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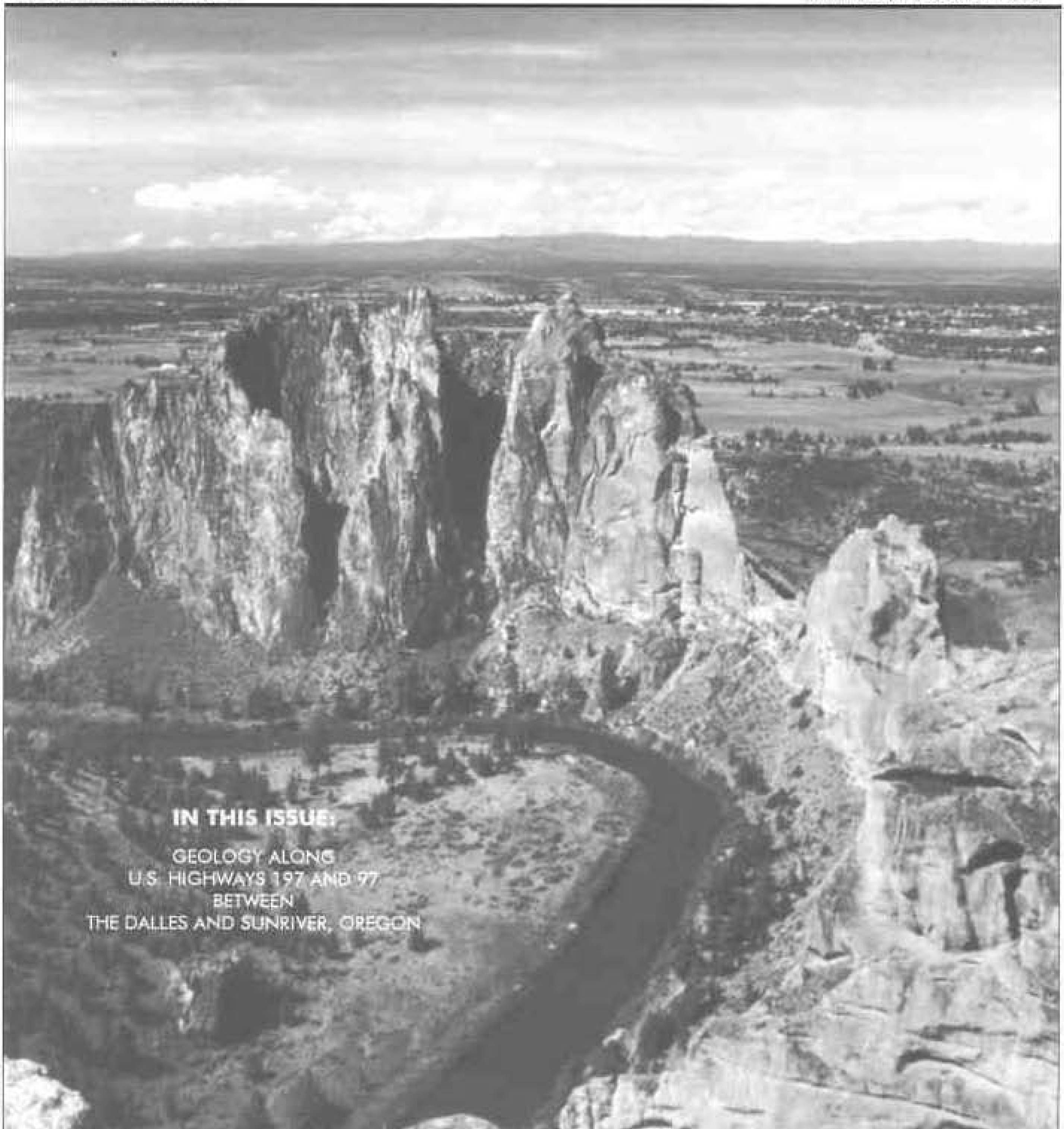

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*Oregon Geology* is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted. If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, high-density diskette only). Graphics should be camera ready; photographs should be black-and-white glossies. All figures should be clearly marked; figure captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS Suggestions to Authors, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Klaus Neuendorf, Editor, at the Portland office (address above).





**POSTMASTER:** Send address changes to Oregon Geology, Suite 965, 800 NE Oregon St. # 28, Portland, OR 97232-2162.


### Cover photo

View to the southwest at Smith Rock State Park. Crooked River flows between basalt lava, on left, and indurated tuff forming Smith Rock. Quarried cinder cones mark the Tetherow Butte volcanoes beyond Terrebonne in the middle ground. Cascade volcanoes are visible on the skyline. Article on geologic tour guide from The Dalles to Sunriver begins on next page.

## Barnett appointed to DOGAMI Governing Board

Arleen N. Barnett of Portland has been appointed by Governor John Kitzhaber and confirmed by the Oregon Senate for a four-year term beginning December 1, 1997, as Governing Board member of the Oregon Department of Geology and Mineral Industries (DOGAMI). Barnett succeeds John W. Stephens of Portland, who served two four-year terms on the Governing Board.

**Arleen N. Barnett**

Arleen Barnett is the Manager of the Human Resources Operations Department of Portland General Electric Company (PGE). She has been working with PGE since 1978, mostly in managing functions and predominantly in the area of Human Resources. She attended Pepperdine University and graduated from Abilene Christian University in Texas. She is married and has two teenaged children. She is on the Advisory Council of the Salvation Army Greenhouse and is active in the music ministry of her church.

In addition to Arleen Barnett, the three-member board includes Jacqueline G. Haggerty of Enterprise and Donald W. Christensen of Depoe Bay. □

## Correction

The index to last year's volume of *Oregon Geology*, published on page 150 of the last (November/December 1997) issue, contains some errors for which we apologize.

If you wish to correct your copy of the index, please note the following:

Under "Field trip guides," the page references for the two entries should be reversed.

Under "Mined land reclamation," the same applies to the first and third entry.

Under "Tsunamis," the page references for "Center for Tsunami Inundation Mapping . . ." and "Hazard signs adopted . . ." also should be reversed. □

# Geology along U.S. Highways 197 and 97 between The Dalles and Sunriver, Oregon

*by Gary Smith, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131*

This highway-geology guide was prepared for an as-yet unpublished travel brochure for the general public. We thank the author for his permission to print it here and for his help in adapting it to a different format. —*Ed.*

## Introduction

### A LAND BUILT BY VOLCANIC ERUPTIONS

The west coast of North America is referred to as an active continental margin. Large-scale geological processes involving horizontal motions of the outermost layers of the earth cause earthquakes, volcanic eruptions, and the uplift of mountains. Volcanoes are responsible for the formation of most of the rocks formed in Oregon over the past 45 million years. The rocks and landscapes that one sees while driving between The Dalles and Sunriver are nearly all related, in one fashion or another, to volcanism.

### TYPES OF VOLCANOES AND VOLCANIC ROCKS

(significant terms printed in **boldface**)

Volcanic rocks are solidified **magma**, molten material produced at depths of 75–150 km beneath the earth's surface. The chemical composition and physical properties of magma are variable, depending on the depth and temperature at which the rocks melt, the type of rocks that are melted, and the degree of solidification that occurs as the magma cools on the way to the surface. This variation produces a wide range of volcanic rocks and an equally varied array of landscape features resulting from volcanic eruptions. **Silica**, a compound of the elements silicon and oxygen, is the most important constituent of magma, comprising about 45–75 percent of the melt by weight.

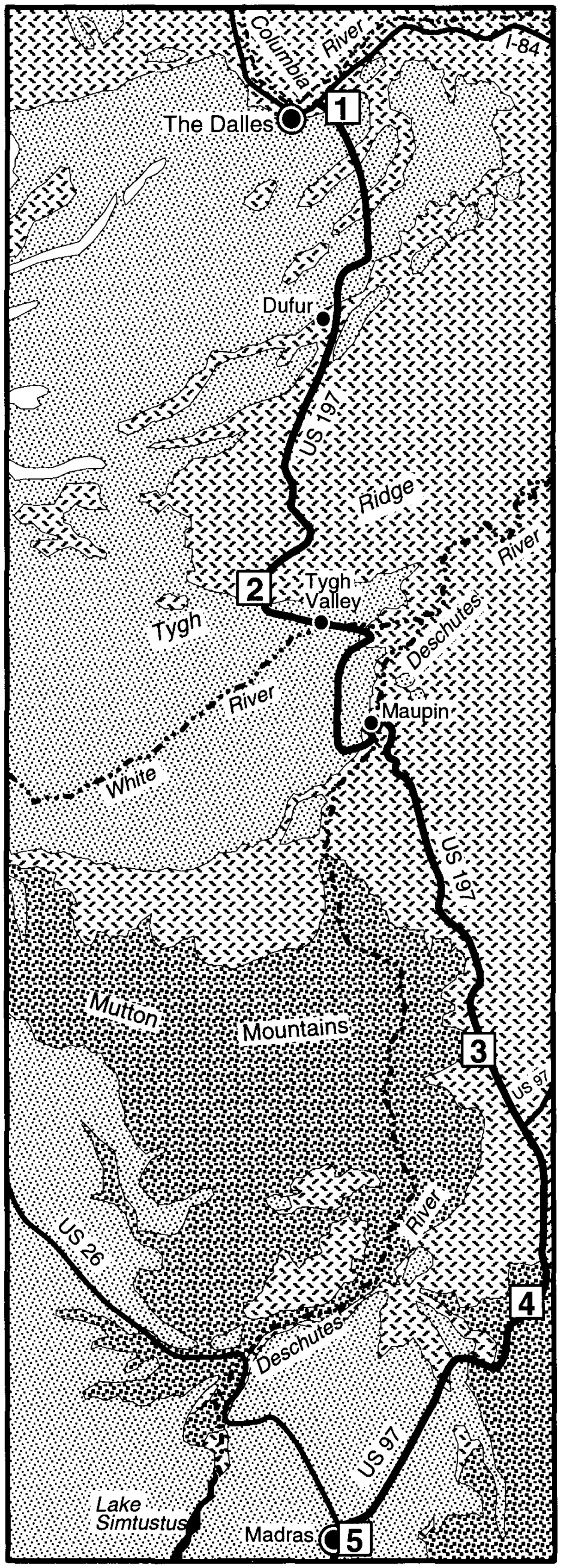
Volcanic rocks represent solidified **lava**, as magma is known when it reaches the earth's surface, and are named on the basis of silica content and the **silicate minerals** that they contain. Rocks formed by crystallization of relatively low-silica lavas are called **basalt**, those derived from high-silica lava are known as **rhyolite**, and the most common intermediate composition is named **andesite**. Low-silica lavas contain more iron and magnesium than higher silica varieties, which gives them darker colors. Basalt is generally dark gray or black, andesite is light gray or greenish gray, rhyolite is most commonly white, pink, or tan.

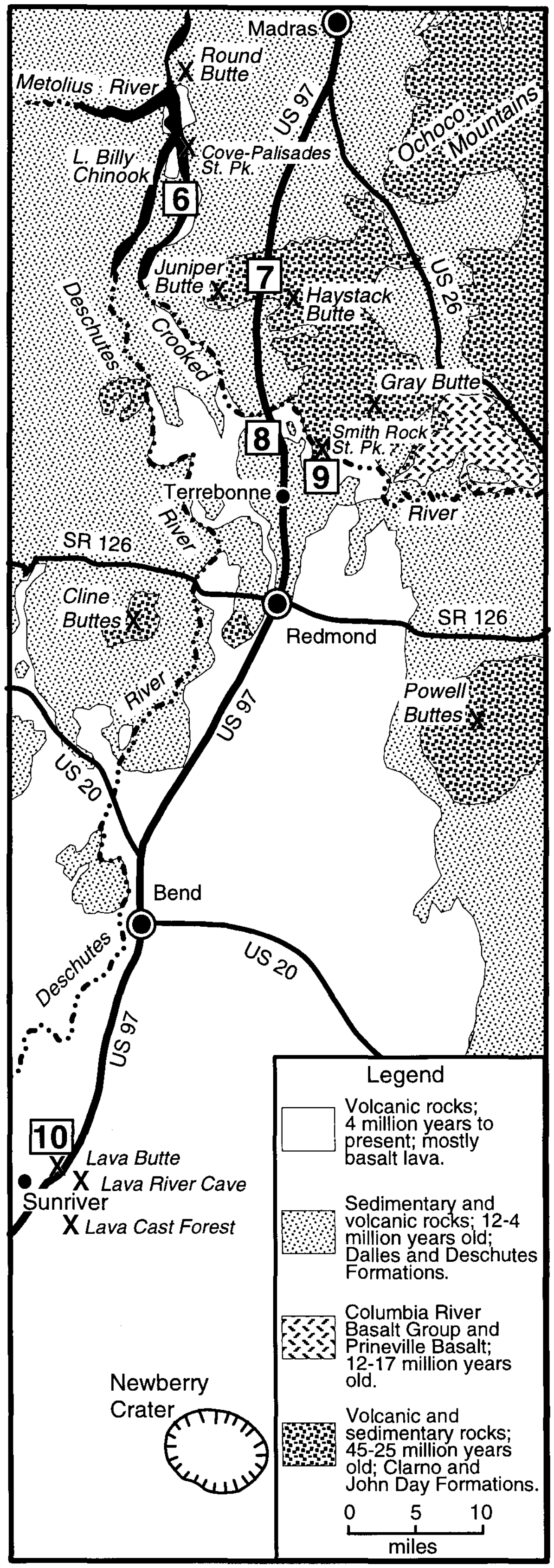
The composition of the magma not only determines what minerals will crystallize from it, but it also controls the nature of the volcanic eruptions that occur when the magma arrives at the surface. Basaltic lava is less **viscous** ("sticky") than andesitic or rhyolitic lava. Basaltic lava, therefore, is more fluid and moves as a thinner and more rapidly flowing lava flow. Andesitic and rhyolitic lavas show greater resistance to flow and generally do not travel more than a few miles from their eruptive **vents**. In some cases, silicic lava does not flow away at all, but accumulates as a high, steep-sided, bulbous mass of lava on top of the vent; these features are called lava **domes**.

Volcanic eruptions are driven by gases that are dissolved in the magma where it is subjected to the great pressures of overlying rock within the earth. As the magma rises near to the earth's surface, this pressure diminishes until it is insufficient to keep the gas from forming bubbles in the melt. This process is analogous to the formation of bubbles in a carbonated beverage when the container is opened. Gas bubbles rise in the magma, pushing some of the magma along, and produce explosions when they burst through to the surface. Basaltic magmas contain less dissolved gas than more silica-rich magma varieties; consequently, eruptions of basaltic volcanoes are less violent than those occurring at andesitic or rhyolitic volcanoes.

During explosive eruptions, some of the bubble-rich lava is blown out as a froth, which is quickly quenched to volcanic glass upon contact with the cooler atmosphere and broken into fragments of widely ranging sizes as the bubbles continue to expand. These fragments, called **pyroclasts** (from Greek words meaning "fire broken"), include **volcanic ash**, **pumice**, and **cinder**. A rock formed of consolidated ash is called **tuff**.

Most pyroclastic fragments are blown skyward by volcanic explosions and fall back to the surface. The bulk of this fallout material accumulates adjacent to the vent from which it was erupted, but if the fragments are ejected to great height, a considerable volume may be carried away by the wind and fall back to the earth at great distances. The resulting deposits become thinner and composed of successively smaller particles at greater distances from the volcano. Because eruptions of gaseous rhyolite are the most violent, rhyolitic tuff is more voluminous and widespread than that of basaltic or andesitic composition. In some cases, rhyolitic and,


Columbia River
I-84
The Dalles
1
Dufur
US 197
Ridge
2
Tygh Valley
Tygh
Deschutes River
River
White
Maupin
US 197
Mutton Mountains
3
US 97
River
US 26
Deschutes
4
US 97
Lake Simtustus
Madras
5


Madras
Round Butte
Metolius River
Cove-Palisades St. Pk.
L. Billy Chinook
6
Ochoco Mountains
US 97
Juniper Butte
7
Haystack Butte
US 26
Deschutes
Crooked
Gray Butte
8
Smith Rock St. Pk.
9
Terrebonne
River
River
SR 126
Cline Buttes
Redmond
SR 126
Powell Buttes
River
US 97
US 20
Bend
US 20
Deschutes
US 97
10
Lava Butte
Lava River Cave
Sunriver
Lava Cast Forest
Newberry Crater
Legend
Volcanic rocks; 4 million years to present; mostly basalt lava.
Sedimentary and volcanic rocks; 12-4 million years old; Dalles and Deschutes Formations.
Columbia River Basalt Group and Prineville Basalt; 12-17 million years old.
Volcanic and sedimentary rocks; 45-25 million years old; Clarno and John Day Formations.
0 5 10
miles

← **Generalized geologic map of road guide area: Left, The Dalles to Madras; right, Madras to Sunriver. Numbers refer to numbered sites in text.**

less often, andesitic pyroclasts are not simply ejected upward, but may flow downslope as rapidly moving, hot avalanches of ash and pumice, called **ash flows.** Ash flows may devastate hundreds of square miles adjacent to volcanoes. The resulting rocks, composed principally of pumice set in a matrix of finer ash and minerals crystallized from the magma are called **ash-flow tuffs.**

Volcanic landforms vary as a result of the difference in eruption character exhibited by magmas of different composition. Basaltic magma erupts without producing much pyroclastic material and generates fluid lava flows. Basaltic vents, therefore, are usually marked by small accumulations of cinder, called **cinder cones,** surrounded by extensive black, solidified lava. If large volumes of lava are erupted, they may construct a gently sloped **shield volcano.**

Andesitic magma generates more pyroclastic debris than basalt, and resulting lava flows are thicker and less extensive than those related to less siliceous magma. The resulting landforms are **stratovolcanoes** that are composed of alternating layers of lava and tuff (e.g., the major Cascade peaks). Because andesitic lavas are more viscous than basaltic ones, the slopes of stratovolcanoes are steeper than those of shield volcanoes.

Rhyolitic magma may also produce stratovolcanoes. More commonly, however, rhyolite is erupted in the form of pyroclastic material that falls or flows over a large area to produce extensive light-colored tuff. When rhyolite lava is erupted, it generally forms domes.

## PERIODS OF VOLCANIC ACTIVITY IN CENTRAL OREGON

### Eocene and Oligocene (45–25 million years ago)

The earliest volcanism recorded in central Oregon occurred during the geologic epochs of the Eocene and Oligocene. Volcanic rocks of this age are most common in the Ochoco Mountains, located to the east of U.S. Highway 97. The oldest of these rocks, referred to as the Clarno Formation, are present in the Mutton Mountains, northwest of Madras and are featured at the Clarno Unit of the John Day Fossil Beds National Monument east of Madras. Clarno Formation rocks are andesite lava flows and mudflow deposits—chaotic mixtures of andesite boulders and smaller fragments formed by landslides and rapid erosion of loose debris from the steep flanks of stratovolcanoes. Overlying the Clarno Formation is the John Day Formation, composed mostly of light-colored tuff recording the fallout of airborne ash from countless eruptions of ancient Cascade volcanoes. Eruptions from small rhyolite volcanoes in central Oregon also produced widespread ash-flow tuffs. Rhyolite lavas formed steep domes south of Madras. John Day Formation tuff and Clarno Formation mudflow deposits and associated sediment, are famous for the abundant and well-preserved plant and vertebrate fossils they contain. The story that these fossils tell about the climate and landscape of long-ago Oregon can be learned from visits to any of the various units of John Day Fossil Beds National Monument located in eastern Oregon.

### Middle Miocene (17–12 million years ago)

The John Day Formation deposition was followed by several million years of erosion without any preservation of volcanic materials in central Oregon. This period ended at about 17 million years ago with the onset of eruption of the gargantuan lava flows referred to as the Columbia River Basalt Group. These basalt lava flows cover 63,000 mi$^2$ of Washington, Oregon, and Idaho to an average thickness of two thirds of a mile. If spread evenly over the state of Oregon, they would produce a layer 3,500 ft thick! Most of the basalt was erupted from long cracks, or **fissures,** located in northeastern Oregon and southeastern Washington; others were erupted in central Oregon near Monument. Similar Prineville Basalt is prominent near and south of Madras (Hooper and others, 1993).

The basalt lava was obviously very fluid to produce such extensive flows. It was also erupted so nonexplosively that very little material accumulated around the fissures to produce recognizable volcanoes. Instead, the sites of eruptions are now marked by the basalt fillings of the fissures themselves, called **dikes,** that can be seen in deep canyons subsequently cut through the basalt flows in central and northeastern Oregon. Over much of the northern half of our route we will see many of these lava flows as layers of dark basalt. The eruption of so much basalt dammed some streams to form lakes, repositioned some rivers to new courses, and reduced some to sluggish streams that meandered across the almost flat upper surfaces of the lava flows after they cooled. Sediment deposited by these streams can be seen as light-colored layers of sand and gravel between basalt flows. The sediment is composed primarily of ash, pumice, and rock fragments eroded from ancient Cascade volcanoes. These beds can be seen at several points along the route but have been officially named only in the area west and north of Madras, where they are called the Simtustus Formation (Smith, 1986).

**Late Miocene and early Pliocene (12–4 million years ago)**

During and following the eruption of the Columbia River Basalt Group flows, the crust of north-central Oregon and adjacent Washington was being horizontally compressed to produce wrinkled ridges and troughs that extend, more or less east to west, for distances of 40–125 mi. The uplifted areas are called **anticlines**, and the depressed areas are called **synclines**. Streams draining eastward from the Cascades followed the low ground of the synclines and deposited hundreds of feet of Cascade-derived sediment.

This sand and gravel is interleaved with far-traveled Cascade basalt lava flows and more silicic ash-flow tuffs, and numerous silicic ash- and pumice-fall layers that accumulated downwind from exploding volcanoes. These mixtures of sedimentary and volcanic materials vary in age and composition from one valley to the next and are largely referred to as the "Dalles Formation," in The Dalles basin and the Tygh Valley areas, and the "Deschutes Formation" in the Deschutes basin. Virtually none of the volcanoes of this vintage can still be seen in the Cascades; they have been eroded away or buried under younger volcanic products. The Dalles and Deschutes Formations, however, provide a decipherable record of Cascade volcanism at that time many millions of years ago.

**Late Pliocene to Present (4–0 million years ago)**

The modern High Cascade Range was largely built in the past two million years. Indeed, the major stratovolcano peaks were all formed in the last few hundred thousand years. Some relatively young volcanic activity also occurred in central Oregon, especially near the southern terminus of our route. Southeast of Bend is a large shield volcano, named "Newberry volcano," which grew in this position just east of the Cascades over the last 1.5 million years.

Some extensive lava flows from near Newberry volcano poured northward into the Deschutes basin to fill the Deschutes and Crooked River canyons as they were being incised into the older Deschutes Formation. Basaltic cinder cones litter the slopes on all sides of Newberry volcano, with the youngest ones extending northwestward along fractures, or **faults**, toward Bend.

Locally, especially south of Bend, layers of light-colored sandy ash along the road can be seen that represent fallout from the great eruption of Mount Mazama. This eruption occurred about 6,700 years ago and led to the formation of Crater Lake, 100 mi farther south in the southern Oregon Cascades.

**Pillow basalt capped by columnar-jointed basalt at Site 1.**

## DESCRIPTION OF THE TRIP AND OF NUMBERED GEOLOGIC SITES

*The entire extent of the trip could easily require more than one day. Keep this in mind as you make your trip plans. And although the main route is on well-maintained highways, be aware of weather conditions and possible closures on side roads.*

*This description of the tour leads south from The Dalles. In order to help users who might wish to travel from south to north, only interval distances are indicated.*

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### SITE 1. BEGINNING OF TRIP, COLUMBIA RIVER BASALT GROUP OUTCROP, PILLOW BASALT

*The Dalles, Oregon. Stop near top of hill on U.S. Highway 197, just south of bridge across Columbia River and interchange with Interstate 84. Parking available on west side of road.*

The route along U.S. Highway 197 southward to the junction with U.S. Highway 97 features two rock formations: the basalt lava flows of the Columbia River Basalt Group and sediments of the Dalles Formation. The prominent roadcut at this locality illustrates the result of a Columbia River basalt flow entering a lake. When lava flows enter standing water, much of the lava is quenched to glass and broken into small fragments during the explosive generation of steam. Larger masses of lava detach from the main body of the flow but remain as coherent spherical or ellipsoidal blocks of quickly chilled, glassy basalt, which are referred to as **pillows**. Ellipsoidal pillows in the lower part of this roadcut are surrounded by ash that was generated by the interaction of the hot lava with the cold water, and is now altered to the yellow-orange mineral palagonite. The long axes of the pillows are oriented at an angle pointed downward toward the southwest, the direction in which the lava flow was moving. The unpillowed basalt at the top of the roadcut is part of the same lava flow that did not interact with the lake water, because it flowed where the pillows and ash had filled in the lake. The thickness of the pillow basalt, therefore, is a measure of the depth of the lake.

To the north are the Columbia Hills, an anticline uplift of folded basalt. Late Miocene sediments of the Dalles Formation accumulated in the basin south of this uplift and now form the bluffs along the south side of the city of The Dalles.

Between here and Dufur, 12.5 mi to the south, roadcuts expose basalt, including more pillow basalt, and consolidated sand, gravel, and tuff of the Dalles Formation. This material was derived about 7–12 million years ago from volcanoes that were in the vicinity of the present Mount Hood stratovolcano, which is intermittently visible from the road.

*12.5 mi from The Dalles to Dufur.*

*10 mi from Dufur to summit on Tygh Ridge.*

### SITE 2. TYGH RIDGE SUMMIT

*Use for orientation and preparation for 7-mi descent through Butler Canyon to Tygh Valley. About 4.5 mi down from the summit, note basalt quarry on east side of road. For side trip west ("county road" mentioned below), turn off about 2.5 mi farther, into Tygh Valley, and continue on Wamic Market Road toward Wamic. Oregon Trail historic marker and viewpoint about 2 mi up this road.*

From Dufur southward to this point, U.S. Highway 197 climbs the flank of the Tygh Ridge anticline, which is underlain by folded basalt and defines the southern edge of The Dalles basin. The highway then descends the steeper south slope of the anticline through Butler Canyon. At least 20 flows of Columbia River basalt, totaling 1,000 ft in thickness, are exposed along the road. The basalt is black, as can be seen on freshly broken surfaces, but appears mostly rust colored because of surficial oxidation of iron and magnesium silicate minerals. These mineral crystals are not visible to the unaided eye, but reflections from small grains of another silicate mineral, **feldspar**, can occasionally be noted. Most of the basalts exhibit **columnar joints** generated by contraction of the cooling lava flow.

Close observation reveals numerous light-gray or tan layers of sediment and tuff between some basalt flows. These layers record deposition of river sediment and ash between basalt eruptions.

At the base of Butler Canyon the road enters the Tygh Valley basin. Dalles Formation sediment underlies most of the prominent mesa in the middle of the valley and can be seen in roadcuts along the county road that extends westward from the village of Tygh Valley toward Wamic. Younger sediment, tuff, and basalt, similar to the Deschutes Formation farther south, overlie the Dalles Formation, including the Juniper Flat basalt that the highway is built on for most of the route between Tygh Valley and Maupin. This basalt differs from the Columbia River basalts on Tygh Ridge by being lighter colored and containing easily visible crystals of white to glassy feldspar and green **olivine**. This lava flowed into a developing Deschutes River canyon to form a prominent bench upon which much of the town of Maupin is constructed.

*10 mi from Tygh Valley to Maupin, where highway crosses Deschutes River.*

**View to the north across Tygh Valley and Butler Canyon on the flank of Tygh Ridge, the scene of Site 2.**

*17 mi from Maupin to Criterion Summit.*

## SITE 3. CRITERION SUMMIT AND MOUNTAIN IDENTIFIER

*Pullout on west side of U.S. Highway 197.*

A (sadly vandalized) monument at this site serves to identify the major Cascade volcanic peaks from Mount Adams, on the north, to the Three Sisters, toward the south, that can be seen from this point in clear weather. The Mutton Mountains, a northeast-southwest oriented uplift underlain by volcanic rocks of the Clarno and John Day Formations lie prominently in the foreground, trending toward Mount Jefferson. These same formations form the Ochoco Mountains, which are visible on the skyline to the south and southeast. John Day Formation rhyolite forms the prominent peaks of the western Ochoco Mountains on the horizon directly south of the viewpoint. Columbia River basalt flows lapped up onto the older volcanic rocks from the north, east, and south, and underlie this site, where they are quarried by the transportation department on the east side of the highway.

The major Cascade peaks are primarily andesite stratovolcanoes, although Three Fingered Jack and Mount Washington are transitional between basalt and andesite, and the lower parts of these cones are broad, gently sloping shields. There are also many small shield volcanoes and cinder cones in the Oregon Cascades, the youngest and most spectacular of which are along McKenzie Pass on Oregon Highway 242, about 50 mi to the west of Bend.

Of the volcanoes visible from here, only Mount Adams, Mount Hood, and South Sister have experienced eruptions since the last ice age glacier advances, 10,000 years ago. Moving glaciers scoured deeply into the easily eroded stratovolcanoes and modified originally smooth cones into sharp ridges, pinnacles, and spines that are best illustrated by Three Fingered Jack, Mount Washington, and the summit area of Mount Jefferson. The most recently active volcano seen from this viewpoint is Mount Hood, which last erupted in about A.D. 1800. Pyroclastic debris from that eruption was washed down river valleys in great floods that reached the Columbia River near Troutdale and through the White River valley to the Deschutes River near Tygh Valley, north of this point.

Mutton Mountains and Mount Jefferson, as seen from Criterion Summit, looking west.

*5 mi from Criterion Summit to intersection of Highways 197 and 97. Continue on Highway 97.*

*2 mi from intersection to rest area on west side of highway; beginning of descent through Cow Canyon.*

*2.7 mi from rest stop to basalt quarry on east side of road.*

*3.5 mi from quarry to intersection of Highways 97 and 293; entering valley.*

*0.4 mi from intersection to historical marker (Cross Keys Post Office on Trout Creek, 1879).*

### SITE 4. HAY CREEK—TROUT CREEK VALLEY

Rocks in this area are among the oldest to be seen along this route. Highway 97 descends through a thick sequence of Columbia River basalt in Cow Canyon. The valleys of Hay and Trout Creeks are eroded in sediment and ash-flow tuff of the John Day Formation that underlie the basalt. One ash-flow tuff, with a distinctive brick-red color, is quarried for building stone just east of the highway.

From here southward to Bend, Highway 97 traverses the Deschutes basin, bounded by the Mutton Mountains to the north, the Ochoco Mountains to the east, the High Cascades to the west and the High Lava Plains near Newberry volcano to the south.

*2.8 mi from historical marker to turnoff "To Hay Creek Road" to the east. A short side trip on that road allows a better look at red tuff quarry.*

*15 mi from Hay Creek Road turnoff to intersection of Highways 97 and 26 at Madras.*

### SITE 5. MADRAS

*No particular stopping point. Continue through Madras on Highway 97.*

The city of Madras rests in a bowl-shaped valley eroded in sediment of the Deschutes Formation, which is noted as light brown sandstone in numerous roadcuts and building excavations within and near the town. There are also lava flows in the Deschutes Formation,

**Cove Palisades State Park. View is to the west from a rim viewpoint, showing the park road passing between The Ship (left) and The Island (right).**

including the prominent rimrock basalt flow capping the mesa along the west side of town. This lava flow was erupted about 5.3 million years ago from a group of cinder cones, named Tetherow Buttes, located near Terrebonne, about 20 mi to the south of here.

*2.5 mi from Highways 97/26 intersection to turnoff east for Highway 26. Continue on Highway 97.*

*6.8 mi to first turnoff for Cove Palisades State Park at Iris Lane. (Various other possibilities exist to reach the park.)*

*5.2 mi to park entrance.*

## SITE 6. COVE PALISADES STATE PARK

This park features spectacular canyon scenery and geologic features near the confluence of the Deschutes, Crooked, and Metolius Rivers. For a more detailed discussion of this park, see earlier articles in Oregon Geology (Bishop, 1990; Bishop and Smith , 1990; Smith, 1991).

*About 7-mi round trip from entrance to four viewpoints (going north along canyon rim; road continues to Round Butte Dam viewpoint.*

*About 10-mi round trip from entrance to petroglyphs (descending into canyon).*

### Highlights of COVE PALISADES STATE PARK

This state park, reached by well-marked roads to the west of U.S. Highway 97, is a most impressive scenic locality where the Deschutes, Crooked, and Metolius Rivers meet in a plexus of 1,000-ft-deep canyons now flooded by the waters of Lake Billy Chinook behind Round Butte Dam. A short excursion to The Cove affords an opportunity to see some of the geologic record of ancient Cascade volcanoes.

*Viewpoints above the east side of the park*

Four viewpoints over the park, reached by a paved road above the eastern edge of the canyons, provide a dramatic panorama of central Oregon geology. The major Cascade peaks of Mount Hood, Mount Jefferson, Three Fingered Jack, Mount Washington, The Three Sisters, Broken Top, and Mount Bachelor form the backdrop to the west on sufficiently clear days. Basalt lava flows 4–5 million years old, from the Cascades and small, nearby volcanoes, form the prominent rimrocks and flat surfaces extending away from the canyons.

One of the local volcanoes, Round Butte, is a gently sloping shield volcano surmounted by a small cinder

**Newberry basalt cliffs at the Cove Palisades State Park, seen from the canyon rim on the east side of the park.**

cone directly north of the viewpoints. An older rhyolite lava dome within the John Day Formation forms Juniper Butte, looming to the south.

The varicolored rocks exposed in the canyon walls are sand, gravel, lava, and ash-flow tuff of the Deschutes Formation that, at this locality, were largely discharged eastward from the Cascades over a period of only a few hundred thousand years during the late Miocene. A prominent, narrow projection of black basalt, rising 550 ft above the lake, separates the Deschutes and Crooked Rivers to form The Island in the middle of the park. This lava flow, determined by radioactive-isotope-decay methods to be about 1.2 million years old, was erupted near Newberry volcano, visible on clear days 60 mi away on the southern horizon. It poured into the Crooked River canyon, already cut to its present dimensions, and continued downstream past the confluence with the Deschutes River for another 3 mi. The rivers carved their canyons anew, leaving The Island and a number of conspicuous wedge-shaped accumulations of basalt clinging to the canyon walls as the record of this great eruption. The prominent columns and other fanning and random arrangements of fractures within the basalt of The Island were produced by contraction during solidification and cooling of the basaltic lava.

*The Ship*

This prominent locality near the center of the park, provides a perspective on the geology from within the great canyons. Adjacent to the parking area is displayed a basalt boulder with petroglyphs that was retrieved from the Crooked River Canyon before the reservoir was filled.

From this vantage point one can look directly northward at the south end of the basalt flows of The Island. Before the eruptions of these lavas, the Crooked and Deschutes Rivers met at this point; now the confluence is another 2 mi downstream to the north.

Looking southward at the prow of The Ship, one can see some of the material that makes up the Deschutes Formation. Sand and gravel represent ancient streams that flowed eastward from the Cascades. The prominent white layer and the irregularly eroded pinkish-gray unit near the bottom of the exposure are ash-flow tuff. Inspection of the lower tuff along the parking area shows the typical texture of ash-flow tuffs, with chunks of pumice and volcanic fragments in a fine, abrasive matrix of ash.

Do not climb the fragile slopes of The Ship itself!

Similar layers of sediment, ash-flow tuff, and lava can be examined along the roadcuts above the Crooked

**Deschutes Formation at The Ship in Cove Palisades State Park. View is from canyon rim on east side. Black Butte is visible on the center skyline.**

River and Deschutes River arms of Lake Billy Chinook.

Also prominent along these canyon walls are chaotic masses of Deschutes Formation and the younger basalt that are tilted, so that the layers are no longer horizontal: these are landslides. These landslides have caused substantial damage to the State Park roadway just east of The Ship, but have also been beneficial by producing relatively flat areas within the otherwise steep-walled canyon that are utilized for campgrounds and day-use areas west of The Ship and the facilities at the marina.

*About 8 mi from park entrance to return to Highway 97 and to top of saddle between Juniper Butte and Haystack Butte.*

## SITE 7. JUNIPER BUTTE GRADE

*No particular stopping point.*

At this point, Highway 97 crosses a saddle between Juniper Butte on the west and Haystack Butte on the east. The Buttes mark the western edge of the Ochoco Mountains, a part of the Blue Mountains, which extend 200 mi northeastward into southeastern Washington. Most high peaks and ridges in this area are composed of volcanic rocks of the John Day Formation. Juniper Butte is a rhyolite dome, as is Cline Buttes, visible about 15 mi to the south. Tilted layers of ash-flow tuff comprise Haystack Butte and are also exposed along the highway in roadcuts. South of Haystack Butte and about 5 mi distant is Gray Butte, composed of basalt flows and sediment containing leaf fossils, and topped by a thick, rhyolitic lava-flow cap. The leaf fossils document a change from subtropical to temperate climate in central Oregon between 30 and 40 million years ago (Ashwill, 1983). On the southern horizon, about 50 mi distant, is the Newberry volcano, a broad basaltic shield.

*6.4 mi from top of saddle to Ogden Wayside*

## SITE 8. PETER SKENE OGDEN STATE SCENIC VISTA

(New official name for what used to be a state park)

This wayside provides an overlook of the 330-ft-deep Crooked River gorge. The railroad bridge to the west of the highway was completed in 1911 and was the final hurdle in a nearly decade-long effort to construct a railroad into central Oregon.

Looking under the highway bridge, one can see a vertical cliff of basalt erupted from Tetherow Buttes, about 4 mi to the south—the same lava flow as seen at Madras to the north. Following the eruption of this basalt, about 5.3 million years ago, the Crooked River

**Juniper Butte, the western edge of the Ochoco Mountains. View is to the northwest. Lava flows erupted from Tetherow Butte underlie fields in the foreground.**

cut this canyon to its present depth prior to about 1.2 million years ago. At that time, a voluminous series of lava flows from Newberry volcano, about 40 mi to the south, flowed into the Crooked River gorge and, at this point, filled it to overflowing. The lava formed the dark cliffs of basalt that can be seen extending along both sides of the river from the highway bridge to the turn in the river downstream from the railroad bridge. The canyon was recut in the same position afterward. Spectacular cliffs composed of this same canyon-filling lava flow can be seen in The Island at Cove Palisades State Park.

*3.2 mi from Peter Skene Ogden wayside to turnoff (east) to Smith Rock State Park.*

## SITE 9. SMITH ROCK STATE PARK

A 3.5-mi side trip from U.S. Highway 97 brings you to this famous rock climbers' challenge. The 600-ft-high rock massif with castellated vertical cliffs represents a small rhyolitic volcano in the John Day Formation. The rock is indurated tuff that was generated by very violent explosions resulting from the chance interaction of a rising rhyolite magma and shallow groundwater. The water quenched the magma to glass that was pulverized and ejected as very fine ash when the water was explosively converted to steam. The resulting **tuff cone** was centered below the visitors' overlook and includes all of the yellow-brown rocks that rise above the river along its wide curve from the east. In the ensuing 30 million years or so, the tuff cone was tilted to the southeast during uplift of the Ochoco Mountains and deeply dissected by streams.

*6.3 mi from turnoff to intersection of Highways 97 and 126 in Redmond. Continue on Highway 97.*

*14.4 mi from Redmond to intersection of Highways 97 and 126 in Redmond. Continue on Highway 97.*

*9.7 mi from Highways 97/126 intersection to entrance to High Desert Museum, on east side of highway (information at 541–382–4754).*

*4.7 mi from High Desert Museum to entrance for Lava Lands Visitor Center (information from U.S. Forest Service, phone in Bend 541-593-2421).*

## SITE 10. LAVA LANDS VISITOR CENTER AND LAVA BUTTE

South of Bend, U.S. Highway 97 climbs out of the Deschutes basin and onto a high, pine-covered plateau

**Crooked River Gorge at Peter Skene Ogden State Scenic Vista. View is to the west, approximately from the location of the highway crossing.**

of volcanic rock. At the surface, these rocks are primarily basalt lava flows and associated cinder cones flanking the large Newberry volcano shield. Many of these basalt flows are less than 10,000 years old and retain many of the fragile surficial features that are characteristic of freshly erupted lava and are generally lacking with the older basalts that have been examined along the route farther to the north. The youngest lavas have little or no vegetation on them, giving the area a stark moonscape appearance, which was utilized for the training of Apollo astronauts in 1966. The U.S. Forest Service Lava Lands Visitor Center is now part of what was established in 1990 as the Newberry National Volcanic Monument.

**Lava Lands**

A variety of interesting volcanic features can be seen in this unique geological area along or near U.S. Highway 97 south of Bend, including Lava Butte, Lava River Cave, and Lava Cast Forest. Trails and interpretive guides to these features are provided by the U.S. Forest Service, which operates the Lava Lands Visitor Center near Lava Butte. A stop at the visitor center is highly recommended, as is a visit to the nearby High Desert Museum. The Lava Lands area is low on the northwest flank of the great Newberry shield volcano, which is best seen from the top of Lava Butte. Dozens of young cinder cones dot the flank of Newberry volcano, with the youngest cones and associated basalt lava flows extending along a northwest fault zone to Lava Butte.

**Lava Butte** (Generally closed from October through March)

Lava Butte is a cinder cone, about 6,160 years old, that can be explored along foot trails and by a paved road to the summit. From the summit observation tower, one can see Newberry volcano to the southeast, the broad Deschutes basin to the north beyond Bend, and a panorama of the High Cascade Range to the west. A trail leads around the 150-ft-deep summit crater. Views to the southeast from this trail across U.S. Highway 97 show smaller accumulations of basaltic spatter that formed along the same fracture through which magma rose to feed Lava Butte. One can also see an accumulation of black spatter around the vent that fed the lava flows surrounding the base of Lava Butte. These lava flows cover about 6,100 acres and have a total volume of approximately 375 million cubic yards.

*1.2 mi from visitor center to entrance to Lava River Cave.*

**Smith Rock at Smith Rock State Park. View is to the southwest from viewpoint in the park.**

**Lava River Cave** (Closed November 1 to April 15 for protection of hibernating bats)

This dramatic volcanic feature is associated with a lava flow erupted before the formation of Lava Butte. The basalt flow cooled and solidified along its edges and top, while molten lava continued to flow within an interior tube. The molten lava eventually drained away downslope, and the solidified walls and roof were strong enough to keep the empty tube open over most of its length as a cave.

A hike into Lava River Cave provides an opportunity to view the interior of a 5,200-ft-long segment of this lava tube with access gained through a point where the roof of the tube collapsed. More than two dozen similar lava tube caves are known in other basalt flows surrounding Newberry volcano.

*3.8 mi from entrance to Lava River Cave to turnoff to east on Forest Service Road 9720 to Lava Cast Forest (also turnoff west to Sunriver and Mount Bachelor).*

**Lava Cast Forest** (Road may at times be closed because of snow)

This fascinating geologic area is reached by an about 20-mile round trip excursion from U.S. Highway 97 on Forest Service Road 9720, which intersects U.S. Highway 97 near milepost 153. A short hike along the interpretive trail provides insight into what happens when basalt lava flows into a forest.

About 6,000 years ago, a basalt lava flow, erupted from fissures located just north of the parking area, entered a forest. The fluid basaltic lava quickly chilled to glass where it came in contact with the colder trees. The trees were, of course, consumed by fire. Lava flowing unimpeded between the burning trees, however, continued downslope, and as the level of the lava flow fell, the locally solidified basalt surrounding former trees projected as hollow columns above the upper surface of the solidifying flow. Many of these low, collarlike columns remain. The interior void represents a mold of the tree trunk that was burned by the solidifying lava. Because of the fluid characteristics of basalt lava, the interiors of some molds include detailed casts of the bark and charred wood of the exterior of the tree.

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*(Continued on page 17)*

Lava Butte at the Lava Lands visitor center.

Newberry volcano as seen from the top of Lava Butte.

**Tree mold in lava flow at Lava Cast Forest.**

*(Continued from page 15)*

State Park and the Deschutes basin: Oregon Geology, v. 52, no. 1, p. 13–16.

Bishop, E.M., and Smith, G.A 1990, A field guide to the geology of Cove Palisades State Park and the central Deschutes basin in central Oregon: Oregon Geology, v. 52, no. 1, p. 3–12.

Hooper, P.R., Steele, W.K., Conrey, R.M., Smith, G.A., Anderson, J.L., Bailey, D.G., Beeson, M.H., Tolan, T.L., and Urbanczyk, K.M., 1991, The Prineville basalt, north-central Oregon: Oregon Geology, v. 55, no. 1, p. 3–12.

Smith, G.A., 1986, Simtustus Formation: Paleogeographic and stratigraphic significance of a newly defined Miocene unit in the Deschutes basin, central Oregon: Oregon Geology, v. 48, no. 6, p. 63–72.

Smith, G.A., 1991, A field guide to depositional processes and facies geometry of Neogene continental volcaniclastic rocks, Deschutes basin, central Oregon: Oregon Geology, v. 53, no. 1, p. 3–20.

## SUGGESTED FURTHER READING

*East of the Cascades*, by Phil Brogan; Binford and Mort, 1977, 304 p.

*High and Mighty: Selected Sketches about the Deschutes Country*, edited by Thomas Vaughan; Oregon Historical Society, 1981, 309 p. □

## DOGAMI PUBLICATIONS

### Released November 10, 1997

**Chronic geologic hazard maps of coastal Lincoln County, Oregon**, by George R. Priest. Open-File Reports O–97–06 through O–97–10, $6 each.

These five maps revise previously published information on landslide hazards and erosion rates along the coast of Lincoln County. The stretch of coastline affected by the revision extends from slightly north of Otter Rock to the north jetty at Newport and about 1.5 mi inland from the shore. The maps serve as basic resources for land-use planning decisions, emergency management planning, and insurance purposes.

The revised maps have been released under the original title and replace the original Open-File Reports O–94–22 through O–94–26. They are based on photo maps, each of them covering a small stretch of coastline. Chronic geologic hazards are mass movement hazards such as landslides, slumps, rock toppling, and soil or rock flows. These, along with shoreline geology and shoreline erosion rates, are shown on the maps.

The table below lists the revised maps and the original maps that are replaced by them:

| Map area | New map number | Replaces |
|---|---|---|
| Otter Crest area | O–97–06 | O–94–22 |
| Beverly Beach area | O–97–07 | O–94–23 |
| Moolack Beach area | O–97–08 | O–94–24 |
| Moolack-Agate Beach area | O–97–09 | O–94–25 |
| Newport area | O–97–10 | O–94–26 |

Explanations and an abbreviated erosion-rate table were originally released as DOGAMI Open-File Report O–94–11 and are not affected by the revision.

The revised maps have been deposited in those places where the original complete set of maps is available to the public. This includes the public libraries of Lincoln City and Newport, the Lincoln County Library District, and the libraries of the Hatfield Marine Science Center and Oregon Coast Community College in Newport. Other libraries that have complete sets are the State Library in Salem, the Multnomah County Library in Portland, and the academic libraries of the University of Oregon, Eugene; Oregon State University, Corvallis; Portland State University, Portland; Southern Oregon University, Ashland; and Eastern Oregon University, La Grande. Complete or partial sets including the maps appropriate for the region are in the planning offices of Lincoln County, Lincoln City, Depoe Bay, and Newport.

All maps must be ordered in Portland and will be printed on demand. Allow two weeks for delivery.

**Erosion and flood hazard map, coastal Lincoln County, Oregon**, by George R. Priest. Open-File Reports O–97–12 through O–97–30, $6 each.
**Coastal shoreline change study, northern and central Lincoln County, Oregon**, by George R. Priest. Open-File Report O–97–11, 45 p., $6.

The series of 19 maps delineates erosion and flood hazard areas, each of them covering a small stretch of coastline, along 31 mi of the Lincoln County coast, from Salmon River to Seal Rocks. The study was conducted to provide the Federal Emergency Management Agency (FEMA) with data for estimating insurance costs to the federal government should it provide coastal erosion coverage to coastal residents. The methods, results, and applications of the study are explained and discussed in the separate text report.

The maps are based on vertical aerial photos at the scale of 1:4,800 (1 in. on the map=400 ft on the ground). Along the total extent of map coverage, they show the current and 60-year positions of an "erosional reference feature," such as the top of a bluff or the headwall of a landslide. Erosion-rate data published earlier (DOGAMI Open-file Report O–94–11) and shown in the margin of the new maps were used to indicate the respective position of the "erosional reference feature" 60 years from now. Active landslide areas are especially emphasized. In a similar way, lines were drawn to indicate the current and 60-year positions of 100-year flood zone boundaries. For the identification of flood zones, standard FEMA terminology was used.

Complete sets of the maps have been made available in the public libraries of Lincoln City and Newport, the Lincoln County Library District, and the libraries of the Hatfield Marine Science Center and Oregon Coast Community College in Newport. Other libraries that have complete sets are the Oregon State Library, Salem; the Multnomah County Library, Portland; and the academic libraries of the University of Oregon, Eugene; Oregon State University, Corvallis; Portland State University, Portland; Southern Oregon University, Ashland; and Eastern Oregon University, La Grande. Complete or partial sets including the maps appropriate for the region are in the planning offices of Lincoln County, Lincoln City, Depoe Bay, and Newport.

The open-file report numbers of individual maps are as follows:

| | |
|---|---|
| Salmon River area | O–97–12 |
| Roads End area | O–97–13 |
| Lincoln City-Wecoma Beach area | O–97–14 |
| Lincoln City-D River area | O–97–15 |
| Taft-Siletz Spit area | O–97–16 |
| Gleneden Beach-Siletz Spit area | O–97–17 |
| Fogarty Creek-Lincoln Beach area | O–97–18 |
| Boiler Bay area | O–97–19 |
| Depoe Bay area | O–97–20 |
| Cape Foulweather-Whale Cove area | O–97–21 |
| Otter Crest area | O–97–22 |
| Beverly Beach area | O–97–23 |
| Moolack Beach area | O–97–24 |
| Moolack-Agate Beach area | O–97–25 |
| Newport area | O–97–26 |
| South Beach area | O–97–27 |
| Newport Airport area | O–97–28 |

| | |
|---|---|
| Lost Creek area | O–97–29 |
| Seal Rock area | O–97–30 |

All reports can be purchased. Report O–97–11, containing the explanations, costs $6 and should always be purchased together with the maps. Maps cost $6 each. The complete set of maps and explanatory text costs $100. The maps must be ordered in Portland and will be printed on demand. Allow two weeks for delivery.

### Released December 3, 1997

**Relative Earthquake Hazard Map of the Portland Metro Region, Clackamas, Multnomah, and Washington Counties, Oregon,** by Matthew A. Mabey, Department of Geology, Brigham Young University; Gerald Black and Ian Madin, DOGAMI; Dan Meier, Woodward-Clyde Consultants of Portland; T. Leslie Youd, and Celinda Jones, Department of Civil and Environmental Engineering, Brigham Young University; and Benjamin Rice, Metro Regional Services. DOGAMI map IMS–1, full-color, scale 1:62,500 (about 1 in. to the mile), $12.

DOGAMI and Metro Regional Services have jointly released the first combined map of relative earthquake hazards that covers the entire area within the Portland metropolitan boundaries, from Forest Grove to Troutdale and from Hayden Island to Wilsonville. It indicates which areas will be most severely affected by earthquakes. The map, which encompasses 24 cities and 1.3 million people, is the culmination of a four-year effort involving the Federal Emergency Management Agency, Metro and DOGAMI. Consulting firms contributing to the map include Dames and Moore, Shannon and Wilson, Fujitani-Hilts, Squier Associates, Kelly Strazer, and Geotechnical Resources, Inc.

The 3- by 5-ft map also includes smaller maps showing the three types of ground responses during an earthquake—liquefaction, ground motion amplification, and slope instability. These hazards were used to determine the overall relative earthquake hazards shown on the large map.

Research on earthquake damage in other parts of the world has demonstrated that earthquake damage varies from area to area because of differences in the way the ground responds to earthquakes. Studies were made of the ground and rock at locations covered by this map to determine how they would respond to an earthquake. That information was used to develop the hazard maps.

Along with the map, Metro also released a new software program to help planners and emergency managers use earthquake hazard information collected over the past few years: *Metro Area Disaster Geographic Information System (MAD GIS) CD-ROM.* This software will be given to local and state emergency managers and will later be made available to other agencies and the public at the cost of production and distribution.

In recent years, DOGAMI has released more detailed relative earthquake hazard maps of the Portland, Mount Tabor, Lake Oswego, Beaverton, Gladstone, and Linnton quadrangles, as well as areas in Vancouver, Wash.

The new map is available rolled or folded for $12 (add $5 for mailing rolled maps). Earlier published earthquake hazard maps are also available from the same outlets.

For information on MAD GIS CD-ROM, contact Mike McGuire of Metro at (503) 797-1823.

### Released December 15, 1997

**Cascadia Subduction Zone Tsunamis: Hazard Mapping at Yaquina Bay, Oregon. Final technical report to the National Earthquake Hazard Reduction Program**, by George R. Priest, DOGAMI; Edward Myers and António M. Baptista, Oregon Graduate Institute of Science and Technology; Paul Fleuck and Kelin Wang, Geological Survey of Canada; Robert A. Kamphaus, Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration; and Curt D. Peterson, Portland State University. Open-File Report O–97–34, 26-pages, 118 pages appendices, $10.

This new report describes the development of tsunami hazard mapping techniques for application to the Yaquina Bay area in coastal Lincoln County. The study was conducted for the National Earthquake Hazard Reduction Program (NEHRP) and is principally aimed at providing information for emergency management planning. The report will be used by DOGAMI in the production and publication of tsunami hazard maps for this and other coastal areas.

Potential tsunami flooding from Cascadia subduction zone earthquakes at Yaquina Bay in Newport, Oregon, was explored by simulating fault ruptures and resulting tsunamis. Flooding from most scenario tsunamis is modest, because of protection by large jetties and sand dunes that guard Yaquina Bay. However, a worst-case tsunami reaches elevations of 35 ft at the open coast and floods all lowlands 1.5 mi inland. Flooding from scenario tsunamis reaching elevations of 12 and 27 ft at the open coast was also mapped to illustrate the range of uncertainty in the mapping technique.

Three scenario earthquakes were chosen in order to provide useful planning scenarios for tsunami hazard mitigation at Yaquina Bay. Inundation for high, moderately high, and moderately low runup cases were mapped, corresponding, respectively, to (1) a magnitude 9+ earthquake with an asperity immediately offshore (an asperity is a rough spot at the interface of the slipping plates that causes more fault movement), (2) the same earthquake without an asperity, and (3) a magnitude 8.5 earthquake with about half the fault slip of the magnitude 9+ case. Resulting open coastal runup elevations at Newport were 36, 26, and 16 ft, respectively. □

# Tree ring studies establish A.D. 1700 as year of huge Cascadia earthquake

*by Shannon Priem, Oregon Department of Geology and Mineral Industries*

Growth rings of ancient trees confirm that an earthquake in North America sent ocean waves to Asia almost three centuries ago, according to two groups of American scientists.

The scientists, in reports that have recently appeared in the journals *Nature* (Yamaguchi and others, 1997) and *Geology* (Jacoby and others, 1997), present tree-ring dates for an earthquake and tsunami that had been previously inferred from geologic observations in the northwestern United States and adjacent Canada. Scientists have compared these dates with the time of a tsunami known from village records in Japan. The agreement is so remarkable, the scientists say, that the Japanese records become written proof that the earthquake really happened.

At issue is the threat posed by an active fault that dwarfs the San Andreas fault and underlies a mostly offshore area from southern British Columbia to northern California. This fault—the Cascadia Subduction Zone—caused little concern until the late 1980s, when scientists began to recognize geologic evidence that the fault has produced earthquakes of magnitude 8 or larger. The most recent of these events was soon dated by radiocarbon methods to the decades between A.D. 1680 and 1720.

These dates caught the attention of Japanese researchers, who checked Japanese village records for signs of an "orphan" tsunami between 1680 and 1720. They found just one candidate, and they used its size and date to calculate that the Pacific Northwest had had an earthquake close to magnitude 9 in January of 1700. Their report was published early last year, in *Nature* (Satake and others, 1996).

American scientists responded by setting out to learn whether their Japanese colleagues had identified the correct year and season of a huge Pacific Northwest earthquake. One team, led by David Yamaguchi of the University of Washington in Seattle, studied trees killed by an earthquake near the mouth of the Columbia River. Another team, led by Gordon Jacoby of Lamont-Doherty Earth Observatory in Palisades, New York, focused on trees that barely survived it.

Each tree-ring team concludes that a huge Pacific Northwest earthquake occurred in the months between August 1699 and May 1700—dates that indeed converge on the time of the January 1700 tsunami in Japan.

The scientists report that trees killed by the earthquake died sometime after the 1699 growing season ended, but before the 1700 growing season began. In addition, the Jacoby team describes signs of trauma that begin with the 1700 ring of several of the trees that survived the earthquake.

The Yamaguchi team also addresses the controversy about the maximum size of Pacific Northwest earthquakes. Previously, some earth scientists had inferred nothing larger than magnitude 8, while others proposed magnitude 9, which is many times larger in terms of energy released, geographic area, and duration of shaking.

Writing in *Nature*, the researchers contend that a huge earthquake is now more plausible, because the new tree-ring dates fail to show that the 1700 event was smaller than magnitude 9.

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Yamaguchi, D.K., Atwater, B.F., Bunker, D.E., Benson, B.E., and Reid, M.S., Tree-ring dating the 1700 Cascadia earthquake: Nature, v. 389, p. 922–923.

Jacoby, G.C., Bunker, D.E., and Benson, B.E., Tree-ring evidence for an A.D. 1700 Cascadia earthquake in Washington and northern Oregon: Geology, v. 25, no. 11, p. 999–1002.

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# DOGAMI honors volunteers

The Oregon Department of Geology and Mineral Industries (DOGAMI) honored all those who volunteered their help to the Department at its annual award dinner held last December.

With their efforts, volunteers have greatly enhanced the department's effectiveness, especially in operating the Nature of the Northwest Information Center, maintaining and developing the department library, and assisting in the department's publication program.

Volunteers have been working with DOGAMI since 1991 and have donated over 9,000 hours in the program. All volunteers have their hours recorded and tallied and receive annual certificates showing their total cumulative hours. Each person who works more than 500 hours receives a gift: an engraved clock for over 500 hours, an engraved pen for over 1,000 hours, and a $50 gift certificate to the Lloyd Center shopping mall for over 1,500 hours.

At the 1997 award dinner, State Geologist Donald Hull presented certificates and gifts to the following volunteers:

John Westgate, 59 hours
Dorothy Blattner, 278 hours
Phil Johnson, 471 hours
Phyllis Thorne, 538 hours

Charlene Holzwarth, 690 hours
Rosemary Kenney, 1,348 hours
Archie Strong, 1,501 hours

The following volunteers were unable to attend the dinner:

Brenda Dolby (Albany), 71 hours
Sonja Bruce, 92 hours
Esther Kennedy, 202 hours
Joan Konner, 512 hours (clock)
Jan Murphy, 749 hours (clock in 1996). □

## Smithsonian has new hall of geology, gems, and minerals

The Smithsonian National Museum of Natural History in Washington, D.C. opened what has been termed "the most ambitious exhibition renovation on the Mall in decades" on September 20, 1997: the Janet Annenberg Hooker Hall of Geology, Gems, and Minerals.

The 20,000-square-foot hall, closed since 1995 for the renovation, was modernized with the help of $13 million in private donations and a team of more than 100 designers, scientists, architects, engineers, artists, educators, writers, and researchers. It features many state-of-the-art presentations, including interactive computer components, animated graphics, special lighting effects, and hands-on specimens. The hall includes more than 3,000 objects, 14 computer stations, two study stations with additional computer interactives, and eight short video presentations. Visitors can see the highlights of the hall by following a "Fast Track" that displays the major pieces in each gallery just in front of the detailed cases with other materials.

**Hooker Emerald, 75.47 carats, surrounded by 109 round and 20 baguette diamonds (totaling 13 carats) in platinum. Emerald from Colombia. Current brooch setting by Tiffany and Co. Gift of Mrs. Janet Annenberg Hooker, 1977. Displayed in the National Gem Collection. Photo courtesy National Museum of Natural History, Smithsonian Institution.**

**Iron pyrite cubes, a specimen from sedimentary deposits near Lagrono, Spain, displayed in the Minerals and Gems Gallery. Photo courtesy National Museum of Natural History, Smithsonian Institution.**

Six of the seven galleries that make up the hall are open now; a seventh, the Rocks Gallery, is scheduled to open in 1998 and is to explain rock formation, including the impact of the forces of wind and water at the Earth's surface and those of intense heat and pressure deep within the Earth. The six open galleries are as follows:

**1. Harry Winston Gallery**, which houses several geologic wonders, such as the 45.52-carat Hope diamond, the Tucson meteorite, a 1,300-lb quartz crystal, and a 324-lb natural copper sheet;

**2. National Gem Collection** with the museum's unparalleled collection of gemstones and jewelry pieces;

**3. Minerals and Gems Gallery** with more than 2,000 remarkable crystal specimens emphasizing mineral science and the importance of minerals in everyday life;

**4. Mine Gallery**, showing crystal pockets and ore veins in dioramas of historic mines and offering displays of minerals, computer interactive displays, and video displays about mining, from ore to final product;

**5. Plate Tectonics Gallery**, illustrating how earthquakes, mountain chains, and volcanoes result from the constant shifting of plates on the earth's surface;

**6. Moon, Meteorites, and Solar System Gallery**, which explores the birth of our solar system and its evolution through film, computer interactives, and touchable specimens, including Moon rocks, the mars meteorite and other meteorites, and stardust.

