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REPORTS ON
EARTHQUAKE SWARM AT MOUNT HOOD
AND
EARTHQUAKE DAMAGE TO LIFELINES IN COLOMBIA

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Cover photo

The Palisades, a prominent cliff in the Clarno Unit of the John Day Fossil Beds National Monument, formed by the erosion of massive debris-flow deposits. Article beginning on next page describes the geology of this region. Photo courtesy of Erick A. Bestland.

Mount Hood earthquake swarm of January 1999

During the month of January, Mount Hood experienced an earthquake swarm similar to past events. This swarm produced 81 recorded events, including 4 events between magnitude 3.0 and 3.2. Events were felt at Timberline, Brightwood, Parkdale, and Mount Hood Meadows. The majority of events (41) occurred on Monday, January 11, followed by 9 events on January 12, 1 event on January 13, 18 events on January 14, and 12 events on January 15. The earthquakes were focused approximately 6 km to the south-southeast of the summit of Mount Hood, with hypocenter depths ranging from 1.1 to 9.4 km below the surface. In the last decade, 15 other similar swarms have been located in approximately the same area, and the largest recorded earthquake was a magnitude 4.0 event in December 1974.

The location and concentration of earthquake swarms in this specific area is believed to indicate a northwest-trending fault that is in line with the overall regional tectonic stresses. Fault plane analysis of the largest event (magnitude 3.2 on January 11) indicates normal faulting.

Mount Hood is considered an active volcano with the potential for damaging earthquakes, eruptions, dome collapses, pyroclastic flows, lahars, debris flows, and jökulhlaups (glacial outburst floods). Current activity includes earthquake swarms and small fumaroles in the Crater Rock area. The last eruptive phase was the Old Maid Flat event occurring between 200 and 300 years ago, although individual reports in 1859, 1865, and 1907 mention small localized ash, pumice, and steam events. The valleys of the Hood and Sandy Rivers are built largely on eruptive and debris material from Mount Hood.

Recent swarm earthquakes with magnitude ≥2.5

Date	Time	Lat (N)	Long (W)	Depth (mi)	Magnitude	Location quality	Distance SSE of Mount Hood (km)
99/01/11	13:48:46	45.31	121.65	7.5	2.5	CB	6.5
99/01/11	16:54:11	45.31	121.65	7.2	3.0	CB	6.5
99/01/11	22:04:14	45.31	121.65	6.8	3.2	BB	7.0
99/01/14	11:56:47	45.31	121.66	7.6	3.2	CB	5.4
99/01/14	16:13:42	45.31	121.65	5.9	3.0	BB	6.2

For more information, visit the websites of the U.S. Geological Survey Cascades Volcano Observatory: http://vulcan.wr.usgs.gov/Volcanoes/Hood/framework.html; and the University of Washington Geophysics Program: http://www.geophys.washington.edu/SEIS/PNSN/HOOD/

Geologic framework of the Clarno Unit, John Day Fossil Beds National Monument, central Oregon

by E.A. Bestland[1], P.E. Hammond[2], D.L.S. Blackwell[1], M.A. Kays[1], G.J. Retallack[1], and J. Stimac[1]

ABSTRACT

Two major geologic events are recorded in the Eocene-Oligocene volcaniclastic strata, volcanic flows, and paleosols of the Clarno Unit of the John Day Fossil Beds National Monument. A major plate-tectonic reorganization in the Pacific Northwest at about 40–42 Ma shifted volcanism from the Clarno volcanic province, represented by Clarno Formation andesitic flows and debris flows, to the Cascade arc, represented by John Day Formation tuffaceous deposits and ash-flow tuffs. Evidence of the second major geologic event comes from paleosols and fossil remains of plants and animals in these two formations and indicates a global paleoclimate change centered around the 34-Ma Eocene-Oligocene boundary, when the earth changed from a tropical Eocene "hothouse" to a temperate Oligocene "icehouse."

In the Clarno Unit area, the lower part of the Clarno Formation consists of structurally domed debris-flow conglomerates, andesite flows (51.2 ± 0.5 Ma), and a dacite dome (53.5 ± 0.3 Ma), both onlapped by less deformed debris-flow conglomerates, andesite flows (43.4 ± 0.4 Ma), and red beds. The onlapping conglomerates are composed of two widespread units that are dominated by debris flows, are separated by red claystones (paleosols), and are each approximately 60 m thick. The lower unit, conglomerate of The Palisades, consists of channel and floodplain debris-flow conglomerates and lahar runout deposits. The overlying conglomerates of Hancock Canyon also contain channel and floodplain debris-flow conglomerates but have, in addition, fluvially reworked conglomerates, reworked tuff beds, a distinctive amygdaloidal basalt flow (43.8 ± 0.5 Ma), and the fossil site known as the "Nut Beds." Both units accumulated on volcanic aprons in response to volcanism (synvolcanic sedimentation) in an area of irregular topography, including hills of a preexisting dacite dome.

Above the conglomerates are thick but discontinuous red claystones (claystone of Red Hill), which record a long period of volcanic quiescence (2–4 m.y.), slow floodplain aggradation, and long periods of soil formation. The Red Hill paleosols and fossil plants from the Nut Beds, which directly underlie the red beds, are evidence of a climate that was subtropical and humid. Disconformably overlying the red beds are gray-brown siltstones and conglomerates of the Hancock Mammal Quarry, which have yielded a titanothere-dominated fossil fauna (Duchesnean North American Land Mammal Age).

The Clarno Formation is overlain abruptly by an ash-flow tuff of the basal John Day Formation (39.2 ± 0.03 Ma). A major lithologic boundary occurs in the lower John Day Formation between kaolinite- and iron-rich claystones (paleosols) of the lower Big Basin Member (upper Eocene) and smectite and tuffaceous claystones of the middle Big Basin Member (lower Oligocene). An age determination of 38.2 ± 0.07 Ma on a tuff in the lower Big Basin Member and a 33.6 ± 0.19 Ma age determination for the Slanting Leaf Beds in the middle Big Basin Member support the interpretation that the contact between these two members is close to the Eocene-Oligocene boundary. These fossil leaf beds are thus earliest Oligocene in age, similar in age to the type locality of the Bridge Creek flora in the Painted Hills area.

INTRODUCTION

The scenic high desert of north-central Oregon contains a colorful volcanic and alluvial sequence of Tertiary age (Figure 1). For the protection and appreciation of the geologic and paleontologic resources in this area, three "Units" (Sheep Rock, Clarno, and Painted Hills) were established in the John Day Fossil Beds National Monument. The strata exposed in the National Monument record two important geologic events: (1) The change from Eocene Clarno arc volcanism, represented by the Clarno Formation, to late Eocene Cascade arc volcanism and John Day Formation back-arc deposition is recorded in these two formations. (2) A dramatic paleoclimatic change occurred across the Eocene-Oligocene transition during which conditions changed in central Oregon from subtropical humid to semiarid temperate climate. The magnitude and timing of these paleoclimatic changes as well as the stratigraphic positions and ages of fossil sites have been worked out from detailed mapping and section-measuring in the Clarno Unit area of paleosols (ancient soils), fossiliferous beds, and radiometrically dated tuff beds. This mapping has also revealed a domal volcanic edifice of Clarno age that was emplaced early in the accumulation of the formation and was subsequently onlapped by volcaniclastic deposits.

The purpose of this paper is to provide a geologic and paleoenvironmental summary of the Clarno and lower John Day Formations in the Clarno Unit area of the John Day Fossil Beds National Monument. This

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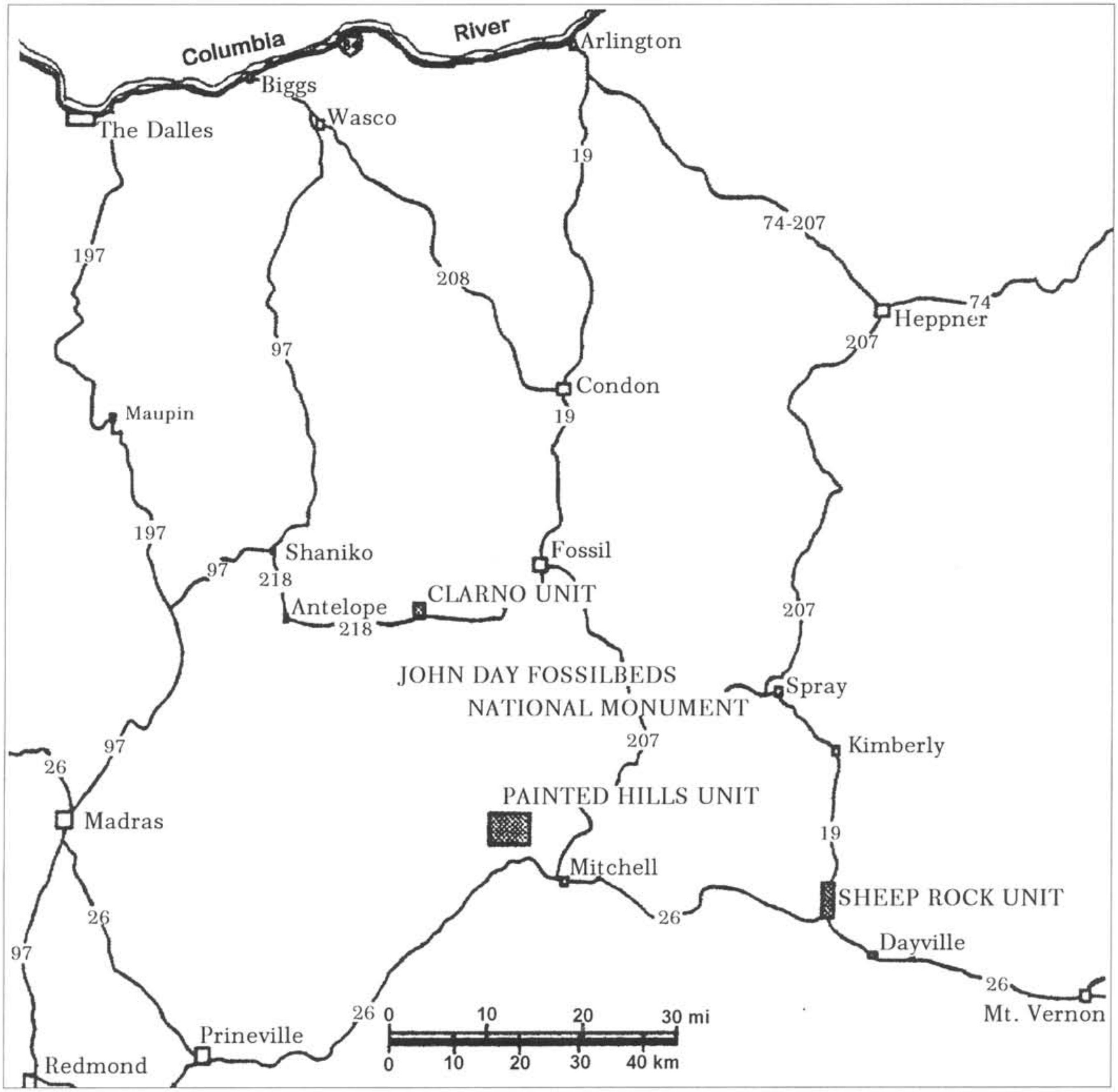

Figure 1. Location map of north-central Oregon showing units of the John Day Fossil Beds National Monument and major access roads.

paper represents a synthesis of the combined efforts of three different groups that have worked extensively in the Clarno area. A three-year study by Bestland and Retallack for the National Park Service generated an extensive and detailed data base of mapping, volcanic and paleosol stratigraphy, new $^{40}Ar/^{39}Ar$ age determinations, and discovery of new fossil sites (Bestland and Retallack, 1994a). The University of Oregon Field Camp has been mapping in this area since 1985 and is developing a regional map of the Clarno and John Day Formations along the north side of the Blue Mountains uplift. Portland State University Geologic Field Methods students and staff have been mapping in this area since 1988 and have concentrated on detailed lithostratigraphic mapping of the National Monument.

The informal stratigraphic subdivisions of the Clarno and John Day Formations presented here are based on rock type and stratigraphic position (Figures 2 and 3). New stratigraphic units identified are all informal in accordance with rules about such units in the North American Commission on Stratigraphic Nomenclature (1983). The new subdivisions will be denoted by lower case such as "lower Big Basin Member."

GEOLOGIC SETTING

Clarno Formation

The Clarno Formation is a thick section (up to 6,000 ft [1,800 m]) of largely andesitic volcanic and volcaniclastic rocks of Eocene age that crops out over a large area of north-central Oregon. The formation was named by Merriam (1901a,b) for exposures of volcanic rocks at Clarno's Ferry, now a bridge over the John Day River west of the National Monument boundary. The Clarno Formation disconformably overlies pre-Tertiary rocks that include highly deformed metasediments of Permian to Triassic age (Hotz and others, 1977), Cretaceous marine rocks in the Mitchell area and sedimentary rocks of uncertain age mapped as Cretaceous sedimentary rocks by Swanson (1969) and interpreted as Paleocene or Eocene sedimentary equivalents of the Herren Formation (Wareham, 1986; Fisk and Fritts, 1987). The formation is overlain for the most part by the John Day Formation. Where the formation formed ancient volcanic highlands, younger rock units such as the Miocene Columbia River Basalt Group, Miocene Mascall Formation, Miocene-Pliocene Rattlesnake Formation, and Miocene-Pliocene Deschutes Formation, disconformably overlie the Clarno Formation.

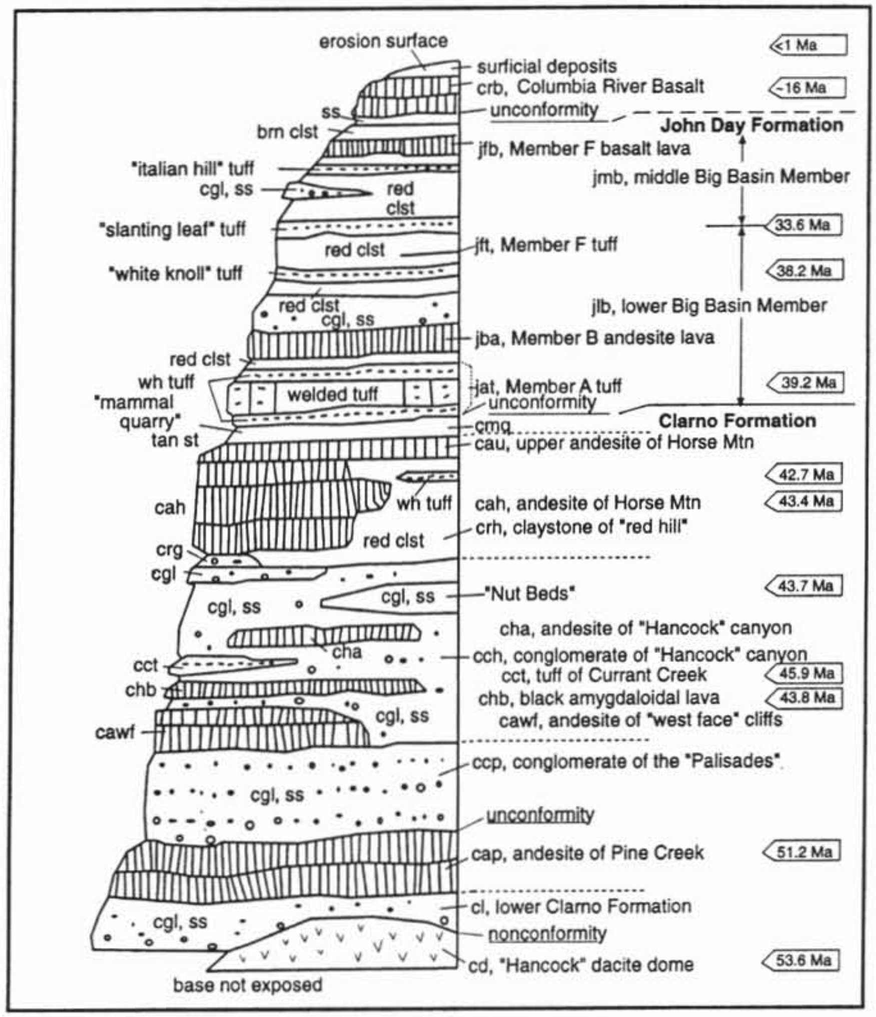

Figure 2. Composite stratigraphic section of the upper Clarno and lower John Day Formations in the Clarno Unit of the John Day Fossil Beds National Monument. Diagram shows informally recognized stratigraphic units and corresponding age determinations. For explanation of symbols to units, see geologic map of Figure 3. Additional symbols are: brn (brown); cgl (conglomerate); clst (claystone); ss (sandstone); st (siltstone); and wh (white).

The Clarno Formation consists of nonmarine volcanic and volcaniclastic units that range in age from middle to late Eocene, some 54 to 39 m.y. old (Evernden and James, 1964; Evernden and others, 1964; McKee, 1970; Enlows and Parker, 1972; Rogers and Novitsky-Evans, 1977; Manchester, 1981, 1990, 1994; Fiebelkorn and others, 1982; Vance, 1988; Walker and Robinson, 1990; Bestland and others, 1997). Volcanic plugs, lava flows, and lahars, with convergent-margin andesitic compositions and textures, indicate accumulation in and around andesitic volcanic cones (Waters and others, 1951; Taylor, 1960; Noblett, 1981; Suayah and Rogers, 1991; White and Robinson, 1992; Bestland and others, 1995). The calc-alkaline volcanic rocks represent subduction-related andesitic volcanism, probably on thin continental crust (Rogers and Novitsky-Evans, 1977; Rogers and Ragland, 1980; Noblett, 1981; Suayah and Rogers, 1991). White and Robinson (1992) evaluated the sedimentology of the volcaniclastic deposits on a regional scale and interpreted the strata as nonmarine volcanogenic deposits that were deposited in alluvial aprons and braidplains that flanked active volcanoes.

John Day Formation

The John Day Formation consists of rhyolitic ash-flow tuff and dacitic to rhyodacitic tuffs and alluvial deposits of latest Eocene, Oligocene, and early Miocene (39–18 m.y.) age (Woodburne and Robinson, 1977; Robinson and others, 1990; Bestland, 1997; Bestland and others, 1997). Robinson and others (1984) interpret these primary pyroclastic, alluvial and lacustrine deposits as the distal deposits from vents to the west in the Western Cascades and from more proximal vents now buried or partially buried by the High Cascade volcanic cover.

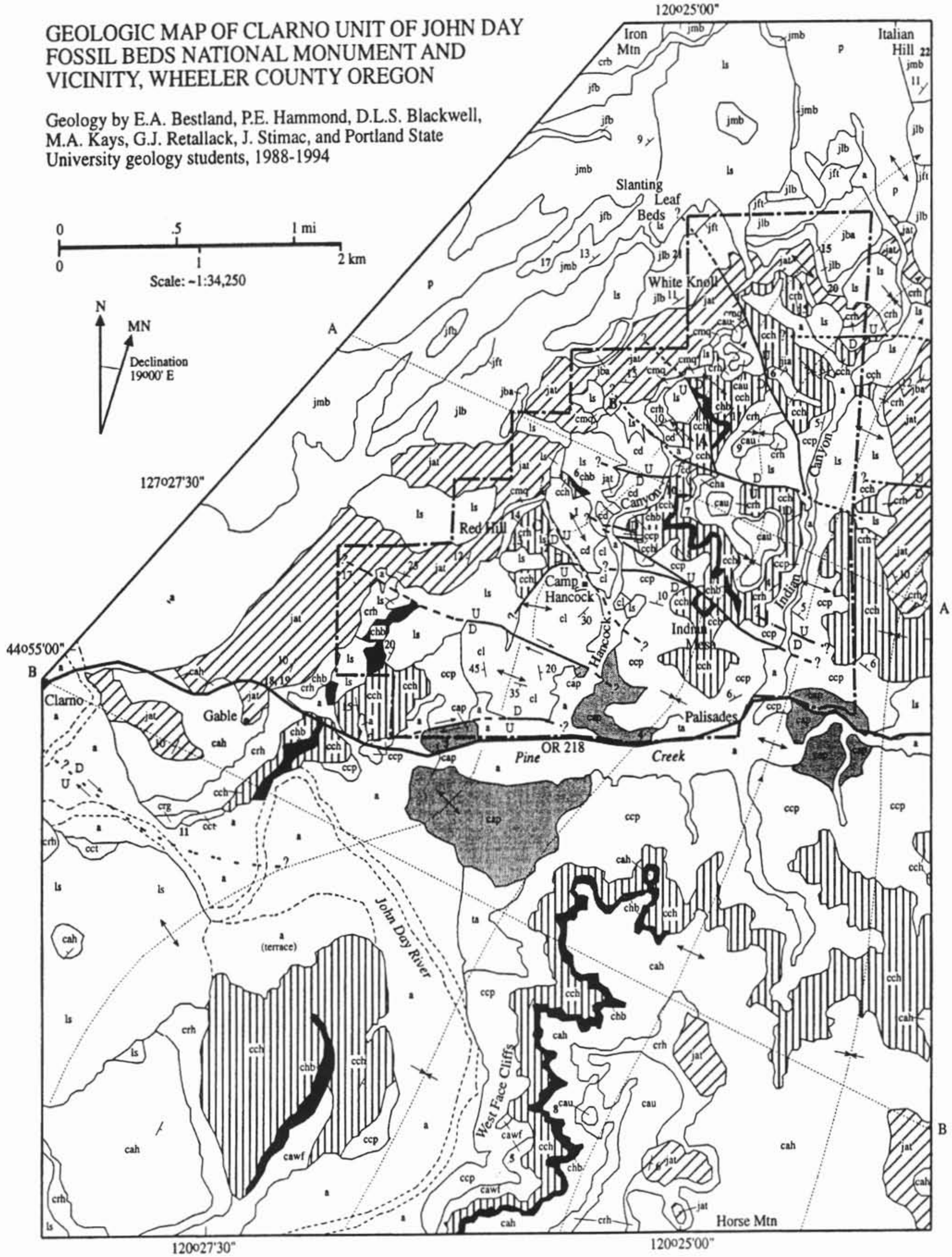

Figure 3. Informal geologic map of the Clarno Unit of the John Day Fossil Beds National Monument and vicinity (modified from Bestland and Retallack, 1994a; unpublished mapping by P.E. Hammond and Portland State University students; and unpublished mapping by M.A. Kays, D.L.S. Blackwell, J. Stimac, and E.A. Bestland).

EXPLANATION

Rock units are symbolized here and on the map without the usual period designation: in this case, "Q" for some Quaternary surficial units and "T" for all other, Tertiary, units.

Surficial deposits

a	Alluvium
ls	Landslide
ta	Talus
p	Pediment

Bedrock units

crb	Columbia River Basalt Group
	John Day Formation
jmb	Middle and upper Big Basin members
jfb	Member F basalts
jlb	Lower Big Basin Member claystones
jft	White tuff of member F
jba	Member B basaltic andesite
jat	Welded tuff of member A
	Clarno Formation
cmq	Siltstone of Hancock Mammal Quarry
cah	Andesite of Horse Mountain
cau	Upper andesite of Horse Mountain
crh	Claystone of Red Hill
cha	Andesite of Hancock Canyon
crg	Conglomerate
cct	Tuff of Currant Creek
chb	Basalt of Hancock Canyon
cch	Conglomerate of Hancock Canyon
cawf	Andesite of West Face Cliffs
ccp	Conglomerate of The Palisades
cap	Andesite of Pine Creek
cl	Lower Clarno Formation
cd	Hancock dacite dome

Contact

Indefinite contact

45 Strike and dip of bedding

U D Fault, showing displacement; U=upthrown side, D=downthrown side

Indefinite fault

Fold axis, showing plunge

Anticline

Syncline

Thus, the transition between the Clarno and John Day Formations records a late Eocene westward jump of the subduction zone in the Pacific Northwest and a corresponding change from Clarno andesitic volcanism to Cascade volcanism and John Day back-arc basin deposition.

The John Day Formation is divided into eastern, western, and southern facies on the basis of geography and lithology (Woodburne and Robinson, 1977; Robinson and others, 1984). The Blue Mountains uplift separates the western and eastern facies; it also restricted deposition of much of the coarser grained pyroclastic material to the western facies.

The western facies is informally divided into members A through I on the basis of laterally extensive ash-flow tuffs sheets (Peck, 1964; Swanson and Robinson, 1968; Swanson, 1969). This facies contains coarse-grained volcaniclastic deposits, welded ash-flow tuff sheets, and a variety of lava flow units, including trachyandesite flows of member B, rhyolite flows of member C, and alkaline basalts of member F. The Clarno Unit area is in the western facies, where the John Day Formation has been mapped in reconnaissance style by Robinson (1975), who used the stratigraphic divisions of members A through I.

The eastern facies is divided into four formal members (Fisher and Rensberger 1972). From bottom to top they are Big Basin Member (red claystones), Turtle Cove Member (green and buff tuffaceous claystones), Kimberly Member (massive tuff beds), and Haystack Valley Member (tuffaceous conglomerates). We report stratigraphic subdivisions of the John Day Formation in the Clarno Unit area following both the A-through-I system of Peck (1964) and the identification of formal members of the eastern facies by Fisher and Rensberger (1972) as modified by Retallack and others (1996) and Bestland and others (1997).

Physiography

In the John Day River canyonlands of north-central Oregon, each of the three major geologic divisions has a distinctive geomorphic expression (Figure 4): (1) Resistant andesite and debris-flow units of the Clarno Formation form dissected hilly canyonlands that are largely covered by thin soils. (2) The much finer grained and less volcanically dominated John Day Formation forms broad benches that are commonly covered by coarse colluvium and landslide debris originating from resistant units upslope. (3) Capping many of the canyons and forming impressive cliffs are the resistant rocks of the Columbia River Basalt Group. Another prominent feature of this area is the thick and resistant welded tuff of member A of the basal John Day Formation, which forms a cuesta that can be traced throughout the area. The John Day Formation above this marker bed can be divided into a lower and upper part on the basis of geomorphic expression. The lower part consists of clayey and kaolinite-rich strata of the lower Big Basin Member, which weather to form a gently-sloping bench covered with

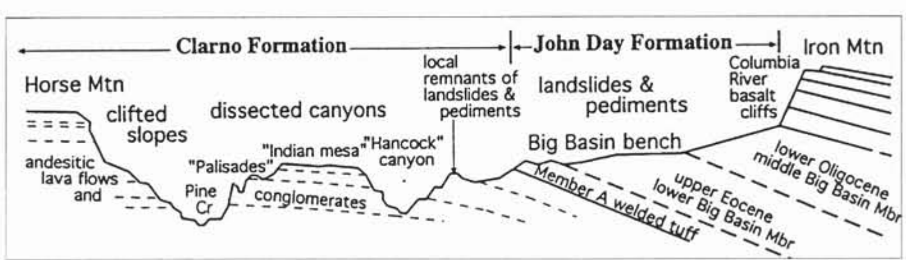

Figure 4. Sketch cross section of the Clarno area, illustrating the physiographic differences between the dissected canyons of the Clarno Formation, the broad, gently sloping benches of the lower John Day Formation, and the prominent cliffs of the Columbia River Basalt Group.

thick clayey soil. The Oligocene part of the John Day Formation contains tuffaceous strata rich in smectite clay that weather into steep badlands and sloping hills.

The erosional history of the area to its present-day topography began in the late Miocene after cessation of Columbia River Basalt Group volcanism and deposition of the mid-Miocene Mascall Formation. A major tectonic break occurred in north-central Oregon between the Mascall Formation, dominated by fine-grained alluvium, and the disconformably overlying late Miocene Rattlesnake Formation, dominated by fanglomerates of basaltic composition. Thus, faulting and uplift of central Oregon must have begun sometime in the late Miocene.

In the Clarno area, landslides consisting of large and seemingly coherent blocks of basalt from the John Day Formation and Columbia River Basalt Group have slid over clayey soils, confusing some of the distribution of basalt units (see map by Robinson, 1975). Pediment surfaces and colluvial soils dominated by basaltic fragments veneer much of the landscape. Small alluvial fans and dissected fanglomerate deposits of Quaternary age are common occurrences proximal to small canyons draining steep terrain of the Columbia River Basalt Group. Most of these Quaternary deposits overlie the John Day Formation. The fanglomerates contain caliche-cemented paleosol horizons.

Structure

Strata of the Clarno and John Day Formations and overlying flows of the Columbia River Basalt Group are gently to moderately folded, forming broad, open, generally northeast-plunging folds (Figure 3). This orientation is parallel to the elongation of the Blue Mountains in northeastern Oregon. Faults, on the other hand, strike west to northwest, generally in a direction normal to fold axes. They commonly show right-lateral strike-slip movement with displacements less than a few hundred meters. Deformation was caused by a northwestward-directed compressive (shear) stress which folded the strata and moved fault-bounded southern Clarno blocks westward, relative to the northern blocks. Because dips of the strata decrease upward stratigraphically, deformation was underway during deposition of Clarno Formation, between 55 and 45 Ma, and continued past the outpouring of Columbia River Basalt Group lava at 16–15 Ma.

CLARNO FORMATION LITHOSTRATIGRAPHIC UNITS (CLARNO AREA)

In the Clarno Unit area, the Clarno Formation contains laterally extensive and mappable lithostratigraphic units (Figures 2 and 3). These units are of three types: (1) andesitic debris-flow packages, (2) andesite lava flows, and (3) claystones. Smaller scale lithostratigraphic units, such as basalt flows or thin andesite flows, tuff beds, and minor red beds, were used to characterize and help identify larger stratigraphic packages. Of the three lithostratigraphic types, the debris- and andesite-flow units constitute the majority of the cliffs along the John Day River in the area south of Clarno bridge along the John Day River and along the western part of Pine Creek.

Lower Clarno Formation (unit Tcl)

Some older debris flows underlie the main Clarno Formation sequence in the Clarno Unit area (Figure 3). These debris flows consist of a sequence of boulder-sized, matrix-supported conglomerates that are exposed just to the west of Hancock Canyon and are referred to as lower Clarno conglomerate. These debris-flow deposits are of uncertain affinity and of local extent (Hanson, 1973, 1995) and are exposed in a structural dome or anticline west of Hancock Field Station (Figure 3). The anticline is a structural window into lower Clarno Formation strata that have been onlapped by later Clarno Formation deposits. The stratigraphic position and relationship of these older deposits with the dacite body are not clear.

Hancock dacite dome (unit Tcd)

A plagioclase-hornblende dacite porphyry is exposed in the hills and gullies to the northeast of Hancock Field Station (Figure 3, unit Tcd). The dome-shaped rock body is pervasively altered and in the northern part of its outcrop consists of compact breccia. Massive, nonbrecciated dacite is exposed in the bottom of gullies, from which a sample was dated at 53.6 ± 0.3 Ma (Table 1, sample no. 93602). Stratigraphic sections of strata directly overlying this igneous body do not show intrusive features such as baking, veining, hydrothermal alteration, and mineralization (Bestland and Retallack, 1994a). The overlying pebbly claystones contain boulders exclusively of weathered, altered hornblende dacite. The claystones are interpreted as well-developed paleosols of the Pswa pedotype (Bestland and Retallack, 1994a) that developed on an igneous body and incorporated colluvial debris (dacite clasts) from the underlying dacite. Thus, the dacite body was an erosional feature that was mantled by colluvium and soils.

Andesite of Pine Creek (unit Tcap)

The base of the stratigraphically coherent section in the Clarno Unit area is a thick andesite flow referred to as the andesite of Pine Creek (Figure 5a). The lava flows consist of dark-colored pyroxene-plagioclase andesite, and a sample from the west lobe was dated at 51.2 ± 0.5 Ma (Table 1, sample no. 93603). West of The Palisades a single flow (>50 m thick) occurs in two lobes, judging by their similar lithologies and chemical composition. These lobes terminate along the north side of Highway 218 and extend northward no more than 600 m into the Clarno Unit. The an-

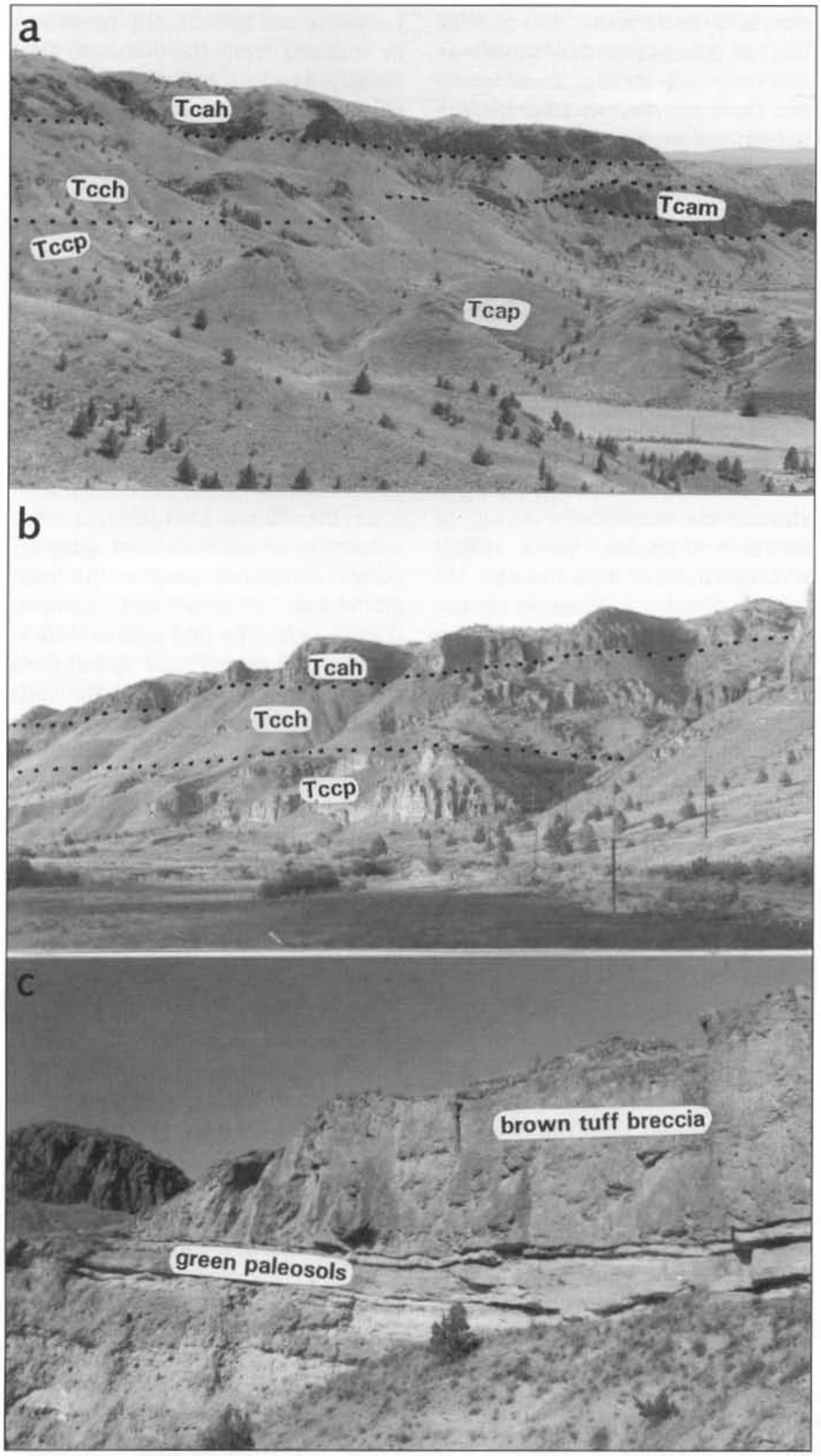

Figure 5. Photographs of West Face Cliffs: (a)—View to the south toward Horse Mountain, showing lithostratigraphic units in the Clarno Formation. (b)—View to the north at West Face Cliffs. (c)—Debris-flow deposits and paleosols in conglomerate of The Palisades in West Face Cliffs. Rock unit symbols as in map of Figure 3, but "T" added and Tcam=cawf.

desite flows have a very irregular upper surface that consists of breccia mantled by a weathered red saprolite.

Paleorelief of this unit is best exposed in cliffs along Pine Creek between The Palisades and the entrance to Hancock Field Station, where more than 40 m of paleotopography is onlapped by debris flows over a lateral distance of 200 m. Pockets of red and white claystones (paleosols) are preserved between the andesite and overlying debris flows and were mapped separately (Bestland and Retallack, 1994a).

Conglomerate of The Palisades (unit Tccp)

Onlapping the irregular surface of the andesite of Pine Creek is a thick (55 m) sequence of debris flows dominated by clasts of andesitic composition (Figures 5b,c). The conglomerate of The Palisades weathers to form the spectacular hoodoos along Pine Creek and in the lower part of the West Face Cliffs along the John Day River (Figures 5a-c). Most of the conglomerate is matrix-supported, moderately clast-rich, laterally continuous, and interpreted as floodplain debris flows (in the sense of Scott, 1988). The Palisade cliffs contain numerous clast-rich, channelized debris flows. Some are clast supported at their base. Hyperconcentrated flood flow deposits (in the sense of Nemec and Muszynski, 1982; and G.A. Smith, 1986) are common at the base of debris flows where they grade into debris-flow deposits. Well exposed at approximately the middle of this unit are several thin, green, clayey paleosols with wood fragments and leaf impressions (Figure 5c).

To the east of Cove Creek, conglomerate of The Palisades onlaps, thins, and pinches out against andesite of Pine Creek. Mantling the conglomerate of The Palisades is a saprolite horizon that is overlain by brown and red claystones (paleosols). These claystones erode to form a bench on the mesa between Hancock Canyon and Indian Canyon. This bench is also present on the north and west sides of Horse Mountain and along the canyon walls of Cove Creek.

Andesite of West Face Cliffs (unit Tcawf)

This thick andesite is locally present in the southern part of the project area south of Clarno along the John Day River (Figure 5a). Here, the unit is exposed in the lower half of the monolithic buttes on the west side of the river (Hills 2441 and 2373, sec. 9, T. 8 S., R. 19 E.) and consists of blocky, dark-colored, pyroxene-plagioclase andesite. At the base of Hill 2441 along the John Day River, the unit fills a paleovalley cut into the conglomerates of The Palisades. In the West Face Cliffs, the unit is clearly onlapped by conglomerate of Hancock Canyon.

Conglomerate of Hancock Canyon (unit Tcch)

Overlying both the red claystone beds at the top of the conglomerate of The Palisades and the andesite of West Face Cliffs is the conglomerate of Hancock Canyon (Figure 6). Like the conglomerate of The Palisades, clasts in this unit are principally of andesitic composition. This unit includes tuffaceous beds and a distinctive basalt flow but is dominated by matrix-supported boulder-debris flows. Deposits of this unit onlap the Hancock dacite dome. In the Clarno Unit area, the conglomerate of Hancock Canyon can be distinguished from the conglomerate of The Palisades by their more prominent bedding, less coarse-grained and massive texture, and common thin tuff interbeds.

The conglomerate of Hancock Canyon contains the Nut Beds fossil site, a 7-m-thick by 300-m-wide lens of silica-cemented sandstone and conglomerate that contains prolific floral remains. Radiometric age determinations on the Nut Beds and the Muddy Ranch tuff (also known as the "Rajneesh Tuff" and named in this paper the "tuff of Currant Creek," unit cct in Figure 3) are approximately 44 Ma; C.C. Swisher obtained a date of 44 Ma from a plagioclase separate from a reworked crystal tuff in the Nut Beds, using the $^{40}Ar/^{39}Ar$ method (oral communication, 1992), and Brent Turrin (for Manchester, 1990, 1994) used the same method on plagioclase of the Nut Beds for an age of 43.76 ± 0.29 Ma. Vance (1988) obtained dates of 43.6 and 43.7 Ma from fission track of zircon crystals in the Nut Beds and 44 Ma in the Muddy Ranch tuff near the Gable (Figure 3). The Muddy Ranch tuff is stratigraphically below the Nut Beds. Many large, well-preserved permineralized tree trunks and limbs of *Cercidiphyllum* (katsura) and *Macginitea* (sycamore) are in the conglomerates of Hancock Canyon.

Basalt of Hancock Canyon (unit Tchb)

A distinctive and widespread amygdaloidal basalt flow occurs stratigraphically in the upper half of the conglomerates of Hancock Canyon (Figure 6c). The basalt is holocrystalline, contains common plagioclase and pyroxene grains, displays pahoehoe flow structures and local columnar jointing, and has been dated at 43.8 ± 0.5 Ma (Table 1, sample no. 93613). The basalt can be mapped from the Hancock Field Station area to the Gable, is thickest (23 m) in the West Face Cliffs, but is not present east of Indian Canyon (Figure 3). This basalt flow can be traced along the cliffs of the John Day River south to Melendy Ridge, a distance of 14 km. The flow is very vesicular at its base, indicating that it flowed over moist terrain, where heat from the lava vaporized the moisture, and the steam penetrated upward into the still molten lava. Locally, these gas holes are filled with agate.

Claystone of Red Hill (unit Tcrh)

In the Clarno Unit area, a thick sequence of reddish and grayish-purple claystones overlies the conglomerate of Hancock Canyon (Figure 7a,b). The unit is 59 m thick in the Red Hill area (Figure 2) but thins dramatically to the east. In the cliffs on the west and north side of Horse Mountain; only a reddish saprolite with thin clay layer is present at this stratigraphic level. The unit at Red Hill contains a lower reddish paleosol sequence of very deeply weathered Ultisol-like paleosols (Lakayx pedotype) and an upper, less well developed Alfisol-like paleosol sequence (Luca pedotype, Retallack, 1981; G.S. Smith, 1988;). A stony tuff bed above the lowest Luca paleosol approximately divides the two paleosol sequences and has been dated at 42.7 ± 0.3 Ma (Table 1, sample no. 93653).

