 m thick, whereas two Imnaha feeders are 23 and 24 m thick.

The best examples of partial melted wall rocks are within 4 km of BLM and in the western two-thirds of the WB. Field relations indicate turbulent flow. Crustal xenoliths are more abundant than is commonly believed but nowhere on the scale of those in the WB, where a few dikes contain more than 200,000 xenoliths. Many dikes in WB contain between 25 and 100,000 xenoliths.

The attitudes of dikes in granitic rocks rather commonly are controlled by joint patterns.

GEOCHEMISTRY OF FERRUGINOUS BAUXITE DEVELOPED FROM COLUMBIA RIVER BASALT, SOUTHWESTERN WASHINGTON, by J.M. Fassio and M.L. Cummings, Department of Geology, Portland State University, Portland, Oregon 97207.

Ferruginous bauxite deposits are developed from flows of the Columbia River Basalt Group in northwestern Oregon and southwestern Washington. The geochemistry of samples of the pisolitic, gibbsite nodular, and fine-grained gibbsite zones from 9 m of drill core from Wahkiakum County in southwestern Washington have been analyzed by instrumental neutron activation. In this core, the upper 1 m is of the pisolitic zone, and the gibbsite nodular zone is 1.2 m thick. The thickness of the pisolitic zone ranges from 0.3 to 4.9 m in different cores from the area.

Within the fine-grained gibbsite zone, ratios of V, TiO_2, Cr, Co, Sc, Ta, and Hf to Fe_2O_3 are similar among samples from over 3 m of core. The Al_2O_3:Fe_2O_3 ratio increases in the same interval. In the gibbsite nodular and into the pisolitic zones, the ratios of Th, Ta, and Hf to Fe_2O_3 increase, and those of Co, Al_2O_3, and Sc to Fe_2O_3 decrease.

La:Lu ratios for basalt and the fine-grained gibbsite zone are consistent with preferential depletion of LREE (basalt = 33; gibbsite zone = 11-16). However, La:Lu ratios increase to 45 from the fine-grained gibbsite into the pisolitic zone. A positive Ce anomaly on chondrite-normalized plots is most pronounced in the gibbsite nodular zone.

Within the pisolitic zone, the order of enrichment of elements in iron-rich pisolites relative to bulk samples is Fe_2O_3 > Cr > Th, Hf > TiO_2, Eu, Ta; the order of depletion is Al_2O_3, La, Ce > Sm > Co, Sc > Lu.

The patterns in trace element abundances and ratios is believed consistent with changing climate conditions from continuously wet during formation of the bauxite profile to alternating wet and dry during formation of the pisolitic zone.

PLUTONISM AND HYDROTHERMAL MINERALIZATION ASSOCIATED WITH THE DETROIT STOCK, WESTERN CASCADES, OREGON, by J.M., Curless, M.W. Vaughan, and C.W. Field, Department of Geosciences, Oregon State University, Corvallis, OR 97331.

The Detroit Stock is a composite pluton (10 m.y.) that consists of at least five stages and intrudes volcanic rocks of early Miocene age in the Western Cascades of Oregon. Cross-cutting relationships exposed near Detroit Dam reveal the relative ages between five intrusive stages. Oldest to youngest, these are: (1) quartz diorite, (2) porphyritic hornblende quartz diorite, (3) porphyritic diorite, (4) porphyritic hornblende granodiorite, and (5) aplitic tonalite.

Intrusive rocks within the adjacent Sardine Creek and Rocky Top areas have mineralogical, textural, and chemical features similar to the nearby Detroit Stock. Early quartz diorites at Sardine Creek and Rocky Top are exposed as dikes with sharp to slightly brecciated contacts that were emplaced along preexisting northwest-trending fractures. Later hornblende granodiorites, with contacts defined by well-developed intrusive breccias, are exposed as irregularly shaped northwest elongate dikes and small stocks. Stratigraphic reconstruction from Sardine Creek to Rocky Top suggests that the later hornblende granodiorites were emplaced at a minimum depth of roughly 1.5 km, with the earlier quartz diorites intruding to shallower levels.

Propylitic alteration is widespread throughout the area and intensifies with proximity to northwest-trending fractures. Potassic alteration is limited to the Detroit Stock where several samples contain incipient veinlets and diffuse replacement zones of hydrothermal biotite. Late-stage quartz-sericite alteration is structurally controlled and overprints earlier propylitic and potassic alteration.