Curator-in-charge Jeffrey E. Post and photographer Chip Clark have produced a book titled *The National Gem Collection* and published in conjunction with the opening of the new hall (National Museum of Natural History/Harry N. Abrams, Inc., 1997).

The National Museum of Natural History is located at Constitution Avenue and 10th Street NW, Washington, D.C. 20560, and is open every day of the year, 10 a.m. to 5:30 p.m., except December 25.

Under http://www.mnh.si.edu.nmnhweb.html you may find the National Museum of Natural History home page on the Internet.

*—from National Museum of Natural History Smithsonian Institution, news release materials*

## BOOK REVIEW

*by Robert M. Whelan, ECONorthwest, Portland, Oregon*

**GeoDestinies**, by Walter L. Youngquist, 1997: National Book Company, P.O. Box 8795, Portland, OR 97207-8795, hardbound, 499 p., $29.95.

*GeoDestinies* discredits the widely held belief that "science will think of something" to solve the depletion of natural resources. In nontechnical terms, author Youngquist describes how world population growth will exhaust, in practical terms, many of the Earth's resources in the near future. He notes that "Geology, not economics, ultimately controls the availability of Earth resources."

Alarmist writings about the world running out of oil and other geological resources have cropped up periodically for more than a century now. Such predictions failed to consider the effects of new technologies, discoveries of additional reserves, substitution of materials, more recycling, and higher efficiencies. Consequently, rather than seeing the classic sign of shortages—prices rising faster than general inflation—we have seen declines in the prices of most mineral resources and those commodities, such as wheat, that use them (fertilizer, topsoil, groundwater). Youngquist discounts all this by noting that population growth is exponential and that science will no longer be able to keep up with the ever rising demands on resources.

Youngquist offers some compelling arguments. He emphasizes many of the geological and scientific realities often ignored by academics who rely too heavily on the belief that technology will protect us from shortages. He does an excellent job exploding popular myths about the environment, energy, and mineral resources. His book is written on a level that can be understood by someone with little background in science or economics.

It is clear, however, that he has very strong views stemming from his personal background working in the oil industry. Consequently, the book is not a balanced presentation. It places little weight on how changing prices and incomes can affect the allocation of scarce resources. Nonetheless, the book is thought provoking and, at times, entertaining to read. □

### ORDER AND *OREGON GEOLOGY* RENEWAL FORM

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**REMEMBER:**

***APRIL IS EARTHQUAKE AND TSUNAMI PREPAREDNESS MONTH!***

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## Cover photo

Enerfin Resources Company plugged four depleted natural gas wells during 1997 at the Mist Gas Field in Columbia County. One of them was the Columbia County well 32-32 shown here during operation.

Summary report on oil and gas exploration and development in Oregon in 1997 begins on next page.

# April is Earthquake and Tsunami Preparedness Month

Each year the Governor proclaims April as Earthquake and Tsunami Preparedness Month. This helps focus awareness and efforts to get Oregonians ready for an earthquake.

We now know that our state has experienced earthquakes with magnitudes between eight and nine. The source of these deadly events is the Cascadia subduction zone located offshore, off Oregon and Washington. It was the process of subduction that produced the magnitude 9.2 earthquake of 1964 in Alaska, killing 122 people in that sparsely populated state. The same earthquake triggered a tsunami that caused damage along the Oregon coast and the deaths of several people at Beverly Beach.

Oregon also experiences smaller earthquakes, such as the ones in 1993, centered near Mount Angel and Klamath Falls. However, consider this: The amount of destructive energy released is 30 times higher for each next-higher number on the Richter scale. The Mount Angel quake was of magnitude 5.6; a magnitude 9 Cascadia earthquake would be over 25,000 times more powerful than that relatively small event!

Although the thought of such a killer quake can be terrifying, there are things we can do to protect ourselves. The most important thing we can do to save lives is to upgrade our buildings to withstand a serious earthquake. Make sure your house is bolted to its foundation and your water heater is strapped to a wall.. Stay away from unreinforced masonry and brick buildings if you feel a ground tremor.

In what condition are your local schools? The Riverdale School District in Portland just completed rebuilding a gym that will now protect its students, rather than endanger them, in the event of a strong earthquake.

Oregon Emergency Management, the Oregon Department of Geology and Mineral Industries, the Red Cross, the Salvation Army, and the Bank of America are supporting the organization of a statewide earthquake drill for Oregon schoolchildren. The drill will be held the morning of April 30, to coincide with a similar effort in the State of Washington.

Earthquakes are the main triggers of tsunamis. Signs explaining tsunami hazards are being erected along Oregon beaches. Tsunami warning systems and evacuation routes are being developed in many coastal communities. Both residents and visitors should note this tsunami information and take a moment to figure out how they would react if they felt an earthquake.

These steps may seem small in relation to the incredible power of earthquakes, but every small piece of information and preparation will increase your chances of making it safely through the next natural disaster. □

# Oil and gas exploration and development in Oregon, 1997

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


## ABSTRACT

There was an increase in oil and gas leasing activity during 1997 compared to 1996. The increase was primarily due to two oil and gas lease sales held by Columbia County during the year, at which approximately 10,405 acres were acquired by four companies. The acreage leased was located within or in proximity to the Mist Gas Field. Four U.S. Bureau of Land Management (BLM) lease sales were held during the year, and no offers were received. A total of 39,131 federal acres were under lease at year's end, and filed applications are pending on 4,943 federal acres. The State of Oregon conducted no lease sales during the year. There were 12 State of Oregon tracts under lease at year's end, comprising 941 acres.

Northwest Natural Gas Company (Northwest Natural) continued underground natural gas injection and withdrawal operations at the Flora and Bruer Pools at the Mist underground natural gas storage project. Operations began for development of additional underground natural gas storage at the Calvin Creek underground natural gas storage project located approximately 3 mi to the south at Mist Gas Field. This included drilling of service wells and installation of pipelines and other infrastructure development.

Northwest Natural drilled four service wells at Calvin Creek. Drilling was under way at a fifth service well at year's end. These wells will be used for injection-withdrawal and monitoring of natural gas stored in depleted reservoirs of former gas producers at Mist Gas Field. Enerfin Resources plugged four former gas producers at Mist Gas Field and worked over two wells to enhance gas production during the year.

At Mist Gas Field, 19 wells were productive during 1997. A total of 1.4 billion cubic feet of gas (Bcf) was produced, less than the 1.7 Bcf produced during 1996. The total value for the gas was about $2.6 million, which is less than the $3.4 million for 1996.

DOGAMI revised administrative rules during the year related to oil and gas drilling bond requirements. Bonding was revised to more closely reflect actual costs to plug and abandon wells and reclaim drill sites.


## LEASING ACTIVITY

After several years of low activity, oil and gas leasing increased during 1997 primarily due to two oil and gas lease sales held by Columbia County, where approximately 10,405 acres were acquired. The leases were offered through an oral auction bidding system, and the majority of the acreage was acquired by Enerfin Resources, Houston, Texas, and Eldorado Exploration, Lakewood, Colorado. In addition, Northwest Natural Gas Company (Northwest Natural), Portland, Oregon, and Northwest Fuels, Lake Oswego, Oregon, also acquired acreage from Columbia County during the year. The leases were all located within or in proximity to the Mist Gas Field, Columbia County, Oregon. The majority of the acreage was leased at a minimum bid of $1.00 per acre, and the highest bid of $13.00 per acre was received for a 120.0-acre parcel located in sec. 31, T. 6 N., R. 5 W. within the Mist Gas Field.

The U.S. Bureau of Land Management (BLM) held four lease sales during 1997, at which no bids were received for any leases on federal lands. A total of 39,131 federal acres was under lease at year's end in Oregon. Pending applications have been filed on an additional 4,943 acres located primarily in eastern Oregon. Total rental income to the BLM was $55,544.50 for 1997.

The State of Oregon held no lease sales during 1997, and no new leases were issued. At year's end, 12 State of Oregon tracts were under lease, comprising 941 acres, which is the same as during 1996. Total rental income to the State of Oregon was $941 during 1997.

## DRILLING

Four underground natural gas storage service wells were drilled by Northwest Natural during 1997, and drilling at a fifth well was under way at year's end. The wells are part of the development of the Calvin Creek underground natural gas storage project at the Mist Gas Field. This project is adding additional underground natural gas storage capacity by converting depleted, formerly producing reservoirs into use for underground storage. The wells will be used for injection-withdrawal and monitoring of natural gas in the storage reservoirs. The injection-withdrawal wells drilled and completed were the IW 23a–22–65, located in sec. 22, T. 6. N., R. 5 W., drilled to a total depth of 2,298 ft, and the IW 32H–22–65, located in sec. 22, T. 6 N., R. 5 W., drilled to a measured depth of 2,600 ft. The latter was the first successful horizontal well drilled and completed in Oregon. The purpose of the horizontal drilling of this well was to avoid unfavorable topography and to expose a greater amount of the storage zone to the wellbore to maximize gas injection and withdrawal efficiency. A third injection-withdrawal well, the IW 22H–22–65, located in sec. 22, T. 6 N., R. 5 W., was horizontally drilled to a measured depth of 1,825 ft. The well was lost due to mechanical problems that occurred during the cementing of the intermediate casing string and was plugged and abandoned. A replacement well, the

**Above and on facing page: Installation of natural gas pipelines was part of the Northwest Natural development of the Calvin Creek gas storage project at Mist Gas field. While the pipes were being assembled, they were temporarily suspended above Highway 202 near Mist, Oregon, before they were permanently buried deep underground—and under the highway.**

IW 22dH–22–65, was being drilled at year's end. One monitoring well was drilled by Northwest Natural, the OM 12–22–65, located in sec. 22, T. 6 N., R. 5 W. It was drilled initially to a total depth of 2,350 ft, when the drillstring became stuck. It was then sidetracked to a final total depth of 2,337 ft.

Enerfin Resources plugged and abandoned four depleted former producers at Mist Gas Field during 1997. These are the JH 31–20–54, located in sec. 20, T. 5 N., R. 4 W.; the CC 22B–19–65, located in sec. 19, T. 6 N., R 5 W.; the CC 32–32, located in sec. 32, T. 6 N., R. 5 W.; and the CFI 34–1–55, located in sec. 1, T. 5 N., R. 5 W. In addition, Enerfin Resources did workovers at two wells during 1997 to increase production capabilities. These wells were the CFI 31–16–54, located in sec. 16, T. 5 N., R. 4 W., and the CER 13–1–55, located in sec. 1, T. 5 N., R. 5 W., both of which were returned to gas production at years end.

During 1997, DOGAMI issued six permits to drill. One permit was canceled during the year. Permit activity is listed in Table 1.

## PRODUCTION

The Mist Gas Field was operated by Enerfin Resources and Northwest Natural during 1997. During the year, 19 natural gas wells were productive at Mist Gas Field, 15 operated by Enerfin Resources and 4 by Northwest Natural. This is slightly less than the 21 wells which were productive at Mist Gas Field during 1996. Gas production for the year totaled 1.4 billion cubic feet (Bcf) of gas, which is lower than the production during 1996, when the Mist Gas Field produced 1.7 Bcf of gas. Most of the decrease in gas production during 1997 can be attributed to the normal decline in the production from existing wells and to the fact that no new wells were brought into production during the year.

The gas price during 1997 remained constant all year at about 21 cents per therm, which is about the same as the 20 cents per therm during 1996. The total value of the gas produced at Mist Gas Field was about $2.6 million, a decline from the $3.4 million during 1996, when there was a greater quantity of gas production. Cumulatively, the Mist Gas Field has produced about 62 Bcf of gas with a total value of about $119 million since it was discovered in 1979.

## GAS STORAGE

The Mist gas storage project, operated by Northwest Natural, remained fully operational during 1996. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora

*(Continued on page 30)*

(Continued from page 28)

Pool, and 13 monitoring service wells. The two pools have a combined storage capacity of 10 Bcf of gas. This allows for the cycling of about 6 Bcf of gas in the reservoirs at pressures between approximately 400 and 1,000 psi and will provide for a maximum peak day delivery capability of 100 million cubic feet (MMcf) of gas per day. During 1997, about 6.6 Bcf of gas was injected and 5.0 Bcf of gas was withdrawn at the Mist gas storage project.

During 1997, Northwest Natural began development of the Calvin Creek natural gas storage project which is located about 3 mi south of the Mist Gas Field storage project. The Calvin Creek storage project will increase maximum peak day delivery capability for the combined total Mist underground gas storage to 145 MMcf of gas from the current maximum of 100 MMcf of gas. Activities currently under way for the expansion include the development of a new storage reservoir with high-capacity injection-withdrawal wells, the installation of new gathering pipelines, and the upgrading of processing and compression equipment at the Miller compression station. These activities will continue during 1998.

## OTHER ACTIVITIES

During 1997, DOGAMI revised the Oregon administrative rules for oil and gas drilling bonds in Oregon. The intent was to provide protection to Oregon while not creating a disincentive for oil and gas operations in the state. Discussions to develop options for action by the DOGAMI Governing Board included the affected industry and interest groups. The final revisions that were adopted include changes to bonding requirements that reflect more closely the actual costs of plugging and drill-site reclamation. The new individual well bonding amounts for each well drilled, redrilled, deepened, or reworked are $10,000 for each well drilled to a depth less than 2,000 ft; $15,000 for each well drilled to a depth of 2,000–5,000 ft; and $25,000 for each well drilled to a depth greater than 5,000 ft. In multi-well operations, a blanket bond in the minimum of $100,000 may be filed in lieu of individual well bonds. In addition, the revisions allow DOGAMI to require that a bond be posted for any well that is idle or suspended for a period of one year or more or a gas producer that does not generate annual revenue greater than the individual bonding amount. Wells that are on production and generating annual revenue greater than that of the individual well bond may be granted an exclusion by DOGAMI. Contact DOGAMI for details.

A DOGAMI oil and gas internet homepage was constructed during 1997. The webpage address is http://sarvis.dogami.state.or.us/oil/homepage.htm. Included on this homepage are Mist Gas Field production data, oil and gas statutes and administrative rules, drilling permit application forms and other forms, a publication list, and other information.

Table 1. *Oil and gas permit activity in Oregon, 1996*

| Permit number | Operator, well, API number | Location | Permit activity (TD=total depth) |
|---|---|---|---|
| 339 | Enerfin Resources Co.<br>CC 32-32<br>36-009-00180 | NE¼ sec. 32<br>T. 6 N., R. 5 W.<br>Columbia County | Abandoned;<br>TD 2,711 ft. |
| 398 | Enerfin Resources Co.<br>CFI 34-1-55<br>36-009-00232 | SE¼ sec. 1<br>T. 5 N., R. 5 W.<br>Columbia County | Abandoned;<br>TD 1,370 ft. |
| 481 | Enerfin Resources Co.<br>CC 22B-19-65<br>36-009-00306 | NW¼ sec. 19<br>T. 6 N., R. 5 W.<br>Columbia County | Abandoned;<br>TD 2,940 ft. |
| 500 | Enerfin Resources Co.<br>CC 22-26-65<br>36-009-00320 | NW¼ sec. 26<br>T. 6 N., R. 5 W.<br>Columbia County | Canceled. |
| 501 | Enerfin Resources Co.<br>JH 31-20-54<br>36-009-00321 | NE¼ sec. 20<br>T. 5 N., R. 4 W.<br>Columbia County | Abandoned;<br>TD 2,436 ft. |
| 503 | Northwest Natural Gas<br>IW 22H-22-65<br>36-009-00323 | SW ¼ sec. 22<br>T. 6 N., R. 5 W.<br>Columbia County | Drilled;<br>abandoned;<br>TD 1,825 ft. |
| 504 | Northwest Natural Gas<br>IW 23a-22-65<br>36-009-00324 | SW ¼ sec. 22<br>T. 6 N., R. 5 W.<br>Columbia County | Drilled;<br>service well;<br>TD 2,298 ft. |
| 505 | Northwest Natural Gas<br>IW 32H-22-65<br>36-009-00325 | NE ¼ sec. 22<br>T. 6 N., R. 5 W.<br>Columbia County | Drilled;<br>service well;<br>TD=2,600 ft. |
| 506 | Northwest Natural Gas<br>OM 12-22-65<br>36-009-00326 | NW ¼ sec. 22<br>T. 6 N., R. 5 W.<br>Columbia County | Drilled;<br>service well;<br>TD 2,337 ft. |
| 507 | Northwest Natural Gas<br>OM 32-22-65<br>36-009-00327 | NE ¼ sec. 22<br>T. 6 N., R. 5 W.<br>Columbia County | Permit issued;<br>proposed TD<br>2,250 ft. |
| 508 | Northwest Natural Gas<br>IW 22dH-22-65<br>36-009-00328 | SW ¼ sec. 22<br>T. 6 N., R. 5 W.<br>Columbia County | Permit issued;<br>drilling; proposed<br>TD 2,800 ft. |

The Northwest Energy Association remained active during 1997 with over 100 members. At its regular monthly meetings, speakers gave talks that were generally related to energy matters in the Pacific Northwest. The 1997 fall symposium was held in Troutdale, Oregon, and plans are being developed for the 1998 fall symposium. For more information, contact the NWEA, P.O. Box 6679, Portland, OR 97228.

A map of the Mist Gas Field is available from DOGAMI: Open File Report O–98–1 contains well locations and status, total depth, date drilled, and other information, including locations of the Mist and Calvin Creek underground natural gas storage projects through the end of 1997. Contact The Nature of the Northwest Information Center (503-872–2750) for a complete publication list including the Oil and Gas Investigations Series. □

# Seismic hazard mapping in Eugene-Springfield, Oregon

*by Yumei Wang [1], David K. Keefer [2], and Zhenming Wang [1]*

This paper was presented at the Seventh U.S.–Japan Workshop on Earthquake Disaster Prevention for Lifeline Systems, held November 4–7, 1997, in Seattle, Washington, and will be published in the Proceedings of that workshop by the National Institute of Standards and Technology, edited by Donald B. Ballantyne, EQE International, Seattle, Washington. We are publishing it here, with minor editorial changes, by permission of the authors. —*ed.*

## ABSTRACT

The Oregon Department of Geology and Mineral Industries (DOGAMI) and the U.S. Geological Survey (USGS) are developing earthquake hazard maps for the Eugene-Springfield area in Lane County, Oregon. The method for producing the map is derived from state-of-practice dynamic analyses for ground-response, slope-stability, and liquefaction analyses; empirical correlations of slope stability with engineering properties of materials; and manipulation of data on local topography, engineering geology, and hydrology, using geographic information system (GIS) tools. Specific types of data used to produce the map include (1) distribution of geologic units, (2) engineering properties of materials in each geologic unit, (3) slope inclinations, (4) regional hydrology, (5) distribution of existing landslide deposits, (6) distribution of artificial slope alterations, and (7) ground motions from design scenario earthquakes (M 6.5 shallow crustal and M 8.3 subduction zone event).

Seismically induced ground deformation is evaluated as follows: Slopes steeper than 25° are analyzed using empirical criteria that relate slope stability to degree of weathering, strength of cementation, spacing and openness of rock fractures, and hydrologic conditions. Slopes between 5° and 25°, which in the project area are commonly mantled with aprons of heterogeneous colluvium, are evaluated with a dynamic slope-stability analysis that uses slope inclinations, engineering geologic characteristics of geologic units, and shaking parameters from design earthquakes as inputs. Slopes gentler than 5° are analyzed for liquefaction and resultant lateral spreading. Results of these analyses are then combined to produce a ground deformation map with five slope instability categories (very high, high, medium, low, and nil potential for slope failure). Site periods and maximum spectral ratio are also shown on the ground deformation hazards map. Site effects of local geology on ground shaking are evaluated using the program SHAKE91. Site periods and maximum amplification of spectral accelerations are determined and used to produce a ground response map.

The 1:24,000-scale maps resulting from this study are intended for use by local communities for regional planning and mitigation purposes. Techniques developed in this study are intended to be applicable to regional-scale mapping in other areas with a wide variety of topographic, geologic, and hydrologic characteristics.

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## INTRODUCTION AND PURPOSE

Many types of earthquake hazards can be evaluated and mitigated to an acceptable level of risk in advance of future damaging earthquakes. Ground failures from slope instability can be a significant threat, especially in urban areas with concentrated development on unstable slopes. Amplified ground shaking can be destructive, intensifying and prolonging ground shaking. Many recent earthquakes have caused significant loss of life and property damage from earthquake-induced landslides and amplified ground shaking.

This paper presents a preliminary method for producing an earthquake hazard map showing (1) dynamic (i.e., earthquake-induced) slope stability for slopes that range from steep to gentle, and (2) dynamic ground response. Dynamic slope stability is evaluated for a wide spectrum of landslide failure types. Steep slopes (>25°) are most susceptible to rockfalls and other fast-moving landslides; moderate slopes (5°–25°) are susceptible to deep-seated rotational and translational block slides; and even gentle slopes (<5°) may be susceptible to liquefaction-induced lateral spreading. Ground response results show site periods and maximum spectral ratio (earthquake-related engineering properties of a site). Site periods and maximum spectral ratios are shown as 0.1-second and 1.0-contour intervals, respectively.

The method described here for producing a hazard map is derived from dynamic ground-response, slope-stability, and liquefaction analyses; empirical correlations of slope stability with engineering properties of materials; and manipulation of data on local topography, engineering geology, and hydrology, using geographic information system (GIS) tools. The final map will be produced at a scale of 1:24,000 and with 30-ft-grid digital elevation model (DEM) data and will provide information for regional planning, design, and mitigation. The map should serve as a useful tool in reducing hazards through effective land-use and emergency planning, regional vulnerability studies, identification of areas that would benefit from site-specific studies, and organization of mitigation efforts.

The project area encompasses three 7½-minute quadrangles (Eugene West, Eugene East, and Springfield) and totals about 200 $mi^2$ (Figure 1). The project area is rectangular, includes the Metro Plan boundary, and extends beyond the three quadrangles. This project involves working closely with an advisory task force composed of local community members. It also includes establishing a temporary local seismograph network to monitor local and distant earthquakes to gain a better understanding of local sources and ground response, and performing an evaluation of structural seismic vulnerability on a limited number of selected buildings.

## BACKGROUND

From beginnings in the 1840s, the population of the Eugene-Springfield metropolitan area is now approaching 200,000 and continues to increase. The population within the Metro Plan boundary (Figure 1), an area slightly larger than both the city and urban growth areas, is projected to increase by approximately 57 percent between 1990 and 2020 (Meacham, 1990).

Building expansion continues to penetrate the hillslope and urban development areas, which tend to be difficult areas for building. Due to the nature of the geology, topography, and climate, certain areas are prone to ground failure and amplified ground shaking, which threaten both existing and new developments.

### Geographic setting

The project area is located in the southern reach of the upper Willamette basin near the confluence of the Coast and Middle Fork Willamette Rivers and the McKenzie River. It includes hills bounding the valley, with the Cascades on the east flank and the Coast Range on the west and south. The climate is moderate in temperature, and the average annual precipitation is 40 in. Generally, the elevation of central Eugene and Springfield is about 400 ft.

### Geologic setting

The Willamette Valley geomorphic province is a broad lowland separating the Oregon Coast Range from the Cascade Range. This terrain is part of the forearc basin associated with the Cascadia subduction zone and consists of interfingering, gently dipping Tertiary rocks ranging from Eocene to Miocene in age,

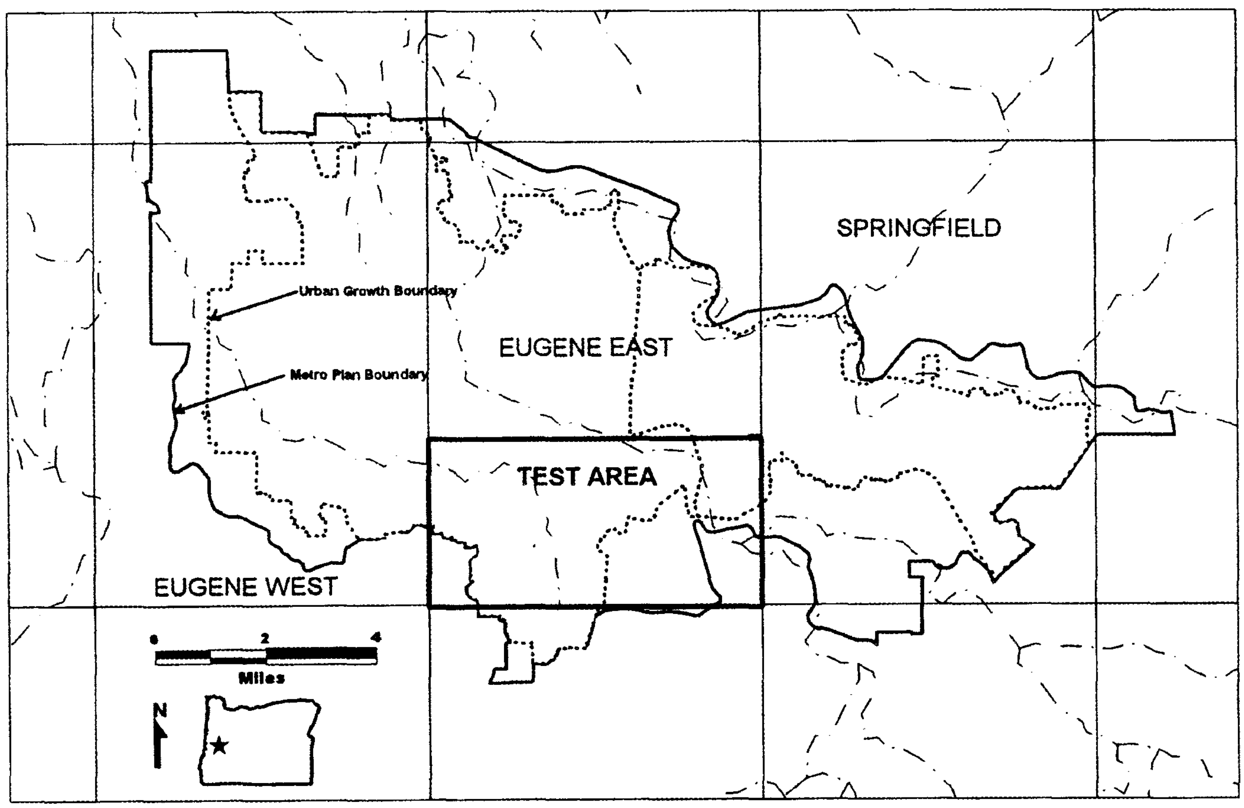


**Figure 1. Location map showing test area for pilot project and its location with respect to urban growth and Metro Plan boundaries of the Eugene-Springfield area as well as main topographic quadrangles. Dash-dot lines mark major drainages.**

including volcanic flows and intrusions, tuffaceous sediments, and sedimentary rocks (Walker and Duncan, 1989). In the Willamette Valley, bedrock units are overlain by Quaternary-age alluvium and thus are not well understood in detail. The smooth alluvial plain of the Willamette Valley is interrupted by occasional flood and stream channels. Table 1 describes the geologic units found, and Figure 2 shows their distribution, in the test area that is discussed later under "Slope Analyses."

## Seismic setting

The physiographic setting of the Pacific Northwest results from its plate tectonic setting. From northern California to British Columbia, oceanic plates, including the Juan de Fuca plate, are being subducted beneath the North American plate along the Cascadia subduction zone. Earthquakes can occur within the subducting Juan de Fuca plate (oceanic intraplate earthquakes), within the overriding North American plate (crustal earthquakes), or along the interface between the two

Table 1. *Geologic units in the Eugene-Springfield metropolitan area. Modified from Walker and Duncan (1989).*

| Symbol | Age | Description |
|---|---|---|
| Qal | Holocene | **Alluvium**—Clay, silt, sand, and gravel in river and stream channels |
| Qoal | Holocene/Pleistocene | **Older alluvium**—Poorly consolidated clay, silt, sand, and gravel marginal to active stream channels and filling lowland plains of Willamette River Basin and tributary drainages |
| Tub | Miocene | **Basalt and basaltic andesite flows and flow breccias**—Grades laterally into palagonitic tuff and breccia and into clastic sedimentary rocks |
| Ti | Oligocene | **Mafic intrusions**—Sheets, sills, and dikes of massive granophyric ferrogabbro; some bodies strongly differentiated and include pegmatitic gabbro, ferrogranophyre, and granophyre |
| Tf | Oligocene/Eocene | **Fisher Formation, undivided**—Predominantly continental volcaniclastic rocks, including andesitic lapilli tuff, breccia, water-laid and air-fall silicic ash, and interbedded basaltic flows |
| Te | Oligocene/Eocene | **Eugene Formation**—Thin- to moderately thick-bedded, coarse- to fine-grained arkosic, micaceous, and, locally, palagonitic sandstone and siltstone, locally highly pumiceous, assigned to the upper Eocene to middle Oligocene, marine Eugene Formation |
| Tfb | Eocene | **Basaltic flows**—Flows, some of which may be invasive into the undivided Fisher Formation (unit Tf), and undivided and questionable sills that may intrude the undivided Fisher Formation |

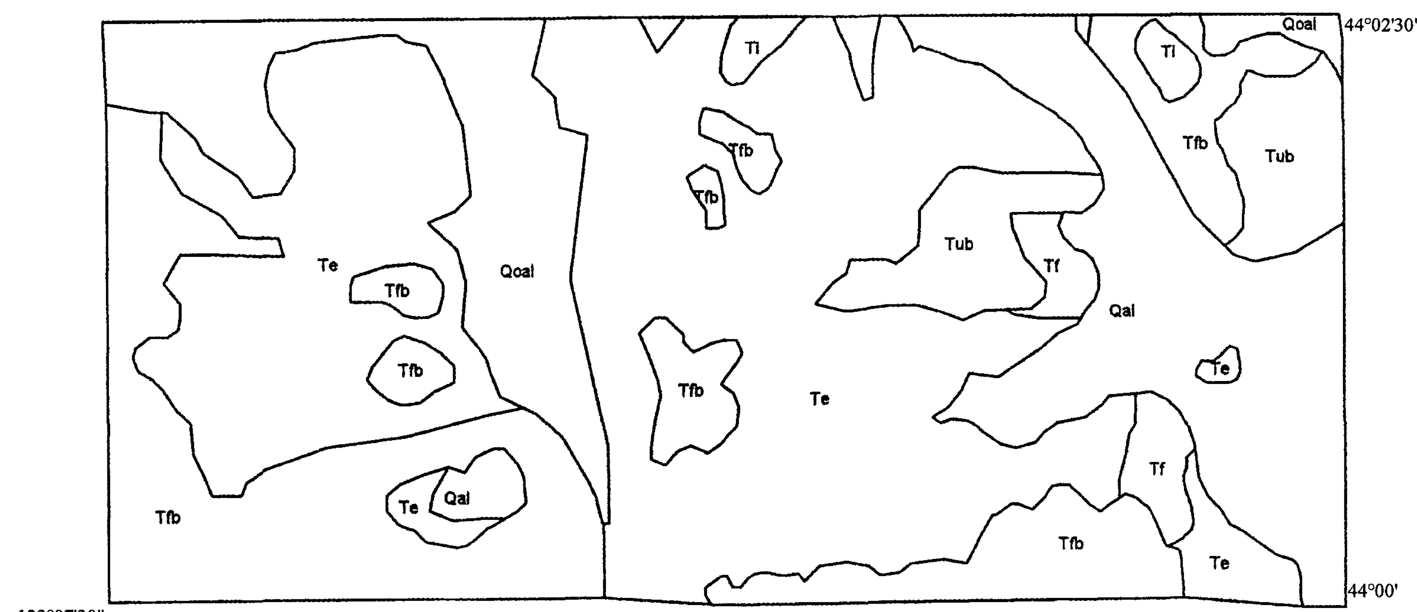


**Figure 2. Simplified geologic map of test area, modified from Walker and Duncan (1989). Coordinates approximate. Geologic unit symbols keyed to Table 1 above.**

plates (subduction zone earthquakes). All three possible earthquake types (subduction, oceanic intraplate, and crustal) can severely impact the project area, and each was considered as part of this study.

Although no damaging earthquakes have occurred during historic times, small local earthquakes have been recorded. A recent study that focused on evaluating ground response in Eugene and Springfield (R. Weldon and S. Perry-Huston, University of Oregon Geological Sciences Department, unpublished data) included the recording of several very small local earthquakes. In January 1996, a cluster of small earthquakes occurred about 15 mi east of Eugene. Later, in May 1996, a small earthquake occurred about 3 mi north-northwest of downtown Eugene. These earthquakes have not been identified with any specific fault structure (S. Perry-Huston, oral communication, 1997) but indicate zones of potential threat to local communities. The project area is located about 60 mi east of the Cascadia subduction zone, where several large-magnitude subduction zone earthquakes are thought to have occurred in the past few thousand years (Atwater, 1996). A strong local crustal earthquake or great subduction zone earthquake would likely produce strong ground shaking for all geologic units in the project area. Bedrock ground motions incorporated in the study were developed by Geomatrix Consultants, Inc. (1995).

## DATA COLLECTION

The method used to evaluate earthquake-induced ground failure and local ground response requires information on the geologic units (their distribution and engineering characteristics), slope angles, hydrology, and the occurrence of existing landslides and large artificial slope alterations. The distribution of geologic units was determined from published geologic maps (Walker and Duncan, 1989; Vokes and others, 1951) and from additional mapping carried out as part of the study. The engineering properties of materials in each geologic unit were determined from field mapping, laboratory testing of selected materials, in situ tests, and engineering judgment. Field work included the mapping of over 200 outcrops considered to be reasonably representative of the geologic units. In situ tests included downhole shear wave velocity profiling, surface refraction profiling, and standard penetration testing. Slope inclinations were determined using geographic information system (GIS) tools and digital elevation models (DEMs) with a grid spacing of 30 ft. Regional hydrology was determined from borehole and well data, mapping of springs and seeps, and also hydrologic modeling conducted by the local water departments. Existing landslide deposits were mapped as part of the study. Input on active landslides was provided by local consultants and public works department staff. Lastly, artificial slope alterations, such as large road and railroad cuts were identified. The method does not specifically address slope aspect, vegetation, and human effects (such as logging and grading practices).

## SLOPE ANALYSES

Preliminary analyses were conducted in a test area that covers about 20 $mi^2$ of the project area (Figure 1). Slopes in the test area are divided into four groups: (A) existing landslides; (B) steep slopes, greater than 25°; (C) moderate slopes, ranging from 5° to 25°; and (D) gentle slopes, less than 5° (Figure 3). It was assumed that groups (B), (C), and (D) have fundamentally different modes of dynamic failure. Consequently, different analytical techniques were applied to these groups as shown in Figure 4.

### (A) Existing landslides

The movement characteristics of existing landslides are highly variable and range from actively moving to stable. To understand the nature of each existing landslide would require numerous site-specific evaluations. In the absence of this landslide information, it was assumed that the slip planes are at reduced shear strengths of unknown values, and that existing landslide masses are inherently unstable under earthquake loading. Thus, existing landslides were assigned to the very high susceptibility rating. No analytical techniques were applied.

### (B) Steep slopes

Bedrock slopes greater than 25° are particularly susceptible to slope failures (Keefer, 1993). Consequently, slopes greater than 25° were assigned to Group B, steep slopes. Engineering properties of geologic units, including degree of weathering, strength of cementation, spacing and openness of rock fractures, and hydrologic conditions, were mapped in outcrops. Each outcrop was assigned to a mapped geologic unit. Then, each geologic unit was evaluated for susceptibility to slope failure, using a decision tree outlined in Keefer (1993) and shown in Figure 5.

For each geologic unit, the average value from the rating category was analyzed, using empirical criteria that relate slope instability to area (Keefer, 1993). Keefer (1993) related engineering properties observable in outcrop to landslide concentrations, expressed as number of landslides per square kilometer ($LS/km^2$) (1 $km^2 \approx 0.4$ $mi^2$). For the geologic units within the test area, each outcrop was rated according to Figure 5. Then, the results were averaged for each geologic unit, using the following landslide concentration relationship:

$$LS/km^2 = (32)(\%\text{ extremely high}) + (8)(\%\text{ very high}) + (2)(\%\text{ high}) + (0.125)(\%\text{ low}),$$

where the multipliers (32, 8, 2, and 0.125) are taken from landslide concentrations used to assign ratings in Keefer (1993). Landslide concentration results are shown in Table 2, column 3. Then, each geologic unit was assigned a new susceptibility rating compatible with the DOGAMI earthquake hazard rating system of high, medium, or low on the basis of calculated landslides per square kilometer value as follows:

$$\text{high} > 2\ \text{LS/km}^2 > \text{medium} > 1\ \text{LS/km}^2 > \text{low}.$$

Table 2. *Landslide concentration and ratings for geologic units. Geology after Walker and Duncan (1989)*

| | Geologic unit | Lithology | LS/km$^2$ | DOGAMI rating |
|---|---|---|---|---|
| Tfb | Basalt flows | Basalt | 10.82 | High |
| Te | Eugene Formation | Sandstone | 5.34 | High |
| Tf | Fisher Formation | Volcaniclastics | 2.73 | High |
| Tub | Basalt flow breccias | Breccias | 1.83 | Medium |
| Ti | Mafic intrusions | Gabbro | 1.30 | Medium |

The resulting dynamic landslide susceptibilities for each geologic unit are shown in Table 2, column 4.

The following illustrates how the susceptibility was determined for a specific geologic unit, unit Tub, which consists predominantly of basalt and basaltic andesite flows and flow breccias: A total of 34 outcrops was mapped and evaluated in accordance with Keefer's (1993) method. Of this total, 31 outcrops, or 91 percent, were assigned a susceptibility rating of high, and 3 outcrops, or 9 percent, were assigned a rating of low. Landslide concentration was determined as follows:

$$2 \times 0.91 + 0.125 \times 0.09 = 1.83$$

and produced a result of 1.83 landslides per square kilometer. This value falls into the medium susceptibility rating.

**(C) Moderate slopes**

Slopes ranging from 5° to 25° were assigned to Group C, moderate slopes. For moderate slopes, we assumed that coherent, relatively deep-seated translational and rotational slides are the most common modes of failure (Keefer, 1984). Moderate slopes in the project area are commonly mantled with aprons of heterogeneous colluvium. Our method for rating these slopes is based on the dynamic slope stability analysis of Newmark (1965), as verified and extended to regional-scale use by Wilson and Keefer (1983, 1985), Wieczorek and others (1985), Jibson (1993, 1996), and Jibson and Keefer (1993).

The selected earthquake input parameters included two controlling events: A magnitude 8.5 subduction zone earthquake at a 100-km (~60-mi) distance from

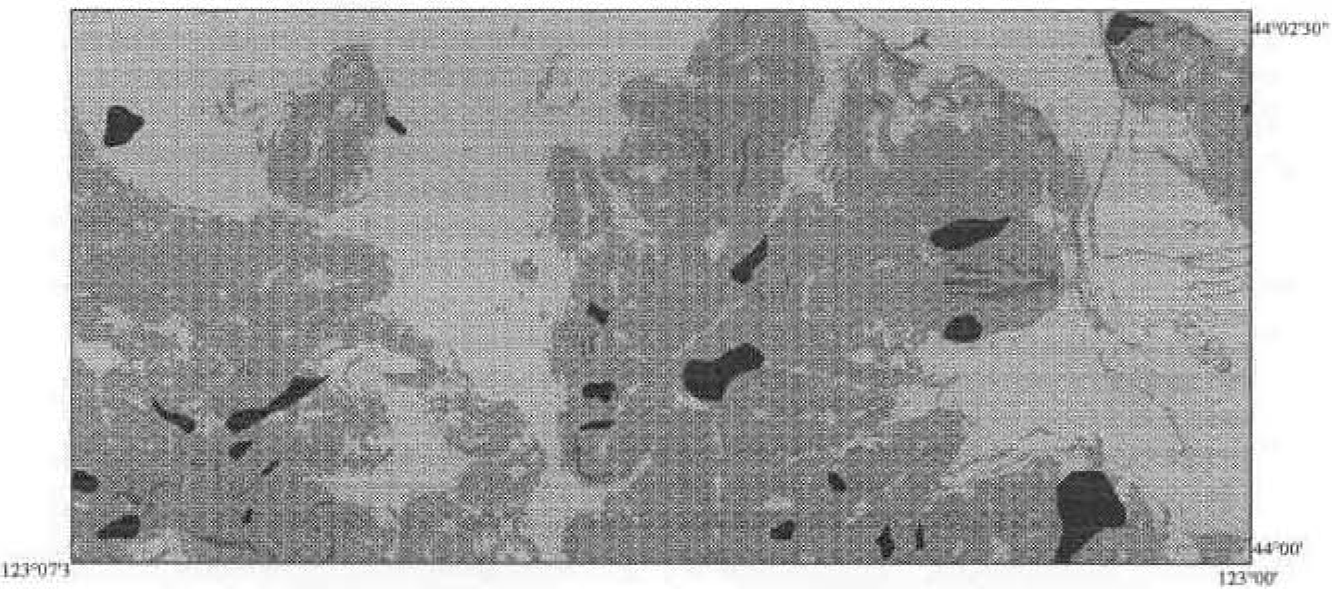


**Figure 3. Distribution of slope types—groups A, B, C, and D—in test area (approximately, bottom third of Eugene East quadrangle). Different analytical techniques were applied to these groups.**


**Group A, existing landslides**

**Group B, steep slopes, >25°**

**Group C, moderate slopes, 25° to 5°**

**Group D, gentle slopes, <5°**

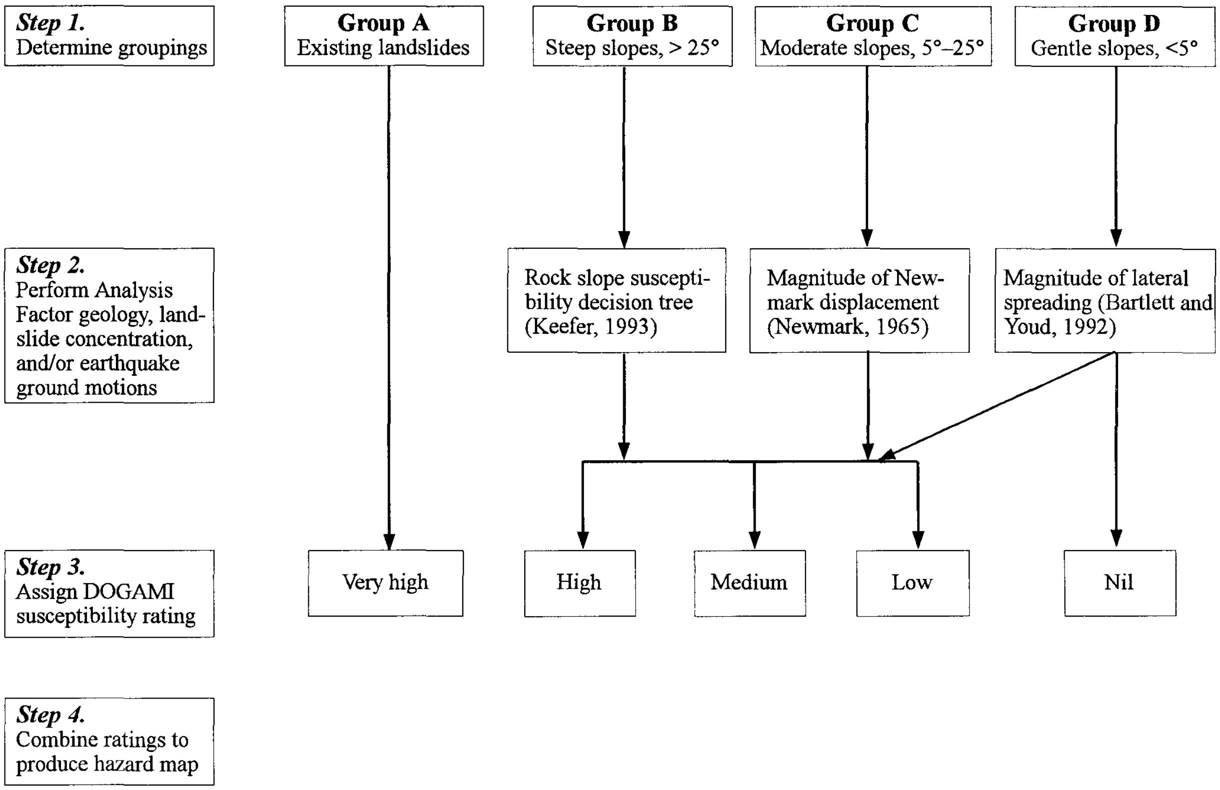


**Figure 4. Method of slope ratings flow chart.**

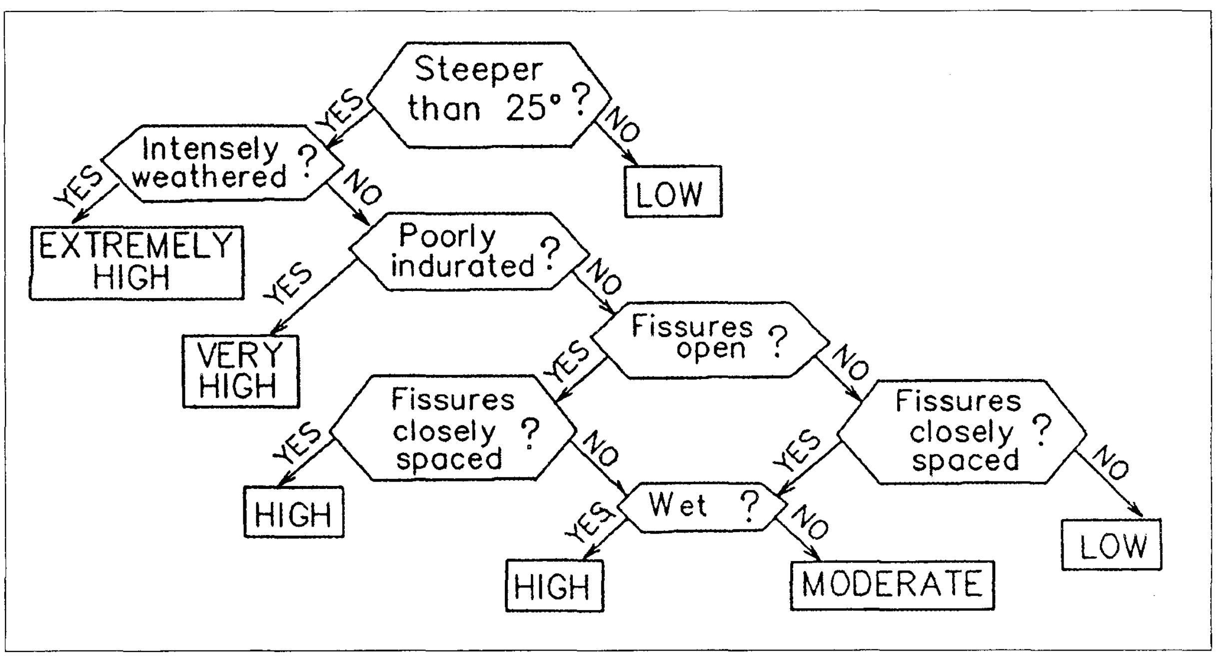


**Figure 5. Decision tree for susceptibility of rock slopes to earthquake-induced landslides (from Keefer, 1993). For the test area, all slopes were assumed to be wet.**

the earthquake source and a magnitude 6.5 event at 10-km (~6-mi) distance. Arias Intensity ($I_a$) values were determined based on magnitude and distance from the source according to the equation developed by Wilson and Keefer (1985):

$$\log (I_a) = \mathbf{M} - 2 \log R - 4.1,$$

where $I_a$ is in meters per second, **M** is moment magnitude, and R is earthquake source distance in kilometers. Next, assuming an infinite slope failure, an equation by Newmark (1965),

$$a_c = (FS - 1)\, g \sin \alpha,$$

was used to calculate the critical acceleration ($a_c$). Here, $a_c$ is the acceleration required to overcome frictional resistance and initiate sliding in terms of $g$, the acceleration due to Earth's gravity; FS is the static factor of safety; and $\alpha$ is the angle from the horizontal by which the center of the mass of the potential landslide block first moves. The Newmark displacement ($D_N$, in cm) was then determined from the relationship (Jibson, 1993; Jibson and Keefer, 1993):

$$\log (D_N) = 1.460 \log I_a - 6.642\, a_c + 1.546.$$

Finally, each slope was assigned a DOGAMI susceptibility rating based on the calculated displacement $D_N$:

high > 100 cm > medium > 10 cm > low,

as shown in Figure 4.

### (D) Gentle slopes

Slopes less than 5° were assigned to Group D, gentle slopes. For these, we calculated lateral-spreading (i.e., slope-instability) susceptibility for Quaternary-aged geologic units that are prone to liquefaction failure. Gentle slopes underlain by pre-Quaternary geologic units were assumed to be stable and were automatically given a susceptibility rating of nil. Areas of Quaternary-aged units were separated in order of depositional age, with artificial fill and the youngest deposits generally being the most vulnerable to slope movement. The selected earthquakes include a **M** 6.5 event at a 10-km distance and a **M** 8.5 subduction zone earthquake at a 100-km (~60-mi) distance and were adopted from an Oregon Department of Transportation study (Geomatrix Consultants, Inc., 1995).

To evaluate for lateral-spreading susceptibility, we first estimated the site effects of local geology on ground shaking by using SHAKE91, a commercially available program for analyzing one-dimensional site-response of vertically propagating (normally incident) shear waves at a level site (Idriss and Sun, 1992). Peak rock accelerations on the synthetic acceleration time history were scaled to 0.34 $g$ and used as input parameters in SHAKE91. The peak surface accelerations determined from SHAKE91 analysis were used as input accelerations in the liquefaction analyses.

Next, initial liquefaction was analyzed by two methods: The first, by Robertson and Fear (1996), is an improvement of the method developed by Seed and others (1984) and is based on standard penetration test (SPT) measurements. The second, by Andrus and Stokoe (1996), is based on shear wave velocity measurements. Both methods were used to maximize the available in situ data in the project area and account for the uncertainties associated with evaluating the predominantly gravelly soils.

For soils that are prone to liquefaction, lateral spreading was estimated using Barlett and Youd (1992). According to Barlett and Youd (1992), lateral spreading due to liquefaction satisfies:

$$\log (D_H) = -15.787 + 1.178\, \mathbf{M} - 0.927 \log R - 0.013\, R + 0.429 \log S + 0.348 \log T_{15} + 4.527 \log (100 - F_{15}) - 0.922\, D50_{15},$$

where $D_H$ is lateral spreading in meters; **M** is moment magnitude; R is horizontal distance to the nearest seismic energy source, in kilometers; S is ground slope, in percent; $T_{15}$ is the cumulative thickness, in meters, of saturated cohesionless soils with $(N_1)_{60}$ value ≤15; $F_{15}$ is the average fines content, in percent; $D50_{15}$ is mean grain size.

To illustrate this method, we used drill hole data from Test Site ES-2, which is located in the Eugene West quadrangle (Figure 1). SHAKE91 was run, and a peak surface acceleration of 0.40 $g$ was achieved. Liquefaction was analyzed using methods of Robertson and Fear (1996) and Andrus and Stokoe (1996). Next, for soils that liquefy, lateral spreading was calculated, using Bartlett and Youd (1992). We assumed: **M** = 8.5, R = 100 (km), $D50_{15}$ = 1.0 (mm), $F_{15}$ = 5 percent, $T_{15}$ = 5 m, and S ranging from 1° to 5°. Results, shown in Table 3, indicate that for this liquefiable deposit, steeper slopes have greater lateral spreading displacements (0.56 m) than gentler slopes (0.28 m). According to the method shown in Figure 4, the DOGAMI susceptibility rating based on the calculated displacement $D_H$,

high > 100 cm > medium > 10 cm > low — or nil,

places all of these slopes in the medium susceptibility category.

Table 3. *Lateral spreading displacements ($D_H$) for test site ES-2. After Bartlett and Youd (1992)*

| Slope (S, in degrees) | Displacement ($D_H$, in meters) |
|---|---|
| 1 | 0.28 |
| 2 | 0.38 |
| 3 | 0.45 |
| 4 | 0.51 |
| 5 | 0.56 |

**Slope susceptibility ratings**

Applying susceptibility ratings within each of the four groups (A—existing landslides, B—steep slopes, C—moderate slopes, and D—gentle slopes) requires professional judgment. The last step involves bringing the independent analytical results from each group together to produce a coherent, uniform, relative hazard susceptibility map. Results from each group fall within one of five susceptibility ratings for dynamic slope instability: very high, high, medium, low, and nil (Figure 4).

## DYNAMIC GROUND RESPONSE ANALYSES

For the local geologic conditions in valley areas with about 10 ft or more of soil deposits (Figure 6), site period and maximum spectral ratio were evaluated. Site effects on ground shaking were determined using SHAKE91. Design earthquakes for M 6.5 crustal and M 8.3 subduction zone events were modeled, assuming epicentral distances of 10 km and 100 km, respectively.

Preliminary results of site period, which was determined for 26 site-specific soil locations, were contoured at 0.1-second intervals (Figure 7). At these locations, amplification curves and Fourier response spectra were plotted to determine maximum spectral ratios, that is, maximum amplification of spectral accelerations. Figure 8 illustrates the process of determining maximum spectral ratios, including the input parameters (initial damping, density, shear wave velocity), input and output acceleration time histories, and spectral response showing the maximum spectral ratios. Figure 9 shows preliminary results of maximum spectral amplification contours. These amplification factors can be correlated with site period (shown in Figure 7) to indicate areas of potential soil-structure resonance that can cause structural damage. Higher damage also occurs in areas with prolonged strong shaking, which can be generally related to areas with longer site periods.

## DISCUSSION

The method described in this paper is still under development, and preliminary results using this method are scheduled to undergo additional review during 1998. The tentative final product is one 1:24,000-scale colored map showing ground failure hazards, site period, and maximum spectral ratios. These data were selected by community representatives with the assistance of DOGAMI and USGS staff for the purpose of predicting high-damage areas for a wide range of users.

Additional research is needed to improve the accuracy of predicting dynamic ground response on a regional basis. To calibrate the reliability of this method, more post-earthquake field calibrations must be performed. Special attention should be given to determining dynamic slope-stability hazards for moderate slopes.

## ACKNOWLEDGMENTS

We owe special thanks to Stephen E. Dickenson of the Oregon State University Civil Engineering Department and Robert E. Kayen of the U.S. Geological Survey for their helpful reviews. We also thank Gerald Black for technical advice, Donald Hull and John Beaulieu for supporting this study, Klaus Neuendorf for editorial assistance, Tom Wiley and Robert Murray for geologic assistance, and Neva Beck for assisting in the preparation of this paper.