Conglomeratic beds are locally present in the claystones. At the southern tip of the Gable, a thick (18-m) coarse-grained conglomerate body (unit

Table 1. $^{40}Ar/^{39}Ar$ incremental heating ages for rocks from the Clarno Formation, eastern Oregon, by R.A. Duncan

Sample no.	Material	Total fusion Age (Ma)	Plateau Age[1] (Ma)	^{39}Ar % of total	Isochron age (Ma)	N[1]	$^{40}Ar/^{36}Ar$ intercept ± 1s	J[1]
93634	Andesite (plagioclase)	45.1	43.4 ± 0.4	70.3	44.1 ± 1.9	6	306.9 ± 14.6	0.001658
93653	Tuff (plagioclase)	43.0	42.7 ± 0.3	91.6	43.7 ± 0.6	5	289.8 ± 5.8	0.001403
91613	Basalt (plagioclase)	43.2	43.8 ± 0.5	74.3	45.2 ± 8.1	5	217.4 ± 264.9	0.001349
93603	Andesite (whole rock)	50.8	51.2 ± 0.5	62.4	48.3 ± 4.4	6	233.6 ± 339.2	0.001555
93602	Dacite (plagioclase)	57.2	53.6 ± 0.3	44.4	56.1 ± 0.6	5	289.8 ± 2.2	0.001680

[1] Plateau ages are the mean of concordant step ages (N = number of steps), weighted by the inverse of their variances.
J is the neutron fluence factor, determined from measured monitor $^{40}Ar/^{39}Ar$.

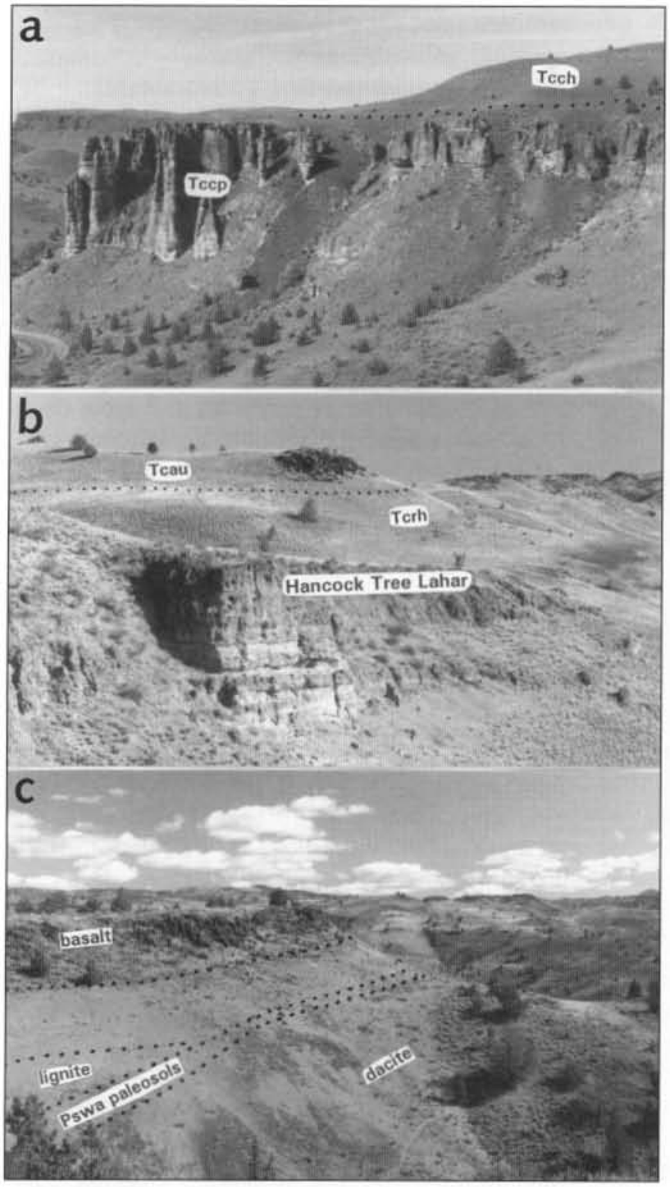

Figure 6. Photographs of The Palisades and Hancock Canyon. (a)—View to the west showing the conglomerates of The Palisades overlain by bench-forming claystone unit which in turn is overlain by conglomerates of Hancock Canyon. (b)—View to the east showing the conglomerate of Hancock Canyon overlain by claystone of Red Hill and the upper andesite unit. (c)—View to the east showing the margin of the dacite dome and onlapping strata. A series of trenches was dug down to bedrock at this location and documented the onlapping nature of a series of colluvial paleosols onto the dacite igneous body. Rock unit symbols as in map of Figure 3, but "T" added.

Tcrg) is interbedded with red claystones. The conglomerates are clast supported and contain rounded clasts of andesite and amygdaloidal basalt. They cut into red claystones and underlying units of the conglomerate of Hancock Canyon.

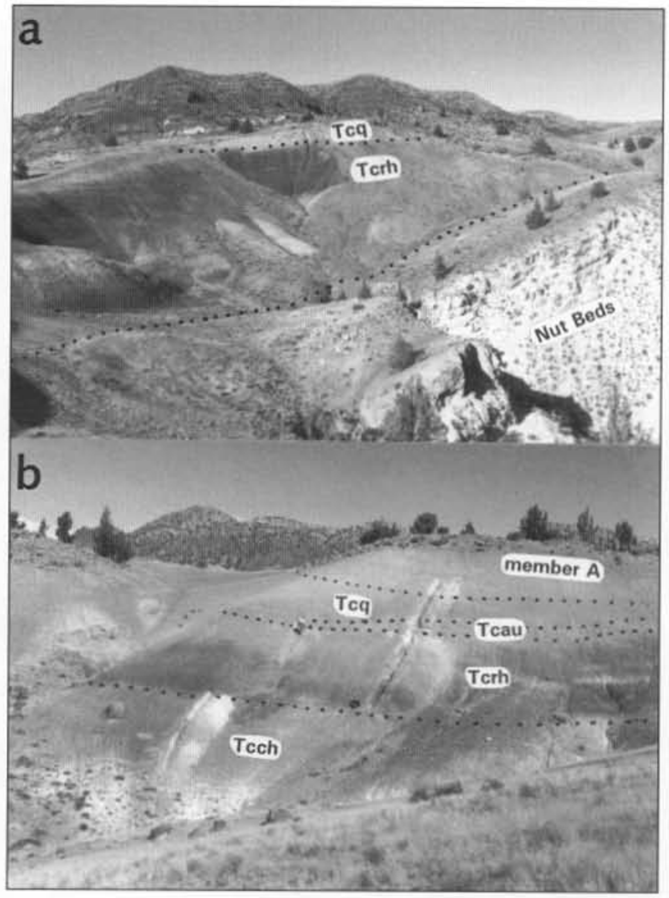

Figure 7. Photographs of upper Clarno Formation units. (a)—View to the north showing Red Hill and lithostratigraphic units in upper Clarno Formation (Nutbeds are in the upper part of the conglomerate of Hancock Canyon. (b)—View to the north showing Red Hill East and lithostratigraphic units exposed in the badlands. Rock unit symbols as in map of Figure 3, but "T" added and Tcq=cmq.

The claystones of Red Hill are prone to landslides. Most landslides in the area occur where thick exposures of these claystones are overlain by the welded tuff of member A of the basal John Day Formation. Good examples of these landslides occur on the east side of Indian Canyon. The landslides do not appear deep seated; the coherent blocks of member A form shallow, rocky slides.

Andesite of Horse Mountain (unit Tcah)

This thick andesite unit is extensively exposed in the Clarno area where it caps much of Horse Mountain (Figure 5a,b) and has been dated at 43.4 ± 0.4 Ma (Table 1, sample no. 93634). The unit consists of platy to blocky andesite that varies from pyroxene-plagioclase andesite to very porphyritic plagioclase dacite with traces of hornblende. Along the west and north side of Horse Mountain, the unit overlies a 2-m-thick red saprolite developed on the amygdaloidal basalt flow (unit Tchb) in the conglomerate of Hancock Canyon. Ramplike flow structures are common in lava flows exposed in the West Face Cliffs. The base of the unit dips gently to the west, probably following a paleoslope.

An upper andesite (unit Tcau) is recognized above the andesite of Horse Mountain, based on stratigraphic position and lithology. On the rolling top of the western part of Horse Mountain, a plagioclase phyric, basaltic andesite flow is exposed above a 1- to 3-m-thick red claystone unit (paleosols) and below member A of the basal John Day Formation. This andesite has been mapped and identified by bulk rock geochemistry (Bestland and Retallack, 1994a). Lithologically and geochemically similar andesite crops out in the upper part of Hancock Canyon, where it underlies the siltstone of Hancock Mammal Quarry. In badland exposures to the east of Red Hill, a saprolitized andesite breccia can be traced into coherent exposure of this upper andesite unit.

Siltstone of Hancock Mammal Quarry (unit Tcmq)

The tan, clayey siltstones and cobble conglomerates of the Hancock Mammal Quarry beds are only locally present in the Red Hill-Indian Canyon area (Figure 8a). A diverse and important vertebrate fauna has been excavated from the Hancock Mammal Quarry, located stratigraphically in the uppermost Clarno Formation and below member A of the John Day Formation (Hanson, 1973, 1989, 1995). Pratt (1988) described Inceptisol-like paleosols from the Hancock Mammal Quarry. By her interpretation, the fossil remains accumulated as carcasses and were disarticulated in a fluvial point bar.

JOHN DAY FORMATION LITHOSTRATIGRAPHIC UNITS (CLARNO AREA)

In the Clarno Unit area, the John Day Formation has been mapped and stratigraphically subdivided by Robinson (1975) following Peck's (1961, 1964) informal subdivision of the John Day Formation on the basis of distinctive pyroclastic and lava flow units. In this paper, these pyroclastic and lava flow units are recognized and given the names defined by Peck (1964) and mapped by Robinson (1975); however, only distinct lithologic units were mapped in the Clarno Unit area. These volcanic units, along with the interbedded claystones, lacustrine shales, and tuffs, are here assigned to eastern facies members of the John Day Formation (Fisher and Rensberger, 1972).

Lower Big Basin Member (unit Tjlb)

The lower Big Basin member in the Clarno Unit area includes all lithostratigraphic units from and including the welded tuff of member A of the basal John Day Formation up to a truncation surface marked in places by conglomerates and sandstones of probable Oligocene age (Figure 2). These sandstones and conglomerates are exposed in gullies to the west of the Slanting Leaf Beds which they stratigraphically underlie.

Welded tuff of member A (unit Tjat)—Rhyolitic pyroclastic volcanism of the John Day Formation is first recorded in north-central Oregon by an ash-flow tuff now redated in the Clarno area at 39.2 Ma and by a 39.7 Ma date from this tuff in the Painted Hills area (Bestland and others, 1997). This basal ash-flow tuff sheet is extensively exposed in the western facies (Peck, 1964; Robinson, 1975) where it is useful for delineating the Clarno surface at the onset of John Day volcanism (Figure 8a).

A lower, densely welded tuff forms prominent outcrops in the Clarno Unit area and is approximately 30 m thick. A perlitic vitrophyre occurs locally at the base and is best exposed in roadcuts at the Gable. At the very base of the ash-flow tuff are unwelded tuff deposits, some containing accretionary lapilli and plant remains (Figure 8b). Lithic fragments are common in the lower tuff as are bi-pyramidal (beta) quartz crystals. An upper, weakly welded to unwelded part of the ash-flow tuff, approximately 25 m thick, crops out extensively in the Clarno Unit area, where it commonly forms the dip slope on the member A cuesta. This unit also contains abundant bipyramidal quartz crystals but less lithic fragments than the lower densely welded part.

Member B basaltic andesite (unit Tjba)—In the Clarno Unit area, distinctive aphanitic basaltic andesite flows overlie member A. Red claystones are locally present between the two units. The flows consist of aphanitic to sub-glassy basaltic andesite that weathers into cobble-sized blocks. These basalts correlate with the member B trachyandesites of Peck (1964) and (Swanson, 1969) and have also been mapped in the Clarno Unit area (Robinson, 1975). Peck (1964) identified 460 m of very dark gray aphanitic flows of trachyandesite in the Ashwood area. In the Clarno Unit area, a 21-m-thick columnar-jointed basaltic andesite lava flow crops out at the head of Indian Canyon and is the thickest occurrence of member B in the area. Other small exposures are scattered throughout the area and are recognizable by their aphanitic texture and a weathering character that produces small, cobble-sized blocks—similar to Peck's (1964) description of member B. A set of basaltic andesite intrusions of this lithology forms a small hill between Hancock Canyon and Indian Canyon (NE¼ sec. 26, T. 7 S., R. 19 E.). The

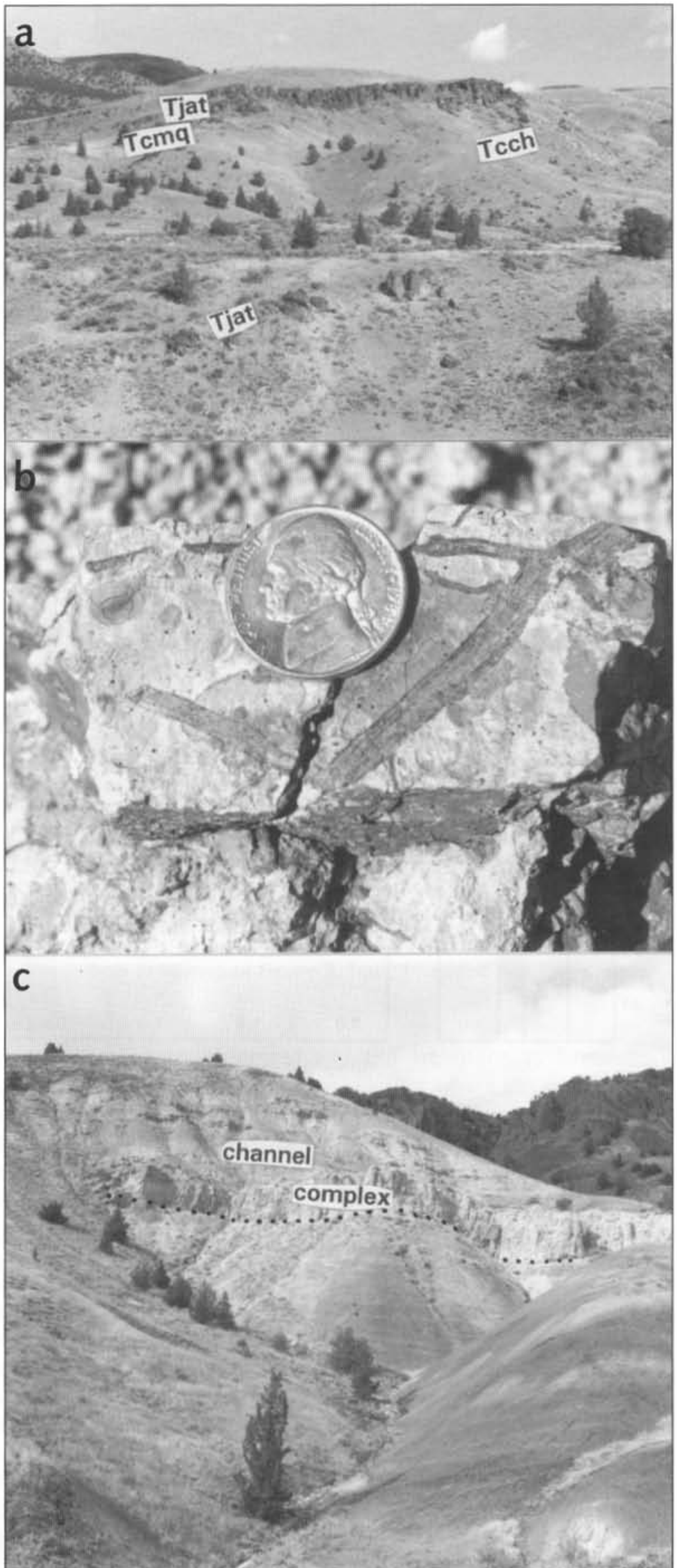

Figure 8. Photographs of lower John Day Formation. (a)—View to the east showing the Hancock Mammal Quarry area and the welded member A tuff (unit Tjat) of the basal John Day Formation overlying the Hancock Mammal Quarry beds (unit Tcmq) and the conglomerate of Hancock Canyon (unit Tcch). (b)—Carbonized plant debris and accretionary lapilli from the unwelded base of the member A tuff. (c)—Tuffaceous claystone of the lower Big Basin member overlain by siltstone channel deposits.

rock contains pebble-sized cognate xenoliths of gabbro. Geochemically, lava flows and dikes are very similar in composition (Bestland and Retallack, 1994a).

White tuff of member F (unit Tjft)—A massive, white vitric tuff approximately 1–3 m thick is widespread but poorly exposed in the lower John Day Formation in the Clarno Unit area. This tuff is interbedded with clayey red beds of the lower Big Basin Member and has been referred to previously as the member F tuff. This vitric tuff was dated at the Whitecap Knoll (=White Knoll on map in figure 3) locality at 38.2 Ma (Bestland and others, 1997). Getahun and Retallack (1991) identified an Alfisol-like paleosol (Luca pedotype) directly below this tuff at Whitecap Knoll. Robinson and Brem (1981) identified a massive, white, vitric tuff located in a road cut just west of the Clarno Grange Hall on Highway 218 as the base of member F in this area. However, recent $^{40}Ar/^{39}Ar$ age determinations on the member F tuff in its type area in the western facies indicate an early Oligocene age (G.A. Smith, oral communication, 1996; Smith and others, 1996). And, according to Peck (1964), the weakly welded ash-flow tuff that defines the base of member F is not a widespread unit. Thus, the correlation of this tuff in the Clarno area with the western facies type area is not tenable with these recent dates.

Lower Big Basin Member claystones (unit Tjlb)—Widespread, thick, clayey, red beds in the lower part of the John Day Formation in the Clarno Unit are mapped as lower Big Basin Member, based on lithologic and stratigraphic similarities with the type section of this member in the Big Basin area of Picture Gorge. Recently recognized subdivisions of this member in a reference section from the Painted Hills area (Bestland and others, 1996, 1997; Bestland and Retallack, 1994b) are also recognized in the Clarno Unit.

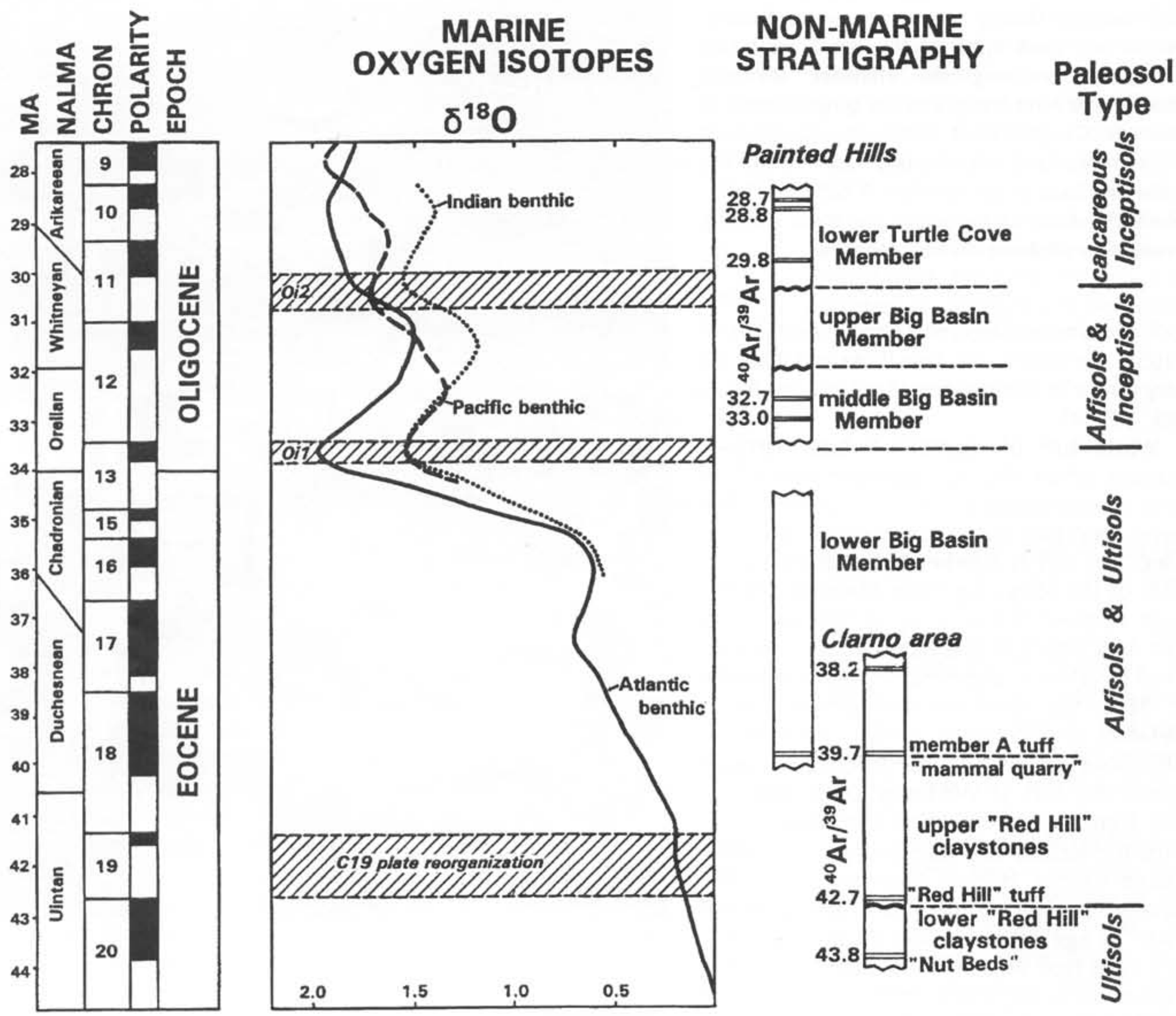

Figure 9. Correlation of nonmarine stratigraphy from central Oregon with marine oxygen isotopic record, using the geomagnetic time scale of Cande and Kent (1992, 1995) as modified by Berggren and others (1992, 1995) and $^{40}Ar/^{39}Ar$ radioisotopic age determinations from tuffs interbedded with paleosols. From Bestland and others, 1997.

The Eocene-Oligocene boundary is placed at 34 Ma (Swisher and Prothero 1990; Berggren and others, 1995). Marine isotopic data are from benthic foraminifera and are smoothed by linear interpolation (Miller and others, 1987). Oi1 and Oi2 are oceanic oxygen isotope cooling events (Miller and others, 1991).

The first major change in paleosol type occurs between the lower and upper red claystones of the Clarno Formation and corresponds with the chron 19 plate-tectonic reorganization (McGowran 1989). The dramatic change in paleosol type and the large truncation surface between the lower and middle Big Basin Members support the placement of the Eocene-Oligocene boundary at approximately 34 Ma according to $^{40}Ar/^{39}Ar$ age determinations from the central Oregon section. An early Oligocene climatic recovery is indicated by the presence of well-developed, clayey paleosols at the top of the middle Big Basin Member approximately dated at 32.0 to 32.7 Ma. A third major change in paleosol type between the upper Big Basin Member and lower Turtle Cove Member, at approximately 30 Ma, is synchronous with the Oi2 oceanic oxygen isotope cooling event.

Middle and upper Big Basin Members (unit Tjmb)

The middle and upper Big Basin Members were not delineated in the Clarno area as they have been in the Painted Hills area (Bestland and Retallack, 1994b). In the Clarno area, red-brown silty claystones, tuffs, and lacustrine shales with leaf impressions, similar to the middle Big Basin member in the Painted Hills, occur above clayey red beds (lower Big Basin Member) and below green tuffaceous strata with sanidine tuff. A sanidine tuff occurs in the lower part of the Turtle Cove Member in the Painted Hills (see Figure 9), where it was dated at 29.8 Ma. Additionally, the 33.6 Ma age determinations from the Slanting Leaf Beds and the well-documented Bridge Creek flora (Manchester and Meyer, 1987; Meyer and Manchester, 1997) from these strata allow correlation of this package with the middle Big Basin Member. In the Painted Hills area, age determinations of 33.0 Ma and 32.7 Ma on tuff beds (Bestland and others, 1997) are associated with the type locality of the Bridge Creek flora (Chaney 1924, 1948) and are contained within the middle Big Basin Member. Red, silty claystones stratigraphically above the Slanting Leaf Beds and below a cliff-forming channel complex (Figure 8c) are similar to Ticam and Skwiskwi pedotypes identified in the middle and upper Big Basin Members from the Painted Hills (see Bestland and others, 1997, for pedotypes).

At the base of the middle Big Basin Member and locally present in the Clarno area, are conglomerates containing weathered clasts of tuff and igneous flow rocks (Figure 2). In gullies to the west of the Slanting Leaf Beds, brown, calcareous paleosols overlie these conglomerates and underlie the lacustrine and carbonaceous shales of the Slanting Leaf Beds. These conglomerates fill an incised surface cut into underlying claystones of the lower Big Basin Member and represent a major truncation surface, similar to a truncation surface identified in the Painted Hills area (Bestland and Retallack, 1994b). This truncation surface approximates the Eocene-Oligocene boundary.

Member F basalts (unit Tjfb)—Alkaline olivine basalts of member F of the John Day Formation (Robinson, 1969) occur extensively in the Clarno area. Below Iron Mountain, John Day Formation basalts of member F are in contact with Columbia River Basalt Group. Lava flows of this unit are also interbedded with tuffaceous deposits and paleosols of the middle and upper Big Basin Members. The stratigraphically lowest alkaline basalt is less than 10 m above the Slanting Leaf Beds.

Turtle Cove Member

Tuffs and tuffaceous siltstones and claystones of the Turtle Cove Member are recognized in the Clarno Unit on the basis of correlation of tuffs in the western facies with this member in the eastern facies (Woodburne and Robinson, 1977). The Turtle Cove Member as well as the ash-flow tuffs of members G, H, and I are exposed in The Cove, on the west side of Iron Mountain above the John Day River, and have been mapped previously by Robinson (1975) and by Bestland, Blackwell, and Kays (unpublished mapping 1986 and 1988). These tuff units are significant in the context of correlating the Turtle Cove Member of the John Day Formation with the western facies of the John Day Formation.

Member G ash-flow tuff and related units are extensively exposed in the western facies (Robinson, 1975) and in the Clarno area along the Iron Mountain escarpment. This sanidine-rich tuff has been correlated with a sanidine tuff in the Painted Hills area (Hay, 1963; Woodburne and Robinson, 1977) which has been recently dated at 29.8 ± 0.02 Ma (Bestland and others, 1997).

The ash-flow tuff sheet of member H is also widespread in the western facies (Peck, 1964; Robinson, 1975) as well as in the eastern facies (Fisher, 1966), where it is referred to as the "Picture Gorge ignimbrite." Member H has been correlated with the Picture Gorge ignimbrite on the basis of lithology and stratigraphic position (Robinson and others, 1990). Two recent age determinations of this unit in the Painted Hills are both 28.7 ± 0.07 Ma (Bestland and others, 1997). This tuff is crystal poor and contains variable amounts of lithic fragments of rhyolite and tuff. In the Clarno area, two cooling units are present in the tuff, as has been recognized in the eastern facies by Fisher (1966). To the west of Clarno, closer to the source, only one cooling unit is recognized (Robinson and others, 1990).

Member I tuff in the Clarno area consists of a distinctive coarse-grained ash-flow sheet that occurs in scattered exposures high on the slopes of Iron Mountain. The tuff is up to 15 to 20 m thick and contains coarse pumice fragments, coarse vitric shards, and obsidian fragments.

SEDIMENTATION, VOLCANISM, AND PAST CLIMATE CHANGE

Clarno Formation depositional setting

The Clarno Formation sedimentary units in this area can be broadly grouped into coarse-grained debris-flow-dominated deposits and fine-grained, alluvial paleosol or overbank deposits. White and Robinson (1992) interpret the coarse-grained Clarno Formation deposits as proximal, nonmarine lahar aprons and reworked fluvial deposits that flanked stratovolcanoes, possibly in fault-bounded minibasins in a tensional arc setting—similar to the Quaternary High Cascade graben of the central Oregon Cascades (Smith and others, 1987; Taylor, 1990). Fine-grained overbank deposits and paleosols are common in the formation, however due to the poor exposure of these claystone units, their distribution and sedimentology has been largely ignored (Robinson, 1975; Swanson, 1969) except in a few places such as Red Hill (Retallack, 1981; 1991a) and in the Cherry Creek area where White and Robinson (1992) briefly describe a thick section of clayey red beds.

Depositional setting of fossil sites in conglomerate of Hancock Canyon—Conglomerates of Hancock Canyon have a mix of debris-flow deposits, fluvial conglomerates, and tuff beds. Compared to the conglomerate of the Palisades, the conglomerate of Hancock Canyon, with its abundance of flood-surge or hyperconcentrated deposits and fluvial reworked beds, indicates a lower gradient or more distal depositional setting.

Within the Clarno area are numerous fossil plant localities (including several new sites, see Bestland and Retallack, 1994a) that indicate apparently dissimilar climates. The classic Nut Beds site yields plant fossils strongly indicative of a tropical to paratropical climate (Manchester, 1981, 1994). In contrast, at the same stratigraphic level and in a similar debris-flow depositional environment, some fossil plants found in Hancock Canyon suggest temperate conditions. It is likely that the Nut Beds flora represents a lowland, floodplain rain forest, like the selva of tropical Mexico, whereas the Hancock Tree flora represents an early successional forest located on an unstable braid plain. The flora has similarities to higher altitude forest with affinities to cooler climate, like the Liquidambar oak forests of Mexico (Gómez-Pompa, 1973).

Paleosols and overbank deposits—An overbank to piedmont alluvial setting is interpreted for the Red Hill claystones, based on laterally continuous paleosol horizons present in Red Hill and channel conglomerates interbedded with the claystones. The upper Red Hill section contains a thick stack of red Luca paleosols with few gleyed intervals. A large channel-fill conglomerate is interbedded with the claystones of Red Hill at The Gable (Bestland and Retallack, 1994a), which indicates that large channels did exist on the alluvial plain.

Thick accumulations of alluvial paleosols occur in scattered pockets elsewhere in the Clarno Formation. Their distribution is not widespread, probably due to rapid aggradation of coarse-grained units followed by incision during volcanic quiescence. Only occasionally did alluvial plains exist for a sufficient length of time for the accumulation of finer grained alluvium. Red Hill sits stratigraphically near the top of the Clarno Formation and probably marks the end of explosive andesitic volcanism in this part of the Clarno arc.

John Day Formation depositional setting

The John Day Formation represents a nonmarine back-arc basin that received mostly pyroclastic detritus from Cascade sources to the west. The formation becomes finer grained from west to east, following the dispersal pattern of pyroclastic material (Fisher, 1966; Robinson and others, 1984). The ash-flow tuffs of the John Day Formation contain sanidine and quartz and are rhyolitic (Robinson and others, 1990). Additionally, geochemical analyses of tuff beds (Hay, 1962, 1963; Fisher, 1966) and C horizons of paleosols (Fisher, 1966; Getahun and Retallack, 1991; Bestland and Retallack, 1994a,b) indicate a rhyolitic to rhyodacitic composition for the tuffs and tuffaceous alluvial deposits. The western facies ash-flow tuff sheets thicken toward the Warm Springs and Mutton Mountain areas. Taken together, these facts support an interpretation of a rhyolitic source for the John Day Formation that was separate from the Western Cascades.

Alluvial paleosols—The thick, colorful claystone and tuff sequences so well known from the John Day and Clarno Formations are now thought to be dominated by paleosol horizons (Retallack, 1981, 1991a,b; Bestland and others, 1994, 1996, 1997; Bestland, 1997). Furthermore, most of the paleosols and their associated, although pedogenically modified, substrates are interpreted as alluvial, and in a few cases colluvial, deposits. Most of the paleosols in the John Day and Clarno Formations are interpreted as floodplain paleosols, based on the following general considerations: They are relatively laterally continuous and show evidence of both well- and poorly drained conditions. They lack coarse-grained channel bodies, which indicates the predominance of vertical floodplain accretion. Many different paleosol horizons have been identified and interpreted, and these paleosols can be broadly grouped into floodplain setting (alluvial) and hillslope setting (colluvial) soil-forming environments. Landscape aggradation in the form of floods, pyroclastic air fall, wind-blown dust and ash, and colluvial movement from upslope locations caused vertical accretion of soil horizons. Larger scale additions of alluvium and colluvium periodically buried the landscape and caused new soils to form on these deposits. Aggradational periods were interspersed with episodes of downcutting, during which the alluvial and colluvial basin fill would be partially removed (Bestland and others, 1997).

Eocene-Oligocene transition

The long stratigraphic sequence of paleosols in the upper Clarno and lower John Day Formations record a dramatic paleoclimatic change. This is the transition from the Eocene to the Oligocene, when the Earth's climate and biota changed from the warm, mostly subtropical world of the Mesozoic and early Cenozoic to the glaciated world of today, or from the "hot house" to the "cold house" (Prothero, 1994). These climatic and biotic changes are centered around the Eocene-Oligocene boundary, with the changes appearing to be stepwise over several million years on either side of this boundary (Wolfe, 1978; Miller and others, 1987, 1991; Retallack, 1992; Bestland and others, 1997).

Recent work on the timing and global correlation of the Eocene-Oligocene boundary (Swisher and Prothero, 1990; Prothero and Swisher, 1992; Cande and Kent, 1992) allows for a comparison of the stratigraphy and age determinations from the central Oregon stratigraphy with the global data base of climate change (Bestland, 1997; Bestland and others, 1997). Many of the existing global climate change data come from deep-sea sediments and their oxygen and carbon isotopic record (Figure 9). In the John Day Formation, climatic steps centered around the Eocene-Oligocene boundary correspond with member boundaries (Figure 9). Most notable is the abruptness of the Eocene-Oligocene climatic transition. The short time span of this change is not apparent from paleontological evidence of vertebrates and plant fossils in the Pacific Northwest because of the incompleteness of the fossil record. The paleoclimatic record from paleosols in the Clarno and John Day Formations, in contrast, is much more complete.

Paleoclimate and depositional summary

A dramatic change in depositional setting from an active volcaniclastic apron of the conglomerates of Hancock Canyon to the quiet floodplain represented by the claystones of Red Hill records the the cessation of proximal volcanic activity in at least this part of the Clarno area. In the lower part of Red Hill, strongly developed, Ultisol-like paleosols dominate the strata and represent long periods of soil formation in a humid subtropical climate. These paleosols are the most weathered paleosols in the upper Clarno and lower John Day Formations. In the upper part of Red Hill, strongly developed Alfisol-like paleosols dominate the section and represent shorter periods of soil formation in a similar but probably drier humid subtropical climate (Bestland and others, 1997). The change from Ultisol- to Alfisol-like Luca paleosols is interpreted to be the result of climatic cooling and drying during the late Eocene (Figure 9). Changing paterns of oceanic circulation and volcanism are hypothesized to have caused a late Eocene climate change at about 42 Ma (McGowran, 1989). The hiatus in volcanism recorded in the Red Hill section from 44 Ma to about 40 Ma, when John Day or Cascade volcanism began, was a period of sporadic volcanism transitional from the Clarno to the Cascade arc. Following this volcanic hiatus of approximately 2–4 million years, renewed volcanism, represented by the andesite of Horse Mountain (unit Tcau), rejuvenated the alluvial system with fresh andesitic material and caused the deposition of the Hancock Mammal Quarry beds. These paleosols are too weakly developed to interpret much in the way of paleoclimate, except that it was relatively humid.

With the onset of John Day volcanism, the alluvial material changed from andesitic detritus to fine-grained rhyodacitic ash. In the lower Big Basin Member of the Clarno Unit area, strata contain strongly developed Alfisol- and Ultisol-like paleosols. The geochemical composition of these lower John Day paleosols is much the same as that of upper Clarno paleosols and indicates little, if any, climatic change from late Clarno time to early John Day time. Not until approximately 34 Ma, at the Eocene-Oligocene boundary, did the climate change dramatically (Figure 9). In the Clarno area, this boundary is marked by the contact between the lower and middle Big Basin Member to the middle Big Basin Members. Paleosols formed after this transition are higher in base cations and lower in Fe and Ti than late Eocene paleosols. The climate change from subtropical to temperate conditions across this boundary is contrasted dramatically by a comparison of the Eocene Nut Beds flora (tropical to subtropical forest) and Red Hill clayey, Ultisol-like paleosols with the Oligocene Bridge Creek flora of the Slanting Leaf Beds (temperate forest) and middle Big Basin Member tuffaceous, Inceptisol-like paleosols.

ACKNOWLEDGMENTS

This report represents the combined efforts of E.A. Bestland and G.J. Retallack under contract with the National Park Service (Bestland and Retallack, 1994a,b), the University of Oregon Geology Field Camp and its director, M. Allan Kays, and Portland State University Geologic Field Methods directed by P.E. Hammond. Discussion with T. Fremd, J. Jones, E. Taylor, R. Goodfellow, and A. Mindzenty have added to our understanding of the geology and paleontology of this area. R.A. Duncan of the College of Oceanic and Atmospheric Sciences, Oregon State University, kindly supplied age determinations for a number of samples.

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DOGAMI PUBLICATIONS

Released July 22, 1998

Tsunami hazard map of the Seaside-Gearhart area, Clatsop County, Oregon, by George R. Priest, Edward Myers, Antonio Baptista, Robert Kamphaus, Brooke Fiedorowicz, Curt D. Peterson, and Thomas S. Horning. Interpretive Map Series IMS–3, scale 1:12,000, $6.

This map shows how three different tsunamis might affect the area. Computers were used to simulate three different local earthquakes and the tsunamis they might cause. These simulations were used in conjunction with field–based mapping and analyses of core samples to produce the map.

The map has an aerial photo as its base, so that streets and buildings can be identified and their danger from flooding or their use as potential evacuation routes assessed. Each potential tsunami flooding area is outlined, as is the actual flooding level of the 1964 tsunami that was triggered by a great earthquake in Alaska and killed people as far away as Crescent City, California.

Because of the potential loss of life and property from these events, many government agencies have contributed to this map and will continue to work with the communities. The Oregon Graduate Institute of Science and Technology, Portland State University, and the National Oceanic and Atmospheric Administration provided scientific research to produce the map. The State of Oregon and the City of Seaside helped fund the project.

Released December 11, 1998

Geology of the Henkle Butte quadrangle, Deschutes County, Oregon, by E.M. Taylor. Geological Map Series GMS–95, scale 1:24,000, 5 p. text, $10.

A new geologic map of the Henkle Butte quadrangle helps explain the geology of the eastern side of the Cascade Range. The map includes part of the Deschutes National Forest.

A diverse mix of volcanic and sedimentary rock covers the area. Construction aggregrate has been mined from the local cinder cones and gravels. Until about 1.6 million years ago, the landscape was mostly rim-rock lava and a few river deposits. Since then, the area has been eroded by streams that carved the Fremont, McKenzie, and Deep Canyons (now

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BOOK REVIEWS

Living with Earthquakes in the Pacific Northwest, by Robert S. Yeats. Oregon State University Press, 101 Waldo Hall, Corvallis, Oregon 97331-6407, osu.orst.edu/dept/press, 1998. 309 p., ISBN 0-87071-437-6, soft cover, $21.95. [Available from DOGAMI: See last page of this issue.]

Accurately forecasting the next major earthquake in the Pacific Northwest is an impossible task. The notion that Mother Earth transmits reliable data for this kind of event isn't supportable by past measurable events. So what is the next best thing to do to prepare for the upcoming inevitable earthquake?

Answer: Read *Living With Earthquakes In The Pacific Northwest* by Dr. Robert S. Yeats!

Dr. Yeats' credentials are well established and revered through a quarter century of earthquake study and scientific analysis on inner earth rumblings around the world. He is a senior consultant for Earth Consultants International and a professor emeritus in the geosciences department at Oregon State University.

Unlike many other earth science authors, Yeats focused on a layman's interest in and background of scientific knowledge. Simply put, the book is an easy read and down to earth. Yeats' use of humor, graphs, and photographs makes this an informed and understandable writing.

What can you expect to learn? For one, inner-earth disturbances result from strained rock. A detailed explanation of this straining and its relation to tectonic movement brings the reader to an understanding of the what, where, and why of earthquakes. Also, shaky ground, landslides, and big sea waves are all possible results of inner-earth disturbances. Readers will recognize the locations of many recent earthquake events like Scotts Mills, Klamath Falls, Oregon's Capitol Building, and Mount St. Helens. For the lay reader, Yeats provides six pages of glossary entries to help bring understanding to geoscience words like asperity, Holocene, P wave, and shear wall. An extensive bibliography suggests additional reading for those interested.

It is true that we cannot prevent earthquakes, but it is also true that we can learn to live with them and to survive them. Are we ready for the next big one? Most experts say we are not, but Yeats' book details a number of measures one can put in place to counter a destructive event. Considerations for purchasing earthquake insurance, readying the home for shaking and shifting ground, and design implications for structures large and small are all clearly detailed. Also, there is a discussion of the role of state and local governments in dealing with earthquakes.

Dr. Yeats has succeeded in communicating vital information to his readers. The public's next step is to pick up a copy and to read it. With recent reports of swarms of small disturbances under Mount Hood and frequent articles about the Cascadia subduction zone, which lies a few miles off Oregon's coastline, it becomes increasingly important that the general public become informed. Reading this book is the right step in that direction.