More than 80 rock-chip samples from the Detroit Stock, Sardine Creek, and Rocky Top areas were analyzed for Cu, Pb, Zn, and other trace metals. Threshold values were determined to be 80 ppm Cu, 50 ppm Pb, and 90 ppm Zn. The relative proportions of these metals in mineralized samples depict a progressive change with increasing horizontal and vertical distance from Cu (Zn) at the Detroit Stock, through Zn (Cu) at Sardine Creek, to Pb (Zn) at Rocky Top.

Although plutonism and hydrothermal mineralization associated with the Detroit Stock have many features in common with nearby mining districts of the Western Cascades, the absence of well-developed breccia pipes, through-going veins, and zones of intense pervasive alteration are consistent with the lack of extensive exploration and previous mining activity in this area.

GEOCHEMISTRY OF UPPER EOCENE BASALTS FROM THE OREGON COAST RANGE, by M.A. Barnes and C.G. Barnes, Department of Geosciences, Texas Tech University, Lubbock, Texas 79409.

The Yachats Basalt at Cascade Head is one of three volcanic centers in the Oregon Coast Range from which alkalic basalt was erupted in late Eocene time. At Cascade Head, the volcanic rocks are interbedded with thin-bedded, tuffaceous, brackish-water to marine siltstones of the Nestucca Formation. The volcanic sequence is 300 m to 600 m thick and marks the transition from submarine to subaerial eruption. Rhyolitic ash deposits are locally present.

The volcanic pile is dominated by mildly alkaline basaltic rocks with lesser hornblende trachyandesite. The suite is characterized by enrichments in high field strength elements (HFSE) and by steeply negative rare earth element (REE) patterns ($[La/Lu]_n$ = 15-20). Transition metal contents are low (Ni, 7-53 ppm; Cr, 5-86 ppm; Sc, 1-22 ppm), indicating that all of the lavas are differentiated. Spidergrams are typical of continental alkalic basalt in that they show K depletion and Nb and Ta enrichment. Most spidergrams also indicate the relative depletion of Sr and Ti. Spidergrams of interbedded rhyolitic ash are distinct from the basalt, are depleted in Nb, Ta, and Ti, and indicate an arc source. The mass-balance calculations and incompatible element ratios are consistent with differentiation from basalt to trachyandesite by fractional crystallization of olivine + clinopyroxene + plagioclase ± oxides ± apatite. The geologic and geochemical evidence is consistent with a forearc tectonic setting that was undergoing extension. □

And the winner is . . .

The response to our contest in the July issue of *Oregon Geology* was a pleasant surprise in many ways. We regret that we cannot answer each individual letter and postcard or print all the interesting extra comments. However, we thank all contestants most deeply for their participation.

Yes, the landmark on the July cover was indeed Sheep Rock—never mind that the name officially applies to 12 "summits" or "pillars" in Oregon! It is, of course, the relationship of this particular Sheep Rock with the John Day Fossil Beds National Monument that gives it a special place in the geology of Oregon—well, at least the paleontology of Oregon. And even if not all contestants could get the name quite right or determine that the view was "probably N. 5° E." or recognize the "sheep atop that funny spire," most of the participants in our contest in the July issue did identify the view correctly. In fact, among 45 valid entries there was only one that had to be disqualified as wrong.

And the winner of the free one-year subscription is—Larry Chitwood of Bend. Congratulations! Since Larry is already a faithful subscriber to *Oregon Geology*, his expiration date will be moved back one year.

Since quite a number of contestants said that they would like to see more such contests, we feel confirmed in our plan to continue the practice—at irregular intervals. We wish all our readers many opportunities to enjoy the visual pleasures that are such an essential part of Oregon's geology! □

NWMA announces convention

The Northwest Mining Association (NWMA) will hold its 96th Annual Convention, Short Course, and Trade Show on December 2-7, 1990, in Spokane, Washington, at the Sheraton-Spokane Hotel, Cavanaugh's Inn at the Park, Spokane Convention Center, and Agricultural/Trade Center.

The theme for this year's convention is "The 90's—Strength Through Balance." The program will consist of 22 technical and practical sessions and present more than 100 speakers on the most important topics of the mining industry. Special sessions and social events will offer additional opportunities to exchange ideas.

This year's short course is entitled "Drilling for Minerals—Management, Techniques, and Systems." The course will take place the first three days prior to the convention, December 2, 3, and 4. The cost of the course is $425.