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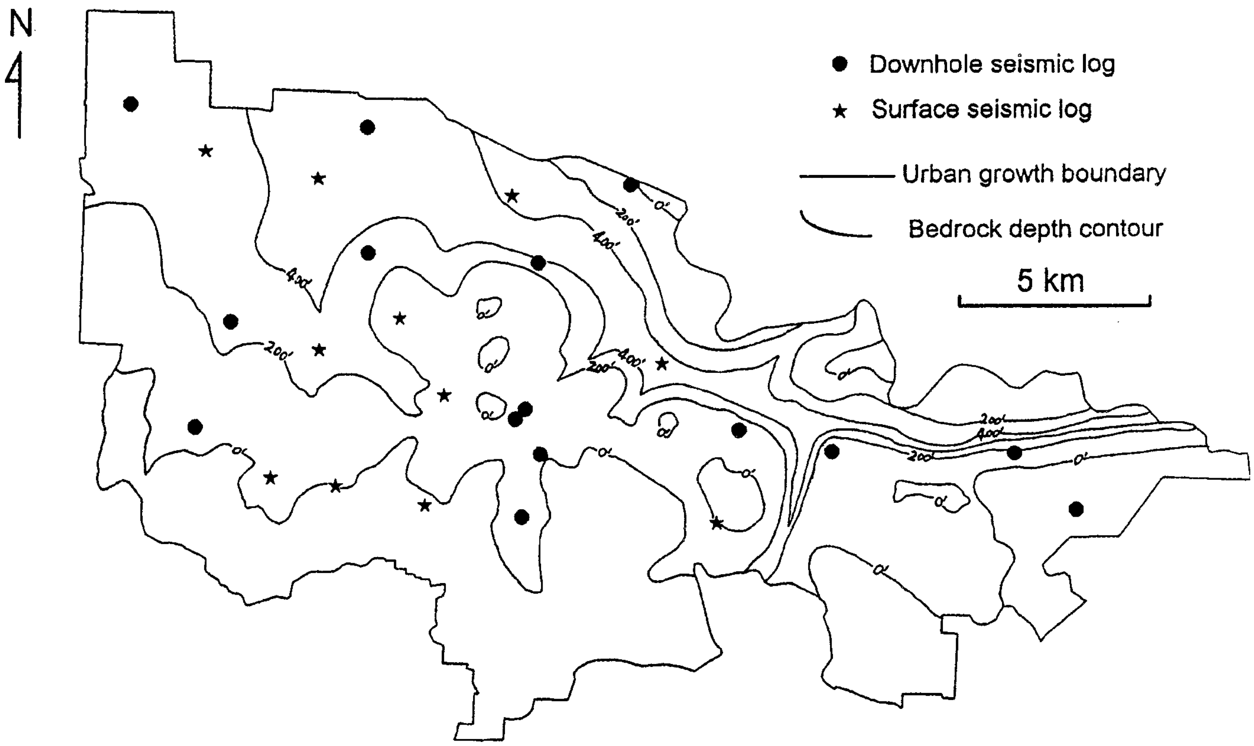


**Figure 6. Location of seismic log and generalized depth to bedrock contours in the Eugene-Springfield urban growth boundary. Contours in 200-ft intervals.**

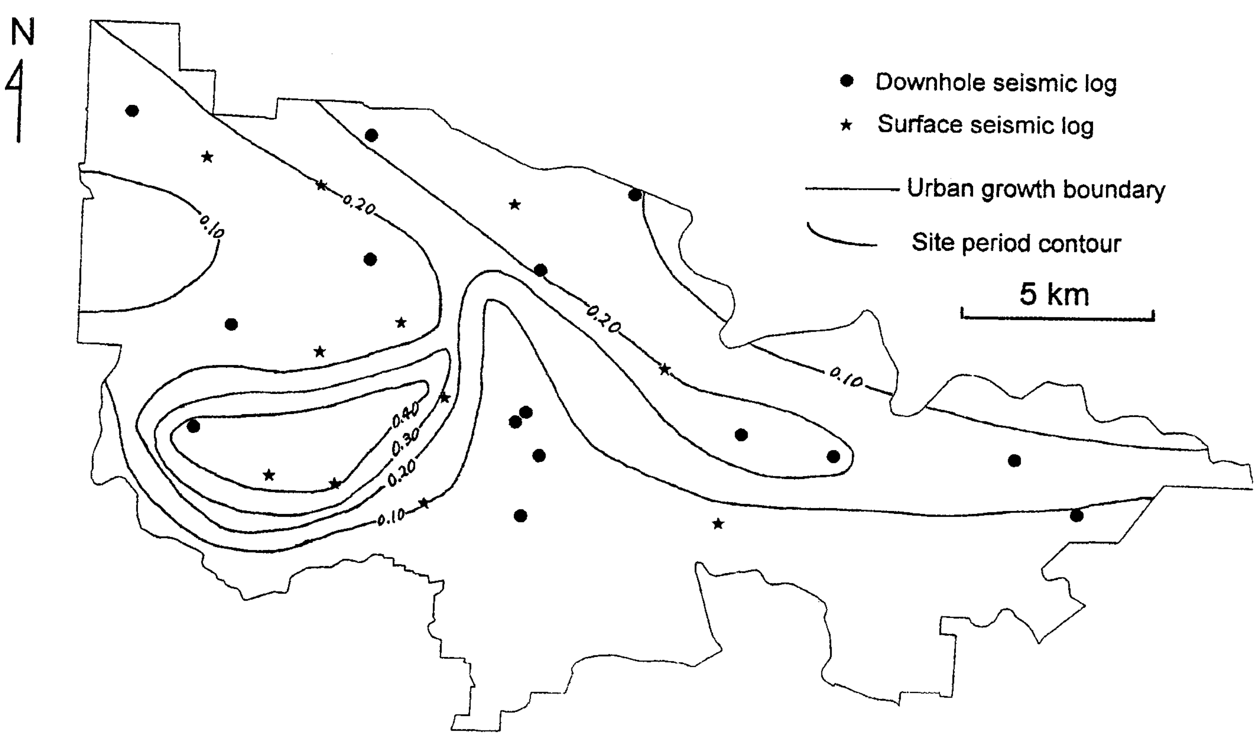


**Figure 7. Site period, preliminary results. Contours in 0.1-second intervals.**

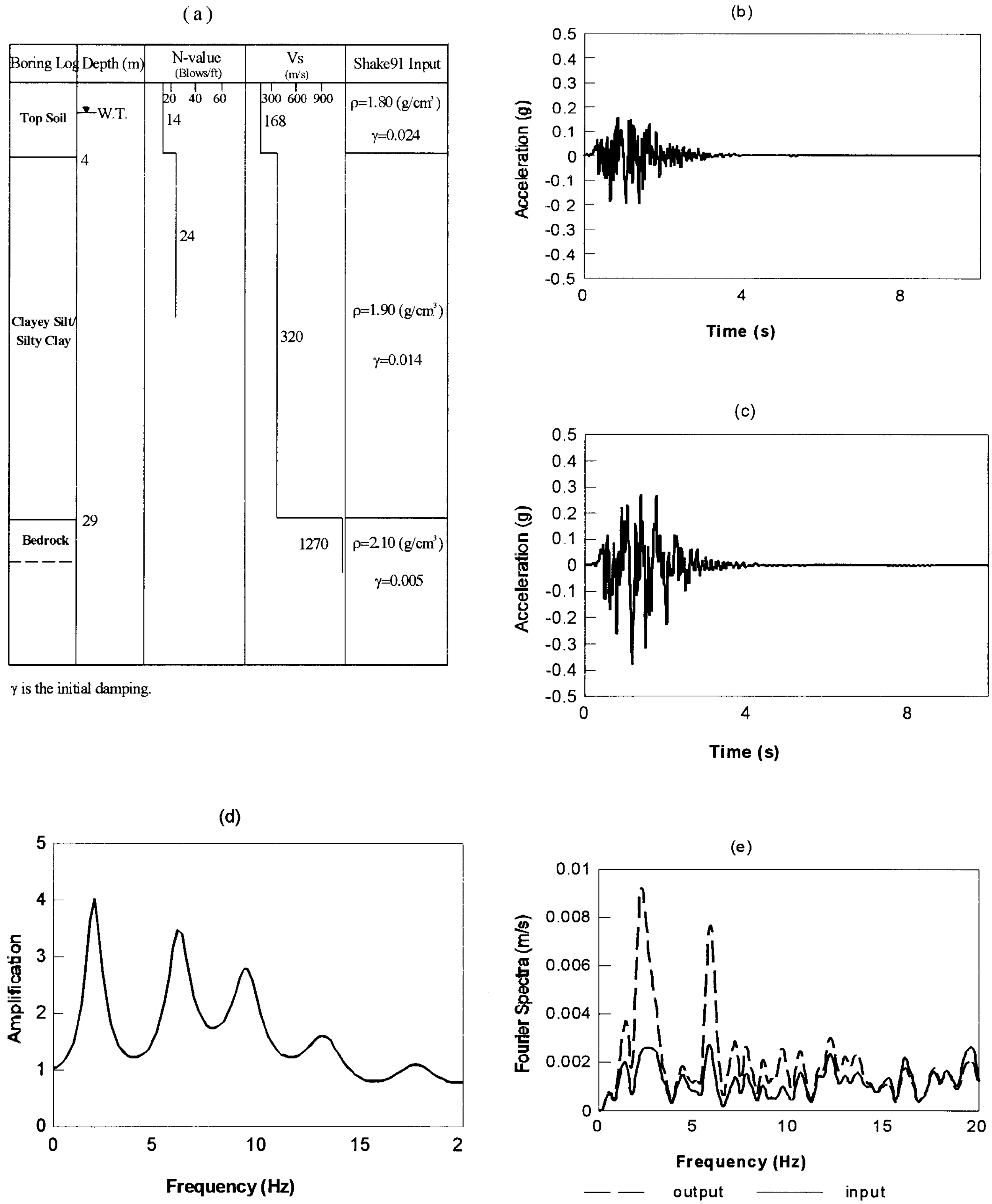


**Figure 8. Soil column and SHAKE91 modeling at Site ES-2. (a) soil column and SHAKE91 input parameters; (b) input ground motion (M 6.5 crustal earthquake) at bedrock; (c) output ground motion on free surface; (d) amplification curve; (e) input and output Fourier spectra.**

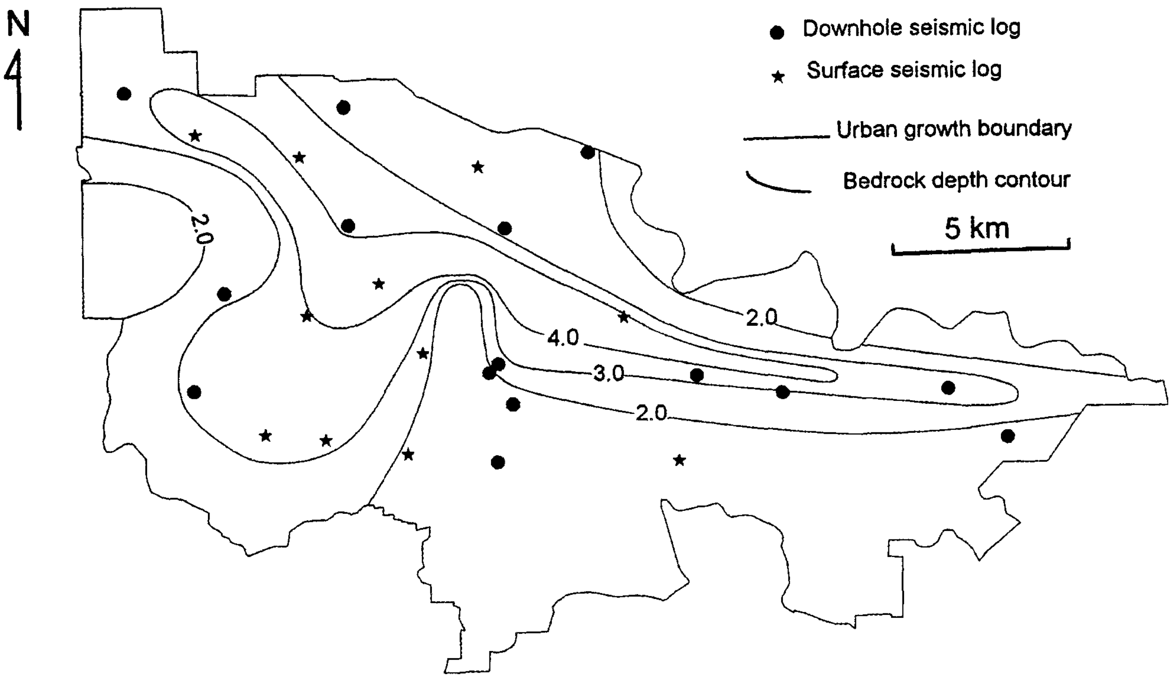


**Figure 9. Spectral amplification, preliminary results. Contours in 1.0 intervals.**

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## Papers on applied geology now available as a book

An important and voluminous treatment of geologic applications in Oregon has been published in conjunction with the 40th annual meeting of the Association of Engineering Geologists held in Portland last fall:

**Environmental, Groundwater, and Engineering Geology: Applications from Oregon**, edited by Scott Burns of Portland State University, is a 689-page, hardbound volume now available from the Nature of the Northwest Information Center. See listing on p. 48. □

# Measuring earthquakes in Oregon

*By Yumei Wang, Zhenming Wang, and Gerald L. Black, Oregon Department of Geology and Mineral Industries*

How do we know when earthquakes occur? Sometimes, earthquakes are felt by people. Sometimes, they are recorded by seismic instruments. In some cases where there are no people and the seismic instrument coverage is poor, earthquakes are not detected at all. A primary goal of earthquake monitoring with specialized instruments is to detect and locate earthquakes and to obtain a better understanding of potential earthquake sources. Instruments measure data that help scientists understand the likely sizes, locations, frequency of occurence, and types of earthquakes and their effects. In the Pacific Northwest, modern seismic instruments have been recording since about 1950 (Shedlock and Weaver, 1991).

The three main types of seismic instruments are strong-motion instruments, short-period instruments, and broadband instruments. These instruments record ground motions for various levels of shaking (i.e., amplitudes) and frequencies. To explain frequencies in terms of sound: A high pitch is characterized by high frequencies, and a low pitch by low frequencies. In general, strong-motion instruments measure strong levels of shaking over a wide range of frequencies (i.e., a wide bandwidth). In contrast, short-period and broadband instruments measure low levels of shaking; at high levels of shaking, the ground motions are "clipped" or "saturated" and are not recorded. Broadband instruments can measure a wide range of frequencies, whereas short-period instruments measure only high frequencies. Oftentimes, at important locations, both broadband and strong-motion instruments are installed so that a full range of amplitudes and frequencies is recorded.

Other important features of seismic instruments include the type of data-recording system and communication linkage. The age and available resources often dictate the data functionality and accessibility. For example, many older instruments record in analog form on photographic film and usually require on-site visits to download data. Newer instruments record data in a digital format. Recorded data may be designed to be accessed via modem (i.e., phoning the site to retrieve data) or even automatically telemetered back to a central network in real time.

The Pacific Northwest Seismic Network (Network) covers a large part of the Pacific Northwest. The Network is operated through the University of Washington (UW) and the U.S. Geological Survey (USGS) at UW in Seattle, Washington. DOGAMI coordinates with Network staff and helps facilitate the development of the Network. The Network maintains an array of strong-motion, short-period, and broadband instruments. These instruments have communication links that include (a) real-time, (b) dial-up, and (c) on-site downloading. The Network archives the data collected, performs routine processing, and provides information to researchers and the public, including DOGAMI.

The latest technological trend involves "real-time warning systems." It is possible to provide real-time information on earthquakes, provided that adequate instruments and communication links are in place. This new technology can determine the magnitude and location of the earthquake while it is in progress. The goal is to relay information to nearby communities before the onset of damaging shaking. Early warning information has a number of applications. One example is to stop trains so that derailment and loss of shipment does not occur. Several real-time systems are currently operational in the United States. The most advanced system, called California Institute of Technology/U.S. Geological Survey Broadcasting Earthquakes (CUBE), is located in southern California.

The Network is developing a real-time monitoring network, called Rapid Alert of Cascadia Earthquakes (RACE). Ground motions from earthquakes are automatically telemetered to central recording facilities in Seattle. A detection algorithm is immediately applied to these data, and the earthquakes are analyzed by a computerized system that determines earthquake arrival times and epicentral locations. For earthquakes larger than magnitude 2.9, magnitude and location information is quickly disseminated via commercial pager to RACE test sites. DOGAMI, which was the first test site for RACE, is helping the Network by testing an off-site prototype.

Over the next few years, the USGS plans to add several instruments along the coast. The purpose is twofold: (1) to detect Cascadia subduction zone earthquakes that can produce near-field tsunamis, that is, big waves that are generated from nearby offshore earthquakes, and (2) to minimize false alarms of tsunamis, that is, to distinguish inland earthquakes that cannot initiate tsunamis from subduction zone earthquakes that can. The sites will include both strong-motion and broadband instruments. A long-term goal is to develop a real-time, near-field tsunami warning system. This system will warn the citizens in tsunami prone (low-lying coastal) areas to evacuate.

The remaining discussion focuses on DOGAMI's involvement with seismic instruments in Oregon.

DOGAMI's instrumentation program focuses on three fundamental areas:

1 To improve the regional seismic network.
2 To evaluate ground response in the greater Portland area.
3 To satisfy regulations stipulated by Oregon Building Code statutes.

## IMPROVE REGIONAL SEISMIC NETWORK

The current instrument density in Oregon is low and needs improvement. DOGAMI's recent survey of all known strong-motion instruments is shown in Figure 1. Public sector owners include the Oregon Department of Transportation Bridge Section, the U.S. Army Corps of Engineers, the U.S. Geological Survey, the Oregon State System of Higher Education, and several local governments. There is only one private-sector owner, who has several instruments at the Trojan power plant in Columbia County.

Strong-motion accelerographs are deployed primarily to record ground motion accelerations generated by earthquakes that might have significant impacts on engineered structures. The primary uses are to provide data for seismological and geotechnical modeling studies and for the design and analysis of engineered structures (e.g., bridges and buildings). Most current systems are designed to trigger the recording mechanism only during substantial shaking (Shaking greater than 0.01 *g* can be felt.) A low level of shaking, for example from traffic vibrations, is ignored.

DOGAMI supports the expansion of the Network to better serve the citizens of Oregon. Oregon's population is concentrated in the greater Portland area and the Willamette Valley. DOGAMI's current records indicate approximately nine strong-motion instruments in this area, of which three belong to the USGS. Instrument density is sparser outside this populated corridor.

DOGAMI has recently proposed to expand the Network in the Portland metropolitan area and the Willamette Valley. We have recommended that 50 free-field strong-motion instruments be added to improve the regional geographic coverage for earthquake monitoring. This would allow scientists to better characterize earthquake seismicity and ground response in developed areas and may lower the current detection threshold for very small earthquakes.

## EVALUATING GROUND RESPONSE IN PORTLAND

Currently, DOGAMI and the University of Oregon Department of Geological Sciences (UO) are deploying a temporary seismic network in the greater Portland area. The purpose is to measure and analyze actual earthquake ground response and to evaluate the ground motion amplification portion of the 1997 DOGAMI/Metro relative earthquake hazard map (Mabey and others, 1997). To collect ground motion data, a total of approximately 12 sites will be occupied for six- to eight-week periods over a one-year time span. DOGAMI is responsible for the site selection, which is based on geologic conditions. UO deploys the portable broadband instruments and performs data analyses. This effort is funded by the U.S. Federal Emergency Management Agency (FEMA) and is scheduled to be completed in late 1998.

## OREGON BUILDING CODE STATUTES AND RULES

In the 1994 Uniform Building Code, Chapter 16 (Structural Forces), Division II, the sections 1646–1649 (Earthquake Recording Instrumentation) describe the

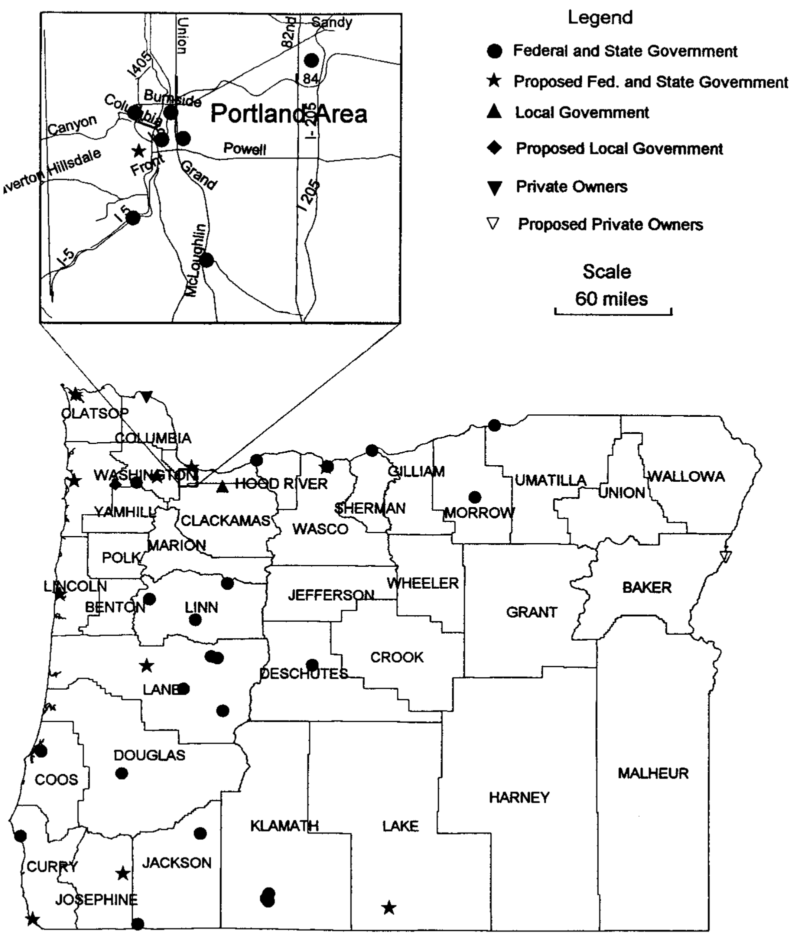


**Figure 1. Strong-motion accelerograph stations in Oregon.**

requirements of seismic instrumentation for certain newly constructed buildings. The owner/developer of these buildings is required to install seismic monitoring equipment and monitor and maintain the equipment once installation is complete. The purpose of instrumenting buildings is to understand and improve the dynamic response of buildings during earthquakes. Alternately, the owner/developer may be allowed to provide DOGAMI with funds equivalent to the cost of instrumenting the building. DOGAMI will use these funds to acquire and install strong-motion instruments. Sites selection will be focused on such sites that will increase our understanding of structural and regional ground motion response during earthquakes.

DOGAMI is adding two new free-field strong-motion instrument sites in 1998 with the fund moneys. The sites will be located in the greater Portland metropolitan area and integrated into the Network. DOGAMI has identified several possible sites. Characteristics influencing site selection include geologic conditions, security, electrical and communication access, and local background "noise" due to culturally induced vibrations (e.g., traffic).

The Department is also pursuing a cooperative project with USGS staff associated with the Network. DOGAMI has selected the potential sites, and the USGS would evaluate the suitability of these sites with respect to background noise. In addition, DOGAMI would like the USGS to perform initial tests of the newly purchased instruments, install and maintain the instruments, and help collect, analyze, and disseminate data.

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## DOGAMI PUBLICATIONS

### Released February 12, 1998

**Best Management Practices for Reclaiming Surface Mines in Washington and Oregon**, revised edition, December 1997, by David K. Norman, Peter J. Wampler, Allen H. Throop. E. Frank Schnitzer, and Jaretta M. Roloff. Open-File Report O–96–02 rev., approx. 130 p., $8.

The manual describes reclamation and mining practices for landowners, land-use planners, and mine operators in Oregon and Washington. The revision incorporates comments from the mining industry as well as other reviewers of the initial 1996 release. In addition, several new diagrams and innovative best management practices have been added.

*Best Management Practices* was produced cooperatively by members of the Washington Department of Natural Resources, Division of Geology and Earth Resources, and the DOGAMI Mined Land Reclamation Program. The project was supported in part by the U.S. Environmental Protection Agency and conducted under the Tri-State Agreement for Mining between Idaho, Oregon, and Washington.

The approximately 130-page, extensively illustrated manual provides information about managing a surface mine from start-up to final reclamation, incorporating water and erosion control during operation and reclamation, soil salvage and replacement, land shaping, and revegetation. The authors urge miners to use this manual as a resource in developing an environmentally and financially sound mine.

**The Capes Landslide, Tillamook County, Oregon**, by George R. Priest. Open-File Report O-98-02, 10 p., $5.

The report concerns the current landslide threat to The Capes development near Netarts on the coast of Tillamook County. It contains a preliminary assessment of the geologic conditions and discusses some possible options for mitigating this hazard.

It was prepared by Dr. Priest as a memorandum to the Director of the Oregon Emergency Management Division of the Oregon State Police Department. The report includes two draft illustrations showing the location of the landslide and a cross section.

### Released February 12, 1998

**Tsunami Hazard Map of the Yaquina Bay Area, Lincoln County, Oregon**, by George R. Priest, Edward Myers, António M. Baptista, Robert A. Kamphaus, Curt D. Peterson, and Mark E. Darienzo. Interpretive Map Series IMS–2, two-color, scale 1:12,000 (aerial-photo base map), $6.

The new map is intended primarily for evacuation planning for the event of a tsunami but could also be adopted as a basis for planning and decisions in the areas of building code, construction, or insurance ratings.

The map was produced by Dr. George R. Priest in cooperation with scientists from the Oregon Graduate Institute of Science and Technology, the Center for

*(Continued on page 46)*

## LETTERS

**Geology along U.S. Highways 197 and 97 between The Dalles and Sunriver,** by Gary Smith, v. 60, no. 1 (January/February 1998), p. 3–17:

I reckon it is correct to say that "dozens" of cinder cones dot the flanks of Newberry volcano. However, we feel that *several hundred* or *over three hundred* sounds considerably more impressive. A minor point, I admit, but we are all slaves to our pet volcanoes, and we are fortunate to have several on the Deschutes that are worth arm-waving about. Unlike those flashy, unstable volcanic showoffs to the north and south of us, "our" volcanoes presently keep to themselves (and in doing so take us out of the running for large appropriations from Congress).

—Sherri L. Lee,
Newberry National Volcanic Monument,
Bend

***GeoDestinies*, by Walter L. Youngquist** (Book review by R.M. Whelan), v. 60, no. 1 (January/February 1998), p. 22:

As Mr. Whelan says, *GeoDestinies* discredits the widely-held belief that "Science will think of something." Population growth on this planet is increasing almost exponentially, especially in the so-called "developing countries," and although technological discoveries have been able to provide the food and energy needed to maintain a reasonably comfortable living for most people, this situation cannot continue forever.

Mr. Whelan asserts that the price of most mineral products has declined over the years and implies that this trend will continue into the foreseeable future. As much as we may wish otherwise, there are *finite amounts* of minerals, including fossil fuels, on this earth, and a point will be reached sometime during the next century when technology simply will not be able to keep up with the increased demand. As a result, commodity prices will rise.

GeoDestinies is a carefully documented report covering a wide range of topics that describe be the ever-growing importance of minerals in both national and international affairs. The two chapters on alternative energy sources are especially worth of study and should be required reading for everyone who feels that such "new technologies" as solar power, wind power, fusion, and hydrogen fuel cells will produce all our energy needs in the 21st century.

I am particularly disturbed by Mr. Whelan's comment that the author's "personal background" as a petroleum geologist with more than 50 years' experience does not allow him to give a completely objective view of the subject. I would argue that, on the contrary, what we need at the policy-making level in this country are people like Dr. Youngquist who are especially knowledgeable in the fields of mineral exploration and development because of the very nature of their expertise.

—R.E. Corcoran,
Mineral Investigations and Land Appraisals,
Portland

It is fashionable to speak of resource-dependent communities, by which we mean those that are immediately dependent upon exploitation of natural resources. Dr. Youngquist's book shows that this concept is flawed: *every* community is resource dependent. Everyone daily exploits energy, food, and materials from the Earth.

Working from the perspective of an experienced petroleum geologist, Dr. Youngquist has given his audiences a lively, readable, realistic, extraordinarily broad survey of global resources. He brings together multiple aspects of human use, abuse, and depletion of resources and explains interconnections among resources, geopolitics, and society. The effect is incisive.

The book is usefully arranged as twenty-nine chapters that range through introductory historical essays on civilizations and peoples to discussions of the geologically fortunate, resource-rich nations and the unfortunate ones; the enormous importance of petroleum and its coming exhaustion; the importance of the mostly hidden depletion of soil and groundwater; alternative sources of energy and their prospects and the energy and resources of the oceans; and on to summary chapters on policy, politics, society, "sustainable" society, and the future. There are ample subheadings and a good index The book is an essential reference for our future. I know of no other quite like it.

—Laurence R. Kittleman,
Geologist, Eugene

*GeoDestinies* comes at the reader like a steamroller with facts, data, logic, and a lot of old-fashioned horse sense to examine the relationship of mineral resources to the destinies of host nations. Youngquist does not pretend the relationship is absolute, but he makes a good case with example after example of nations that have emerged to prominence and power when the mineral resources they controlled became appropriate to the technology of the day—and then faded when those mineral resources became depleted. With no mineral resource is this more clearly demonstrated than with petroleum.

Youngquist, a veteran of *The Oil Patch*, speaks with authority of the most critical mineral resource of our day. It is clearly appropriate to call this *The Petroleum Interval*, in contrast to the Iron Age or the Bronze Age, in that this interval began about a hundred years ago and won't last more than another hundred. There's a good reason: We're clearly running out of the stuff. He explains in some detail why there's no more to be found.

The book treats with the oil-generated affluence of the nations of the Persian Gulf and with our own affluence; but however fascinating it gets, there is the feeling that there is the *Skull Looking In at the Banquet*: About the year 2007, this planet's ability to produce oil will have peaked and begun a nosedive that will not be reversed. At the same time there will be an increasingly sophisticated demand for greater production by a population that is growing at an exponential rate.

Youngquist meets head-on the inevitable suggestion that the depletion of resources, be they petroleum or groundwater or copper, be resolved by exploiting ever lower grade deposits. This proposed solution withers rather readily when confronted with the mathematical proof that such exploitation rapidly creates a negative return. You put more into the ground than you get out.

It's not a pretty picture, and you might not read this thing just for he fun of it, but you can't put it down, either. It makes too much sense, scary sense.

Robert G. Russell,
Metals exploration geologist (ret.),
Coeur d'Alene, Idaho

*(Continued from page 44)*
Tsunami Inundation Mapping Effort of the National Oceanic and Atmospheric Administration (NOAA) at Newport, Oregon, and the Department of Geology at Portland State University.

The tsunami hazard map shows a black-and-white air-photo image of the coastal zone, approximately from Northwest 15th Street in the north to Henderson Creek and the south end of King Slough in the south with elevation contours superimposed. The scale of 1:12,000 (1 inch = 1,000 feet) allows identification of streets and medium-sized structures. Three different types of red lines mark expected tsunami runup elevations that serve to separate risk zones: high runup, moderately high runup, and moderately low runup. The map also identifies drill sites where cores revealed buried soils and, in some cases, tsunami sand layers from prehistoric events.

Detailed discussion of the map and its use, the methods used, and the geologic evidence of prehistoric earthquakes and tsunamis on the coast is provided in a separate publication, entitled Cascadia Subduction Zone Tsunamis: Hazard Mapping at Yaquina Bay, Oregon. Final Technical Report to the National Earthquake Hazard Reduction Program, and released in December 1997 as DOGAMI Open-File Report O–97–34 (price $10).

For ordering information, see order form on last page of this issue; for field office addresses, see masthead on page 26. □

## AVAILABLE PUBLICATIONS
## OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

| BULLETINS | Price | ☑ |
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| **033** Bibliography (1st supplement, 1936-45). 1947 | 4.00 | |
| **036** Papers on Tertiary Foraminifera (v. 2 [parts VII-VIII]). 1949 | 4.00 | |
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## Cover photo

Nestucca Spit, projecting south from Cape Kiwanda, demonstrates the erosion power of storm waves in this picture of March 1978. Two articles in this issue describe the intensifying effect the El Niño and La Niña phenomena exert on coastal hazards in Oregon. Photo by Oregon Department of Transportation.

## Chinese earthquake scientists visit to learn from Oregon

A 12-member delegation of seismologists and engineers from eastern China met with staff of the Department of Geology and Mineral Industries (DOGAMI) in April. The visit was organized by the Oregon Office of Emergency Management (OEM) as a means to exchange information on earthquake hazards and communication techniques

Each of the delegates was a director of a local branch of the Chinese National Earthquake Bureau. The function of the bureau is to disseminate earthquake-related information and to assist local government on earthquake issues. The visitors were especially interested in the methods used by DOGAMI to communicate information to various sectors of the public.

Dr. Zhenming Wang, a geotechnical specialist with DOGAMI, helped organize the trip and provided translation assistance. Dr. Wang previously worked for nine years at the Earthquake Bureau of Fujian Province before coming to the United States. Fujian Province is a sister state to Oregon and was one of the stops Governor John Kitzhaber made during his visit to China earlier this year.

State Geologist Don Hull and director of earthquake programs Yumei Wang explained Oregon's earthquake hazards and how Oregonians deal with them. They discussed ways of disseminating earthquake information and how state and local governments and the public are partners in earthquake hazard mitigation efforts. As in China, many Oregon areas are at risk from multiple hazards, where shaking is followed by such disasters as collapsed buildings, landslides, and tsunamis.

Although Chinese experts have predicted a few of the many large earthquakes that have occurred in China in this century, most earthquakes came without any warning. The Chinese government has adopted a new policy, Earthquake Prevention and Disaster Reduction, that places emphasis on mitigation rather than prediction.

The Chinese shared valuable lessons in preparedness, particularly from their public schools. On September 16, 1995, the city of Zhangzhou was shaken by an earthquake (M 7.3). The students in a middle school without earthquake education reacted in a panic, and several thousand suffered injuries. But students in a city primary school that had conducted earthquake education reacted correctly, and no one was hurt. Because of other experiences like this around the world, Oregon law requires schools to hold at least two earthquake drills a year. Coastal schools must hold three drills a year and include tsunami evacuation drills.

Delegates also visited OEM, Portland State University, the Portland area Metro office, the Emergency Management Center in Keizer, Marion County, and the Rural Fire Protection District of Cannon Beach, Clatsop County. □

# Impacts of the El Niño Southern Oscillation on the Pacific Northwest

*by George H. Taylor, State Climatologist, Oregon State University, Corvallis, Oregon 97331*[1]

## INTRODUCTION

The El Niño Southern Oscillation (ENSO) exerts a profound influence on global weather and climate patterns. A great deal of time and effort has been spent investigating the phenomenon, with good success. Increasingly, ENSO predictions and assessments are being used for decision-making, with benefits for the economy, public safety, and the environment. Oregon and the Pacific Northwest are strongly influenced by ENSO, and as ENSO information has improved and become more publicized it is being used more frequently in both the public and private sectors for everyday and long-term decisions. Below is a brief overview of ENSO effects in this region, followed by several examples of how such information is influencing decisions.

## HISTORY OF ENSO

Residents of the west coast of South America have long been aware of occasional changes in weather patterns that dramatically change the landscape. Northern Chile and southern Peru are among the driest areas in the world, while cold offshore currents and strong upwelling produce some of the richest fishing grounds anywhere. Every few years, however, a warm, southward moving current flows along the coast that raises water temperatures significantly and abruptly ends upwelling. The warm current is accompanied by heavy rains that turn the desert into a lush garden and replace barren sand with green pastures. Such episodes were known as "años de abundancia" (years of abundance) to the locals (Philander, 1990). Unfortunately, the effects on the ocean conditions were just the opposite: the normal abundance of bird and marine life virtually disappeared, devastating a major portion of the local economy. These periods of warm offshore waters became known as "El Niño" (Christ Child) because they generally appeared immediately after Christmas. Later, they were often known as "warm events" or "warm episodes."

Early in the 20th century, Sir Gilbert Walker began to study large-scale weather patterns in the tropics in hopes that they could explain the occasional disastrous failures of Indian monsoons. Walker became Director-General of Observatories in India in 1904; a few years earlier, a poor monsoon had led to a widespread famine in that country. Walker discovered that interannual pressure changes over the Indian Ocean and the eastern tropical Pacific Ocean are out of phase: lower than average pressures over the Indian Ocean correspond with higher than average pressures over the east Pacific and vice versa. Walker named this phenomenon the "Southern Oscillation." It became clear that monsoons are part of a global climate system, and Walker undertook an effort to better understand the components and variables in hopes of producing better predictions for monsoon timing and intensity.

Between 1923 and 1937, Walker and his associates published many papers and reports and successfully found correlations between the Indian monsoon and weather in various parts of Africa, Asia, North America, and the Atlantic and Pacific Oceans. Unfortunately, the attempts to produce a prediction scheme failed. This lack of a prediction scheme and of a good physical explanation for the cause-effect relationship, caused Walker's contemporaries to be very skeptical of his work. As a result, interest in the Southern Oscillation faded during the mid-20th century (Philander, 1990).

If Walker had had better sea-surface data, his findings might have been much more significant (and better accepted). Unfortunately, the available data were quite inadequate. It was not until the International Geophysical Year of 1957–58 that thorough measurements were made during a period of significant ocean and atmosphere anomalies. A strong "warm event" occurred that year, and warm surface waters were found to extend nearly to the Date Line. For the first time the true extent of El Niño was revealed. Accompanying the large area of warm surface waters were weak trade winds and heavy rains throughout the eastern tropical Pacific. After many decades, Walker's theory had been observed and verified.

Nonetheless, El Niño events remained poorly understood and infrequently studied. In the 1960s and 1970s, Dr. William Quinn of Oregon State University, an oceanographer, became interested in the El Niño phenomenon and began making trips to South America to study it. Quinn taught himself Spanish and Portuguese so he could pore over explorers' log books, fishing records, and other Peruvian and Chilean documents in search of anecdotal information about El Niño occurrences. His published results (Quinn and Neal, 1987) list

[1] Oregon weather and climate are the subject of the internet home page of the Oregon Climate Service at http://www.ocs.orst.edu/

El Niño events back to A.D. 1525. At the time of his death in 1994, Quinn was working on an El Niño data set dating to A.D. 622. Quinn's conclusion was: The El Niño phenomenon has been with us for millennia.

In 1982–83, the strongest El Niño event of the century formed in the Pacific and began affecting the Pacific Rim and most of the rest of the world. Severe weather and climate effects were widespread and disastrous on almost every continent. Australia, Africa, and Indonesia suffered droughts, dust storms, and brush fires. Peru was hit with the heaviest rainfall in recorded history—11 ft in areas where 6 in. was the norm. Some rivers carried 1,000 times their normal flow. The United States, particularly California, was hit very hard. Worldwide, the event was blamed for between 1,300 and 2,000 deaths and more than $13 billion in damage to property.

The El Niño devastation of 1982–83 gave the world a wake-up call. Suddenly, the potential effects of a strong El Niño event were recognized and understood. Scientists began measuring and studying the tropical Pacific in hopes of being able to identify and forecast the conditions and help citizens of the world to prepare for trouble. In the past 15 years, El Niño has been thoroughly studied and discussed. Philander (1990) and Diaz and Markgraf (1992) provide excellent overviews of the ENSO phenomenon.

This improved understanding paid off handsomely in 1997. Quite suddenly in the early spring, an El Niño event began to develop. It was immediately identified by scientists, who began to inform regulatory agencies and emergency response teams, as well as the media. Despite a great deal of hype (some have called this "the weather event of the century," which it certainly is not!), agencies have been able to prepare for this event like no other in history. When California and the Gulf Coast began to be pummeled by massive storms in early 1998, just as scientists had predicted, the advance warning was appreciated.

## EL NIÑO AND LA NIÑA

Typical El Niño events begin with a decrease in easterly winds off South America, reducing upwelling and causing sea-surface temperatures to increase. This warms the atmosphere and lowers the pressure over the eastern Pacific, causing the trade winds to be further reduced. Gradually this process continues until El Niño develops. In strong El Niño situations, anomalously warm waters cover nearly all of the eastern and central tropical Pacific. The area of strong convection (large rain clouds) usually shifts eastward as waters in those areas warm.

El Niño has a counterpart, which happens approximately as often: it is known as "La Niña" or "cold event." During normal conditions, the sea-surface temperatures across the tropical Pacific increase steadily from east to west. El Niño conditions cause a reduction in this temperature gradient. La Niña events, on the other hand, see an increase in the east-west gradient, with western Pacific temperatures even warmer than average and eastern waters cooler. The result is an even stronger, more concentrated area of convection in the western Pacific with above-average precipitation and more tropical storms than usual.

The sequence of events that is thought to cause El Niño conditions (described above) may also apply to La Niña formation, except in reverse. In the latter case, increased easterly winds off South America would cause greater upwelling, cooler sea temperatures, higher air pressure, and hence still stronger winds. Bjerknes (1969) suggested "a never-ending succession of alternating trends by air-sea interaction in the equatorial belt." He added, "just how the turnabout between trends takes place is not yet quite clear." Bjerknes believed that investigations of ocean dynamics held the key to understanding these transitions.

## EFFECTS OF ENSO IN THE PACIFIC NORTHWEST

The earliest systematic study of ENSO in the Northwest was conducted by Redmond and Koch (1991). They concluded that there are "a few dominant modes which account for most of the temporal variation in the surface climate." They determined that the Southern Oscillation Index (SOI) can be used as a predictor for climate, especially during winter. SOI, originally used by Walker to define and detect the Southern Oscillation, is based on pressure differences between Tahiti and Darwin, Australia. SOI values less than zero represent El Niño conditions, near zero values are "normal" or average, and positive values represent La Niña conditions. According to Redmond and Koch, the greatest correlations between SOI and winter climate patterns in the Northwest occurred with about a 4-month time lag, with summer average SOI correlating well with conditions in the Northwest during the following winter The results were sufficiently strong that the authors suggested a cause-effect relationship.

In recent years, the Oregon Climate Service (OCS) has studied various aspects of this SOI-climate relationship in the Northwest. We have also investigated use of other indices and correlations involving averages other than the summer SOI. Some general results are listed below.

### Precipitation

For the most part, El Niño or warm events correlate with below-average precipitation the following winter in the Northwest. In southern Oregon, the correlation is fairly weak, but north of about Roseburg (and extending into Bristish Columbia) the correlation is fairly strong. The winter of 1982–83 was a notable exception in that it was a very wet winter throughout the Northwest, but the intensity and timing of that event was unprecedented, at least in the last 75 years.

Figure 1 is a plot showing the summer average SOI versus precipitation during the following winter at Bonneville Dam on the Columbia River. El Niño years (negative SOI values) are associated with average or lower than average winter precipitation, while La Niña conditions (positive SOIs) are likely to produce wetter than average winters. The horizontal lines denote the average for each SOI category.

Figure 2 shows the water-year (October-September) precipitation for the Oregon coast climate division compared with the previous summer's SOI (by categories), showing a similar relationship as Figure 1.

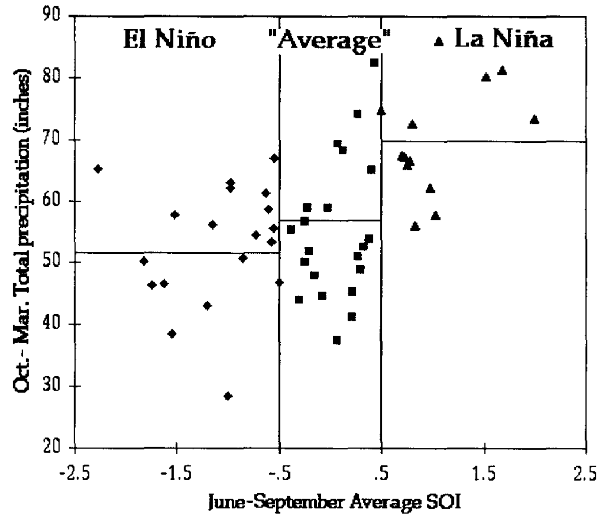


**Figure 1. Bonneville Dam winter precipitation vs. previous summer's SOI. Data points show correlation of negative SOI values (El Niño, diamonds) with low precipitation and positive SOI values (La Niña, triangles) with high precipitation during the following winter months. Squares = average; horizontal lines = average of category.**

## Temperature

Winter temperatures correlate well with SOI values. In general, negative-SOI (El Niño) conditions are associated with mild winter temperatures, while positive-SOI (La Niña) conditions have a greater likelihood of colder than average winter temperatures. These correlations apply for both long-term (monthly and seasonal averages) and short-term (individual days) periods.

Figure 3 shows mean monthly February temperatures at Astoria, Oregon, compared with the average SOI of the previous October-December period. El Niño years (negative values) generally result in mild conditions during late winter, while La Niña years are associated with colder temperatures. Figure 4 shows extreme low temperatures in Salem, Oregon, in February compared with the same October-December SOI average. Extreme cold events occur almost exclusively during La Niña years.

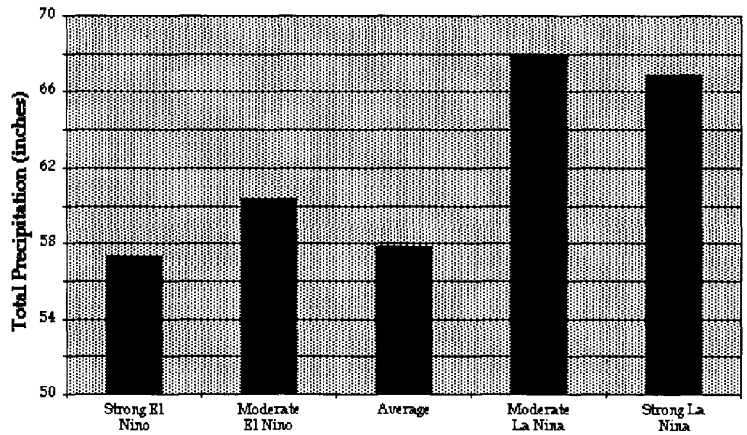


**Figure 2. Water-year precipitation, Oregon coast, vs. previous summer SOI.**

## Snowfall

A consistent correlation throughout Oregon exists between SOI and total snowfall. At either end of the SOI distribution (strong El Niño or strong La Niña), total snowfall in valley locations is relatively low; this is true both east and west of the Cascades. Although years with moderate (near-zero) SOI values may also have low snowfall totals, the years with greatest snowfall occur in conjunction with these moderate values. Figure 5 shows a plot of total winter snowfall compared with the SOI of the previous summer for Hood River, Oregon.

## EFFECTS OF ENSO NATIONWIDE

ENSO conditions cause greatly differing impacts in the northern and southern halves of the United States. In the southern tier of states (from California on the west to Florida on the east), the wettest winters occur during El Niño years, while La Niña years tend to produce dry winters. The northern states, on the other

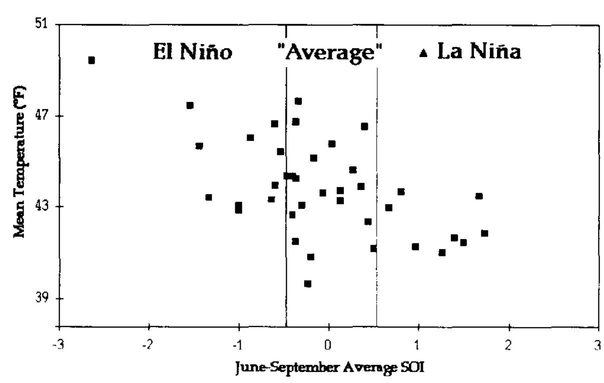


**Figure 3. Mean January-March temperature in Astoria, Oregon, vs. preceding October-December average SOI.**

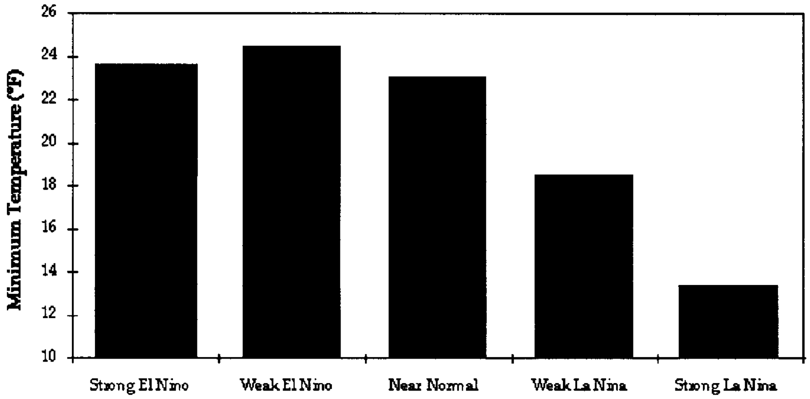


**Figure 4. Extreme low temperature, Salem, Oregon, February, vs. preceding October-December average SOI.**

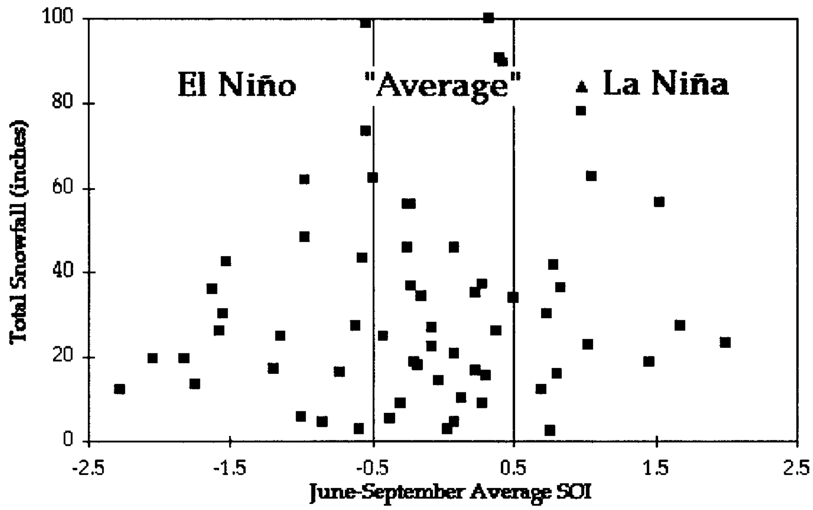


**Figure 5. Total winter snowfall, Hood River, Oregon, vs. SOI values of previous summer.**

hand, experience their driest winters during El Niño periods and the wettest during La Niña periods. Figure 6 is a chart of precipitation extremes during El Niño events for the months of December through February.

In the case of temperatures, El Niño events generally bring mild winters to the entire West Coast and the northern tier of states as far east as the Great Lakes. Figure 7 shows December-February temperature extremes during El Niño periods and indicates that only in the western Gulf Coast and western Great Plains are cold winters likely during El Niño periods. For the past winter (1997–98), observed temperature patterns have closely paralleled those in Figure 7. Oregon and Washington have been unusually mild all winter, as have the northern central states. In Minnesota, where the ice-fishing season generally begins in November, most lakes did not freeze until early January.

## IMPLICATIONS FOR DISASTER POTENTIAL AND EMERGENCY RESPONSE

As the 1997 El Niño began to unfold, emergency response personnel were warned to take preventive action to mitigate the disasters that were expected to occur. In many cases, this was justified and was borne out by the very severe weather that affected California and other parts of the United States. On the other hand, many areas were not adversely affected, including Oregon. Yet, this should not surprise us, for El Niño winters are generally quite benign here, milder than normal, and with average or below-average precipitation.

Nonetheless, many stern warnings were given Oregonians this year. In August, 1997, a "Watch Out For El Niño" article appeared in the Los Angeles Times. It warned of potentially serious weather during winter and suggested that readers prepare their homes and property for heavy rains, mudslides, and flooding. The abundant rains of January and February 1998 are testimonies to accurate forecasts of El Niño effects. In Oregon, the same article, without modification, ran in the Salem *Statesman-Journal* with the headline "Prepare for a Wild Winter." What is true for California is sometimes completely untrue for Oregon, as in this case.

What Oregonians should fear, however, is La Niña. Severe flooding during the winters of 1995–96 and 1996–97 was attributable largely to the combination of heavy snows and warm, intense tropical rain. The tropical moisture arrived in Oregon from the western tropical Pacific, where ocean temperatures were well above normal (La Niña conditions), causing greater evaporation, more extensive clouds, and a greater push of clouds across the Pacific toward the northeast. During such conditions Oregon is on the receiving end. Severe flooding, the worst in the state since 1964, killed several people and caused widespread property damage. Mudslides and landslides were numerous. The Oregon coast was lashed with strong winds, violent surf, and heavy rains. Nearly every river in Oregon reached or exceeded flood stage, some setting all-time records.

Looking back over similar damaging winters in the past, we see them coinciding frequently with La Niña events. There is now evidence that El Niño and La Niña

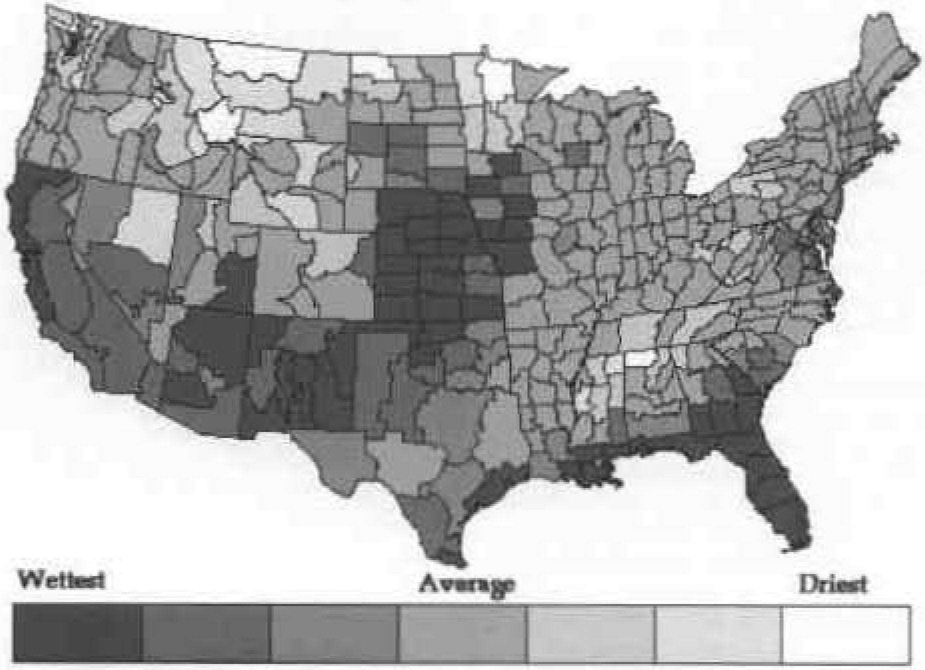


Figure 6. Precipitation extremes between December and February during El Niño years in climate divisions of the conterminous United States. Darkest = most likely rather wet winters. Lightest = most likely rather dry winters. Graphic from NOAA Climate Diagnostics Center.

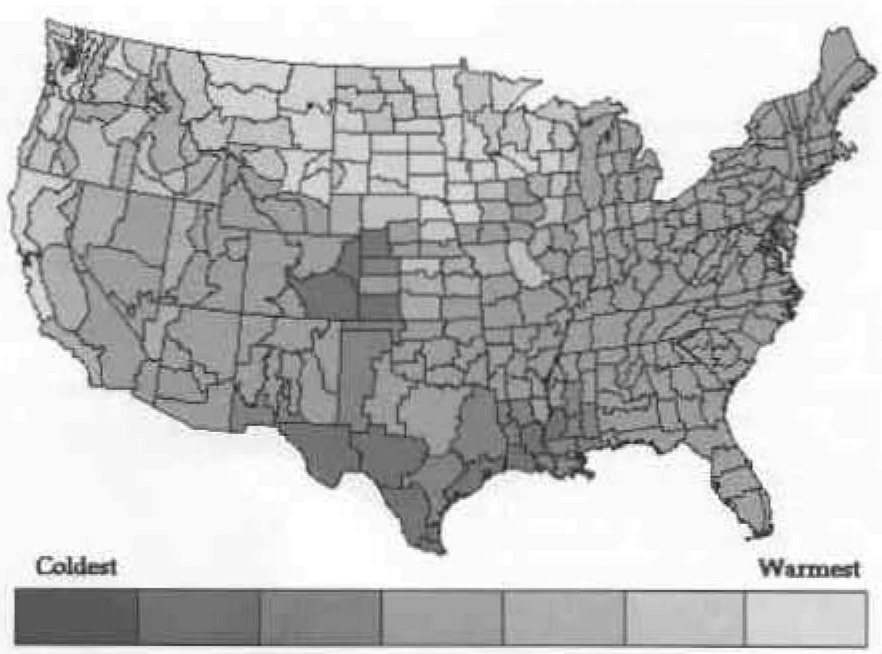


Figure 7. Temperature extremes between December and February during El Niño years in climate divisions of the conterminous United States. Darkest = most likely rather cold winters. Lightest=most likely rather warm winters. Graphic from NOAA Climate Diagnostics Center.

events, which historically occur with about the same frequency, are bunched into periods of 20–25 years, some of those years dominated by El Niño, others by La Niña. There is also evidence that a regime shift has occurred and that we have moved from an El Niño period (1975–1994) to one with many more La Niña events. The latter regime would resemble that which occurred here from about 1948 through 1973, a period dominated by cool, wet weather, abundant snows, and floods. Based on what has been observed in such periods in the past, it is likely that about 75 percent of the years will be wetter than normal in the next 20 years.

This year's rather dull winter (mild temperatures, lower than average snow pack, and only average precipitation) may be merely a brief respite in what may be an exciting and perhaps very damaging period between now and 2020. Watch for La Niña, and be prepared!


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# Oregonians need more information about tsunamis to save lives

Do you know how to save your life if a tsunami strikes the Oregon coast? Poll results recently released by the Oregon Department of Geology and Mineral Industries (DOGAMI) suggest Oregon coastal residents need more information to protect themselves from these giant waves. Tsunamis are waves that are generally up to 25 ft high, but can be 50 ft high, and are generated by undersea earthquakes.

Tsunamis can be generated by earthquakes off the Oregon coast, or they can be triggered by undersea earthquakes elsewhere in the Pacific Ocean. When asked, "If you feel an earthquake at the Oregon coast, how much time do you have to evacuate to a safe place before the first tsunami wave hits?", only 31 percent of coastal residents correctly answered 30 minutes or less. Almost half (49 percent) said they didn't know.

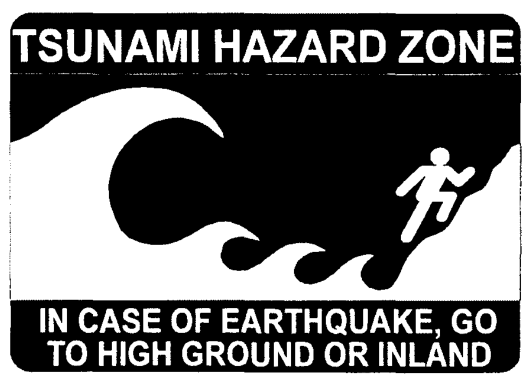
Only 27 percent knew that after a distant earthquake, they would have 1 to 8 hours before the first tsunami wave hit the Oregon coast.

When asked, "After a tsunami has struck, when is it safe to return to low-lying areas?", nearly one-fourth (22 percent) of the respondents incorrectly said it was safe to return when the wave receded. "Tsunamis are a series of waves," explained Lou Clark, Earth Science Information Officer for DOGAMI. "If you go back to the areas that were flooded by the first wave, you might get trapped by a second, third, or later wave." About a third of respondents (31 percent) gave the correct answer: "Return only when given approval by appropriate authorities."

On the positive side, 80 percent of coastal residents understood that a tsunami is a huge amount of water, and two-thirds (69 percent) understood that an earthquake along the Oregon coast could cause a tsunami. Only 3 percent incorrectly said an offshore earthquake would definitely not cause a tsunami.

To better prepare school children, coastal schools are required to participate in three earthquake and tsunami drills a year. One-fourth of respondents (24 percent) knew schools were holding drop, cover, and hold drills. About the same number (27 percent) knew schools were conducting tsunami evacuation drills.

Residents in 18 coastal cities (Astoria, Bandon, Brookings, Cannon Beach, Coos Bay, Florence, Gold Beach, Lincoln City, Newport, North Bend, Pacific City, Port Orford, Reedsport, Rockaway, Seaside, Tillamook, Waldport, and Yachats) were polled. The survey has a margin of error of plus or minus 5 percent. □



# El Niño and coastal erosion in the Pacific Northwest

*by Paul D. Komar, College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon 97403*

## INTRODUCTION

El Niño Southern Oscillation (ENSO) has a profound effect on the Earth's weather and climate and on ocean processes including water temperatures, currents, mean sea level and wave generation. The paper by Taylor on the preceding pages of this issue focused on changes in weather and climate in the Pacific Northwest, while the present paper deals with the oceanic processes that are important in causing beach and property erosion.

We became particularly aware of the importance of El Niño to coastal erosion in the Northwest during the extreme 1982–83 event (Komar 1986, 1997; Komar and others, 1988; Komar and Good, 1989), and this awareness has been reinforced by the 1997–98 El Niño event. We have seen much news coverage of the erosion El Niño produced along the coast of California (with accounts of floods and landslides). Beach and property erosion also has been severe in the Pacific Northwest, having occurred at numerous sites along the coast.

The main objective of this paper is to examine the atmospheric and oceanic processes produced by El Niño that are important in causing erosion. Most of the discussion of the processes will center on the 1982–83 event, since data collected from that period have been thoroughly analyzed. While measurements of the processes during the ongoing 1997–98 event are still being collected, it is evident that the processes important to coastal erosion are very similar to those experienced in 1982–83. The paper will end with a brief account of erosional "hot spots" experienced during the 1997–98 El Niño event along the Oregon coast, which serve to illustrate how these processes combine to produce beach erosion and property losses.

## PROCESSES OF COASTAL EROSION

Most occurrences of coastal erosion involve one or more of the following processes or factors:

- *storm-generated waves;
- high predicted tides;
- *elevated water levels above the predicted tidal elevation;
- an increase in relative sea level due to glacial melting plus land-level change;
- *erosion of embayments by rip currents;
- *alongshore movement of beach sediment;
- *jetty or breakwater disruption of beach sand movement;
- *migrations of tidal inlets and river mouths.

The processes and factors that are enhanced during an El Niño event are designated by an asterisk (*). The greatly increased erosional impacts along the west coast of the United States during an El Niño event are accounted for by the increased intensities of these processes and by the fact that they generally reinforce one another to maximize their impacts. These important processes and factors are briefly recounted here.

### Enhanced sea levels

Particularly unusual during an El Niño occurrence are the processes that locally alter mean water levels in the ocean. They become readily apparent when we compare predicted tides, those found in tide tables, with the measured tides that are actually experienced. During both the 1982–83 and 1997–98 El Niño years, tides were typically on the order of 1.5 ft higher than predicted. The elevated water levels tended to drown out the beaches and were extremely important at times of high tides, since the water was able to reach sea cliffs and foredunes, allowing waves to attack and erode coastal properties.

Part of this elevated water level on the Northwest coast owes its inception to changes in processes acting along the Earth's equator during an El Niño event. Historically, the first recognized impacts of El Niño were dramatic changes in water temperatures and effects on fisheries off the coast of Peru. Upwelling normally brings deep ocean water to the surface, much as it does off Oregon and Washington. The cold water, high in nutrients, has made the Peruvian fisheries one of the richest in the world. However, during an El Niño occurrence this system breaks down: the water becomes warm and fish and sea birds die en masse. Such an event usually develops during the Christmas season—hence its name, El Niño, Spanish for "The Child."

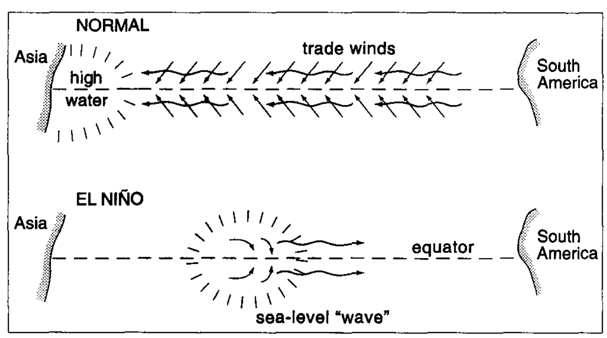



**Figure 1. Schematic diagram of the shift in trade winds and ocean currents along the equator in the Pacific Ocean during a normal year (upper part) versus an El Niño year (lower part). The cessation of the trade winds during El Niño produces a sea-level "wave" that travels eastward along the equator.**

It once was thought that the onset of El Niño off Peru was caused by the cessation of local coastal winds that produce upwelling. This view changed when the physical oceanographer Klaus Wyrtki demonstrated that these local winds do not necessarily diminish during an El Niño event (Wyrtki, 1975). Instead, he found that the breakdown of the equatorial trade winds in the central and western Pacific trigger El Niño, far away from the Peruvian coastal waters where its chief impact is felt. The process is illustrated schematically in Figure 1, contrasting a normal period with an El Niño year. During normal years, the trade winds blow toward the equator, but with a component directed toward the west, and generate ocean currents that flow toward the west parallel to the equator. The stress of the wind on the water and the westward flow of currents combine to produce an elevated water level in the western Pacific, centered in the area where the equator intersects the coast of Asia. The same effect is obtained when you blow steadily across a cup of coffee: the surface of the coffee becomes highest on the side of the cup away from you. If you stop blowing, the coffee surges back and runs up your side of the cup. The process is similar in the ocean, when the trade winds stop blowing during an El Niño year. This condition is depicted in the lower half of Figure 1. The potential energy of the sloping water surface is released, and it is this release that produces the eastward flow of warm water along the equator toward the coast of Peru, where it kills fish not adapted to warm temperatures.

Associated with this warm-water movement eastward along the equator is a wavelike bulge in sea level, also depicted in the lower diagram of Figure 1. The eastward progress of the sea-level wave has been monitored at tide gauges located on islands near the equator. Data from a tide gauge can be averaged to remove the tidal fluctuations, yielding a measure of the mean level of the sea during that time interval. Such analyses were undertaken by Wyrtki to demonstrate the eastward movement of sea-level waves during El Niño events (Wyrtki, 1977, 1984). Figure 2 shows the results for the 1982–83 El Niño. From this series one can easily see the passage of the released sea-level wave as it traveled eastward across the Pacific, affecting in turn tide gauges on a series of equatorial islands. Sea level at Rabaul in the western Pacific reached a peak in March or April 1982 and then began to drop. The crest passed Fanning Island south of Hawaii in late August, Santa Cruz in the Galapagos at the end of the year, and reached Callao on the coast of Peru in January 1983.