—Don Christensen
DOGAMI Governing Board Member
Depoe Bay, Oregon

Islands and Rapids. A Geologic Story of Hells Canyon, by Tracy Vallier. Confluence Press, Lewiston, Idaho, 1998. 151 p., ISBN 1-881090-30-2, soft cover, $25. [Available from DOGAMI: See last page of this issue.]

Islands and Rapids is highly recommended reading for anyone planning a visit to the Hells Canyon country of eastern Oregon. Here at last is a comprehensive geologic guide to one of North America's scenic treasures, written by Dr. Tracy Vallier, the man who has spent the most time and effort to decipher the geologic mysteries of Hells Canyon.

Published by Confluence Press (Lewis-Clark State College), the 151-page volume is an entertaining and informative geologic expose, filled with pictures and maps and geologic descriptions. The author, Tracy Vallier, has taken the time to explain complex geologic terms. Dr. Vallier has also provided the reader an intimate look at his personal 30-year struggle in unravelling Hells Canyon's geologic history. I strongly recommend that anyone interested in the geologic story of Hells Canyon take a look at this book. It is an enjoyable read.

—Mark L. Ferns
Oregon Department of Geology and Mineral Industries, Baker City Office

Correction

Author Frank Hladkey has called to our attention that an error slipped into Table 1 of his recent article about Upper Table Rock and Lower Table Rock. In the July/August 1998 issue (v. 60, no. 4), on page 85, in the analyses for oxides, the numbers for Na_2O were reported incorrectly. The correct values are listed below along with the respective sample numbers:

Sample no.	Na_2O
BAG-614	4.51
BAG-615	4.52
BBG-202	4.59
BBG-203	4.18
BBG-207	3.98

We apologize to our readers for the oversight and are grateful to Frank for catching it. □

New fossil book at Nature of the Northwest

Oregon Fossils, by Elizabeth and William Orr. Kendall/Hunt Publishing Company, Dubuque, Iowa, 1999. 381 p., ISBN 0-7872-5454-1, soft cover, $40.95.

The book discusses Oregon's fossils in the context of their original environments and of the people who discovered and studied them. □

Report on Colombia earthquake damage to lifelines

by Yumei Wang, Oregon Department of Geology and Mineral Industries

On January 25, 1999, a magnitude 5.9 earthquake occurred near the city of Armenia, Colombia, and so far more than 400 aftershocks have been registered. Current reports include over 700 confirmed deaths, over 180,000 homeless, and numerous survivors needing food, medical aid, and clothing. Conditions are made worse by civil unrest, particularly in the two major cities of Armenia and Pereira, and by continuing rainfall that acts as an additional cause for more landslides that have already affected most of the mountain roads.

Structures and lifelines were considerably damaged. Quantification of the damage and losses is practically impossible, because among the local authorities there is no uniform terminology and system of distinguishing types of damage and loss.

A preliminary lifeline damage summary was compiled by Curt Edwards, Chair of the Earthquake Investigation Committee of the American Society of Civil Engineers Technical Council on Lifelines Earthquake Engineering (ASCE-TCLEE). Edwards is currently assessing the need and feasibility to dispatch a TCLEE investigation team to report on the lifeline damage. [Yumei Wang from DOGAMI is one of the possible team members.–*ed.*] However, Edwards warns that Colombia is "considered one of the most dangerous countries in the world for travel, even without the effects of an earthquake," and such a team would put an additional burden on local authorities who are already stretched to the limits of their capabilities in the face of the current situation of food shortages, looting and protesters, limited trash collection, and spreading diseases.

Edwards provided the following list of selected lifeline damage to towns shown on the map below:

Armenia (223,000 inhabitants, more than 500 fatalities, more than 57 percent of homes affected): Civil unrest; no trash service; health problems evident, and vaccinations underway; no water, no electricity, aqueduct out, airport control tower out of service.

Pereira: Civil unrest, landslide threat to sever-water aqueduct, airport available only to relief efforts, electricity interrupted.

Cajamarca: Landslides blocking roads; other transportation problems.

Alcalá: Only partial telephone service, landslides, road blockages, and other transportation problems.

Ulloa: No communications.

Caicedonia: Very difficult telephone communications, hospital damaged.

Obando: Health center damaged.

Calarcá: Hospital damaged, only extreme emergencies treated, aqueduct inlet destroyed, roads blocked.

Montenegro: No electricity, landslides.

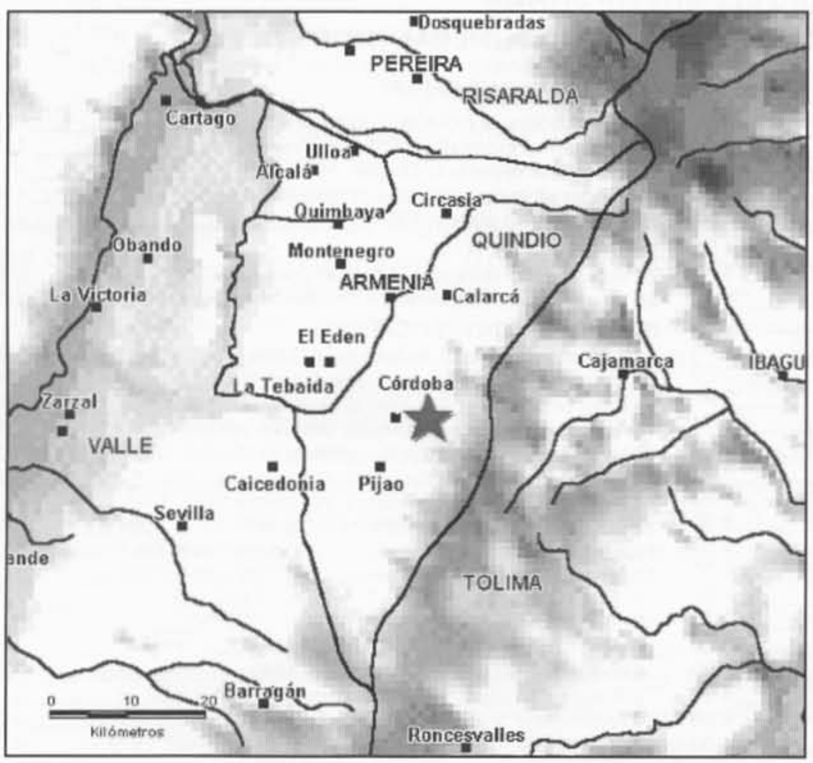
Córdoba: Hospital collapsed.

La Tebaida: Water and electricity services interrupted.

Pijao: Electrical service out.

Quimbaya: Electrical service out.

More information can be obtained (in Spanish only) from the website pages of the Observatorio Sismológico del SurOccidente (O.S.S.O.) at the following address: http://osso.colombianet.net □



Above and left: Location maps of western portion of Colombia. Rectangle indicates approximate outline of detail map on left. Star indicates earthquake epicenter. Sources: Observatorio Sismológico del SurOccidente and Lexikografisches Institut, München.

(Continued from page 19)

dry) and by Squaw Creek. The broad, level plains now support residential and agricultural development.

Released December 16, 1998

Using earthquake hazard maps. A guide for local governments in the Portland metropolitan region, by Spangle Associates, Urban Planning and Research, Portola, California. Open-File Report O–98–04, 45 p., $10.

The report was prepared for Metro, the regional government for the Portland metropolitan area, and originally published by Metro. The release by DOGAMI is intended to make the report available to a wider audience, because it applies in other densely populated regions as well..

The 45-page report discusses the state and regional context for the local use of earthquake hazard maps in zoning, subdivision, siting of public facilities, and seismic retrofitting. It focuses on local government actions but recognizes that all levels of government, businesses, community organizations, households, and individuals play roles in reducing a community's vulnerability to earthquakes.

Released January 4, 1999

Earthquake damage and loss estimate for Oregon, by Yumei Wang. Open-File Report O–98–03, 208 p., $40.
Earthquake damage in Oregon: Preliminary estimates of future earthquake losses, by Yumei Wang and J.L. Clark. Special Paper 29, 61 p., $10.

Statewide, county-by-county earthquake damage estimates are presented in the two reports, in full detail (Open-File Report) and in a less technical summary (Special Paper).

Wang's study analyzed the Cascadia subduction zone and all faults in the state that have a 10-percent chance of causing an earthquake in the next 50 years.

Released January 14, 1999

Water-induced landslide hazards, western portion of the Salem Hills, Marion County, Oregon, by A.F. Harvey and G.L. Peterson. 1998, Interpretive Map Series IMS–6, 1:24,000, $10.

This is a pilot project with participation by federal, state, and local governments. The Salem Hills are a landslide-prone area with intensive development in the southern part of the city. This area is important because the sliding is regional and cannot be easily studied or controlled in tax-lot-sized parcels.

The map outlines six levels of risk. The consulting firm Squier Associates mapped the area.

Geology of the Fly Valley quadrangle, Union County, Oregon, by M.L. Ferns. 1998, Geological Map Series GMS–113, 1:24,000, $10.

The Fly Valley area covers about 55 mi^2 on the headwaters of the Grande Ronde River in the Wallowa Whitman National Forest and marks the eastern flank of a large, newly recognized, 25-million-year-old volcanic center.

Major geologic resources found in the area include aggregate for road building, perlite, and decorative facing stone. Some of the hydrothermal alteration zones contain thundereggs and opal that may be of interest to mineral collectors and rockhounds.

Released February 1, 1999

Mist Gas Field map, 1999 edition. Open-file Report O–99–01, map scale 1:24,000, production statistics for 1993–1998, $8. □

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APRIL—Earthquake and Tsunami Preparedness Month: New K–12 Curriculum for Oregon Schools

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Cover photo

Teacher Kathy Malarkey and pupil Alisha Karel are working on an exercise during a workshop at the Hatfield Marine Science Center in Newport, testing a new curriculum for earthquake and tsunami preparedness. See article on activities and events for "April—Earthquake and Tsunami Preparedness Month" on page 50.

Roddey joins DOGAMI staff

James Roddey has joined the Oregon Department of Geology and Mineral Industries (DOGAMI) as Community Education Coordinator. He has an extensive background in educational and commercial media including over 20 years of marketing and public relations experience in the television industry. He joins the department from Boise, Idaho, where he was Promotion and Community Relations Manager of KIVI-TV, an ABC affiliate.

Prior to his service in Boise, Roddey worked at Northern Arizona University in Flagstaff, Arizona, where he produced and directed over 60 educational earth-science television programs for The Learning Channel (TLC). "GEONAUTS" was produced in partnership with the National Park Service and included a year-long curriculum for upper elementary students that could be used in conjunction with the twice-weekly television program. "GEONAUTS" explored the geology of the Colorado Plateau and featured many of the national parks in the area, including Grand Canyon National Park, Dinosaur National Monument, Petrified Forest National Park, and Canyonlands National Park.

As partner in the DOGAMI outreach and earthquake teams, Roddey will help the department promote its natural hazards awareness programs, including seismic rehabilitation and education, and landslide and tsunami awareness. "It's exciting to be able to combine my media skills with my love of geology to help the people of Oregon learn about the dynamic environment they live in," said Roddey. "DOGAMI's work has the potential to save lives. I can't think of anything that's more important than that."

Roddey grew up in Atlanta, Georgia, and attended Wofford College in Spartanburg, South Carolina, where he majored in English with a minor in Geology. He notes that Oregon and the Northwest have always intrigued him. "Ever since I visited the Northwest when I was 11 years old, I've wanted to know this area better. Portland makes a great home base for exploring," said Roddey. □

Meteorites from the Pacific Northwest

by George E. Mustoe, Geology Department, Western Washington University, Bellingham, WA 98225.

INTRODUCTION

One day, long before Europeans arrived in the Pacific Northwest, the fiery trail of a large meteorite illuminated the skies over southern Oregon. Unlike the distant shooting stars that can be seen on any clear night, the glow in the sky warned of an imminent arrival of a 1,167-kg (1.3-ton) mass of nickel-iron alloy that had once been part of the core of an asteroid. After more than 4 billion years in orbit, the eggshaped object hurtled into our atmosphere at a velocity of somewhere between 11 and 32 km per second. The meteorite's trajectory was toward the lava beds of southern Oregon and northern California, but the object's final resting place was a high mesa near Goose Lake in northern Modoc County, California, only a mile short of the Oregon border.

The meteorite was found on October 13, 1938, by three deer hunters and was recovered the following year by meteorite scientist H.H. Nininger, assisted by three professors from the University of California at Los Angeles, several local residents, and a team of boy scouts. The specimen was loaded onto a sturdy wagon and hauled by four draft horses over 2.5 mi (4 km) of muddy, boulder-strewn trail to reach the nearest road (Figure 1), ultimately headed for the exhibition halls of the National Museum in Washington, D.C. The Goose Lake meteorite is presently the largest meteorite in the Smithsonian's collection (Leonard, 1939).

Oregon's near-miss experience with the Goose Lake meteorite provides an appropriate background for this review of meteorites from the Pacific Northwest, because the state is better known by meteorite enthusi-

Figure 1. Goose Lake, California, meteorite loaded on cart for transport. From Nininger (1972), p. 177.

asts for tales of frustration rather than for happy discoveries. Examples include the Willamette meteorite, which triggered a bitter property-rights dispute that ultimately resulted in the removal of the nation's largest recovered meteorite to the east coast. The well-publicized story of the "lost" Port Orford meteorite has given several generations of Oregonians the hope of another spectacular find, but this legendary discovery now appears to have originated as a hoax (Clarke, 1993).

Disappointments continue to plague meteorite hunters: a spectacular fireball and smoke trail marked a meteorite arrival in Grant County on the afternoon of October 23, 1987. Witnesses described a "whomping" sound similar to the noise made by a helicopter, as well as an explosion that probably marked the meteorite's disintegration during its final passage through the atmosphere. The flight path was established by compass bearings made by a Forest Service archaeologist who happened to be working at a site in the Ochoco Mountains, and a logging crew at Pismire Camp on a ridge northwest of Mount Vernon happened to be almost directly beneath the object when it exploded at an altitude of 18,000 ft (5,500 m). This evidence allowed the impact site to be determined within a few miles. But the steep, forested terrain presents adverse conditions for meteorite hunting, which is made even more difficult by the abundance of black basaltic rocks that camouflage the presence of extraterrestrial arrivals. So far, the meteorite has not been found (Pugh and others, 1989; Norton, 1994). Fireballs are relatively common astronomical events, but meteorites are rarely recovered. Oregon fireballs have been described by Pugh (1982, 1984, 1987, 1993, 1995, 1997); Pugh and Stratton (1991); Pugh and McAfee (1993).

ORIGIN OF METEORITES

The vast majority of meteorites are fragments of asteroids, microplanets that orbit the sun within a series of well-defined belts that are located between Mars and Jupiter. Asteroids were once thought to be pieces of a single planet that broke apart billions of years ago, but the wide range of compositional variations observed in meteorites suggests that they derived from many different parent bodies (McSween, 1987).

Most asteroids travel in the same direction in which the planets in our solar system rotate but along paths that cause them to periodically approach the Earth. These orbital intersections may cause an asteroid to be captured by our planet's gravitational field. *Meteors* are bits of extraterrestrial matter that are accompanied by a blaze of light as they are heated by friction during their transit through the atmosphere. *Meteorites* are objects that actually strike the Earth's surface.

A few meteorites have been discovered that contain trapped gasses resembling the composition of the Martian atmosphere. This suggests that these objects originated as crustal rocks ejected from Mars by large meteorite impacts (Bartusiak, 1981; Vickery and Melosh, 1987). These specimens also show radiometric ages of only about 1.3 billion years, compared to the 4.5 billion years of meteorites derived from asteroids. Among the rarest of all are meteorites are fragments of the moon. Of the more than 10,000 meteorite specimens that have been recovered from Antarctica, eight appear to be of lunar origin.

DISTRIBUTION

Most asteroids travel in orbital planes that are approximately parallel to the Earth's equator. This causes impacts to be somewhat more abundant at middle latitudes than in the polar regions. Otherwise, meteorite impacts have a random distribution pattern, and they occur with surprising frequency. Perhaps 100 to 1,000 tons of extraterrestrial matter strikes our planet each day, mostly in the form of dust-sized particles (Dodd, 1986). Over the past 4.5 billion years, this volume is equivalent to a surface layer about 5 in. (12.7 cm) thick. Meteorites weighing 1 g (0.04 oz) or more arrive at an annual rate of about 8 per square mile, but only a tiny percentage of these are ever discovered. Several hundred meteorites weighing 1 ton or more strike the Earth each year, but most escape detection, partly because 72 percent of the planet is covered by water.

Geography plays an extremely important role in determining the success rate for meteorite recovery. Most meteorites are discovered in prairies, deserts, and other regions that contain few surface rocks. Antarctic glaciers have recently been discovered as particularly favorable collecting locations. Extensive ice sheets provide large areas where cosmic debris accumulates free of rocks. Ice that melts and evaporates in "ablation zones" causes meteorites to be concentrated in a relatively small area, where they are gathered by packs of scientists traveling on snow machines (Marvin and MacPherson, 1992).

Meteorites are susceptible to rapid oxidation, and the combined forces of weathering, erosion, and sedimentation cause most impact craters to be quickly obliterated. Without such geologic processes, the surface of our planet would resemble the Moon or Mercury, two locations where impact craters have been preserved for billions of years (Figure 2).

Meteorites that hit land are likely to be recovered only when they strike densely populated regions, particularly in nations where people have been educated in basic principles of geology and astronomy. This principle is well illustrated by the spectacularly successful efforts of Harvey Nininger, who abandoned his college teaching career to devote his life to searching for meteorites. Over a span of nearly 50 years, Nininger tirelessly spoke at schools, churches, taverns, and any other location

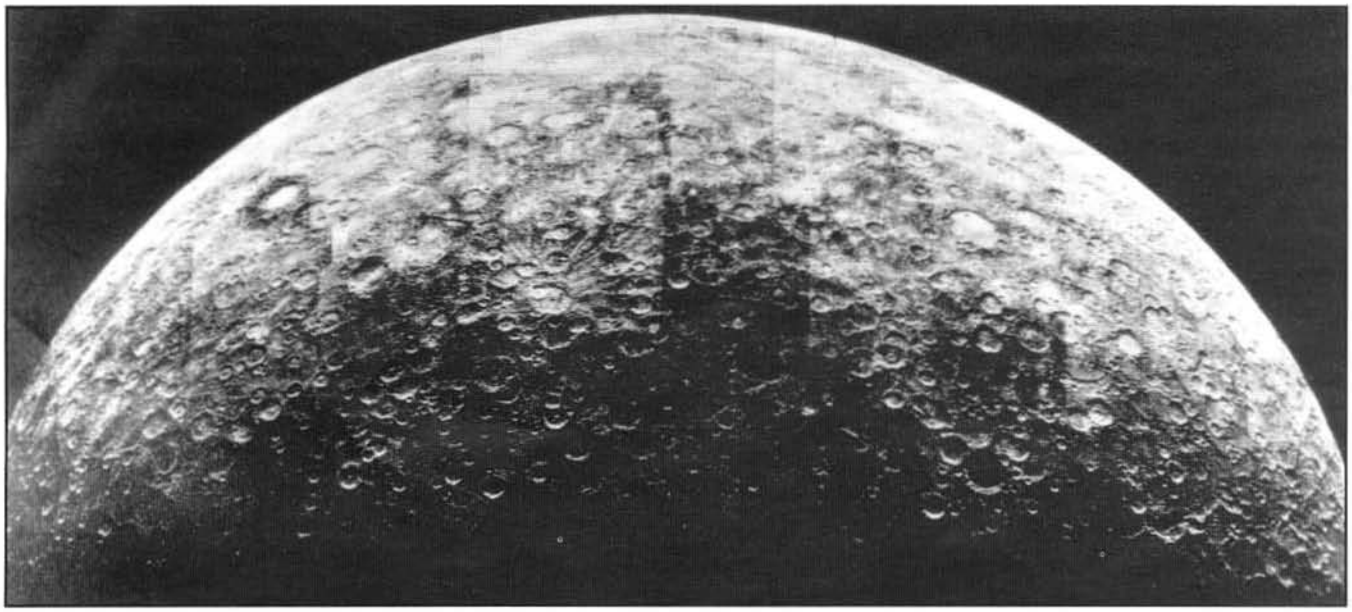


Figure 2. Meteorite impact craters on Mercury. From photos taken March 29, 1974, by the Mariner space probe. The largest craters are 200 km in diameter. Source: National Aeronautics and Space Administration.

where people gathered. Passing around a few specimens, the scientist asked his audience to contact him if they found any odd rocks. As a further reminder, he distributed as many as 200,000 leaflets. These efforts resulted in his acquisition of more than 2,000 meteorites, accompanied by a trove of new scientific information (Nininger, 1972).

On a much smaller scale, then Oregon State Geologist Hollis Dole, science writer Phil Brogan, and Portland State University professor Erwin Lange organized a publicity campaign to declare 1968 "The Year of the Meteorite," in the belief that more specimens might be found in Oregon if residents knew what to look for. This campaign failed to turn up any new meteorites, but the project resulted in the publication of a monograph that is still in print (Oregon Department of Geology and Mineral Industries, 1968). A similar plea by the Washington Division of Geology and Earth Resources produced no new specimens (Moen, 1973). In recent years, Portland science teacher Richard N. Pugh has been a leading investigator in the continuing search for meteorites from the Pacific Northwest.

Figure 3 shows the location of all known meteorite discoveries in the western United States. These data show the effect that geography and demographics have on the statistics of meteorite recovery. A multitude of meteorites probably remains undiscovered in the fields, forests, and deserts of the Pacific Northwest. Most discoveries have occurred in open, arid terrain, particularly in regions like eastern Colorado, where intensive agriculture causes the land to be inspected with great care. In addition, the presence of extensive loess deposits increases the likelihood that chunks of rock might be visitors from space. In contrast, Nevada and Utah both contain large desert areas where meteorites are likely to be preserved, but the scantness of population makes the odds of discovery very low, and the abundance of terrestrial rocks makes the recognition of meteorites difficult.

METEORITE RECOGNITION

Meteorites are seldom easy to recognize except in the rare cases where their arrival has been observed. Even alleged eye-witnessed impacts should not be taken for granted, and the literature contains many examples where nonmeteoritic specimens were collected from "observed" falls. These errors usually result from the failure of witnesses to realize that a meteorite's final impact site may be many miles distant from locations where the vapor trail was visible.

Meteorites can be divided into three main groups: irons, stones, and stony irons. Scientists further divide these categories into many additional subunits on the basis of data that can only be obtained by careful microscopic examination of thin sections (Mason, 1962; Wasson, 1974; Dodd, 1981; Sears, 1978).

As their name suggests, iron meteorites or "siderites" are composed mostly of interlocking crystals of nickel-iron alloy, often containing small inclusions of carbon and sulfur minerals. Iron meteorites are believed to originate within the inner core of asteroids, released when the parent bodies became fragmented during orbital collisions.

Such metallic meteorites are dark in color, strongly attracted to a magnet, and heavy for their size. The exterior surfaces rapidly alter to form a rusty rind. Unfortunately, these same

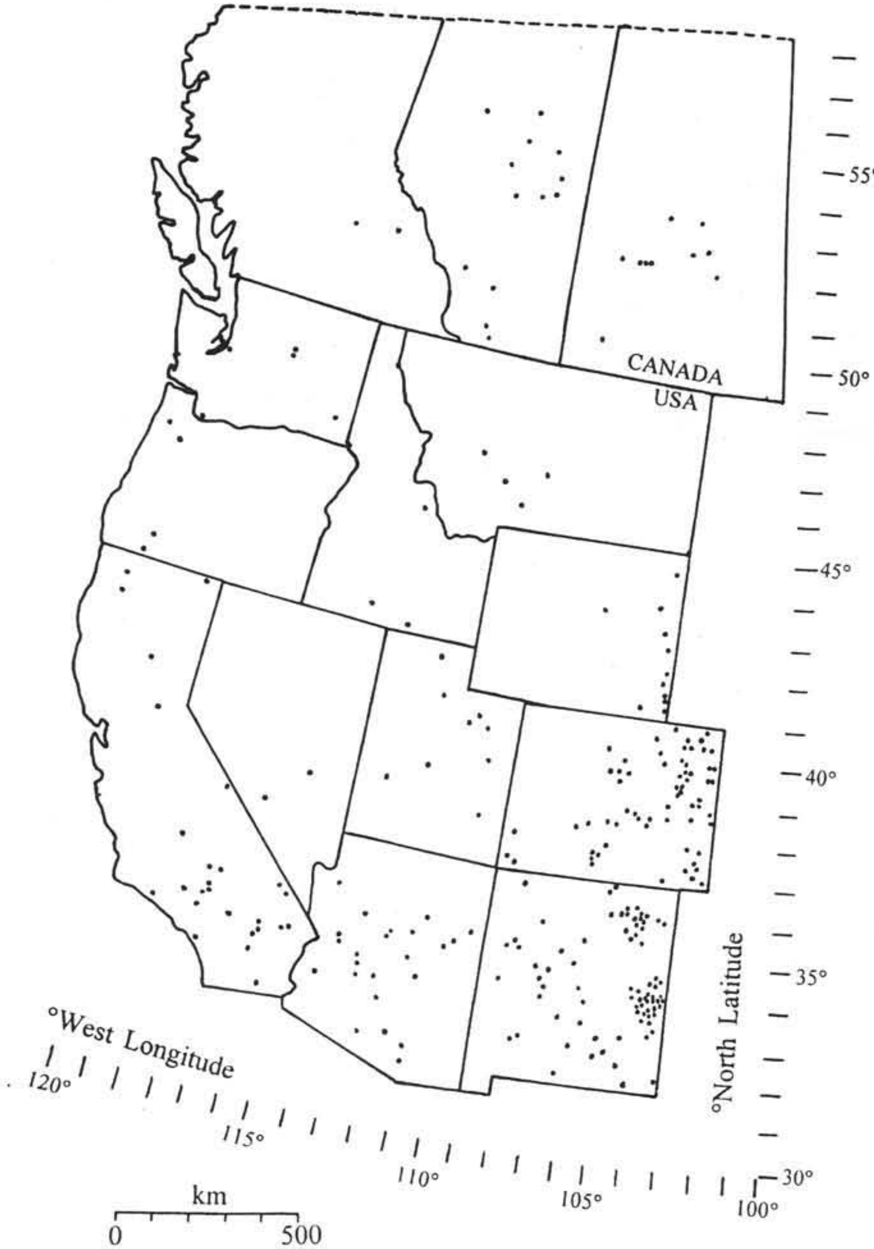


Figure 3. Known meteorite discoveries from the western United States. Data from Graham and others (1985).

characteristics are shared by slag, scrap metal, and some terrestrial iron ores. Metallic meteorites can most reliably be recognized by the presence of nickel, as revealed by chemical analysis. Etching sawn surfaces in dilute nitric acid sometimes reveals complex Widmanstätten patterns, which were created by crystals of kamacite and taenite, two types of nickel-iron alloy. Specimens from Sams Valley, Jackson County, Oregon, provide excellent examples of characteristics typically found in metallic meteorites (Figure 4).

Stony iron meteorites consist of approximately equal mixtures of nickel-iron alloy and crystalline silicates such as olivine and hypersthene. Pallasites are a variety that is particularly prized by collectors. They are composed of pea-sized crystals of olivine enclosed within a matrix of silver-colored metal. The only pallasite that has been reported from the Pacific Northwest is the meteorite fragment allegedly collected in 1856 near Port Orford, Oregon, a specimen now believed to actually have been found in Chile.

Stone meteorites are by far the most common variety to strike the Earth, although they are difficult to recognize because of their resemblance to terrestrial rocks. For example, a 26-kg (57-lb) rock was used as a door stop at Oklahoma's Beaver County jail for more than 40 years before it was identified as a meteorite. These asteroid fragments are primarily composed of mafic and ultramafic silicate minerals with small amounts of nickel-iron metal.

Stone meteorites are easy to identify only if they contain remnants of *fusion crust*, a glassy or sooty coating that forms from frictional heating (Figure 5). Otherwise, these meteorites may look much like various types of terrestrial rock, but magnetism remains a useful clue: Grains of nickel-iron alloy may not be visible to the naked eye, but stony meteorites are attracted to a magnet. Textures are commonly granular, resembling basalt or andesite, but some specimens show well-developed brecciation. Although some metallic meteorites contain rounded holes caused by weathering of inclusions, stony meteorites do not contain cavities, and nonmetallic rocks that show vesicular textures are almost certainly of terrestrial origin.

Careful examination of suspected meteorites by use of a hand lens (or better yet, a petrographic microscope) provides valuable evidence. Stony meteorites typically contain olivine, members of the pyroxene group (hypersthene, enstatite, and bronzite), and small amounts of plagioclase feldspar. Pyrite, mica, hornblende, and orthoclase feldspar do not occur in meteorites, and the presence of these minerals even in small amounts is clear evidence of the specimen's terrestrial origin. Quartz is exceedingly rare, and never present as a major constituent. Many stony meteorites contain *chondrules* (and are then called "chondrites")—tiny

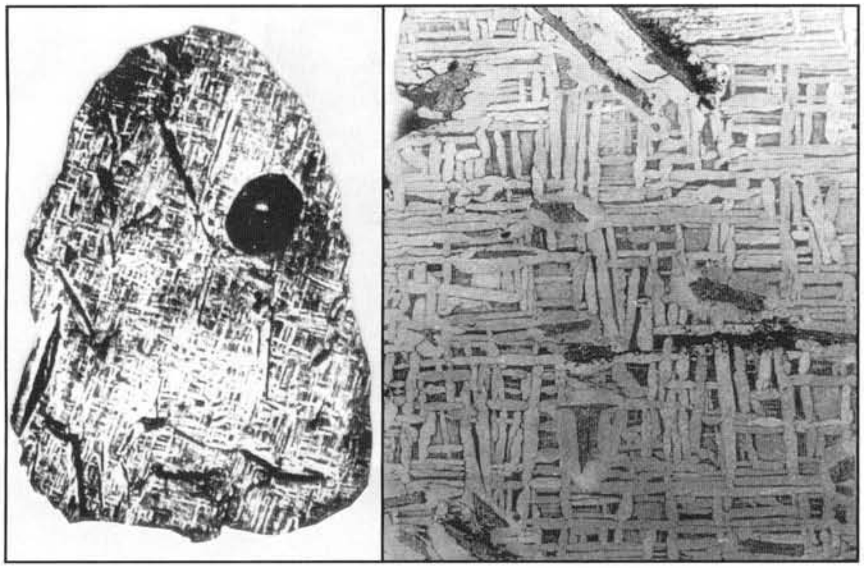


Figure 4. Widmanstätten pattern on etched slice of metallic meteorite from Sams Valley, Oregon. Actual size 12×17 cm. Right: Close-up of etched slab (magnification approximately 4X). Left picture from Foote (1915), right picture from Norton (1994).

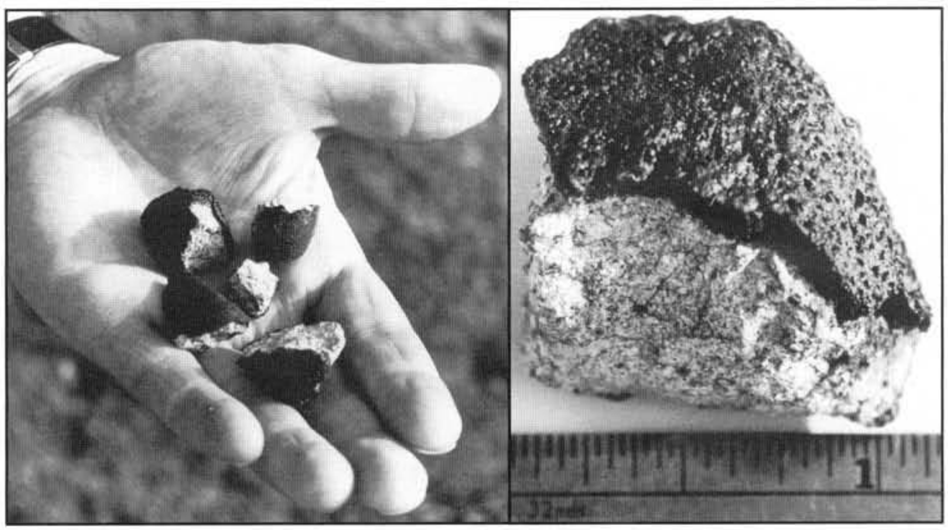


Figure 5. Fusion crust shown on the five recovered fragments of stony meteorite from Salem, Oregon (left), and in close-up view of one of the pieces (right). From Pugh (1983).

spherical grains that may be visible on broken surfaces or polished slabs. Metallic grains of nickel-iron alloy are almost always visible on polished surfaces as tiny silver specks dispersed within the silicate matrix.

Most geologists have little or no training in the recognition of meteorites, and identifications made by local universities or governmental agencies are not always reliable. Instead, meteorite identification is a task that should be left to experts. The appendix lists museums and universities that will identify specimens at no charge. In most cases, these institutions will offer to purchase samples that prove to be meteorites, but collectors need to keep in mind that meteorites legally belong to the person who owns the property on which they were found. Specimens found on state or federal land belong to the government, and legal ownership cannot be acquired by filing a mining claim, as meteorites are not considered to be a type of ore deposit. However, institutions such as the Smithsonian have sometimes been willing to pay finder's fees to people who report discovery of a meteorite on public land.

METEORITE OCCURRENCES IN OREGON

The following list includes alleged meteorite discoveries that have been described in publications ranging from scientific journals to local newspapers.

Willamette meteorite, Clackamas County, Oregon

The Northwest's most important meteorite discovery was made in the autumn of 1902 by Ellis Hughes, a 43-year-old emigrant from Wales. Hughes noticed an unusual rusty outcrop while he was cutting firewood near his farm just northwest of Willamette, a small community that has since been engulfed within the boundaries of West Linn, a Portland suburb. Previous experience as a prospector caused Hughes to believe that the rock was evidence of an ore deposit, and he notified his neighbor, William Dale. Dale pounded on the outcrop with a piece of stone, producing a metallic clang that led the

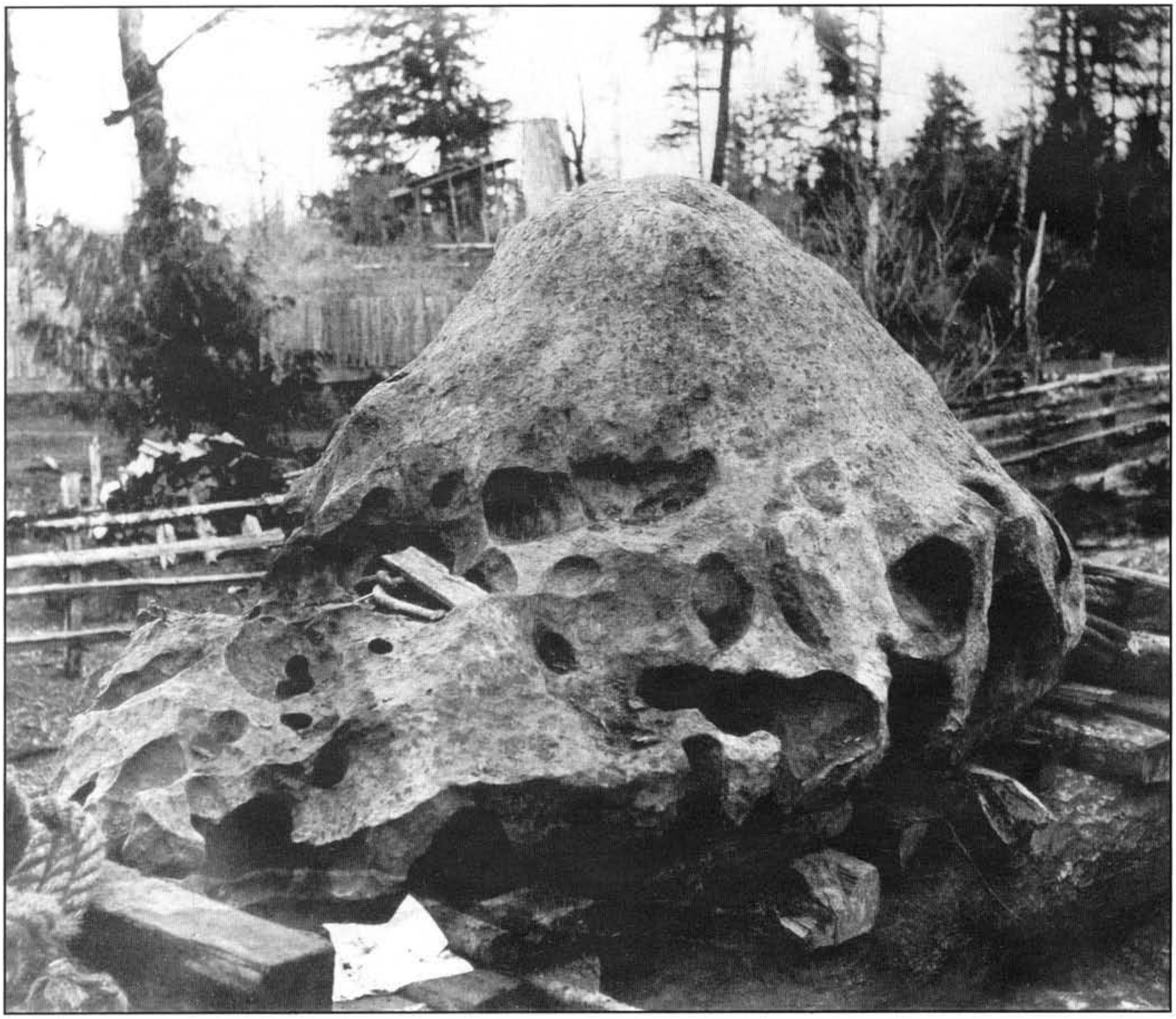


Figure 6. Willamette meteorite in front of the Johnson farm in the town of Willamette, on the southern outskirts of Portland, Oregon, at the time when it was being transported to its current location in New York. Photo by Harold Johnson from cover for Pugh and Allen (1986).

two men to conclude that they had discovered an enormous meteorite (Figure 6). Their excitement was dampened by the fact that the land was owned by the Oregon Iron and Steel Company, and they decided to hide the partially excavated meteorite under a layer of fir boughs, while they concocted a scheme to acquire ownership.

Dale traveled to eastern Oregon to sell a piece of property and thus raise money for purchasing the tract where the meteorite was located, but for reasons that are not clear he failed to return to Willamette. Lacking funds of his own, Hughes decided to transport the meteorite secretly to his farm. This ambitious task required moving the 15.5-ton (14,000-kg) mass three quarters of a mile through dense forest. Aided by his wife and their 15-year-old son, Hughes began excavating the meteorite in August 1902. During fall and winter, they cut a wagon road to the site, also constructing an additional stretch of road in the opposite direction as a distraction. By spring, they were ready to begin transporting the meteorite, using a massive wooden-wheeled cart attached to a hand-braided steel cable that was connected to a crude windlass. A single horse walked in circles around the capstan to provide the locomotion. Progress was tediously slow, on some days amounting to only a few feet; the best day's progress was only 150 ft (46 m). By summer's end, rain turned the path to a sea of mud, requiring construction of a plank road. After months of effort, the meteorite finally reached the Hughes family farmyard, and they attempted to profit from the enterprise by building a display shed and charging visitors 25 cents to view the largest meteorite ever found on United States soil. In North America, the Willamette meteorite is surpassed only by the 59-ton (54,000-kg) Ahnigito meteorite found at Cape York, West Greenland, in 1918.

The November 6, 1903, issue of the *Oregon City Enterprise* reported the rumor that the meteorite had been found on property adjoining the Hughes farm. On November 27, the Oregon Iron and Steel Company filed a suit demanding the return of the specimen after an unsuccessful attempt to purchase it for 50 dollars.

Hughes offered an innovative legal defense, claiming that the meteorite was an abandoned Indian relic that should be defined as personal property rather than land. Two elders from the Clackamas tribe testified that their ancestors had named the meteorite "Tomanawos" ("visitor from the Moon") and that it was considered a holy object that belonged to the Clackamas people. Earlier generations of warriors had dipped their arrows in rainwater that collected in cavities on the meteorite's surface to ensure success in battle, and young men were sent to the sacred stone to undergo secret initiation rites. This testimony is consistent with recent discoveries that Native Americans erected an adobe citadel around a 1.5-ton (14,000-kg) meteorite at Casas Grandes, Mexico (LeMaire, 1980). Other tribes may have made regular pilgrimages to meteorite sites at Red River, Texas, and Iron Creek, Canada (Nininger, 1952). Small meteorites have been found carefully wrapped and buried in Native American graves in Arizona and Montana (Lange, 1958b).

Hughes' lawyer expanded his arguments by pointing out the possibility that the meteorite had fallen at some other location and had been transported to the discovery site by glaciers, an argument that has been revived by scientists in recent years. The lawyer argued that the thorny property-rights issue could best be resolved by granting ownership of the meteorite to its discoverer, Ellis Hughes. Instead, the court awarded possession of the meteorite to Oregon Iron and Steel Company and assessed its value at $150. The decision was reaffirmed by the Oregon State Supreme Court on July 17, 1905, with the assessed value increased to $10,000.

The company announced that the Willamette meteorite would remain in Oregon forever, and it was displayed at the 1905 Lewis and Clark Exposition in Portland. When the exposition closed, a wealthy benefactor, Mrs. William E. Dodge, purchased the meteorite for $20,600 and donated it to the American Museum of Natural History in New York City. At that time, it was the highest price that had ever been paid for a specimen in the Museum's collection (Preston, 1988). In 1936, the Willamette meteorite was moved to the Museum's Hayden Planetarium, where it remains one of the most popular displays.