For more information, contact Northwest Mining Association, 414 Peyton Building, Spokane, WA 99201, phone (509) 624-1158.

—*NWMA news release*

(***Oil and Gas,*** continued from page 122)

8) **Volcanic magnetic susceptibility and wet bulk density analyses of strata from the Texaco Federal no. 1 well, Crook County, and the Standard Oil Kirkpatrick no. 1 well, Gilliam County.** The study by Terra Exploration concludes that there is sufficient contrast between the volcanic rocks and underlying Cretaceous and older rocks to warrant the use of gravity data for mapping basement structures in the study area. However, the lack of contrast in the magnetic susceptibility of these rocks rules out the use of aeromagnetic data to map such structures.

Additional analyses are being done at this time and will be made available in the future. Other studies already completed are listed in DOGAMI's 1987 publication OGI-16, *Available Well Records and Samples of Onshore and Offshore Oil and Gas Exploration Wells in Oregon*, available at the DOGAMI Portland office (address on page 122 of this issue). Contact Dennis Olmstead or Dan Wermiel at DOGAMI if you are interested in reviewing any of these studies. □

SSPAC lays base for its work

The Seismic Safety Policy Advisory Commission (SSPAC) for Oregon was created by Governor's Executive Order earlier this year "to provide policy recommendations regarding the establishment of a statewide earthquake hazard reduction and emergency response program." The eight-member commission is composed of representatives from the Department of Geology and Mineral Industries, the Oregon State System of Higher Education, the Department of Human Resources, the Emergency Management Division, the Building Codes Agency, and, appointed by the Governor, one member of the legislative assembly, one person with expertise in structural engineering, and one person with expertise in building, contracting, or project development. The following is the mission statement the Commission has recently adopted:

"The mission of the Seismic Safety Policy Advisory Commission shall be to reduce exposure to earthquake hazards in Oregon by developing or influencing policy, facilitating improved public understanding, and encouraging identification of risk, implementation of appropriate mitigation, and preparation for response and recovery.

"The commission shall monitor and influence programs and policies at the federal, state, and local level to address Oregon's broad needs in terms of earthquake risk mitigation. Included are communication of Oregon's needs to federal programs, review of state legislative concepts related to earthquakes, and review of state and agency budget decision packages of program direction related to earthquakes. Also included is identification of program level oversights of earthquake related needs at the state program level.

"The commission shall utilize and influence existing agencies and institutions in meeting its goals and is in no way intended to replace or compete with existing authorities relative to earthquakes. Emphasis shall be on coordination and linking of existing resources and authorities.

"Policy areas of interest to the commission may include but not be limited to: earthquake risk data, building codes, land use plans, local government response, recovery, coordination, budgets, legislation, earthquake advice to policy makers, and public information." □

AEG elects Mavis D. Kent president

The Association of Engineering Geologists (AEG) has announced the election of new officers for 1990-1991. They are President Mavis D. Kent of Walnut Creek, California; Vice-President Stephen L. Garrison of Jessup, Maryland; Secretary Alvin L. Franks of Sacramento, California; and Treasurer Alan D. Tryhorn of San Francisco, California. The announcement was released during the 33rd annual AEG meeting held in Pittsburgh, Pennsylvania, October 1-5, 1990.

President Mavis D. Kent, a former Oregon resident and a graduate of Portland State University, is the first woman to be elected president of AEG. Kent, who served on the Oregon Board of Geologist Examiners during the early 1980's, stated that one of her goals will be to "remain committed to seeking the registration of geologists in all states." She plans to take action on specific concerns of AEG, including ethical practice in the environmental arena, a new editor for and a new category of technical publications, and enhanced computer utilization within AEG. She also noted that AEG has "sound prospects for growth and achievement" and will strive to retain AEG as the premier association to serve the special needs of the professional engineering geologist working in engineering, environmental, and ground water geology.

President Kent is employed as Senior Engineering Geologist by the California Water Quality Control Board for the San Francisco region in Oakland, California. She is completing her doctoral degree in geology at Texas A&M University. Ms. Kent is a Registered Geologist and Certified Engineering Geologist in California and Oregon.

The Association of Engineering Geologists was established in 1957 to aid public welfare in concerns of engineering geology and to promote engineering geology in the professions.

—*AEG news release*

Sweet Home club displays at Capitol

The Sweet Home Rock and Mineral Society is the current exhibitor for the display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem. The 55 specimens displayed were furnished by six members of the society and collected in 13 Oregon counties and will remain at the Capitol until January 15, 1991.