Upon its arrival on the coast of South America, the sea-level wave splits, and the separated parts respectively move north and south along the coast. Analyses of tide-gauge records along the full length of the west coasts of North and South America have demonstrated that the sea-level waves can travel as far north as Alaska (Enfield and Allen, 1980). The wave travels at a rate of about 50 mi per day, so it quickly reaches California and Oregon. The passage of the sea-level wave along the Oregon coast is depicted in Figure 3, which also shows the locations of tide gauges used to monitor its movement. Figure 4 gives the monthly mean sea levels measured by the tide gauge in Yaquina Bay, Oregon, during the 1982–83 El Niño year, contrasting the levels with more normal years (Huyer and others, 1983). As in the analyses of Wyrtki, the tide-gauge record was averaged

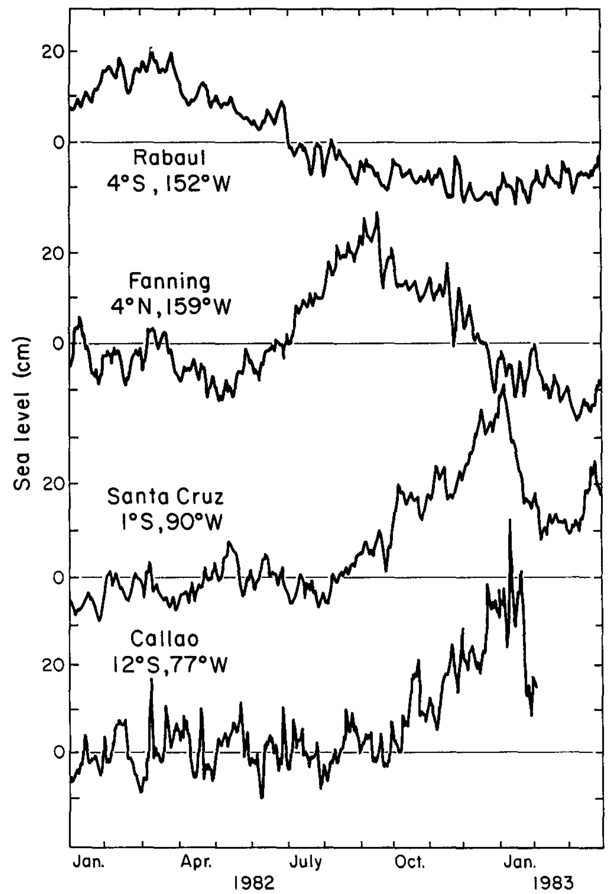



**Figure 2. Sea-level waves measured on tide gauges of islands located along the length of the equator during the 1982–83 El Niño event (after Wyrtki, 1984).**

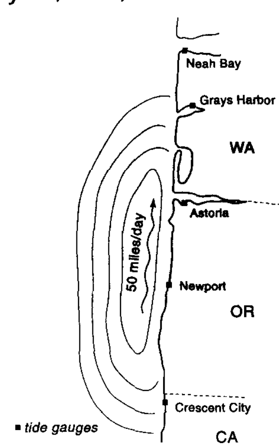



**Figure 3. Schematic depiction of the sea-level wave moving northward along the Oregon coast as measured by the series of tide gauges also indicated.**

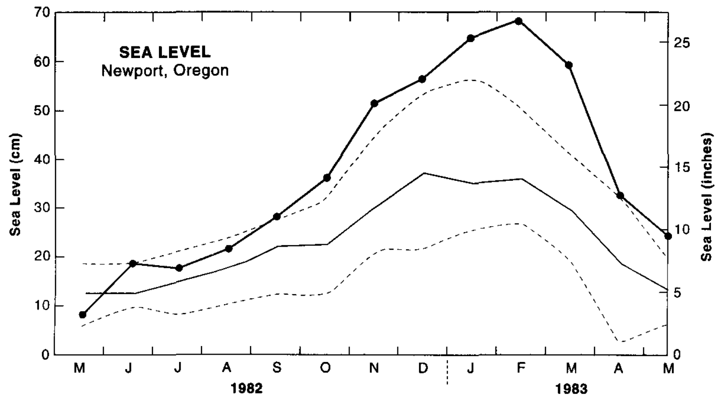



**Figure 4. Monthly averaged sea levels measured on the tide gauge in Yaquina Bay, with the 1982–83 El Niño extreme levels (heavy solid line) compared with previous years. The thin solid line in the figure follows the ten-year averages for the seasonal variations, and the dashed lines give the previous maxima and minima measured at Newport (after Huyer and others, 1983).**

to remove the tides, leaving the net difference between the predicted and measured tides for the month. During the 1982–83 El Niño year, sea level reached a maximum during February 1983, nearly 24 in. higher than the mean water surface in May 1982, nine months earlier.

The increased elevations in mean sea level along the Northwest coast during El Niño are only in part due to a sea-level wave originating at the equator. Other factors include changes in water temperatures along the coast and the development of a northward-flowing current. The curves in Figure 4 in part reflect the normal seasonal cycle of sea level that is produced by parallel variations in water temperatures—colder during the summer than during the winter, due to the occurrence of upwelling in the summer. The thermal expansion of the warm water of the winter raises the water level along the coast, while the cold, dense water of the summer depresses the level. There is also a reversal in current directions from winter to summer. During the winter, the current flows toward the north, and the rotation of the Earth (the Coriolis effect) deflects the current toward the right, that is, toward the coast, elevating the level of the sea along the shoreline. These processes tend to occur every year, causing sea levels along the Northwest coast to be higher during the winter than the summer. But in an El Niño year, these processes are more intense: the water during the winter is warmer than usual and the northward current stronger. So these factors add to the sea-level wave moving northward from the equator to produce the observed extreme water levels during an El Niño winter.

It is seen in Figure 4 that the 1982–83 sea levels were truly exceptional, reaching some 8–16 in. higher than previous winter maxima, about 14 in. above the average winter level. Similar analyses are underway for the 1997–98 El Niño. During January and February 1998, the measured sea levels were again 14–16 in. above the average winter level, indicating that water levels during this El Niño event reached higher elevations than during the 1982–83 event.

The water-level increase during an El Niño year along the Northwest coast is seen to be substantial, making the measured tides significantly higher than predicted (both high and low tides are elevated). For example, in the 1982–83 El Niño year, during a January 1983 storm, the highest spring tides of the month reached +12.4 ft MLLW (Mean Lower Low Water, the standard reference), 34 in. higher than the predicted tide (elevated by both the El Niño processes and the strong onshore winds of the storm). During a February storm, high tides of +10.3 ft were measured, 17 in. above the predicted level. All of these tides were exceptional for the Oregon coast, where a spring tide level of +9.0 ft MLLW is fairly representative (Komar, 1997). This elevated water level is extremely important in producing coastal erosion during an El Niño event. Beaches along the Oregon coast typically have a slope of about 1-in-50, so an increase in water level of 17–34 in., as experienced during the 1982–83 El Niño winter, shifts the shoreline landward by about 70–140 ft, drowning out most beaches at high tide. This moves the shoreline to the base of the sea cliffs or foredunes, and permits the direct attack of waves against coastal properties, in large part accounting for the extreme erosion during El Niño winters.

### El Niño storm waves

Coastal property erosion usually occurs when storm waves combine with elevated water levels, and this is especially true during an El Niño event, when these processes are intensified and act to reinforce one another. During El Niño, the high-altitude jet stream in the atmosphere becomes narrow and strong and spins off cyclonic storms over the Pacific that are more intense than usual. The jet stream is also shifted further south than normal, so the storms cross the North American coast in southern California rather than in the Northwest. These storm system are important to the generation of high-energy waves, and in an El Niño year, with the shift of storms to the south, communities such as Malibu Beach in southern California have a taste of wave energies to which they are not accustomed.

Wave conditions along the Northwest coast are also intensified during an El Niño year (Komar, 1986). Daily measurements obtained during the 1982–83 event demonstrated the occurrence of several storms that generated high-energy waves, three having produced deep-water significant wave heights on the order of 20–25 ft ("significant wave height" is the average of the highest one-third of the waves). The strongest storms occurred during January and February 1983, simultaneous with the occurrence of the highest water levels (Figure 4). Given this combination, it is understandable that extensive erosion took place during the El Niño winter of 1982–83.

An intensification of wave conditions along the Northwest coast also occurred during the 1997–98 El Niño. The first major storm of the winter arrived on November 14, 1997, when deep-water significant wave heights reached 16 ft. The first substantial property erosion of the El Niño winter occurred during a storm on December 13–14. Although the wave conditions were comparable to those on November 14, the tides were higher, and the beaches had been cut back during the preceding month, allowing the waves to attack sea cliffs and dunes. Storm wave activity increased significantly in January and continued through February. During those two months, 12 storms generated waves having deep-water significant wave heights in excess of 20 ft. Far and away the largest storm occurred on January 17, when the deep-water significant wave height reached 30 ft—the waves often growing to some 35 to 40 ft in height as they traveled to the nearshore and broke on Northwest beaches.

While we observed an overall intensification of wave energies along the Northwest coast during both the 1982–83 and 1997–98 El Niño years, compared with normal years, this intensification is significant more in the frequency of storm-wave occurrences than in the absolute extreme sizes of the generated waves. The 30-ft waves of January 17, 1998, have an expected return interval of about 10–20 years and so are exceptional, while the 20- to 25-ft storm waves have return periods of roughly one year, which means that we experience waves with those heights essentially every winter. The decisive difference is that we saw more storm wave occurrences having 20- to 25-ft heights during the El Niño winters than during normal years. Higher waves can occur along the Northwest coast even during normal years, in part because the paths of storms cut directly across our shores. While extreme waves are generated by El Niño storms (Seymour and others, 1985), their impacts are felt more directly in southern California than on the Northwest coast.

### Longshore movement of beach sand

An important aspect of coastal erosion in the Northwest caused by El Niño storms and the waves they generate is the southerly shift of the storm systems. The result of this shift is that the storm waves approach the Northwest coast more frequently from the far southwest quadrant, compared with normal years. This results in the northward movement of sand along Northwest beaches, which exerts a strong control on the alongshore centers of "hot spot" erosion.

Important to this control is the fact that the Oregon coast is divided naturally into a series of littoral cells, stretches of beach isolated by large rocky headlands (Komar, 1997). The stretches of beach may range from only a couple of miles to as long as 50 mi (in the case of the Coos Bay littoral cell that extends from Cape Arago in the south to Cape Perpetua in the north). There is little or no exchange of beach sand around the bounding headlands (shown by differences in beach sand grain sizes and mineralogies), so the stretch of beach within a littoral cell is largely isolated and self contained.

A schematic diagram of a littoral cell is depicted in Figure 5, contrasting the wave directions and alongshore sand movements during normal years (left) with El Niño years (right). In a normal year the summer waves dominantly approach the coast from the northwest, causing sand to move southward along the beaches, while the winter waves arrive from the south-

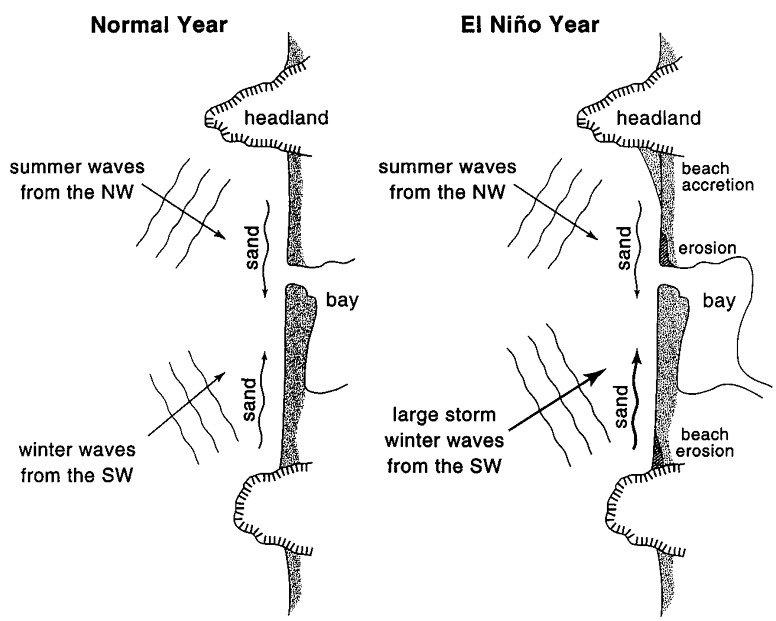



**Figure 5. Schematic depiction of alongshore movement of beach sand within a littoral cell on the Oregon coast due to the seasonal shift in directions of waves approaching the coast. During normal years, there is an approximate balance of north and south sand movements, but in an El Niño year the strong storm waves from the southwest move large amounts of sand to the north, causing "hot spot" erosion as shown.**

west and move sand back toward the north. Over the span of several normal years we observe an equilibrium, with approximately equal amounts of sand moving north and south. This equilibrium was seen in the shoreline changes that occurred when jetties were constructed along the coast early in the century (Komar, 1997), with a symmetrical pattern of shoreline change north and south of the jetties. In contrast to the equal north and south movements of sand in a normal year, during an El Niño event (Figure 5, right) more sand moves toward the north under the more frequent storm waves arriving from the southwest. One effect is that sand is systematically moved away from the south ends of the littoral cells, producing erosion there, while sand accumulates at the north ends, where the beaches widen.

Jetties on inlets can have much the same effect as a headland. During an El Niño year with the enhanced sand movement toward the north, the jetties block this drift, causing beach accretion to the south of the jetties, while erosion occurs to the immediate north. This pattern may be obscured in part by the seasonal cross-shore movement of sand along the beach profile: During the winter, the high waves erode sand from the dry part of the beach and transport it to offshore bars, while low waves of the summer reverse this process (Komar, 1998). Thus the actual response of the beach (net erosion or accretion) at a specific site depends on the combined effects of the alongshore movement of sand related to El Niño and the cross-shore movement associated with the seasonal cycle of beach profile change.

Natural inlets to bays and estuaries on the Northwest coast, that is, inlets not controlled by jetties, tend to migrate toward the north during an El Niño event, due to the stronger northward movement of beach sand. This can result in beach and property erosion to the immediate north of inlets, as depicted in Figure 5. The shift is temporary—during subsequent normal years, the inlets tend to migrate back toward the south.

## OCCURRENCES OF EROSION DURING THE 1997–98 EL NIÑO EVENT

In the preceding section it was seen that a number of processes are involved in producing enhanced coastal erosion during an El Niño. In this section we will examine several erosional "hot spots" that occurred along the Oregon coast during the 1997–98 El Niño and attempt to understand their development in light of the processes described above.

### Port Orford

The erosion at Port Orford during the 1997–98 winter illustrates several factors that are important in an El Niño year. Port Orford is a small community on the southern Oregon coast, with the center of the city situated immediately south of a headland known as The Heads. However, the community extends to the north of The Heads, and it is this area that has been experiencing severe erosion. This stretch of beach comprises a littoral cell that extends north to Cape Blanco, a distance of about 8 mi. The erosion occurred at the south end of the littoral cell and fits the normal pattern of El Niño impacts with storm waves arriving from the southwest, moving the beach sand alongshore toward the north.

The shore erosion is centered on the narrow beach/dune barrier that separates the ocean from Garrison Lake. The beach is composed of coarse sand with some gravel, is steep, and has a narrow surf zone. This type of beach erodes very rapidly when attacked by storm waves that break directly on the beach face close to shore (Komar, 1997). Prior to the El Niño erosion, extensive dunes had accumulated in this area, and the City of Port Orford had installed the drainage field for its sewage treatment system within the dunes. Erosion this winter has all but eliminated the dune field and destroyed most of the drain field (Figure 6). The threat now is that continued erosion may break through the beach/dune barrier into Garrison Lake. This lake is the principal source of fresh water for the community, and a several homes have been built along its shore and may be adversely affected by a breach. The combined elevated mean water levels and runup of storm waves from El Niño have frequently washed over the barrier into the lake. This overwash process has eroded sand from the beach and carried it over the top of the barrier and into the lake. This has had a positive effect of building up the elevation of the barrier, making it less likely that the erosion will break through and create an

**Figure 6: Erosion at Port Orford, north of The Heads, during the 1997–98 El Niño event. The erosion of sand dunes has destroyed the drain field of the sewage treatment plant.**

**Figure 7. Erosion at Port Orford, north of The Heads, during the 1997–98 El Niño event. View is to the south from the location of Figure 6. The erosion is now threatening to break through the beach/dune barrier and wash into Garrison Lake, which is being prevented by the placement of a gravel ridge.**

inlet connecting the ocean with Garrison Lake. There is still a critical area at the south end of the barrier, where the erosion is cutting back the dunes and forming a nearly vertical scarp. Although washovers of ocean water have occurred frequently in this area, they did not carry sand to build up the elevation of the barrier, as has occurred further to the north. The barrier at the south end is now very narrow, so there is the possibility that the ocean could break through into the lake. The City of Port Orford has placed a ridge of gravel and cobbles along the top of the barrier (Figure 7) to prevent further washover that, at this stage, could develop into a breach of the barrier and form an inlet. If dune erosion continues, the mass of gravel and cobbles will slough off onto the eroding dune scarp and upper beach, where its presence should provide some temporary protection from continued wave attack. It is hoped that this is a sufficient defense until the impacts of the 1997–98 El Niño end.

### Alsea Spit

One of the main areas of erosion during the 1982–83 El Niño event took place along Alsea Spit on the central Oregon coast (Komar, 1986, 1997; Komar and Good, 1989). The primary factor important to erosion was the northward migration of the inlet to Alsea Bay. This inlet migration combined with elevated water levels and storm waves and completely eroded away the beach along nearly the full length of the spit. The waves and currents then began to cut back the foredunes, where a number of homes had been constructed. One house was lost, while the others were saved by the placement of riprap at the base of the eroding dunes.

In the years subsequent to the 1982–83 El Niño event, the return of lower water levels and less severe wave conditions has allowed the beach to recover along Alsea Spit. The beach has become very wide, and onshore winds have blown sand into the dunes so they had fully recovered from the El Niño erosion. Eventually the riprap revetment was covered by the accumulating dune sand, and apparently forgotten. Development began once again, and a number of new homes were build on the spit. Unfortunately, some were constructed atop and across the now buried revetment, seaward of this line of defense, in the area where erosion had occurred only a decade earlier.

The return of El Niño during the winter of 1997–98 has brought about a recurrence of erosion processes and problems on Alsea Spit. Older homes landward from the line of riprap placed in 1982–83 are likely safe from the renewed attack, but the newly constructed homes that extend seaward from the riprap line are now in danger. It is possible that another line of riprap will have to be installed to protect those homes.

### Cape Lookout State Park

Another area of significant erosion during the 1982–83 El Niño event occurred at Cape Lookout State Park on Netarts Spit (Komar, 1997; Komar and others, 1988; Komar and Good, 1989). This park is located at the south end of the Oceanside littoral cell, so again much of its erosion can be attributed to the northward transport of sand by the approach of high storm waves from the southwest during El Niño, moving sand toward the north. Much of this sand has disappeared from the beach, apparently carried into Netarts Bay. The reduction of sand volumes on the beach along this littoral cell now makes the beach more susceptible to attack by waves, during normal years as well as in an El Niño event. Another factor in the erosion during the 1982–83 El Niño event was the presence of a large rip current flowing seaward from the area of the park, carrying sand offshore, and contributing to the local erosion. Erosion in the park partially destroyed an old log seawall and then eroded away the high ridge of dune sand that had sheltered the park development.

Erosion of Cape Lookout State Park during the 1997–98 El Niño year has essentially picked up where the 1982–83 event left off (Figure 8). The last remnants of the log seawall are rapidly disappearing, leaving the tall iron beams that had supported the logs sticking up from the beach—the beams remaining after the 1982–83 erosion were cut off by the Parks and Recreation Department. Additional dune erosion has occurred, and

Figure 8. Recent erosion at Cape Lookout State Park on Netarts Spit has cut back the large coastal dunes and is now eroding the campground.

the public bathrooms were in danger of being undermined by waves until a line of riprap was placed for protection. High water elevations have combined with storm wave runup to wash over into the park lands, depositing a large amount of beach sand in the campground. Such extensive washovers did not occur during the 1982–83 El Niño event.

### The Capes

Most dramatic and newsworthy during the 1997–98 El Niño year has been the erosion at The Capes, a development consisting of expensive condominiums recently built on the high bluff to the immediate north of the inlet to Netarts Bay (Figure 9). The site is centered within the Oceanside littoral cell, about 6 mi north of Cape Lookout State Park. Erosion at The Capes is dramatic not only in its potential economic impact for the home owners, but also with regard to the number of coastal hazards involved.

Since the condominiums are situated immediately north of the inlet to Netarts Bay, the northward migration of the inlet during the 1997–98 El Niño winter has acted to erode the fronting beach and has created deepened water directly offshore. Normally, the low-sloping beaches in this littoral cell cause the waves to break well offshore, so that most of their energy is dissipated before they run up on the beach face at the shore (Komar, 1997). With the creation of deeper water due to the migration of the inlet, the waves can now travel closer to shore before breaking and lose less energy in the process. The runup of the stronger waves now combines with the elevated mean water levels associated with El Niño, allowing the runup to reach the toe of the high bluff below The Capes. The resulting toe erosion has made the bluff unstable, and slippage of the land now poses the immediate threat to the front line of condominiums (Figure 10). Unfortunately, the condominiums had been constructed with only a 10-ft setback distance—insufficient, considering the potential for erosion and instability of the site. So now many of the homes have immediately been placed in danger.

The development site is located atop an old massive landslide. The lower portion, now exposed by the toe erosion, consists of a layer of mud that is extremely mobile. Rather than participating in the rotational slippage typical of many landslides, this mud appears to be squeezed out like toothpaste by the weight of the overlying material. This overlying material is sand of old dunes deposited atop the bluff—sand that has minimal internal strength, so that it tends to cascade downslope, much like the loose sand of an active modern dune. Thus, only part of the problems at The Capes can be attributed to the occurrence of El Niño and its erosion processes. The preexisting hazardous conditions are that the development was constructed on a landslide, the upper part of which consists of dune sand. The present instability and movement of the landslide can, however, be attributed to the 1997–98 El Niño occurrence and its erosional impact, which has cut away the toe of the landslide.

Figure 9. The Capes, north of Netarts Bay, is a recent development of condominiums, located on the edge of an old massive landslide.

**Figure 10. Homes at The Capes. Erosion of the toe of the landslide during the 1997–98 El Niño winter has caused the slide to become unstable, and slippage is threatening the first line of homes.**

## CONCLUSION

The Northwest coast now has experienced two major El Niño events, in 1982–83 and again in 1997–98. Both have resulted in substantial beach erosion and damage to or loss of coastal properties. Although data from the recent event are still being collected and analyzed, the evidence thus far is that the processes are very similar to those which occurred during the 1982–83 El Niño event. Important to coastal erosion are the elevated water levels that cause tides to be 1–1.5 ft higher than predicted, the generation of high energy waves by more frequent storms, and the fact that the waves approach the coast more from the southwest, causing a northward movement of sand that redistributes beach sand volumes along the coast and causes inlets to migrate toward the north. It is the combination of these processes and the fact that they reinforce one another that accounts for "hot spot" erosion areas along the Oregon coast such as at The Capes.

At the time of this writing (April 1998), El Niño is continuing but it looks as if it is decreasing and will likely soon come to an end. Water temperatures and sea levels in the equatorial Pacific are returning to more normal levels. The same can be expected off the Northwest coast. As discussed above, wave energies along the coast abruptly declined at the end of February, following the usual pattern of decreasing wave conditions in the summer (Komar, 1997). The eroded beaches have noticeably begun to rebuild. So additional property erosion is unlikely, at least through the summer. But we may not have seen the last of the impacts that can be attributed to El Niño of 1997–98. Following the 1982–83 event, significant erosion took place during subsequent winters, returning to the areas that had eroded during the El Niño winter. The processes directly associated with El Niño had ceased (unusually high water levels, etc.), but the beaches were unable to fully recover during the following summer. Sand that had been shifted far offshore to deep water did not completely return to the dry beach, and sand moved alongshore to the north within the littoral cells did not all shift back to the south. So when the next winter returned with its high storm waves, the beaches still depleted of sand were not able to adequately buffer coastal properties, so that erosion began once more. It took two to three years before the beaches finally recovered and the lingering impacts of the 1982–83 El Niño event finally ended. It remains to be seen whether history repeats itself and whether or not we have seen the last of El Niño 1997–98.

## ACKNOWLEDGMENTS

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*(Continued on page 70)*

# Slope stability at aggregate mines in Oregon: Regulatory requirements and selected case histories

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This paper is a contribution to *Environmental, Groundwater, and Engineering Geology: Applications from Oregon,* edited by Scott Burns, Portland State University, and published 1998 in coordination with the Association of Engineering Geologists (AEG) as AEG Special Publication 11 by Star Publishing Company, Belmont, California (available from the Nature of the Northwest Information Center). We are printing it here by permission, with minor editorial changes, and apologize for the low quality of the figures for which the originals were unavailable due to circumstances beyond our control. —*ed.*

## I.

The Oregon Department of Geology and Mineral Industries (DOGAMI) administers the Mined Land Reclamation Act passed in 1971 by the Oregon Legislature (ORS 517.750–517.992). In the policy statement enacted by the legislature, mineral extraction was recognized as making an essential contribution to the economic well-being of the state. Policy directs DOGAMI to allow mining and to protect natural resources during and after mining through reclamation of undesirable conditions. DOGAMI's authority exists for all types of surface and underground mining on lands under private, state, and federal ownership. The following discussion pertains exclusively to aggregate mines and includes all commodities except coal and precious metals. Federal law requirements for waterways and other federally protected lands such as the Columbia River Gorge Scenic Area are not discussed.

The Reclamation Act is implemented through the issuing of an operating permit that requires an approved mining and reclamation plan plus financial security based on the actual cost of reclamation. An application for a mine requires an on-site inspection by a reclamationist who is to evaluate the environmental conditions at the site and the adequacy of the proposal. A draft permit is then prepared and is circulated with the application to appropriate local, state, and federal agencies. Comments from these agencies are reviewed, and revisions are incorporated into the final permit as attached conditions.

Certain activities require state and local agencies to issue separate permit approvals. All necessary approvals are listed in Table 1 below. Permits or approvals are not required by the Oregon Department of Fish and Wildlife (ODFW). However, ODFW provides expertise and participates in the permit decisions at the time the siting decision is made by the county or city and also when the individual state agency approvals are issued.

The DOGAMI-issued operating permit requires approval of a reclamation plan submitted by the mine operator. Reclamation plans determined to be complete can be further modified or restricted by conditions of approval attached to the operating permit issued by DOGAMI. Reclamation plan requirements also include mine development issues such as soil salvage and storage, storage of mine waste, mine sequence, mine dewatering, maximum depth, backfilling and slope reconstruction, and interim and final slope angles.

After mineral extraction is completed (or concurrently with mining if practicable), reclamation of the disturbed areas is required and must be compatible with local zoning. In most cases, the site is reclaimed to upland or aquatic habitats. Minimum reclamation requirements include stable revegetated uplands and gently sloping pond banks.

## II.

Unloading and loading slopes are two common mining activities that often lead to instability problems. Regulation of these activities is handled on a case-by-case basis during the permit approval process. For an application for an operating permit, ORS 517.790 (1) allows DOGAMI to customize information requirements on an application for an operating permit by requiring that the applicant submit specific information considered pertinent by the department.

The DOGAMI permits are not static approvals. If field inspections indicate that a potential or existing

Table 1. *Agency permits for aggregate mines in Oregon*

| Permit type | Regulatory agency |
|---|---|
| Water rights | Water Resources Department |
| Air quality | Department of Environmental Quality |
| Water quality—process wastewater/storm water | Department of Environmental Quality |
| Fill/removal—in wetlands or streams | Division of State Lands |
| Mine zone designation or conditional use | County or local zoning authority |
| Scenic waterway | State Parks and Recreation Department |
| Operating | DOGAMI |

slope stability problem is present, the permit can be modified by attached new requirements. These new requirements can be attached to preexisting permit approvals for protection of natural resources and reclamation during the life of the mine. This is frequently the case with many of the more than 800 commercial aggregate mines in the state.

Regulations provide general requirements on the angle of slopes left after mining (ratio of 1½ horizontal [H] to 1 vertical [V] = 1½H:1V on cut slopes and ratio of 2H:1V on fill slopes). DOGAMI has authority to allow steeper or require flatter final slopes. If a natural resource protection or reclamation concern exists, DOGAMI may attach conditions to the permit to regulate slopes, both those cut during mining and final slopes.

For new sites or boundary expansions of existing sites, the requirements for a slope stability evaluation or engineered design and construction for a mine cut or disposal area are determined through permit application review or field inspection. The statutes allow DOGAMI to make site-specific requests for additional data collection based on site characteristics. During both field and office reviews, DOGAMI receives assistance from specialists in other agencies.

In addition to reclamation plan forms, regulations, and statutes, guidelines were developed in 1995 to assist applicants and staff reclamationists. The guidelines list the types of additional baseline data that may be needed prior to permitting. They were written with the recognition that some sites inherently present a greater risk to natural resources than others and require more data collection and analysis prior to permit approval to provide sufficient certainty in natural resource protection. The guidelines were developed with review and input by state agencies, aggregrate operators, and consulting firms.

With respect to slope stability, these guidelines request a written plan to explain how the resource will be protected in situations where downslope risk to waters of the state is high or the probability of slope failure is high. The necessary information may range from a report describing preexisting conditions (springs, slumps, hummocky terrain, and ancient landslide features) to a geotechnical investigation and design.

The DOGAMI guidelines include parameters to evaluate the downslope risk to waters of the state. Table 2 shows the parameters determining high risk for slopes.

Complete information is often unavailable during the development stages of a quarry. As a site is mined, site conditions may change, or additional information may become available. The performance-based standards in the DOGAMI regulations allow a more flexible response to changing conditions than rigid construction-based standards for each activity or mine. This flexible regulatory approach relies on a field inspection program and operator cooperation to recognize and correct situations before they become problems.

## III.

The following text discusses three case histories of aggregate mines that illustrate the application of Oregon's reclamation program.

### Mosier Quarry

This is a basalt quarry site where mining began in the 1950s to help build the Columbia River Highway. It is located 75 mi east of Portland in Wasco County. Ownership at the site includes both public and private property. The quarry properties cover lands located in the City of Mosier urban growth boundary and within the Columbia River Gorge National Scenic Area and encompass several hundred acres (Figure 1).

The quarried areas are situated in the Pomona Member of the Columbia River Basalt Group and consist of talus deposits in ancient landslide terrain.

Intermittent mining by the Oregon Department of Transportation (ODOT) over the last several decades on the public property has caused slope movement. The effect of the slope movement is the formation of a head scarp in the talus and exposure of unweathered angular basalt blocks. This is considered a visual impact that should be avoided, because the scarp can be seen from key viewing areas within the boundaries of the National Scenic Area.

A large basalt block, 190 ft thick, has separated from the ground above. The block is sliding on a thin interbed of volcanic tuff. Mining occurs on the talus material below the block.

No potential impacts to other natural resources exist as a result of the current slope movement or the risk of continued slope movement. An intermittent stream is on ODOT property, and the Columbia River is nearby, but the amount of erodable fines present and the potential for erosion are both minimal.

In 1993, the owner of the private quarry section

Table 2. *Guideline parameters for high downslope risk to waters of the state*

| Slopes | Fills of waste rock, overburden, or soils | Depth of cuts in rock steeper than 1½H:1V | Depth of cuts in soil |
|---|---|---|---|
| >60% | >2 ft | >20 ft | — |
| >30% | >25 ft | >100 ft | >20 ft |
| 15%–30% | >25 ft<br>or any storage within 300 ft of a stream | — | — |

**Figure 1. Mosier Quarry properties, aerial view to the east. Aggregate mining on ODOT property developed headscarp right of center. Photo courtesy of Landslide Technology, Division of Cornforth Consultants, Inc., Portland.**

requested that Wasco County authorize land use approval to renew and expand the mining area on the talus slope below the basalt block. Because of the issues surrounding this site, Wasco County officials requested DOGAMI participation in the land use hearings. DOGAMI advised that the site could be safely mined if the mine plan was sequenced and designed to address geotechnical issues. Land use approval was conditioned on DOGAMI approval of a mine plan that was technically feasible and would protect visual resources.

The National Scenic Area boundary runs across the upper part of the talus slope and the block that has slid. Consequently, impacts of mineral extraction must be confined to the property below or outside the scenic boundary. The mine company hired an engineering firm. Borings recently completed on the ODOT property were studied. Additional borings were performed, and inclinometers were installed on the private parcel. A phased extraction and reclamation plan using calculations of slope stability was developed to minimize the risk of slope stability problems. The plan requires excavation of a key trench to penetrate through a clay interbed and replace it with higher strength rock. This allows removal of the talus below the key and protects the slope above.

### Cochran Quarry

The Cochran Quarry is located near a former historic sawmill site with the same name west of Timber in the Coast Range in western Washington County. This 98-acre parcel is situated adjacent to the Port of Tillamook Bay railroad. The rail runs between Tillamook and Hillsboro. In 1991, Washington County determined the quarry parcel to be a significant mineral resource and zoned it for mining. The quarry is situated in the Tillamook Volcanics. Pennoyer Creek, a perennial tributary to the Salmonberry River, flows below the site and the rail line. The Salmonberry River is rated by some as having the largest remaining stocks of native sea-run cutthroat trout in the state.

Seeps occurring where the quarry's storm water retention ponds were to be constructed had been mapped as wetlands. Approval for wetland fill was obtained from the Division of State Lands. Approval for the pond design and construction was obtained from the State Department of Environmental Quality (DEQ). The Salmonberry River, located several miles downstream from the pond discharge point along Pennoyer Creek, needed protection as an important fish habitat. To provide such protection, DEQ required that the ponds be designed to accommodate heaviest storm runoff (a 100-year/24-hour event). However, in designing the appropriate ponds, the design engineers hired by the mine company may not have considered slope stability conditions.

State agency approvals were obtained to begin construction in the fall of 1992, and mining began in 1993. Crushed rock was railed into the Portland market during 1993 and 1994.

In November 1994, tension cracks appeared in the crusher site area. In the winter of 1995, the site showed slope movement that was interpreted by a DOGAMI geotechnical investigation to be the reactivation of an ancient "slump earth flow" landslide feature. The storm water retention ponds located at the debris runout portion of the ancient landslide appeared to increase the risk to slope stability. Quarry operation was halted, and the operator was required to provide geotechnical data, dewater the storm water retention ponds and redirect storm water flow.

In the resulting geotechnical investigation, several borings were drilled and inclinometers and piezometers installed that confirmed and defined the reactivated landslide. The storm water retention ponds were viewed by DOGAMI as the first order of concern for protecting Pennoyer Creek. Draining of the ponds seems to have improved slope stability at the site.

As landslide features developed at the site, the crushing plant was removed. The mine company monitored

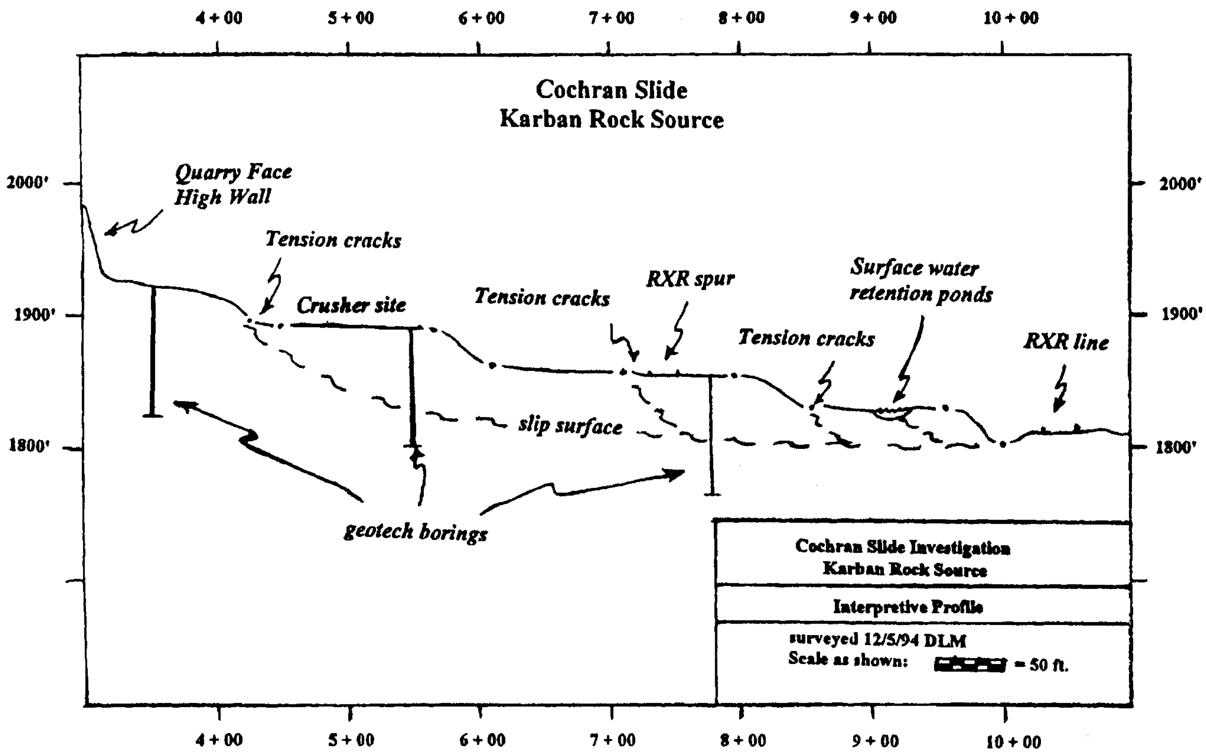


**Figure 2. Section profile of slope movement at the Cochran Quarry. Figure drawn by Dave Michael, Oregon Department of Forestry.**

the site and maintained equipment and materials for storm water and erosion control work. Slide movement affected the crusher pad, a reject storage area west of the crusher, the storm water retention ponds and ditches, the load-out facilities along the rail spur, and the main railroad line.

The slide halted year-round production at the site. Since 1994, this approximately 20-acre site is used only for short-term, small-scale crushing projects during the summer. During the summer of 1996, the original storm water retention ponds were removed, and the land was reclaimed. Year-round production is not possible until newly located storm water retention ponds are designed and built.

The storm water retention ponds had been located immediately upslope from the railroad main line. Cochran Pond and Pennoyer Creek are located on the opposite side of the railroad line. Periodic episodes of sedimentation have reached Pennoyer Creek. However, measurable amounts of sediment were not found in the creek channel downstream from the operation. Since fish cannot migrate up Pennoyer Creek because they are stopped by a waterfall, impacts to the sea-run cutthroat were likely minimal.

### American Sand and Gravel

Sand and gravel extraction and processing began at this site in the early 1970s. The 92-acre property is located near Barton in Clackamas County. The gravel source is an elevated terrace above the Clackamas River valley. Water draining from the site enters an unnamed tributary to Deep Creek, which then enters the Clackamas River 3–4 mi below the site. The Clackamas River is a protected scenic waterway at this location.

The mine is situated in the Troutdale Formation, a series of interbedded layers of gravel, sand, and silt. At this location, it has a gravelly seam about 100 ft thick. The gravels have an overburden layer of silts and clays that ranges up to 40 ft in thickness. Below the Troutdale Formation lies the Sandy River Mudstone. This lower formation is a fine-grained rock that tends to be an impermeable barrier to groundwater. At the contact between the two formations along the Clackamas River valley wall, seeps and springs are found.

These seeps and springs are located on the terrace escarpments, and wetlands occur on the flatter slopes below. The steep terrace escarpments are characterized by debris-flow and debris-avalanche landslide areas and talus slopes. Because of these features, the 1979

**Figure 3. Slope failure at American Sand and Gravel site below processing area. Impacted wetlands located in background. Photo taken in 1993 by E. Frank Schnitzer.**

DOGAMI Bulletin 99, *Geology and Geologic Hazards of Northwestern Clackamas County*, mapped the escarpments as landslide hazards.

This site has had a history of slope stability problems. The unstable slope conditions that had existed before any mining activity were exacerbated by such past mining practices as sidecasting overburden over the outslopes, creating fills, building ponds, or otherwise ponding water on fill slopes.

In the late 1970s, DOGAMI inspected the site, noted unstable slope conditions, and ordered ponds removed from fills on the outslopes. Through most of the 1980s, Clackamas County regulated the site under delegated authority from the DOGAMI Mined Land Reclamation Program. DOGAMI reassumed regulation of the site from Clackamas County in 1991. At that time, several slides were present on the slope below the operation, and sediment was polluting the unnamed tributary to Deep Creek.

After the reclamation bond was increased from $10,000 to $140,000, the operating permit was issued by DOGAMI in 1992. Within a short time, the permittee violated the permit by sidecasting overburden in a landslide hazard area. In January 1993, DOGAMI issued a "Closure Order," which resulted in the shutdown of the operation plus reclamation and interim stabilization of approximately 10 acres.

The area where overburden was illegally sidecast had experienced slope stability problems and remained unstable. Lack of access and the potential for destabilizing unaffected areas on steep slopes led to the decision not to unload the slope with earth moving equipment. Most of the sediments eroding from this area were trapped in a bermed wetland adjacent to the unnamed drainage. The wetland was covered by a reclamation plan and bond.

In 1995, a new operator leased the processing site and proposed to mine the nearly level ridge top (0- to 10-percent slopes) above the terrace escarpments. For this proposal, baseline data requirements included three borings in the expansion area, so that information on the angle of the contact between the Troutdale Formation and the Sandy River Mudstone could be obtained. During the summer of 1996, three borings were completed with conventional water-well drilling equipment. The drilling data suggest that the contact in the expansion area slopes toward the west and the existing processing site and away from the terrace escarpments.

In 1997, wild fish tagged by the Oregon Department of Fish and Wildlife (ODFW) were observed passing by this site as they went up the Deep Creek channel to seek out another tributary for spawning. In the interest of habitat protection, DOGAMI expressed concerns about resumption of mining at this site. DOGAMI permit conditions were written with certain restrictions to mining and processing activities: They had to provide the assurance that downstream water quality would be protected during mining and reclamation and that the existing unstable slope conditions would not be aggravated by additional mining or storage of overburden or water. The applicant was required to obtain a geotechnical evaluation of the slope above the processing site and its potential to affect Judd Road that runs along the north boundary of (and below) the site.

Prior to approval of the current plan, negotiated agreements between DOGAMI and the mine company specified restrictions to protect slope stability. Future mining will occur on a cutslope ranging from 2H:1V to 3H:1V. All overburden stripped in the expansion area will be hauled away from the site. With no loading in the expansion area, the probability of failure is now low. However, even though the risks are low, visual monitoring of the area will continue during future inspections of the site. Due to the slope stability concerns, the operator is prohibited from using recognized unstable areas for storage of rejects or aggregrate. The operation is also required to shut down if turbidity levels in the creek violate DEQ standards. □

## DOGAMI PUBLICATIONS

**Released May 1, 1998**

**Geologic map of the Tucker Flat quadrangle, Union and Baker Counties, Oregon**, by Ian P. Madin. Geological Map Series GMS–110, scale 1:24,000, $6.

**Index to geologic maps of Oregon by U.S. Geological Survey topographic quadrangle name**, 1883–1997, by Peter L. Stark, rev. by Ronald P. Geitgey and Klaus K.E. Neuendorf. Open-File Report O–97–33, 65 pages, $6.

**Mined Land Reclamation Program status map, Douglas County, Oregon**. Oregon Department of Geology and Mineral Industries MLR Status Map 10, scale 1:250,000, $10.

**Mined Land Reclamation Program status map, Marion County, Oregon**. Oregon Department of Geology and Mineral Industries MLR Status Map 24, scale 1:250,000, $10.

The two MLR status maps are the first of a set planned for all counties of the state, with annual updates. They show all mining sites contained in the database record of the Mined Land Reclamation Program, differentiating between open and closed sites, various types of reclamation requirements, and nonmetal and metal mining sites. The overall status of the program is indicated by acres of land reclaimed and acres subject to reclamation. Completion of the map set is planned in increments of two maps per month. □

*(Continued from page 64)*

Komar, P.D., and Good, J.W., 1989, Long-term erosion impacts of the 1982–83 El Niño on the Oregon coast: Coastal Zone '89, American Society of Civil Engineers, p. 3785–3794.

Komar, P.D., Good, J.W., and Shih, S.-M., 1988, Erosion of Netarts Spit, Oregon: Continued impacts of the 1982–83 El Niño: Shore & Beach, v. 57, p. 11–19.

Seymour, R.J., Strange, R.R., Cayan, D.R., and Nathan, R.A., 1985, Influence of El Niño on California's wave climate: American Society of Civil Engineers 19th Coastal Engineering Conference, Proceedings, p. 577–592.

Wyrtki, K., 1975, Fluctuations of the dynamic topography in the Pacific Ocean: Journal of Physical Oceanography, v. 5, p. 450–459.

———1977, Sea level during the 1972 El Niño: Journal of Physical Oceanography, v. 7, p. 779–787.

——— 1984, The slope of sea level along the equator during the 1982/1983 El Niño: Journal of Geophysical Research, v. 89, p. 10,419–10,424. □

### Editor's note

The author, Paul D. Komar, has just published a new book in which he describes and discusses comprehensively the processes and forces that shape and change the coastline of the Pacific Northwest.

This book, ***The Pacific Northwest coast: Living with the shores of Oregon and Washington***, is now available from the Nature of the Northwest Information Center for $18.50 (plus $3 for shipping).

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# OREGON GEOLOGY

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VOLUME 60, NUMBER 4 JULY/AUGUST 1998

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MINED LAND RECLAMATION PROGRAM AWARDS OUTSTANDING MINING AND RECLAMATION

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## Cover photo

View to the east of Lower Table Rock (foreground), Upper Table Rock (middle), and Mount McLoughlin (distant background) in Jackson County. Article beginning on page 81 presents the first comprehensive geologic description of the Table Rocks and the andesite of Table Rock that created their caps.

# Innovation and creativity highlighted at annual mined land reclamation awards

A logger-turned-miner has been named one of Oregon's **Reclamationists of the Year**. Vern Perry spent a lifetime working in the forests of Oregon. As a student he planted trees for a Toledo lumber company, then as an adult his company, Gem Logging Inc., harvested those trees for Georgia Pacific. Perry retired from logging in 1989 but decided to try a new career – working for Dalton Rock, a new aggregate producer in the Dallas area. As equipment operator, Perry has been instrumental in getting this venture off the ground. His knowledge of facilities and plant layout allowed the Dalton operation to develop into a major aggregate resource. His lifelong love of the outdoors is evident in his dedication to completing the reclamation at Dalton Quarry and Perry was recognized for his commitment to developing natural resources in an environmentally sound manner.

Walter Matschkowsky of Glenbrook Nickel Company was also named as a **Reclamationist of the Year**. Matschkowsky was highly regarded for his leadership and initiative in creating environmentally sound mining practices. He spent his long career on Nickel Mountain in southern Douglas County near Riddle, first with Hannah Mining, then with Glenbrook. During his years at Glenbrook, Walter supervised the mining activities along with annual grass and tree planting efforts. He also assisted with ideas and efforts to maintain good water quality from the many permitted discharge points. A significant accomplishment of Matschkowsky's was his lead role in the Thompson Creek reclamation project. He supervised the process that turned an area affected by mining into a green, healthy part of the forest indistinguishable from unaffected land. Matschkowsky was recognized for a career of responsible mining and reclamation. He passed away in September 1997, but his work will always be a part of Nickel Mountain.

Six other businesses and two government agencies were also recognized at the annual awards event. Winners were chosen by the Oregon Department of Geology and Mineral Industries (DOGAMI) for their exemplary efforts to reclaim sites creatively and for their commitment to enhance the environment. "These companies are being recognized because they go above and beyond the standards required by the law in their reclamation efforts," said Gary Lynch, Supervisor of DOGAMI's Mined Land Reclamation (MLR) Office. "They lead the industry by their good example."

The mining awards were developed by the MLR program of DOGAMI to recognize environmentally conscious miners. The seven-person staff, based in Albany, regulates mining operations throughout the state of

*(Continued on page 91, **MLR**)*

A new approach to earthquake hazard identification in Oregon

# Creating a map of Oregon UBC soils

*by Yumei Wang, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97223, and Ray J. Weldon and Dennis Fletcher, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403*

## INTRODUCTION

In the mid-1990s, the Oregon Department of Geology and Mineral Industries (DOGAMI) encountered a number of questions regarding earthquake hazard mapping methods in several of its projects throughout the state. One particular question was whether hazard ratings based on established methods really meant the same for different areas of the state. What was needed was to provide a uniform, statewide basis to judge regional earthquake hazards.

For seismic engineering design and construction purposes, site characterization of soil properties is a necessary step in determining ground motions. The 1996 edition of *Recommended Lateral Force Requirements* by the Structural Engineers Association of California (SEAOC)(Shea, 1996) introduced improved descriptions of soil types and became a model for the 1997 Uniform Building Code (UBC) (International Conference of Building Officials, 1997). Initially, DOGAMI scientists used the 1996 SEAOC soil profile types to determine the statewide earthquake hazards. These soil types are identical to the 1997 UBC soil profile types, which will go into effect for Oregon's building codes in October of 1998 and serve as the basis of the map described in this paper.

The 1997 Uniform Building Code, Chapter 16, Division V, defines six soil profile types (hereafter referred to as UBC soils) that are to be used in the determination of earthquake design requirements for building sites. The UBC soils range from hard rock to special soils that require site-specific investigations for characterization, such as thick soft clays. In general, harder UBC soils provide stronger foundation materials, and softer types provide weaker foundation materials. In addition, harder UBC soils transmit earthquake waves faster, which often results in less ground shaking damage than with slower, softer types.

In accordance with the 1997 UBC, the authors of this paper are developing a statewide map that shows Oregon's soil profile types and provides general information on areas with harder and softer UBC soils over a broad region.

This map shows the statewide earthquake hazards and serves to provide a uniform basis of evaluating these hazards from geologic conditions. Its primary use is to identify regions of higher and lower hazards and to understand areas of higher and lower risk. It is also to be used in a statewide earthquake damage and loss estimate. Other uses of the map include regional emergency planning and facility siting.

The map data may be combined with such information as elevations, slope angles, and earthquake ground shaking potential for the evaluation of specific hazards. The map does not have site-specific accuracy and should not be used for site-specific purposes.

The map shows concentrations of high-value (high-hazard) soil types, i.e., soil types $S_D$, $S_E$, and $S_F$ in coastal estuaries, the Willamette Valley, and basins in central and eastern Oregon. Areas of highest value soil types are landslides and margins of open water. Western Oregon is made up largely of type $S_C$ (soft rock).

## BACKGROUND AND METHODS

The map of Oregon UBC soils was developed on the basis of earlier work by Fumal (1978), Fumal and Tinsley (1985), Joyner and Fumal (1985), Rogers and others (1985), Mabey and Madin (1992 and 1995), Borchert (1994), Wang and Priest (1995), and Wang and Leonard (1996). This previous work had investigated the relationship between shear-wave velocity and surficial geologic units and was based on extensive measurements of shear-wave velocity in a variety of surficial geologic units.

The UBC soil types shown on the map have been derived from evaluations of published, digital, regional geologic and agricultural soil maps: the 1:500,000-scale *Geologic Map of Oregon* (Walker and MacLeod, 1991) and the 1:500,000-scale general soil map of Oregon by the Soil Conservation Service (U.S. Department of Agriculture, 1995; hereafter referred to as "SCS"). Consequently, the accuracy of the UBC soil map is dependent on the accuracy of those maps. For areas of high accuracy, the finest resolution is ±250 m, which is the standard line width on the geologic map used in this study.

For the development of the UBC soil types on the map, we first assigned one of the 1997 UBC soil profile types to each mapped geologic unit. The six UBC soil profile types ($S_A$ through $S_F$) are listed in Table 1, which is taken from the 1997 UBC, volume 2, Table 16-J and Section 1636.2. Section 1636 also defines average shear-wave velocity, average field standard penetration resistance, and average undrained shear strength. The assignment was based on the previously mapped and measured geologic and soil properties and on shear-wave velocities measured on the unit or on similar units. No new field investigations were performed.

*(Continued on page 78)*


**Preliminary sample of map of Oregon UBC soils.**

*Table 1. UBC soil profile types. From International Conference of Building Officials (1997), v. 2, p. 23 and 30*

| SOIL PROFILE TYPE | SOIL PROFILE NAME/GENERIC DESCRIPTION | AVERAGE SOIL PROPERTIES FOR TOP 100 FEET (30 480 mm) OF SOIL PROFILE | | |
|---|---|---|---|---|
| | | Shear Wave Velocity, $\bar{v}_s$ feet/second (m/s) | Standard Penetration Test, $\bar{N}$ [or $\bar{N}_{CH}$ for cohesionless soil layers] (blows/foot) | Undrained Shear Strength, $\bar{s}_u$ psf (kPa) |
| $S_A$ | Hard Rock | > 5,000 (1,500) | — | — |
| $S_B$ | Rock | 2,500 to 5,000 (760 to 1,500) | | |
| $S_C$ | Very Dense Soil and Soft Rock | 1,200 to 2,500 (360 to 760) | > 50 | > 2,000 (100) |
| $S_D$ | Stiff Soil Profile | 600 to 1,200 (180 to 360) | 15 to 50 | 1,000 to 2,000 (50 to 100) |
| $S_E$[1] | Soft Soil Profile | < 600 (180) | < 15 | < 1,000 (50) |
| $S_F$ | Soil Requiring Site-specific Evaluation. See Section 1629.3.1. | | | |

[1] Soil profile type $S_E$ also includes any soil profile with more than 10 ft (3,048 mm) of soft clay defined as soil with a plasticity index $PI > 20$, $w_{mc} \geq 40$ percent and $s_u < 500$ psf (24 kPa). The plasticity index $PI$ and the moisture content $w_{mc}$ shall be determined in accordance with approved national standards.

[2] Soil profile type $S_F$ includes:

1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils.
2. Peats and/or highly organic clays [H > 10 ft. (3,048 mm) of peat and/or highly organic clay where H = thickness of soil].
3. Very high plasticity clays [H > 25 ft. (7,620 mm) with PI > 75].
4. Very thick soft/medium stiff clays [H > 120 ft. (36,580 mm)].

If the site corresponds to any of these criteria, the site shall be classified as Soil Profile Type $S_F$ and a site-specific evaluation shall be conducted.

Table 2. *Sample of table for UBC Soil Profile Types. After Walker and MacLeod (1991) and U.S. Department of Agriculture, 1975*

| Geologic units[1] 1 = with, 0 = without influence from SCS soils | | Base value[3] | SCS soil units.[2] 1 = with, 0 = without influence on UBC soil type designation A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Coast Range and Klamath Mountains** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Qal** | **0** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Qls** | **0** | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| **Qt** | **1** | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Tc** | **0** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Tms** | **1** | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Cascade Range** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Qyb** | **1** | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Qmp** | **1** | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Qs** | **0** | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Tn** | **1** | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| **Thi** | **1** | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Eastern Oregon (northern Basin and Range, Blue Mountains, and Deschutes Plateau)** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Qpl** | **0** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Ql** | **0** | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **Ts** | **1** | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| **Tbas** | **0** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **KJi** | **0** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

[1] Refer to Table 3 for geologic unit descriptions.
[2] Refer to Table 4 for SCS soil unit descriptions.
[3] Assigned UBC soil type based on geologic unit only.

(Continued from page 75)

In using surficial geologic units to assign the UBC soil types, we assumed that for each geologic unit and assigned UBC soil type the range of shear-wave velocities falls within the range of defined velocities for that UBC soil type. In some cases, this assumption will be erroneous due to the mixed nature of the geologic unit. For example, a single alluvial unit may consist of point bar gravels (producing higher velocities), crevasse splay sands (producing intermediate velocities), and overbank fines (producing slower velocities) and could have several UBC soil types assigned to it. However, the map scale we were using did not allow work to be conducted at this level of detail. Furthermore, while it is possible for a thin unit to overlie a unit with much different characteristics, it was considered to be outside the scope of this project to address the thickness dimension to this degree of detail.

In cases where the properties of a geologic unit fell on the boundary between two UBC soil types, we used the SCS agricultural soil map to further differentiate the unit. Geologic units overlain by a mantle of thick, deeply weathered, clay-rich soils were assigned a value one step higher than the same geologic units with poorly developed soil horizons.

For example, geologic unit Qt (Holocene and Pleistocene terrace gravels) is variable enough to span the boundary between two UBC soils—in this case, $S_C$ (soft rock and very dense soil) and $S_D$ (stiff soil). In an attempt to make this distinction, we used the SCS agricultural soil map to assign a higher value if the deposit occurred in an area associated with thick, deeply weathered soils, such as are common in the wetter and higher parts of the state, and a lower value in regions characterized by poorly developed soils, such as deserts.

To define the UBC soil profile type, we constructed a table (sample portion in Table 2). The (horizontal) rows of the table list all surficial geologic units as represented on the *Geologic Map of Oregon* (Walker and MacLeod, 1991) but simplified to show each unit only once (abbreviated descriptions of these geologic units in Table 3). The columns of the table represent the major SCS soil groups (A through Y) as mapped on the *General Soil Map, State of Oregon* (U.S. Department of Agriculture, 1995) (descriptions in Table 4). They are preceded by a column indicating the basic UBC soil designation that is derived from an evaluation of the geologic unit before including SCS soil designations in that evaluation. The numbers "1" and "0" adjacent to the geologic units (rows) and agricultural soil types (columns) represent, respectively, "influence" and "no influence" of the SCS soil designations on the UBC soil designations of the geologic units.

The matrix of the table presents the numerical results of the UBC soil assignment, with 1 = $S_A$, 2 = $S_B$, and so on, down to 6 = $S_F$ For example, unit Qd (Holocene sand dune deposits) typically consists of well-sorted, slightly indurated sand with a shear-wave velocity of about 250 m/s. This places the unit in UBC soil category 4 = $S_D$ (stiff soil). By contrast, unit Tc (Miocene Columbia River Basalt Group and related flows) has a shear-wave velocity of about 1,110 m/s, which places it in UBC soil profile type 2 = $S_B$ (rock).

How to read the table matrix is demonstrated in the following example of unit Qt (terrace deposits), which occupies row 4. The "1" adjacent to the unit designation indicates that certain SCS agricultural soil types affect the basic UBC soil type designation. The "3" in the next column indicates that UBC soil type $S_C$ was initially assigned to the unit as basic designation. As you read across the row, you will find that the number is changed to "4" in those columns referring to SCS soils whose presence influences the UBC soil profile type designation—as indicated by the "1" adjacent to the SCS soils column headings. In contrast, columns with the number "3" in this row mean that the basic UBC soil type designation remained unaffected by the presence of SCS agricultural soils—as indicated by the "0" adjacent to the column headings.

All occurrences of unit Qls (Holocene and Pleistocene landslide and debris flow material) were designated as UBC soil type 6 = $S_F$ While many landslides may not meet the stated description of $S_F$ ("soils vulnerable to potential failure or collapse under seismic loading, such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils"), we feel that mapped landslides require site-specific studies due to potential reactivation of the landslide mass.

UBC soil type 5 = $S_E$ (soft soil) was assigned to all occurrences of unit Qal (Quaternary alluvium). This choice is appropriate in most places, but in some cases, the active alluvium is probably more properly classified as $S_F$ $S_D$, or even $S_C$.

For one unit in south-central Oregon, we chose to change the UBC soil type designation in a nonsystematic way: Geologic unit Qs (Pleistocene lacustrine and fluvial sediments) is designated in the table as 4 = $S_D$ (stiff soil), which is consistent with its average character throughout the state. However, in the large closed basins of south-central Oregon, the unit contains large amounts of fine-grained, water-saturated lacustrine sediments and thus should be 5 = $S_E$ (soft soil). Consequently, we selectively changed unit Qs outcrops from $S_D$ to $S_E$ in places around the Klamath and Harney basins. Because these outcrops of unit Qs are quite large and contain a wide variety of material, this choice probably overstates the amount of $S_E$ in the area. At the scale of the existing 1:500,000 geologic map, it is not possible to define each location separately. In this single case, however, it was considered prudent to override the systematic approach and change the individual units.