The Willamette meteorite has an asymmetric shape that indicates that the object maintained a constant orientation as it travelled through the atmosphere rather than tumbling randomly. The blunt side represents the leading face, and tapered bell-shaped sides formed as trailing surfaces. When it was initially discovered, the meteorite mysteriously rested in the soil in an upside down position. Prior to impact, the meteorite was possibly affected by air turbulence in the lower atmosphere. However, the immense mass of metal penetrated only about three feet into the soft forest soil, which suggests that the meteorite was not found at the original impact site. The meteorite may have been transported to its place of discovery by an iceberg during one of the great floods that swept across the Columbia basin during the late Ice Age. If so, the impact may have occurred in northern Idaho, western Montana, or southwestern Canada (Pugh and Allen, 1986). The story of this meteorite is also discussed in Lange (1958 a,b; 1962; 1968), LeMaire (1980), and Preston (1988).

Mulino meteorite, Clackamas County, Oregon

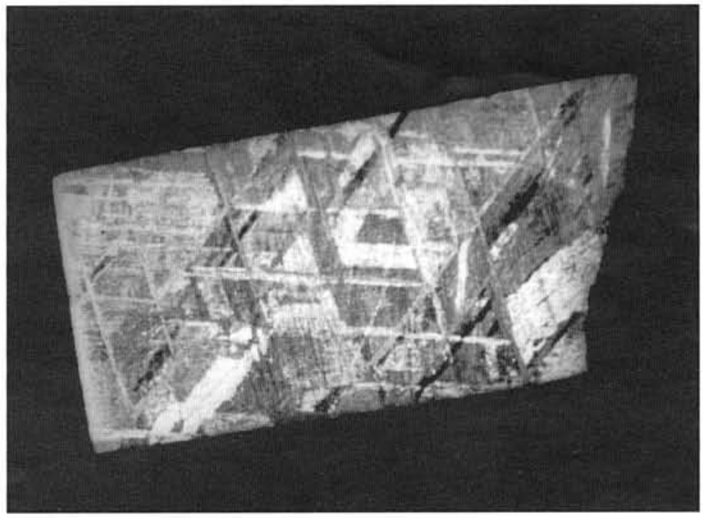
A very small chondrite in the U.S. National Museum is labeled as having fallen May 24, 1927, near Mulino. Later correspondence failed to reveal any local record of a meteorite fall on that date, and the authenticity of the specimen is ranked as "very doubtful" (Hay, 1966; Graham and others, 1985).

Sams Valley meteorite, Jackson County, Oregon

In 1894, a 6.8-kg (15-lb) metallic meteorite was found lying on rocky soil about 10 mi (16 km) northwest of Medford (Figure 7). The specimen was sold in 1914 to the Foote Mineral Company in Philadelphia, then one of the world's largest meteorite dealers. The meteorite was sawn into four main slices and several smaller remnants that were sold to museums and private collectors. A 1.1-kg (2.4-lb) specimen was purchased for $585 by the American Museum of Natural History in New York City, and a slightly smaller slice was purchased by Harvard University. Since then, four other Sams Valley specimens have been discovered, although the circumstances are poorly documented. In 1938, a 1.2-kg (2.6-lb) specimen acquired by the American Museum of Natural History from a Medford resident was forwarded to University of Oregon astronomer J.H. Pruett, who agreed to saw the specimen in exchange for a 1-lb portion. The actual cutting operation was performed by Eugene high school teacher C.A. Coulter and his teenage son Donald, an endeavor that took 11 hours and wore out 18 hack saw blades. Pruett's portion of the meteorite is now in the University of Oregon Museum of Natural History, along with a plaster cast of the

← Left: Figure 7. Two views of plaster cast of metallic meteorite found at Sams Valley, Oregon, in 1894. From Lange (1967).

↓ Below: Figure 8. Etched slice of Klamath Falls meteorite, showing Widmanstätten pattern. Photo courtesy O.R. Norton.



original 6.8-kg Sams Valley specimen. A 2-lb (1-kg) Sams Valley specimen on display at the Jacksonville Museum was discovered in 1949 among a box of uncurated minerals. This meteorite was one of three specimens that were found at Sams Creek in the 1880s by a local resident who was panning for gold. The other two pieces are presently unaccounted for. (See also Foote, 1915; Morley, 1950; Lange, 1967).

Klamath Falls meteorite, Klamath County, Oregon

In January, 1952, a resident in the area discovered a 17-kg (38-lb) metallic meteorite (Figure 8) somewhere in Klamath County. From examination of a small piece, meteorite expert H.H. Nininger confirmed that the sample was indeed a meteorite (Lange, 1968). The finder never returned to inquire about his discovery, and the location of his discovery site remains a mystery. The meteorite was acquired by the University of New Mexico and later subdivided. Small specimens have recently been sold to private collectors (Keith Kaler, Washington State Library, Olympia, oral communication, 1997). A 12.6-g (0.44-oz) sample is in the meteorite collection at the University of Arizona at Tempe.

Salem meteorite, Marion County, Oregon

At 1:05 a.m. PDT, on May 13, 1981, five small chondrite fragments struck the roof of the home of Deputy Sheriff James P. Price in Salem. At the time of the impact, Price was sitting on the curb talking to another deputy. Both men heard a peculiar "fluttering" noise that was followed by the sound of small rocks striking nearby. A search by flashlight produced a still-warm piece that had fallen within 10 ft of the officers. The next morning, four more fragments were recovered, consisting of angular gray stones with outer surfaces covered by a 1-mm-thick dark fusion crust (Figure 5). The specimens were sent to J.C. Evans, Senior Research Scientist at Battelle Pacific Northwest Laboratories in Richland, Washington, where they were analyzed by scanning electron microscopy and energy dispersive X-ray fluorescence analysis (Pugh, 1983). The specimens are now in the possession of Price. (See also Pugh, 1983; Clarke and Pugh, 1988).

South Slough meteorite, Coos County, Oregon

Dodge (1898, p. 442) recounts the tale of an alleged meteorite impact:

"One of the largest meteors on record fell on the head of South Slough, Coos County, January 17, 1890, at 11 o'clock at night, knocking a hole in the hill thirty feet across. It came from the northwest and lighted up the heavens in fine style. A report, as of thunder, awoke people for many miles around. It was plainly heard at Coquille City. Excavations reveal a chunk of lava twenty-two feet across that resembles slag from an iron furnace."

The reported size of the object far exceeds the 9'x9'x3' dimensions of the Hoba meteorite, the world's largest authenticated specimen, and a twenty-two foot meteorite would be unlikely to survive the thermal shock created during its passage through the atmosphere without being explosively fragmented. In the absence of additional information, the reliability of this historic report is very questionable.

Port Orford meteorite, Curry County, Oregon

A pallasite with an estimated weight of 10,000 kg (11 tons) was allegedly discovered in 1856 on a hillside about 40 mi east of Port Orford by John Evans, leader of a government-sponsored expedition to explore possible routes for the railroad. A 30-g (1.1 oz)specimen was turned over to the Boston Natural History Society. Several hundred parties have unsuccessfully attempted to locate this meteorite site in the Siskiyou National Forest in southwestern Oregon, beginning shortly after the discovery was publicly reported in 1859. The Smithsonian Institution organized searches in 1929 and 1939, and although these expeditions were unsuccessful, three articles written by University of Oregon astronomy professor J.H. Pruett triggered an avalanche of interest in the "lost meteorite" (Pruett, 1937, 1939a, 1950). For decades, professional and amateur treasure seekers have trudged the hills bordering the headwaters of the Sixes River looking for the "bald mountain" described by Evans as the site of the meteorite. Possible geographic clues have been described in detail by Henderson and Dole (1964).

Over the years, Evans' account of his discovery has continued to be the subject of considerable scrutiny, and the specimen he collected has been rigorously analyzed. A recent compilation of this information indicates that Evans made up the meteorite story as a hoax that was intended to attract funding for a future expedition and to generate money the geologist needed badly to repay the considerable personal debt that he had amassed from overspending his budget during the original trip.

The texture and composition of Evans' specimen are nearly identical to the Imilac meteorite discovered in the Atacama desert of Chile in 1822, and its weathered surface seems more likely to have been produced in the arid environment of the Atacama region rather than in the humid coastal forests of Oregon. This evidence suggests that Evans might have acquired a fragment of the Imilac pallasite when he passed through the isthmus of Panama on his return from Oregon, hoping that the specimen could provide the means of allaying his pending financial troubles. At present, a 24-g (0.8 oz) "Port Orford" specimen is in the Smithsonian collection (Figure 9), and small fragments are located at the Vienna Natural History Museum and the India Geological Survey Museum, Calcutta. (See also Buchwald and Clark, 1993; Plotkin, 1993; Sedell, 1968).

OTHER NORTHWEST METEORITES

All of the meteorites that have so far been discovered in Oregon have come from the region west of the Cascade Range, even though the less vegetated terrain in the central and eastern parts of the state offer more favorable conditions for meteorite recovery. This discrepancy is explained by the low population density east of the Cascades. In Washington, the most important meteorite specimens were found in the wheat fields of the Columbia Plateau, where extensive cultivation increases the chances that unusual rocks will be noticed.

Waterville meteorite, Douglas County, Washington

The first meteorite to be found in Washington was a 37-kg (82-lb) nickel-iron specimen discovered in 1917 on the Fred Fachnie farm, 16 mi northeast of Waterville (Figure 10). Fachnie's combine struck the Waterville meteorite with such force that the machine's bull wheel was broken. No obstacles had been encountered when the same field had been planted in the spring—with equipment that drilled holes at a 6-in. spacing. The farmer took the specimen to William Schluenz, owner of the local hardware store. Schluenz recognized it as a meteorite, and for the next few years the rock was dis-

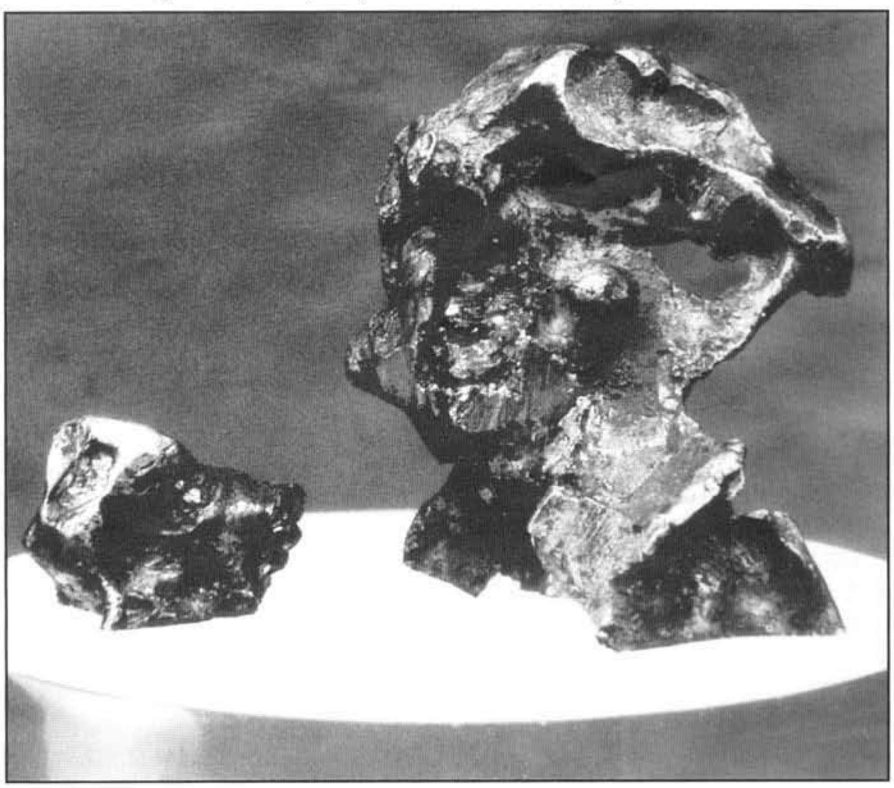


Figure 9. Fragments of meteorite allegedly found in 1856 near Port Orford, Oregon. The larger specimen weighs only 24 g. Photo by Chip Clark from Clarke (1993).

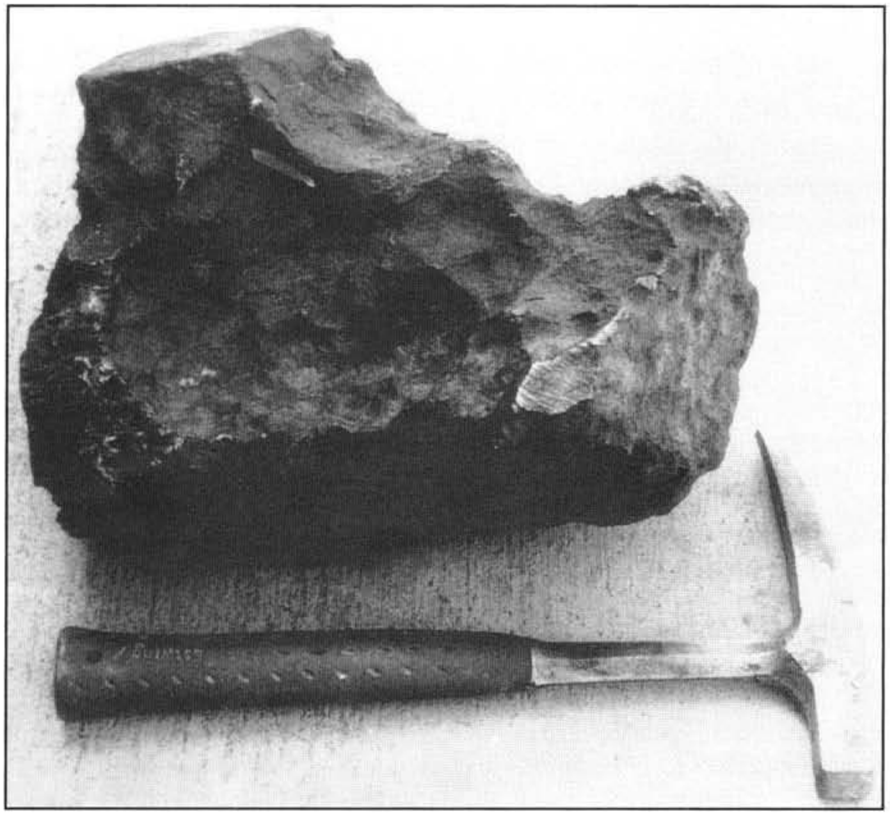


Figure 10. The 37-kg metallic meteorite from Waterville, Washington. From Knoblach (1994).

played in his store. Customers were permitted to try their hand at breaking the dense metallic mass with a hammer, and the meteorite's surfaces bear the scars of many unsuccessful attempts.

In 1921, Fachnie retrieved the somewhat battered specimen and used it as a decoration in his flower garden. In March 1925, a member of the Washington State Historical Society borrowed the meteorite for display at the Ferry Museum in Tacoma. In 1958, Wenatchee residents Mr. and Mrs. Walter Grizzle became disturbed by the museum's careless treatment of the specimen. Slices had been sawn from several of the surfaces, so that the original weight was reduced by nearly 4 kg (9 lb). The Grizzles instigated a four-year legal campaign to have the meteorite returned to the Fachnie family. The museum was unable to produce evidence that the specimen had been received as a donation rather than a temporary loan. In 1963, the meteorite was placed on permanent display at the Douglas County Historical Society Museum in Waterville. A large etched slice is in the Nininger collection at Arizona State University. (See also Read and others, 1967; Grizzle, 1963; Grizzle and Eller, 1961; Weinke and others, 1979).

Withrow meteorite, Douglas County, Washington

In the spring of 1950, an 8.75-kg (19.25-lb) metallic mass was found 1 mi west of Withrow in a wheat field owned by W.C. Nollmeyer, (Figure 11). Since 1966, the specimen has been on display at the Douglas County Historical Society Museum in Waterville. Another 5-kg (11-lb) meteorite found sometime prior to 1951 by a Withrow school teacher is presently unaccounted for. The Waterville and Withrow specimens are similar in composition and appearance, and they may have originated as part of a single shower (Read and others, 1967).

Albion meteorite, Whitman County, Washington

A 12.28-kg (27-lb) specimen found in the winter of 1966–1967 by Kenneth Oliphant in a wheat field adjacent to the Palouse River near Albion was confirmed to be an iron meteorite in 1991 by John Wasson, professor at the University of California at Los Angeles. The Albion meteorite is noteworthy because of the presence of irregular vacuoles that range in diameter from 4 to 9 mm (0.16–0.35 in.). These small cavities are lined with spherical masses that are covered with intergrown cubic crystals of almost pure iron, a feature never before observed in a meteorite (Kempton, 1995).

Washougal meteorite, Cowlitz County, Washington

On the morning of July 2, 1939, climbers on Mount Adams observed the glowing trail of a meteorite streaking across the western sky. Residents of the Portland area heard the accompanying sonic boom, and at 7:35 a.m. PST, a 225-g (8-oz) stony meteorite struck the ground near a person who was picking raspberries near the Columbia River town of Washougal, Washington. This arrival probably involved a mass that fragmented into many pieces just before impact, but searches failed to yield other specimens. The main body of the meteorite is at the University of Oregon Museum of Natural History (Figure 12), while small portions are in collections at Arizona State University and the British Museum. (See also Graham and others, 1985; Carver and Anders, 1975; Jerome and Michel-Levy, 1972; Nininger, 1939; Pruett, 1939b).

Tacoma meteorite, Pierce County, Washington

A single 16.7-g (0.6-oz) nickel-iron meteorite was found on a farm near Tacoma in 1925. Today, 12.1 g (0.4 oz) of it are left at the University of California, Los Angeles, and 2.2 g (0.08 oz) in the Smithsonian Institution. (Graham and others, 1985).

Colton meteorite, Whitman County, Washington

A highly oxidized metallic meteorite fragment was found a few years ago in the Palouse region of southeastern Washington. The specimen, which is presently at the Smithsonian Institution, has not yet been formally described (R.N. Pugh, oral communication, 1997).

Roy meteorite impact, Pierce County, Washington

On August 2, 1929, the *Tacoma News Tribune* reported the following story: "After a thorough investigation of the meteorite landing place on the farm of John L. Murray, two miles south of Roy, less than two weeks ago, it was discovered that the only trace of it left was a hole in the ground three feet in diameter and three feet deep, lined with grayish ash. This investigation led to the belief that in spite of the explosion, which broke windows and tore a door from its hinges on the Murray farm, the phenomenon was so hot as to be of a gaseous nature, when it reached the earth, disintegrating upon landing."

Small meteorites typically produce indentations that are only slightly larger than their own diameter, and failure to discover an object at the impact site is perplexing. Many incoming bodies undergo explosive disintegration as they make their final passage through the atmosphere, but the absence of fragments suggests that the Roy "impact" was possibly a lightning strike. As with many other anecdotal accounts of alleged meteorite impacts, the true story of this event may never be known.

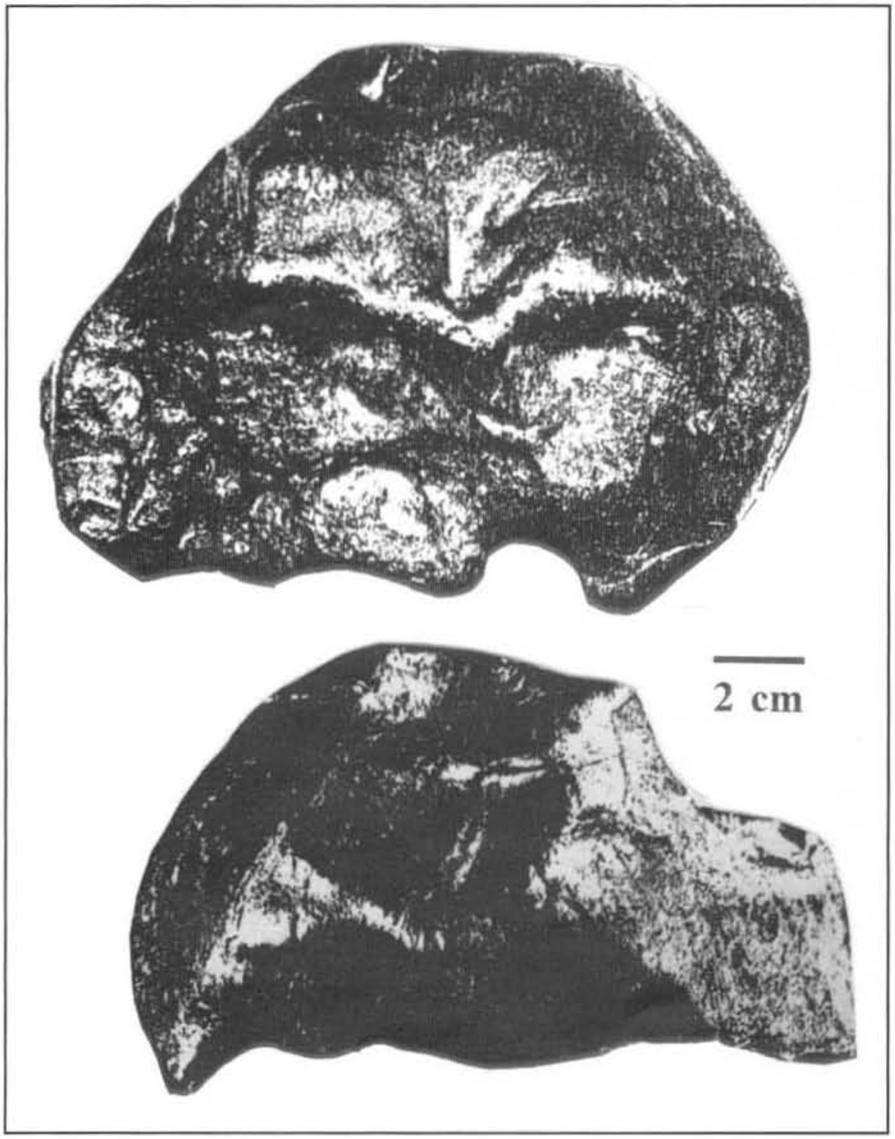


Figure 11. Two views of the 8.75-kg metallic meteorite found in 1950 at Withrow, Washington. Photos courtesy Douglas County Historical Society Museum, Waterville, Washington, which has the Withrow meteorite on display.

Kirkland hoax (?), King County, Washington

Two small metallic objects pierced the dome of an amateur observatory just northeast of Kirkland at approximately 11 a.m. PST, January 17, 1955. The story began when Luther Hawthorne called the local fire department to report smoke issuing from his observatory, shortly after he had heard an explosive report. He discovered that the smoke was coming from a fire in a small shelf of reference books inside the building, and that two small holes were visible in one of the aluminum panels that formed the dome-shaped roof. He discovered two small metallic objects near the book shelf. The specimens proved to be metallic meteorites of somewhat different composition. Read (1963) provided a detailed discussion of this alleged fall, concluding that the event was a legitimate meteorite arrival. The implausible odds of a cosmic impact occurring at a back yard observatory causes most scientists to question the validity of this alleged meteorite arrival. Editions 3 and 4 of the *Catalogue of Meteorites* (Hay, 1966; Graham and others, 1985), a compendium of all known meteorite discoveries, rank the Kirkland fall as "very doubtful." The Kirkland specimens and the damaged dome panel were acquired by the Wenatchee meteorite enthusiasts

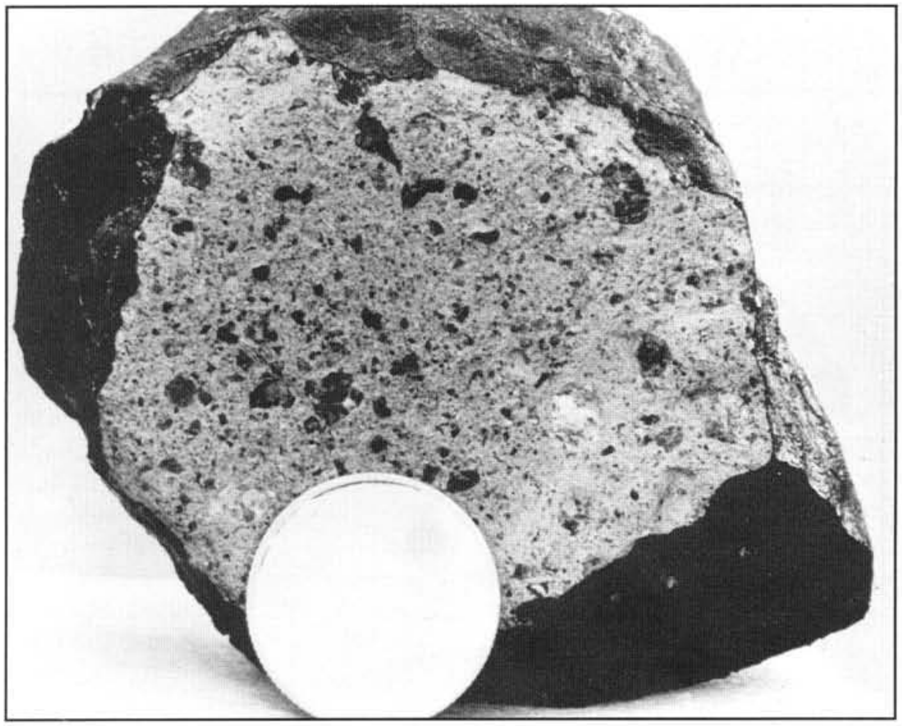


Figure 12. The 220-g stony meteorite that fell near Washougal, Washington, on July 2, 1939. Coin at bottom for scale is a dime (1.7 cm diameter). From Pugh (1982).

Walter and Ellen Grizzle and displayed in 1963 at the Douglas County Historical Society Museum in Waterville, Washington. The present whereabouts of the meteorites, however, are unknown.

Revelstoke meteorite, British Columbia, Canada.

The province of British Columbia ranks as one of the world's worst places to search for meteorites because of the rugged terrain, dense forests, and low population density. However, on the clear night of March 31, 1965, the spectacular arrival of a meteorite was witnessed by thousands of people in British Columbia and Alberta. An extraterrestrial object exploded high in the atmosphere somewhere above the peaks of the Monashee Range, producing shock waves that were detected by seismographs as far away as Colorado. These vibrations were evidence of a blast that had an estimated energy of 20 kilotons of TNT, approximately equal to the atomic bomb that destroyed Nagasaki in 1945 (Chyba, 1993; Carr, 1970, Folinsbee and others, 1967). The Canadian event caused no ground-level damage, however, and an extensive search failed to discover an impact crater. The only physical evidence consisted of millimeter-size meteorite fragments that two fur trappers found darkening the snow near Shushap Lake. Analysis of less than 1 g (0.04 oz) of recovered material revealed that the Revelstoke meteorite was a carbonaceous chondrite, one of the rarest types. As their name suggests, these meteorites contain significant amounts of carbon. Their overall chemical composition resembles the chemistry of the sun, and carbonaceous chondrites may provide us with samples of matter that existed during the earliest stages in the evolution of our solar system.

Beaver Creek, British Columbia, Canada.

Prior to the Revelstoke arrival, the only known meteorites from British Columbia were a pair of stones weighing 2.3 kg (5 lb) and 11.4 kg (25 lb) that struck Beaver Creek in the West Kootenay District on May 26, 1893 (Lange, 1973; Graham and others, 1985). These specimens were cut into slices that were dispersed among many collectors. The largest remnants are a 3-kg (6.6-lb) piece owned by the American Museum of Natural History in New York and a 2-kg specimen in the Field Museum of Natural History in Chicago.

All Pacific Northwest meteorites recovered to date came from relatively small impacts, but some think that the Pacific Northwest has also been the scene of very large cosmic events. Alt and Hyndman (1995) have suggested that an asteroid impact about 17 million years ago during the Miocene Epoch might actually have weakened the crust and triggered outpourings of basaltic lava over the Columbia Plateau and adjacent regions of Washington, Idaho, Oregon, and Nevada. Most geologists believe that conventional plate tectonic forces were responsible for this volcanism, but our increasing knowledge of numerous asteroids that travel in Earth-crossing orbits can suggest that some "extraterrestrial visitors" might play important roles in the geologic evolution of our planet.

ACKNOWLEDGMENTS

Helen Grande, Douglas County Historical Society Museum curator, provided historical information about the discoveries of the Waterville and Withrow meteorites. Dick Pugh and Beverly Vogt contributed helpful reviews of the manuscript.

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APPENDIX

Resource addresses for meteorite identification

Center for Meteorite Studies, Arizona State University, Tempe, AZ 85281.

Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131.

Department of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560.

The American Museum of Natural History, Central Park West at 79th Street, New York, NY 10024.

Institute of Geophysics and Planetary Sciences, University of California, Los Angeles, CA 90024.

Lunar and Planetary Laboratory, Space Sciences Building, University of Arizona, Tucson, AZ 85721. □

Oil and gas exploration and development in Oregon, 1998

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

ABSTRACT

There was a small decrease in oil and gas leasing activity during 1998 compared to 1997. The decrease occurred primarily because Columbia County held no lease sales during 1998, whereas the County held two oil and gas lease sales during 1997, at which approximately 10,405 acres was acquired in the Mist Gas Field area. Four U.S. Bureau of Land Management (BLM) lease sales were held during the year, and no offers were received. During the year, the BLM sold five over-the-counter noncompetitive leases consisting of 11,622 acres located in eastern Oregon. A total of 31,734 federal acres were under lease at year's end. The state of Oregon conducted no lease sales during the year. Eight State of Oregon tracts were under lease at year's end, comprising 3,741 acres.

Six exploratory wells, two redrills, and two underground natural gas storage wells were drilled in Oregon during 1998. One of the exploratory wells was drilled by Jefferson Gas LLC in the Willamette Valley near Albany and was plugged and abandoned. Enerfin Resources shot 3-D seismic data at the Mist Gas Field, Columbia County, and drilled five of the exploratory wells and the two redrills. Of these, two exploratory wells and two redrills were successful gas wells, and three exploratory wells were plugged and abandoned. Northwest Natural drilled two underground natural gas storage service wells, which will be used for injection-withdrawal and monitoring at the Calvin Creek Underground Natural Gas Storage Project.

At the Mist Gas Field, 19 wells were productive during 1998. A total of 1.3 billion cubic ft of gas (Bcf) was produced during the year with a total value of $2.6 million.

The Oregon Department of Geology and Mineral Industries constructed an oil and gas internet webpage that contains production and other data, drilling application forms, statutes and rules, available publications and other information.

LEASING ACTIVITY

Oil and gas leasing activity was slightly lower during 1998 compared to 1997. The U.S. Bureau of Land Management (BLM) held four lease sales during 1998, at which no bids were received. The BLM sold five over-the-counter noncompetitive leases consisting of a total of 11,622 acres. These leases are located in eastern Oregon in the Prineville District. A total of 31,374 federal acres was under lease at year's end in Oregon, which is a decrease from the 39,131 federal acres under lease at the end of 1997. Total leasing income to the BLM was $43,500 for 1998.

Columbia County held no lease sales during the year, whereas two lease sales were held during 1997, at which four companies leased 10,405 acres, all located near the Mist Gas Field.

The State of Oregon held no lease sales during 1998. At year's end, eight State of Oregon tracts were under lease, comprising 3,741 acres. Total rental income was $3,741 during 1998.

DRILLING AND EXPLORATION ACTIVITY

Six exploratory gas wells, two redrills, and two underground natural gas storage wells were drilled in Oregon during 1998. This is an increase from the four underground natural gas storage wells drilled during 1997.

All but one of these wells were drilled at the Mist Gas Field, Columbia County, where most of the state's oil and gas drilling activity has occurred since the field was discovered in 1979. The other exploratory well was drilled by Jefferson Gas LLC of Park City, Utah, in the Willamette Valley about 5 mi north of Albany. This well, the Clayton #1, located in NW¼ sec. 20 (NE¼ sec. 58 land grant section), T. 10 S., R. 3 W., was drilled as an exploratory well for natural gas and also for possible use as an underground natural gas storage well. It was drilled to a total depth of 1,356 ft and was plugged and abandoned.

At the Mist Gas Field, Enerfin Resources Company, Houston, Texas, conducted a 3-D seismic program and, on the basis of the data obtained, drilled five exploratory wells and two redrills during the year. Of these, two exploratory wells and two redrills were successful gas wells.

The successful gas wells are the JH 22-27-64, located in NW¼ sec. 27, T. 6 N., R. 4 W., drilled to a total depth of 2,211 ft; and JH 32-27-64, located in NE¼ sec. 27, T. 6 N., R. 4 W., drilled to a total depth of 2,212 ft. These are both located in the Cedar Point area and are the easternmost successful gas producers discovered to date at the Mist Gas Field. At year's end, these two wells were suspended, awaiting pipeline connection.

Two redrills were also successful during 1998. The first is the CC 32-27-65 RD, located in NE¼ sec. 27, T. 6 N., R. 5 W. This well was a reentry of the Enerfin Resources well CC 32-27-65, drilled in 1996 and suspended, pending further evaluation, now redrilled to a depth of 2,092 ft and completed as a gas producer. The second successful redrill is the CC 41-6-65 RD, located in NE¼ sec. 6, T. 6 N., R. 5 W., originally drilled to a total depth of 2,975 ft and now redrilled to a total depth of 2,970 ft. This well is in the northwestern part of the Mist Gas Field and, at year's end, was suspended, awaiting completion and pipeline connection.

Redrilling the Enerfin Resources well CC 32-27-65 RD was completed in 1998 and resulted in successful gas production.

Three additional exploratory wells drilled by Enerfin and plugged and abandoned are the Busch 34-15-65, located in the SE¼ sec. 15, T. 6 N., R. 5 W., drilled to a total depth of 2,576 ft; the CC 22-26-65, located in the NW¼ sec. 26, T. 6 N., R. 5 W., drilled to a total depth of 1,743 ft; and the CC 41-6-65, located in the NE¼ sec. 6, T. 6 N., R. 5 W., drilled to a total depth of 2,975 ft.

Two underground natural gas storage service wells were drilled by Northwest Natural during 1998. 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 natural gas storage. One of the wells drilled will be used for injection-withdrawal and the other well for monitoring of natural gas in the storage reservoirs. The injection-withdrawal well drilled and completed during 1998 is the IW 22dH-22-65, located in sec. 22, T. 6 N., R. 5 W., and drilled to a total depth of 2,746 ft. This well was horizontally drilled to avoid unfavorable topography and to expose a greater amount of the storage zone to the wellbore to maximize gas injection and withdrawal

Table 1. Oil and gas permit activity in Oregon, 1998

Permit number	Operator, well, API number	Location	Permit activity (TD=total depth)
324	Enerfin Resources CFI 23-15 36-009-00166	SW¼ sec. 15 T. 5 N., R. 4 W. Columbia County	Abandoned; TD 2,770 ft.
436	Enerfin Resources CER 13-1-55 36-009-00265	SW¼ sec. 1 T. 5 N., R. 5 W. Columbia County	Abandoned; TD 1,480 ft.
502RD	Enerfin Resources CC 32-27-65 RD 36-009-00322-01	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD 2,092 ft.
507	Northwest Natural OM 32-22-65 36-009-00327	NE ¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Drilled; service well; TD 2,365 ft
508	Northwest Natural IW 22dH-22-65 36-009-00328	NW ¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Drilled; service well; TD 2,746 ft.
509	Enerfin Resources Busch 34-15-65 36-009-00329	SE ¼ sec. 15 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 2,576 ft.
510	Enerfin Resources CC 22-26-65 36-009-00330	NW ¼ sec. 26 T. 6 N., R. 5 W. Columbia County	Abandoned; dry hole; TD 1,743 ft.
511	Enerfin Resources Larkin 43-23-65 36-009-00331	SE ¼ sec. 23 T. 6 N., R. 5 W. Columbia County	Permit issued; proposed TD 2,240 ft.
512	Jefferson Gas LLC Clayton #1 36-043-00019	NW ¼ sec. 20* T. 10 S., R. 3 W. Linn County	Abandoned, dry hole; TD 1,356 ft.
513	Enerfin Resources CC 22-26-65 36-009-00330	SW¼ sec. 23 T. 6 N., R. 4 W. Columbia County	Application, proposed TD 2,390 ft.
514	Enerfin Resources CC 22-26-65 36-009-00330	NW¼ sec. 27 T. 6 N., R. 4 W. Columbia County	Completed, gas; TD 2,211 ft.
515	Enerfin Resources CC 22-26-65 36-009-00330	NE¼ sec. 27 T. 6 N., R. 4 W. Columbia County	Completed, gas; TD 2,212 ft.
516	Enerfin Resources CC 22-26-65 36-009-00330	SE¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Application, proposed TD 2,453 ft.
517	Enerfin Resources CC 22-26-65 36-009-00330	SW¼ sec. 22 T. 7 N., R. 5 W. Columbia County	Permit issued; proposed TD 2,825 ft.
518	Enerfin Resources CC 22-26-65 36-009-00330	NE¼ sec. 28 T. 7 N., R. 5 W. Columbia County	Application, proposed TD 2,825 ft.
519	Enerfin Resources CC 22-26-65 36-009-00330	SE¼ sec. 22 T. 7 N., R. 5 W. Columbia County	Permit issued; proposed TD 2,550 ft.
520	Enerfin Resources CC 22-26-65 36-009-00330	SE¼ sec. 28 T. 7 N., R. 5 W. Columbia County	Application, proposed TD 3,000 ft.
521	Enerfin Resources CC 22-26-65 36-009-00330	NE¼ sec. 6 T. 6 N., R. 5 W. Columbia County	Abandoned; dry hole; TD 2,975 ft.
521RD	Enerfin Resources CC 22-26-65 36-009-00330	NE¼ sec. 6 T. 6 N., R. 5 W. Columbia County	Suspended, gas; TD 2,970 ft.

* NE¼ sec. 58 land grant section

efficiency. The well was drilled as a replacement to the IW 22d-22-65, which was drilled during 1997 but was lost and subsequently plugged because of echanical problems that occurred during cementing of the intermediate casing string. The monitoring well drilled and completed is the OM 32-22-65, located in NE¼ sec. 22, T. 6 N., R. 5 W., and drilled to a total depth of 2,365 ft.

Total footage drilled for 1998 was 22,715 ft. Average depth per well was 2,272 ft.

Enerfin Resources plugged and abandoned two depleted former producers at the Mist Gas Field during 1998. These are the CFI 23-15, located in SW¼ sec. 15, T. 5 N., R. 4 W., and the CER 13-1-55, located in SW¼ sec. 1, T. 5 N., R. 5 W. In addition, Enerfin did a workover at the formerly suspended LF 32-20-65R RD well to increase production capabilities, and the well was returned to gas production at year's end.

Enerfin Resources received permits and shot 2-D seismic programs at the Rocky Point Prospect located south of Vernonia, Columbia County, and the Looney Butte Prospect located in the Willamette Valley south of Salem.

During 1998, the Oregon Department of Geology and Mineral Industries (DOGAMI) issued 10 permits to drill. Permit activity is listed in Table 1.

PRODUCTION

The Mist Gas Field was operated by Enerfin Resources and Northwest Natural during 1998. During the year, 19 natural gas wells were productive at the Mist Gas Field, 15 operated by Enerfin Resources and four operated by Northwest Natural. This is the same number of productive wells at the Mist Gas Field as during 1997. Gas production for the year totaled 1.3 billion cubic feet (Bcf) of gas, which is slightly less than the 1.4 Bcf produced during 1997. Most of the decrease can be attributed to the normal decline from existing wells and the addition of only one new well during the year.

The gas price remained constant all year at about 23 cents per therm, which is slightly higher than the 21 cents per therm during 1997. The total value of gas produced at the Mist Gas Field during 1998 was about $2.6 million, which is about the same as during 1997. Cumulatively, the Mist Gas Field has produced about 63 Bcf of gas with a total value of $122 million since it was discovered in 1979.

GAS STORAGE

The Mist and the Calvin Creek Underground Natural Gas Storage Projects were both operational during 1998. The Mist Gas Storage Project has nine injection-withdrawal service wells and 13 monitoring service wells. The Calvin Creek Gas Storage Project has 3 injection-withdrawal service wells and four monitoring service wells. The two gas storage projects have a total storage capacity of about 15 Bcf of gas in the reservoirs at pressures between approximately 400 and 1,000 psi and will provide maximum daily peak delivery capability of approximately 145 million cubic feet (MMcf) of gas per day.

During 1998, Northwest Natural began an evaluation of the depleted Busch Pool located in SW¼ sec. 15, T. 6 N., R. 5 W., to determine if it had any possible future use for underground natural gas storage. Previous gas injection testing of this pool was unsuccessful because of water invasion into the reservoir. Northwest Natural began an evaluation wherein gas would be injected into the reservoir at a pressure slightly greater than initial reservoir pressure, in an attempt to move the water from the reservoir and return it to usefulness for gas storage. This evaluation was ongoing at year's end.

OTHER ACTIVITIES

DOGAMI has constructed an oil and gas internet homepage. The webpage address is http://sarvis.dogami.state.or.us/oil/homepage.htm. Included on this homepage are Mist Gas Field production figures data, oil and gas statutes and administrative rules, drilling permit application forms and other forms, a publication list, and other information. Plans are to add a historical database to the homepage that will show wells drilled in Oregon, locations, and dates drilled, total depth, available well logs and samples, and other data.

The Northwest Energy Association (NWEA) remained active during 1998 with over 100 members. At its regular monthly meetings, speakers give talks on subjects related to energy matters in the Pacific Northwest. The annual fall symposium was held in the Portland area, and plans are being developed for the 1999 fall symposium. For more information, contact the NWEA, P.O. Box 6679, Portland, OR 97228.

Triennial revisions to Oregon Administrative Rules Chapter 632, Division 10 (oil and gas) and Division 15 (information and seismic test hole) will be performed during 1999. For information, contact DOGAMI.