Sweet Home's own Linn County is represented by specimens of petrified wood, blue lace agate, an agate sphere, a frame of Holley Blue agate cabochons, two large crystal and three sagenite pieces, and six spectacular specimens of carnelian. The display also includes frames of cabochons of polka dot agate, thunder egg centers, petrified wood, and Carey Plume agate; slabs and rounds of petrified wood and bookends made from petrified wood; Biggs jasper; obsidian; Owyhee picture rock; spheres made from Lake County cinnabar and from petrified wood; and various pieces of jewelry made from Lincoln County beach agates and the State Gem, Oregon sunstone. —*OCRMC news release*

***(Field Trip**, continued from page 126)*

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MINERAL EXPLORATION ACTIVITY

MAJOR MINERAL-EXPLORATION ACTIVITY

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services, Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	Jessie Page Chevron Resources Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
May 1989	Hope Butte Chevron Resources Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App
June 1990	Racey Billiton Minerals USA	T. 13 S. R. 41 E. Malheur County	Gold	Expl
June 1990	Grouse Mountain Bond Gold Exploration, Inc.	T. 23 S. Rs. 1, 2 E. Lane County	Gold	Expl
June 1990	Freeze Western Mining Corporation	T. 23 S. R. 42 E. Malheur County	Gold	Expl
August 1990	Lava Project Battle Mountain Exploration	T. 29 S. R. 45 E. Malheur County	Gold	Expl
September 1990	Bourne Simplot Resources, Inc.	T. 8 S. R. 37 E. Baker County	Gold	App
September 1990	Baboon Creek Chemstar Lime, Inc.	T. 19 S. R. 38 E. Baker County	Lime-stone	App
September 1990	Prairie Diggings Western Gold Exploration and Mining Co.	T. 13 S. R. 32 E. Grant County	Gold	App
September 1990	Pine Creek Battle Mountain Exploration	T. 20 S. R. 34 E. Harney County	Gold	Expl
September 1990	Calavera NERCO Exploration Company	T. 21 S. R. 45 E. Malheur County	Gold	Expl
September 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E. Malheur County	Gold	Expl
September 1990	Mahogany Project Chevron Resources Company	T. 26 S. R. 46 E. Malheur County	Gold	App

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

Mining Issues Forum

Three state agencies, the Departments of Geology and Mineral Industries, Environmental Quality, and Fish and Wildlife, and two federal agencies, the Bureau of Land Mangement and the Forest Service, sponsored the Mining Issues Forum held September 8, 1990, in Bend.

The purpose of the forum was to provide an opportunity for dialogue on controversial and polarizing issues regarding precious-metal mining. The numerous excellent questions generated by the speakers showed that the purpose was fulfilled. Proceedings of the conference will be available soon, and copies will be sent to those who attended. Additional copies will be available at cost.

The program included the following panel discussions:

1. *Anatomy of a mine: Financial aspects of the industry*, with moderator Don Fordyce of U.S. National Bank and panelists from FMC Gold Company and NERCO Minerals Company.

2. *Economic and social effects of large-scale gold mining in Oregon*, with Dr. Bill Lee as moderator and panelists from US Bancorp, the Northern Plains Resource Council, and Pegasus Gold Corporation.

3. *Environmental issues*, investment advisor Dennis Hanson as moderator and with panelists from the Mineral Policy Center, the Nevada Wildlife Department, EIC Corporation, and the Coeur d'Alene Mines Corporation.

4. *The regulatory framework*, moderated by public policy consultant Jim Mann and with panelists from the U.S. Bureau of Land Management, the USDA Forest Service, and the U.S. Fish and Wildlife Service and the Oregon Departments of Geology and Mineral Industries, Environmental Quality, Water Resources, and Fish and Wildlife.

Proposed legislation

The Department is proposing legislation that will mandate an economic and environmental evaluation of all major metal mining facilities. Public participation in the evaluation process would be encouraged. Another proposal calls for the use of 1½-in. square wooden stakes as claim corner monuments and reduces the required number of stakes per claim.

Status changes

Eight new applications were received for exploration projects in August and September. The location and status of those applications is shown in the table above.

Questions or comments about exploration activities in Oregon should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office, 1534 SE Queen Avenue, Albany OR 97321, telephone (503) 967-2039. □

Index to *OREGON GEOLOGY*, volume 52, 1990

Numbers refer to volume and beginning page of entry. Most subject entries include cross-references to author entries (in parentheses).

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