Finally, a 1-km-wide $S_F$ zone was placed around all

Table 3. *Oregon geologic units and abbreviated descriptions from Walker and MacLeod (1991) for selection of geologic units listed in Table 2*

| | |
|---|---|
| | **Coast Range and Klamath Mountains** |
| **Qal** | **Alluvial deposits (Holocene)**—Sand, gravel, and silt forming flood plains and filling channels of present streams. In places includes talus and slope wash. Locally includes soils containing abundant organic material, and thin peat beds |
| **Qls** | **Landslide and debris-flow deposits (Holocene and Pleistocene)**—Unstratified mixtures of fragments of adjacent bedrock. Locally includes slope wash and colluvium. May include some deposits of late Pliocene age |
| **Qt** | **Terrace, pediment, and lag gravels (Holocene and Pleistocene)**—Unconsolidated deposits of gravel, cobbles, and boulders intermixed and locally interlayered with clay, silt, and sand. Mostly on terraces and pediments above present flood plains. |
| **Tc** | **Columbia River Basalt Group and related flows (Miocene)**—Subaerial basalt and minor andesite lava flows and flow breccia; locally includes invasive basalt flows. Flows locally grade laterally into subaqueous pillow-palagonite complexes and bedded palagonitic tuff and breccia. In places, includes tuffaceous sedimentary interbeds. Joints commonly coated with nontronite and other clayey alteration products. Occurs principally in the Willamette Valley from Salem north to the Columbia River, and in the northern Coast Range |
| **Tms** | **Marine sedimentary rocks (middle and lower Miocene)**—Fine- to medium-grained marine siltstone and sandstone that commonly contains tuff beds. Includes the Astoria Formation, which is mostly micaceous and carbonaceous sandstone and the middle Miocene Gnat Creek Formation, which overlies Frenchman Springs Member of the Wanapum Basalt east of Astoria |
| | **Cascade Range** |
| **Qyb** | **Youngest basalt and basaltic andesite (Holocene)**—Little-modified flows and associated breccia of basaltic andesite and some basalt in both central part of Cascade Range and on slopes of Newberry volcano |
| **Qmp** | **Mazama pumice deposits (Holocene)**—Primary and reworked air-fall rhyodacite pumice related to climactic eruptions of Mount Mazama |
| **Qs** | **Lacustrine and fluvial sedimentary rocks (Pleistocene)**—Unconsolidated to semiconsolidated lacustrine clay, silt, sand, and gravel; in places includes mudflow and fluvial deposits and discontinuous layers of peat. |
| **Tn** | **Nonmarine sedimentary rocks (Eocene)**—Continentally derived conglomerate, pebble conglomerate, sandstone, siltstone, and mudstone containing abundant biotite and muscovite. Dominantly nonvolcanic; clastic material derived from underlying older rocks |
| **Thi** | **Hypabyssal intrusive rocks (Miocene and Miocene?)**—Hypabyssal, medium-grained, hornblende diorite and quartz diorite in small stocks and large dikes; includes intrusions of medium- to fine-grained gabbro and plugs and small stocks of medium-grained, holocrystalline, olivine andesite. Also includes medium-grained, commonly porphyritic biotite quartz monzonite and leucocratic granodiorite. Many of these intrusive bodies are moderately to intensely propylitized, as are wallrocks they intrude; locally, along shears, the rocks also are sericitized |
| | **Eastern Oregon**<br>(northern Basin and Range, Blue Mountains, and Deschutes Plateau) |
| **Qpl** | **Playa deposits (Holocene)**—Clay, silt, sand, and some evaporites |
| **Ql** | **Loess (Holocene and Pleistocene)**—Windblown clayey silt and fine sand. Includes the Pleistocene Palouse Formation and deposits derived mostly from reworking of Palouse Formation. Contains local interbedded layers of soil, caliche, and some water-laid silt and gravel |
| **Ts** | **Tuffaceous sedimentary rocks and tuff (Pliocene and Miocene)**—Semiconsolidated to well-consolidated mostly lacustrine tuffaceous sandstone, siltstone, mudstone, concretionary claystone, pumicite, diatomite, air-fall and water-deposited vitric ash, palagonitic tuff and tuff breccia, and fluvial sandstone and conglomerate. In places, includes layers of fluvial conglomerate and, in parts of the Deschutes-Umatilla Plateau, extensive deposits of fanglomerate composed mostly of Miocene basalt debris and silt. Also includes thin, welded and nonwelded ash-flow tuffs |
| **Tbas** | **Andesitic and basaltic rocks on Steens Mountain (Miocene)**—Lava flows and breccia of aphyric and plagioclase porphyritic basalt and aphyric andesite |
| **KJi** | **Intrusive rocks (Cretaceous and Jurassic)**—Hornblende and biotite quartz diorite (tonalite), trondhjemite, granodiorite, and small amounts of norite, in batholithic masses and large dikelike bodies |

bodies of water large enough to be shown on the 1:500,000-scale map. In many places, this is reasonable because swampy, organic-rich material often occurs on the edge of bodies of water, and such material is categorized as $S_F$ However, some bodies of water, especially west of the Cascade Range, are bounded by firm materials (such as bedrock) with only a thin soil veneer. Such is also the case with most reservoirs.

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## DISCLAIMER

The views and conclusions contained in this map are those of the authors and should not be interpreted as necessarily representing official state policies. The map serves as a tool for regional applications. The map does not have site-specific accuracy and should not be used for site-specific purposes.

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*Table 4. – SCS soil units from U.S. Department of Agriculture (1975)*

| | |
|---|---|
| **A** | Udic isomesic soils of the coastal fog belt |
| **B** | Udic mesic soils on terraces and flood plains of western Oregon |
| **C** | Udic mesic soils on forested uplands of the coastal and Cascade mountains |
| **D** | Udic frigid and cryic soils on forested uplands of the coastal and Western Cascade mountains |
| **E** | Udic cryic soils of the High Cascade and Wallowa mountains |
| **F** | Xeric cryic soils of the high plateaus and mountains in south-central and southeastern Oregon |
| **G** | Xeric cryic soils on pumice-mantled, forested plateaus |
| **H** | Aquic frigid and cryic soils of basins and valleys in eastern Oregon |
| **I** | Xeric mesic soils on terraces and flood plains of western Oregon interior valleys |
| **J** | Xeric mesic soils on forested uplands of western Oregon |
| **K** | Xeric mesic soils on forested mountains and hills of southwestern Oregon |
| **L** | Xeric mesic soils on flood plains and terraces of eastern Oregon valleys |
| **M** | Xeric mesic soils on grass-shrub uplands of eastern Oregon |
| **N** | Xeric frigid soils on forested mountains of southwestern Oregon |
| **O** | Xeric frigid soils on forested mountains and plateaus of eastern Oregon |
| **P** | Xeric frigid soils on terraces and flood plains of eastern Oregon |
| **Q** | Xeric frigid soils on grass-shrub uplands of eastern Oregon |
| **R** | Xeric/aridic mesic soils on terraces and flood plains of eastern Oregon |
| **S** | Xeric/aridic mesic soils on grass-shrub uplands of eastern Oregon |
| **T** | Xeric/aridic frigid soils on grass-shrub uplands of eastern Oregon |
| **U** | Aridic/xeric mesic soils on flood plains and terraces of eastern Oregon |
| **V** | Aridic/xeric mesic soils on grass-shrub uplands of eastern Oregon |
| **W** | Aridic/xeric frigid soils on terraces and in basins of eastern Oregon |
| **X** | Aridic/xeric frigid soils on plateaus and uplands of eastern Oregon |
| **Y** | Lava flows |


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# OCAPA honors Gary Lynch

The Oregon Concrete and Aggregate Producers Association (OCAPA) thanked DOGAMI Mined Land Reclamation (MLR) Program Supervisor Gary Lynch by presenting him with the association's President's Award. The OCAPA award is given to someone who has helped the association greatly. It is usually awarded to an association member.

MLR program supervisor Lynch was chosen this year because of his work in helping the association with a number of difficult issues, including key legislative bills, projects involving the confluence of the McKenzie and Willamette Rivers, and issues concerning Goal 5 of the Land Conservation and Development Commission.

Association President Rich Angstrom presented Lynch with the award and said that Lynch's style of rewarding good work was a great help in raising standards in the industry. A good example of that, he added, were the MLR awards for outstanding mining practices and reclamation.

Lynch was surprised by the recognition, saying he was just doing his job. He credited the entire MLR staff for developing a positive working relationship with the industry while maintaining Oregon's high standards for mining and reclamation. □

# Age, chemistry, and origin of capping lava at Upper Table Rock and Lower Table Rock, Jackson County, Oregon

*by Frank R. Hladky, Oregon Department of Geology and Mineral Industries, 5375 Monument Drive, Grants Pass, Oregon 9797526*

**ABSTRACT**

Upper Table Rock and Lower Table Rock, prominent landmarks in southern Oregon, are capped by the upper Miocene andesite of Table Rock. This capping lava is lithologically and chemically distinct from other lavas in the Cascade Range of southern Oregon. In particular, the lava is more alkaline. The unit varies in thickness, from a maximum of 220 m (730 ft) at Lost Creek Lake, to about 30–60 m (100–200 ft) at the buttes north of Medford. Isotopic ages indicate that the lava was erupted most likely about 7 Ma. It spread over terrain of variable relief. The lava flow was not confined to the channel of the ancestral Rogue River, but spread like a sheet over much of the ancient valley of the Rogue River and its tributaries. The present shape of the two buttes is the result of erosion. Since the andesite of Table Rock was emplaced, faulting is known to have displaced the unit west of Lower Table Rock. Source vents for the andesite of Table Rock have not been discovered. They are most likely covered by younger lavas. Chemical data indicate a compositional link with younger alkaline lavas at Olson Mountain, a broad, extinct shield volcano near Lost Creek Lake. The andesite of Table Rock is more similar to lavas at Olson Mountain than to lavas from stratovolcanoes of the High Cascades, formerly considered to be the source for the andesite of Table Rock.

**INTRODUCTION**

North of Medford in southern Oregon are two prominent, horseshoe-shaped, flat-topped buttes: Upper Table Rock and Lower Table Rock (Figure 1). Southern Oregon residents often refer collectively to the buttes as the Table Rocks. The buttes are located near the Rogue River between Sams Valley and Central Point. The unincorporated community of Table Rock is located between the two buttes. Unlike the surrounding rounded hills, the buttes have vertical cliff faces in their upper portions that change abruptly to flat tops at their summits. The buttes stand more than 240 m (800 ft) above the valley floor and owe their distinctive morphology to a cliff-forming cap of upper Miocene lava that overlies sandstone, conglomerate, and mudstone of the upper Eocene Payne Cliffs Formation. The capping trachyandesitic lava is exposed at Upper Table Rock, Lower Table Rock, Castle Rock, and at several places near the Rogue River upstream from Upper Table Rock. Collectively, these exposures compose the andesite of Table Rock. The andesite of Table Rock was erupted from vents in

**Figure 1. View to the southeast showing Upper Table Rock (left) and Lower Table Rock (right). Sams Valley is in the foreground.**

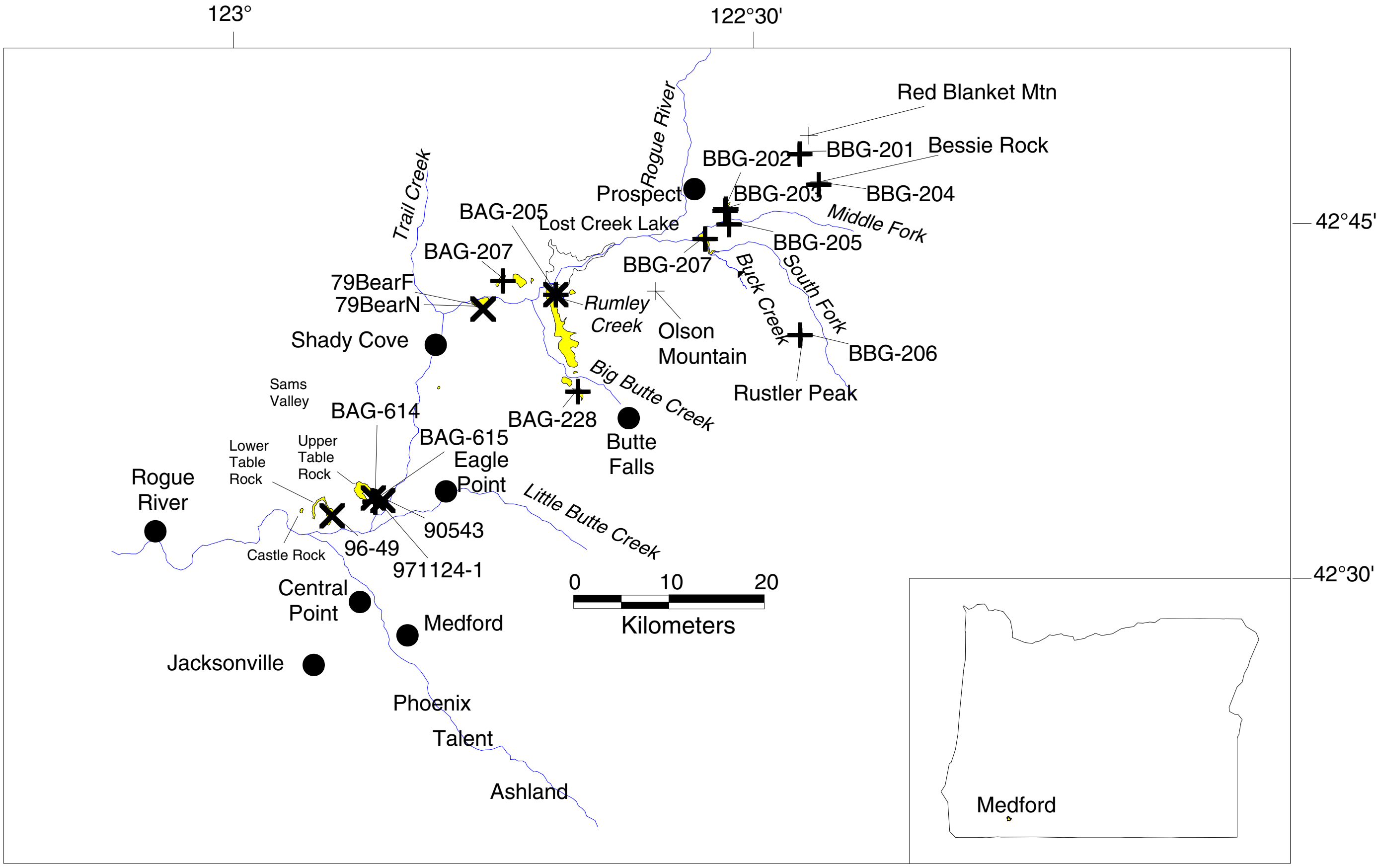


**Figure 2. Sketch map showing location of the study area, outcrops of the andesite of Table Rock (stippled areas), whole-rock samples (marked by "+"; analyses in Tables 1–3), and samples used for isotopic age determinations( marked by "×"; analyses in Table 4.**

the Cascade Range of southern Oregon probably about 7 Ma. The source is thought to lie near Olson Mountain, a large extinct shield volcano southeast of Lost Creek Lake and south-southwest of Prospect, Oregon.

Previous investigators noted the capping lava at Upper Table Rock and Lower Table Rock and recognized that its source lay in the Cascade Range (Winchell, 1914; Wells, 1939; 1956; Williams, 1942; Beaulieu and Hughes, 1977;. Smith and others, 1982; Hladky, 1993; Wiley and Smith, 1993). Exposures of trachyandesite crop out intermittently along the valley and canyon of the Rogue River and overlie older rocks of the Western Cascades. The easternmost exposures of andesite of Table Rock are east of Prospect in the High Cascades, a geomorphic subprovince of the Cascade Range dominated by slightly to moderately eroded shield and stratovolcanoes that are mostly less than 2 million years old (Sherrod and Smith, 1989). The westernmost bedrock exposure is found on top of a small hill, known locally as Castle Rock, west of Lower Table Rock (Figure 2). Northwest of Castle Rock residual cobbles of andesite of Table Rock are found as far west as the western edge of Sams Valley along State Highway 234.

## LITHOLOGY AND PETROGRAPHY

The andesite of Table Rock is a distinctive, plagioclase-speckled, dark-gray to black, glassy rock that typically crops out as poorly shaped pseudo-hexagonal columns. The conspicuous tabular feldspar, as large as 0.5 by 6 mm, has been determined petrographically to be mostly oligoclase, a variety of plagioclase. It varies in abundance from 10 to 30 percent, although its abundance decreases virtually to zero near chilled margins. The normative plagioclase composition, or theoretical composition based upon chemical analyses of the whole rock, is $An_{32-38}$ (andesine). Olivine and augite phenocrysts are typically small (up to 1 mm) and usually each comprise less than 2 or 3 percent of the rock. The olivine is often iddingsitized either partially or completely. Phenocrysts of equant alkali feldspar (up to 3 mm), most easily identifiable in thin section, are also present. The groundmass comprises brown to black glass, and tiny andesine and labradorite laths, magnetite and hematite, hexagonal apatite, and orthopyroxene.

There is little petrographic variability in the unit except near chilled margins, where the lava cooled against adjacent soil and bedrock. Hand samples and thin sections of the unaltered rock are comparable, whether taken from the Table Rocks or from the canyon of the South Fork Rogue River in the High Cascades. Plagioclase phenocrysts can be white or nearly translucent, depending upon local weathering, but they characteristically stand out against the black, glassy groundmass. As might be expected, the abundance of phenocrysts of all types decreases near chilled margins. The rock commonly contains as much as 5 percent vesicles as large as 1 cm near chilled margins.

As the andesite of Table Rock cooled, it contracted to produce two distinct patterns of columnar jointing. Columnar jointing in solidified lavas consists of parallel, prismatic columns, either hexagonal or pentagonal in cross section. Two zones of jointing occur in the andesite of Table Rock: the colonnade and the entablature. Columns in the colonnade, the zone of jointing that has thicker, more regular columns than the entablature, are typically 30–45 cm (12–18 in.) across. In the canyon of the South Fork Rogue River, however, the colonnade contains some moderately well-formed columns slightly more than 200 cm (80 in.) across (Figure 3). Columns in the colonnade are observed to be mostly perpendicular to the ancient land surface. The colonnade is typically in the middle of the unit; however, at the Table Rocks, the colonnade is intermittently found near the bottom. The entablature is the most common jointing pattern of the andesite of Table Rock. In the entablature, columns are poorly formed and typically about 15 cm (6 in.) across. They are also more chaotically oriented than in the colonnade. The unit shows vesiculation locally near its top and bottom and commonly where entablature meets colonnade.

In a roadcut exposure along Highway 62 in NW¼ sec. 35, T. 35 S., R. 1 E., south of Lost Creek Dam, is what is interpreted to be an autoclastic flow breccia. It is up to 8 m (25 ft) thick. Autoclastic flow breecia develops when chunks of solid and semi-molten lava calve off the edges of the lava flow; the advancing flow then overrides its breccia. In some places at Upper Table Rock the basal 2 m (6 ft) of the flow is commonly partially palagonitized and scoriaceous, having been in contact with water when the rock was molten. Similar palagonitized scoria is found in some basal outcrops between Shady Cove and Lost Creek Lake.

The thickness of the andesite of Table Rock varies from place to place. The maximum cumulative thickness the unit attains is about 220 m (730 ft) on the south bank of Lost Creek Lake. Paleosols and other indicators of depositional breaks indicating multiple flows have not been found. Because of talus and soil cover, no more than about 40 m (130 ft) of continuously uncovered section is exposed—except at Lost Creek Dam quarry, where about 60 m (200 ft) is exposed. The typical thickness of the andesite of Table Rock between Shady Cove and Olson Mountain ranges between 130 and

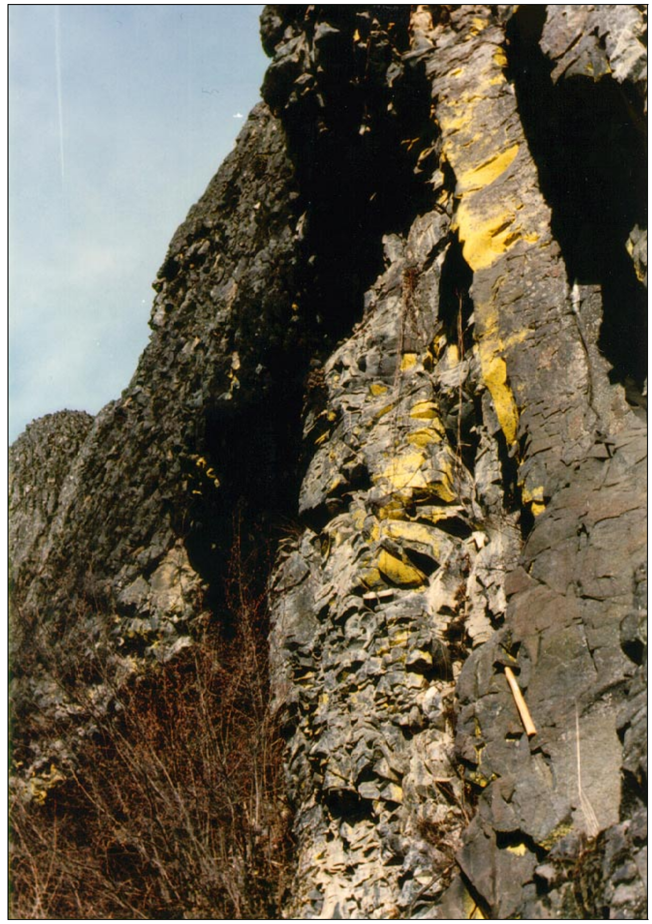

**Figure 3. As the andesite of Table Rock cooled, joints produced the smaller, poorly formed columns of the entablature (top and left sides of photo) and the larger columns of the colonnade (right and lower parts of photo). Hammer at lower right is approximately 40 cm long.**

180 m (400 and 600 ft). In this area, outcrops of the andesite of Table Rock occur at and near the top of the canyon on either side of the present Rogue River, and the unit is thickest toward the river (inferred center of the flow). Near the course of present-day Big Butte Creek, the unit averages about 130 m (400 ft) in thickness and crops out over a wide area. More than 80 m (260 ft) of andesite of Table Rock was measured in the canyon of the South Fork Rogue River east of Olson Mountain; however, the base is not exposed there. About 50 percent of the section in the South Fork is covered by soil or talus. The maximum thickness at Upper Table Rock and Lower Table Rock is about 60 m (200 ft), but talus typically covers about 20 m (65 ft) of section. In general, the unit is thought to be thickest near its source and thinnest nea flow margins and north of Medford, where it is most distant from its source.

## DISTRIBUTION

Today, outcrops, boulder trails, and monoliths of the andesite of Table Rock extend from east of Prospect in

Table 1. *Whole-rock analyses from the andesite of Table Rock, Jackson County, Oregon. Unless otherwise noted, all data are new. Samples BAG-205 and BAG-207 originally reported in Hladky (1993). Samples BAG-614 and BAG-615 originally reported in Wiley and Smith (1993).* (Continued on opposite page ➤)

| Sample number | ¼ | ¼ | Sec. | T. (S.) | R. | UTM coordinates | Elev. (ft) | Location description | Lithology |
|---|---|---|---|---|---|---|---|---|---|
| **BAG-205** | SE | NE | 35 | 33 | 1 E. | 4723081N 527706E | 2,480 | Lost Creek Dam quarry | Trachyandesite |
| **BAG-207** | SE | NW | 29 | 33 | 1 E. | 4724497N 522173E | 2,560 | Schoolhouse Rock/Elk Ridge | Trachyandesite |
| **BAG-228** | NW | SW | 31 | 34 | 2 E. | 4712985N 530046E | 2,220 | Butte Falls Highway | Basaltic trachyandesite |
| **BAG-614** | NW | SW | 1 | 36 | 2 W. | 4701445N 508860E | 2,030 | Top of Upper Table Rock | Trachyandesite |
| **BAG-615** | NW | SW | 1 | 36 | 2 W. | 4701412N 508872E | 1,920 | Flow base, Upper Table Rock | Trachyandesite |
| **BBG-202** | NW | SE | 34 | 32 | 3 E. | 4732080N 545405E | 2,680 | Borrow Pit | Weathered trachyandesite |
| **BBG-203** | NW | SE | 34 | 32 | 3 E. | 4731895N 545345E | 2,620 | Middle Fork Rogue River | Trachyandesite |
| **BBG-207** | NE | SW | 9 | 33 | 3 E. | 4728975N 543265E | 2,560 | South Fork Rogue River | Trachyandesite |
| **971124-1** | SE | SE | 2 | 36 | 2 W. | 4701830N 508650E | 2,020 | Near top, Upper Table Rock | Trachyandesite |
| **96-49** | NE | SW | 9 | 36 | 2 W. | 4699960N 504340E | 2,045 | Top of Lower Table Rock | Trachyandesite |

Table 2. *Whole-rock analyses of rocks taken from selected ancient High Cascade volcanoes that were mapped by Smith and others (1982) as the same unit as the andesite of Table Rock but, in fact, overlie the andesite of Table Rock. These areas were formerly thought to be possible sources.* (Continued on opposite page ➤)

| Sample number | ¼ | ¼ | Sec. | T. (S.) | R. | UTM coordinates | Elev. (ft) | Location description | Lithology |
|---|---|---|---|---|---|---|---|---|---|
| **BBG-201** | NW | NE | 16 | 32 | 4 E. | 4737885N 553080E | 4,980 | Red Blanket Mountain quarry | Andesite |
| **BBG-204** | NE | NE | 27 | 32 | 4 E. | 4734710N 555075E | 5,690 | Bessie Rock | Basaltic andesite |
| **BBG-205** | NE | SE | 3 | 33 | 3 E. | 4730495N 545775E | 2,750 | Middle Fork quarry | Basaltic andesite |
| **BBG-206** | SW | SE | 9 | 34 | 4 E. | 4719025N 553265E | 5,490 | Rustler Peak | Andesite |

Table 3. *Whole-rock analyses of rocks taken from Olson Mountain that overlie the andesite of Table Rock. Originally reported in Hladky (1993).* (Continued on opposite page ➤)

| Sample number | ¼ | ¼ | Sec. | T. (S.) | R. | UTM coordinates | Elev. (ft) | Location description | Lithology |
|---|---|---|---|---|---|---|---|---|---|
| **BAG-224** | NE | NW | 36 | 33 | 1 E. | 4723203N 528711E | 2,200 | Andesite along HWY 62 | Trachybasalt |
| **BAG-229** | NW | SE | 1 | 34 | 1 E. | 4720853N 528853E | 2,600 | Andesite of Olson Mtn | Basaltic trachyandesite |

the High Cascades to the east edge of the Klamath Mountains at Sams Valley, a distance of approximately 70 km (44 mi). The andesite of Table Rock overlies rocks of late Miocene, Oligocene, Eocene, and Mesozoic age (Hladky, 1993; Wiley and Smith, 1993)—a result of having traversed the course of the ancestral Rogue River during Miocene time. The andesite of Table Rock probably emanated from near Prospect and Olson Mountain and was subsequently buried beneath lavas of Olson Mountain and High Cascades volcanoes. The easternmost exposures crop out above the confluence of the Middle and South Forks of the Rogue River. In both forks the base is covered and the thickness exceeds 80 m (265 ft).

These easternmost exposures of the andesite of Table Rock are overlain by younger basaltic andesite and andesite lavas of Red Blanket Mountain and Bessie Rock; the age of Bessie Rock is about 4.88 Ma (Fiebelkorn and others, 1983). To the west, at Olson Mountain (Figure 2), younger lava flows of light-gray basalt and basaltic trachyandesite overlie the andesite of Table Rock near Lost Creek Lake (Hladky, 1993). At Lost Creek Lake (Figure 2), where thicknesses average 180 m (600 ft), a narrow exposure crops out in Rumley Creek 2 to 8 m (25 ft) below the spillway elevation, about 75 m (250 ft) below where it was mapped by Hladky (1993), making the maximum thickness there about 220 m (730 ft). There, the andesite of Table Rock fills a narrow paleochasm.

Outcrops of the andesite of Table Rock are found as far south as Butte Falls highway west of Butte Falls (Figure 2). The preserved thickness of bedrock exposures of the ancient lava flow near its western terminus at Castle Rock is about 45 m (150 ft) (Figure 2). Near Lost Creek Lake, the andesite of Table Rock unconformably overlies lower Miocene andesite. Between Shady Cove and Lost Creek Dam, flow remnants on either side of the Rogue River canyon walls thicken toward the river. Between Shady Cove and Upper Table Rock, detailed mapping has revealed only one intact outcrop of andesite of Table Rock. In the same stretch, however, a few monoliths of andesite of Table Rock can be found, most of them near Upper Table Rock. The monoliths are typically several meters across and are the residuum of erosion; they are not attached to bedrock. The horse-shaped buttes of Upper Table Rock and Lower Table Rock owe their existence to the resistant capping

Table 1 (continued). *Analyses by X-ray fluorescence (XRF) performed by X-Ray Assay Laboratories (XRAL), Don Mills, Ontario, Canada, except for sample 9*6-49, whose data were supplied by Stanley Mertzman (unpublished data, 1998). For sample locations, see Figure 2

| | Oxides (weight percent) | | | | | | | | | | | | Selected trace elements (ppm) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample no.** | **$SiO_2$** | **$Al_2O_3$** | **$TiO_2$** | **$Fe_2O_3T$** | **MnO** | **CaO** | **MgO** | **$K_2O$** | **$Na_2O$** | **$P_2O_5$** | **LOI** | **SUM** | **Cr** | **Rb** | **Sr** | **Y** | **Zr** | **Nb** | **Ba** |
| **BAG-205** | 57.1 | 16.5 | 1.34 | 7.96 | 0.15 | 5.75 | 2.65 | 2.28 | 4.46 | 0.61 | 1.05 | 100.1 | 16 | 25 | 734 | 29 | 174 | 36 | 796 |
| **BAG-207** | 57.4 | 16.3 | 1.34 | 7.82 | 0.15 | 5.29 | 2.67 | 2.71 | 4.20 | 0.62 | 0.30 | 100.0 | 13 | 38 | 698 | 30 | 195 | 27 | 883 |
| **BAG-228** | 55.0 | 16.9 | 1.32 | 8.56 | 0.15 | 6.73 | 3.7 | 2.22 | 4.1 | 0.61 | 0.60 | 100.1 | 44 | 41 | 702 | 17 | 164 | <10 | 696 |
| **BAG-614** | 56.7 | 17.0 | 1.32 | 7.67 | 0.15 | 5.81 | 2.71 | 2.36 | 0.51 | 0.62 | 0.25 | 100.3 | 74 | 35 | 712 | 27 | 172 | 25 | 776 |
| **BAG-615** | 56.5 | 17.1 | 1.31 | 7.75 | 0.14 | 5.93 | 2.86 | 2.17 | 0.52 | 0.59 | 0.50 | 100.6 | 76 | 37 | 731 | 33 | 172 | 15 | 782 |
| **BBG-202** | 57.9 | 17.2 | 1.14 | 7.15 | 0.11 | 4.86 | 1.56 | 2.64 | 0.59 | 0.50 | 0.20 | 100.1 | <10 | 50 | 712 | 33 | 211 | 46 | 928 |
| **BBG-203** | 55.9 | 16.9 | 1.25 | 7.85 | 0.15 | 6.14 | 2.77 | 2.23 | 0.18 | 0.64 | 0.95 | 100.2 | <10 | 44 | 767 | 14 | 179 | 45 | 907 |
| **BBG-207** | 56.2 | 16.7 | 1.25 | 8.03 | 0.16 | 6.05 | 2.72 | 2.44 | 0.98 | 0.66 | 0.05 | 100.5 | <10 | 25 | 721 | 28 | 182 | 17 | 880 |
| **971124-1** | 56.5 | 16.3 | 1.25 | 7.73 | 0.14 | 6.08 | 2.84 | 2.31 | 4.71 | 0.62 | 1.00 | 99.7 | <10 | 27 | 698 | 24 | 208 | <10 | 815 |
| **96-49** | 57.6 | 16.8 | 1.28 | 7.27 | 0.14 | 5.69 | 2.63 | 2.46 | 4.35 | 0.59 | 1.32 | 100.3 | 25 | 26 | 672 | 29 | 184 | 10 | 866 |

Table 2 (continued).
*For sample locations, see Figure 2*

| | Oxides (weight percent) | | | | | | | | | | | | Selected trace elements (ppm) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample no.** | **$SiO_2$** | **$Al_2O_3$** | **$TiO_2$** | **$Fe_2O_3T$** | **MnO** | **CaO** | **MgO** | **$K_2O$** | **$Na_2O$** | **$P_2O_5$** | **LOI** | **SUM** | **Cr** | **Rb** | **Sr** | **Y** | **Zr** | **Nb** | **Ba** |
| **BBG-201** | 58.4 | 18.8 | 0.719 | 6.57 | 0.11 | 5.57 | 2.67 | 1.18 | 3.82 | 0.17 | 2.1 | 100.3 | <10 | 22 | 872 | <10 | 81 | 18 | 409 |
| **BBG-204** | 56.3 | 16.8 | 0.627 | 7.43 | 0.13 | 8.06 | 6.2 | 0.85 | 3.63 | 0.13 | 0.05 | 100.4 | 20 | 22 | 829 | <10 | 40 | 15 | 284 |
| **BBG-205** | 51.4 | 17.4 | 0.956 | 8.87 | 0.16 | 9.12 | 5.84 | 0.73 | 2.98 | 0.36 | 2.1 | 100.1 | <10 | 13 | 999 | 12 | 82 | 20 | 350 |
| **BBG-206** | 61.5 | 18.0 | 0.517 | 5.17 | 0.11 | 5.42 | 1.88 | 1.35 | 4.57 | 0.22 | 1.55 | 100.5 | <10 | 18 | 1,050 | <10 | 86 | <10 | 479 |

Table 3 (continued).
*Data indicate compositional similarity to the andesite of Table Rock*

| | Oxides (weight percent) | | | | | | | | | | | | Selected trace elements (ppm) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample no.** | **$SiO_2$** | **$Al_2O_3$** | **$TiO_2$** | **$Fe_2O_3T$** | **MnO** | **CaO** | **MgO** | **$K_2O$** | **$Na_2O$** | **$P_2O_5$** | **LOI** | **SUM** | **Cr** | **Rb** | **Sr** | **Y** | **Zr** | **Nb** | **Ba** |
| **BAG-224** | 50.2 | 17.6 | 1.50 | 11.3 | 0.18 | 8.24 | 4.43 | 1.44 | 3.73 | 0.77 | 0.75 | 100.4 | 94 | 30 | 902 | 29 | 166 | 19 | 627 |
| **BAG-229** | 52.9 | 17.3 | 1.31 | 9.77 | 0.22 | 7.46 | 3.89 | 1.76 | 3.97 | 0.86 | 0.5 | 100.2 | <10 | 18 | 791 | 38 | 215 | 28 | 939 |

lava and their shape to erosion. Castle Rock, immediately west of Lower Table Rock, is the westernmost bedrock outcrop. A few large monoliths are located in and near the gravel pits south of Lower Table Rock (Wiley and Smith, 1993). A string of monoliths and cobbles occurs northwest of Castle Rock.

## GEOCHEMISTRY

Geochemical data for the andesite of Table Rock and volcanoes that have been suspected as sources are shown in Tables 1, 2, and 3. Whole-rock geochemistry data for andesite of Table Rock are shown in Table 1. Geochemical data from High Cascade volcanoes once mapped as the same unit as the andesite of Table Rock are shown in Table 2. Limited geochemical data from Olson Mountain indicate chemical similarities to the andesite of Table Rock (Table 3).

Previous workers have referred to the distinctive capping lava flow at Upper Table Rock and Lower Table Rock as basalt. Sodic plagioclase, alkali feldspar, pyroxene content, and ratio of alkalis to silica qualify this rock as a trachyandesite (Bates and Jackson, 1987, p. 694; Cox and others, 1979, p. 14). Applying the IUGS classification scheme (Le Bas and Streckeisen, 1991) of silica versus alkali metals to the whole-rock chemical data for rocks in the Cascade Range of southern Oregon shows that the andesite of Table Rock plots conspicuously in the trachyandesite field (Figure 4). One sample is as mafic as basaltic trachyandesite.

The andesite of Table Rock is substantially more alkaline than typical basalt, basaltic andesite, and andesite of the Western Cascades and High Cascades (Figure 4). In addition, the $P_2O_5$ content of the andesite of Table Rock is substantially higher than in most Cascade rocks of southern Oregon (Figure 5). Chemically similar fine-grained to aphanitic trachybasalt and basaltic trachyandesite lavas at Olson Mountain directly overlie the andesite of Table Rock near Lost Creek Lake and have more $P_2O_5$. These younger, slightly more mafic, alkaline lavas are only chemically similar. Petrographically, their phenocryst assemblage, when visible, is different. The total alkali-to-silica ratio of the andesite of Table Rock is more similar to lava flows at Olson Mountain than to lava flows in the High Cascades or the Western Cascades (Figure 4). Analyses from High Cas-

*(Continued on page 87)*

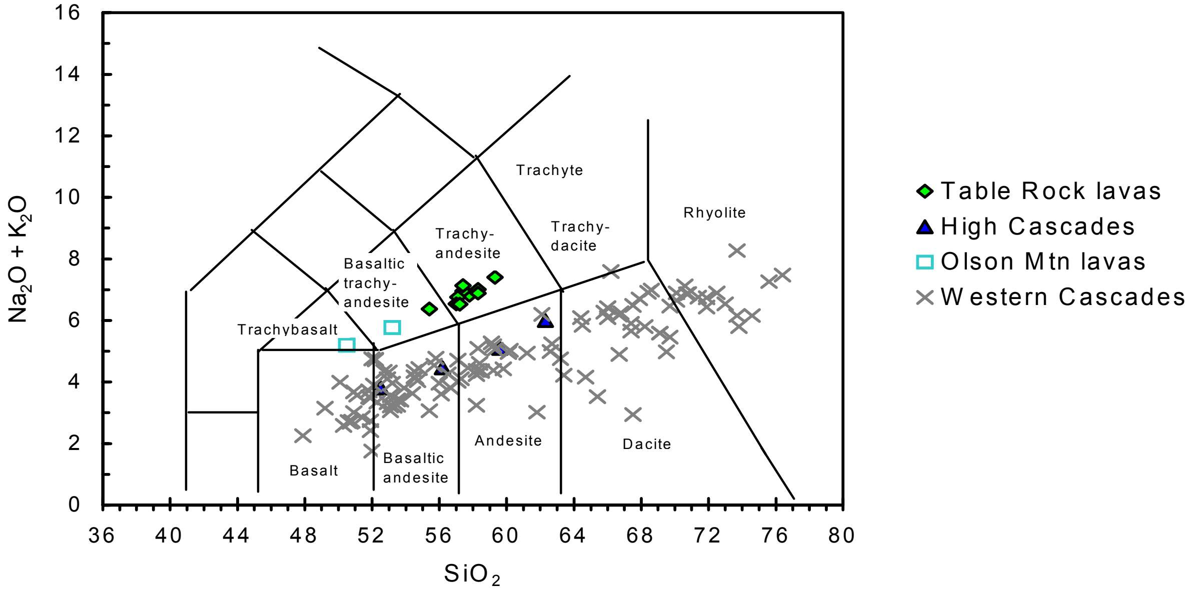


**Figure 4. Diagram showing total alkali vs. silica of volcanic rocks of the Cascade Range of southern Oregon. Data from geologic maps of the Shady Cove, McLeod, Lakecreek, Grizzly Peak, Cleveland Ridge, Boswell Mountain, Medford East, Medford West, Eagle Point, and Sams Valley 7½-minute quadrangles, (Hladky, 1992; 1993; 1995, 1996; Wiley and Hladky, 1991; Wiley, 1993; and Wiley and Smith, 1993) and Tables 1–3 of this report. Major oxides were recalculated anhydrous to 100 percent according to the IUGS recommendation of Le Bas and Streckeisen, (1991). Divisions on diagram after Le Bas and others (1986).**

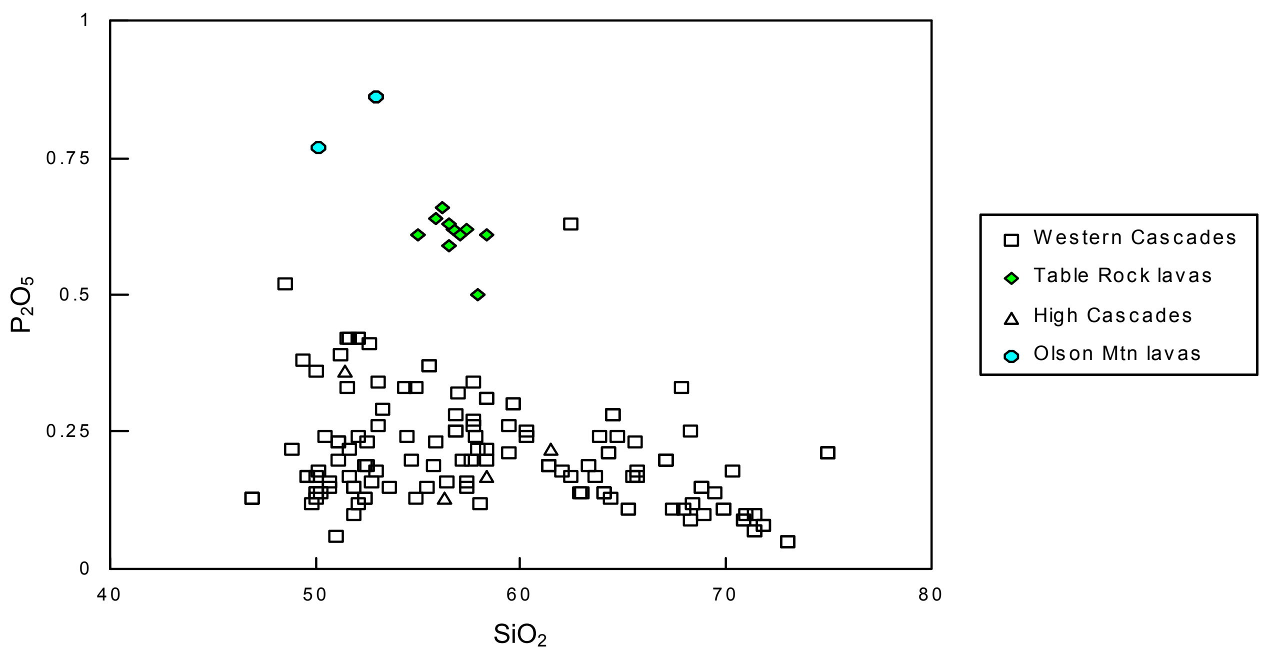


**Figure 5. Diagram showing $P_2O_5$ vs. $SiO_2$ for volcanic rocks of the Cascade Range of southern Oregon. Data from geologic maps of the Shady Cove, McLeod, Lakecreek, Grizzly Peak, Cleveland Ridge, Boswell Mountain, Medford East, Medford West, Eagle Point, and Sams Valley 7½-minute quadrangles, (Wiley and Hladky, 1991; Hladky, 1992; 1993; 1994, 1996; Wiley, 1993; and Wiley and Smith, 1993) and Tables 1–3 of this report.**

(Continued from page 85)
cade volcanoes (Table 2 and Figure 4) are more similar to those from the Western Cascades than to those of the andesite of Table Rock. There is limited trachyandesite in the Western Cascades in the Brownsboro quadrangle southwest of Butte Falls (Hladky, in press a), but these rocks consist of isolated exposures of altered vent agglutinate and tuff and have no petrographic similarity to the andesite of Table Rock.

Trachyandesitic lavas are rare in the Cascade Range of southern Oregon (Figure 4). Rocks with elevated $P_2O_5$ are also rare in the region. The andesite of Table Rock and alkaline lavas at Olson Mountain contain two to three times as much $P_2O_5$ as found in most volcanic rocks in the region (Figure 5). The andesite of Table Rock and overlying rocks at Olson Mountain are chemically similar to each other, yet chemically distinct from virtually all other volcanic rocks in the Cascade Range of southern Oregon.

The chemical similarity, stratigraphic relationship, and proximity of alkaline rocks at Olson Mountain to exposures of the andesite of Table Rock indicate that perhaps high-$P_2O_5$ alkaline lavas were derived from the same or proximally-located magma chambers. If this is so, then the earliest alkaline eruptions at Olson Mountain produced the andesite of Table Rock and later produced slightly more mafic, increasingly $P_2O_5$-enriched, alkaline lavas.

## MAGNETIC POLARITY

The andesite of Table Rock shows normal-polarity magnetization. Numerous determinations were made with the aid of a fluxgate magnetometer at the Lost Creek Dam quarry (Figure 6) and at Upper Table Rock. Results varied greatly near the tops of cliffs at Upper Table Rock, but this is an area where lightning strikes would be expected to modify the thermal remnant magnetic signature of the lava flow. A few meters below the uppermost surface of the butte, both along cliff faces and within crevices, the andesite of Table Rock consistently yielded normal-polarity readings.

## AGE

Samples from the andesite of Table Rock have yielded isotopic ages ranging from 6.77 ± 0.2 Ma to 9.6 ± 0.13 Ma (Table 4), i.e., within the late Miocene (Palmer, 1983). The confidence intervals for all of these samples do not overlap, which could indicate the presence of multiple lava flows. An examination of the data, however, shows that one of the analyses is flawed.

Five out of six analyses of the andesite of Table Rock have returned ages of about 7 Ma. Samples 79BearN and 79BearF are two whole-rock analyses from the same site with different ages (Table 4). Fortunately, their confidence intervals overlap. The only difference between the two was in the preparatory treatment of the samples: The thinking was that the glass in the groundmass might be retaining potassium while letting argon slip away, thereby yielding too young an age. For sample 79BearN, the rock was treated in nitric acid only. For sample 79BearF, the rock was treated in nitric acid and hydrofluoric acid which dissolves glass. Investigators thus expected to get an older age from 79BearF which was treated in nitric acid and hydrofluoric acid (Jim Smith, oral communication, 1997). Instead, a slightly younger age was produced. The precision of the results overlap, however, suggesting an age of about 7 Ma.

The age from the Ar-Ar analysis from Lost Creek Dam Quarry (sample BAG-205) is close to that of the samples from Bear Mountain, and overlaps that of sample 79BearN. Even though the Ar-Ar method is newer and supposed to be more accurate, the level of precision is probably overstated. These rocks are probably the same age, and probably from the same flow.

Sample 971124-1 taken recently from Upper Table Rock returned an age of about 7 Ma. The reason for testing this sample was to test the validity of an age obtained several years ago from an Upper Table Rock sample (90643) that yielded an age of 9.6 Ma. Interest-

**Figure 6. Looking north at Lost Creek Dam quarry, with Lost Creek Lake in the background. Rock from this quarry was used to construct and face the dam. Magnetic polarity readings here indicated normal magnetization, just as at Upper Table Rock. Sample BAG–205 was obtained from the base of the prominent pinnacle on the left.**

Table 4. *Isotopic ages of the andesite of Table Rock, Jackson County, Oregon. All analyses are whole-rock*

| Sample number | UTM coordinates[1] | Location description[2] | Method | Reported age (Ma) |
|---|---|---|---|---|
| **90543** [3] | 4701560N 509660E [4] | Monolith several meters across near Upper Table Rock, Sams Valley quadrangle | Ar-Ar, incremental heating | 9.60 ± 0.13 |
| **971124-1** | 4701830N 508650E | Upper Table Rock, east face, 5 m below top surface, Sams Valley quadrangle | Ar-Ar, incremental heating | 7.13± 0.15[5] |
| **BAG-205** | 4723081N 527706E | Lost Creek Dam quarry, McLeod quadrangle | Ar-Ar, total fusion | 7.32 ± 0.08[5] |
| **79BearN** | 4721570N 520090E [6] | Bear Mountain, Trail quadrangle | K-Ar, whole-rock | 7.10 ± 0.2[7] |
| **79BearF** | 4721570N 520090E [6] | Bear Mountain, Trail quadrangle | K-Ar, whole-rock | 6.77 ± 0.2[7] |
| **96-49** | 4699960N 504340E | Lower Table Rock, top surface | K-Ar, whole-rock | 7.7 ± 0.2[8] |

[1] UTM coordinates shown for Zone 10, North American datum 1927.

[2] Quadrangles are U.S. Geological Survey 7.5-minute series topographic sheets.

[3] Sample collected by Clifton Mitchell (formerly University of Oregon), analysis by R.A. Duncan (Oregon State University).

[4] Approximate location described by Gerry Capps (BLM, oral communication, 1993) and Wiley and Smith (1993).

[5] New data. Analysis by R. A. Duncan.

[6] Latitude/longitude coordinates from Fiebelkorn and others (1983) plotted to Trail quadrangle map and UTM coordinates extracted. Extracted position accurate to the number of significant figures shown.

[7] Reported in Fiebelkorn and others (1983).

[8] New data (unpublished) from Stanley A. Mertzman, Franklin and Marshall College, Lancaster, Pennsylvania.

ingly, as this report was going to press, it was discovered that Stanley A. Mertzman of Franklin and Marshall College, Lancaster, Pennsylvania, had obtained a whole-rock K-Ar age of 7.7 ± 0.2 Ma from Lower Table Rock (Table 4).

Chemical, lithologic, and map data indicate that exposures of the andesite of Table Rock are so similar that they are part of the same flow. The 9.6 Ma age indicated that the trachyandesite at Upper Table Rock was older than trachyandesite above Shady Cove, in other words, a different flow. Newly obtained ages of about 7 Ma from Upper Table Rock and Lower Table Rock accord with ages above Shady Cove, indicating that perhaps the 9.6-Ma age is in error. The original sample that yielded the older age is no longer available, so that it is impossible to determine what caused the age discrepancy. Presuming that the analsis was carefully handled, then perhaps some mineral phase in the rock contained excess argon, thereby skewing the results.

## GRADIENT AND TECTONIC DEFORMATION

The gradient of the modern Rogue River and the top and bottom of the andesite of Table Rock are plotted in Figure 7. The method employed was to draw straight lines beginning at a datum point at the intersection of the Rogue River and longitude 123°W. From the datum point, straight lines were drawn with bends at the following upstream confluences with the Rogue River: Little Butte Creek, Trail Creek, Big Butte Creek, South Fork Rogue River, and Middle Fork Rogue River. The gradient chart terminates at the confluence of Buck Creek with the South Fork Rogue River, well above exposures of the base of the andesite of Table Rock. The straight lines were then marked at one-kilometer intervals. Elevations of the modern river and of the andesite of Table Rock were projected perpendicularly to the kilometer ticks on the straight lines. The reasoning for choosing straight lines rather than actual river mile markers is that although the actual course of the ancient river is not known, a plot of the base of the lava might mimic the approximate elevation of the ancient river.

Although plenty of data exist for determining the gradient of the modern Rogue River, the data for the andesite of Table Rock are discontinuous. I hoped that plotting the base of the andesite of Table Rock would yield the approximate, albeit sporadic, trace of the gradient of the ancient Rogue River. The irregular plot of the base of the andesite of Table Rock, indicates that it is not possible to find the thalweg, that is, the deepest centerline, of the ancient river with this method. The irregular gradient plot indicates that the basal measurements are not necessarily near the center of the channel but, in many cases, well up the sides of the retaining channel and away from the thalweg. This situation manifests itself upstream at Lost Creek Lake where pronounced, narrow, deep paleochasms are filled with the andesite of Table Rock (Hladky, 1993)—below the bulk of the flow.

It has been suggested that the horseshoe-shaped outcrop pattern of the andesite of Table Rock at Upper and Lower Table Rocks and the distribution of residual monoliths of andesite of Table Rock represent the inverted topography of an ancient river channel (Gerald Capps, BLM, written communication, 1992). The one-kilometer-spaced gradient plot of the base of the andesite of Table Rock, derived from the geology of Wiley and Smith (1993), however, does not indicate a regular gradient (Figure 7). Furthermore, a map examination of the lower contact of the lava reveals as much as 30 m (100 ft) of undulating elevation relief at both of the two buttes. At Upper Table Rock, this relief is irregular. At Lower Table Rock, the general orientation of the basal contact is higher in the north and lower at the southerly tips, which could indicate that perhaps the butte is gently folded about a north-south axis that plunges south. The lower lava contact at Castle Rock is irregular with a variance of up to 12 m (40 ft), which indicates that the lava flowed onto an uneven surface.

The top surfaces of Upper and Lower Table Rocks also yield insight into the nature of emplacement of the andesite of Table Rock and subsequent tectonic deformation. Although the top surfaces have been modified by erosion, they are still flat enough that they indicate no major structural deformation at the two buttes. At Upper Table Rock, the top surface is lowest at the tips of the horseshoe. This configuration would be expected if the butte were tilted to the southeast. The west arm of the butte, however, is higher that the east arm, suggesting eastward or northeastward rather than southeastward tilting. Erosional relief on the west arm complicates the issue. In addition, although the lower contact varies in elevation by as much as 30 m (100 ft), the top surface varies by only by about 20 m (60 ft). If the butte were folded, we would expect the elevation differences between the top and bottom surfaces to be about the same amount and in the same place, but they are not.

Therefore, the stratum of lava at Upper Table Rock is not only irregular in thickness, but also irregularly shaped along its bottom surface, the result of having molded itself to the irregular topography onto which it was erupted. A small amount of folding cannot be ruled out, but the resolution of the data is not precise enough to discern folding. A similar argument can be made for Lower Table Rock.

Wiley and Smith (1993) show a fault between Castle Rock and Lower Table Rock with as much as 30 m (100 ft) of down-to-the-east offset. This magnitude of offset is also indicated in the gradient chart in Figure 7: Both top surface and bottom contact are offset roughly 30 m (100 ft) across the fault between Castle Rock and Lower Table Rock.

It was thought that plotting the gradient of the andesite of Table Rock would indicate whether more than one lava flow was involved. It was hoped that the gradient data for the lava might display one or more regular gradient curves. The gradient data, however, do not resolve the issue.

## PALEOMORPHOLOGY

The andesite of Table Rock was erupted onto terrain of the Western Cascades, a volcanic arc that had developed at least as early as 42 Ma in western Oregon (Fiebelkorn and others, 1983). The Western Cascades were active in southern Oregon from Eocene time through Miocene time (Hladky, 1992, 1993, 1994, 1996, in press a,b; Wiley and Smith, 1993; Smith and others, 1982). Some of the oldest rocks in the region attributed to High Cascade volcanoes were erupted about 6 Ma (Fielbelkorn and others, 1983; Medford Water Commission, 1990), and these rocks overlie rocks of the Western Cascades. The andesite of Table Rock is the oldest known rock exposed in the High Cascades. Its suspected source area at or near Olson Mountain lies in both the High Cascades and the Western Cascades.

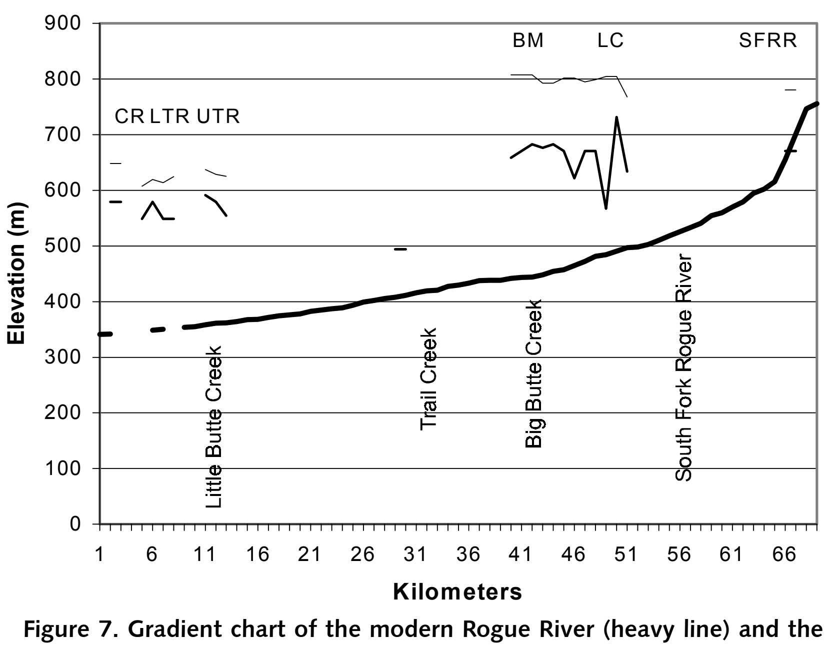


**Figure 7. Gradient chart of the modern Rogue River (heavy line) and the top (light line) and bottom (medium heavy line) of outcrops of the andesite of Table Rock. Datum (starting point) is the Rogue River at long 123°W. CR = Castle Rock, LTR = Lower Table Rock, UTR = Upper Table Rock, BM = Bear Mountain, LC = Lost Creek Lake, SFRR = South Fork Rogue River.**

It can be inferred from outcrop patterns and thicknesses that the andesite of Table Rock was erupted onto rolling and mountainous terrain. The Rogue River had already established itself between Lost Creek Lake and Castle Rock in approximately its present course. Between Big Butte Creek and Prospect, broad exposures of the andesite of Table Rock indicate that perhaps Olson Mountain did not exist, or that it was far smaller than it is today. The andesite of Table Rock filled in the ancestral Rogue River valley at Lost Creek Dam, Bear Mountain, and the upland areas of what is now Big Butte Creek. The flow conformed to the morphology of the paleovalley between Shady Cove and Lost Creek Lake. Remnants of the unit have a bowl-shaped cross section, being thinner at the margins and thicker toward the center. How far the flow traveled down the ancestral Rogue River remains unknown. Remnants of the flow are found as far west as the western edge of Sams Valley.

Between Shady Cove and Lost Creek Dam and at Upper Table Rock and Lower Table Rock, the present elevation of the base of the flow indicates that at the time the flow was erupted, valley floors were generally about 180–210 m (600-700 ft) higher than at present. Downcutting of the Rogue River and its tributary drainages has generally kept pace with gradual orogenic uplift in the region. At Upper Table Rock, the bed of the Rogue River has lowered itself 210 m (700 ft) in 7 million years.

The ancient Rogue River was displaced to the margins of the flow as lava filled the channel. After the molten lava cooled and solidified, the river cut through it, leaving remnants on both sides of the river above Shady Cove. Downstream from Shady Cove, the river meandered back and forth across the valley and removed most of the flow. The river and its tributaries preferentially cut through softer sedimentary rocks of the Payne Cliffs Formation north of Central Point and stranded remnants of the lava. Continued erosion modified these remnants and the underlying sedimentary rocks to form Upper Table Rock and Lower Table Rock.

It has been suggested that the distribution of sporadic cobbles and monoliths between the west edge of Sams Valley and Lost Creek Lake and the shape of the two buttes indicates the approximate course and shape of the bed and banks of the ancestral Rogue River when it was displaced by the lava flow; however, an evaluation of gradient data at the buttes indicates that it is not possible to define a thalweg that accords with the centerline of the buttes. The andesite of Table Rock probably flowed out over a broad plain north of Medford and was not confined to a river channel. The shape of Upper Table Rock and Lower Table Rock, therefore, is primarily a product of erosion. The many cobble trails and monoliths that have no nearby bedrock source are residual deposits, the erosional remains of a once more extensive lava flow.

## SOURCE

Little is known about the physical character of the vent or vents that produced the andesite of Table Rock. Today, that area is covered by younger basalt and trachybasalt lava flows of the broad shield volcano of Olson Mountain and by andesitic lava flows from High Cascade volcanoes east of Prospect. Gradient data used in Figure 7 indicate a source in the upper reaches of the present-day Rogue River. Gradient data and mapped exposures indicate that the greatest thicknesses of the andesite of Table Rock are along the western flanks of Olson Mountain. The alkaline lavas that flank Olson Mountain indicate a compositional link to the andesite of Table Rock (Figures 4 and 5). Because alkaline lavas are rare in the Cascade Range of southern Oregon, perhaps the andesite of Table Rock and the basaltic trachyandesite lavas at Olson Mountain are derived from the same parent magma. It is possible that the earliest eruptions of Olson Mountain were those of the andesite of Table Rock. Alternatively, the greatest accumulaions and the fissures or vents that produced the andesite of Table Rock may lie east of Olson Mountain, but are now covered by the younger lavas at Olson Mountain and from the High Cascades, and the chemical similarities with lavas at Olson Mountain are merely fortuitous.

## DISCUSSION

Current age data indicate that trachyandesitic lava flowed down the ancestral Rogue River about 7 Ma. This study found, from a new isotopic age, that trachyandesite at Upper Table Rock is about 7 million years old and probably not 9.6 million years, as a previous isotopic age indicated. The reason for the discrepancy has not been discovered; however, the 7-Ma age for Upper Table Rock accords with three ages for the unit upstream from Shady Cove. In addition, an isotopic age from Lower Table Rock also indicates an age of about 7 Ma (Stanley A. Mertzman, Franklin and Marshall College, written communication, 1998). Field mapping has not discovered boundaries between trachyandesitic flows, such as paleosols, that would indicate multiple flows. Gradient data do not resolve whether there are multiple flows or not, but chemical and petrographic data for the andesite of Table Rock, at the current level of examination, are sufficiently similar to argue for a single flow.

## ACKNOWLEDGMENTS

The author wishes to acknowledge the thorough and thoughtful reviews of Tom Wiley (DOGAMI) and Dave Sherrod (USGS) and assistance in the field by Tom Wiley, Gerry Capps BLM), and Tom Olive. Dave Sherrod graciously lent a fluxgate magnetometer for magnetic polarity readings. Thanks to Jim Smith (USGS) for his thoughts and recollections of the andesite of Table Rock. I would also like to thank Stanley A. Mertzman (Franklin and Marshall College) who supplied an isotopic age from Lower Table Rock to be included for publication in this report.