The annually updated *Mist Gas Field Map,* DOGAMI Open-File Report O-99-1, 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 attached production summary for 1993–1998 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.

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. Contact the Nature of the Northwest Information Center (503-872-2750) for a complete publication list. □

Geothermal exploration in Oregon, 1996–1998

by Dennis L. Olmstead, Oregon Department of Geology and Mineral Industries

ABSTRACT

Geothermal-resource drilling and leasing activity in Oregon passed its peak during the 1980s and the first half of the 1990s. Lease expirations and releases greatly outnumbered new filings from 1996 to 1998, and drilling activity was nonexistent during those years.

Several previously drilled wells still exist at Newberry volcano, and a small amount of well logging and instrument testing has occurred, but there is no promise of renewed activity in the near future. CE Exploration has moved its project from Newberry to Glass Mountain in northern California. Anadarko Petroleum plugged three wells in the Borax Lake area of Harney County, and no more drilling is likely in the Alvord Desert any time soon. The Bureau of Land Management compiled weather and water data from Borax Lake, covering several years in the 1980s and 1990s. These background data could be valuable in the event of future exploration in the Alvord Desert.

The Department of Geology and Mineral Industries produced a report on the geothermal resources of southeast Oregon. The study included air-photo fault analysis and satellite image analysis.

Direct use of hot water for space heating, snow melting, and greenhouses continues, primarily in the Klamath Falls, Lakeview, and Vale areas. The Oregon Institute of Technology Geo-Heat Center continues to publish its *Quarterly Bulletin* with national and international papers on direct use of geothermal energy and now maintains a web page.

LEASING

No geothermal lease sales were held during the 1996–1998 time period. Table 1 shows existing leasing levels for those years. USDA Forest Service (USFS) and USDI Bureau of Land Management (BLM) geothermal leasing consisted mainly of expiring or terminated leases and relinquished acreages. At the end of 1998, federal acreage under lease in Oregon for geothermal exploration totaled 58,027 acres.

DIRECT USE

The Geo-Heat Center at the Oregon Institute of Technology (OIT) in Klamath Falls has published its third edition of "Geothermal Direct-Use Engineering and Design Guidebook" (Lund and others, 1998). Last published in 1991, this update contains 19 chapters based on technical experience at OIT and reflecting current trends in the industry. The book covers material on the nature of geothermal resources, exploration for direct-heat resources, geothermal fluid sampling techniques, drilling and well construction, well testing and reservoir evaluation, materials selection guidelines, well pumps, piping, heat exchangers, space-heating equipment, absorption refrigeration, greenhouses, aquaculture, industrial applications, egineering cost analysis, regulatory and commercial aspects, and environmental considerations.

The Geo-Heat Center has also prepared a "Geothermal Greenhouse Information Package". It is intended to provide a foundation of background information for developers of geothermal greenhouses. The material consists of seven sections covering crop culture and prices, operation costs for greenhouses, heating system design vendors, and a list of other sources of information. Copies are available from the Geo-Heat Center. In addition, OIT has also published an update of greenhouse direct-use development (Lienau, 1997).

Technical assistance from the Geo-Heat Center is on the increase, due in part to their web page

http://www.oit.edu/~geoheat

Figures for 1996 and 1997 are 583 and 761 respectively for inquiries handled. Geothermal (ground-source) heat pumps seem to be a popular informational item, consuming about 30 percent of the OIT technical assistance activity. In addition to the web page, a publication on this topic is "An Information Survival Kit for the Prospective Geothermal Heat Pump Owner" by Kevin Rafferty. He has also written a paper for local Klamath Falls use concerning

Table 1. Geothermal leases in Oregon, federal land, 1996–1998

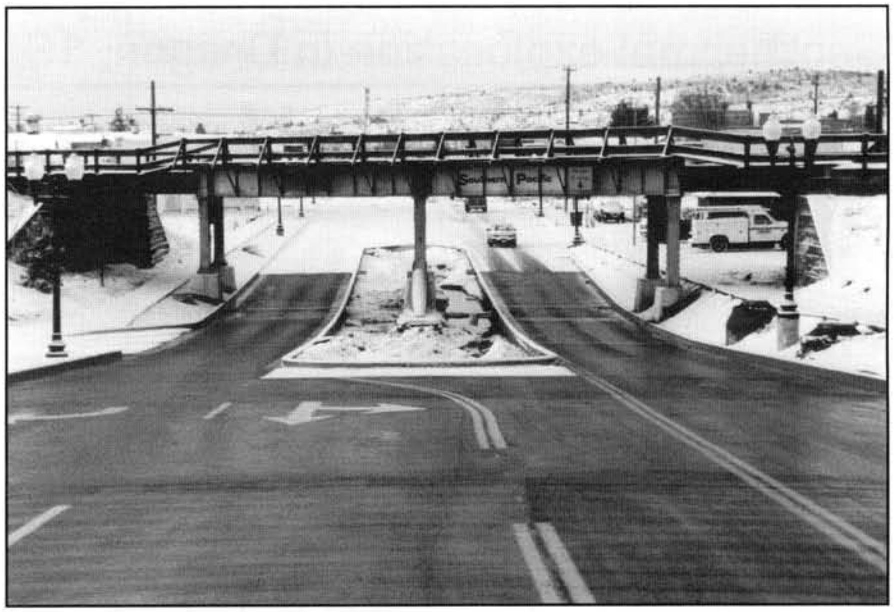
Activity	Number of leases, 1996	Acres, 1996	Number of leases, 1997	Acres, 1997	Number of leases, 1998	Acres, 1998	3-year total acres
Acres filed	1	680	0	0	0	0	680
Acres issued	1	320	0	0	0	0	320
Acres expired	1	623	3	1,961	0	0	2,584
Acres terminated/relinquished	7	13,580	3	3,627	5	6,858	24,065
Leases in effect as of 12/31/96	74	70,473	—	—	—	—	—
Leases in effect as of 12/31/97	—	—	68	64,885	—	—	—
Leases in effect as of 12/31/98	—	—	—	—	63	58,027	—

downhole heat exchangers: "Information for the Prospective Geothermal Home Buyer."

In 1997, the Geo-Heat Center published "Fossil Fuel-Fired Peak Heating for Geothermal Greenhouses" (Rafferty, 1997), outlining how a facility with limited geothermal flow can expand to provide a portion of the heating requirements with a conventionally-fueled peak heating system. The report examined the economics of fossil-fuel peaking for three different climates, including Klamath Falls, Oregon. Data included cost in dollars per square foot of greenhouse floor area and details on capitalization of the equipment, fuel costs, and maintenance for the fossil-fuel peaking system. An additional report (Rafferty, 1996) explored some of the issues related to costs in the installation of geothermal district heating in existing residential areas.

The Klamath Falls district heating system and the OIT geothermal system are still in operation, and status, challenges, and improvements have been summarized in two reports (Brown, 1996; Lienau, 1996). The two systems have added pavement snow melting. OIT now has two main stairs and two handicap ramps heated by geothermal energy; and in downtown Klamath Falls, almost all of the Main Street sidewalks are geothermally heated. In addition, the main downtown bus stop, the new Klamath County Building, and the Catholic church sidewalks are heated. The bridge deck and approach on Esplanade was recently reconstructed, and the 1948 snow melting system was replaced (Figure). About 20 buildings are now part of the downtown geothermal district heating system. These recent updates are documented in two papers presented at the Geothermal Resources Council annual meeting in September 1998 (Boyd, T.L., 1998; Brown, B., 1998). Finally, Lund has summarized geothermal research at the Geo-Heat Center (Lund, 1998).

Additional direct use geothermal heating is under construction in Lakeview, where the new USFS/BLM building will be geothermally heated. A 72°F water well has been drilled and completed, and an injection well is now planned. The building is currently being heated with propane, which will be the backup system after the geothermal system is in place.



Oregon Department of Transportation project on Esplanade in Klamath Falls. Buried warm-water pipes keep snow melted. Photo courtesy John Lund, Geo-Heat Center, Oregon Institute of Technology.

OREGON OFFICE OF ENERGY, DEPARTMENT OF CONSUMER AND BUSINESS SERVICES (OOOE)

With the apparent demise of the Newberry volcano project by CE Exploration, the OOOE has not had much geothermal activity in the past three years. A site certificate for the project was issued by OOOE in early 1996 and has never been terminated. Shortly afterward, the company decided to discontinue operations there and move their efforts to Glass Mountain in northern California (see BPA section below).

OREGON WATER RESOURCE DEPARTMENT (WRD)

WRD has a low-temperature geothermal program, primarily concerned with production and disposal wells for heat-pump space heating. Over the past three years, the program has seen very little activity, with only a handful of permits issued for disposal of spent warm water. Geographically, the permitting is widespread, however, including the Klamath basin, Willamette basin, Umatilla basin, and the Burns area.

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (DOGAMI)

DOGAMI produced a report on the geothermal resources of southeast Oregon (Madin and others, 1996). The presence of numerous hot springs, high regional heat flow, several Known Geothermal Resource Areas (KGRAs), and broad geologic similarities with the geothermal zones of Nevada suggest significant potential. The study covered 11 major regions: North and south Steens, Catlow Valley, Guano Valley, Owhyee Uplands, Lake Abert, Antelope Valley, Turpin Knoll, Gold Creek, Christmas Lake-Summer Lake, and Drewsey. The study combined air-photo fault mapping and satellite-image analysis with some field visits to determine whether the local geology showed evidence of blind geothermal systems. Two areas, Lake Abert and Christmas Lake-Summer Lake, were the subject of more detailed studies of mineralization, oxygen-isotope geothermometry, and soil-mercury (Hg) anomalies. Some areas show low heat flows, no Holocene faulting, and few mineral occurrences, which indicates a poor chance for a blind late Quaternary geothermal sytem. Other areas, such as the southern Steens, have numerous Quaternary faults and extensive mineralization associated with range-front faulting, as well as many active geothermal systems.

Landsat thematic mapper imagery was examined for a large area of southeast Oregon to see whether mineralization at active hot springs could produce a signal to use in searching for inactive hot springs. Several targets were field-checked and some had a definite zone of mineralization and silicification. This technique therefore can be used to find some types (generally silicification) of bedrock units under some circumstances. Hot springs in desert environments are often surrounded by vegetation, which may mask local anomalous mineralization.

The study concluded that the use of indirect methods to prospect for undiscovered blind geothermal systems is only moderately useful. At best, the techniques can eliminate some areas and determine priorities for those that might be targets for further exploration.

INDUSTRY DRILLING ACTIVITIES AND REGULATORY ACTIONS

Anadarko Petroleum Corporation, former operator of three geothermal wells in the Pueblo Valley of southeast Oregon, failed to obtain a power contract and has plugged and abandoned its wells (Table 2). Permits G-153, G-154 and G-155 resulted in wells to depths of about 2,500 ft and capable of 250 gpm flows at around 300°F. The resource was therefore proven, but without a power contract the operator decided against developing the resource. The project had attracted widespread interest due to the existence of the Borax Lake chub in the nearby 10-acre Borax Lake. Ultimately, the three wells were plugged and abandoned in 1996.

Table 2. Geothermal permits and drilling activity in Oregon, 1996–1998

Permit number	Operator, well, API number	Location	Status, date of action
G-153	Anadarko Petroleum Pueblo Valley 25-22A 36-025-90009	NW¼ sec. 22 T.37 S., R. 33 E. Harney County	Abandoned, 1996
G-154	Anadarko Petroleum Pueblo Valley 52-22A 36-025-90010	NE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Abandoned, 1996
G-155	Anadarko Petroleum Pueblo Valley 66-22A 36-025-90011	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Abandoned, 1996
G-174	CE Exploration 88-21 TCH 36-017-90035	SE¼ sec. 21 T. 21 S., R. 12 E. Deschutes County	Suspension status extended.
G-175	CE Exploration 76-15 TCH 36-017-90036	SE¼ sec. 15 T. 21 S., R. 12 E. Deschutes County	Suspension status extended.
G-176	CE Exploration 76-15 36-017-90037	SE¼ sec. 15 T. 21 S., R. 12 E. Deschutes County	Permit canceled, 1997
G-177	CE Exploration 47-15 36-017-90038	SW¼ sec. 15 T. 21 S., R. 12 E. Deschutes County	Permit canceled, 1997
G-178	CE Exploration 23-22 36-017-90039	NW¼ sec. 22 T. 21 S., R. 12 E. Deschutes County	Suspension status extended.
G-179	CE Exploration 86-21 36-017-90040	SE¼ sec. 21 T. 21 S., R. 12 E. Deschutes County	Suspension status extended.
G-182	CE Exploration 88-21 36-017-90041	SE¼ sec. 21 T. 21 S., R. 12 E. Deschutes County	Suspension status extended.

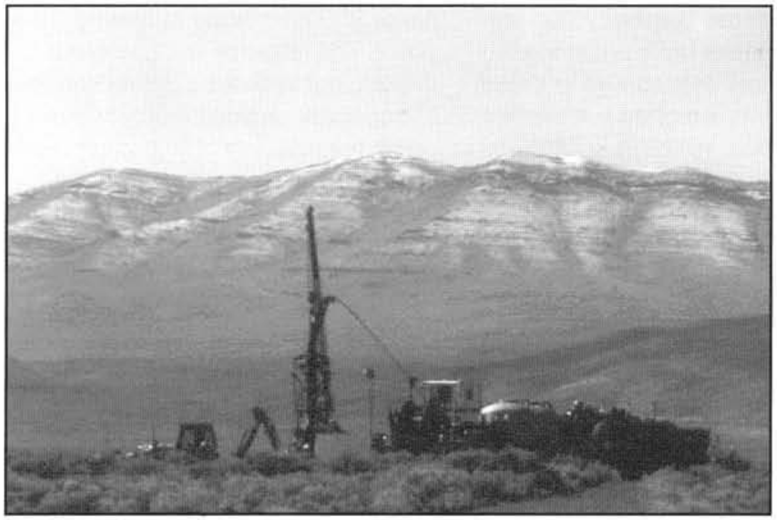
At Newberry volcano, the wells at the CE Exploration project on the west flank of the volcano have been in suspended status since being drilled in 1995. Two will maintain this status through October 31, 1999. The DOGAMI Governing Board has extend the suspended status for the remaining three wells to October 2000. The company has moved its project to Glass Mountain in northern California and has made the Newberry wells available for scientific experimentation. A small amount of work has been done by the U.S. Geological Survey.

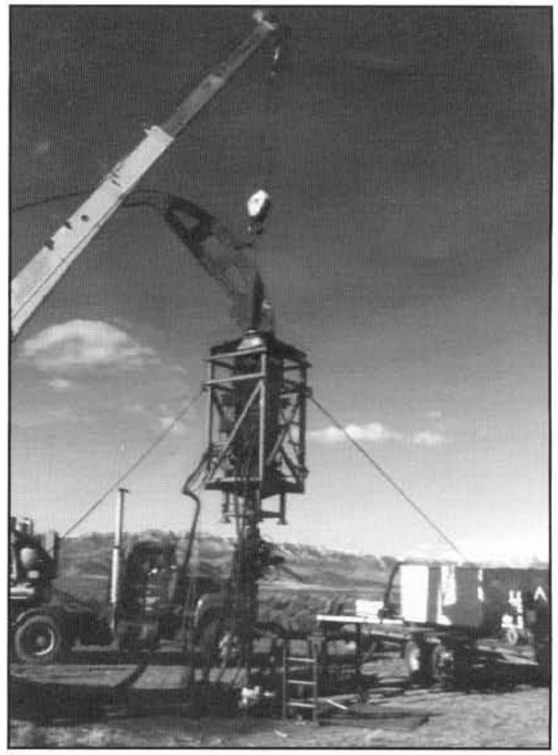
Vulcan Power Company, holder of large amounts of acreage on the west flank of Newberry volcano, has joined with Davenport Resources to form Northwest Geothermal Company. The new company has responded to a request for proposals from Portland General Electric (PGE) with a proposed 30-megawatt (MW) geothermal power plant (Freeman, 1999). The success of such a program is contingent in part on legislative approval for PGE to charge more for the "green" power. Northwest Geothermal is pursuing other potential avenues to make the power-plant plan viable.

No statute or rule changes have taken place for geothermal drilling during the 1996–1998 period.

U.S. GEOLOGICAL SURVEY (USGS)

The USGS maintains three geothermal prospect wells that were drilled in the Western Cascades in 1991. Located in the Mount Hood and Willamette National Forests, the wells are part of a larger set of wells throughout the country and are used to monitor for contemporary climate change. The USGS periodically logs





Plugging of Anadarko Petroleum wells in Pueblo Valley, using Halliburton coiled tubing rig, 1996. Above: Well 52–22A. On right: Well 25–22A. The third well that was plugged was well 66–22A.

the temperatures in the wells. Comparison of the logs acquired over a number of years reveals whether climatic changes have occurred that affect the subsurface temperature regime. The data from the array of holes provide information on the magnitude of the climatic changes and their duration and spatial extent.

Charles Bacon and Manuel Nathenson have published a study of the Crater Lake area geothermal resources (Bacon and Nathenson, 1996). They found that the main heat source in the upper crust in the area is the magma chamber that was responsible for the caldera-forming eruption 7,700 years ago. The amount of heat transferred to the upper crust during development of the chamber and the heat stored in the remains of the chamber following the eruption have been estimated on the basis of geologic data and petrologic models. Some of the heat currently is being lost through discharge of the springs of the Wood River group and through venting of fluids into Crater Lake—manifestations of the Crater Lake hydrothermal system. The Mazama hydrothermal system is identified on the basis of data obtained from drill hole MZI-11A in Winema National Forest east of Crater Lake National Park. This system may be supplied by intrusions related to Pleistocene volcanic rocks near the east rim of the caldera.

USDA FOREST SERVICE (USFS)

USFS involvement in geothermal resources over the 1996–1998 time period consisted mainly of surface oversight for the Newberry volcano exploration activity by CE Exploration. This included sale of timber to be cut for pad construction, along with regulation of surface disturbance.

U.S. BUREAU OF LAND MANAGEMENT (BLM)

The BLM has released the results of several years of monitoring Borax Lake in Harney County. The unpublished report includes data on the lake itself as well as data from a Remote Automated Weather Station (RAWS) from 1990 to 1997. Borax Lake is located in the extreme southeastern corner of Oregon and is formed by a hot spring that formed the 10-acre thermal lake. It is located within the Alvord Known Geothermal Resource Area. The lake averages 3 ft in depth but has a main vent with a depth in excess of 90 ft.

Over the past 20 years, the Alvord basin was the subject of leasing and exploration by the geothermal industry. Significant wells were drilled near Borax Lake by Union Oil Company and Anadarko Petroleum Corporation. Bottom hole temperatures were in the 300°F range. Meanwhile, the U.S. Fish and Wildlife Service (USFWS) listed the Borax Lake chub as an endangered species in 1982. The threat of geothermal development on adjacent public lands was a factor in the listing.

Prior to 1980 lease agreements, the BLM consulted the USFWS and agreed to monitoring of the lake as a condition of geothermal development. The agreement resulted in the data collection on lake and weather conditions. Anadarko initiated a monthly monitoring program for the lake in 1981. Data collection included water temperature, water elevation, and air temperature, used three monitoring sites, and was carried out through 1983. The company also placed thermographs in the lake in 1989 when is was conducting drilling operations nearby. The BLM data collection at its RAWS site was carried out from August 1990 to November 1997. Water samples were analyzed for over 20 components.

In addition, the USFWS and the Nature Conservancy conducted quarterly fish population surveys of the Borax Lake chub from July 1986 to October 1987; then, in 1991, a multi-year study of the chub was started by the USFWS.

Neither the exact character of the geothermal system nor the interconnection of the lake, hot springs, and drilled acreage, if any, is known with any certainty. Additional monitoring of the lake and hot springs may be appropriate, should geothermal development occur in the future.

BONNEVILLE POWER ADMINISTRATION (BPA)

The BPA no longer has geothermal projects in Oregon but maintains involvement nearby in northern California. The BPA is considering power purchases from two geothermal power facilities proposed in the Glass Mountain Known Geothermal Resource Area, about 50 mi south of Klamath Falls, along the border between the Modoc and Klamath National Forests. The power facilities began as parts of a BPA geothermal pilot project program in 1991, formed to encourage the development of geothermal resources.

One of the geothermal projects was located near Vale in Malheur County. It was a joint project with the Springfield Utility Board. When test wells at the Vale site failed to discover hot water to run a power plant, the developer, TransPacific Geothermal Corporation, formed a joint venture with Calpine Corporation of San Jose, California (Calpine Siskiyou Geothermal Partners. L.P.), and asked BPA to consider a relocated project at Glass Mountain in northern California, still within BPA's marketing area. In December 1996, BPA ended its commitment to this facility at a cost of $12 million. Calpine is now developing a 49-MW dual-flash facility at Fourmile Hill, in the Medicine Lake Highlands northwest of the Glass Mountain caldera. The facility will also include the associated geothermal production and injection wells, well pads, roads, interconnected pipelines, and a 24-mi, 230-kV transmission line. BPA is considering buying output from the facility. The Final Environmental Impact Statement (FEIS) for the power plant and transmission line was issued in October 1998. If the project is approved, commercial operation could begin in 2001.

In September 1996, BPA agreed to pay Calpine Siskiyou Geothermal Partners up to a total of $14.5 million in exchange for a release of all claims related to the Vale Project and proposed relocation to Glass Mountain. As part of the agreement, BPA received an option on future development on Calpine's geothermal leases at Glass Mountain. Calpine also agreed to work toward the successful conclusion of the environmental work already underway. BPA and Calpine have negotiated a power purchase agreement, but BPA is under no obligation to execute it.

The second geothermal project was proposed for Newberry volcano in Deschutes County. CalEnergy Company (doing business as CE Exploration Company in Oregon) had proposed a 30-MW plant on the west flank of the volcano. BPA would have bought two-thirds of the plant's power production and subsidized the purchase of the remaining power by the Eugene Water and Electric Board (EWEB). CalEnergy explored for a resource by drilling several wells (Table 2) but without success. The wells are still suspended, pending data gathering and plugging. CalEnergy is now developing a 48-MW facility at Telephone Flat, located southwest of Medicine Lake, inside the caldera. A reservoir capacity of 15 MW has been confirmed by earlier wells drilled by Unocal. BPA is also considering buying output from this facility. CalEnergy acquired the leases in 1994, an environmental impact statement has been prepared, and permitting decisions will be made this year. The Glass Mountain KGRA could ultimately yield as much as 500 MW of power, according to U.S. Geological Survey estimates. If the project is approved, commercial operation could begin in 2001.

When CalEnergy determined that the geothermal resources at Newberry volcano were insufficient to meet its obligations under the power purchase agreement with BPA in a cost-effective manner, the company notified BPA that it was relocating the project to Glass Mountain. A dispute arose over whether CalEnergy had the unilateral right to move the project and contract. In December 1996, CalEnergy and BPA executed a settlement agreement under which CalEnergy, in return for an initial payment of $9 million, released BPA from all claims arising from the Newberry contract. A power purchase agreement for Glass Mountain was negotiated, which contains terms more favorable to BPA than those in the Newberry agreement. BPA is not under obligation to execute the Glass Mountain agreement, but must pay CalEnergy an additional $9 million if the project is approved by the USFS and BLM and BPA then decides not to execute the contract. If BPA executes the contract, it will instead pay CalEnergy $10 million upon commercial operatin.

RELATED ACTIVITIES

The Geothermal Resources Council (GRC) held its national convention in Portland in October 1997. Several companies had activities in the Northwest at that time, and attendance at the conference was good. The local GRC chapter is now inactive, however.

ACKNOWLEDGMENTS

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OOOE; George Darr, BPA; Bob Fujimoto and Alice Doremus, USFS; Gary Clow and William Scott, USGS; Michael Zwart, WRD; and John Lund, OIT.

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Residents feel small earthquakes shaking various parts of Oregon

A magnitude 2.7 (M 2.7) earthquake centered just west of Molalla ("epicenter"), about 25 mi northeast of Salem, was felt by people throughout the northern Willamette Valley on Wednesday morning, February 24, 1999, at 8:45 a.m. The earthquake originated at an estimated depth of 25–35 km ("hypocenter"). It caused minor damage to Oregon City High School and shifted an 83-year-old home in West Linn from its foundation.

From Salem to Hillsboro to Vancouver, people reported feeling the small earthquake, observing effects from lamps swinging to tables bouncing on the floor. Several people went outside to see whether a tree branch had landed on their roof but found nothing to explain the sound and shaking they had noticed.

Other earthquakes have occurred in the same area as the small February temblor: Two smaller earthquakes (M 2.1 and M 1.6) were recorded earlier in February, and a M 3.6 earthquake occurred in February 1995. Although the 1995 earthquake was larger, it was felt by few people because it occurred at night. Geologists throughout the state do not believe these earthquakes were aftershocks of the M 5.6 Scotts Mills earthquake that occurred on March 25, 1993.

Gerald L. Black, geologist with the Oregon Department of Geology and Mineral Industries (DOGAMI) said it was unusual for an earthquake of this small size to have been felt over such a wide area. "Typically, quakes of that strength are barely felt. Normally, if you're on the ground, you wouldn't feel anything unless you were on top of it," Black said. "It would be a gentle vibration."

One reason why shaking was felt and sounds were heard so widely is the depth of the event. For comparison, the Scotts Mills quake was only 15 km deep, while this event was about twice that. So the shock waves could spread farther in all directions before they reached the surface.

Another reason for the widespread shaking is the soil of the Willamette Valley. "We have a lot of alluvium, the loose, unconsolidated deposits from rivers that have been flowing through the Valley for thousands of years," explains Lou Clark, Earth Science Information Officer with DOGAMI. "Unfortunately, these are the perfect soils to amplify the effects of earthquakes."

At Oregon City High School, cracks were opened in walls and ceilings throughout the 67-year-old building. Bob Walker, a structural engineer, inspected the building and found no structural damage but did say the building could not handle a

Table 1. *List of some recent (1999) small earthquakes centered in Oregon*

Date	Location	Magnitude	Depth (km)
January 30	Northwest of Salem	2.1	25
January 31	Southwest of Coos Bay (offshore)	2.6	25
February 10	Southeast of Scappose	2.1	19
February 15	Southeast slope of Mount Hood	2.6	7
March 3	Southeast of Joseph	3.0	19
March 3	Southeast of Joseph	2.2	18
March 10	East of Milton-Freewater	2.6	5
March 15	North of Bend	2.0	28
March 17	East of Milton-Freewater	2.3	3

larger earthquake (M 5.0 or higher). School officials and structural engineers are also worried that the cumulative effects of many small to moderate earthquakes over the years could be undermining the building's structural integrity.

Clark notes that there are thousands of buildings in the state similar in design to the High School brick building. "Buildings have only so much ability to resist earthquake damage," she adds. "We know older, unreinforced brick buildings do not stand up well to earthquakes unless they've been specially strengthened." Without such improvements, each small earthquake robs the building of a little more of its ability to cope with the strain of shaking in the ground below it.

Small earthquakes are a daily event in Oregon, and events over a M 2.0 happen every week or so (See Table 1).

"We know there will be another damaging earthquake in Oregon," warns Clark. "We don't know where or when, so we all need to be prepared." □

Seeking a new Director for DOGAMI

The State of Oregon seeks a Director for the Oregon Department of Geology and Mineral Industries (DOGAMI). In concert with the Governing Board, the Director oversees the management of the Department, including goals, policy, budget, and legislative liaison in technical and regulatory programs.

The Department is responsible for developing information about and mitigation strategies for natural hazards such as earthquakes, landslides, floods, and tsunamis. The Department is also the leading regulatory agency for mining, oil and gas, and geothermal energy exploration, production, and reclamation.

Interested applicants can obtain a detailed job description and information on the application process by contacting Laura Trevizo, Recruitment and Career Services, 155 Cottage Street NE, Salem, Oregon 97310. Phone: 503-378-3040. Applications must be received by 5:00 p.m., May 14, 1999.

WSSPC *Award in Excellence* goes to Benton County

The Benton County Emergency Management Council (BCEMC) was honored with one of the 1998 "Awards in Excellence" by the Western States Seismic Policy Council (WSSPC). The "Excellence in Response Plans" award was presented at a banquet in Pasadena, California, at the WSSPC annual conference and was accepted by Diane Merten, the current chair of the BCEMC. The Council was nominated for recognition by the Benton County Board of Commissioners. In the words of WSSPC Executive Director, Steve Ganz, the BCEMC "is an outstanding example of a coordinated, public-private partnership focused on emergency preparedness."

The BCEMC is a partnership of regional government, business, and nonprofit professionals concerned with making the community safer and more resilient following a disaster. The brainchild of a dedicated and tenacious community volunteer, Diane Merten, the BCEMC was officially formed in April, 1991. Merten, a former California resident and advocate for emergency preparedness, has chaired the Council since 1991.

The BCEMC embraces all phases of emergency management: mitigation, preparedness, response, and recovery. Four subcommittees support the efforts of the full council: Plans; Training and Exercise; Logistics, Facilities and Equipment; and Public Education. Among the many Council-member initiatives have been the following:

- Sponsorship of regional disaster training and exercise.
- Coordinated and cooperative response to actual emergencies.
- Public education campaigns and presentations including the Linn-Benton Neighborhood Emergency Training ("LB-NET") program.
- Development of emergency operations plans and protocols.
- Seismic/structural and nonstructural hazard studies and retrofitting of critical community facilities, including Oregon State University and the Corvallis School District, the Corvallis Fire Department and the Law Enforcement Building (Sheriff/Police).
- Flood study and mitigation projects by the City and County.
- A regional, "all-hazards," mitigation study, involving Benton, Linn, Lane, and Lincoln Counties and State Economic Development grant funding.
- Support for the "Oregon Emergency Management Act" to establish a Governor's Advisory Council on Emergency Management, create an Oregon disaster relief fund, establish a competitive grant/mitigation fund and bolster Oregon's existing emergency management system.
- Designation as one of the Federal Emergency Management Agency's 50 pilot programs, "Project Impact: Building a Disaster Resistant Community," and eligibility for $300,000 in federal funding for mitigation projects.

The BCEMC works without a formal budget. It is largely funded by participating agencies, donations, and the Benton County Sheriff's Office, Emergency Management Division. The latter is the official administering agency and provides staff support, partly with its own volunteers—which has included the integral thesis work of two Oregon State University students.

For more information about the BCEMC, visit the web site that is being developed with BCEMC member and partner Oregon State University at

http://osu.orst.edu/groups/bcemc

Earthquake and tsunami preparedness month

Several activities and new products are available during April to help you prepare for earthquakes and tsunamis.

Duck, cover, hold drill

On April 22 between 9:30 and 10:00 am, schoolchildren and businesses across Oregon and Washington will be practicing how to duck, cover, and hold to stay safe in an earthquake (**duck** down, take **cover** under a sturdy piece of furniture, **hold** on until the shaking stops).

You may want to see if your school is participating, or even practice yourself.

Earthquake and tsunami curricula and videos

How do you explain plate tectonics to an 8-year-old? Or make high school students understand the probability of earthquakes in Oregon? These and many other topics are addressed in a new earthquake and tsunami curriculum available to Oregon schools.

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All materials were designed with the cooperation of the Oregon Department of Education and an advisory group of teachers and should meet state educational standards. Three separate volumes are available: grades K–3, 4–6, and 7–12. Each volume is available for $25 from the Nature of the Northwest (order form on back of magazine).

Tsunami safety materials

The Oregon Department of Geology and Mineral Industries has produced everything from mugs to roadside signs explaining various aspects of tsunami dangers. Several products have been designed for hotels, motels, and restaurants along the coast to give potentially life-saving information to their guests. □

Sample exercise for grades 4-6

How Likely Are Earthquakes in Oregon?

1. Tell your students that scientists try to determine the chances of earthquakes happening.

- Have the students determine how old they would be in 50 years.
- In Oregon, the chances of a large earthquake are thought to be between 1 in 10 (1/10 or 10%) to 1 in 5 (1/5 or 20%) in the next 50 years.
- Ask your students how we might represent that kind of chance using blocks, a spinner, or a die.
- Show the students what this would look like with blocks (at least the 1 in 5).

2. Show the students 1 blue block and 4 orange blocks. This represents 1 in 5. Put the blocks in the bag.

Ask the students how likely they think it is that the blue block would be picked. Have a student ***reach in one time.*** This is our 1 in 5 chance in the next 50 years. It will probably be an orange block. No quake!

- Should we still be prepared? YES, because there **is** a chance. It may be slight, but it still could happen; therefore, we should be prepared.

3. This is a good time to relate to your students the connection between fire drills and earthquake drills. We practice and prepare for both dangerous situations, even though the chances of either one occurring are small.

These disasters are not likely to happen often, but if either one does occur, we will be much safer if we know about the safe thing to do.

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OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries

Volume 61, Number 3, May/June 1999

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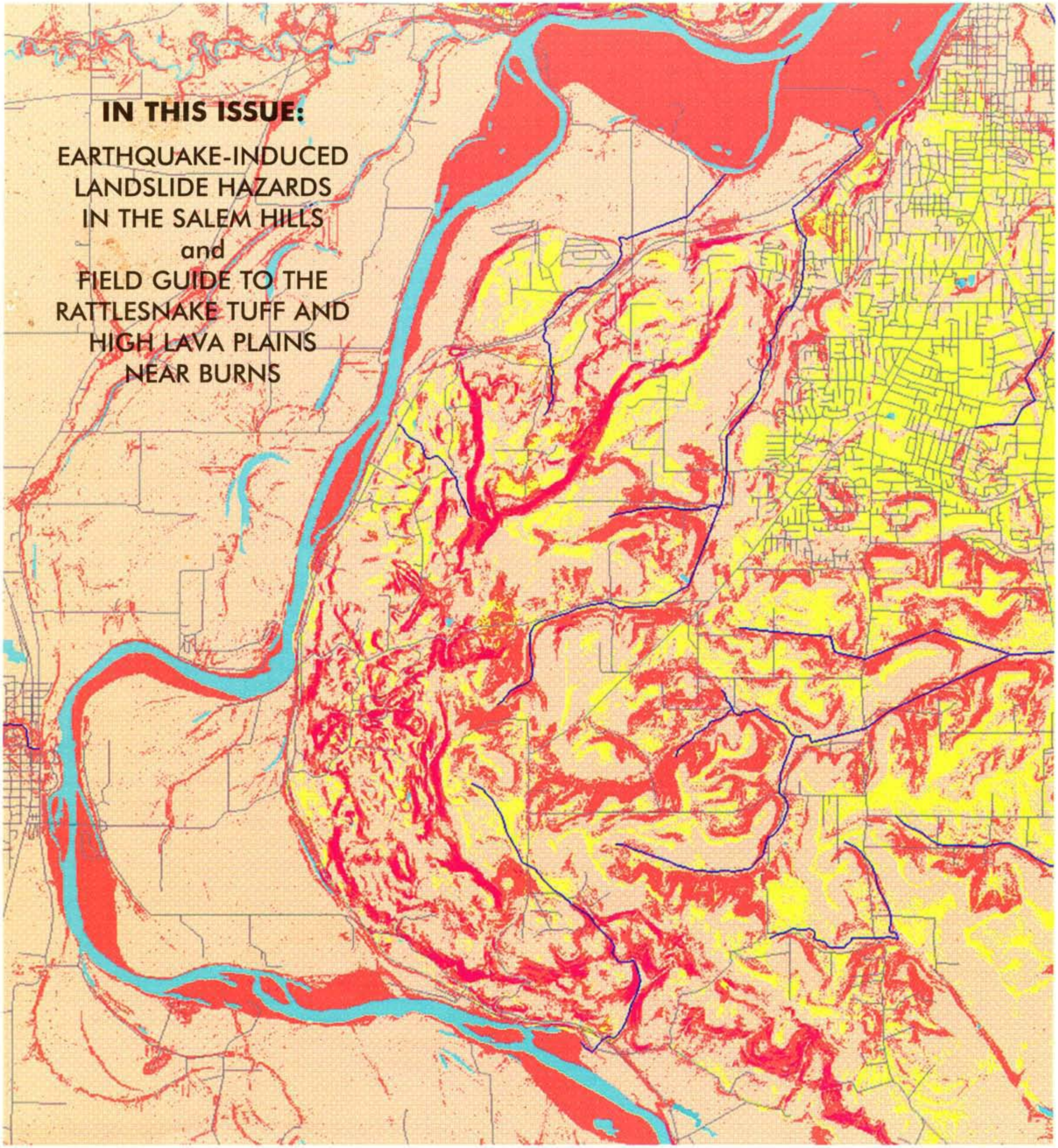

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Klaus Neuendorf, Editor, at the Portland office (address above).

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Cover illustration

New relative hazard map of earthquake-induced slope instability for the vicinity of the Salem Hills on the southwest edge of the city of Salem, Oregon (see also page 63). Developing this map is the subject of the article beginning on the next page.

Sign dedication at Beverly Beach remembers children drowned in 1964 tsunami

On March 27, 1964, four children died on Beverly Beach, after a magnitude-9.2 earthquake off the coast of Alaska spawned a tsunami that slammed the Oregon coast. A Tacoma family was asleep in a small driftwood shelter when the first tsunami wave struck the coast at approximately 11:30 p.m. The four McKenzie children were swept out to sea.

A new geologic information sign with life-saving information about tsunamis was unveiled and dedicated at the Beverly Beach State Park campground, 7 mi north of Newport, on March 27.

Invited speakers included State Representative Terry Thompson; Robert Meinen, Director, Oregon Parks and Recreation Department; June S. Spence, Commission member of the Oregon Parks and Recreation Department; Alberta Bryant, Retired Lincoln County Commissioner; and Donald Christensen, Governing Board of the Department of Geology and Mineral Industries (DOGAMI). Comments from Congresswoman Darlene Hooley were read. Donald A. Hull, DOGAMI Director and State Geologist, welcomed the attendants and introduced the speakers.

The sign warns people about the dangers of tsunamis (large waves caused by great undersea earthquakes), tells them what to do to save themselves if a tsunami should occur, and explains how and why tsunamis periodically strike the Oregon coast. The sign was funded by DOGAMI, the Federal Emergency Management Agency, Leading Edge Entertainment, Southpaw Productions, and the Oregon Parks and Recreation Department and designed by Sea Reach, Ltd.

A walking tour of the newly signed tsunami evacuation route designed for Beverly Beach State Park was led by John Allen, Area 1 Parks Manager; Mark Darienzo, Oregon Emergency Management; and Jim Hawley, Lincoln County Emergency Services.

The Oregon Parks and Recreation Department is an active partner in educating coastal visitors. "A goal of State Parks is more emphasis on partnerships, and we are delighted with the opportunity to work with DOGAMI on a number of tsunami public awareness programs. We are very pleased to be a part of this very important tsunami public awareness campaign," said Commission member June Spence.

To get information about how to protect yourself in an earthquake or to purchase tsunami inundation maps or a tsunami educational videotape, contact the **Nature of the Northwest Information Center**, or the DOGAMI field offices in Baker City and Grants Pass. See addresses, phone numbers, and internet access in the box on the left side of this page. □

Earthquake-induced slope instability: A relative hazard map for the vicinity of the Salem Hills, Oregon

by R. Jon Hofmeister, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97232

INTRODUCTION

Public and private agencies that create regional hazard maps can benefit from the use of a standardized regional hazard mapping methodology. The methodology should be uniform yet flexible enough to remain appropriate for, and verifiable across, vast and geographically diverse regions. The ideal is to produce the most accurate maps possible (that is, the best predictors of high-risk versus low-risk areas) in the least amount of time and at the lowest cost.

A recently-developed methodology by David Keefer of the United States Geological Survey (USGS) and Yumei Wang of the Oregon Department of Geology and Mineral Industries (DOGAMI) is aimed at this ideal in evaluating slope stability hazards on a regional scale (Keefer and Wang, 1997). Their methodology is specifically intended for implementation using Geographic Information Systems (GIS) and utilizes common methods for scientific and engineering analysis of slope stability.

The Salem study presented here is the second project employing that methodology. The first was a study for the Eugene-Springfield metropolitan area in Lane County, Oregon (Wang and others, 1998; Black and others, 1999).

This project had two primary objectives:

1. To implement and evaluate the methodology for assessing regional earthquake-induced slope instability by Keefer and Wang (1997) and to refine the method, where applicable, for subsequent regional mapping efforts in Oregon and elsewhere.

2. To create the most accurate and representative hazard map feasible for earthquake-induced slope instability in the Salem Hills vicinity, given the existing time and economic constraints.

The resulting hazard map provides a rational basis for evaluating the spatial variability of landslide hazards within the Salem area. The calculations were performed with GIS tools and a 10×10 m grid spacing, and the final hazard map depicts zones of *Very Low, Low, Moderate, and High* potential for earthquake-induced slope instability.

The map is intended to help guide regional decisions by planners, emergency management officials, and others responsible for planning and implementing measures aimed at minimizing potential loss of life and property damage from future earthquake events.

BACKGROUND

Salem is the third largest city in Oregon. As population growth has expanded city boundaries, new development has spread into the marginal, steeper areas south of downtown Salem, including the Salem Hills area, and is expected to accelerate. Slope instability hazards are of particular concern in the area. Several rainfall-induced slides have recently caused damage to development in the study region. Extensive portions of the Salem Hills vicinity, particularly along the north and west flanks, are characterized by jumbled, "hummocky" terrain that resulted from major historical landslide events. These features are a noteworthy reminder that the area has been unstable in the past and that portions will inevitably move again in the future.