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*(**MLR**, continued from page 74)*

Oregon. The MLR is charged with issuing new permits, inspecting current operations and ensuring reclamation of closed sites. An awards selection team composed of an industry consultant, a mine operator, a county planner, a natural resource expert, and a private citizen chose the winners. The awards were presented at the Oregon Concrete and Aggregate Producers Association (OCAPA) annual meeting in June at Salishan.

Other award winners include:

**Outstanding Operator –** *Westside Rock, Parkin Quarry*

Parkin Quarry, located northwest of Forest Grove, first broke ground in the early 1900s. Westside Rock, owned by John Malnerich, assumed operation in 1996. This site was recognized for efforts that exceed state requirements to protect adjacent natural resources. This basalt quarry, which is a side hill cut, is adjacent to Roderick Creek, a tributary to Gales Creek. Protection of Roderick Creek was a high priority in this project. From the beginning the company worked with neighbors to address concerns with the operation and a proposed expansion. They removed unstable overburden material, reconstructed and seeded a faulty storm water berm, constructed a new sediment retention pond, planted shade trees along Roderick Creek, and monitored storm-water control systems daily. The extensive operating agreement reached with neighbors highlights Westside Rock's commitment to work in harmony with the community.


**Westside Rock operation**

**Outstanding Reclamation –** *Rogue Aggregates Inc., Table Rock Site*

Situated on the floodplain 500 feet from the Rogue River, the Table Rock mine provided sand and gravel for the Jackson County Road Department. Rogue Aggregates acquired the operation in 1988 and completed mining in 1995. The proximity to the river presented an opportunity to focus reclamation activities on the construction of ponds for a diverse wetland habitat. Berms were added to separate individual ponds, and complex


**Rogue Aggregates reclamation at former Table Rock mine near the Rogue River.**

**Freeman Rock operation, showing stable, benched highwall. The operator was recognized for outstanding stormwater control and slope stabilization.**

slopes were created and planted with a variety of vegetation. Irregular shorelines and many native plant species make the reclamation a success.

**Outstanding Small Operator** (two winners) —
*Ted Freeman, Freeman Rock*

The Freeman Rock site is northeast of Brookings in Curry County. Two streams are nearby, the Chetco River and Jack Creek, both containing migrating fish runs. Two primary concerns at this site were control of storm water and erosion. Storm water was handled by the creation of numerous settling ponds around the perimeter rather than concentrating the water in one area. Erosion of a slope near the access road was controlled by the planting of Escallonia bushes on the slope. Freeman also works with the Department of Environmental Quality (DEQ) to control storm water in the winter months. This site was recognized for aggressive efforts to protect the Chetco River and Jack Creek from mine-related effects.

*Philip and Connie Johnson*

Located north of Myrtle Creek in Douglas County, this quarry has been owned and operated by Philip and Connie Johnson since 1993. This operation is being recognized for its use of Best Management Practices to control storm water. The Johnsons have completely eliminated offsite discharge. A series of settling ponds divided by a vegetated swale screens storm water from the excavation area. Storm water from processing and stockpile areas was diverted to a pasture where it soaks into the ground. The Johnsons were recognized for their unflagging efforts to protect adjacent natural resources.


**Rebuilt access road in quarry operation of Coos County Road Department near Myrtle Point, commended for control of erosion and storm water runoff.**

**Good Neighbor Award** – *David A. Peterson, Pacific Rock Products*

Mining at Peterson Rock Pit, a basalt quarry near North Plains in Washington County, began in 1980. During the heavy rains of 1996, a landslide was activated that threatened nearby McKay Creek and Dixie Mountain Road. Pacific Rock Products moved its primary jaw crusher off the slide area to help reduce movement. Moving the crusher and adding a fill slope between it and the county road diminished noise both on and off the site. In an effort to reduce the stockpile of material, the company reprocessed reject material into saleable products. Always concerned with safety, Pacific Rock has also worked with the county and adjacent landowners to widen the county road and provided CB radios to the school buses to avoid potential accidents. Pacific Rock Products was honored for creating an operation that is sensitive to the community.

**Outstanding Exploration** – *Eagle-Picher Minerals, Inc.*

An exploration permit was issued in 1992 for this site located in the Beede Desert in Harney County. Eagle-Picher Minerals explored the site for diatomite, an organic substance used in industry for filters and absorbents. In order to make reclamation simpler, the company elected not to build any access roads to the drill sites but to drive to them by means of all-wheel-drive vehicles. Ponderosa pines were later added to conceal track marks. A single access road was cut across a hill but was eventually reshaped with a backhoe and successfully replanted with native species. The overall success in replanting in this harsh climate, as well as attention to detail, make this reclamation noteworthy.

**Outstanding Reclamation – Agency** –*Oregon Department of Transportation – Region IV*

Located west of Bend, this 80-acre site has been used by the Oregon Department of Transportation (ODOT) since the 1960s. The first reclamation attempt failed when the planted grass seed died in the sun. The members of the ODOT Region 4 Geology Crew went to work. On their own time and using their own resources, they rented equipment, then prepared and seeded the surface of the site. Knowing the original seed mixture did not grow, the men developed their own mix of native grass seed. The reclamation proved so successful that now big game frequent the area. The ODOT Region 4 Geology Crew was recognized for using its own initiative and working far beyond legal requirements for this site.

**Outstanding Operation – Agency** – *Coos County Road Department*

This site is east of Myrtle Point in Coos County and was operated by the Coos County Road Department. To protect water quality the department extensively mulched and seeded bare areas. Because the site is located at the top of a ridge, erosion was a primary concern. To alleviate this, the access road to the site was elevated and completely reconstructed with sloping and ditches to contain storm water. The Coos County Road Department is recognized for its aggressive approach to this project, which implements Best Management Practices to reduce off-site impacts. ☐

## DOGAMI PUBLICATIONS

### Released June 2, 1998

**Mined Land Reclamation Program status map, Clackamas County, Oregon**. Oregon Department of Geology and Mineral Industries MLR Status Map 03, scale 1:250,000, $10.

**Mined Land Reclamation Program status map, Josephine County, Oregon**. Oregon Department of Geology and Mineral Industries MLR Status Map 17, scale 1:250,000, $10.

The MLR status maps show all mining sites within a county that are contained in the database record of the DOGAMI Mined Land Reclamation Program (MLR). This includes open and closed sites, various types of reclamation requirements, nonmetal and metal mining sites, and numbers of acres reclaimed and acres subject to reclamation.

### Released June 29, 1998

**Map showing faults, bedrock geology, and sediment thickness of the western half of the Oregon City 1:100,000 quadrangle, Washington, Multnomah, Clackamas, and Marion Counties, Oregon**, by Scott Burns, Lawrence Growney, Brett Brodersen, Robert S. Yeats, and Thomas Popowski: Oregon Department of Geology and Mineral Industries Interpretive Map Series IMS–4, scale 1:100,000, $10.

The new map outlines potential earthquake hazards for the populated northern Willamette Valley (including much of Portland), covering an area from Aloha and Mount Scott in the north to Brooks, Mount Angel, and Molalla in the south.

Numerous faults in the region are outlined, including the Mount Angel fault that caused the 5.6-magnitude earthquake in 1993. Other potentially active faults on the map include the Portland Hills, Beaverton, Sherwood, Newberg, and Bolton-Marylhurst faults. The area's earthquake history, with the magnitudes of historic earthquakes, is also included.

The map also explains some of the geologic history of the area. "This is not just a map with fault lines on it," said Lou Clark of DOGAMI. "We have incredibly diverse geology in this relatively small area. Whether you're interested in earthquakes, volcanoes, landslides, or floods, we've had them on a big scale around the Willamette Valley.

Various hazards that could occur in future earthquakes are described in the map text. *Liquefaction* is the process when the ground becomes liquid from shaking during an earthquake, causing damage to buildings. *Amplification* occurs in unconsolidated soils where the shaking of an earthquake may feel stronger. *Landslides* can be triggered by earthquakes.

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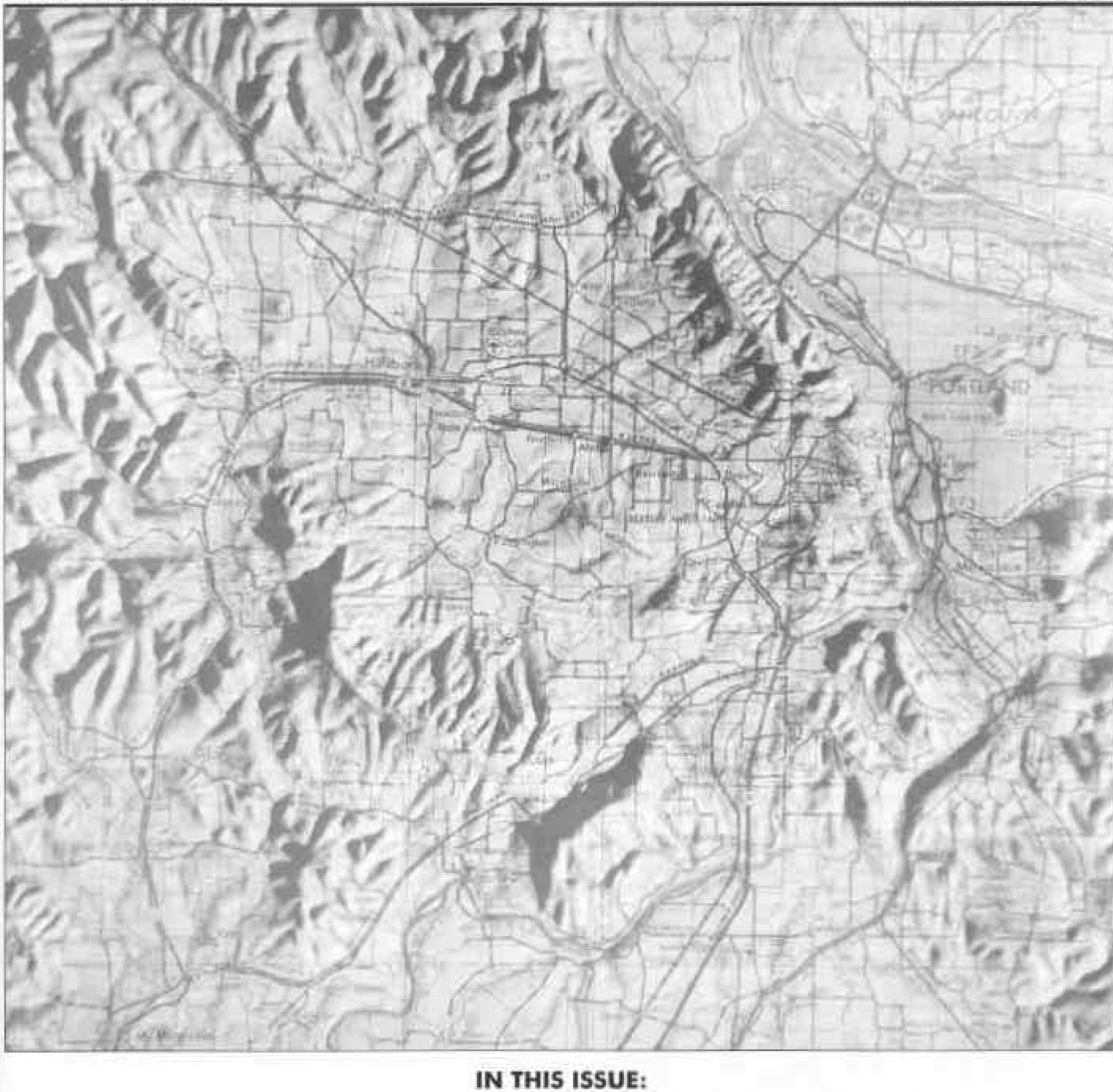

**IN THIS ISSUE:**

POST-MIDDLE MIOCENE GEOLOGIC EVOLUTION OF THE TUALATIN BASIN, OREGON
and
READER SURVEY RESULTS

***EARTH SCIENCE WEEK OCTOBER 11–17 !!! EARTH SCIENCE WEEK OCTOBER 11–17 !!! EARTH SCIENCE WEEK OCTOBER 11–17***

# OREGON GEOLOGY

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Style is generally that of U.S. Geological Survey publications. (See USGS Suggestions to Authors, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Klaus Neuendorf, Editor, at the Portland office (address above).



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## Cover photo

The Tualatin Valley in Washington County, as seen on an old plastic relief map. Vertical exaggeration is 2:1. The article beginning on page 99 takes a new look at what is found under the surface of the valley and calls it the "Hillsboro Formation."

## Reader survey results

Many thanks to everyone who took the time to reply to our survey in the March/April issue! Almost 150 people responded, and many suggested good ideas about how to improve the magazine.

About 90 percent of those who responded said they were "satisfied" or "very satisfied" with *Oregon Geology*. Almost half of all those who responded said they had been subscribers for 10 years or more. Since the magazine's inception as the *Ore Bin* in 1939, there have been different editors and contributors, but most readers still see it as a good place to find out about geology.

Readers have a wide variety of favorite topics. These include:

| Number of responses | Topic |
|---|---|
| 101 | Geology of specific areas |
| 89 | Field trip guides |
| 68 | Plate tectonics |
| 68 | Volcanoes |
| 67 | Earthquakes |
| 51 | Mineral/gemstone localities |
| 51 | Announcements of new publications |
| 42 | Fossil localities |
| 42 | Hazards, such as landslides |
| 38 | Paleontology |
| 32 | Stratigraphy |
| 31 | Mining history |

When asked about including new topics in *Oregon Geology*, about half the respondents thought it was a good idea, and about half didn't. However, even those who were interested in exploring other subjects want to make sure that it's still tied to geology. Among the leading suggestions were:

| Number of responses | Topic |
|---|---|
| 58 | Archaeology |
| 47 | History |
| 37 | Geography |
| 30 | Climate |
| 25 | Hiking |
| 24 | Conservation issues |
| 22 | Wetlands |

More than half the respondents were interested in articles about other states. Some wanted this restricted to states with geology that could be tied to Oregon's. Others were interested in finding out about areas of the country they grew up in or visited.

When asked whether we should add color photographs, only 49 people said yes. However, 80 people said they would be willing to pay more for a subscription if it included color.

We are always interested in why people subscribe to *Oregon Geology*. Knowing a little about our readers allows us to try to focus the magazine.

*(Continued on page 118, **Reader survey**)*

# Post-middle Miocene geologic evolution of the Tualatin basin, Oregon[1]

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## ABSTRACT

The geologic history of the Tualatin basin and its sedimentary fill after emplacement of the Columbia River Basalt Group (CRBG) are described in this paper. The core from the 334-m-deep hole HBD-1, drilled by the Oregon Department of Geology and Mineral Industry at the Portland-Hillsboro Airport, provides the primary information for the study, which is also supported by over 2,400 well logs and cores and by four seismic reflection lines.

The sedimentary section above the 26-m-thick paleosol at the top of the CRBG in drill hole HBD-1 is divided into two main groups: a 25-m-thick section of Missoula flood sediments called the Willamette Silt and an underlying, 263-m-thick, fine-grained sequence of fluvial and lacustrine Neogene sediments introduced here as the Hillsboro Formation.[2]

Pollen, diatom, and paleomagnetic data support dividing the Hillsboro Formation into a 230-m-thick Pleistocene package and an underlying, 75-m-thick Pliocene to upper Miocene unit. Heavy-mineral and INAA chemical analyses indicate that sediments of the Hillsboro Formation were primarily derived from local highlands surrounding the Tualatin Valley.

The structure at the top of the CRBG in the Tualatin basin shows a larger northern subbasin, with few faults cutting the Hillsboro Formation above the CRBG, and a smaller, more complexly faulted subbasin south and east of the Beaverton fault. Hillsboro Formation sedimentation rates increased tenfold from the late Miocene-Pliocene to the Pleistocene, concomitant with increased basin subsidence. Comparison of Neogene basin evolution among Willamette Valley depositional centers shows that they all began to form in the late Miocene. Studies of gravity anomalies and seismic reflection characters indicate that the Tualatin basin and the northern Willamette basin probably have similar depositional histories with accelerated subsidence in the Pleistocene. In contrast, the southern Willamette Valley, Stayton basin, and Portland basin experienced decrease or cessation of downwarping in late Pliocene to early Pleistocene time.

The Tualatin River knickpoint is unusually close to the river's mouth and has remained essentially unchanged since the Missoula floods filled the basin 12,700 years ago. The fact that the CRBG underlies the last stretch of the river's course has kept the river from cutting back into the valley, which has resulted in the low river gradient evident today in the Tualatin basin. Three identified geomorphic surfaces around the Tualatin River are related to ebbing Missoula Flood waters and more recent fluvial activity.

## INTRODUCTION

The Tualatin basin, located in Washington County, is a northwest-southeast trending elliptical structure surrounded by the Portland Hills and Tualatin Mountains to the north and east, the Chehalem Mountains to the south, and the Coast Range to the west (Figure 1). Cooper and Bull Mountains lie within the southeastern part of the valley. Elevations range from approximately 335 m (1,100 ft) in the surrounding highlands to an average of 53 m (175 ft) on the valley floor. The elevation at the confluence of the Tualatin River, the major waterway that drains the Tualatin Valley, with the Willamette River is approximately 16.8 m (55 ft) above mean sea level.

The basin occurs as a partially isolated western extension of the Willamette Valley fore-arc regional low west of the Cascade Range volcanic arc complex. Approximately 4,300 m of Paleogene (Eocene to lower Miocene) marine and continental sediments overlie an Eocene oceanic basaltic basement in the Tualatin basin (Hart and Newcomb, 1965; Schlicker and Deacon, 1967). As much as 300 m of the middle Miocene Columbia River Basalt Group (CRBG) and up to 460 m of overlying Neogene continental sediments blanket the marine sediments. A thin capping of Late Pleistocene Missoula flood silt covers the Tualatin Valley to elevations of approximately 76 m (250 ft).

Excellent documentation exists on the hydrogeology and engineering geology of the CRBG and surficial features in the Tualatin Valley (Hart and Newcomb, 1965; Schlicker and Deacon, 1967) as well as the Paleogene history of the basin (Popowski, 1996). Detailed studies of the overlying sedimentary material in the basin are lacking. This report presents the post-CRBG Neogene (late Miocene to Holocene) history of the Tualatin basin and relates the sedimentary and structural conditions to the Willamette Valley–Coast Range region.

[1] This paper is a greatly reduced excerpt from the author's doctoral dissertation: **Post-Middle Miocene Geologic History of the Tualatin Basin, Oregon, with Hydrogeologic Implications**, completed 1997 at Portland State University (Wilson, 1997).

[2] As of this printing, the formation name is informal; steps to establish a formal geologic name have been initiated by the author.

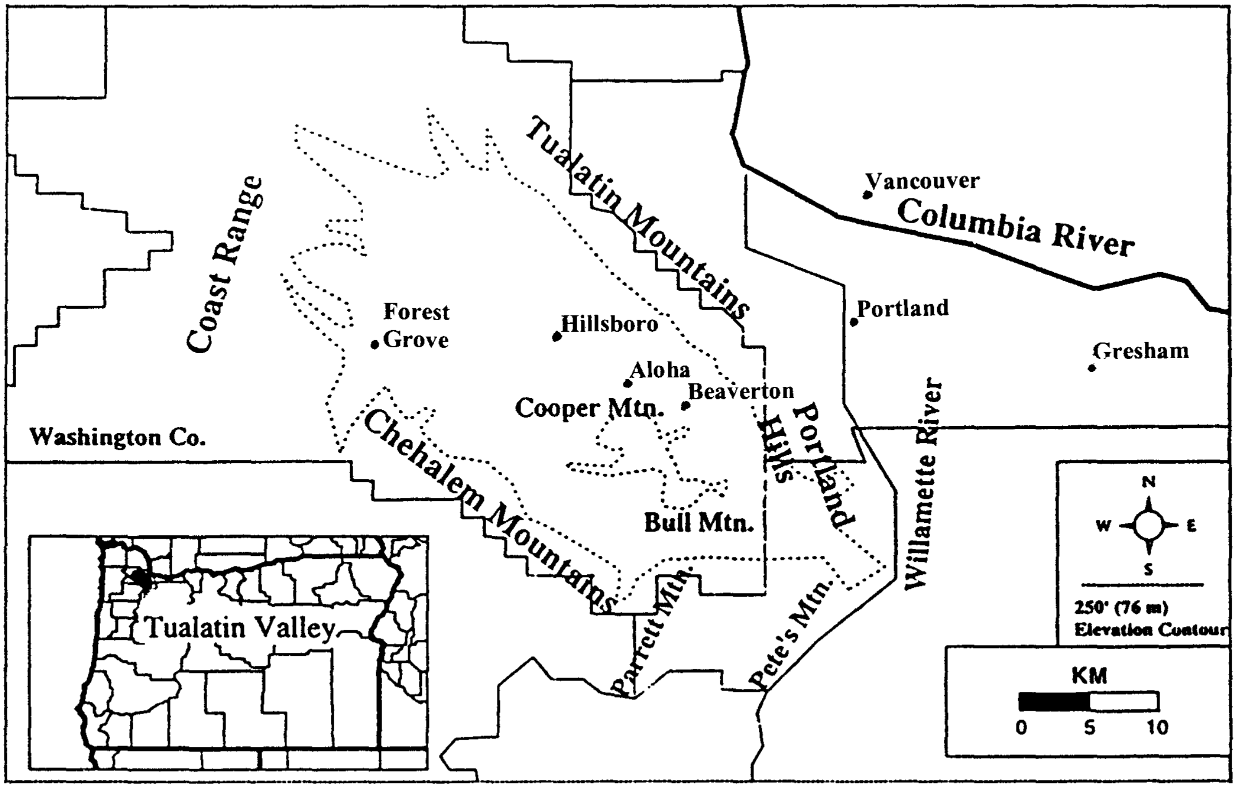


Figure 1. Location map of the Tualatin Valley and associated physiographic features. The northwest-southeast oriented valley is essentially surrounded by highlands. Dotted line marks 76-m (250-ft) elevation contour.

## GENERAL GEOLOGIC SETTING

Many of the geologic studies around the Portland region have concentrated on the Portland basin, the Coast Range, and the Tualatin Mountains-Portland Hills area but have also included references to the Tualatin basin, leading to general stratigraphic relationships in the Tualatin and Portland basins (Figure 2).

### Paleogene stratigraphy

Middle Eocene ocean-floor basalt, equivalent to the Siletz River Volcanics, is thought to form the basement rock of the Tualatin basin. These volcanic rocks are exposed in the Coast Range west of the valley, along with the overlying middle to upper Eocene Tillamook Volcanics and the upper part of the sedimentary Yamhill Formation (Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Wells and others, 1994).

The middle to upper Eocene basalt of Waverly Heights is found around the southeast end of the Portland Hills and is believed to have been part of an oceanic island that docked on to western Oregon during the Eocene (Beeson and others, 1989a,b).

Eocene to lower Miocene marine sedimentary rocks overlie the Eocene volcanic rocks in the subsurface and in exposures along the western and southwestern edges of the valley (Popowski, 1996; Wells and others, 1994; Schlicker and Deacon, 1967). The units consist of tuffaceous mudstones, siltstones, and sandstones of the Eocene Yamhill, Cowlitz, Spencer, and Keasey Formations and the Oligocene Pittsburg Bluff and Scappoose Formations (Baldwin, 1981; Timmons, 1981; Van Atta and Kelty, 1985; Yeats and others, 1991; Van Atta and Thoms, 1993). Maximum thickness of the sediments is approximately 4,300 m.

### Neogene stratigraphy

The middle Miocene Columbia River Basalt Group (CRBG) unconformably covers the Paleogene sediments and volcanics (Figure 3). This unit composes the majority of the surrounding highlands and Cooper, Bull, and Sexton Mountains within the Tualatin Valley. Flows of the Grande Ronde Basalt entered the Tualatin basin through the Sherwood trough (Beeson and others, 1989a). The Frenchman Springs Member (15.3 Ma) of the Wanapum Basalt has been mapped in the highlands bordering the southern margin of the basin (Beeson and Tolan, 1984; Beeson and others, 1985; Beeson and others, 1989b) and is present in the center of the basin (M.H. Beeson, oral communication, 1993). The CRBG is as much as 305 m thick under the Tualatin Valley, with separate flows as thin as 6 m (Schlicker and Deacon, 1967). The sequence has undergone structural deformation in the surrounding highlands and is faulted in the subsurface (Madin, 1990; Popowski, 1996).

Nonmarine clay, silt, sand, and a few gravel units of Neogene age unconformably overlie the CRBG and extend upward almost to the valley surface. The thickness of these deposits varies from feather edge at the basin margins to over 450 m in the central part of the basin under the city of Hillsboro (Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Madin, 1990; Yeats and others, 1991). These sediments have been labeled in past work as age equivalent to the Pliocene Troutdale Formation and Sandy River Mudstone in the Portland basin. They are the primary focus in the following sections and are given formation status in this report.

Schlicker and Deacon (1967) distinguished a basal, laterized unit overlying the CRBG along most edges of the valley. They named it Helvetia Formation, assigned it to an early Pliocene age, and considered it equivalent to the earliest Troutdale Formation. In this paper, the Helvetia Formation is not separated out from the rest of the Neogene sediments.

The gray, pilotaxitic to diktytaxitic, olivine-bearing, Pliocene-Pleistocene Boring Lava is exposed around local volcanic centers in the Portland Hills (Trimble, 1963; Schlicker and Deacon, 1967). The Boring Lava stratigraphically lies within and on top of the Neogene sediments and the Portland Hills Silt and underlies Willamette Silt. Recent work indicates that the age of the Boring Lava flows of the Tualatin Mountains near Sylvan is between 0.26 Ma and 0.96 Ma, while the flows around Oregon City date back to to 2.4 Ma (Conrey and others, 1996).

The Willamette Silt is up to 37 m thick and occurs as an extensive surficial deposit of dominant medium-brown, micaceous, clayey to sandy silt, with sands throughout the valley plain and gravels in the east end of the valley near Lake Oswego (Schlicker and Deacon, 1967; Madin, 1990). The sediments unconformably overlie the Neogene sediments and are interpreted as catastrophic flood deposits from recurring jökulhlaups from glacial Lake Missoula in Montana during the late Pleistocene, between 12,700 and 15,300 years ago (Allison, 1978a; Waitt, 1985; Beeson and others, 1989b). Occasional ice-rafted erratics of metamorphic and plutonic rocks not originating in western Oregon are found in the sediments. Mullineaux and others (1978) document the age of the last flood cycle at 13,080 years ago.

Rhythmite sequences along the Columbia River in Washington and the Willamette River indicate that more than 90 flood cycles occurred during this time period, with at least 22 entering the southeastern part of the Tualatin Valley (Waitt, 1996). The floods were strong enough to scour the preexisting divide (presently 46 m in elevation) between the Tualatin and Willamette Valleys (Allison, 1978b) at the Tonquin scablands near Sherwood.

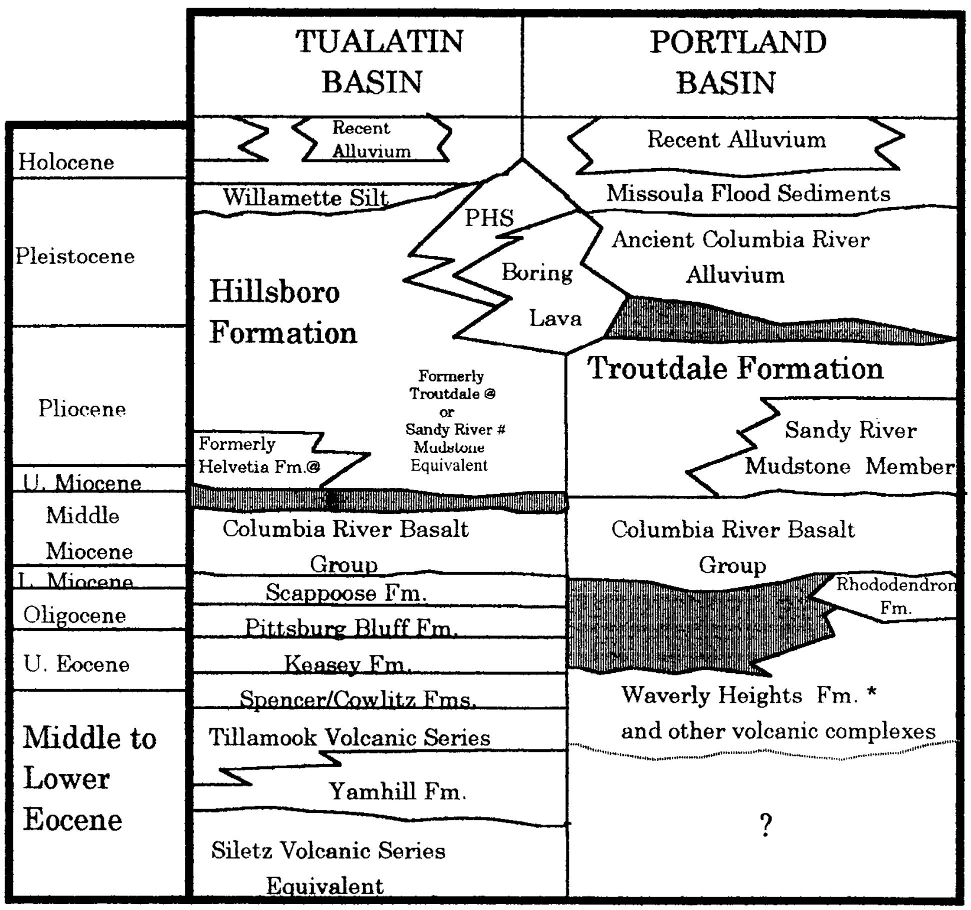


**Figure 2: Generalized Tertiary stratigraphic sections for the Tualatin and Portland basins, illustrating correlations from past work. Shaded areas = unconformities; @ = Schlicker and Deacon (1967), # = Madin (1990), * = Beeson and others (1991).**

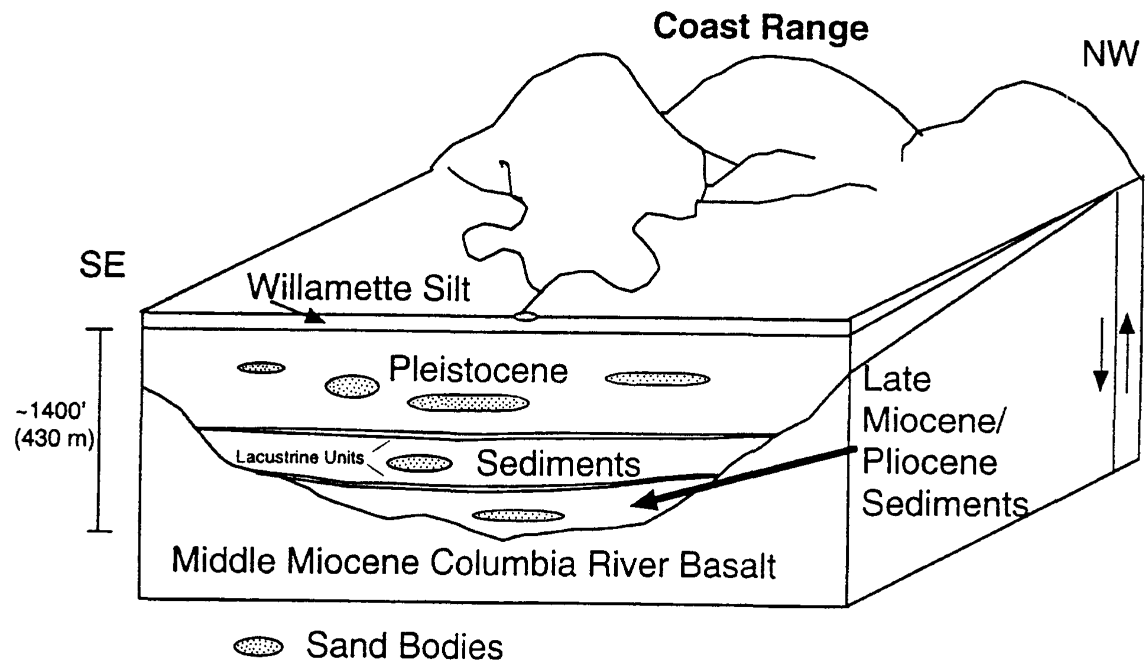


**Figure 3. Schematic geologic model of Neogene sediment deposition overlying the Columbia River Basalt Group. The fluvial/lacustrine clastic rocks were primarily derived from the surrounding highlands, particularly the Coast Range.**

Pleistocene loess deposits, the Portland Hills Silt, mantle the adjacent highlands and are thicker on the Portland Hills to the northeast than on the Chehalem Mountains to the southwest (Lentz, 1981). The micaceous unit has a uniform massive texture and may be as thick as 30 m on the Portland Hills. The eolian silt was arbitrarily mapped down to the 76-m (250-ft) elevation, below which are catastrophic flood deposits of the Willamette Silt (Schlicker and Deacon, 1967; Madin, 1990). The two units are almost impossible to distinguish in the field on a lithologic basis.

### Regional structure of the Tualatin basin

The Tualatin basin is a fore-arc depression extending northwest from the Willamette Valley and is part of the Willamette-Puget Sound lowland and the fore-arc region related to the Cascade Range magmatic arc. It has been described as a broad syncline surrounded by sometimes faulted anticlines and monoclines (Figure 4; Trimble, 1963; Hart and Newcomb, 1965; Schlicker and Deacon, 1967; Frank and Collins, 1978; Al-Eisa, 1980; Brodersen, 1995). Within the valley, Cooper and Bull Mountains have also been described as faulted anticlines.

The Portland Hills fault zone, the boundary between the Tualatin Mountains-Portland Hills and the western margin of the Portland basin, consists of three named faults in the Tualatin Mountains-Portland Hills area: the Portland Hills fault, the Oatfield fault, and the East Bank fault on the northeast side of the Willamette River. Seismicity in the Portland area indicates that the Portland Hills fault and the Oatfield fault are still active (Yelin and Patton, 1991; Blakely and others, 1995). This fault zone is part of a major structural lineament across the Willamette Valley to the Clackamas River drainage (Balsillie and Benson, 1971; Perttu, 1981; Beeson and others, 1985, 1989a; Madin, 1990; Yeats and others, 1991; Yelin and Patton, 1991; Blakeley and others, 1995).

The northeast trending Sherwood fault bounds the southeast part of the basin (Yeats and others, 1991). The Gales Creek and Newberg faults just to the west and southwest of the basin are part of the Gales Creek-Newberg-Mount Angel fault zone that forms a parallel couple with the Portland Hills-Clackamas River fault zone (Al-Eisa, 1980; Yeats and others, 1991; Werner and others, 1992; Popowski, 1996). Recent field mapping suggests that the Gales Creek fault zone has played a major role in the deformation of this portion of the northern Coast Range (Wells and others, 1994; Popowski, 1996).

### TUALATIN BASIN POST-CRBG STRATIGRAPHY

The Oregon Department of Geology and Minerals Industries (DOGAMI) cored the 334-m-deep Hillsboro Deep Test No. 1 (referred to in this report as HBD–1) at the Portland-Hillsboro Airport (NW¼ sec. 28, T. 1 N., R.

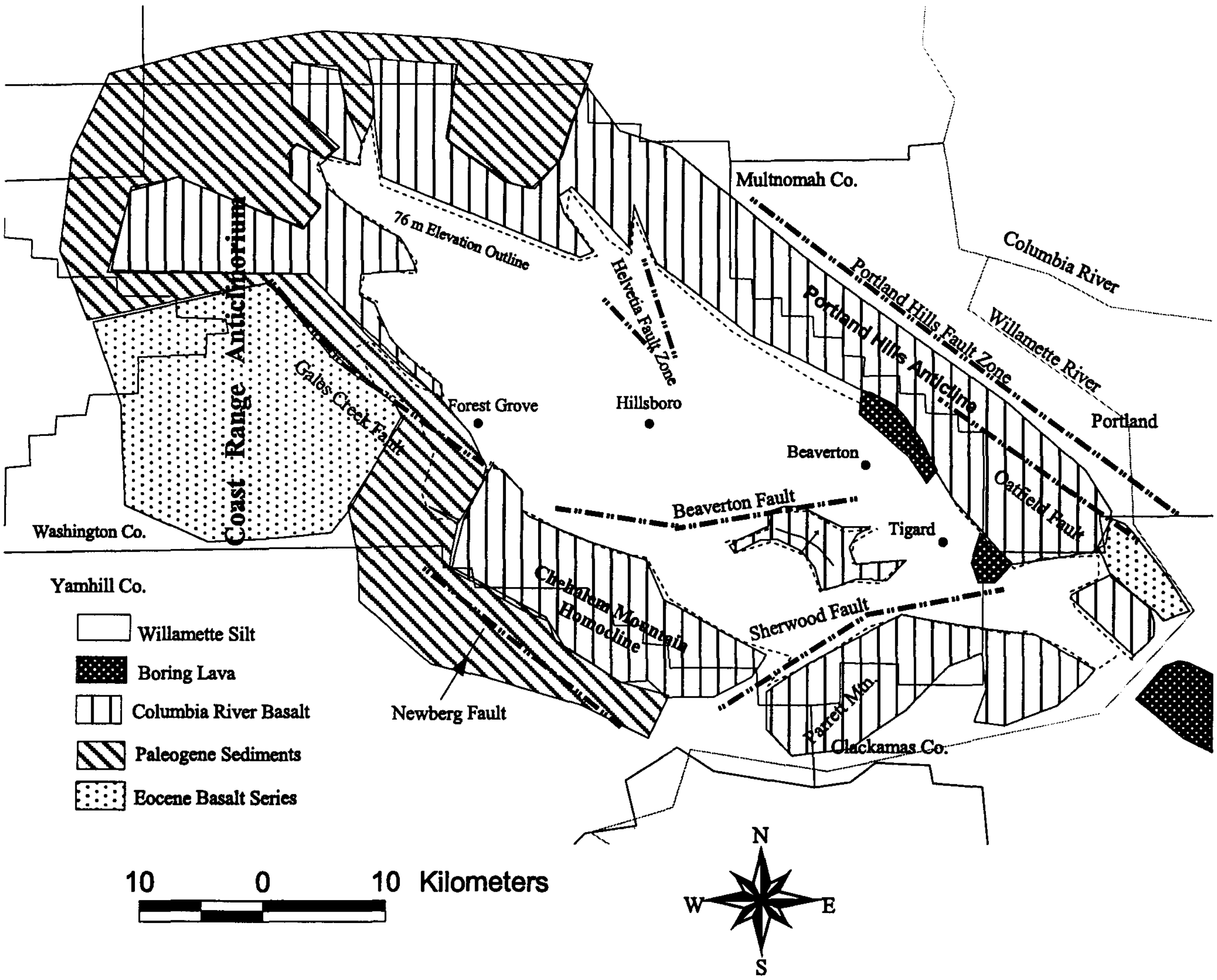


**Figure 4. Generalized geologic map and major structural features related to the Tualatin basin. Modified from Schlicker and Deacon, 1967, and Beeson and others, 1991.**

2 W.) in 1993 as part of a regional seismic hazards study (Figure 5). HBD-1 encountered 288 m of fluvial and lacustrine sediment overlying 30.5 m of lateritic soil and weathered basalt of the Columbia River Basalt Group (CRBG). Black, unweathered basalt underlies the weathered zone from 314 m to a drilled total depth of 334 m. In this report, the sedimentary section is divided into two units: (1) Missoula flood deposits known as the Willamette Silt (Schlicker and Deacon, 1967) at the top of the section and (2) the bulk of the section overlying the CRBG and introduced in this report as the Hillsboro Formation. The term Hillsboro Formation is used to disassociate these sediments, in contrast to past practice, from those of the Troutdale Formation or Sandy River Mudstone in the Portland basin. The HBD-1 core is the type section for the Hillsboro Formation. From it, correlations are made to other parts of the basin. Most of the author's analytical work on the Hillsboro Formation originates from this cored unit.

Depositional and stratigraphic relationships within the Hillsboro Formation and the Willamette Silt away from HBD-1 were developed using three exposures (two were created at construction sites and have since been covered); cores and drill samples from government, industry and private drill holes; gamma-ray profiles of 60 drill holes; approximately 2,400 water wells and private and government lithology logs of drill holes; and four regional seismic reflection data lines. The gamma logs were generated to locate the boundaries between the Willamette Silt and the Hillsboro Formation and the Hillsboro Formation and the top of the CRBG. Copies of the water well logs were obtained from the Watermaster of Washington County in Hillsboro and the Oregon Water Resources Department in Salem.

The Helvetia Formation of Schlicker and Deacon (1967) has not been separated from the rest of the Hillsboro Formation in this study. Available information does not warrant separation of these sediments. Several

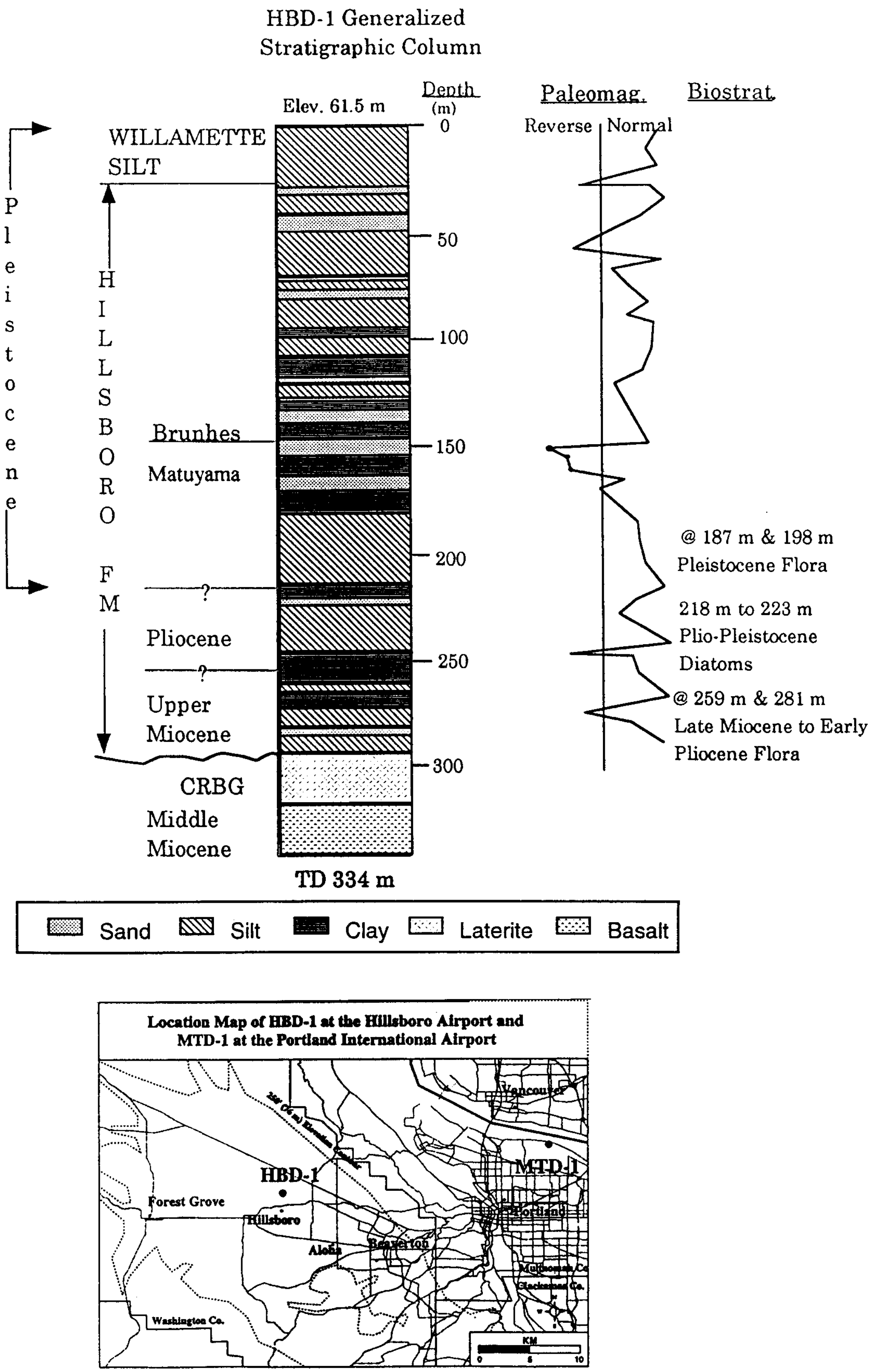


Figure 5. Stratigraphic section of HBD-1 core boring at the Portland-Hillsboro Airport and and location map of HBD-1 and drill hole MTD-1 at the Portland International Airport. Both core tests were drilled in 1993 by the Oregon Department of Geology and Mineral Industries as part of a seismic-hazard study. Pollen, diatom, and paleomagnetic data indicate that the bulk of the Hillsboro Formation is Pleistocene.

samples collected at the type locality just north of Helvetia, Oregon, contain the same materials and textures as the Hillsboro Formation.

## HBD-1 stratigraphy and sedimentology

### *Willamette Silt*

The Willamette Silt at the HBD-1 site primarily consists of massive, micaceous, clayey, very fine sandy silt with scattered layers of silty clay, and some dispersed organic woody material near the base from 23 m to 24 m. The formation color changes at 6 m from an oxidizing medium yellow-brown to a reducing blue-gray. The color becomes mottled with blue-gray and light-brown in the basal 1.5 m of the unit. Crude laminations occur in thin sandy stringers at 20 m and gravel up to 4–5 mm is scattered about in the basal silt at 24 m.

### *Hillsboro Formation*

The underlying Hillsboro Formation extends from 25 m to 288 m and consists, by thickness, of 20 percent sand units, 48 percent silt units and 32 percent clay units (Table 1). The sediments are generally poorly sorted and range from silty sands to muds, as classified by Folk (1968). Silt and clay are present in all samples, while very fine sand may be present in silt and clay units.

Sand units occur as thin beds ranging from millimeter-thick stringers to 3.7-m-thick layers. The sands are generally loose to slightly compacted, subangular to rounded, poorly to moderately poorly sorted, clayey, silty, and very fine to fine grained, although scattered layers of medium-grained to gravelly sands are present. The sand constituents include lithic fragments (mostly weathered basaltic grains), plagioclase and potassium feldspars, quartz, micas, and a variety of heavy minerals.

The clay and silt layers also contain micas and are generally massive in character. The clay colors vary (light-brown, blue-gray, gray-green, gray-brown, olive-brown, greenish-black), depending on the amount and oxidation level of iron in the material. The clay layers also exhibit various levels of competency; many clay layers are stiff to dense with plastic consistencies, while others crumble easily and are slightly or not plastic. Highly weathered basalt nodules ranging from very fine sand to gravel-sized are commonly included in the clays and silts.

Sedimentary structures are found sporadically in all three lithologies and include parallel and wavy micro-laminations, low angle cross-laminations, and possible burrow or root structures. Wood debris is present in small to moderate amounts throughout the Hillsboro Formation. Nearby water wells have penetrated woody zones up to 4 m thick. The section from approximately 152 m down to 271 m is peppered with the iron phosphate mineral, vivianite. The mineral dominantly occurs as a microcrystalline powder in small nodules. At two depth intervals, 152 m and 201.5 m, crystals up to 1 mm in length line fracture surfaces.

**Table 1. Sand-silt-clay content of selected sediments from DOGAMI drill hole HBD-1**

| Depth (m) | Lithology | Total sand % | Total silt % | Total clay % |
|---|---|---|---|---|
| 10.4 | Silt | 0.7 | 60.2 | 39.1 |
| 22.3 | Silt | 1.5 | 59.0 | 39.5 |
| 27.4 | Silt | 14.1 | 62.5 | 23.4 |
| 43.0 | Sand | 43.7 | 38.3 | 18.0 |
| 49.4 | Silt | 8.9 | 57.8 | 33.2 |
| 50.6 | Clay | 4.3 | 32.8 | 63.0 |
| 68.9 | Sand | 40.5 | 43.7 | 15.8 |
| 75.9 | Clay | 0.2 | 42.0 | 57.8 |
| 91.4 | Sand | 41.0 | 40.0 | 19.0 |
| 117.3 | Sand | 61.7 | 13.3 | 25.0 |
| 128.0 | Sand | 26.1 | 33.5 | 40.4 |
| 136.6 | Sand | 43.8 | 32.3 | 24.0 |
| 147.5 | Sand | 76.0 | 21.0 | 3.0 |
| 152.1 | Clay | 7.5 | 37.4 | 55.2 |
| 163.7 | Sand | 59.0 | 31.9 | 9.1 |
| 172.2 | Silt | 17.7 | 57.8 | 24.6 |
| 176.5 | Silt | 0.3 | 62.1 | 37.6 |
| 185.8 | Sand | 53.9 | 40.9 | 5.2 |
| 192.6 | Silt | 0.3 | 85.4 | 14.4 |
| 195.1 | Sand | 25.9 | 61.7 | 12.4 |
| 206.3 | Clay | 4.3 | 45.3 | 50.4 |
| 208.2 | Silt | 18.7 | 44.3 | 37.0 |
| 211.1 | Sand | 50.4 | 28.2 | 21.3 |
| 217.6 | Sand | 61.1 | 25.0 | 13.9 |
| 223.7 | Sand | 63.5 | 25.3 | 11.2 |
| 234.4 | Clay | 0.0 | 31.2 | 68.8 |
| 236.8 | Clay | 2.5 | 38.9 | 58.7 |
| 253.9 | Silt | 0.1 | 54.3 | 45.6 |
| 254.8 | Silt | 9.4 | 55.8 | 34.9 |
| 257.9 | Silt | 20.2 | 63.3 | 16.6 |
| 267.3 | Sand | 49.3 | 36.1 | 14.6 |
| 273.7 | Silt | 24.1 | 43.6 | 32.3 |
| 282.2 | Clay | 1.0 | 49.2 | 49.7 |
| 283.2 | Silt | 32.3 | 51.5 | 16.2 |
| 284.1 | Sand | 35.9 | 42.4 | 21.7 |
| 286.2 | Clay | 0.4 | 32.1 | 67.5 |

A diatomaceous zone from 218 m to 224 m consists mostly of a blue-gray, micaceous, silty clay with minor sand units and contains vivianite (Wilson, 1997). A low-density claystone of alternating brown and green-gray laminations is present between 221 and 221.5 m. *Aulacosira canadensis* is the predominant species present in the section (Edward Theriot, written communication, 1995).

No other units in the entire section have been recognized as containing diatoms. The interval between 218 and 222.5 m is interpreted as a lacustrine deposit bounded above and below by fluvial sediments.

A green-gray, well-indurated, silicified, 15-cm-thick mudstone, encountered at 231.5 m, is underlain by 2.5 m of somewhat less indurated, friable siltstone, and very fine sandstone. The mudstone and underlying siltstone contain highly contorted laminae, rippled claystone lenses, cross-bedding, and organic debris, which is indicative of active stream conditions.

The section underlying the silicified zone down to the lateritic soil of the CRBG is essentially similar to most of the Hillsboro Formation above the silicified zone, but with fewer sand units. A unique 30.5-cm-thick conglomerate at 283.5 m consists of rounded, highly weathered, red-brown basalt gravel in a white, siliceous cement. Red-brown, clayey, silty, very fine sand extends almost 1.8 m below the conglomerate. Below the sand are found 1 m of medium-brown, cross-laminated, clayey silt at 285–286 m and 1.7 m of brown-gray, silty clay with red-brown clay clasts and 1-mm-diameter weathered basalt nodules at 286–288 m. This zone has a sharp lower boundary at 288 m with the lateritic weathered zone of the CRBG.

The Hillsboro Formation can roughly be divided into upper and lower sections based on the percentage of sand present. Almost 62 percent of the cumulative sand unit thicknesses in HBD-1 is in the top 149 m of the Hillsboro Formation, with 24 percent of the total thickness of sand units occurring from 28 m to 58 m. Seven to ten fining-upward sand sequences beginning with poorly-sorted, medium-sized sands are recognized in the upper section. Some of the basal sands have associated gravel, mostly in the form of weathered, basaltic rock fragments. More units may be interpreted as fining upward when one considers an upward trending sand-silt-clay sequence. Thin clay drapes are present on top of some fining upward sand units.

Only 14.6 m of cumulative sand units (26 percent of the total sand) exist below 183 m with beds up to 1.8 m thick, averaging 1m thick. Four sand-to-clay fining-upward sequences 1–6 m thick are widely spaced apart in this interval. The sequences are identified by noting the following observations: either the sand components fine upward or the sequence trends upwards from sand to silt to clay. More fining-upward sequences may be counted if direct sand to clay relationships are allowed.

### *Columbia River Basalt Group*

**Lateritic weathered zone**. The underlying weathered zone of the CRBG is 26 m thick and consists of red-brown lateritic soil from 288 m to 308 m composed of rounded, highly weathered, pisolitic basalt nodules and more irregularly shaped, gravel-sized weathered basalt in a clay matrix. The color of the clay matrix becomes highly variegated (red, ochre, light blue gray, yellow, and gray brown) at 291 m and shifts to medium gray, ochre, and red brown at 293 m. Highly weathered basalt zones gradually become more common with depth. The weathered basaltic material contains white plagioclase crystals and a greenish-yellow silicate mineral which is probably an alteration product. Streaks of weathered basalt gradually thicken and increase in number with depth. Moderate brown to black, finely crystalline, weathered basalt with streaks of fresher, hard, black basalt begins at 308 m and continues to 314 m.

**Basalt**. Black, hard, fine-grained basalt underlies the weathered basalt at 314 m and continues downward to total depth of the test hole. Elemental signatures from XRF data on samples of this basalt suggest that the unit is part of the Frenchman Springs Member of the Wanapum Basalt, which is the first recognition of this unit this far west, under the floor of the Tualatin Valley (Marvin Beeson, personal communication, 1993). The estimated age of the Frenchman Springs Member is approximately 15 Ma (Beeson and others, 1989a).

### *Sediment characterization*

**Sand classification and composition**. Fourteen sand and silt unit samples from HBD-1 and three sand unit samples from other borings in the Tualatin Valley were examined to determine their sand classification. Almost all the samples consist primarily of lithic fragments, particularly weathered basalt grains. Sedimentary rock fragments in the form of polyquartz grains were the only other lithic type noted in the samples. The lithic composition averages 49 percent of the total sand.

The Hillsboro Formation sands plot in the feldspathic litharenite to litharenite regions, according to Folk's classification (Folk, 1968). The quartz to total feldspar ratios are consistent with other fore-arc sand compositions of the circum-Pacific region (Dickinson, 1982).

Hillsboro Formation sands are texturally immature, as they contain more than 5 percent clay matrix, exhibit poor to very poor sorting, and include angular grain shapes (Folk, 1968). The sands in the Hillsboro Formation have a mean maturity index of 0.21; thus are are very immature sands as prescribed by Pettijohn (1975). The immature nature of the sands suggests they accumulated in a low-energy environment free from turbulent current action that could have caused winnowing and sorting of the sands (Folk, 1968). Flood-plains or small, low-gradient streams are suitable depositional environments in the case of the HBD-1 sands.

**Clay mineralogy**. Hillsboro Formation clay and silt samples from HBD-1 contain variable amounts of smectite, kaolinite, and illite clay. Smectite is the dominant clay mineral in most samples analyzed, ranging up to 90 percent relative abundance of the clay minerals. The preponderance of smectite is indicative of a volcanic influence; however, Cunderla (1986) and Caldwell (1993) noted that the Yamhill and Spencer Formation sedimentary rocks in the northern Coast Range also contain a large percentage of smectite in the clay-size fraction, as do the Cowlitz, Pittsburg Bluff, and Keasey

Formations (Van Atta, 1971). This becomes important in considering the provenance of the sediments.

Kaolinite dominated the clay fraction in 27 percent of the samples tested and may reach significant percentages, composing 90 percent of the clay minerals in the clayey silt at 287 m in HBD-1, just above the weathered CRBG lateritic soil. Weathered feldspars such as found in the CRBG could provide a source for the kaolinite and illite (Mason and Berry, 1968). Illite composes less than 20 percent relative abundance in most samples.

The HBD-1 clay mineral samples were extracted from clay and silt units that exhibit different textural properties concerning their density and plasticity. Some of the units are characterized as dense and mildly to highly plastic, while others are classified as incompetent and nonplastic to slightly plastic in nature. Smectite percentages are high among both populations.

## BASIN STRATIGRAPHY AND SEDIMENTOLOGY

### Sediment exposures

Two Willamette Silt exposures were investigated during this study: a short series of cutbank exposures along the Tualatin River in sec. 21, T. 1 S., R. 2 W., approximately 3.2 km south of Hillsboro, and a temporary construction exposure on the south side of U.S. Highway 99W, just east of State Highway 217, in sec. 36, T. 1 S., R. 1 W., in the city of Tigard. The Tualatin River exposures consist of 2- to 3-m-tall cutbanks composed of uniform moderate yellow-brown, micaceous, very fine sandy, clayey silt. One contains a 0.8-m-thick and 5-m-wide debris channel consisting of basalt cobbles in a muddy matrix (Figure 6). The existence of the scour-and-fill sequence suggests a time break in silt deposition and supports the notion that multiple late Pleistocene catastrophic flood events extended into the Tualatin Valley (Waitt, 1985).

The temporary construction exposure just off Highway 99W in Tigard consisted of a 4.6- to 6.1-m-thick section of light yellow-brown, massive, Willamette Silt unconformably overlying approximately 6–7.6 m of variegated red-brown, tan, and yellow-brown interbedded clay, silt, and very fine sand of the uppermost Hillsboro Formation. The unit lies horizontal to subhorizontal, although a pebble zone in the middle of the exposure demonstrates an apparent slight dip to the northeast. This area of the exposure may contain a low-angle reverse fault (Ian Madin, personal communication, 1996). The Willamette Silt exhibits little structure within the unit, although occasional shallow channel-like scours are apparent the base of the unit. The Hillsboro Formation displays a complex depositional style of discontinuous layers typical of fluvial environments and a postdepositional feature of interest: vertical silt dikes.

The vertical to steeply dipping sandy silt dikes in the Hillsboro Formation are 5 cm in width, extend to the bottom of the Willamette Silt (Figure 7), and probably resulted from liquefaction of an underlying sandy silt unit during earthquake activity in this part of the Tualatin Valley 12,000 to 15,000 years ago, some time after deposition of the catastrophic flood silts.

**Figure 6: Willamette Silt exposure with a 0.8-m-thick, 5-m-wide channel of clayey silt and cobble-sized basalt clasts between flood silt layers. The existence of this channel supports the contention of multiple Missoula flood events into the Tualatin Valley.**

**Figure 7: A 5-cm-wide dike of silt to very fine sand in the Hillsboro Formation and into the overlying Willamette Silt (approximately separated by dashed line) in Tigard.**

Neogene sediments probably related to the Hillsboro Formation were exposed during the construction phase of the Tri-Met West Side Light Rail Tunnel system through Sylvan Hill in the Tualatin Mountains-Portland Hills region. These sediments occur west of the summit at elevations from approximately 122–182 m and overlie lava flows of the Frenchman Springs Member of the Wanapum Basalt. The sediments were exposed in both tunnels and consist of two distinctive facies, a stratified unit of clayey silts with subordinate clayey, silty, sand and gravelly sand layers that unconformably overlies massive clayey silts that represent loess deposits. The gravel in the sands is weathered basalt from the CRBG. The boundary between the two units follows an irregular concave geometry suggesting that the overlying stratified sediments were produced by local reworking of the massive unit and underlying CRBG and final deposition downslope as channel cut-and-fill deposit.

### Seismic-reflection data interpretation

Geometries and textures of four proprietary seismic reflection data lines were used to interpret depositional styles and to suggest modes of structural development. Three of the lines run north-south, and the fourth line extends east-west across the valley, intersecting the other three lines (Figure 8).

Three seismic reflection horizons were correlated throughout the line coverage in the Tualatin Valley. Horizon R at the top of the Columbia River Basalt Group is stratigraphically the lowest continuous horizon mapped. This horizon actually approximates the top of the hard basalt rock at the base of the lateritic weathering zone, as indicated in a synthetic seismogram generated from velocity data shot by DOGAMI in the HBD-1 boring (Wilson, 1997). Most of the velocities of the lateritic soil zone above the hard basalt in HBD-1 are not significantly higher than the overlying sediments.