This project focuses on seismic slope stability hazards in the Salem study area. The Oregon Emergency Management Office has received funding from the Federal Emergency Management Agency (FEMA) for a complementary project to evaluate rainfall-induced landslide hazards in the Salem Hills. That funding is being used by DOGAMI, the City of Salem, and Marion County to study the hazards in the Salem area and develop mitigation measures to reduce future losses. The characterization of precipitation-induced landslide hazards was contracted to Squier Associates, a geotechnical engineering firm based in Lake Oswego, Oregon. Results have been released as DOGAMI Interpretive Map Series map IMS-6 (Harvey and Peterson, 1998), a generalized hazard map depicting relative hazard zones from 1 to 6 (low to high susceptibility) and associated text outlining development recommendations for each zone (Harvey and Peterson, 1998).

The study region used for this study of earthquake-induced slope instability includes the area analyzed for rainfall-induced landslide hazards, and the two maps should serve as useful complements for evaluating critical hazard areas in the Salem vicinity.

This project builds upon previous earthquake hazard mapping in the Salem area published by DOGAMI in 1996 (Wang and Leonard, 1996). The Wang and Leonard analysis included an evaluation of ground shaking amplification, landslide, and liquefaction hazards in the Salem East and Salem West 7½-minute quadrangles. Those quadrangles overlap the northern portion of the region evaluated in this new study. The landslide hazard categories in the Wang and Leonard project were purely a function of calculated slope angles. In addition to expanding the geographic area mapped, the current study bolsters the slope stability portion of the earlier analysis by augmenting topographic data with soil property and other physical data to further differentiate areas of relative hazard within the critical Salem Hills vicinity.

METHODOLOGY

The Salem Hills study area includes some challenging and complex geologic conditions that provide a unique opportunity to test the methodology introduced by Keefer and Wang (1997). Field evaluation by David Keefer of the USGS, Yumei Wang of DOGAMI, consulting geologist Robert Murray, and myself in March 1998 verified both the geologic complexity as well as the geographic importance of the study region.

Keefer and Wang methodology

The Keefer and Wang methodology uses three different methods to evaluate overall earthquake-induced slope stability hazard. The purpose in separating the analysis into three distinct facets is to account for the range of commonly observed modes of slope failure in earthquake events.

Steep slopes (generally rock) tend to fail as rock falls, rock slides, and debris slides (Keefer, 1984).

Moderate slopes (generally soil) most often fail as translational block slides and rotational slumps (Keefer, 1984).

For more gently sloping topography, the soil and rock slope hazards are usually lower, but in regions with saturated granular materials, liquefaction-induced lateral spread displacements can be significant.

The engineering and scientific methods differ depending on whether rock-slope, soil-slope, or lateral-spread hazards are evaluated. Since all three hazards may be present in a regional study, different methods are selected for modeling each of these hazards. The choice also takes into account technical merit and applicability for regional GIS analysis.

For steep rock slopes, an empirical decision tree developed by Keefer (1993) is used. The method is based on empirical correlations between recorded landslide concentrations (number of landslides per km^2) and material properties such as degree of weathering, cementation, fracture spacing and openness, and degree of saturation.

Moderate soil slopes are evaluated by means of a simplified Newmark sliding block analysis (Newmark, 1965) adapted for natural slopes by Jibson (1993).

For evaluating lateral spread hazard, an empirical relationship based on a regression analysis by Bartlett and Youd (1995) is used to establish relative hazard categories.

The results from these three methods of analysis are combined to create an overall relative slope instability hazard map.

Keefer and Wang proposed using slope groupings of <5°, 5°–25°, and >25° to differentiate between gentle, moderate, and steep slopes, respectively, and select the appropriate hazard analysis model. Table 1 summarizes the methods of analysis by slope group.

In the Keefer and Wang methodology, no analytical techniques are applied to mapped landslide areas, but these areas are assigned a "very high" hazard rating.

Application in the Salem Hills

The approach implemented in this study maintains the intent of the grouping into "gentle, moderate, and steep" slopes, but the methodology is slightly modified. Changes for the Salem study include the following:

1. A 6-percent (=3.4°) slope value is used to distinguish between "gentle" and "moderate" slope groups, rather than the 5° (=8.75 percent) break used by Keefer and Wang (1997). The 6-percent value corresponds to the maximum slope used in the regression analysis performed by Bartlett and Youd (1995).

2. The 6-percent slope value does not function as a strict cutoff between the Bartlett and Youd and simplified Newmark analyses. Lateral spread hazards may be significant on steeper slopes, particularly along cut banks in river and stream channels. Therefore, lateral spread hazard ratings are assigned to all susceptible sedimentary deposits, including those with calculated slopes of >6 percent.

3. The simplified Newmark analysis is used to evaluate all soil deposits, including some sites with slopes of <6 percent and some sites with slopes of >25°.

4. Steep-slope cutoff values are incorporated in the simplified Newmark analysis to ensure reasonably conservative hazard ratings in steep terrain.

5. Mapped preexisting landslide areas are assigned reduced residual strength values and are then analyzed with the simplified Newmark method. Large portions of the northern and western flanks of the Salem Hills have experienced movement in the past.

Table 1. Summary of hazard analysis methodology by slope group (adapted from Keefer and Wang (1997)

	Gentle Slopes	Moderate Slopes	Steep Slopes
Typical materials	Loosely-consolidated sediments	Semi-consolidated soils	Rock
Dominant hazard	Liquefaction-induced lateral spread	Soil slides	Rock falls, rock slides and debris slides
Analysis method based on:	Regression analysis by Bartlett and Youd (1995)	Simplified Newmark Sliding Block analysis adapted by Jibson (1993)	Decision tree analysis by Keefer (1993)

Grouping these regions into a uniform high-hazard category does not provide information on relative hazards within these extensive zones and would limit the usefulness of the final hazard map for planning and other uses. Incorporating a strength reduction factor and performing the simplified Newmark method allows the inclusion of other parameters, such as slope and material property variations, and the differentiation of the relative hazards within these important zones.

These modifications result in dual hazard analyses for some slopes, and as a result there is a less obvious differentiation between the three modes of slope failure being modeled. These changes, however, expand the applicability of the methodology and ensure that each area is analyzed for all potential hazards that may be relevant. Figure 1 presents a schematic flow chart of the Keefer and Wang methodology as modified for this study.

Four general steps are designated on the flow chart. The first step outlined is to select the applicable regions for each hazard type (lateral spread, soil slide, and rock slope). This step involves a consideration of the types of materials that are susceptible to each of the hazard groups. It also requires an evaluation of the best and most appropriate sources of information for each method of analysis.

After gathering the information available for the study area, the next general step is to assign the corresponding input parameters for each of the three analytical techniques and perform the analyses. This is the most time consuming and difficult portion of the method and depends greatly on the nature and resolution of the data available within a given study region. For this study, a lateral spread analysis using equations developed by Bartlett and Youd (1995) is performed for all Quaternary sedimentary deposits delineated on a surface geologic map. The soil slide analysis, based on a simplified Newmark analysis (Jibson, 1993), is performed for all soil units contained in databases obtained from the Natural Resource Conservation Service (NRCS). The rock slope analysis, based on a decision tree developed by Keefer (Keefer, 1993), is performed for all bedrock units on the geologic map with calculated slopes >25°.

The final steps outlined on the flow chart include translating the outputs from each analysis into relative hazard ratings, then combining the results to generate an overall hazard map. These steps require the application of good professional judgement and depend to some extent on the particulars of the region being analyzed. For this study, the three hazard types are first evaluated as separate data layers, then combined to create an overall map of earthquake-induced slope instability.

STUDY REGION

The size of the study region is approximately 13.5 km (8.4 mi) north/south by 12.3 km (7.6 mi) east/west. This region includes the southwest portion of the Salem urban growth boundary. Figure 2 is a map showing the location of the study area, and Figure 3 shows some of the local political boundaries. The Willamette River divides Polk County on the west from Marion County on the east. The

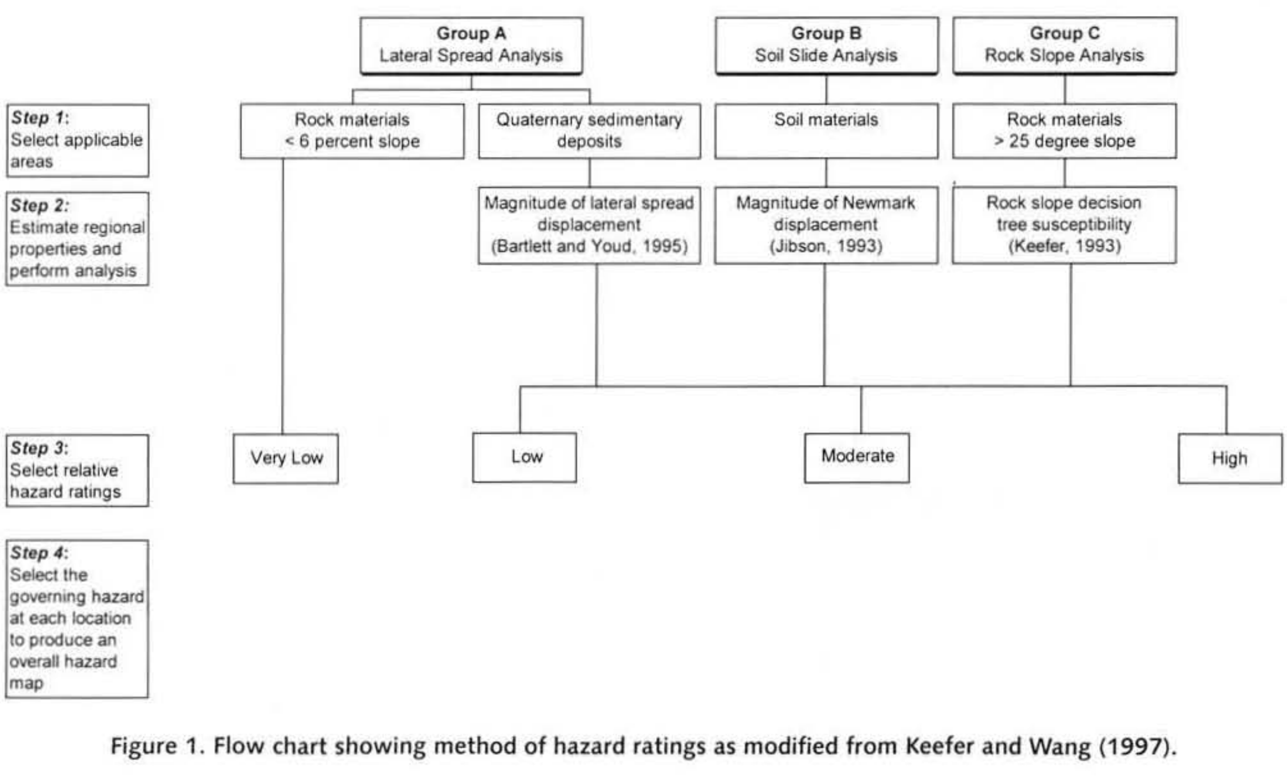


Figure 1. Flow chart showing method of hazard ratings as modified from Keefer and Wang (1997).

topography is predominately flat in the low-lying alluvial plains in the western portion of the study area, with moderate-to-steep slopes in the Salem Hills area to the east. Elevations range from approximately 38 m (125 ft) along the banks of the Willamette River to 345 m (1,130 ft) in the Salem Hills.

Figure 2. Vicinity map showing location of Salem Hills study area.

Extensive portions of the west and south sides of the Salem Hills are mapped as "landslide topography" by Bela (1981). The landslide terrain is distinguished by weathered headscarps, hummocky topography, mixed geologic materials, translated blocks of bedrock, interspersed sag ponds, and complex drainage patterns. The upslope topography of the eastern portion of the study area is marked by more regular topography and drainage patterns.

Active seismic setting

The Willamette Valley is located approximately 150 km inland from the Cascadia subduction zone, a convergent plate boundary where the Juan de Fuca plate is being subducted beneath the North American plate (Figure 4). Similar environments exist off the coasts of Japan, Mexico, Alaska, and Chile, where the largest earthquakes have occurred in recorded history. Three potential earthquake sources are associated with colliding tectonic plates: subduction zone, intraplate, and crustal events. Subduction zone earthquakes occur along the interface between the overriding North American plate and the subducting Juan de Fuca plate. Deep events that occur within the subducting Juan de Fuca slab are referred to as intraplate events. Intraplate events are associated with internal deformation and volume changes due to high temperature and pressure gradients within the earth's crust. The third potential source for earthquakes in the Pacific Northwest is associated with deformation within the overriding North American plate. These events, referred to as crustal earthquakes, occur at shallower depths (typically 10 to 20 km) and are usually associated with fault zones within the crust.

In the Pacific Northwest, as in other similar settings, a great deal of uncertainty limits estimating the size and location of future earthquakes, because the events are infrequent and the mechanisms are not fully understood. Using the best available methods, this study includes estimates of probable magnitude (M) and source-to-site distance (R) to evaluate subduction, intraplate, and crustal sources that could affect the study area.

SOURCE DATA AND ANALYSIS

The Salem Hills study area was selected, in part, because of the range of available and usable geologic, topographic, and geotechnical data. In preparation for and throughout the analysis, a number of data sources

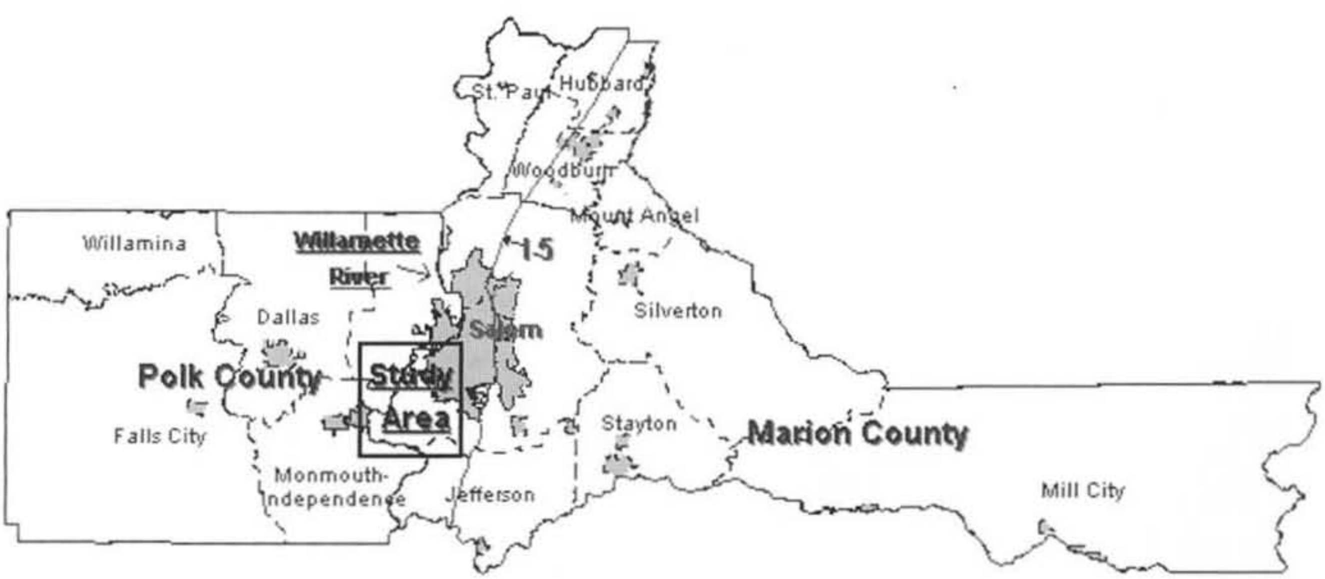


Figure 3. Outline of local political boundaries for the Salem Hills study area.

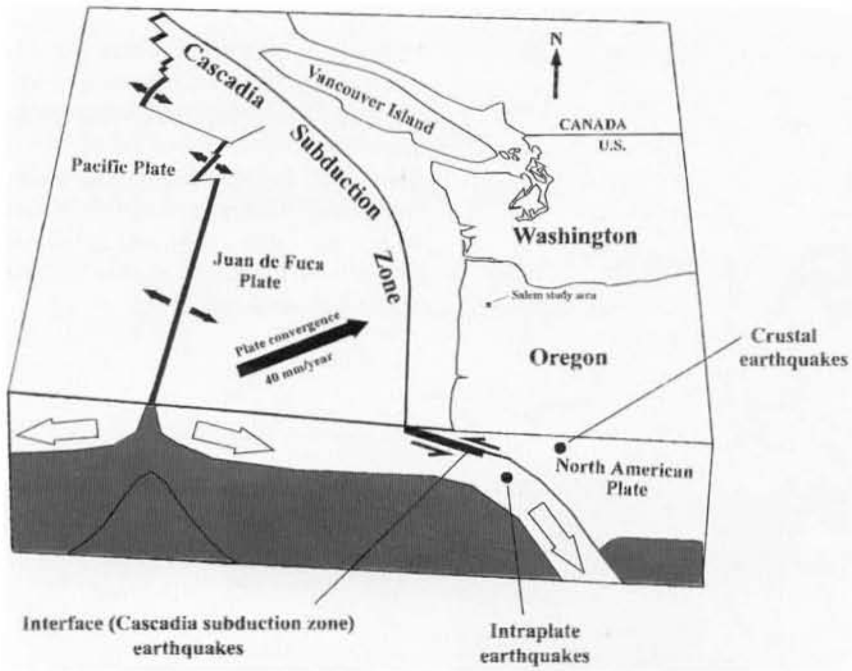


Figure 4: Schematic of the Cascadia subduction zone showing typical locations for the three types of earthquake sources in the Pacific Northwest.

was utilized. These are summarized below, organized by subject. Solid bullets (•) indicate that information from these sources was either available in digital form or was converted to digital form.

Topographic data

- ❍ 1:24,000-scale USGS 7.5-minute topographic map series (10-ft contour interval)
- • DOGAMI 10-m Digital Elevation Model (DEM[1])
- • USGS 30-m DEMs

Geology/soils

- • 1:24,000-scale DOGAMI geologic map GMS–18
- ❍ Geologic information in Burns and others (1992), McDowell (1991), Crenna and others (1994), and Wang and Leonard (1996)
- • USDA Soil Conservation Service [now Natural Resource Conservation Service] map of Polk County (Knezevich, 1982)
- • USDA Soil Conservation Service map of Marion County (Williams, 1972)
- • Oregon Water Resources Department water-well database
- ❍ Borehole and laboratory data collected by DOGAMI

Other sources

- ❍ U.S. Army Corps of Engineers Color Infrared (CIR) photographs, scale 1:30,000, taken September 11, 1979
- ❍ Black-and-white aerial photographs, scale 1:48,000, taken April 6, 1986
- ❍ Geotechnical consultant reports collected by DOGAMI

For this project, the Keefer and Wang (1997) methodology, modified as described above, was implemented mainly with the GIS application MapInfo. GIS applications are specifically designed for working with geographic databases and manipulating spatial data. With the GIS application, various layers of information can be overlaid, combined, and analyzed accurately and efficiently. The combination of spatial data, databases, and analytical tools allows for convenient updating and modifying of spatial databases within one environment.

Several other applications were used in conjunction with MapInfo, including Vertical Mapper, 3D Mapps, ArcView, and IDRISI (Eastman, 1990,1993).

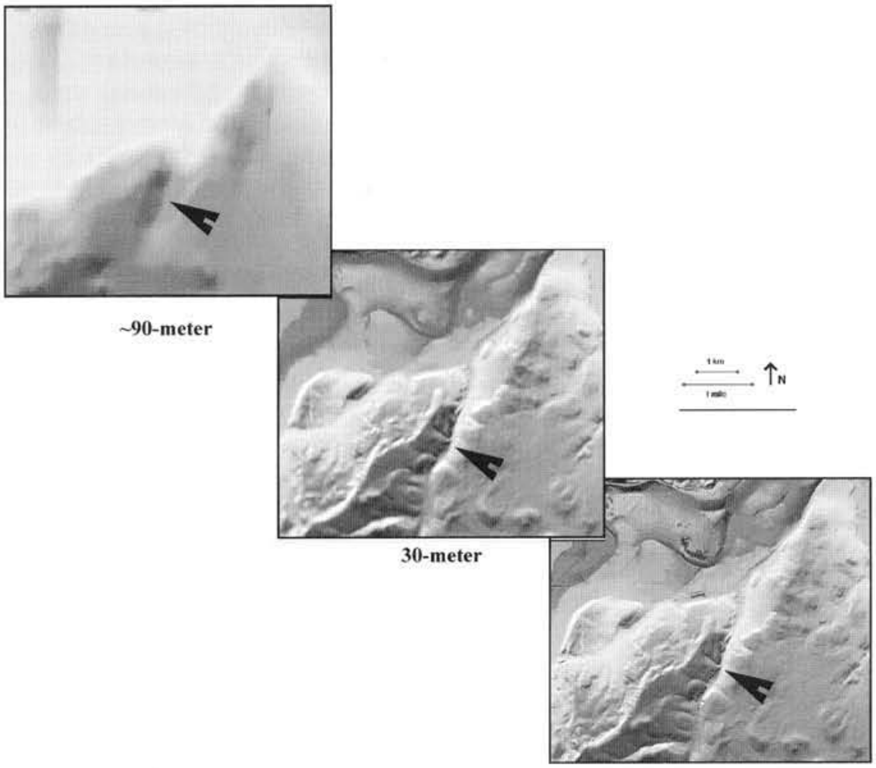
For working with digital spatial information within a GIS, resolution of the data is an important consideration. For the topographic data, DEM with a 10-m grid spacing was used. An illustration of the significance of resolution is shown in Figure 5, where 10-m, 30-m, and approximately 90-m DEMs of the same area are shown side by side. A superimposed arrow points out a southwest-northeast-trending drainage ditch that is visible in the 10-m DEM, but is difficult to distinguish in the 90-m elevation file due to the larger sample spacing.

While the 90-m and 30-m DEMs are USGS products that have been produced for most of the United States, 10-m DEMs are not as widely available. For the Salem study area, DOGAMI funded the creation of a 10-m DEM from the 10-ft contour interval topographic quadrangles of the USGS. A shaded-relief map derived from the DOGAMI DEM is shown in Figure 6.

With the 10-m DEM as basis, the GIS program Vertical Mapper was used for the generation of a slope map (Figure 7). The calculated slope values are stored at the same grid points as the original DEM. The slope map, then, served as the database used for reporting hazard values. It was overlaid on both the geology and soils map layers, and the properties associated with each were assigned to the slope map grid points. A schematic of the GIS overlay operation to create a single database with slope, geology, and soils data stored at grid points is shown in Figure 8. The subsequent hazard analyses outlined in the following sections were performed on this combined data file, with values stored at a 10-m grid spacing throughout the study area.

(Continued on page 62)

[1] A DEM is a regularly spaced series of points (a grid) with an elevation value and geographic coordinates (e.g., latitude, longitude) stored for each point. Grid spacing is the distance between the points.



⇐ Left:

Figure 5: Resolution comparison between a USGS 1:250,000-scale (~90-meter grid spacing), USGS 1:24,000-scale (30-M=meter) and the 10-meter DEM used for the Salem Hills study. The arrows mark a drainage ditch that stands out in the 10- and 30-meter DEMS but is barely visible in the 1:250,000-scale USGS file.

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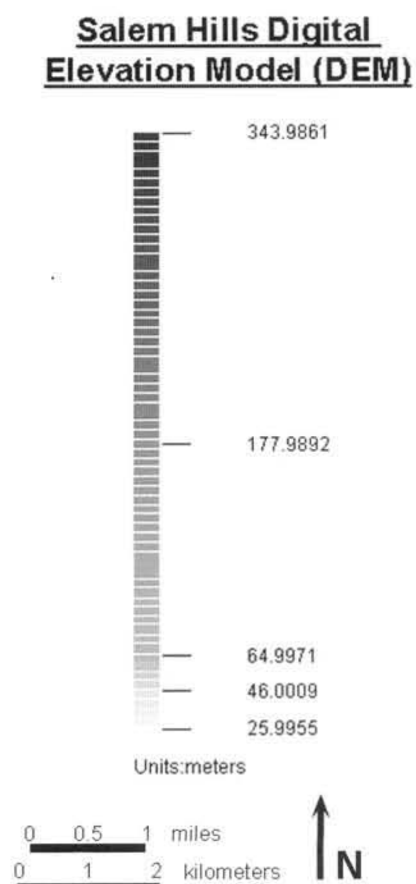
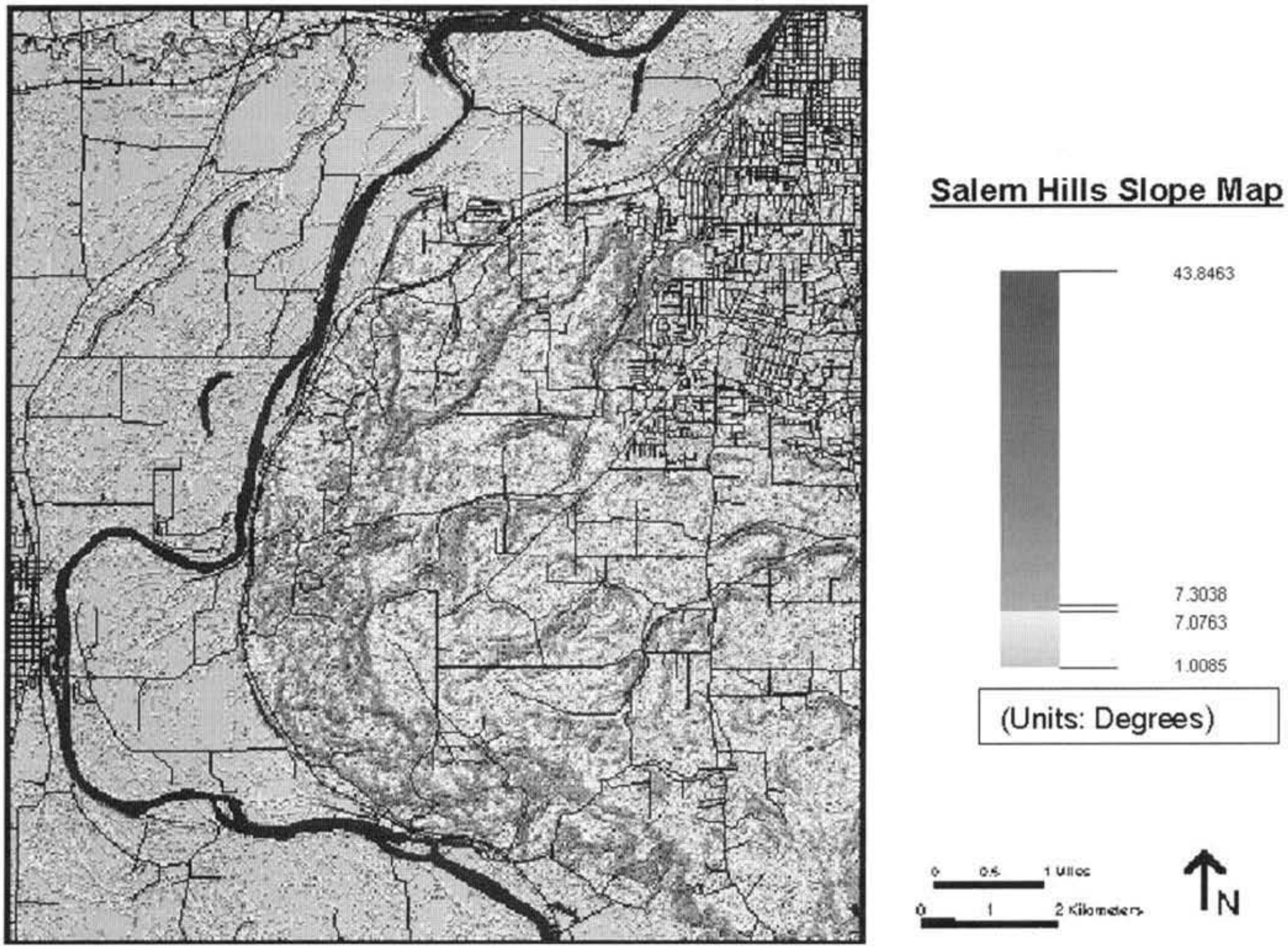
Figure 6: Shaded relief map from the 10-meter DEM used for the Salem Hills study area.





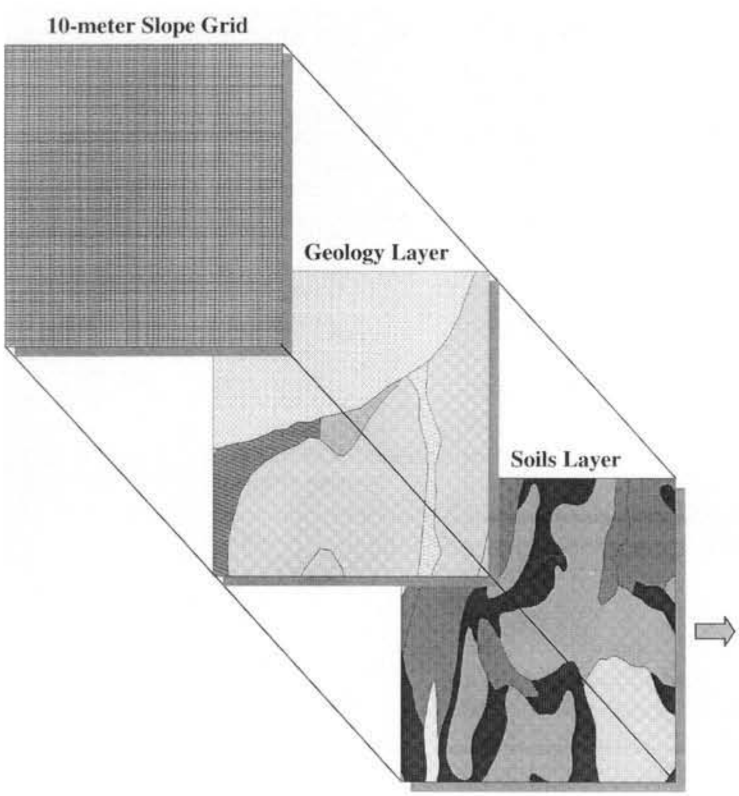


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Figure 7: Slope map for the Salem Hills study area.

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Figure 8: Schematic of the GIS overlay operation to create a single database with slope geology and soils data stored at grid points with 10-meter spacing.

Database with Slope and Material Properties

Global_ID	Slope_deg	Geo_Unit	Geo_Modifier	Soil_Unit	Total_Stress	Effective_Stress	Cohesion	Phi_Angle
1	2.5333	Qtm	LS_topo	21	46.3324	20.9167	22.5036	0
2	4.6442	Qtm		20	51.053	24.8897	28.728	0
3	2.2225	Qtm		25	48.0938	24.1731	22.5036	0
4	3.4444	Qtm		77A	48.19	28.7544	28.728	0
5	1.3342	Qtm		14	48.2498	48.2498	28.728	0
6	2.6528	Qtm	LS_topo	20	51.053	24.8897	28.728	0
7	3.6643	Qtm	LS_topo	33	48.8143	25.4412	22.5036	0
8	2.8736	Qtm		20	51.053	24.8897	28.728	0
9	1.6778	Qtm		77A	48.19	28.7544	28.728	0
10	1.9962	Qtm		45	47.5783	47.5783	28.728	0
11	2.0023	Qtm		20	51.053	24.8897	28.728	0
12	2.4567	Qtm	LS_topo	77A	48.19	28.7544	28.728	0
13	2.8892	Qtm		20	51.053	24.8897	28.728	0
14	3.0356	Qtm		20	51.053	24.8897	28.728	0
15	3.6723	Qtm		3	47.3416	23.4209	28.728	0
16	3.9818	Qtm		3	47.3416	23.4209	28.728	0
17	4.0561	Qtm		20	51.053	24.8897	28.728	0
18	3.8714	Qtm		3	47.3416	23.4209	28.728	0
19	3.5912	Qtm		20	51.053	24.8897	28.728	0

(Continued from page 59)

A more detailed discussion of analyses performed and equations used for the analyses of lateral spread, soil slide, and rock slope is found in the respective sections of DOGAMI Special Paper 30 (Hofmeister, 1999).

SUMMARY OF RESULTS

The relative hazard map of earthquake-induced slope instability of the Salem Hills vicinity (shown in Figure 9) is the combination of the lateral spread, soil slide, and steep slope analysis maps. The overall map delineates hazard zones, using a simple, relative scale from "Very Low" to "High." The hazard ratings in the Salem Hills portion of the study area are governed primarily by the soil slide and the rock slope susceptibility ratings. For the more gently sloping alluvial deposits in the low-lying areas, the hazard ratings primarily reflect the lateral spread hazard ratings.

The relative nature of the hazard ratings needs to be emphasized. Developing the scale of hazard zones includes using potential earthquake scenarios and includes a number of regional assumptions. The extent and severity of slope instability that occurs during an actual earthquake depends on the size and location of the event. A hazard rating of "high" does not necessarily mean that a slope will fail in any earthquake, and a rating of "very low" does not mean that there is no potential for movement. In a large earthquake event, there may, in fact, be instability in zones of moderate, low, and very low hazard as well as in a high hazard zone. In small earthquakes, only slight damage may occur even in zones of high hazard. In general, however, one would expect a higher percentage of earthquake-induced ground failures in "high" zones than in the "moderate," "low" and "very low" zones in any given earthquake event.

While a relative hazard map cannot serve as a replacement for site-specific studies in critical areas, it can, and should, serve as a useful tool for estimating the regional impact of future earthquake events. Creation of a regional hazard map is an initial step, which ideally is followed by hazard mitigation programs that focus efforts on the higher risk areas. Realistic evaluations of relative hazards are vital for planning and development, for emergency response management, as inputs for damage and loss estimations, and in making informed land use decisions. Potential users may include public policy makers, land use planners, civil engineers, developers, insurance adjusters, public safety officials, home owners, and home buyers, to name a few.

The Salem area is growing at a rapid rate; some predict it may soon surpass Eugene to become Oregon's second-most-populated urban area. In recent years, residential and commercial development has steadily expanded southward, and this study covers an area that is likely to experience increased development in the near future. This map is intended to be used in conjunction with other available resources to make informed decisions regarding regional development as well as retrofit or other mitigation measures to limit loss of life and property damage in future earthquake events.

The Keefer and Wang (1997) methodology, slightly modified for this study, proves to be one of the most promising approaches available for the accurate mapping of earthquake-induced slope instability hazards within reasonable time and cost limits. The successful completion of this study advances the ongoing efforts by DOGAMI to map hazards in major population areas statewide. A mapping project is now underway in Klamath Falls, and future studies are expected in Klamath and Tillamook Counties.

ACKNOWLEDGMENTS

I have benefited from the expertise, advice and encouragement of many people. I offer special thanks to the entire staff at DOGAMI for generously providing expertise and resources, particularly to Yumei Wang and Gerald Black, who made this project happen. I am grateful to Dale Carlson and the rest of the Valle Scholarship personnel for their generous financial support of the original study. I am also very grateful to University of Washington Professors Pedro Arduino, Robert Holtz, Steven Kramer, and Teresa Taylor for their valuable insight and mentorship throughout my graduate studies, and to Stanford Professors Ronaldo Borja, Anne Kiremidjian, Gordon Brown, and David Pollard for laying the groundwork in my undergraduate studies. I would also like to thank David Keefer of the USGS, Andrew Harvey of Squier Associates, George Freitag of Geotechnical Resources, Inc., and William Leonard of AGRA Earth & Environmental, each of whom provided valuable technical insight. I appreciate the critical data assistance I received from Brandi Baird of the USDA Natural Resource Conservation Service, Loren Mell of Group Health Cooperative, Tim Spear of the Oregon Department of Corrections, and Stephanie King of the Blume Earthquake Engineering Center. Finally, I wish to thank Robert Murray for his help with field outcrop mapping and David Keefer for reviewing this paper.

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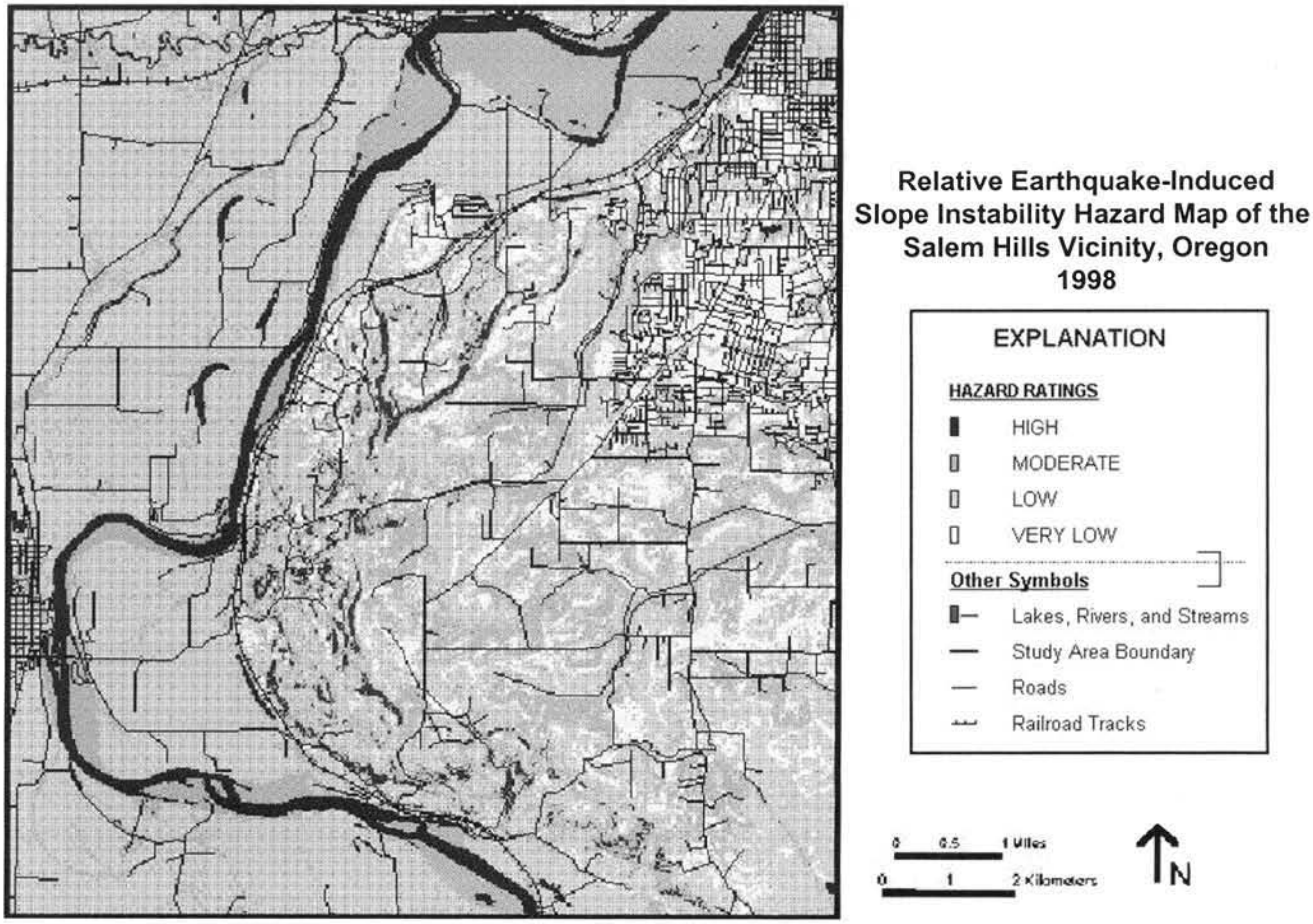

Figure 9: Overall hazard layer for the Salem Hills study area, with gray shades instead of color for ratings in original map.

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Field guide to the Rattlesnake Tuff and High Lava Plains near Burns, Oregon

by *Martin J. Streck, Department of Geology, Portland State University, Jenda A. Johnson, Hawaii Volcano Observatory, Hawaii National Park, and Anita L. Grunder, Department of Geosciences, Oregon State University*[1]

This field trip guide was prepared for the 1996 meeting of the Geological Society of America, Cordilleran Section, in Portland, Oregon.—*Ed.*

INTRODUCTION TO THE HIGH LAVA PLAINS

The High Lava Plains Province of central and southeastern Oregon lies at the northwestern margin of the Basin and Range Province and extends from the Cascade Range to the east, to merge with the Owyhee Plateau and Snake River Plain (Figure 1). The High Lava Plains are mainly widespread flows of high-alumina olivine tholeiite (HAOT) (Hart and others, 1984), typically a few meters thick, some regionally extensive ash-flow sheets, and locally intercalated silicic tuffaceous sediments. The province is punctuated by rhyolitic and lesser dacitic dome complexes.

Volcanism of the High Lava Plains is strongly bimodal, composed mainly of basalt (48–51 weight percent SiO_2) and high-silica rhyolite (>75 weight percent SiO_2), although individual eruption centers commonly exhibit a range of compositions. Silicic volcanism less than 11 Ma in age is progressively younger to the northwest and mirrors an opposite age progression of silicic volcanism along the Snake River Plain, ending at Yellowstone (Figure 1B) (MacLeod and others, 1976). The average rates of progression along the two trends are similar: ~3–4 cm/year (Armstrong and others, 1975; MacLeod and others, 1976). The High Lava Plains temporal trend complicates a hot-spot interpretation of the Snake River Plain-Yellowstone plateau.