A prominent pair of continuous reflectors were noted near the middle of the Hillsboro Formation, one labeled

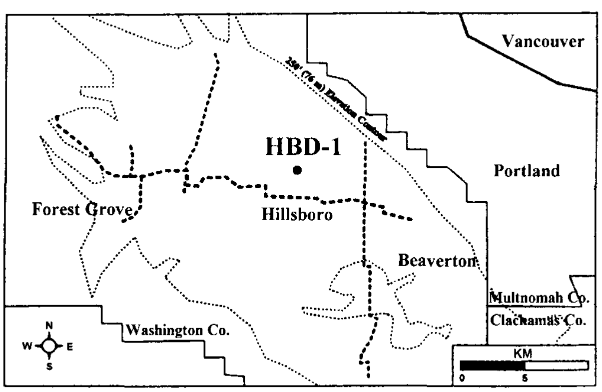


**Figure 8. Location map of proprietary seismic reflection data in the Tualatin Valley. Data courtesy of Geophysical Pursuit, Inc., Houston, Texas.**

"G" and the underlying labeled "O" on the seismic lines (Figure 9). The lithology at horizon G in the HBD-1 boring is silty clay (178–182 m below the surface) that displays a noticeable radioactive low response on the HBD-1 gamma log. Horizon O at the HBD-1 boring corresponds to silt and clay units that lie between a high-velocity, hard, siliceous layer at a depth of 231.6 m and a low-velocity clay layer at the 250-m depth. The lacustrine diatomaceous unit in HBD-1 consists of laminated clay and lies just above the stratigraphic level of horizon O which covers a large portion of the Tualatin basin. Interpretations made from the identification of the diatom species supports the notion of a widespread lake environment in this interval. Another lacustrine unit consisting of clay probably exists at level G; however, no diatoms have been identified in this clay in the HBD-1 boring.

Horizons G and O mark contrasting seismic characters in the Hillsboro Formation. The section above horizon G is noisy and discontinuous, suggestive of mixed fluvial lithologies that have different velocities (Sangree and Widmier, 1977). The section between horizons O and R is relatively quiet reflecting more continuity in lithologies. (These sections have been labeled PMf and PPlf by Popowski, 1996.)

The section between horizons G and R thins toward the edges of the northern and western valley boundaries. The three known lateral limits of horizons O and G occur approximately at the 122–152-m isopach lines of the Hillsboro Formation isopach map (Wilson, 1997, Figure 69), indicating uniform depositional limits of the main basin to the north and west edges. The overall geometry of the Hillsboro Formation observed on the seismic reflection data is indicative of a syndepositional sequence with continued basin subsidence.

Sediments older than horizon O pinch out progressively farther from the basin center with decreasing age. This trend leads to the conclusion that the main depositional basin has become larger with time.

## AGE OF THE HILLSBORO FORMATION

Available pollen, diatom, and paleomagnetic data from Hillsboro Formation in the HBD-1 boring allow development of a time-stratigraphic relationship that is correlatable via seismic reflection data.

The age of the Hillsboro Formation from the base of the unit overlying the CBRG laterite to at least the 259-m depth in HBD-1 is upper Miocene to lower Pliocene. Sediment samples from 259 and 281 m below the surface contain abundant *Cupressaceae* (cypress, 44.6 percent of the assemblage at the 259-m level), while *Pinus* (pine), *Alnus* (alder), *Salix* (willow), and *Abies* (fir) make up most of the rest of the samples (Cathy Whitlock, written communication, 1994, Table 2). The important families present in these samples are *Carya* (hickory), *Cupressaceae*, *Fagus* (beech), *Ilex*

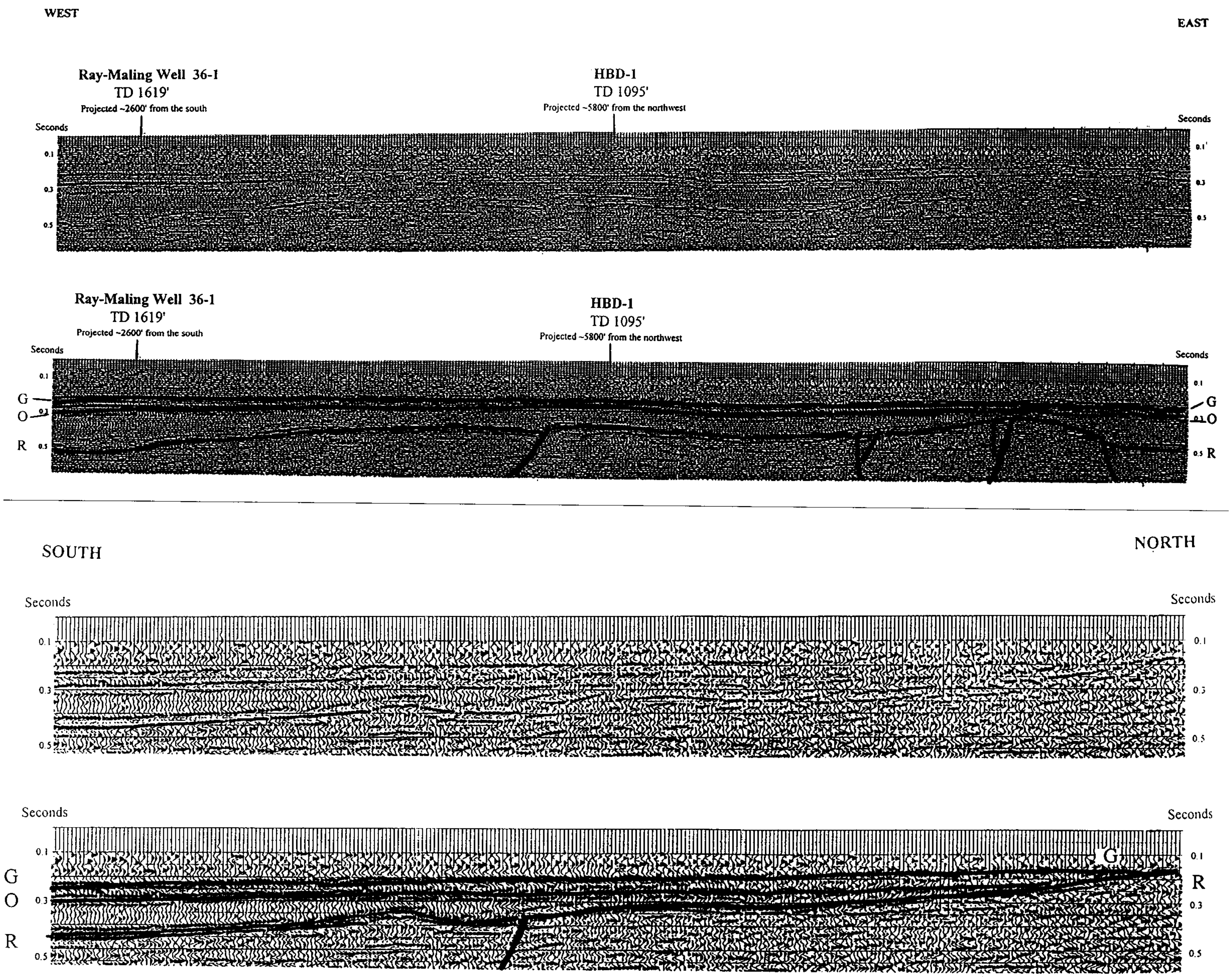


**Figure 9.** Seismic reflection profiles (interpreted version below the original) of the Tualatin basin, east-west (top pair) and north-south in the western part of the valley (bottom pair), showing three reflection horizons: the top of the Columbia River Basalt Group (horizon R) and indicators of lacustrine deposits within the Hillsboro Formation (horizons G and O). Profiles courtesy of Geophysical Pursuit, Inc., Houston, Texas.

(holly), *Juglans* (walnut), *Liquidamber* (sweetgum), *Nyssa*-type (tupelo), *Pterocarya* (wingnut), and *Tilia* (basswood). These specimens are not native to the modern Pacific Northwest but to eastern North American hardwood forests or to Asia. All except *Cupressaceae* occur in minor amounts.

Similar floral collections are reported from two other localities in the Willamette Valley, northwest of Monroe (Roberts and Whitehead, 1984) and just east of Corvallis (Scott Billings, written communication, 1996). The age interpretations from these two sites are late Miocene to early Pliocene. These species also have been reported from upper Miocene sediments in the foothills around the Willamette-Puget Sound lowland region (Wolfe, 1969). Pliocene flora has been described from the Troutdale Formation in the eastern Portland basin area (Wolfe, 1969). The broadleaf species *Pterocarya*, *Ulmus* (elm), *Platanus* (sycamore), and *Aesculus* (buckeye) are represented in the Pliocene sediments but are not found in nearby early Pleistocene strata.

Diatoms present in a laminated mudstone and an underlying fine-grained sand from 218 m to 224 m in the HBD-1 drill core suggest that lower to upper Pliocene deposits continue farther uphole to at least 218 m (Edward Theriot, written communication, 1995). The prominent diatom species in two examined samples, *Aulacosira canadensis*, is a common planktonic Neogene diatom that has been identified in several other Pacific Northwest sites, including Harper, Oregon (Hustedt, 1952), and the Yakima region in Washington (Van Landingham, 1991). The species ranges from early Miocene to Recent. Rare specimens of the centric genus *Pliocaenicus* indicates that the sediments are Pliocene to lower Pleistocene in age (Edward Theriot, written communication, 1994). This genus is global in its Pliocene range. Rare fragments of the benthic genera *Rhopalodia* and *Melosira* and the generally poor preservation of most specimens suggest that the environmental conditions were alkaline, eutrophic lacustrine. The lack of abundant benthic forms suggests either deep-water conditions or a turbid, shallow water environment.

Pleistocene-aged Hillsboro Formation sediments occur above the diatomaceous zone in HBD-1 up to the Willamette Silt boundary at 25 m. Pollen samples at 186.5 m and 198 m are dominated by the tree families *Picea* (spruce), *Abies*, and *Pinus* with subordinate amounts of *Cupressaceae*, *Alnus*, *Quercus* (oak), *Salix*, *Tsuga heterophylla* (western hemlock), *Pterocarya*, *Rhus* (sumac), *Ulmus*, and *Fagus* (Table 2). A small amount of *Pterocarya* present may be from older material, as the species is currently restricted to Asia (Cathy Whitlock, written communication, 1994). The preponderance of spruce, pine, and fir indicates a closed coniferous forest with cooler than present conditions. This assemblage type indicates that the sediment of this interval is of late Pliocene to middle Pleistocene age.

**Table 2. HBD-1 pollen species abundancies with comparison to pollen identified by Roberts and Whitehead (1984) at the Monroe, Oregon, locality, in percent**

| Tree and shrub species | HBD-1 depths (m) 186.5 | 197.8 | 259.1 | 281 | Monroe, Oreg. pollen ranges |
|---|---|---|---|---|---|
| *Abies* | 8.8 | 12.0 | 2.1 | 6.5 | 10-15 |
| *Acer macropyllum* | 0.0 | 0.0 | 0.5 | 0.0 | n/a |
| *Alnus* | 1.0 | 1.3 | 7.4 | 3.4 | 10-20 |
| *Betula* | 0.0 | 0.0 | 0.0 | 0.3 | 0.9-3.3 |
| *Carya** | 0.0 | 0.0 | 0.3 | 0.0 | < 1 |
| *Cuppressacae* | 1.3 | 1.3 | 44.6 | 0.3 | 10.0 |
| *Ericaceae* | 0.0 | 0.0 | 0.0 | 0.6 | 0.3-3.2 |
| *Fagus* | 0.0 | 0.3 | 1.1 | 0.0 | 0.3-2.6 |
| *Fraxinus* | 0.0 | 0.5 | 0.3 | 0.0 | 1.8-3,3 |
| *Ilex** | 0.0 | 0.0 | 0.0 | 0.1 | 0.3-5.6 |
| *Juglans** | 0.0 | 0.0 | 1.1 | 0.0 | 0.3 |
| *Liquidambar** | 0.0 | 0.0 | 0.3 | 0.3 | 0.8-2.4 |
| *Nyssa* | 0.0 | 0.0 | 0.3 | 0.0 | 0.5 |
| *Picea* | 27.0 | 42.3 | 1.1 | 10.1 | 4-20 |
| *Pinus* | 37.3 | 22.9 | 19.0 | 38.6 | 1.2-22 |
| *Pseudotsuga* | 0.3 | 0.3 | 0.3 | 0.6 | 0.8-2.4 |
| *Pterocarya** | 0.0 | 0.5 | 0.3 | 0.3 | 1.0 |
| *Quercus* | 0.0 | 1.1 | 1.1 | 0.0 | 2.8-26 |
| *Rhus* | 0.0 | 0.3 | 0.3 | 0.0 | n/a |
| *Rosacae* | 0.0 | 0.0 | 0.5 | 0.0 | 0.5 |
| *Salix* | 0.7 | 0.8 | 5.0 | 0.0 | 0.6 |
| *Taxodiaceae-Taxaceae* | 0.0 | 0.0 | 0.3 | 0.0 | n/a |
| *Tilia** | 0.0 | 0.0 | 0.0 | 1.7 | 0.5-1.0 |
| *Triporate* | 0.0 | 0.0 | 0.0 | 1.1 | n/a |
| *Tsuga heterophylla* | 0.0 | 0.5 | 0.8 | 3.1 | 0.3-2.8 |
| *Tsuga mertensiana* | 0.3 | 0.0 | 0.0 | 0.0 | n/a |
| *Ulmus/Zelkova* | 0.0 | 0.3 | 0.5 | 0.3 | 0.8-1.6 |

* = Genus is no longer extant in the Pacific Northwest

Identified specimens of herbs and pteridophytes include *Artemisia*, *Asteraceae*, *Cyperaceae*, *Dryopteris*, *Monolete* spores, *Poaceae*, *Pteridium*-type, *Tubuliflorae*, and *Urtica*-type. Aquatic and algal species of *Potamogeton* and *Sagittaria* were also recognized in the samples.

Forty thermally demagnetized (250°C and 350°C) paleomagnetic inclinations recorded for the Hillsboro Formation in HBD-1 exhibit a downhole switch from normal to reverse inclinations at a depth of 150.3 m (Figure 5). This probably marks the 0.78-Ma boundary between the Brunhes and Matuyama magnetic epochs (Izett and Obradovich, 1991). Three successive samples at 150.3, 155.8, and 164 m, half-way down in the Hillsboro Formation, comprise a zone of reverse magnetism in the boring. A fourth sample at 181.7 m has a zero inclination at 350°C. This interval is the only succession of reversals noted in the Hillsboro Formation, although more inclinations around this zone are needed to confirm this interpretation. Placement of the Brunhes-Matuyama boundary at 150.3 m fits within the confines of the pollen data.

Results from the HBD-1 synthetic seismogram, together with HBD-1 pollen and diatom ages, indicate that the seismic reflection horizon G occurs within lower Pleistocene sediments and the seismic reflection horizon O correlates with Pliocene to late Miocene deposits. Seismic reflection data in the region display successive pinchouts of older to younger event layers away from the basin center, including horizons O and G. The Hillsboro Formation is all Pleistocene in the Tualatin basin north and west of the pinchout of seismic horizon G, where the sediment section is 122 m thick or less.

The age of Hillsboro Formation deposition may be further defined in the northeastern part of the Tualatin basin using the 0.26- to 0.96-Ma Boring Lava flows that partially intertongue and mostly overlie the sediments. Layered sediments in the Tri-Met Westside Light Rail Tunnel underlie the 0.96-Ma Boring Lava flow and sit on top of the 15-Ma weathered Wanapum Basalt of the CRBG. The eolian and water-laid sediments are loess and reworked loess that were originally derived from Pleistocene glaciation.

Pieces of wood from the Gillenwater No. 1 water well on River Road south of Hillsboro (NE¼ sec. 21, T. 1 S., R. 2 W.) were recovered from 29 m below the surface. The contact between the Willamette Silt and the underlying Hillsboro Formation in this well is approximately at a depth of 21.3 m. This wood sample was $^{14}$C-dated to determine a minimum age of the Hillsboro Formation below the Willamette Silt. The sample was found to be older than the 43.7-ka dating limit for $^{14}$C analysis. At this locality, the uppermost Hillsboro Formation below the Willamette Silt is older than 43.7 ka, in contrast to the 12.7–15.3 ka of overlying Willamette Silt deposits (Waitt, 1985).

The >43.7-ka $^{14}$C date of wood at the top of the Hillsboro Formation south of Hillsboro indicates slow sedimentation in the upper Pleistocene, until the Missoula flood events of 15.3–12.7 ka (Waitt, 1985) entered the Tualatin Valley. Stream-terrace and valley-floor development postdate the catastrophic flood sediments.

## PROVENANCE OF THE HILLSBORO FORMATION

In past studies (Trimble, 1963; Schlicker and Deacon, 1967; Madin, 1990), most of the Tualatin basin sediments have been associated with the Troutdale Formation or the Sandy River Mudstone of the Portland basin. Determining the provenance of the Hillsboro Formation sediments was attempted in this study to define the relationship of the sediment packages.

The Portland basin and the northern Willamette Valley directly receive sediments from streams draining the Cascade Range. The Portland basin has also directly received sediments from the northern Rocky Mountain area. Barnes (1995) noted that the geochemical signatures from the lower Troutdale Formation sediments fit with Columbia River source sediments.

Analysis of heavy-mineral and INAA geochemistry data from Hillsboro Formation samples collected in the Tualatin Valley indicate that most of the sediments entered the basin from the surrounding highlands, and some of the finer fractions were airborne from outside the region.

Fifty-eight mounted slides of sand grains from Hillsboro Formation in DOGAMI drill hole HBD-1 and water wells around the Tualatin Valley were used to determine the augite-hypersthene-hornblende (AHH) relative percentage in each sample. Recent stream sediments in the Tualatin Valley and on the Columbia River and ancient sediment samples from the Troutdale Formation were also analyzed for their AHH relative percentages to compare with the Hillsboro Formation.

Instrumental Neutron Activation Analysis performed by Barnes (1995) and this author (Wilson, 1997) on 56 sediment samples from drill hole HBD-1 and other DOGAMI core borings of the Tualatin Valley confirms that there is a general consistency in the Hillsboro Formation provenance over time in the central part of the Tualatin Valley.

The Tualatin Mountains-Portland Hills along the north and east boundaries of the valley apparently have had enough relief since the middle Miocene to keep most of the Columbia River sediments from entering the Tualatin Valley. Quartzite pebbles found in Hillsboro Formation in the Tri-Met westside light-rail tunnel may be clues to local flood events of the Columbia River through canyons in the Portland Hills into the valley. Upper Hillsboro Formation sands in the Lake Oswego-Tigard area were delivered by the proto-Willamette River during the Pleistocene.

## NEOGENE STRUCTURE OF THE TUALATIN BASIN

The geometry of the Tualatin basin at the top of the CRBG consists of a large west-northwest-oriented synclinal downwarp north of Chehalem and Cooper Mountains. The CRBG surface in the basin around the Hillsboro area is as much as 460 m below the Tualatin Valley surface. The Beaverton fault, which bounds this downwarp on the south side, extends from the north side of Cooper Mountain westward almost to the Fern Hill area of the northern Chehalem Mountains.

The CRBG rises to the surface at David Hill, north of Forest Grove, and other smaller hills to the north. The Gales Creek fault zone in the Gales Creek Valley west of David Hill separates Paleogene sedimentary rocks to the east from Tillamook Volcanics to the west and extends southeast into Forest Grove. The Gales Creek fault zone probably has played a part in the uplift of the Paleogene sedimentary rocks and CRBG at the southwestern margin of the Tualatin basin (Popowski, 1996).

The Tualatin basin at the top of the CRBG south of the Beaverton fault is structurally more complex than north of the fault (Figure 10). Cooper and Bull Mountains break up the structural low, and faulting is more prevalent in the area, especially on the east side of these two uplifts. An eastern horst extension of Cooper Mountain in secs. 25–28, T. 1 S., R. 1 W., is buried under Willamette Silt. South of the horst is a complex graben structure bounded on the south side by the northeast-southwest-trending Sherwood fault. This narrow subbasin has a maximum width of only 3 km. The structural low wraps around the southern end of Bull and Cooper Mountains to join a subbasin west of Cooper Mountain. Two east-west-trending, fault-controlled CRBG structural highs extending west from Cooper Mountain discontinuously reach the surface and divide the west-side subbasin into two separate depressions. South of the Sherwood fault there is at least one narrow subbasin that follows the topographic low of the Tualatin River floodplain to the mouth of the current river.

The Hillsboro Formation fills a depression that wraps around the west, south, and east sides of Cooper and Bull Mountains developed during the Pleistocene as a result of the associated uplifting.

The axis of the Hillsboro Formation parallels the CRBG west-northwest orientation, and the sediment unit obtains a thickness of >451 m just west of downtown Hillsboro.

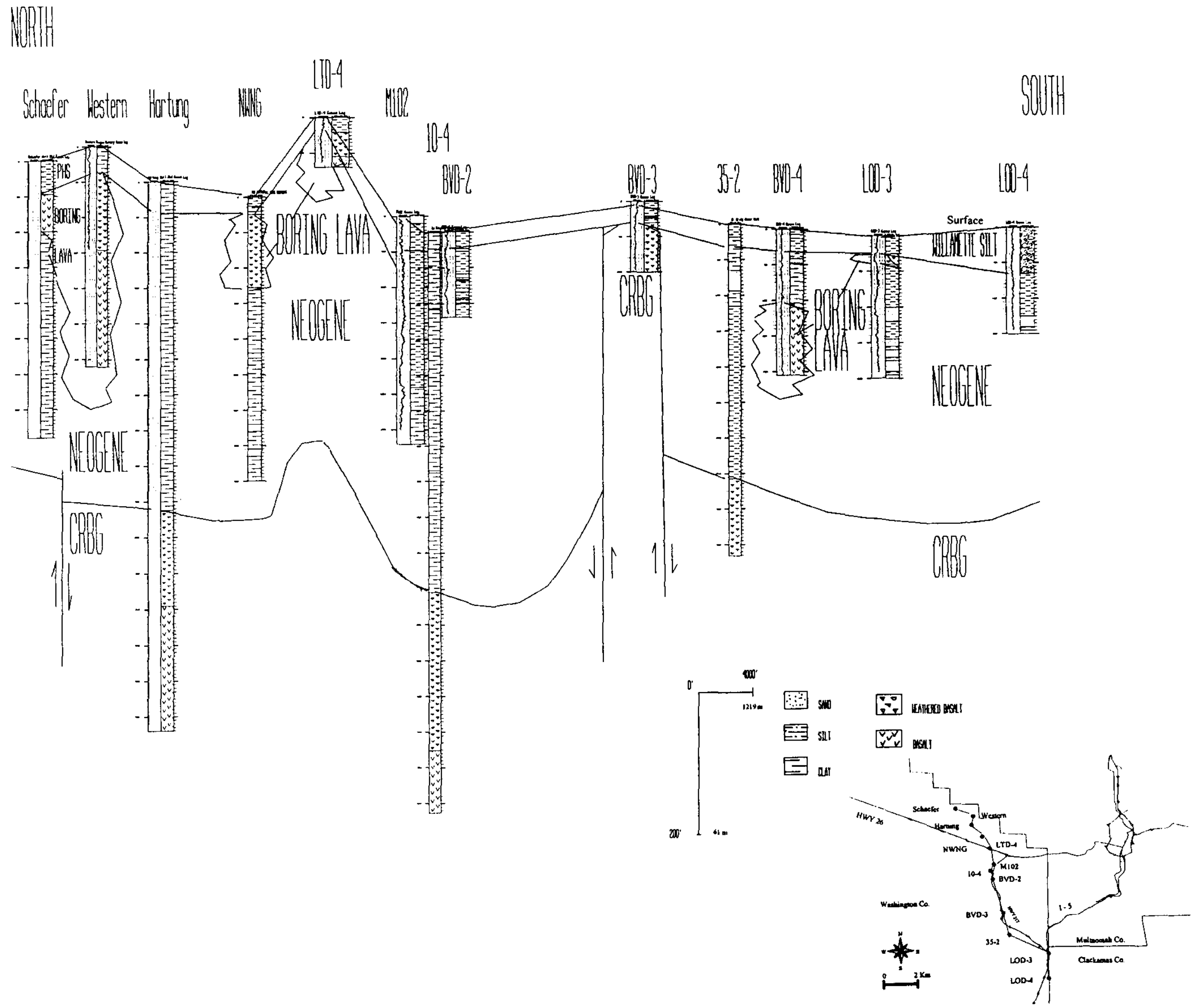


Figure 10. North-south section across the eastern margin of the Tualatin Basin, demonstrating the faulted nature of this portion of the basin. The Neogene sediments, consisting almost wholly of silts and clays, are faulted out in the region of BVD-3. Boring Lava flows are interlayered with the younger Neogene sediments.

The top Hillsboro Formation surface displays a gentle downwarp from 55–67 m above mean sea level at the basin edges to 18 m above sea level near the basin center at Hillsboro. Uplifted Hillsboro Formation is present in the Tri-Met light-rail tunnel at an elevation of 183 m. The gross pattern of the top Hillsboro Formation contours within the basin may represent paleostream flood plains prior to burial by the catastrophic floods that produced the Willamette Silt deposits. The present Dairy Creek and McKay Creek drainages overlie the low troughs of the top Hillsboro Formation as does the Tualatin River flood plain throughout most of the valley. Beaverton Creek, Cedar Mill Creek, Willow Creek, Holcomb Creek, Fanno Creek, and most of Rock Creek also follow Hillsboro Fomation troughs. These drainages were evidently able to reestablish themselves after each Missoula flood event, probably because the floodplain depressions were never completely buried.

Few faults break into the upper Hillsboro Formation package in the central basin; although one seismically identified fault north of Cornelius cuts into the upper part of the Hillsboro Formation This fault may extend into the Chehalem Mountains between Fern and Spring Hills. The entire group of Hillsboro Formation reflection horizons abruptly stop at the Beaverton fault, indicating that the fault was actively uplifting Cooper Mountain at least during the late stages of sedimentation.

## OTHER DEPOSITIONAL BASINS IN THE REGION

The Tualatin, Portland, and northern Willamette basins all contain Neogene sediments (with initial deposition during the late Miocene) that reach comparable thicknesses in the basin centers and are influenced to some degree by the same dextral fault shear couple (Portland Hills-Clackamas River fault zone and Gales Creek-Newberg-Mount. Angel fault zone).

South of Salem, Neogene sediment deposition occurs in two main subbasins, the Stayton basin and the southern Willamette Valley (Yeats and others, 1991). These basins initiated subsidence independently from the northern Willamette basin in the late Miocene (Crenna and others, 1994). The Stayton basin stopped sinking by Pliocene to middle Pleistocene time, accumulating more than 400 m of Neogene sediments.

The Tualatin and northern Willamette basins appear to have had similar depositional histories since the post-middle Miocene. Subsidence of the northern Willamette basin from late Miocene to at least late Pleistocene and into the Holocene is evidenced by warping of the Pliocene-Pleistocene fan gravel base and by the broad convexity of the modern Willamette River profile (Crenna and others, 1994). The thickening of fan gravel deposits in the southwest portion of the northern Willamette basin reflects greater rates of subsidence during the Pliocene-Pleistocene interval in this part of the basin, possibly due to accelerated uplift in the northern Coast Range.

In the Portland basin, the presence of <100 m of probable Columbia River alluvium directly overlying the Troutdale Formation in the MTD-1 boring suggests that insignificant Pleistocene deposition took place within the basin as the eastern side uplifted. Any Pleistocene sediments deposited prior to the Missoula flood events were stripped away during the glacial flood episodes. Troutdale Formation sediments exposed in the Bridal Veil channel of the Columbia River Gorge illustrate basin uplift during Pliocene-Pleistocene time.

The Tualatin basin, by contrast, contains up to 213 m of Pleistocene sediments at the HBD-1 boring (and more in the center of the basin), demonstrating a marked difference in the timing and rate of basin subsidence from the Portland basin (Table 3).

**Table 3. HBD-1 and MTD-1 estimated sediment thickness based on age and corresponding sedimentation rates**

| Boring no. | Thickness | For 1.6 Ma | For 2.4 Ma |
|---|---|---|---|
| | Pleistocene sedimentation rate | | |
| HBD-1 | ~213.4 m | 0.13 mm/yr | 0.09 mm/yr |
| MTD-1 | <85 m?? | <0.05 mm/yr?? | <0.03 mm/yr?? |
| | Pliocene/upper Miocene sedimentation rate | | |
| HBD-1 | 74.7 m | 0.011 mm/yr | 0.007 mm/yr |
| MTD-1 | 335.3 m | 0.053 mm/yr | 0.03 mm/yr |

An explanation for the basin subsidence timing difference between the two basins may rely on the proximity of the subsiding Tualatin basin to the uplifting Coast Range, while the Portland basin is farther away with an intervening structure, the Tualatin Mountains-Portland Hills, between the two basins.

Early subsidence and cessation of the Portland, Stayton, and southern Willamette basins at the Pliocene-Pleistocene boundary contrast with continued subsidence of the Tualatin and northern Willamette basins into the latest Pleistocene or Holocene. The result is an interesting pattern of relative Pleistocene uplift at the northern and southern ends of the Willamette Valley region with relative downwarping between.

## GEOMORPHOLOGY OF THE TUALATIN RIVER

Parsons (1969) described the Tualatin River flood plain as part of a hanging valley above the Willamette Valley. Most of the Tualatin River channel downstream from Forest Grove is approximately 18.3 to 21.3 m above the Willamette River confluence. The flat profile in the valley indicates that the river has not yet had a chance to fully recover and erode the catastrophic flood sediments of the Willamette Silt (Waitt, 1985) that cap the valley surface. The Tualatin River knick point, the first change from steeper to gentler river gradient upstream, is located 2.8 km from its mouth near West Linn. This is unique in comparison to other Willamette River tributaries. The closest knick point to a river mouth is 16 km in the Clackamas River. CRBG underlying the last 3 km of the Tualatin River has been more resistant to erosion than the Willamette Silt or other sediments that underlie the lower stretches of most of the other major tributaries to the Willamette River.

Two primary terrace surfaces are present along the Tualatin River main stem and at the downstream end of Dairy Creek, Gales Creek and McKay Creek in the western part of the Tualatin Valley. The surfaces consist of the present-day floodplain and a terrace surface that represents the main Tualatin Valley floor. An intermediate bench between the flood plain and the valley floor is intermittently present in the lower stretches of the river, south of Hillsboro 6–10 m below the floodplain surface. The flood plain is most likely more than 300 years old, yet the river has evidently not abandoned the surface during flood events. The inability of the Tualatin River to cut through the knickpoint near West Linn may have contributed to this unique situation.

Lithostratigraphic and geomorphic evidence suggests that the Tualatin River experienced erosive periods of incision soon after the Missoula flood events. Lowering of the Tualatin River's base level due to erosion of the river's knick point downstream or climatic factors that intermittently alter the magnitude of the river's discharge could influence terrace development (Shelby, 1985). The geographic pattern of the mapped terraces is reminiscent of paired, polycyclic terrace development (Chorley and others, 1984).

## CONCLUSION

The post-middle Miocene Tualatin basin is characterized by a subsiding structural low and is filled with fluvial and lacustrine clastic sediments. The HBD-1 core at the Portland-Hillsboro Airport consists of 288 m of sediment overlying a lateritic paleosol belonging to the Frenchman Springs Member of the CRBG. The top 25 m of the sediment package is assigned to the Willamette Silt, which is the depositional result of the late Pleistocene Missoula catastrophic glacial flood episodes. Sediments between the Willamette Silt and the top CRBG laterite are named the Hillsboro Formation in this report.

Study of Hillsboro Formation sand, silt, and clay unit percentages indicates that most of the Hillsboro Formation was deposited in a fluvial environment, that stream activity increased with time in the area of HBD-1, and that most sand deposition occurred close to the basin center in broad, linear trends.

Two probable lacustrine sections are recognized in the Hillsboro Formation of HBD-1. The upper section occurs from about 178 m to 184.7 m in depth and correlates to the prominent, basin-wide seismic-reflection horizon G. The reflector either signifies an extensive lacustrine environment or a disconformity. A more certain interpretation of a lacustrine environment is found in a unique diatomaceous unit between 217.9 m and 222.5 m in depth. The diatomaceous interval closely correlates to the relatively continuous seismic reflection horizon O, which supports the extensive nature of the lake environment.

Hillsboro Formation sands are immature with moderate to poor sorting, medium to very fine grained textures and containing significant levels of silt and clay. The sand unit compositions are classified as either litharenites or feldspathic litharenites.

Smectite is the most abundant clay mineral in most of the Hillsboro Formation silts and clays analyzed, yet kaolinite dominates in some units. Illite typically occurs in minor amounts, but may comprise up to 40 percent of the clay minerals.

The age of the Hillsboro Formation in HBD-1 is derived from pollen, diatom, and paleomagnetic data. The pollen assemblage at 186.5 m and 197.8 m in HBD-1 characterizes the Pleistocene interval with open spruce, fir, and pine forests. Paleomagnetic inclinations from silts and clays in HBD-1 switch from normal to reversed at 149.4 m, signifying the 0.78 Ma Brunhes-Matuyama paleomagnetic epoch boundary. Pliocene to upper Miocene sediments underlie the Pleistocene sequence to the top laterite soil of the CRBG. The diatomaceous zone contains probable late Pliocene forms; therefore the top 213 m is considered Pleistocene. Pollen extracted from 259 m and 281 m in HBD-1 belong to a partially exotic assemblage dated in other parts of the Willamette Valley as late Miocene.

Radiometric ages from wood and Boring Lava samples in other parts of the Tualatin Valley are used to determine stratigraphic relationships away from HBD-1. A radiocarbon date from wood at the top of the Hillsboro Formation south of Hillsboro is older than 43,700 years. This suggests that the central Tualatin Valley surface prior to the Missoula flood events is at least this age. Available ages from Boring Lava flows near Sylvan Hill in the eastern part of the valley imply that the underlying Hillsboro Formation in this part of the valley is one million years or older.

Heavy-mineral-suite and INAA geochemistry analyses from HBD-1 and other penetrations in the Tualatin and Portland basins indicate that the Hillsboro Formation was primarily derived from the Coast Range and surrounding highlands. Augite-hornblende-hypersthene (AHH) relative percentages from the Hillsboro Formation in the Tualatin basin are deficient in hypersthene and contain dominant levels of augite or hornblende, which supports local sources for fluvial sediment deposition. In contrast, sediments from the Portland basin and northern Willamette Valley have highly variable AHH relative percentages, including a large percentage of hypersthene, a mineral primarily derived from the Cascade Range. Unusually low scandium and chromium levels from a siliceous mudstone at 231.6 m suggest that volcanic ash from Cascade Range air-fall events at least once covered the Tualatin Valley.

The Hillsboro Formation geometries from seismic reflection data demonstrate that sedimentation first took place near the basin center and progressively filled the basin as subsidence continued. Reflection characteristics mark a relatively quiet interval of more consistent lithologies below horizon G and a noisier section of more varied clastic sediments above horizon G, agreeing with observations of more sand deposition in the upper 152 m found in HBD-1.

The faulted CRGB basement of the Tualatin basin segregates a large, northern subbasin, with few faults cutting into the sediments from the CRBG, and a smaller, more complexly faulted southern subbasin south and east of the Beaverton fault. Most faulting in this area is restricted to the CRBG and below; however, there are exceptions, denoting structural activity in the basin during the Pleistocene. Most faults at the top of the CRBG south of the Beaverton fault are roughly oriented east-west and cut into the Hillsboro Formation. This area was active in the Pleistocene, since all of the Hillsboro Formation has been removed south of the Beaverton fault on Cooper and Bull Mountains and on a buried horst to the east in the Beaverton-Tigard area.

Hillsboro Formation sedimentation rates in the Tualatin basin calculated from age relationships in HBD-1 increase one order of magnitude from the late Miocene-Pliocene to the Pleistocene. Increased sediment supply to the basin implies an increase in basin subsidence and/or relative uplift of surrounding highlands, particularly the Coast Range. The 335-m-thick Troutdale Formation at the MTD-1 Portland International Airport boring of the Portland basin, in contrast, is all pre-Pleistocene, indicating a temporal difference in subsidence between the two basins.

The temporal development of the Tualatin basin compares well with the northern Willamette basin. Both basins have thick sequences of fine-grained, Neogene clastic material. Seismic-reflection line data exhibit similar reflection characters and trends in both basins. They have subsided during the Pleistocene, share a common major structural lineament in the Gales Creek-Mount. Angel fault zone, and are adjacent to the northern Coast Range. The south Willamette Valley, including the Stayton basin, was downwarped, received thick sequences of late Miocene and Pliocene sediments, and stopped subsiding at the beginning of the Pleistocene. In the Portland basin, Cascadian uplift during the Pleistocene may have slowed or stopped subsidence.

The Missoula floods entered the Tualatin Valley at least 22 times through the Lake Oswego gap. One or more flood events transported ice-rafted sediments to elevations of 122 m.

The Tualatin River knickpoint is within 3.2 km of its confluence with the Willamette River, in contrast to other Willamette River tributaries whose knickpoints are tens of miles upstream from their mouths. Boring information at the Tualatin River mouth reveals that the river is riding on top of CRBG which is slowing the erosion process of the river and leading to the flat longitudinal profile upstream.

Three post-Missoula flood geomorphic surfaces are present along the Tualatin River and two persist into the adjoining major tributaries. The main valley floor is equivalent to the Senecal surface (12,700 years old) of the Willamette Valley. A middle, discontinuous level is the upper Winkle surface (10,000–12,700 years old). The age of the modern Tualatin River flood plain is between that of the Horseshoe (300 years old) and Winkle surfaces.

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## Oregon joins AGI, other states in proclaiming Earth Science Week

The countdown to the first Earth Science Week has begun. Mark your calendars now for the October 11–17 celebration. This year, Earth Science Week is one of the most ambitious 50th anniversary initiatives for the American Geological Institute (AGI), and it offers the geoscience community new opportunities to demonstrate the importance of the earth sciences. Geoscience organizations have responded enthusiastically to the idea, and AGI member societies and state geological surveys are planning Earth Science Week activities and events. "The goal for Earth Science Week," says AGI President Susan Landon, "is to have all geoscientists in the country do something in their communities to promote the earth sciences." AGI's role in sponsoring an annual Earth Science Week is to provide a clearinghouse for ideas, activities, and special events and to provide support materials that make it easy for geoscientists participate. Information about Earth Science Week is available from the American Geological Institute and on the World Wide Web at **www.earthsciweek.org**.

Oregon Senator Ron Wyden demonstrated his support for the earth sciences by reading the AGI-adopted resolution on Earth Science Week into the Congressional Record. The governors of seventeen states, Alabama, Arizona, Colorado, Connecticut, Florida, Illinois, Kansas, Kentucky, Maine, Nevada, North Carolina, North Dakota, Ohio, Oregon, South Dakota, Tennessee, and Vermont, have already issued Earth Science Week proclamations and resolutions, and more are expected to follow.

A common thread in the proclamations is recognition that the role of geology and the earth sciences are fundamental to society and to our quality of life. An understanding of geology and the earth sciences can help citizens make wise decisions for land management and use, is crucial to addressing environmental and ecological issues, and provides the basis for preparing for and mitigating natural hazards.

Earth Science Week has enormous potential for increasing public awareness and understanding of the importance of the earth sciences in our lives. The celebration, which will be held annually during the second full week of October, will give geoscientists and organizations repeated opportunities:

To give students new opportunities to discover the earth sciences

To highlight the contributions that the earth sciences make to society

To publicize the message that earth science is all around us

To encourage stewardship of the Earth, and

To develop a mechanism for geoscientists to share their knowledge and enthusiasm about the Earth and how it works

Many Earth Science Week activities will focus on education. AGI has recently published a colorful 18"x24" poster on Geoscience Careers and will produce a second poster in time for Earth Science Week. The first module of EarthWorks, a set of middle-school student and teacher activities on soils, will be available in time for Earth Science Week, as will a general-interest booklet on soils that is part of AGI's Environmental Awareness series. *—AGI news release*

## MLR welcomes hydrogeologist Bob Brinkmann to its staff

Bob Brinkmann joined the Department of Geology and Mineral Industries on August 12, 1998. Bob will serve as the staff hydrogeologist for the Mined Land Reclamation program. He was selected from a very competitive field of 24 candidates. The six-person interview team that recommended hiring him, was made up of people from DOGAMI, the Water Resources Department, and the mining industry. The final three candidates were subjected to a three-hour interview, which included a visit to an operating mine site.

Staff hydrogeologist is a new position at MLR, established during the last legislative session. Bob will provide needed expertise in the field of hydrogeology and will allow the program to make better decisions in this complex and controversial area. In addition, he will conduct approximately 150 statewide site inspections per year to support the program's field presence. The foundation of the MLR program is working directly with mine operators.

Bob has a Bachelor of Science degree in Geology from Colorado State University and 12 years of experience working as a hydrogeologist in the mining industry and as a private consultant. After graduation, Bob went to work for Chevron Resources, Inc., for 6 years and most recently was with Olympus Environmental Consulting, Inc. He has worked all around the West, including the Northwest. While with Chevron, he gained experience dealing with mine dewatering in fracture-flow volcanic environments; and he has experience working with water-supply and contaminant hydrogeology issues. □

## In the next *Oregon Geology*: Special focus on earthquake damage-and-loss estimates

DOGAMI earthquake scientists have developed a statewide, county-by-county estimate of earthquake damage and losses for two of the possible cases of earthquake events in Oregon.

The November/December issue will focus on this special subject. □

*(**Reader survey**, continued from page 98)*

People indicated several different reasons why they subscribe:

| Number of responses | Reason |
|---|---|
| 97 | General interest in geology |
| 76 | Latest scientific papers on Oregon geology |
| 69 | Keep up with geology activities in Oregon |
| 62 | For professional reasons |
| 49 | Geologic hazards information |
| 47 | Earthquake information |
| 36 | Mining information |

More than two thirds of those responding said they share the magazine with others in the office or family.

People from many occupations read our magazine. Responses to this question yielded a significant number (28) under "other," including, for example, registered nurse, mobile park manager, real estate professional, retailer, physician, and photographer.

| Number of responses | Occupation |
|---|---|
| 49 | Retired |
| 48 | Professional geologist |
| 29 | Educator |
| 22 | Scientist other than geologist |
| 20 | Government worker |
| 14 | Prospector or explorationist |
| 12 | Engineer |
| 10 | Work in energy industry |

Almost 85 percent of those responding are male, 63 percent are over 50, and 63 percent have done graduate work in college.

The breakdown in demographics includes:

| Number of responses | Age |
|---|---|
| 6 | 18–34 |
| 44 | 35–50 |
| 41 | 51–64 |
| 51 | 65+ |

| Number of responses | Education |
|---|---|
| 17 | High School |
| 44 | College |
| 92 | Graduate work |

In short, our readers come from a variety of backgrounds and have a variety of interests. We often get comments that *Oregon Geology* has too many technical articles. It's sometimes difficult to balance the needs of professional geologists with those of other professionals or the interested public.

Since the department began publishing a magazine in 1939, we have been constantly adjusting the content and format to keep up with the changing needs of our readers. For example, the first *Ore Bin* had three articles: the value of Oregon's mineral production, a description of the area around Newberry Crater, and a new metallurgical process. We will continue to try to publish a magazine that is useful to our readers.

We appreciate your interest in geology and hope you will always feel free to contact us about what you like and suggestions to make our magazine better. □

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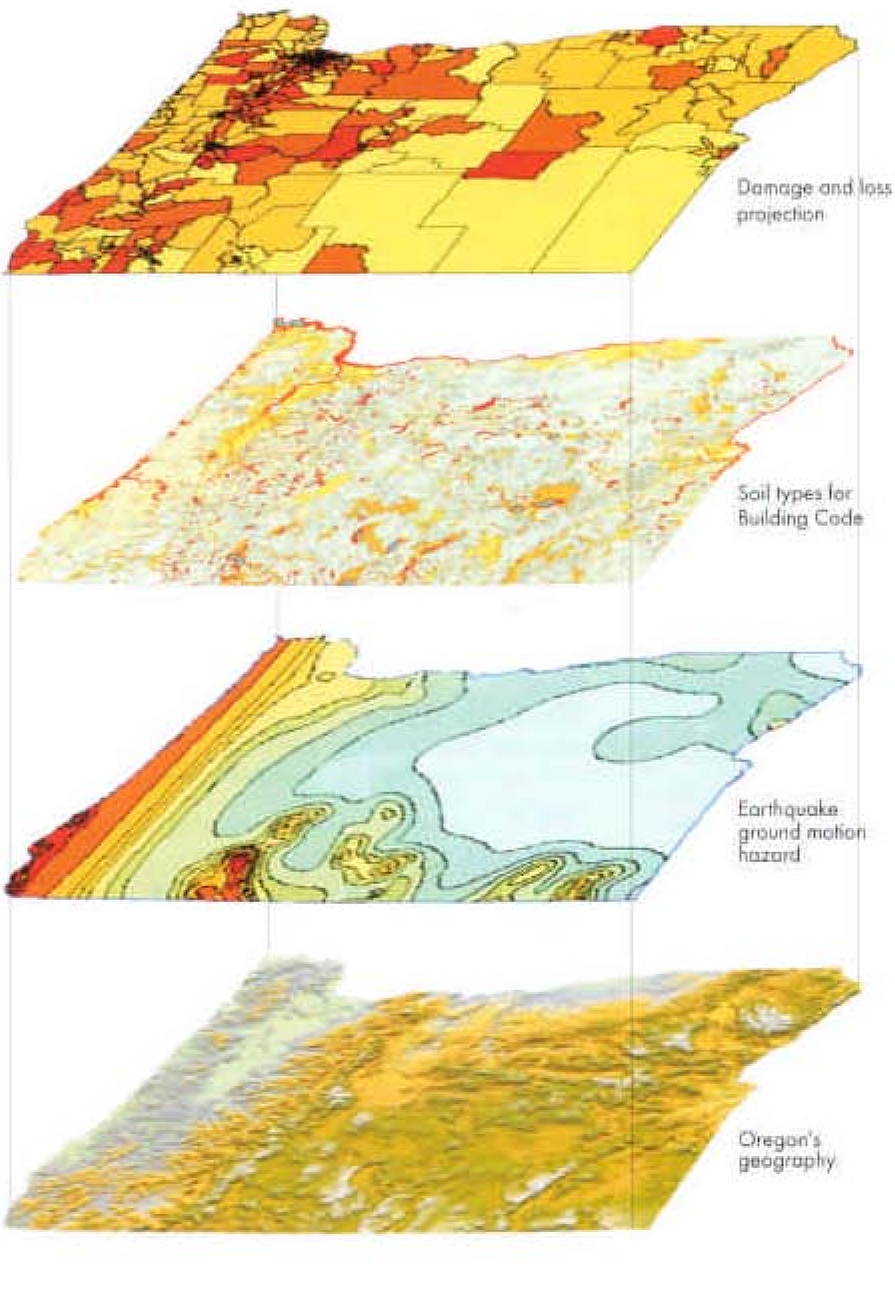


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## Cover illustration

Four maps are shown that make up individual layers of the GIS-based analysis associated with the damage and loss assessment discussed in the article beginning on page 123. Highest hazard is indicated by most intensely red coloring.

## Klamath Falls—five years after the earthquakes

Klamath County and the Oregon Department of Geology and Mineral Industries (DOGAMI) sponsored a commemorative celebration on October 30, five years after the earthquakes that shook the region on September 20, 1993. The event took place at the new Klamath County Government Center and Courthouse, a structure that had suffered damage in 1993 but has been rebuilt and expanded since. Among the participants were the three County Commissioners, Chairman Bill Garrard, Steve West, and Al Switzer and representatives of DOGAMI, county government, organizations related to emergency management, the local engineering community, the Federal Emergency Management Agency, Oregon Emergency Management, and the U.S. Geological Survey.

Remembering the experience of the 1993 quakes and what has been achieved in recovering from them served as a basis for looking to the future of this region, which will certainly have earthquakes again.

After a morning meeting moderated by Klamath County Emergency Manager Bill Thompson, an afternoon field trip led the participants to an example of a fault exposure within the urban boundary of the City of Klamath Falls; to Modoc Point, where the danger of earthquake-induced landslides is particularly obvious; and to Ponderosa Middle School, where ground subsidence related to both geothermal groundwater extraction and faulting has caused damage to buildings.

DOGAMI is currently involved in several earthquake-related activities in the Klamath Falls area. In concert with county, state, and federal agencies, the department is creating earthquake hazard maps for Klamath County; damage and loss assessments and a slope stability assessment for the county; and a partial building inventory that especially targets unreinforced masonry (URM) structures. □

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Klaus K. Neuendorf, Editor

# Oregon earthquakes: Preliminary estimates of damage and loss

*by Yumei Wang, Oregon Department of Geology and Mineral Industries*

## INTRODUCTION

Oregon is especially vulnerable to earthquake hazards because of its location on the Pacific "Ring of Fire" and its plate-tectonic setting. To better understand public needs that involve earthquake hazards and the health, safety, and welfare of the state's population, the Oregon Department of Geology and Mineral Industries (DOGAMI) has conducted earthquake damage and loss estimation studies for Oregon. Results from this study can be used to help increase earthquake awareness, stimulate mitigation and risk reduction action (e.g., strengthening facilities), support and set policies and legislation, and develop emergency response plans.

This paper reviews the modeling of estimated damage and losses for (1) a magnitude 8.5 (M8.5) subduction zone earthquake off the coast of Oregon and (2) 500-yr return interval probabilistic ground motions for the entire state. The two data sets included detailed geologic information contained in a statewide Uniform Building Code (UBC) soil map.

Results from the statewide estimates show that Oregon is unprepared for earthquake hazards. A large subduction zone earthquake will cause over ten billion dollars of building damage alone. Losses from the 500-yr ground motions are almost three times the amount of the subduction zone earthquake. Most of the damage costs are located in western Oregon, where the expected ground motions and population density are higher than in eastern Oregon.

## BACKGROUND

Recent earthquakes have caused damage in Oregon, and future damaging earthquakes are inevitable. Damage and losses from recent worldwide earthquakes have devastated local communities due to the vulnerable developments in those areas. The earthquakes of Kobe, Japan (1995, M6.9); Northridge, California (1994, M6.7); and Loma Prieta, California (1989, M7.1), caused about 100, 42, and 10 billion dollars, respectively, in direct economic losses.

Oregon has numerous potential earthquake sources that can produce strong ground shaking and damage to the communities. The Cascadia subduction zone fault, which lies just offshore, can produce a M8.5 earthquake or perhaps even larger (Yamaguchi and others, 1997). Inland faults, such as the Mount Angel fault that triggered the M5.6 Scott Mills ("Spring Break") quake in 1993 and the West Klamath Lake fault zone that, during the same year, triggered the two Klamath Falls main shocks of magnitudes 5.9 and 6.0, are examples of crustal earthquake sources. About 30 and 10 million dollars in damage were inflicted by the Scotts Mills and Klamath Falls earthquakes, respectively. As a result of growing awareness of earthquake hazards in Oregon, steps are being taken to better understand and prepare for the threat of a large-magnitude Cascadia subduction zone earthquake as well as for inland earthquakes. The present study is one such example. Another example is that more stringent building code requirements have been adopted. In 1993, the Seismic Zone designation for western Oregon was raised from 2B to 3 in the Uniform Building Code (UBC); in October 1998, the central and south coast area was raised from Zone 3 to Zone 4.

Balancing the public safety benefits with limited funds can be more effective with a better understanding of the economics at stake, that is, the possible damage and losses. With these estimated losses, planners and policy makers have useful information to guide public policy issues to reduce future loss of life and property. Various interest groups can reduce the possible impact in specific areas by targeting information in the predicted damage and loss estimates. Although loss estimations have inherent uncertainties and limitations, the results can be viewed as important information. Both regional and local mitigation can be implemented based on these results. For example, this work may help formulate state legislation that focuses on improving the state's building inventory database and furthering the state's risk reduction efforts. Or, this work may help instigate or substantiate the seismic evaluation or strengthening of older school buildings in a local school district.

## METHOD

The damage and loss estimates for future earthquake ground shaking were obtained using HAZUS97 software produced by the Federal Emergency Management Agency (FEMA) (National Institute of Building Sciences, 1997; Risk Management Solutions, Inc., 1997). HAZUS97 has recently become available to the public and operates through a geographic information system (GIS) to display earthquake hazard information, inventory data, and estimated losses in the form of both maps and tables. This software was developed through a cooperative agreement between FEMA and the National Institute of Building Sciences (NIBS). Risk Management Solutions, Inc., of Menlo Park, California, developed the software under the oversight of a panel of recognized experts in their respective fields. The software was calibrated with past earthquakes and pilot-tested in two communities in the nation, one of them Portland, Oregon The estimates discussed here are only samples of the possible types of damages and losses that can be modeled with this software.

The method involves modeling an earthquake source and attenuation relationships or ground motions, determining the damage based on fragility curves, which indicate the probable degree of damage, and then quantifying the losses on the basis of the inventory database. The procedure yields quantitative estimates of losses in terms of direct costs for repair and replacement of damaged buildings, direct costs associated with loss of function (e.g., loss of business revenue, relocation costs), casualties, displacement of people from residences, and removal of debris generated. In addition, functionality losses for emergency and essential facilities and components of transportation and utilities are quantified.

In HAZUS97, the ground motions are characterized by spectral response based on a standard spectrum shape, peak ground acceleration (PGA), and peak ground velocity (PGV). Elastic response spectra (5-percent damping) are used to characterize ground shaking. The spectra have the same standard shape defined by a PGA value at zero period, spectral response at a 0.3-second period in the acceleration domain, and spectral response at a 1.0-second period in the velocity domain. The shape is adjusted for site amplification and distance from the source to the site.

Building damage is estimated by applying fragility curves, capacity curves, building type, seismic design level, and ground response. Owing to the limited amount of building inventory data and the regional approach of this method, model groups of buildings (or population groups) are evaluated on a census tract basis. Single buildings at specific locations are not evaluated. The damage functions include (1) building fragility curves that describe the probability of reaching or exceeding different damage states at a given peak building response; and (2) building capacity ("pushover") curves that are used with damping-modified demand spectra to determine peak building response. The damage state probabilities are used as inputs to estimate induced physical damage and direct economic and social loss, such as casualties, monetary losses, and shelter needs. For this study, all buildings were placed at low seismic design level.

Loss estimates are based on (1) structural repair costs depending on extent of damage, model building types and occupancy classes; (2) nonstructural repair costs for all occupancy classes, both acceleration-sensitive damage (from the shock waves themselves) and drift-sensitive damage (from the structure's deformation in response to the shock waves); (3) value of building contents as a percentage of building replacement value for all occupancy classes; (4) contents damage as a function of damage state; (5) annual gross sales or production for agricultural, commercial, and industrial occupancy classes; (6) business inventory as a percentage of gross annual sales for agricultural, commercial and industrial occupancy classes; and (7) business inventory damage as a function of damage state for agricultural, commercial and industrial occupancy classes. A large amount of default economic data is included in the method to develop the direct economic losses.

### Study region and source data

The study region is the state of Oregon, with a population of just over 3 million people. The highest population concentration is in the western part of the state, especially in the Willamette Valley.

HAZUS97 evaluates the study region by census tracts. Oregon has a total of 727 census tracts. HAZUS97 includes numerous databases from a variety of sources, including information on geography, demographics, economics, buildings, and lifelines. Demographics and residential buildings are obtained from the 1990 data of the United States Census Bureau. Nonresidential data, such as commercial and industrial structures, are obtained from 1995 reports by Dunn and Bradstreet. HAZUS97 estimates a total building exposure (i.e., replacement value, not market value) of about $160 billion for the state.

The soil map (see second map from top on cover illustration) includes the six soil categories defined in the 1997 Uniform Building Code (UBC) (Wang and others, 1998). UBC soil types were estimated on the basis of published digital regional geologic and agricultural soil maps, previously mapped material properties, and shear-wave velocities measured on the unit or similar units. In order to conduct the HAZUS97 analyses, soil profile type $S_F$ (soil requiring site-specific evaluation) has been reclassified into type $S_E$ (soft soil). Also, the soil map is modified within HAZUS97 to a census tract basis for analyses of most buildings.

Except for the soil data, this study has relied on the HAZUS97 default databases. Therefore, the results provide relative, not absolute, estimates of losses. Statistical uses, for example at the county level, are appropriate.

### Earthquakes modeled

Two earthquake types were evaluated: (1) a (deterministic) M8.5 Cascadia subduction zone earthquake and (2) 500-yr return interval probabilistic bedrock ground motions.

#### *M8.5 Cascadia earthquake*

The M8.5 earthquake is produced by a rupture along the Cascadia margin that lies generally parallel to Oregon's coastline. The M8.5 model assumes a rupture length of 480 km and a hypocentral (or focal) depth of 10 km. The fault is modeled as a low-angle reverse (or thrust) fault with an equal bi-directional rupture pattern (i.e., a rupture extending equally in both directions from the center of the quake). For this model, we used the Project 97 Pacific Northwest attenuation relationship available in HAZUS97, which is based on earlier work by Frankel and others (1996). This relationship applies to rock sites and uses 50 percent each of (1) the attenuation curves for deep and subduction zone earthquakes by Youngs, Chiou, Silva and Humphrey (1997) and (2) the attenuation curves by Sadigh, Chang, Abrahamson, Chiou, and Power (1993). Attenuation ("lessening") relationships are used to calculate the peak ground acceleration (PGA) which decreases with distance from the earthquake.

After the PGA is calculated, deterministic ground motions (spectral responses) are calculated from algorithms stored in HAZUS97 relational databases. Those values are then amplified by factors based on local soil conditions as determined by the soil map described earlier. The ground motions in the general building damage analyses are computed at the centroid (the mathematical "middle") of a census tract.

Output ground motions for PGA (Figure 1), peak ground velocity (PGV), and spectral acceleration ($S_A$), spectral velocity ($S_V$), and spectral displacement ($S_D$) at periods of 0.3 and 1.0 seconds are provided on a census track basis. The maps include soil influence and thus represent motions at the ground surface.

*500-yr return interval ground motions*

The ground motions modeled are taken from the U.S. Geological Survey (USGS) earthquake ground motion hazard map with a 10-percent probability of exceedance in 50 years (Frankel and others, 1996; see cover illustration, second layer from bottom). This map represents single median ground motions for the region over the next 475-year period, commonly referred to as the "500-year" return interval. These probabilistic ground motions include peak ground acceleration (PGA), peak ground velocity (PGV), and spectral velocity ($S_V$) at 0.3 seconds and 1.0 seconds.

The USGS probabilistic maps, which were used as the basis for design value maps of the 1997 *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures* (Building Seismic Safety Council, 1997), show the ground motion levels with specified probabilities of being exceeded in a 500-yr return interval. Ground shaking motions with a 500-yr return interval are equivalent to a 10-percent probability of being exceeded in 50 years or, in other terms, an annual frequency of exceedance of 0.002. The probabilistic approach incorporates all fault sources capable of generating earthquake ground shaking and includes earthquake wave propagation from the sources to include all areas

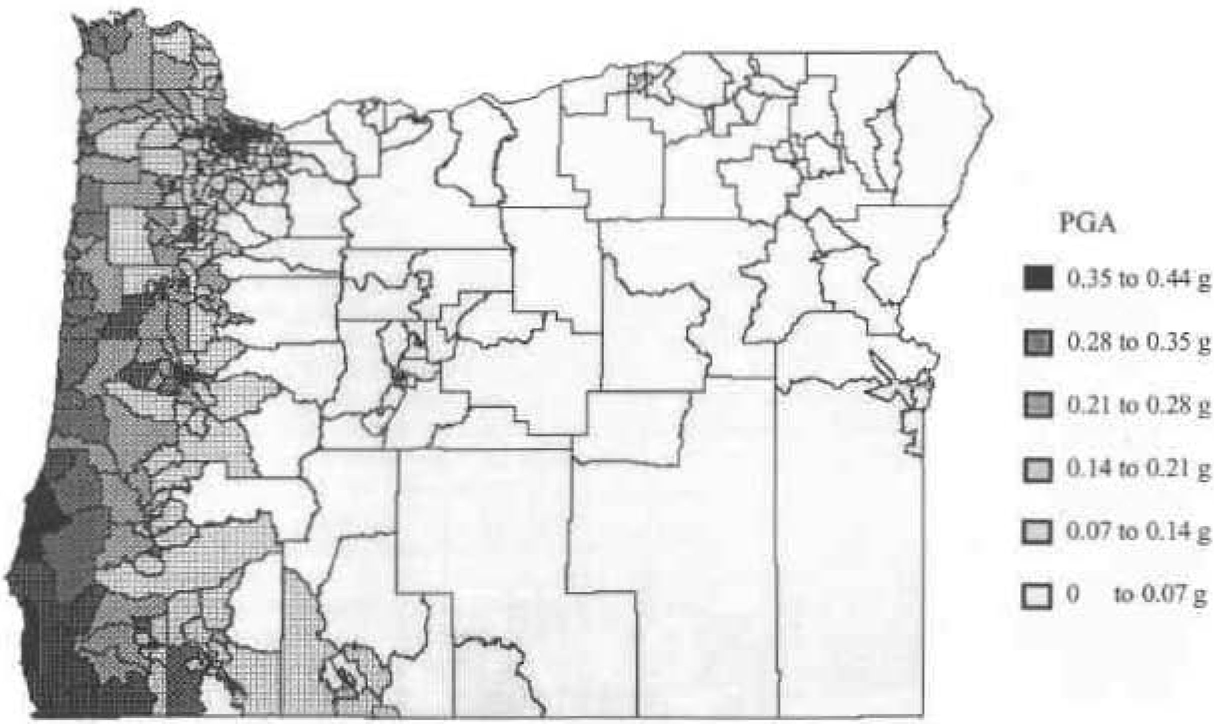



**Figure 1. Peak ground acceleration (PGA) for M8.5 Cascadia subduction zone earthquake on census tract basis. Convention of yellow-to-red coloring for progression from least to most dangerous rendered here as light-to-dark shading.**

of Oregon. Thus, for each given site, the ground motion levels (peak ground accelerations) for all the earthquake locations and magnitudes in the vicinity are represented. Probabilistic maps provide an equal representation of likelihood of various levels of ground motions across the state.

Output ground motions for PGA (Figure 2); PGV; and $S_A$, $S_V$, and $S_D$ at periods of 0.3 and 1.0 seconds are provided on a census track basis. These maps include soil influence and thus represent motions at the ground surface.

The damage and loss estimate from the 500-yr model does not represent a single earthquake occurrence nor does it provide an uppermost estimate of losses. This is because the 500-yr map does not represent a single earthquake event. Also, smaller earthquakes that produce lower levels of ground shaking and are not represented on the probabilistic map are expected to occur and produce additional damage and loss not estimated in this study. Thus, if all expected earthquakes were included, the cumulative losses over the next 500 years would be higher than the estimated losses reported in this study.

### Discussion of method

From a user's standpoint, HAZUS97 is a powerful tool to assess earthquake losses. A user can obtain a sense of the order of magnitude of damage and loss for the items reported in Figures 3 and 4, such as casualties and building losses.

HAZUS97 has a number of limitations. A notable example of a limitation is that HAZUS97 evaluates most building losses on a census tract basis. However, many geologic hazards are not easily portrayed and represented by a single census tract value. Other geology-related limitation examples are, e.g., that user-supplied ground motion models are not able to incorporate user-specified soil maps and that certain specifics of fault ruptures, such as fault dip and oblique senses of motion, cannot be modeled.

One significant limitation is that the default inventory database is incomplete. Thus, the estimated losses are necessarily in error. For example, although there are numerous unreinforced masonry structures (URMs) in Oregon, the currently available default building database does not include any URMs. Thus, the reported damage and loss estimates may seriously underrepresent the actual threat. In studies that incorporate URMs in the inventory, the death and injuries toll is likely to increase significantly due to the nature of catastrophic failure of URMs.

Other examples of incomplete building inventory involve schools and emergency facilities. A simple case study for Klamath County shows the default inventory

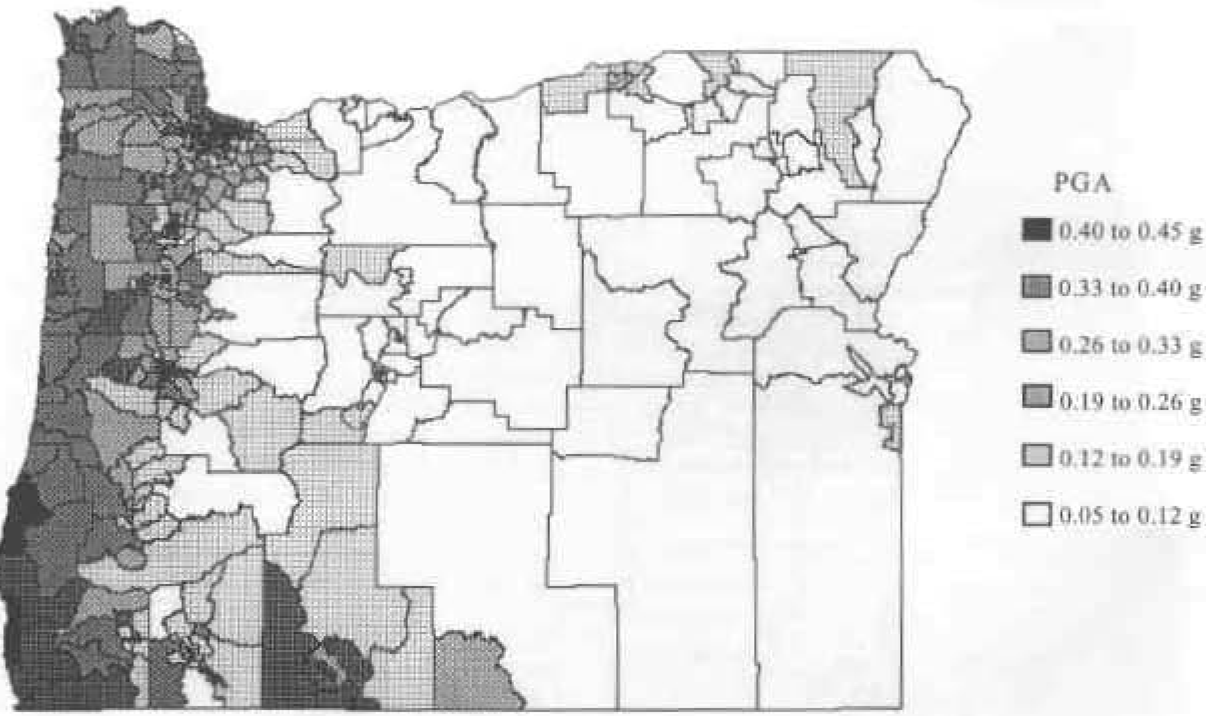



**Figure 2. Peak ground acceleration (PGA) for 500-yr return interval ground motions on census tract basis. Convention of yellow-to-red coloring for progression from least to most dangerous rendered here as light-to-dark shading.**

to have eight schools and five emergency facilities. The actual count is 34 schools and 35 emergency facilities (William Thompson, Klamath County Emergency Services, personal communication, 1998). For emergency facilities, a simple statewide assessment was made. The default database includes 438 emergency facilities, whereas the assessment shows 792. Thus, assuming the counts were approximated in a similar manner, the default database underestimated the emergency facility count by almost a factor of two. An underrepresentation of schools and emergency facilities could produce erroneously results, especially involving damage and functionality. The default lifeline inventory also appears to be seriously incomplete and requires user input to achieve a sense of damage and loss values.

HAZUS97 has several programming errors, which are being corrected in later versions. One example is obtaining a probability of 1 when summing the computed damage states for buildings by building type in the summary reports. Also, the summary reports, at times, failed to print the results from several counties. In addition, conducting successive runs without creating a new scenario is problematic in that previously calculated numbers are reported as the new calculations. A related problem seems to arise with the export function for individual study regions.

## RESULTS

The statewide results from the two modeled earthquakes, the M8.5 Cascadia earthquake (referred to below briefly as "the M8.5") and the probabilistic 500-yr return interval ground motions (referred to below briefly as "the 500-yr") are summarized in Figures 3 and 4, respectively. Estimates include social losses (deaths and injuries, displaced households, short-term shelter needs) (Figures 3a and 4a), monetary building losses (Figures 3b and 4b) and number of buildings damaged (Figures 3c and 4c). Also discussed below are the functionality of emergency facilities, schools, transportation systems (highway and airport economic loss and bridges damage state and functionality), and communication facilities; and the debris generated.

The method used generates estimated loss results for both the direct physical damage and the direct economic loss resulting from damage to the inventory in the study region. Damage and loss results are reported for each census tract and may be viewed as maps or tables produced by HAZUS97. Additional information from this study, such as summary tables on a county basis, ground motion maps, and other information that is not discussed in this text can be found in Wang (1998). Certain results from the 500-yr ground motion model are not provided here, because they are not appropriately applied to real-world conditions: they cannot be experienced in a single event. Thus, for example, the functionality of schools, emergency facilities, transportation systems, and the like is not reported for the probabilistic model.

### Social losses

Social losses including casualties, displaced households, and short-term shelter needs are reported below. The census data are used to help estimate these losses.

#### *Deaths and injuries*

Deaths and injuries are estimated at 7,700 and 24,600 for the M8.5 and 500-yr, respectively (Figures 3a and 4a). These values are divided into four severity levels: Severity 1 is described as "Injuries requiring only basic medical aid but no hospitalization"; severity 2 is described as "Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life-threatening status"; severity 3 is described as "Injuries that pose an immediate life-threatening condition if not treated adequately and expeditiously. The majority of these injuries are a result of structural collapse and subsequent collapse [trapping -*ed.*] or impairment of the occupants." Severity 4 is described as "Instantaneously killed or mortally injured."

For the M8.5, about 6,300 are estimated at severity 1; 1,200 at severity 2; 200 at severity 3, and 100 at severity 4. For the 500-yr, about 19,700 are estimated at severity 1; 3,800 at severity 2; 600 at severity 3; and 500 at severity 4.

For both models, estimated casualties are highest for a 2 p.m. earthquake. These casualties can be attributed mostly to damages of commercial and industrial buildings. The number of casualties varies depending upon time of day of the earthquake, building type, occupancy class, and traffic pattern. Casualties in residential buildings are higher at 2 a.m. and 5 p.m. earthquake events.

#### *Displaced households*

The displaced households are estimated at 17,300 and 47,400 for the M8.5 and 500-yr, respectively (Figures 3a and 4a).

#### *Short-term shelter needs*

The short-term shelter needs are estimated at 12,400 and 32,700 for the M8.5 and 500-yr, respectively (Figures 3a and 4a).

### Buildings

#### *Building damage*

States of structural and acceleration-sensitive and drift-sensitive nonstructural damage to the general building stock are generated for each occupancy class and for each building type according to five damage states: None, Slight, Moderate, Extensive, and Complete. Reported values include: (1) building damage by count by general occupancy, (2) building damage by general occupancy, and (3) building damage by building types for low seismic design level.

(1) *Building damage by count by occupancy class.* For the M8.5, the building damage by count of buildings is estimated at 717,000, 130,000, 75,000, 35,000, and 19,000 for damage states None, Slight, Moderate, Extensive, and Complete, respectively. From these damage state results, about 885,000 buildings are estimated to be green-tagged (i.e., the building has been inspected, and there are no restriction on use or occupancy), 55,000 are estimated to be yellow-tagged (i.e., off limits to unauthorized personnel), and 37,000 are estimated to be red-agged (i.e., unsafe, not to be entered or occupied) (Figure 3b).

For the 500-yr, the building damage by count of buildings is estimated at 425,000, 253,000, 182,000, 75,000, and 41,000 for damage states None, Slight, Moderate, Extensive, and Complete, respectively. From these results, about 769,000 buildings are estimated to be green-tagged, 129,000 are estimated to be yellow-tagged, and 79,000 are estimated to be red-tagged (Figure 4b).

(2) *Building damage by percent by occupancy class.* For the M8.5, building damage by general occupancy is estimated at 51, 11, 13, 9, and 5 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. For the 500-yr, building damage by general occupancy is estimated at 24, 13, 19, 18, and 16 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

(3) *Building damage by percent by building type.* For the M8.5, the building damage by building types assuming low seismic design levels for all buildings were estimated at 41, 10, 15, 12, and 7 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. For the 500-yr, the building damage by building types assuming low design levels for all buildings were estimated at 18, 10, 19, 20, and 19 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

*Direct economic losses to buildings*

The total direct economic losses to buildings are estimated at $11.8 and $31.6 billion for the M8.5 and 500-yr, respectively. These losses include both capital stock losses and income losses.

For the M8.5, capital stock losses are $2.03 billion for structural damage, $4.31 billion for nonstructural damage, $0.95 billion for contents, and $0.03 billion for inventory damage. Income losses are $1.21 billion for relocation, $1.35 billion for capital-related loss, $1.20 billion for wages, and $0.73 billion for rental income (Figure 3c).

For the 500-yr, capital stock losses are $5.05 billion for structural damage, $12.22 billion for nonstructural damage, $2.76 billion for contents, and $0.06 billion for inventory damage. Income losses are $3.04 billion for relocation, $3.76 billion for capital-related loss, $2.94 billion for wages, and $1.80 billion for rental income (Figure 4c).

**Essential facilities**

In HAZUS97, police stations, fire stations, and emergency operation centers are considered to be essential facilities. These are facilities that provide services to the community and should be functional after an earthquake.

The functionality of emergency facilities and schools is estimated for the day following the earthquake. For the M8.5, functionality of 65 percent for emergency facilities and 66 percent for schools is estimated. As mentioned above, because the 500-yr ground motions cannot be experienced in a single event, the functionality of essential facilities for the entire state is not reported.

**Transportation**

Transportation include highway, railway, light rail, bus, port, ferry, and airport systems. Selected results are provided for highways, including major and urban roadways and bridges; airports, which consists of control towers, runaways, terminal buildings, parking structures, fuel facilities, and maintenance and hangar facilities; and bridges.

*Direct economic loss for transportation*

For the M8.5, the direct economic loss is estimated at $0.37 billion for highways and $0.12 billion for airports. For the 500-yr, the direct economic loss is estimated at $1.26 billion for highways and $0.32 billion for airports.

*Damage states and functionality for bridges*

For the M8.5, the highway bridge damage is estimated at 67, 21, 9, 1, and 7 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively. The estimated functionality on the day of the earthquake is 72 percent. For the 500-yr, the highway bridge damage is estimated at 31, 32, 26, 4, and 6 percent for damage states None, Slight, Moderate, Extensive, and Complete, respectively.

**Utilities**

Utility systems include potable water, wastewater, oil, natural gas, electric power, and communication systems. Results are provided for the communication systems, which consist of broadcasting stations from the default inventory. For the M8.5, the estimated functionality for communication systems is 71 percent.

**Debris**

The total amount of debris generated is estimated for the M8.5 at 9.3 million tons and for the 500-yr at 23.3

*(Continued on page 131)*

Figure 3. Cascadia M 8.5 damage and loss estimates: (a) Social losses for individuals and households. (b) Number of buildings by damage tags: green tag = building has been inspected, no restrictions on use or occupancy; yellow tag = off limits to unauthorized personnel; red tag = unsafe, not to be entered or occupied. (c) Direct economic losses to buildings.

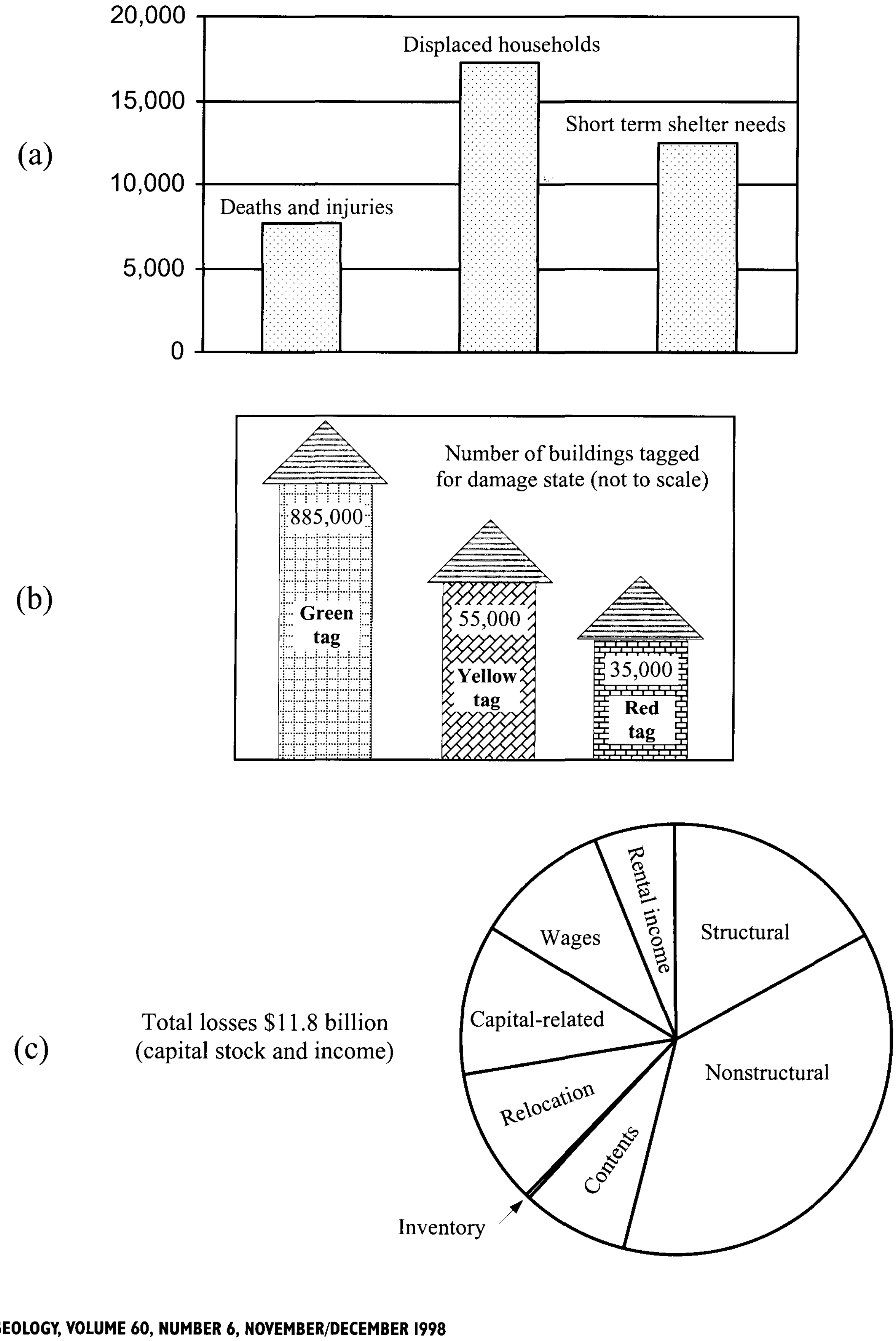
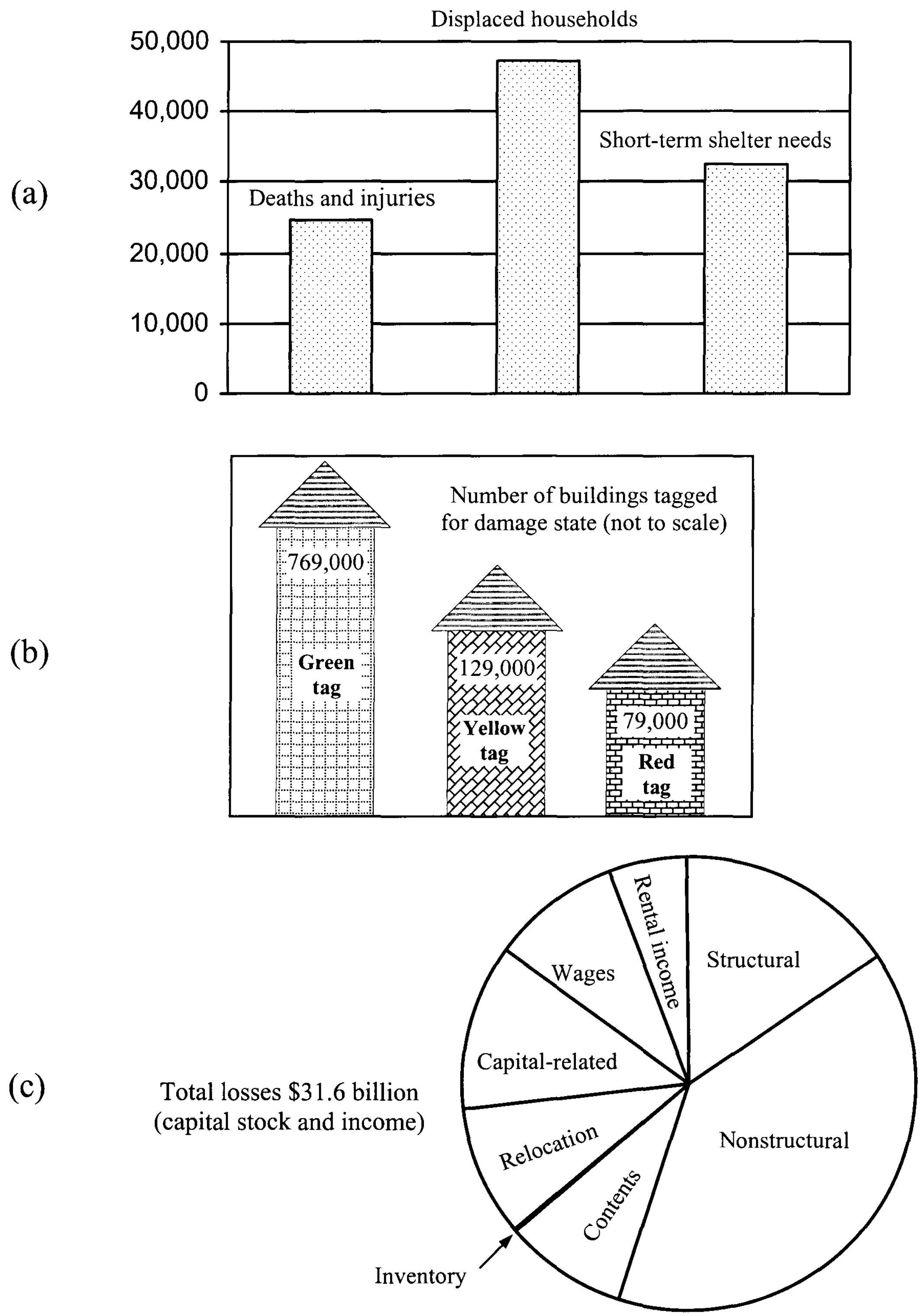


Figure 4. 500-year return interval damage and loss estimates: (a) Social losses for individuals and households. (b) Number of buildings by damage tags: green tag = building has been inspected, no restrictions on use or occupancy; yellow tag = off limits to unauthorized personnel; red tag = unsafe, not to be entered or occupied. (c) Direct economic losses to buildings.



*(Continued from page 128)*
million tons. The debris is categorized under two types: The first type of debris is easily movable with bulldozers and includes brick, wood, glass, building contents, and other materials. The second type of debris falls in large pieces, such as steel members or reinforced concrete elements.

### SUMMARY

The preliminary results from this study suggest that there is a serious risk in Oregon from both a M8.5 Cascadia event and 500-yr probabilistic ground motions. Studies of the M8.5 event indicate that over 10 billion dollars of building damage and about 7,000 casualties or more will be inflicted. The 500-yr ground motion studies indicate losses of more than 30 billion dollars, which is considerably higher than the M8.5 model. The 500-yr study produces higher losses because the modeled hazards span the entire state (i.e., offshore subduction zone and local inland earthquakes). Results from this study can be used to help increase earthquake awareness, stimulate mitigation and risk reduction action (e.g., strengthening facilities), support and set policies and legislation, and develop emergency response plans.

### FUTURE STUDIES

Future studies for Oregon may involve evaluating additional earthquake scenarios, specialized hazards (e.g., tsunami inundation, liquefaction, and slope stability), and expanded inventory data and focused study regions, such as counties. Inventory data may include unreinforced masonry structures, which are currently not included in the default database, or a more accurate inventory of schools or emergency facilities. Development of a more complete inventory would provide more accurate inventory damage and loss estimates.

### ACKNOWLEDGMENTS

Special thanks are extended to Stuart Nishenko of FEMA and Jawhar Bouabid of Risk Management Solutions, Inc., for their thoughtful reviews. My sincere appreciation goes to John D. Beaulieu of DOGAMI and William M. Elliott of the City of Portland for their support of this study. Thanks also to Klaus Neuendorf and Neva Beck for their assistance in producing this paper. Research was supported by State of Oregon funds.

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## Hells Canyon subject of new book

*Islands & Rapids. A geologic story of Hells Canyon,* is an exciting new book by retired U.S. Geological Survey geologist Tracy Vallier. It is published by Confluence Press, Lewis-Clark State College, Lewiston, Idaho.

Vallier's book tells the geologic history of the region but also serves as a field guide and entertains the reader with natural and human history and the author's own reminiscences. It has four maps and many photographs.

The book sells for $25 and can be purchased from the Nature of the Northwest Information Center. See back cover of this issue for ordering information. ☐

# Oregon Schools Seismic Safety Project

*by Eugene L. Trahern*[1], *P.E., Linda Lawrance Noson*[2], *and Dan E. Wermiel*[3]

## INTRODUCTION

The purpose of this project was to assist in the development of a statewide earthquake vulnerability analysis of Oregon schools and to use the results to prepare a mitigation planning methodology for use by school facilities personnel. Western Oregon has approximately 1,200 public schools in 173 districts. Historic earthquake activity, including recent damaging earthquakes in the Scotts Mills and Klamath Falls communities, and the results of earthquake studies by the Oregon Department of Geology and Mineral Industries (DOGAMI), the U.S. Geological Survey (USGS), and other scientists indicate that western Oregon is an area of high earthquake hazard. Schools located in western Oregon are potentially vulnerable to earthquake-induced damage and associated human and economic losses.

The Oregon School vulnerability project was to be carried out in three phases: (1) develop a general screening tool to assess school earthquake vulnerability, (2) complete data analysis and validate study data collected in the general survey using detailed studies of representative districts, and (3) develop a methodology to assist school facility planners in the management of school mitigation projects. This report focuses on the progress made in phase 1. The Oregon Emergency Management and the Federal Emergency Management Agency provided funding for the completion of phase 1. Phases 2 and 3 were not funded.

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[3] Geologist, Oregon Department of Geology and Mineral Industries

Figure 1. Earthquake damage at Molalla High School from the Scotts Mills ("Spring Break") earthquake, March 25, 1993.

## BACKGROUND

The extensive Oregon public awareness program on regional earthquake hazards and their potential impact on buildings, combined with the recent occurrence of several damaging Oregon earthquakes, have raised concerns about the potential vulnerability of Oregon school buildings to earthquake damage. The building standards used to design schools and other buildings in Oregon and other parts of the country have changed over time as new information on regional earthquake hazards and the response of buildings to earthquake shaking has been developed. Oregon schools built before 1991 used earthquake design standards below those required in Oregon today. Schools built before about 1952 were unlikely to have used any earthquake design measures. Figure 2 shows changes in the Uniform Building Code (UBC) seismic zone map from 1946-1998 (see Technical Note). A survey of school buildings was needed to identify the level and the distribution of vulnerability among Oregon Communities.

The screening tool to collect data to be used in the vulnerability assessment was developed as a means to manage costs. The Oregon Department of Education estimated that it would take $1.2 million dollars to collect data on school buildings if one were to use standard building inventory techniques. A less expensive approach to identify areas of particular concern was desired. The screening tool developed relies on local

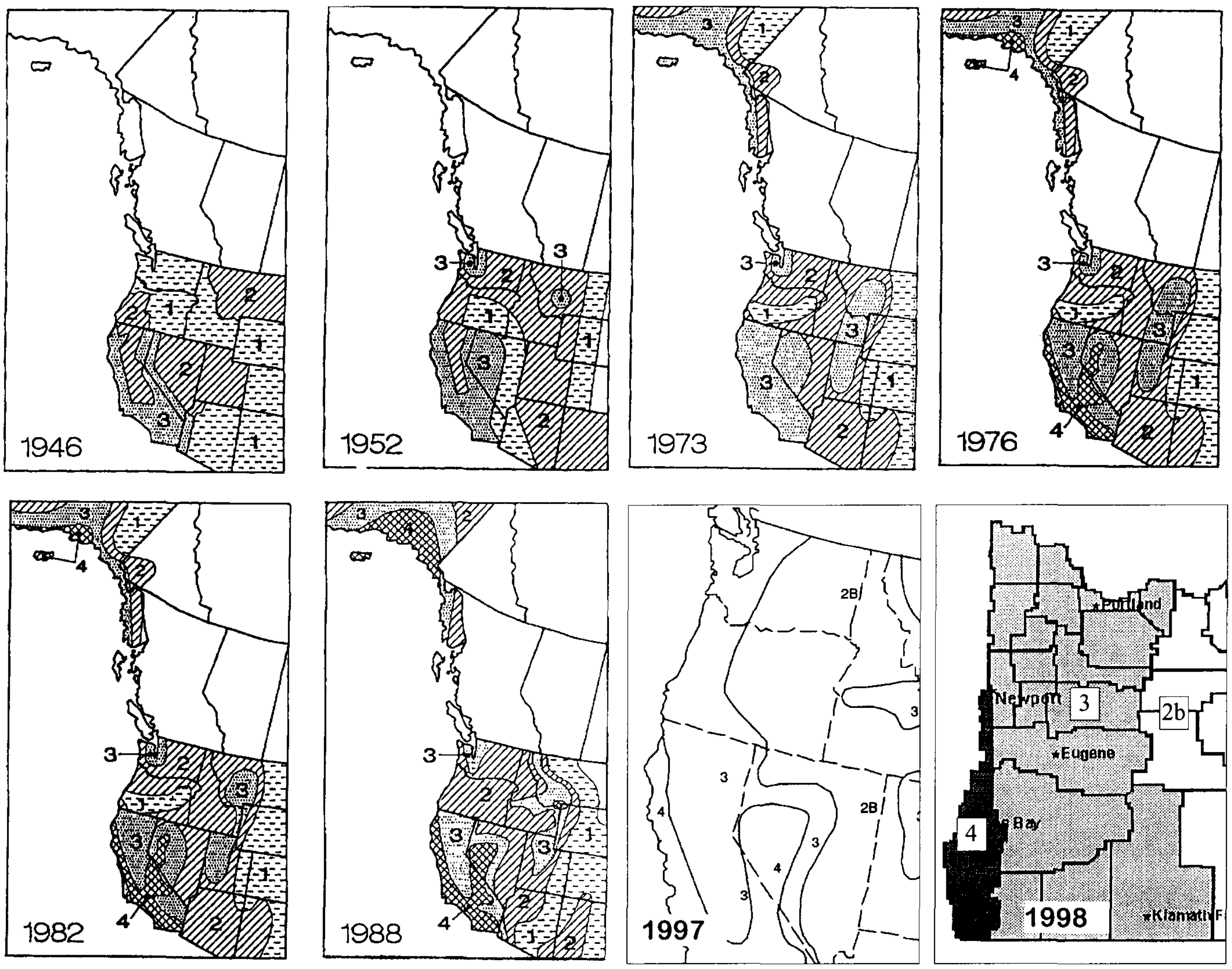


**Figure 2. Diagrams showing history of Uniform Building Code zoning for the West Coast. Partially modified from International Conference of Building Officials (1997) and earlier issues of that series, except for 1998 diagram, which shows the western portion of the seismic zone map of Oregon, taken from Structural Engineering Committee (1998), as adopted by the Oregon Building Codes Division, Department of Consumer and Business Services. All eastern counties not shown here are included in Seismic Zone 2b (white); most of western Oregon is assigned to Seismic Zone 3 (light shade); and "all that land which lies westerly of Range 10 West of the Willamette Meridian from the north line of Coos County to the northerly line of Township 10 South (just south of Otter Rock), and all of Coos and Curry Counties" are included in Seismic Zone 4 (dark shade).**

**Technical Note**

The Uniform Building Code (UBC) sets design standards adopted by most communities in the western United States. UBC earthquake design standards vary according to (1) the amount of ground shaking expected to occur in an area and (2) the distance of buildings to the fault or faults that may cause the shaking. The modern UBC defines five seismic zones based on these criteria, ranging from the highest level of ground shaking and nearest faults (Zone 4) to the lowest level (Zone 0). The Oregon State Building Code Agency assigned western Oregon to Seismic Zone 3 in 1991 as did the UBC in 1994.

district personnel to provide information to an initial survey questionnaire.

A "risk management" approach to the project was utilized to initially identify and analyze loss exposures. "Risk management" is defined herein to mean the process of making and implementing decisions that will minimize adverse effects of accidental and business losses on an organization. Terminology for risk managers differs depending upon the interested stakeholders, but generally for engineers, earth scientists, and other earthquake professionals, **hazard** refers to the earthquake itself and **risk** refers to the potential damages and losses caused by an earthquake and combines **hazard**, **vulnerability**, and **exposure**. **Vulnerability** refers to the degree of loss or damage to particular structures, or segments of society. **Exposure** refers to the items at risk (life, property, business interruption, etc.).

### Risk management approach to mitigation and preparedness

Seismic mitigation by structural engineers most commonly means strengthening or otherwise improving the building's response to earthquakes in order to obtain a better building performance. A broader risk management perspective would define mitigation as those actions taken to implement risk-control measures that will be completed before the earthquake occurs. This definition includes traditional strengthening projects (retrofit), new design standards, maintenance procedures to improve building conditions, real-estate purchasing criteria, and occupancy criteria to reduce exposure, e.g., using older buildings for storage rather than for classroom use.

Emergency preparedness actions to develop an effective and rapid response capability to be implemented when an emergency occurs, may also help reduce the severity of losses by limiting the amount of additional damage and injury that may occur after the earthquake or during aftershocks.

Mitigation and preparedness are complementary loss-reduction strategies that are a part of any comprehensive risk control program.

A problem facing the school districts is that of funding costly building upgrades or replacement structures. Any program developed to reduce earthquake risk should identify those strategies that provide the "biggest bang for the buck".

## STUDY METHODOLOGY

A seven-step process (Figure 3) is intended to screen out facilities of lower risk and direct funds to those in need. For individual buildings, a small number of buildings at an individual school site or for a small school district, step 2 is often undertaken to evaluate each building. With 1,200 public school buildings located throughout western Oregon, this task would be costly and time consuming. Thus, this project focused on the initial screening in step 1 (general questionnaire). The results of this step were to support the development of a methodology for school facilities personnel to use in preparing a seismic mitigation plan.

The Oregon Department of Education provided a directory of school facilities in Oregon. This information was used to develop a database of contact information for each school district located in seismic zone 3. Critical building information required to screen the vulnerability of school buildings and to develop an overall mitigation plan was not available from the state. Oregon school facility construction and funding is carried out at the school district level. Thus, the first task was to develop a survey questionnaire that could be filled out by facility personnel in each school district. The results of the survey would then be assembled in a database for prioritizing the school buildings.

### Questionnaire

The general questionnaire developed was a nine-page document used to collect information on the vulnerability of the building structures, the exposure or value at risk (occupancy, use, historical value), and the opportunity for potential upgrades. The following items give a general indication of the types of information requested:

- General school district information (name, city, enrollment, etc.).
- General school information (name, address, contact person, enrollment, etc.).
- Building vulnerability/construction (construction date, type of structural system, number of stories, size/square footage, shape, deterioration, upgrades, etc.).
- Site (settlement, slopes, landslides, soil conditions, etc.).
- Building documents (availability of drawings or previous studies).
- Historic registry or value.
- Mitigation opportunities (schedule for demolition, repair, reroofing, etc.).
- Environmental risks (natural gas, asbestos, chemicals, etc.).

| | |
|---|---|
| **STEP 1**<br>**Develop Seismic Mitigation Plan and Perform Initial Screening** | Agency facility managers complete their surveys<br>Set program goals and objectives<br>Define exemptions (filter exclusions)<br>Perform initial screening<br>Costs based on typical retrofit costs ($/sq. ft.) for building type<br>Highest evaluated buildings of Step 1 are sent to Step 2 |
| **STEP 2**<br>**General Structural Assessment** | Seismic Program Structural Engineer:<br>ATC-21 approach plus<br>Modify structural ranking<br>Completes plan review of existing drawing<br>Brief building field observation<br>Evaluates buildings<br>Costs based on typical costs for identified deficiencies<br>Highest evaluated Step 2 buildings are sent to Step 3 |
| **STEP 3**<br>**Detailed Structural Evaluation** | Population Consultant Structural Engineer:<br>Prepares structural analysis of selected buildings<br>Prepares evaluation report<br>Highest Step 3 buildings sent to Step 4<br>Costs based on engineer's analysis and identified deficiencies |
| **STEP 4**<br>**Cost Analysis (Cost)** | Consultant Structural Engineer prepares Schemes and Structural Estimate<br>Benefit-cost ratio (BCR) prepared for:<br>Part 1: Structural retrofit only (Structural BCR)<br>Part 2: Structural retrofit plus (Total BCR)<br>Fire and life safety<br>Asbestos and other hazards<br>Access<br>All of Step 4 buildings are sent to Step 5 |
| **STEP 5**<br>**Recommendation (Report)** | Final report<br>Recommendations made for projects to be included in budget |
| **FOLLOWING BUDGET APPROVAL:** | |
| **STEP 6**<br>**Detailed Design** | |
| **STEP 7**<br>**Implementation** | |

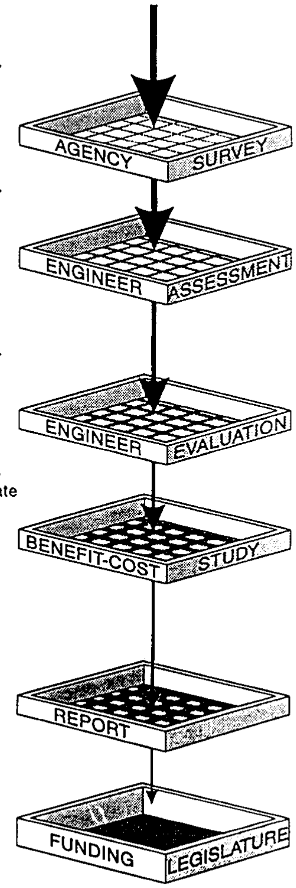


Figure 3. Summary description of seven-step procedure to assess school earthquake vulnerability and act on it.

- Past earthquake damage.
- Occupancy (occupancy, hours, etc.).
- Building function (school use, nonstudent use, plans for community shelter).
- Relocation (alternate sites).
- Comments on completing the survey.

The questionnaire was sent out to 173 school districts in western Oregon. Responses were received and logged for 93 districts (55-percent response). Data entry using Microsoft Access and preliminary data analysis was completed for approximately 20 percent of the districts surveyed. Late responses and the termination of funding for the project prevented the input and analysis of the remaining data.

### Screening/ranking methodology

Initial results for the completed questionnaires were screened using a methodology and ranking system previously developed for the City of Seattle buildings. The informal prioritization method shown in Figure 4 utilizes a weighted point-ranking system based on the structural risk (exposure, vulnerability, and hazards), function rank, opportunity, and historic value.

## PRELIMINARY RESULTS

Examples of the results are displayed graphically in Figures 5 and 6. As noted above, data entry was not completed for all of the responses received, data were not verified, and the informal prioritization method was not modified to account for items specific to the project such as benchmark years of local construction. However, preliminary results of the data can indicate some interesting trends.

## THE NEXT STEP AND BEYOND:

In order to complete the Step 1 initial screening and data collection, which will assist in developing the mitigation plan, several tasks should be completed as follows:

1. Complete Oregon school vulnerability study.
- Complete data entry (late responses), review building

*(Continued on page 137)*

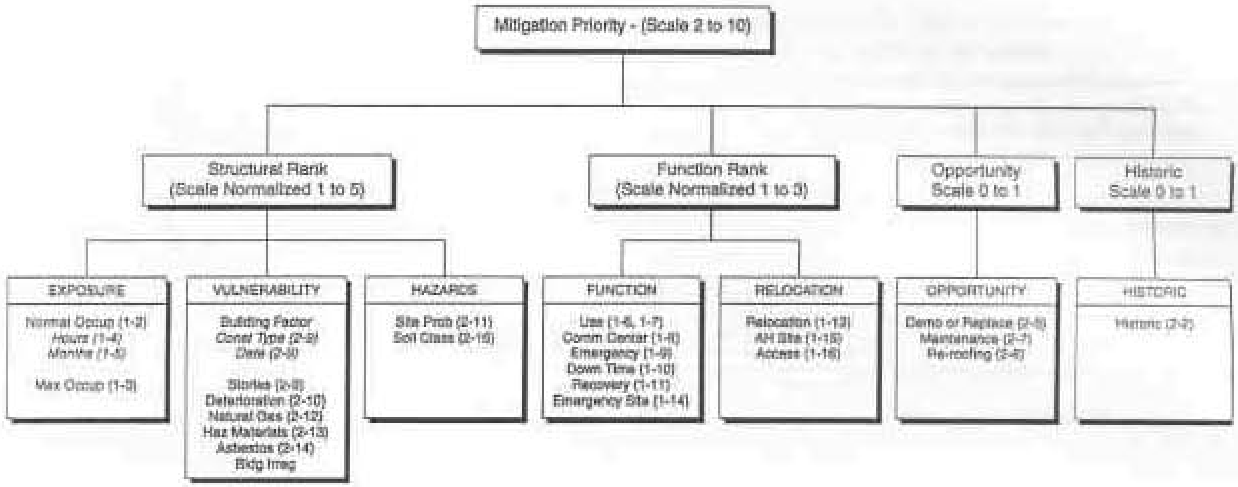


Figure 4. Schematic representation of Informal Prioritization Method developed for buildings of the City of Seattle

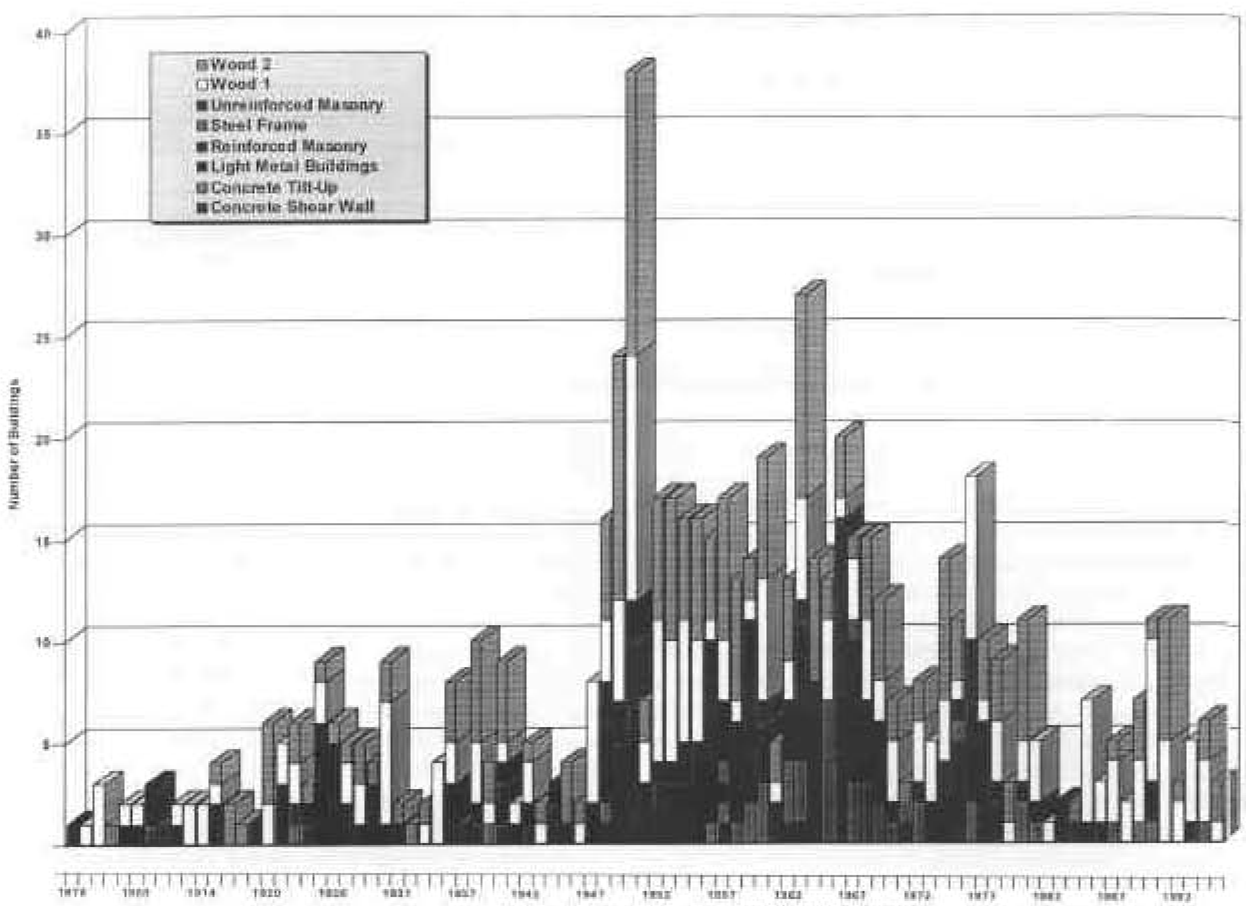


Figure 5. Number of surveyed Oregon schools by age, also indicating construction type.

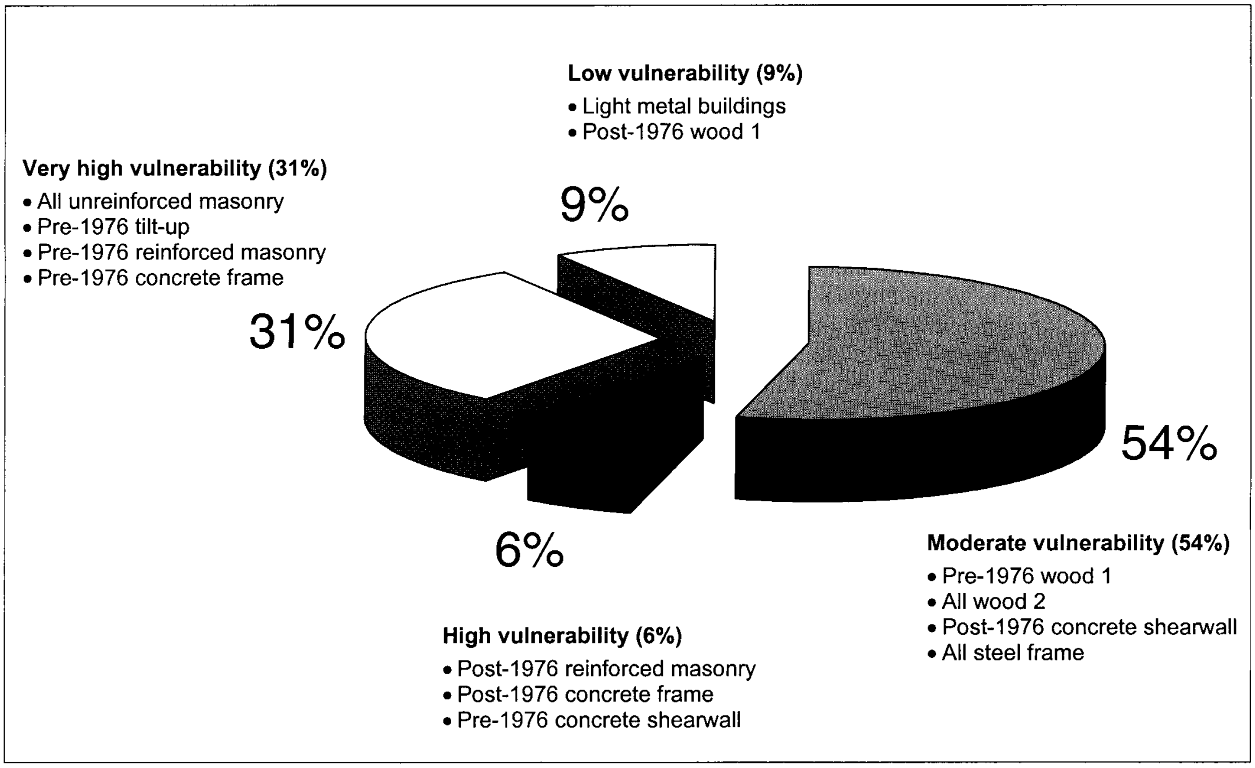


**Figure 6. Distribution of surveyed schools according to vulnerability category: very high, high, moderate, and low.**

*(Continued from page 135)*

surveys, confirm missing/confusing data, modify responses as needed (e.g., construction dates of 1996 and unreinforced masonry are not feasible).

- Establish weighted functions to sort collected data into mitigation priorities, including benchmark years showing dates when critical earthquake design requirements were adopted, buildings to be exempted from the program, etc.
- Complete database design.
- Complete Oregon school vulnerability study by sorting weighted database by selected mitigation parameters. Determine vulnerability groupings by schools and districts.
- Report findings.

2. Prepare risk-based mitigation methodology.

- Conduct field evaluations of four to five representative school districts to verify vulnerability study.
- Revise database and mitigation weighting functions as appropriate.
- Prepare mitigation planning methodology based on the results, including criteria, district qualifications and ranking procedures.

3. Develop and deliver mitigation planning workshops.

- Topics to include overall vulnerability of the Oregon schools, approaches for seismic screening and evaluation of school buildings, cost estimation, integrated school planning models, criteria for State mitigation program.

## SUMMARY

A general questionnaire was developed and completed to assist in the identification of earthquake exposures and the associated risk to western Oregon schools. Returned data were not complete nor were they standardized. However, several interesting trends can be concluded. In order to reduce the potential risk to the Oregon school system, a combination of mitigation and planning should be performed. Step 1 information can assist in prioritizing funding for both the mitigation and planning process. Proper evaluation of the needs of public schools in Oregon with respect to seismic design will require additional professional survey work with standardized procedures.

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International Conference of Building Officials, 1997, 1997 Uniform building code, v. 2, Structural engineering design provisions: International Conference of Building Officials, Figure 16–2, p. 2–37.

Structural Engineering Committee, 1998, Seismic zonation for the Oregon coast.: Final report submitted to the Building Codes Structures Board, February 12, 1998 (for Oregon Building Codes Division), p. 9. □

## Seismic risk reduction efforts in Tillamook honored by WSSPC

Tillamook County General Hospital (photo below) has received an "Award in Excellence" for new technology from the Western States Seismic Policy Council (WSSPC).

With the award, the multi-state Council recognized the successful efforts of the County to improve the structural safety of the hospital from the destructive effects of earthquakes. The goal was to strengthen the facility so that it would allow immediate occupancy after a 500-year return interval earthquake.

In the course of renovating and expanding the hospital facilities, fluid viscous dampers were installed in "dynamic" braces (example in photo on right) that will dissipate shaking energy. The improved elastic design exceeds the required standards of Seismic Zone 3. It actually satisfies Seismic Zone 4 standards, which are required only in areas along the southern Oregon coast.

The fluid damper technology itself is a century old. However, its use in Tillamook is the first time in history that it is applied to a "fixed-base" hospital, i.e., a hospital with a base not already specially designed to ride out earthquakes.

The use of this approach made construction of additional shear walls unnecessary and kept construction-related disturbance of the hospital to a minimum.

For a description of the project, see Craig Keller, 1998, "When in doubt, damp it out": Connections (a publication of the Structural Engineers Association of Oregon), April 1998, p. 5–6. □


## BOOK REVIEW

*by Gregory J. Retallack, Department of Geological Sciences, University of Oregon, Eugene, OR 97403: e-mail gregr@darkwing.uoregon.edu.*

**The Oligocene Bridge Creek flora of the John Day Formation, Oregon**, by Herbert W. Meyer and Steven R. Manchester. Berkeley, University of California Press, University of California Publications in the Geological Sciences 141, October 1997, 195 p., including 75 plates, $50.00.

The Bridge Creek flora is one of the most famous fossil assemblages in Oregon, and its investigation extends back into prehistory. Fossil leaves from one of the localities for this fossil flora (Iron Mountain) have been found in archaeological excavations of a Native American campsite dating back some 1,460 years (Ashwill, 1987; Aikens, 1993). Oregon's pioneer paleontologist, Thomas Condon, while a congregational missionary at The Dalles, first made collections for scientific study in 1865, from the main locality near Bridge Creek, currently in the Painted Hills Unit of the John Day Fossil Beds National Monument (Clark, 1989). He sent his specimens to authorities on the east coast, and they were illustrated in classical monographs of fossil floras of the western United States. These fossils have continued to attract collectors ever since, especially the popular site behind Wheeler County High School in Fossil, Oregon. Despite a number of signs around Fossil, the town is not known for dinosaurs, which are scarce in Oregon, but for these fossil leaves of early Oligocene age (33–32 Ma).

The best known of the Bridge Creek fossils is the dawn redwood (*Metasequoia*), which has been nominated (though not approved) as Oregon's state fossil. This distant relative of the coast (*Sequoia*) and giant redwoods (*Sequoiadendron*) of California was once abundant in Oregon, but has been extinct here since the late Miocene (5 Ma). *Metasequoia* fossils were known long before small populations were discovered still living in China. *Metasequoia* is now a popular ornamental plant. There is a splendid example planted beside Cascade Hall on the University of Oregon campus. It was grown from a seedling brought to Oregon by Ralph Chaney, the Berkeley paleobotanist, on the occasion of his visit for the Condon lecture in 1948. Although it has been widely assumed that he collected the seeds during his visit to China, he was unsuccessful in collecting seeds during his winter visit, and grew his seedlings from seed independently purchased from the Chinese by E.D. Merrill of Harvard's Arnold Arboretum. Our fine *Metasequoia* tree near Cascade Hall is appropriately enough under the gaze of a nearby bronze bust of Thomas Condon, who became a foundation professor of Natural Sciences at the University of Oregon in 1876.

The Bridge Creek flora has been described and featured in paleontological and paleoecological studies by a variety of authors since its nineteenth century discovery. At last Meyer and Manchester have assembled a coherent and well illustrated revision of this important fossil flora that should be of interest to paleontologists both professional and amateur, as well as to botanists, paleoclimatologists, and geologists. Picture-matching to identify fossils is made easy by an extensive selection of unretouched photographs on 75 plates. Also offered is an extensive listing of current identifications of specimens in previously published studies of the flora.

In the relentless give and take of taxonomic revision, some familiar old names have been changed. *"Celtis"* leaves for example are now referred to *Plafkeria*, and *"Tremophyllum"* to *Cedrelospermum*. The old and widely-used species name *Metasequoia occidentalis* has technical problems, and Meyer and Manchester recommend calling these common fossils just plain *Metasequoia* (species indeterminate). Meyer and Manchester now recognize 125 species in the flora, a higher diversity than previously suspected. Many of the additional genera are unfamiliar conifers such as *Calocedrus*, *Tetraclinis*, *Folkeniopsis*, and *Keteleeria*. There also are newly-recognized dicots of tropical affinities, such as *Parrotia* and *Fothergillia*.

The Bridge Creek flora has featured prominently in discussions of the mid-Tertiary climatic cooling, or "Paradise lost" in Don Prothero's (1994) memorable allusion. The early Oligocene Bridge Creek flora is the oldest known flora of temperate climatic affinities, following tropical floras of the Eocene. In discussing this climatic shift, Meyer and Manchester note that newly recognized diversity and taxa of tropical affinities undermine its reputation as a dicot flora of temperate climatic affinities, but not by much. The climatic affinities of the flora still reveal substantial cooling compared with the Eocene floras of the underlying Clarno Formation. Mean annual temperature during Oliocene time estimated from the various Bridge Creek floras was 8°–10°C, with likely winter frost. Little regard is given to other climatic parameters, such as seasonality and lowered precipitation, or to the rapidity of the climatic shift, all currently better revealed by fossil soils (Retallack and others, 1996). Such additional climatic parameters and likely paleoaltitudes can be revealed by fossil floras with appropriate computer-analysis (Wolfe and others, 1998). Clearly there is more to learn from the Bridge Creek flora, but Meyer and Manchester have set a high standard for the description of this important step in the evolution of modern North American vegetation.

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## DOGAMI PUBLICATIONS

### Released September 1, 1998

**Mist Gas Field Map, 1998 edition**, Open-File Report O–98–01, 1 map sheet, scale 1:24,000, 33 p. text, $6.

The map of the Mist Gas Field in Columbia and Clatsop Counties that has been published by the Oregon Department of Geology and Mineral Industries since 1981 has been updated over its 1997 edition and released as Open-File Report O–98–01. The release includes the map and a production summary for the years 1993 through 1997.

The annually updated *Mist Gas Field Map* shows the field divided into quarter sections. It displays location, status, and depth of all existing wells and serves as a basis for locating any new ones. It also shows the area and wells that are used for storage of natural gas. The production summary includes well names, revenue generated, pressures, production, and other data. The map and accompanying data are useful tools for administrators and planners, as well as explorers and producers of natural gas.

The *Mist Gas Field Map* is available both as the usual paper copy and, on request, in digital form (price $25). It is offered in three different CAD formats (.DGN, .DWG, and .DXF), all on one 3½-inch high-density diskette formatted for DOS, for use by different software systems. Using a digitized version allows customizing the map to suit individual needs.

A cumulative report of past production at the Mist Gas Field between 1979 and 1992 is available in a separate release under the title *Mist Gas Field Production Figures* as DOGAMI Open-File Report O–94–6 (price $5).

### Released October 9, 1998

**Geology and mineral resources map of the Rio Canyon quadrangle, Jackson County, Oregon**, by Frank R. Hladky. Geological Map Series GMS–108, scale 1:24,000, 12 p. text, $6.

The Rio Canyon quadrangle is dominated by Grizzly Peak, an ancient volcano that has been deeply eroded by the headwaters of Antelope Creek. The *Geology and Mineral Resources Map of the Rio Canyon Quadrangle, Jackson County, Oregon* and accompanying report reveal many newly discovered facets of the area's geology over about 50 million years of geologic history.

The earth is a dynamic system, and at a certain scale its surface literally changes from day to day. The changes can either add to the surface ***(deposits)*** or scour it down ***(erosion)***. Deposits are made, for instance, by events like volcanic eruptions leaving volcanic rocks behind or by streams overflowing their banks and leaving sedimentary flood deposits. Such events can be easily read in the geologic record of the Rio Canyon quadrangle.

In the map area, the oldest rocks are in the sedimentary Payne Cliffs Formation. Between about 37–50 million years ago, (we can't be more precise than that) a large braided river system carried material from the Siskiyou Mountains, depositing it during flood events. Toward the end of this period, some of the earliest Cascade Range volcanism began; it happened to start in or near the Rio Canyon quadrangle. This volcanism continued for 8 million years.

When the early Cascade volcanic activity stopped, it was followed by 20 million years of uplift and ***erosion***. During this period, the ground rose just as slowly as streams were able to erode rock. The net result was that for most of this 20 million year period, there aren't any deposits of rock to tell the story.

Besides volcanism and uplift, adjacent Bear Creek valley has been greatly influenced by massive landslides shown on the new map. Although we do not have precise dates, these slides are geologically recent (within a couple of million years) and may have been triggered by earthquakes, either from the offshore Cascadia subduction zone or from crustal earthquakes like those felt in Klamath Falls in 1993.

An important application of geologic mapping is to better understand groundwater resources. In the Rio Canyon quadrangle, the production of wells depends on the degree of fracturing and hardness of the rocks. Highly fractured, rigid rocks (as in many volcanic areas) tend to produce larger quantities of water than softer rocks. In areas underlain by the soft sediments of the Payne Cliff Formation, well production is often less than in the volcanic rocks.

Chemical analyses of the groundwater show that

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high levels of arsenic are found in wells in sedimentary strata east of Bear Creek valley. This report ties high levels of arsenic, mercury and base metals (copper, zinc, and lead) to silicic tuffs at nearby Shale City, just east of the map.

Mapping of mineral resources is another reason for geologic mapping. It appears the only mineral occurring in economic quantities in the area is crushed rock. Other resources have been prospected but not developed.

## Emergency plan and drills prepare ODOT for "the real thing"

District 4 gets the call just after noon. Benton County has declared an emergency. An 8.5 earthquake has jolted the Corvallis area, and the damage is extensive. A major landslide on Highway 20 has traffic blocked—emergency responders can't get through. ODOT [Oregon Department of Transportation] crews are quickly dispatched to the scene. Kevin Bryan, District 4 incident response coordinator, immediately heads for the county's Emergency Operations Center where he will monitor ODOT's response efforts throughout the disaster. More reports come in. A derailed train spills diesel fuel into the Mary's River—the Harrison Street Bridge has collapsed—there's another landslide. Suddenly, a 7.1 aftershock rocks the area. And the calls keep coming.

Luckily, this earthquake was only a drill. Recently, ODOT, along with a host of other response agencies, schools and businesses participated in a five-hour emergency exercise staged by Benton County. The drill provided valuable training for ODOT, Bryan reported.

"We tested our equipment, our response time, and, most importantly, our thinking," he said. "During real emergencies, we need to react quickly—drills like this help us prioritize our actions."

According to ODOT Emergency Response Planner Rose Gentry, ODOT will increasingly participate in multiagency drills statewide, so crews can hone and test their emergency response skills. Gentry chairs ODOT's 10-member Emergency Preparedness Committee, made up of employees appointed by the Maintenance Leadership Team. Committee members, who meet monthly in Redmond, have just completed a rigorous internal and external review of its draft operations plan.

"Once Director Crunican approves the plan, we will then distribute copies throughout ODOT and to state and county agencies—probably in October," said Gentry.

ODOT's emergency preparedness training will begin statewide early next year, and when it's completed, the agency will accelerate its participation in external emergency drills.

"Our goal is to continually practice our skills so we are prepared for any emergency," said Gentry. "We want to make good use of our operations plan, not just store it on a shelf." (Written by Jayne Stewart, strategic communications coordinator, 503/986-4329.)

—From *Transcript* (ODOT newsletter), v. 6, no. 10 (October 1998), p.5. ☐

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