A relationship between the two provinces is reinforced by geomorphic and compositional continuity between the basalt plateaus, persistence of Quaternary basalts along the length of the two provinces, and a continuous, narrow, low-velocity zone in the upper mantle (Dueker and Humphreys, 1990; Hearn and Barazangi, 1991). An important difference between the two is that silicic vol-

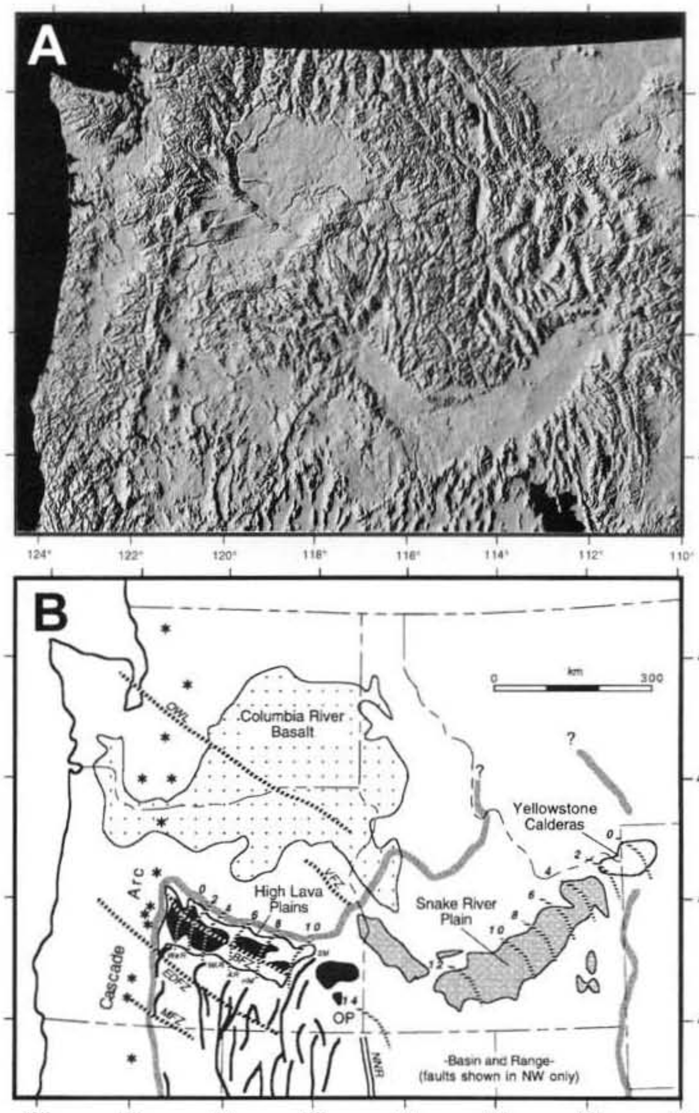

Figure 1. A. Digital topographic image from Pike (1991). B. Geologic features superimposed on area of A. High Lava Plains, Owyhee Plateau (OP), and Snake River Plain define a basalt plateau extending from the Cascades to Yellowstone. Isochrons (in Ma) of silicic age progression are modified from MacLeod and others (1976) and Smith and Braille (1994). Quaternary basalts of Snake River Plain shaded gray, of High Lava Plains and OP black. *=Cascade volcano; NNR=Northern Nevada Rift. Major horst escarpments of the Basin and Range: WaR=Walker Rim, WiR=Winter Rim, AR=Abert Rim, HM=Horse Mountain, SM=Steens Mountain. Fault zones: MFZ=McLaughlin; EDFZ=Eugene-Denio, BFZ= Brothers, VFZ=Vale. OWL=Olympic Wallowa lineament. Thick gray lines indicate limits of topographic expression of the Basin and Range Province.

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canism of the High Lava Plains is about one tenth the volume of that of the Snake River-Yellowstone trend according to the relative volume of ash-flow sheets.

The High Lava Plains are also an important structural boundary. North-northeast-striking Basin-and-Range-style block faults die out northward in southeastern Oregon and intersect steep, northwest-striking faults. The Brothers fault zone is a concentration of such northwest-striking faults. It transects the High Lava Plains obliquely to the trend of the silicic vents. Several parallel fault zones have been identified (Figure 1), but the Brothers fault zone is the only one to have Quaternary volcanic expression. The age of the Brothers fault zone is not known. Faults offset Pleistocene and some Quaternary basalt flows, but alignment of silcic vents suggests an older, subparallel, structural grain. Along the Snake River-Yellowstone trend, episodes of faulting migrate with the advance of volcanism. The regional work to demonstrate such a relationship for the High Lava Plains has not been done, but movement of the Steens Mountain range-front fault is in part synchronous with 11-Ma-old silicic volcanism in the eastern High Lava Plains (Johnson and Deino, 1994).

The Rattlesnake Tuff, defined as the Rattlesnake Ash-Flow Tuff by Walker (1979), is one of the several ash-flow sheets that crop out widely in southeastern Oregon and are part of the High Lava Plains silicic trend. The largest of these tuffs are the Devine Canyon, Prater Creek, and Rattlesnake Tuffs, 9.68 ± 0.03, 8.48 ± 0.05, and 7.05 ± 0.01 Ma, respectively, which have inferred sources in the Harney Basin (eastern High Lava Plains) (Walker, 1970; MacLeod and others, 1976; Streck and Grunder, 1995; Grunder and Deino, unpublished data). Other tuffs have been identified to the west. They appear to be fewer and smaller. No caldera structures have been identified.

REGIONAL TRENDS OF THE HIGH LAVA PLAINS

Age progression

Additional dating of silicic centers of the High Lava Plains bears out the age progression of MacLeod and others (1976) (Figure 2). New $^{40}Ar/^{39}Ar$ ages are typically at the old end of published ranges of ages. We have identified more dacite centers older than the age progression, and Iron Mountain is anomalously young. There is no compelling argument for a change in rate, mainly because the endpoint of the silicic volcanism can be identified at Newberry volcano or at the South Sister volcano in the Cascades. Trends in the age distribution of basalts is less clear. There are basalts both older and younger than the rhyolites all along the High Lava Plains.

Compilation of existing data suggests that mafic volcanism preceeded northwestward-younging silicic volcanism by as much as a million years and that it persisted afterwards. The youngest mafic volcanism may be a continuation or a rejuvenation of magmatism.

Compositional trends

Although most of the rhyolites have over 74 weight percent SiO_2, there is remarkable diversity in composition. Each center has its own characteristics and petrologic history. Strongly peralkaline rhyolites appear to be restricted to the area close to long 120° W. Interestingly, strongly peralkaline rhyolites (pantellerites) occur to the south at Hart Mountain; they are about 26 m.y. old (Mathis, 1993). Within individual centers, compositional variation of the rhyolites is best accounted for by crystal fractionation (MacLean, 1994; Johnson, 1995; Streck and Grunder, 1997). Rhyolites from eastern Harney Basin to Duck Creek Butte (about 11–8 Ma) typically have lower Zr/Nb and Y/Nb and higher Ce/Yb than do rhyolites of western Harney Basin (about 8–5 Ma), except for the highest silica rhyolites in which zircon fractionation has lowered Zr/Nb. Basalts have the same trend, but for the cases studied, rhyolites do not appear to be derived by crystal fractionation from basalt. Instead, it is possible that rhyolites are derived by partial melting of crust that has Zr/Nb imparted by basalt, which in turn varies regionally.

Sparse isotopic data for basalts indicate a westward decrease in $^{87}Sr/^{86}Sr$ across the Harney Basin from values around 0.704 to 0.703 (Carlson and Hart, 1987). Rhyolites have values close to basalts with the exception of the highest silica rhyolite at Duck Creek Butte and the Rattlesnake Tuff, which have slightly elevated values around 0.705, indicating some other crustal influence. Such rhyolites are low in Sr (a few to a few tens of ppm), and so they are sensitive to shifts in $^{87}Sr/^{86}Sr$.

Intermediate-composition rocks are few but ubiquitous. They are derived chiefly by mixing between silicic and mafic melts as in the case of Duck Creek Butte (Johnson, 1995), western Juniper Ridge (MacLean, 1994), the Rattlesnake Tuff (Streck, 1994; Streck and Grunder, 1999) and Newberry volcano (Linneman and Myers, 1990). At Duck Creek Butte, the rate of mixing and eruption exceeded the rate of production of silicic melt and was likely linked to concurrent fault activity along the north end of the Steens escarpment. At eastern Juniper Ridge, intermediates are derived by combined crystal fractionation of basalt and assimilation of silicic melts (MacLean, 1994). Several mafic andesites have, or trend toward, high Fe and P and have extreme trace element enrichments (best exemplified by Paiute Butte). These are most succesfully modeled as derived from mafic magma chambers that were repeatedly recharged and fractionated (Grunder and others, 1995; Streck and Grunder, 1999).

Working model

Our working model proposes that age-progressive silicic volcanism and related basaltic activity of the High Lava Plains represent the westward propagation of Basin and Range ex-

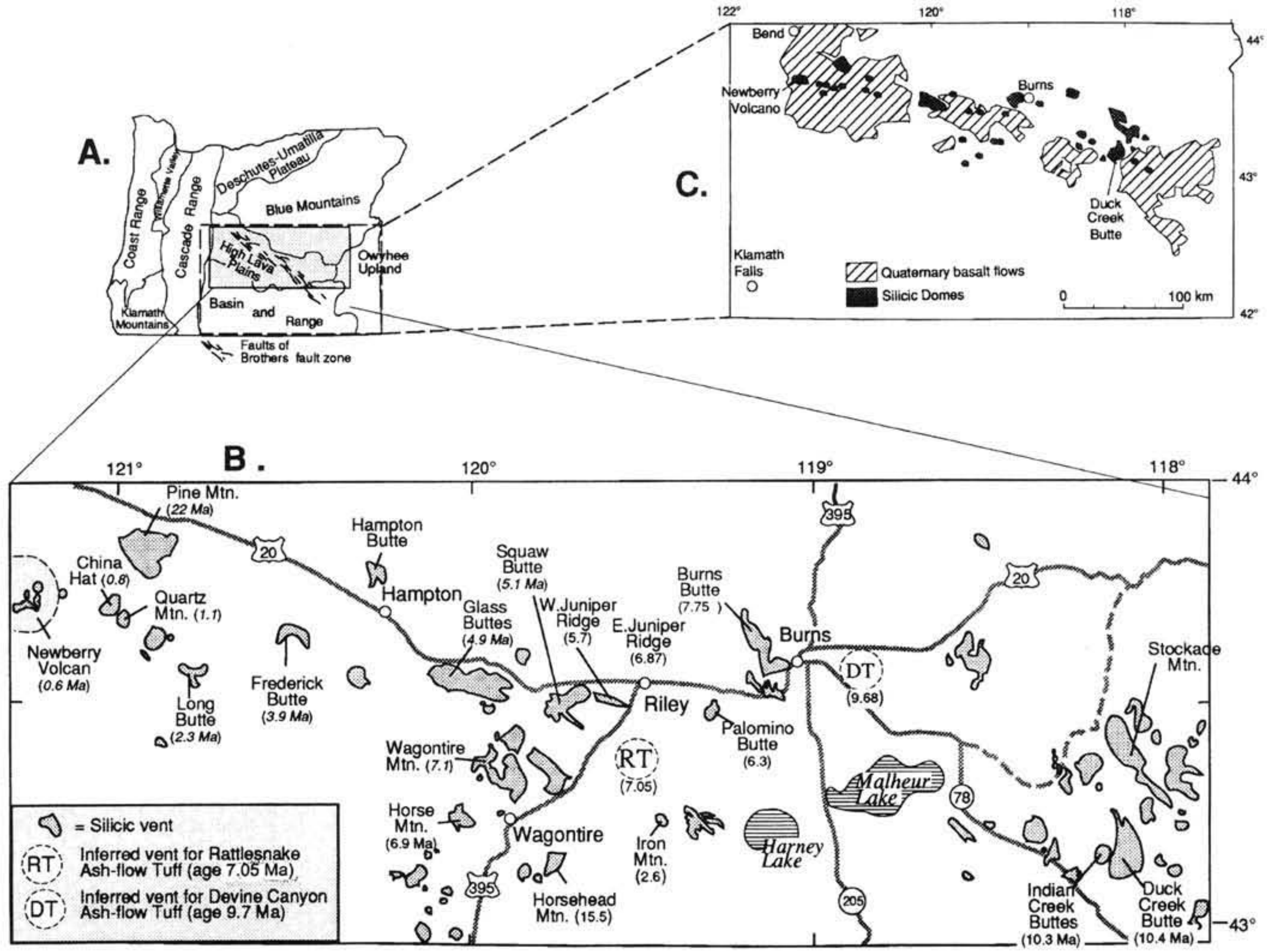

Figure 2. Oregon's High Lava Plains. (A) Physiographic provinces; (B) Age distribution of High Lava Plains silicic vents. Ages from MacLeod and others (1976), Streck and Grunder (1995), and Grunder and Deino, unpublished data. (C) Distribution of Pliocene-Pleistocene primitive olivine basalts.

tension from about 11 Ma to the present. The Quaternary expression of the High Lava Plains we view essentially as a leaky intracontinental transform boundary (Johnson, 1995). The compositional variation of rhyolites and of intermediates is linked to an interplay of mafic input and tectonic (fault) activity. By integrating regional temporal and geographic variations in composition and tying them to fault history where possible, we aim to understand the High Lava Plains Province.

RATTLESNAKE TUFF

The Rattlesnake Tuff is a single cooling unit that was deposited from multiple high-energy ash flows. The tuff covers about 9,000 km^2 (as indicated by isopach map shown in Figure 3) with an estimated tuff volume of 130 km^3. Original coverage was between 30,000 and 40,000 km^2 with reconstructed magma volume of the outflow about 280 km^3 DRE (dense rock equivalent) (Figure 3).[1] Pumice distribution and grading characteristics indicate that the transport medium consisted of highly expanded flows, and the deposition medium consisted of much less expanded flows near the ground.

The tuff was erupted from an area near the center of today's outcrop distribution, as can be inferred from a radial decrease in pumice clast size and general radial decrease of welding and crystallization (see discussion of source area at Stop 3). The size distribution of lithic fragments gives little insight into locating the vent area; the tuff picked up cobbles from the substrate as far as 66 km from the source (Streck and Grunder, 1995).

Vitric welding facies range from nonwelded to densely welded with three intermediate welding degrees: incipiently welded, partially welded with pumice, and partially welded with fiamme. Crystallization facies include the early pervasively devitrified and vapor phase zones, and the later spherulitic and lithophysal zones (Figure 4) (Streck and Grunder,

[1] Added in proof: Newly recognized outcrop of Rattlesnake Tuff ~80 km east-northeast from Burns, near the town of Juntura (M.L. Cummings, Portland State University, oral communication, 1999), extends confirmed original coverage eastward (see Figure 7).

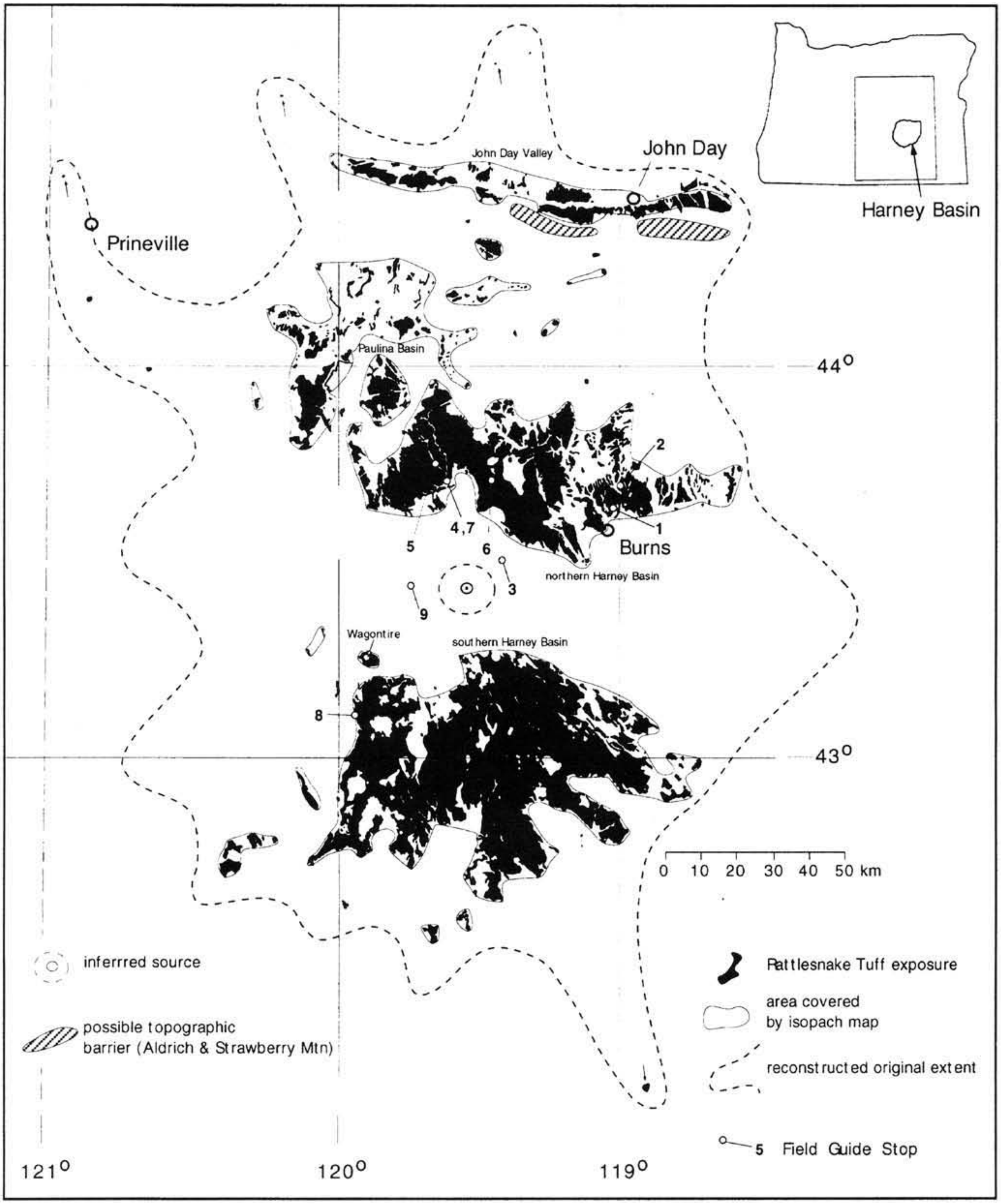

Figure 3. Field trip stops superimposed on outcrop map of Rattlesnake Tuff.

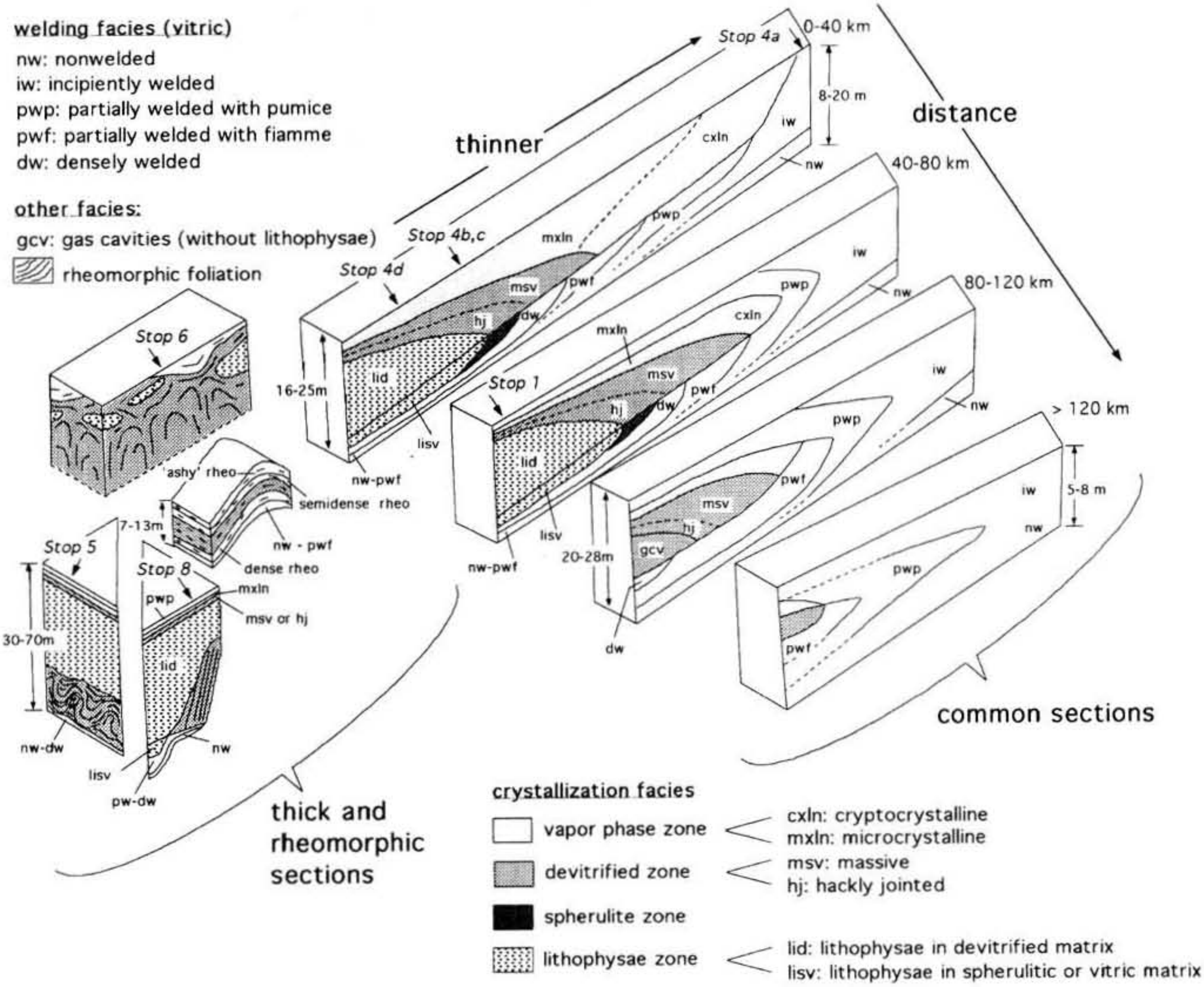

Figure 4. Three-dimensional model representing welding and crystallization facies distribution in the Rattlesnake Tuff showing sections seen at field trip stops (modified from Streck and Grunder, 1995).

1995). All overprint welding. The pervasively devitrified zone is restricted to partially welded with fiamme to densely welded tuff. The vapor phase zone occurs in partially welded tuff with pumice or less welded tuff and is divided into two subzones: (1) cryptocrystalline and (2) microcrystalline facies, distinguishable by the size of crystals. Spherulites occur in densely welded vitric tuff, and lithophysae overprint vitric and all other crystallization facies, except possibly vapor-phase tuff. Vitric to devitrified rheomorphic tuff occurs within 50 km of the source area and formed mainly during or after welding but before devitrification.

Strong local variations over 1–3 km include the complete spectrum of regional variations exhibited over tens to hundreds of kilometers. The drastic local changes suggest that facies variations result from subtle differences in emplacement, such as thickness or accumulation rate, which in turn lead to slightly different residence times above, at, or below threshold conditions (high temperature, volatiles) that are required for welding and crystallization.

The Rattlesnake Tuff contains white, gray, black, and mingled (banded) pumices and white and gray shards. White and gray pumices and shards are high-silica rhyolite and black pumices are slightly alkalic dacite (Streck and Grunder, 1997, 1999). The compositions of non-banded rhyolite pumices define five compositional clusters called Groups *A*, *B*, *C*, *D*, and *E*, from most to least evolved. Outcrop proportions vary from subequal proportions of white, gray, and mingled pumice to almost exclusively white. In general, the proportion of white pumice and shards is greatest at the base and in distal outcrops, and the abundances of gray and black pumice and gray shards increase upward within the first 1–2 m. Pumice clasts range from 1 to 90 cm; the largest pumices at any given location are always of the white and gray type. Average sizes of the five largest pumice clasts at many localities show an exponential decrease in size away from the inferred source. No vertical grading of pumices was observed, except for lack of largest pumice sizes near the base.

Group ***A*** and ***B*** pumices are white and ***A*** is essentially aphyric. Pumices of the other groups range from beige to gray and are sparsely phyric. Phases observed in all phyric pumices are alkali feldspar, Fe-rich clinopyroxene, titanomagnetite, quartz and accessory zircon, and apatite. Additional minerals that occur in some pumices are fayalite, biotite, pyrrhotite, and chevkinite. Feldspars change from anorthoclase to sodic sanidine with differentiation, pyroxenes become more magnesian (from Fe-hedenbergite to Fe-augite) and titanomagnetites more Fe rich. Zircon saturation temperatures indicate a pre-eruptive thermal gradient from 880° to 795°C from ***E*** to ***A*** (Streck and Grunder, 1997).

SUMMMARY OF FIELD TRIP STOPS

The route of this field trip leads north from Burns to look at (1) gradation within the Rattlesnake Tuff (RST) as well as the contact with the underlying tuffaceous sedimentary rocks; and (2) the contact between the three major Harney Basin ash-flow tuffs exposed in the stream-cut canyon of Poison Creek. The trip then returns south through Burns and west to a panoramic overview of western Harney Basin. This is followed by several stops to see facies variations and rheomorphic structures within the RST in the Silver Creek area, north of Riley. Finally, the trip heads south from Riley to look at a thick cliff of rheomorphic RST overlying basalt and older tuff and ends with the crossing through Juniper Ridge, one of the silicic dome complexes that are so characteristic of the High Lava Plains. Also, near Juniper Ridge, one of the few but ubiquitous intermediate magma centers will be crossed. All travel is on paved roads or maintained dirt roads readily traversed by passenger cars. Mileages are not cumulative but begin from established map locales. All stops can be comfortably visited during a two-day trip with Burns as place of departure and overnight stay. Figure 3 shows the geographic locations of field trip stops in relation to all Rattlesnake outcrops, and Figure 4 shows the approximate lithologic position of field trips stops in relation to the facies model of the Rattlesnake Tuff.

Day 1

DIRECTIONS TO STOPS 1 AND 2

Begin from junction of Highways 395/20, and 78 in downtown Burns. Drive north on Hwy 395 about 6.5 mi for Stop 1. Road bends left as it enters mouth of Devine Canyon. Park in turn-out on right side of road across from rimrock cliffs seen directly on left side of road. For Stop 2, continue 2–3 mi north on Hwy 395 into Devine Canyon drainage and stop at turn-out on west (left) side of road at prominent confluence with Poison Creek, near milepost 61.

STOP 1. TYPE LOCALITY OF RATTLESNAKE TUFF

The Rattlesnake Ash-Flow Tuff (Walker, 1979) is here referred to as Rattlesnake Tuff (RST), named for the original type locality on Rattlesnake Creek (John Day valley), ~100 km north from here. Total thickness of the tuff at Stop 1 is 22 m. It is a highly zoned section (Figure 5).

The underlying pale-orange to buff-colored, fine-grained, poorly consolidated tuffaceous sedimentary sequence is a ubiquitous slope-forming unit in Harney Basin.

The lowermost, white, 1-m-thick, finely laminated fallout deposit consists almost entirely of clear glass shards and was likely a precursor to the eruption(s) that formed the RST.

This is conformably overlain by 0.5 m of nonwelded vitric RST with "mixed" shard matrix (clear and brown rhyolitic glass shards) and 7–10 percent white pumice to 2 cm in diameter. In some places, the transition from the lower laminated deposits, representing likely surge deposits, to the nonwelded tuff is gradational, and the transition may be overemphasized by the change from white to mixed shard matrix. Bubble wall shards can be seen in both nonwelded and surge deposits.

The nonwelded zone grades abruptly to 0.5 m of partially welded vitric tuff, overlain by 1 m of black vitrophyre.

The >19-m-thick, capping, cliff-forming unit is entirely lithophysal tuff. The lower 4 m of this section are divided into a perlitic black matrix base and an upper part with spherulitic matrix. The upper 15 m are entirely lithophysae in devitrified matrix and are capped by float of pervasively devitrified tuff. Just across the highway (east) from this location, float on top of cliff-forming RST includes upper vitric, partially welded tuff, indicating proximity to the inferred original top of the unit.

STOP 2. HARNEY BASIN TUFFS

This stop shows excellent exposures of Harney Basin tuff stratigraphy (Figures 6, 7). Lowermost cliff is Devine Canyon (Ash-flow) Tuff (DCT) separated from the overlying Prater Creek (Ash-flow) Tuff (PCT) by poorly exposed tuff and tuffaceous sedimentary rocks. The sequence is capped by the RST. The tuffs are high-silica rhyolites that range from the peralkaline DCT to the peralkaline/metaluminous RST and form important regional stratigraphic and structural markers. The tuffs dip slightly southward to the Harney Basin, and the thickness of intercalated tuffaceous sediments also increases basinward.

Devine Canyon Tuff

The Devine Canyon Tuff is crystal-rich and originally covered more than 18,600 km^2 of southeastern Oregon, with a total volume of approximately

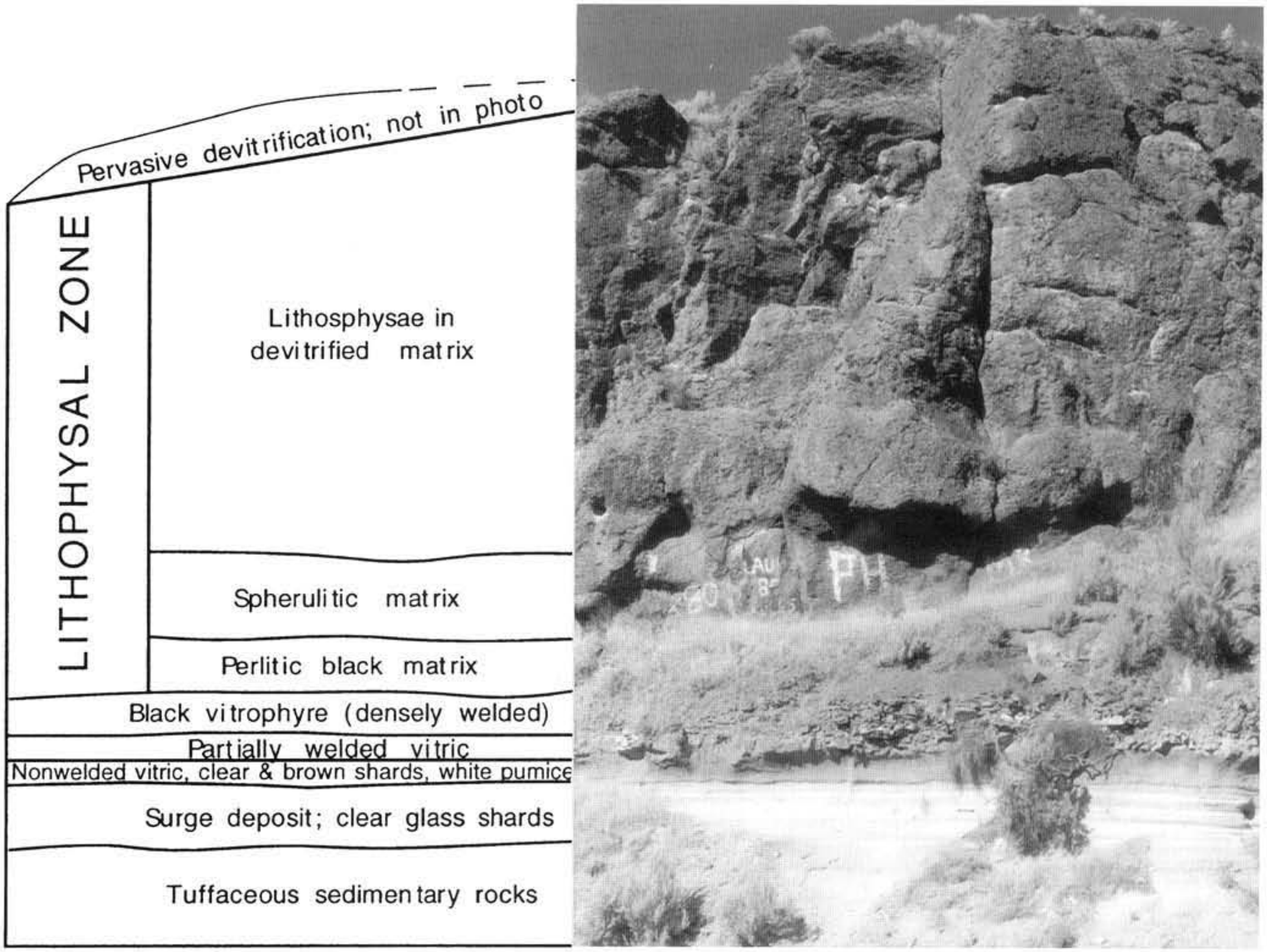

Figure 5. Outcrop photograph and line drawing of zonal variations in tuff at Stop1 on Hwy 395.

195 km^3 (Greene, 1973). It is characterized by 10–30 percent phenocrysts of alkali feldspar and quartz, with sparse clinopyroxene. It varies from nonwelded to densely welded; most commonly it occurs as greenish-gray glassy or stony devitrified tuff. Thickness is ~30 m near the type section about 0.5 km northeast of the confluence of the canyon with Poison Creek and corresponds to observed maximal thicknesses (Greene, 1973). $^{40}Ar/^{39}Ar$ age of 9.68±0.03 Ma was obtained from sanidine separates (Deino and Grunder, unpublished data). At this location, the tuff is partially welded and pumice rich, with pumices up to 30 cm in diameter.

Prater Creek Tuff

The Prater Creek Tuff is mainly a devitrified, crystal-poor ash-flow tuff. Exposures of the type section (designated by Walker, 1979) can be seen from Hwy 395 on the walls of Poison Creek, where the maximum thickness is 12 m. Lithologic variations can be seen in reference sections in Prater Creek, about 5 km east of Poison Creek. The type section consists chiefly of pale grayish-red, devitrified tuff with grayish-pink gas cavities to ~2 cm in diameter. Flattened, devitrified pumice fragments are present throughout but are not abundant. Alkali feldspar and quartz are sparse, and the tuff contains rare lithic fragments (Walker, 1979). Devitrified whole-rock tuff gave an age of 8.48±0.05 Ma (Deino and Grunder, unpublished data).

Rattlesnake Tuff

This is nonwelded to densely welded pumice-rich to ash-rich tuff with spherulitic, lithophysal, devitrified and vapor-phase crystallization zones. The phenocryst content is <1 percent throughout the bulk of the tuff. Where pumiceous, the tuff commonly has distinctive white, gray, black, and banded pumice clasts set in a salt-and-pepper matrix of white and gray glass shards. Typically, the tuff occurs as 10- to 20-m-thick, cliff-forming rimrock; maximum thickness is ~70 m. Analyses of 15 single-crystal $^{40}Ar/^{39}Ar$ samples of alkali feldspar yielded a weighted mean age of 7.05±0.01 Ma (Streck and Grunder, 1995).

SCENERY BACK TO BURNS

Return south on Hwy 395 toward Burns. View is across the central Harney Basin with snow-capped Steens Mountain to the south-southeast. Wrights Point is seen due south as a

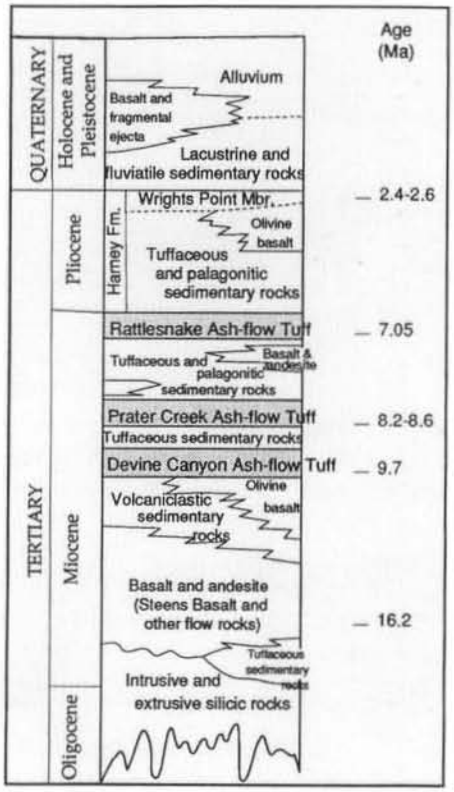

Figure 6. Lithologic units of Harney Basin (modified from Walker, 1979)

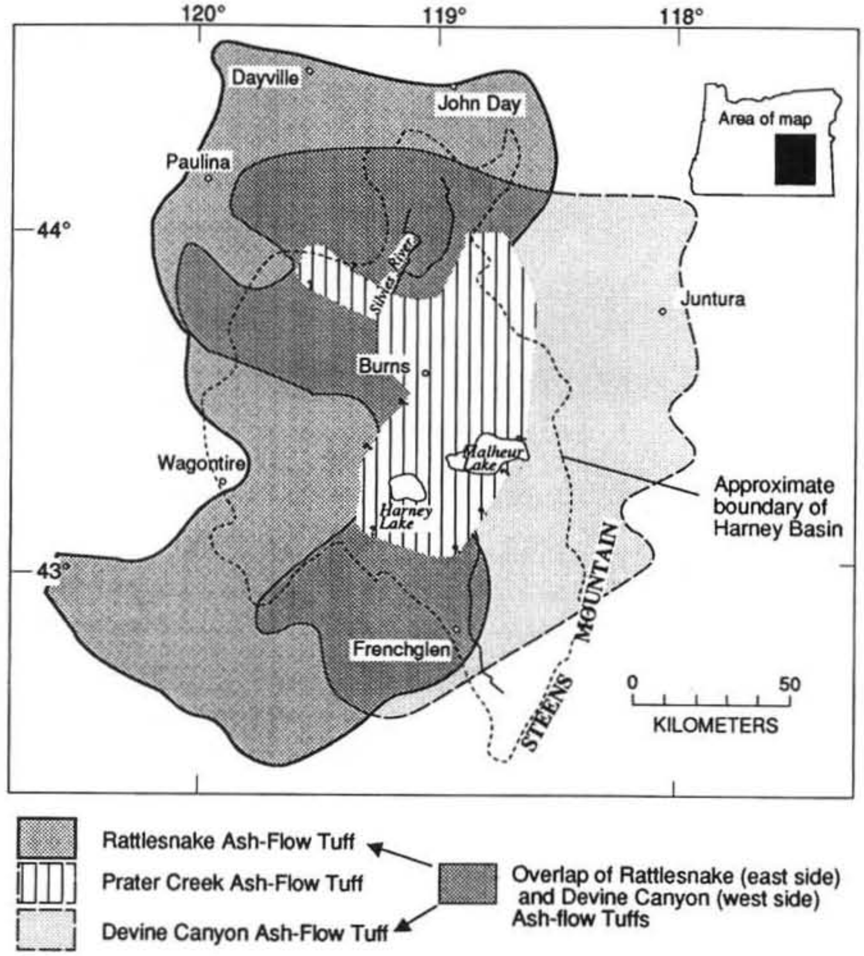

Figure 7. Regional distribution of Rattlesnake, Prater Creek and Devine Canyon Tuffs (from Walker, 1979)

flat-topped structure. It is a sinuous, 12-km-long erosional remnant of ~2.5-Ma olivine-basalt (HAOT) intracanyon lava flows overlying well-bedded tuffaceous sedimentary strata (Niem, 1974). The Malheur lowland, seen to the east of Wrights Point, and Harney lowland, hidden behind Wrights Point, host ephemeral lakes in Harney Basin, a closed depression.

DIRECTIONS TO STOP 3

Drive through Burns on Highway 395/20 and continue west. At ~24 mi (3.5 mi east of Riley) pull into gravel pit on north (right) side of road. Borrow pit of Pliocene basalt provides road metal for the State Highway Division.

STOP 3. PANORAMIC VIEW OF WESTERN HARNEY BASIN

Clockwise from southeast the following centers are visible (Figure 2): Palomino Butte, Iron Mountain (prominent sharp peak to the south), Horsehead Mountain, Little Juniper Mountain, Wagontire Mountain, Sheep Mountain, Paiute Butte (sharp peak to the west; called Squaw Butte prior to 1996), and Juniper Ridge. All are silicic domes except Paiute Butte, which is basaltic trachyandesite. Dry Mountain, the broad peak to the northwest, is an older andesite volcano.

The silicic centers form kipukas (areas sticking out of a lava flow) surrounded by Pliocene and Quaternary olivine basalt, and most conform to the westward younging trend. Iron Mountain is anomalously young, and Horsehead Mountain, Little Juniper Mountain, and parts of Wagontire Mountain are substantially older than the High Lava Plains volcanic trend. Abundant mafic cinder cones are scattered throughout the basalt field south of the highway.

The younger basalt is found throughout the High Lava Plains with no apparent age progression (Figure 2). These basalts are commonly tholeiitic with Al_2O_3>16 weight percent (wt.%), MgO>8 wt.%, P_2O_5~0.1 wt.%, TiO_2<1.0 wt.%, and Cr≥200 ppm. They have a flat REE (rare-earth-element) pattern characteristic of MORB (mid-oceanic ridge basalt)-like tholeiites, although some LIL (large-ion-lithophile-element) enrichment relative to MORB could indicate involvement of minor crustal material in their genesis (e.g., Bailey and Conrey, 1992).

Source area for Rattlesnake Tuff

No caldera structure related to the Rattlesnake Tuff is exposed. By analogy with pyroclastic deposits of similar volume, we might expect a caldera with an approximate diameter of 20 km (cf. Smith, 1979). Several source areas have been proposed, all lying within the Harney Basin. Walker (1969) and Parker (1974) proposed the Buzzard Creek area, based on rheomorphic features interpreted as venting features. Walker (1970, 1979) proposed a caldera under Harney Lake. MacLeod and others (1976) favored a site in the western Harney Basin based on the clustering of silicic domes of similar age.

The source area of the Rattlesnake Tuff (Figure 3) was chosen to be consistent with the areal distribution, distribution of facies within the tuff, increasing pumice size toward the vent, and flow direction indicators in the tuff (Streck and Grunder, 1995). The pumice-size data locations were compared for all proposed source areas, and the best mathematical fit for the source area is "Capehart Lake" located in the western Harney Basin (18 km south-southwest of the town of Riley, i.e., in the flat between the panoramic view point [Stop 3] and the town of Wagontire along Hwy 395). This area is almost identical with the source area proposed by MacLeod and others (1976), based on the regional age distribution pattern of silicic volcanism and suggested by magnetic anisotropy patterns within the tuff that are thought to be related to flow during deposition (Stimac, 1996).

DIRECTIONS TO STOP 4

Continue west on Hwy 20 to Silver Creek Road ~1.7 mi west of the Riley Post Office and turn right (north). At intersection with Oakerman Lane (~1.5 mi) turn left. Road wraps around ~15 Ma andesite volcano Dry Mountain. Drive ~15.5 mi to junction of Forest Service Roads 45 and 4130 at confluence of Silver and Wickiup Creeks. Turn left onto Road 45. Make stops along the route cautiously.

Prominent outcrop in the confluence is Stop 4a. Outcrop on west side of road, 0.6 mi from intersection is Stop 4b; ~1 mi further at junction of Roads 45 and 4535, rim rock at south wall is Stop 4c, north wall is Stop 4d (Figure 8).

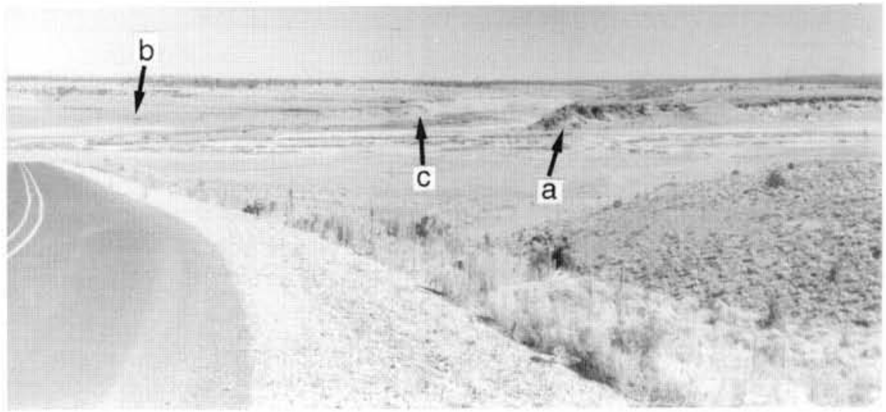

Figure 8. Overview of area around Stop 4 (4d not visible behind 4c). View is to the northwest from Forest Service Road 45, about 1 mi south of the intersection of Forest Service Roads 45 and 4130. All rim rocks in the picture are Rattlesnake Tuff.

Important: Part of this area is private land, with right of entry by permission of landowner only (Ranch to the north of Stop 4a)!

STOP 4. EXTREME LOCAL FACIES VARIATIONS

Strong local facies variations observable at Stop 4 are found at various places throughout the vast ignimbrite sheet but are strongest near the vent area. Stop 4 is an example for this (Figure 8).

Stop 4a consists of 16-m-thick, mainly incipiently welded RST with large pumices (average maximum pumice ~35 cm).

Outcrop at Stop 4b shows exposure of basal contact with underlying tuffaceous sedimentary rocks; there, RST grades from nonwelded to densely welded lower vitric zone overlain by pervasively devitrified zone. RST outcrop at Stop 4c includes lower partially welded zone with pumice (~1 m) overlain by zone that is partially welded with fiamme, in turn overlain by 7 m of black vitrophyre. The base is not exposed. Upper hackly jointed devitrified tuff is marked by sharp, commonly planar, transition. On north wall of road junction (Stop 4d), devitrified part of RST outcrop includes dominantly hackly jointed tuff intermixed with portions of lithophysal tuff (lithophysae in devitrified matrix).

DIRECTIONS TO STOP 5

Drive west on Forest Service Road 4535 for ~2.5 mi to first dirt road on left. Park and walk to outcrop north of intersection.

STOP 5. RHEOMORPHIC SANDWICH SECTION

The more than 30 m of RST visible here consist of ~20 m of rheomorphic tuff that is sandwiched between lower and upper normal (nonfolded) tuff (Figure 9). Lower half of outcrop is devitrified rheomorphic tuff. Folding in the middle part of this zone is steeply inclined with isoclinal fold hinges. The upper and lower parts of this zone exhibit more open fold hinges with less steep inclination. Pumice, best observed along base of outcrop, is flattened but not strongly stretched despite pronounced foliation.

Basal contact can be inferred from rare float of undeformed lower vitric tuff found along base of exposure and from lower open fold hinges. Upper half of outcrop is undeformed RST, with crystallization facies grading from a lithophysal zone with devitrified matrix to a pervasively devitrified zone and to a capping microcrystalline vapor-phase zone.

Note that macroscopic axiolitic structures are well-developed in

Figure 9. Outcrop photo of Stop 5 showing facies boundaries (dashes) and orientations of flow foliations (arrows). One isoclinal fold hinge is indicated (U-shape). Abbreviations of crystallization facies as in Figure 4.

some fiamme, particularly near the top of the section.

DIRECTIONS TO STOP 6

Return to intersection of Roads 45 and 4130. Go east on Road 4130 ~9.2 mi to Egypt Well. Turn right (south) on Road 4135 and drive 1.7 mi to fork in road; take left fork, Road 4120, for 2.8 mi to outcrop that is ~0.7 mi up Curly Canyon from intersection of Roads 4120 and 4126.

Editor's note: The name "Curly Canyon" appears only on the 1995 map of the Snow Mountain Ranger District, Ochoco National Forest. On the Forest Service 1993 "visitors' map" of the Ochoco National Forest and on the U.S. Geological Survey's 7½-minute map of the Egypt Canyon quadrangle (1992), the canyon is identified as the continuation of Dick Miller Canyon.

STOP 6. CURLY CANYON SECTION

Almost exclusively rheomorphic RST; locally overlain by undeformed lithophysal tuff, pervasively devitrified, and vapor phase zones. Rheomorphic tuff is either devitrified, with vapor phase minerals lining the elongate openings, or is vitric with flame-shaped lozenges of deformed pumice. Locally, lithophysal tuff is intercalated with devitrified rheomorphic tuff. The vitric part, which is partially to densely welded, occurs at the top of the section, indicating that it is near the original top. Although it has eutaxitic structure, it is not strictly vitroclastic, and we interpret the less welded, vitric tuff as the pumiceous carapace. In one location, float of the vitric tuff is weathering out of the central part of the devitrified tuff, which suggests that the vitric tuff was folded into the devitrified. Foliation and folds are gently inclined at base and top of tuff. In the central part, foliation is almost always nearly vertical. Although the base is not exposed, fold hinges at the base of the exposure indicate proximity to basal contact.

Optional addition: Return to Egypt Well (intersection of Roads 4130 and 4135), turn right (east), and continue for 1.1 mi to ~10-m-high outcrop of freshly exposed lithophsal tuff (lithophysae in devitrified matrix facies). Note range of lithophysae from completely filled to hollow varieties (cf. Figure 11 in Streck and Grunder, 1995). Return to Egypt Well.

DIRECTIONS TO STOP 7

From Egypt Well, drive back west for 9.2 mi on Road 4130 to junction with Road 45 and Silver Creek Road. Turn south (left) on Silver Creek Road toward Highway 20. Stop 7 is 0.6 mi down Silver Creek Road from the intersection. Park in turn-out on the east side of the road.

Important: Please leave lithic-enriched zone undisturbed for future visitors.

STOP 7. ASH-RICH SECTION

Nonwelded to partially welded ash-rich section. Basal contact of RST with lithic-enriched zone at contact

This is an unusual section in that it is pumice poor at this proximal locality. The color grades upsection from white to gray. Although part of the color change can be attributed to increased welding upsection, mostly it reflects upward increase in the proportion of brown to white shards.

Continue south to Hwy 20 and follow it for ~30 mi east back to Burns.

Day 2

ROUTE AND SCENERY TO STOP 8

From Burns, drive 27 mi west on Highway 20 to the junction with Highway 395 at Riley. Drive south on 395.

The small butte just southwest of Riley is Shields Butte, a strombolian basalt cone. Several such cones crop out near the highway on the way to Stop 8. The low ridge about a mile south of the junction is the eastern end of 6.87-Ma Juniper Ridge, a silicic flow and dome complex (MacLean, 1994). Note the turnoff to the Northern Great Basin Experimental Range (a few miles further). We will return via this road.

The prominent butte on your right side is Paiute Butte (formerly Squaw Butte), a basaltic trachyandesite with unusual trace-element enrichments. The next northwest-trending ridge to the south is Egli Ridge, composed of nearly aphyric rhyolite. The more massive buttes to the southwest are Sheep Mountain and Wagontire Mountain, mainly rhyolites, around 7 Ma. A rhyolite tuff (ash-flow tuff of Wagontire Mountain) with spectacular rheomorphic features is exposed at Wagontire Mountain (Walker and Swanson, 1968). Part of Wagontire Mountain has a reported age of 14.7 Ma (MacLeod and others, 1976). The alluvial cover is thin and underlain mainly by Rattlesnake Tuff or basalts, which make up the rimrocks.

The town of Wagontire—commonly for sale, population 2, coffee sold by the hour—is 28 mi south of Riley. The plain here is mainly Rattlesnake Tuff overlain by the 6.87-Ma tuff of Buckaroo Lake (first rimrock above the plain). The buttes to the south and southeast are 15-Ma dacites called Horsehead Mountain and Little Juniper Mountain.

Drive another 15 mi south toward the town of Alkali Lake. The hills seen to the west as you pass the junction to Christmas Valley are Horse Mountain, the most peralkaline of the rhyolite domes. The rimrock to the east is Rattlesnake Tuff, locally overlain by tuff of Buckaroo Lake. From the intersection of Hwy 395 with Christmas Valley Road, go ~4.8 mi south and take a gravel road east to the base of the cliff (toward Hotchkiss Cow Camp).

This is the northern end of the Abert Rim range-front fault escarpment. At the cow camp, turn south and go about 1 mi. This is Stop 8.

STOP 8. ALKALI RIM SECTION

The prominent rim is the Alkali Rim fault scarp. The fault scarp is mainly (~90 percent) rheomorphic and lithophysal Rattlesnake Tuff, reaching the maximum thicknesses observed throughout the tuff sheet (~70 m). Primitive tholeiitic basalts are exposed here underneath, in (dark layers in upper half of escarpment), and above (at northern termination of fault scarp) the Rattlesnake Tuff. The base of the thick, mainly rheomorphic and lithophysal RST section is exposed and can be observed as very thin white horizontal band. At the nearby cow camp, the base of Rattlesnake Tuff overlies basalt with a ropy surface that overlies another ash-flow tuff. Partially to densely welded vitric zone of Rattlesnake Tuff is extremely thin (~30 cm) and sandwiched between nonwelded and rheomorphic facies.

Three basalt sills (thin lower, thick middle, thin upper) intrude (or invade?) the Rattlesnake Tuff. Near the northern termination of the ~1-m-thick upper sill, pipe vesicles developed at the top and basal contact to the Rattlesnake Tuff. Intruding features, ripped off pieces of Rattlesnake Tuff, and well-developed vesicle sheets can be observed along upper contact of the thick middle and the upper sill.

DIRECTIONS TO STOP 9

Drive back north, past Wagontire to the sign pointing to the U.S. Agricultural Research Service's Northern Great Basin Experimental Range. Turn onto that road that leads northwest. Continue ~5 mi to Stop 9 to see some lavas of the Juniper Ridge center and Paiute Butte.

After this stop, continue north to Highway 20, crossing the entire silicic dome complex of Juniper Ridge.

Note: Before you reach Stop 9, be sure to TURN RIGHT when you get to the "dead-end" (T-) intersection in the road. It will lead you past the Experimental Station.

STOP 9. JUNIPER RIDGE-PAIUTE BUTTE

The small cliff is composed of a dacite lava with several percent phenocrysts, overlain by an aphyric rhyolite, both part of the Juniper Ridge volcanic center (MacLean, 1994).

Juniper Ridge (JR) is divided into two suites of rocks designated western and eastern JR based on their position relative to the northwest-striking Tin Mine fault (TMF in Figure 10). A diktytaxitic high-alumina olivine basalt laps onto the north side of the entire complex. Eastern JR is elongate, bounded to the northeast by a fault. Basal aphyric rhyolite (75 percent SiO_2) has a $^{40}Ar/^{39}Ar$ age of

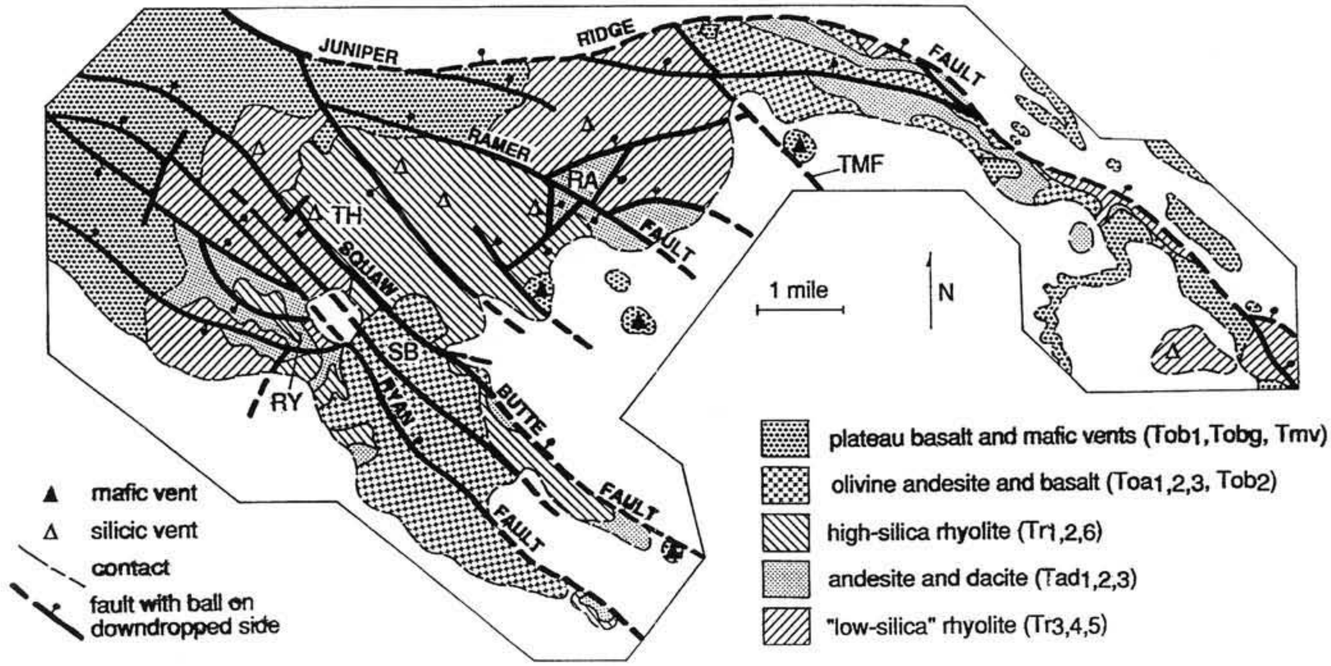

Figure 10. Geologic map of the Juniper Ridge silicic dome complex (from MacLean, 1994). RY = Ryan Peak; SB = Paiute (formerly Squaw) Butte; TH = Thomas Peak; RA = Ramer Peak; TMF = Tin Mine fault.

6.87±0.02 Ma. The basal rhyolite is overlain by porphyritic rhyolite (73 percent SiO_2), aphanitic olivine basalt, some andesites and dacites, and aphyric rhyolite (77 percent SiO_2). The oldest unit at the western JR is rhyolite (75 percent SiO_2), which is overlain by porphyritic andesite and dacite. The section is capped by high-silica (77 percent) rhyolite with a $^{40}Ar/^{39}Ar$ age of 5.7±0.02 Ma (Figure 10).

Paiute Butte is a prominent, partially eroded cone of basaltic trachyandesite in the center of the western JR. It is composed of alternating thin lava flows and scoria. Two dikes intersect at the summit. Paiute Butte has high concentrations of Fe and P, akin to FeTi basalts, and has extreme enrichments in REE and HFSE (high field strength elements), about twice that in Juniper Ridge high-silica rhyolites, and in Ba, Sc, Zn, and Ga. In contrast, Sr, Cs, Rb, U, Pb, and Th are similar to local, more calc-alkaline basaltic andesite. Trace element patterns like those of Paiute Butte are seen in basaltic andesite rocks issued from a few other mafic vents within the western Harney Basin (i.e., between Iron Mountain and Paiute Butte) and in inclusions of the Rattlesnake Tuff, although enrichments of the latter are less extreme (Streck and Grunder, 1996; Streck and Grunder, 1999).

End of trip at junction of Experimental Range road with Highway 20. Bend lies about 100 mi west and Burns about 30 mi east.

ACKNOWLEDGMENTS

The field trip based on this guide was held during the GSA Cordilleran Section meeting at Portland, Oregon, in 1996. We thank the participants for their enthusiasm and insights. We thank Scott Burns and Michael Cummings for their support in our endeavor. Thanks also to our colleague James MacLean, wherever he and Elmer might be. Funding for the research came from National Science Foundation grant EAR-9220500 to A.L.G., Geological Society of America Penrose grants to M.J.S. and Jim MacLean, and U.S. Geological Survey internship support awarded to J.A.J.

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Study tip: Earthquake cycles

Background information

Earthquakes occur along faults. Faults are fractures in the rock below the Earth's surface, places where two masses of rock separate from each other, usually by sliding past each other. The Earth's crust is in motion (as explained by the theory of plate tectonics). This motion results in stresses within the Earth. Normally, a fault is locked or stuck and will not move. However, if the stresses build up high enough, the rocks along the fault will move suddenly. This makes the rocks "shiver,"—and that is an earthquake. Seismologists and geologists have a model for this. For some faults they believe that the stress must reach a certain level before it is high enough to overcome the frictional resistance to sliding in the fault rocks. If the stress buildup is continuous, the earthquakes occur at regular intervals and are part of an earthquake cycle.

Seismologists have learned that some faults are more likely to move at short intervals, and others are more likely to move at long intervals. Not all faults fit a cyclic or predictable pattern, and even very cyclical faults do not always fit a pattern. In general, however, studies of a fault's earthquake history help geologists determine how likely it is that an earthquake may occur in the future.

Parkfield background

This town in central California is located right on the San Andreas fault.

To attempt to answer the questions about when, where, how big, and how often an earthquake will happen along a fault, scientists look at the historical record of the fault. A good example of this is a segment of the San Andreas fault near Parkfield, the site of a moderate earthquake (about magnitude M6) about every 20 years. Based on the historical record and other evidence, the U.S. Geological Survey predicted in the 1980s that an earthquake near Parkfield would occur before the end of 1993. Although the expected earthquake has yet to occur, Parkfield remains the most likely site in California for a moderate earthquake. A list of the dates of recent earthquakes there is shown below. For more information, look on the web at http://quake.wr.usgs.gov/QUAKES/Parkfield/.

Earthquakes near Parkfield, California	
1.	1857
2.	1881
3.	1901
4.	1922
5.	1934
6.	1966

To understand the cycle of earthquakes at Parkfield, answer these questions:

1. What was the shortest time period between the earthquakes?
2. What was the longest time period between the earthquakes?
3. Plot these dates on graph paper and draw a straight line on the graph that best fits the data points.
4. Continue the line on your graph and use it to predict when the next big earthquake (no. 7) will hit Parkfield. What year did you get?
5. Calculate the **average** time between earthquakes. This is also known as the average recurrence interval.
6. (a). What is one of the least predictable earthquakes? (Falls farthest from the line or had a time interval farthest from average?)
   (b) In what year would you predict this earthquake should have occurred?
7. Looking at your answers to the above questions, do you think that this method of predicting earthquakes works in the Parkfield area? Why or Why not?

When it comes to determining the earthquake cycle of an area, Parkfield, is an unusual case. Most areas subject to earthquakes do not have them this often or this regularly. Oregon has not had any great earthquakes (greater than M 7.5) in historic time (since about 1800). Because of this, we used to think that Oregon did not have much risk of earthquakes.

Geologists are just beginning to learn about the Oregon earthquake cycle from the sedimentary deposits formed by great Northwest earthquakes. With this method, the dates of the earthquakes are difficult to determine, and some quakes may be missed. The table below shows the approximate dates of the last great earthquakes in Oregon.

Cascadia subduction zone earthquakes	
1.	1400 BCE
2.	1050 BCE
3.	600 BCE
4.	400
5.	750
6.	900
7.	1700

To understand the cycle of earthquakes on the Cascadia subduction zone, answer these questions:

1. What was the shortest time period between the earthquakes?
2. What was the longest time period between the earthquakes?
3. Plot these dates on graph paper and draw a straight line on the graph that best fits the data points.
4. Continue the line on your graph and use it to predict when the next big earthquake (no. 8) will hit Oregon. What year did you get?
5. Calculate the **average** time between earthquakes. This is also known as the average recurrence interval.
6. Looking at your answers to the above questions, do you think that this method of predicting earthquakes works for Cascadia subduction zone earthquakes? Is it more or less accurate than in Parkfield?
7. Based on this information, when do you think the next great earthquake will occur in Oregon? Do you think an accurate prediction can be made?

—From T. Atwill, Oregon earthquake and tsunami curriculum, grades 4–6, 1998.

BOOK REVIEW

Oregon Fossils, by Elizabeth L. and William N. Orr. Dubuque, Iowa, Kendall/Hunt, 1999. ISBN 0-7872-5454-1, 381 p., soft cover, $40.95.

In preparation for the coming field season, amateur and professional paleontologists alike will enjoy perusing Orr and Orr's "Oregon Fossils". Out this year by Kendall/Hunt Publishing as an adjunct to the authors' standby *Handbook of Oregon Plant and Animal Fossils*, the book provides far more than field-type information concerning where to look for fossils in Oregon. As in the previous book, there are sections detailing each of the major groups of fossils that occur in the state. But the table of contents gives no hint to the added wealth of information about Oregon paleontologists, their specialties in research, and their backgrounds. Much of this is transmitted in an anecdotal manner, giving a delightful dimension to the book, and revealing the human side of the science. This aspect of the book alone should provide inspiration to budding paleontologists and is one of the few sources of which I am aware that preserves some of the treasure of stories passed along in the "oral tradition" of professional paleontologists. Many photographs, some formal, but some blessedly not, greatly add to this feature. In addition to these photos, the book is packed with well-executed line drawings and photos of fossils (including restorations) and charts and maps detailing statigraphic and geographic settings of the fossils. Typography and layout are equally well done, and the text reads smoothly, pleasantly spiced with the aforementioned personal and historical anecdotes.

Each section begins with a general introduction, proceeds to a discussion of some of the peculiarities of the group or the main applications of research on the group, then reviews the floras or faunas in stratigraphic order. Woven into this is information on the general geology of parts of the state and prevailing interpretations of age, climate, paleogeography, and other aspects of applied paleontological knowledge. Because different kinds of fossils are used to determine different aspects of the past (age, climate, etc.), each section is somewhat different in format and emphasis. This definitely helps in avoiding a "catalog" style, as does the inclusion of several items that deal with problems of interpretation of age or paleoclimate or the occasional "lost locality."

For the reader's further research or reference, eighteen pages are devoted to an excellent bibliography, covering more technical, historical, and related geological subjects. In fact, one could hardly go wrong using the bibliography as a starting point for researching a number of Oregon-related paleontological or geological themes.

In summary, *Oregon Fossils* is a very well done, useful, and enjoyable book, and it should give those interested in the paleontology of our state a good deal of help and encouragement.

—Richard E. Thoms
Emeritus Professor of Geology
Portland State University

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OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries

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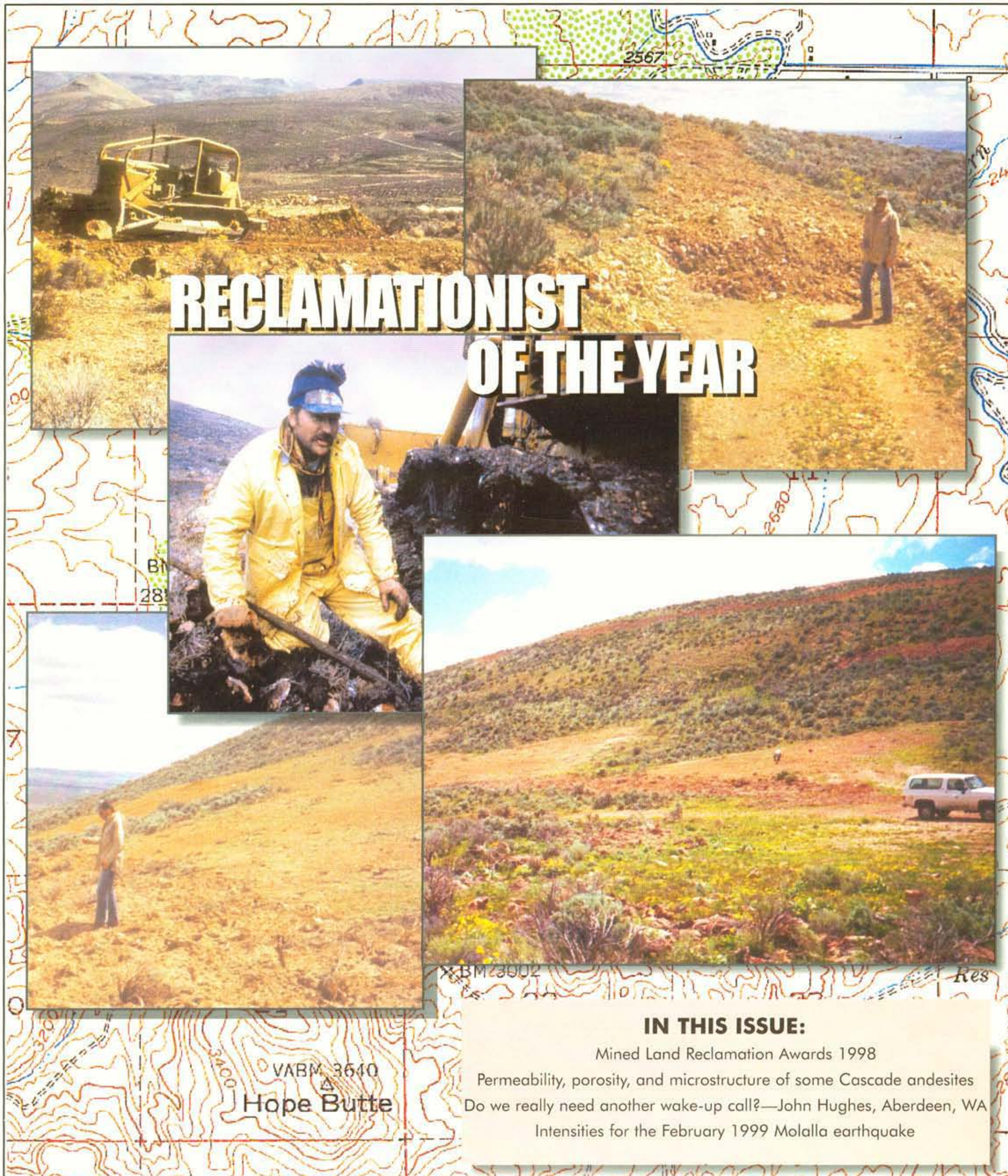

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Mined Land Reclamation Awards 1998

Permeability, porosity, and microstructure of some Cascade andesites

Do we really need another wake-up call?—John Hughes, Aberdeen, WA

Intensities for the February 1999 Molalla earthquake

THROUGH THE EYES OF THE STATE GEOLOGIST

John D. Beaulieu
Oregon State Geologist

Over the years I have been privileged to learn many things about the geology and natural systems of Oregon. As the new State Geologist and Director of the Oregon Department of Geology and Mineral Industries, I will continue to learn. In this column, with each issue I will communicate some of my insights to our readers.

One (just one) of the core values of a geology department is the production and delivery of useful geologic maps. Good geologic maps are simply diagrams of the earth beneath our feet. They depict how and when various earth events happened (or are happening). As such, geologic maps become four-dimensional translating devices that can be used to discern what Mother Nature is telling us with patterns of rocks and soil.

This information and other insights imbedded in geologic maps are central to management of our resources, to managing geologic hazards, and to approaching sustainable relationships with our ecosystems. Our job is to bring these insights to the busy public in the quest to solve earth-related problems.

To solve today's complex problems, especially those involving ecosystems and endangered species, however, we also need parallel insights from other fields besides geology, such as engineering, range science, biology, hydraulics, and soil science. This broad view is particularly acute at DOGAMI in our responsibilities to guide the reclamation of mined lands.

Integration of sciences within the programs of the agency and partnering by the agency with other agencies and the private sector are central to our services now and will be the foundation of our successes in the future.

Creative delivery systems for our information to the public are also required. These include traditional publications, digital files, web sites, personal presentations, policy discussions, and enlightened earth-resource workshops and regulations.

The task assigned to the Oregon Department of Geology and Mineral Industries is to provide the geology- and earth-science-related information needs of society and to see ways to best provide the right information to the right people at the right time.

It is a privilege for me to serve this agency as it serves the people of Oregon.

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Cover photos

Successful and exemplary reclamation is demonstrated in these pictures of ongoing and completed work at Hope Butte in eastern Oregon, which earned John Jordan of Vale the award of Reclamationist of the Year 1998.

The honor is one of several given annually by the Oregon Department of Geology and Mineral Industries through its Mined Land Reclamation Program and the winners are chosen by a panel of representatives from private industry and environmental and regulatory agencies.

See story beginning on next page (83) for complete report on this year's awards.

DOGAMI honors outstanding mined land reclamation

Salmon habitat enhancement, agricultural land reclamation, water-quality protection, and an educational partnership entitled, "Let's Rock" were highlights of this year's Reclamation Awards presented by the Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries (DOGAMI).

Winners were chosen by a panel of regulatory, industry and environmental experts, and the awards were presented at the annual conference of the Oregon Concrete and Aggregate Producers Association. The annual awards recognize mining companies and individuals who lead by example, surpassing the basic requirements of planning, operation, and reclamation at Oregon mine sites.

"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 show a deep commitment to the environment and the communities where they are based."

This year, Reclamation awards, judged on performance in the past year, were given in eight categories: Outstanding Operator, Outstanding Reclamation, Outstanding Small Operator, Outstanding Voluntary Reclamation, Good Neighbor Award, Salmon Enhancement Award, Outstanding Reclamation by Government Agency, and Reclamationist of the Year.

OUTSTANDING OPERATOR

Bayview Transit Mix, Inc.
Square Creek Quarry
Joe Perrigo
Seaside, Oregon

The Square Creek Quarry is located 2 mi south of Seaside in Clatsop County. A small perennial stream, Square Creek, flows between the quarry floor and the stockpile site. The creek drains into Circle Creek and then into the Necanicum River and is a spawning and rearing habitat for sea-run cutthroat and steelhead trout.

Square Creek quarry operated by Bayview Transit, winner of the Outstanding Operator Award.

Bayview Transit has been operating it for over ten years, expanding the affected area from about 2–3 acres to currently 17 acres.

This site has been operated in an exemplary manner from the beginning. All barren areas are seeded every fall. Areas where heavy equipment is used have been covered in a rock veneer. All storm water is conveyed through French drains and culverts to a settling pond. Interior haul roads have been paved, which significantly reduces the amount of sediment generated by the mine operation. Reshaping and scalping of waste rock prevent runoff over the highwall. Diversion ditches have been placed between the conically stacked waste piles to increase infiltration and redirecting runoff into stable areas above the highwall.

The operation is an excellent example of careful planning and implementation of a mine plan that protects fragile adjacent natural resources while providing a high quality aggregate resource for asphalt and concrete production.

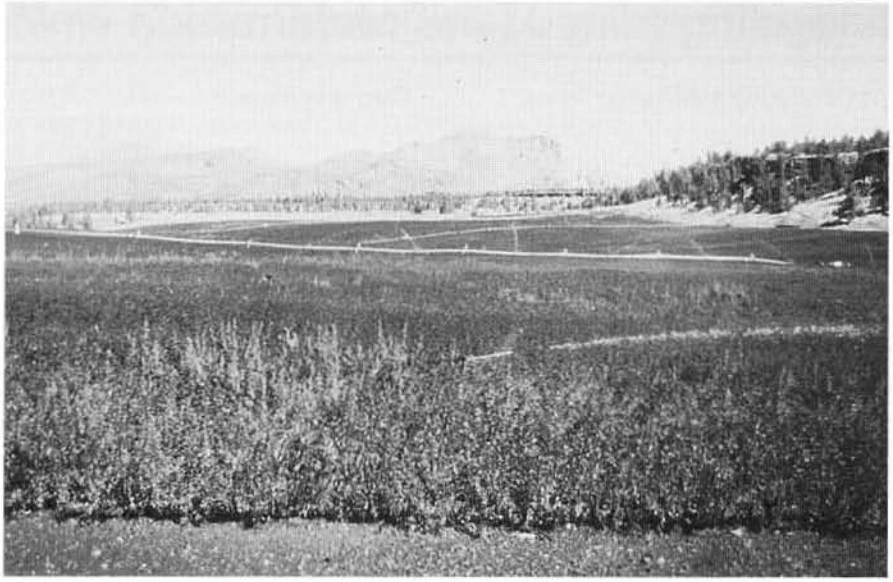
OUTSTANDING RECLAMATION

O'Neil Sand and Gravel Division
Lexus Johnson
Redmond, Oregon

This site is located 7 mi northeast of Redmond in Crook County. Two separate extraction areas within the approved 180-acre permit boundary had been mined prior to 1972. The operator has voluntarily reclaimed one of the areas, and will have reclaimed the other, once mining is complete at this site.

The site is surrounded by agricultural fields in the Crooked River valley. Since 1990, the operator has made a concerted effort to improve the aesthetics at this mine site. This operation is unique for a sand and gravel pit in that the mined area is returned to original grade, making it suitable for farming, while most sand and gravel excavations develop below-grade ponds for wildlife habitat as a beneficial use.

Since 1990, over sixty acres of ground have been mined, graded, topsoiled, and replanted to commercial crops of alfalfa and mint. The areas where the gravel layers have been removed and the soil



Hooker Creek operation of the O'Neil Sand and Gravel Division and winner of the Outstanding Reclamation Award, showing agricultural fields that were taken out of production for less than 12 months.

layer has been replaced are actually sloped smoother than unmined areas, so that wheel line irrigation systems will be more easily managed over the recontoured fields. In 1995, 20 acres of mint root were planted. After the harvest, the operator went back in and regraded some rough spots in the field. The entire reclamation process on this 20-acre parcel, from grading to harvest, was 12 months.

Over the past four years, O'Neil Sand and Gravel has also worked closely with neighbors to remove high areas of ground in agricultural fields to allow irrigated farming where it was not previously possible. One farmer stated the crop yield on a reclaimed piece of ground, the first season after reclamation, was at least 90 percent of the same crop yield on adjacent unmined lands.

OUTSTANDING SMALL OPERATOR

Powelson Pit
Keith Powelson
Timber Rock Enterprises
Elgin, Oregon

This basalt quarry is located 2 mi west of Elgin in Union County. It was first opened in 1974 required an Operating Permit in 1977. After several slow years, this site was reclaimed, the bond was released, and the file was closed.

The quarry was reopened in 1995 and mined for aggregate by several different operators, while Keith Powelson obtained and held the Operating Permit for the site.

Throughout the most recent development, Powelson has diligently employed all best management practices (BMPs) necessary to insure that the site remained in compliance with all applicable regulations and was operated in an environmentally sound manner.

Mature trees were left to provide visual and noise screening. Storm water controls were put into place to prevent any turbid water discharges into adjacent Phillips Creek. Storm water is discharged from several points, rather than in one concentrated flow, to a low-angle, well-vegetated slope within the permit boundary. The excavation and processing areas are sloped toward the working face so as to retain storm water. In order to further reduce storm water impact, mining has been voluntarily restricted to the summer months. Overburden stockpiles were immediately stabilized to prevent wind or rain erosion.

OUTSTANDING VOLUNTARY RECLAMATION

Nickel Mountain
Glenbrook Nickel Company
Greg Schoen
Riddle, Oregon

This site is located 3 mi west of Riddle in southern Douglas County. Mining began on this property prior to World War II, and hundreds of acres are exempt from reclamation rules and regulations at this mine complex. However, Glenbrook Nickel has done extensive reclamation work to protect the site's as well as adjacent natural resources.

Reclamation has begun on approximately 10 acres that had been mined by the previous mine operator. In the 1970s, a storm water control program was begun. A two-acre pond was constructed as a sediment control structure, with the pond and accompanying dam disturbing around four acres. This impoundment was approximately 20 ft deep and had a discharge system that required constant maintenance.

The pond has now been drained. Much of the fill from the dam was pushed into the impoundment, and a permanent surface outfall was constructed. The pond that remains has side slopes of 4:1 or flatter and is no deeper than 8 ft. Wetland-type vegetation and hundreds of willow and ash cuttings have been planted around the margins of the pond. The regraded embankment has been hydroseeded and planted with Douglas fir. The permanent outfall will require no maintenance, and the limited pond capacity poses no threat, should the remaining dam fail. Use of this site as a water source for big game animals will continue.

A severely eroded water diversion ditch was filled in and the water flow returned to approximately the pre-mine drainage. The reclaimed ditch line was left in a very rough condition, which reduces erosion, and then planted with Douglas firs.

In additional reclamation work, a pit area was ripped to decompact the surface and then planted with 1,000 Ponderosa pines. A new water course that caused slumping of an old fill slope was diverted. Old culverts that no longer serve the storm water control system, the access road to the pond and the old mine area, and a 2-mi-long tram system that transported ore from the mine to the smelter were removed. A total of 5,000 firs were planted in various places of the mine area, as well as additional willows and ash trees to stabilize new intermittent water courses.

Reclaimed storm water settling pond at Nickel Mountain, one of the many projects performed voluntarily by Glenbrook Nickel Company that were awarded with the Outstanding Voluntary Reclamation Award.

GOOD NEIGHBOR AWARD

"Let's Rock" School Partnership Program
Morse Brothers, Inc.
Eileen Shufelt
Tangent, Oregon

Morse Brothers, in partnership with mid-valley school districts, has developed an educational curriculum that provides an understanding of the value of the aggregate industry, the process of mining for aggregate, and the steps taken to preserve the land for future generations.

The "Let's Rock" curriculum can be used in grades two through four and meets the Oregon Department of Education's earth science requirements for the Certificate of Initial Mastery (CIM). Curriculum packs contain lesson plans, material samples, and video and audio cassettes and were made available free to over 300 schools in the market area served by Morse Brothers.

An additional element of the curriculum is a tour of Morse Brothers facilities with several hands-on activities. During the tour season (November through March), 12 to 14 groups of up to 25 students tour the corporate offices in Tangent and the mine site at Corvallis.

Students of the 3rd grade class from Jefferson Elementary School in Corvallis and their teacher Mary Anne Pullam assisted in preparing a demonstration slide program of the curriculum.

SALMON ENHANCEMENT AWARD

Copeland Sand and Gravel, Inc.
Dave Staley
P.O. Box 608
Grants Pass, Oregon

Copeland Sand and Gravel has mined aggregate in the lower reaches of the Applegate River for decades. Most of the sand and gravel was mined from large, deep pits adjacent to the river channel. This was an efficient way of operating for the producer, and was a process preferred by regulatory agencies because it kept the operation out of the active river channel. Unfortunately large pits do not always remain separate from the stream during high water flows and can actually capture the stream and change the channel location.

In 1997, Copeland Sand and Gravel representatives posed a question to state and federal regulators: "Is there a way that gravel extraction could be done in the Applegate River that would not be detrimental to fish and wildlife, would not impact water quality, and could perhaps improve fish habitat?" This question began a long planning and permitting process to develop a design to mine gravel within the active stream channel with the potential to enhance conditions for fish.

Educational pack of the "Let's Rock" curriculum, which is part of the partnership efforts that earned Morse Brothers, Inc., the MLR Good Neighbor Award.

The plan developed by private consultants proposed removing a thin veneer (up to 8 ft) of gravel from two gravel bars within the

Applegate River near Murphy, Josephine County, showing gravel bar that was mined and off-channel salmon habitat behind the gravel bar. For this project, Copeland Sand and Gravel received the MLR Salmon Enhancement Award.

main stem of the Applegate River upstream of Murphy. Copeland Sand and Gravel completed the work in the summer of 1998. Even though in the active channel, the mining operation was out of the water at all times. Water quality was protected in this way. After the gravel was removed, Copeland excavated alcoves on the bars to provide off-channel habitat for fish. The alcoves were planted with native vegetation such as willows and alders to provide stability, wildlife habitat, and shade. About 88,000 cubic yards of material were removed from the project site.

This experiment will be monitored over the next several years to determine the effectiveness of the project. The success of this project shows that industry and regulatory agencies can seek solutions together to allow natural resource extraction in the face of endangered species listings and provides a framework for other operators to follow.

OUTSTANDING RECLAMATION—GOVERNMENT AGENCY

Mount Meares Quarry
Tillamook County Road Dept.
John Oshel
Tillamook, Oregon

The Mount Meares Quarry is located 6 mi southwest of Tillamook on property now owned by Shiloh Forest Enterprises.

The Tillamook County Road Department obtained a permit for the site in 1978. From the first inspection in April 1977, protection of an adjacent stream, Short Creek, was the principal environmental concern, primarily because this small drainage is part of the watershed for the City of Oceanside.

Sloping of the floor and the benches of the quarry directs storm water away from the creek to a retention pond. An undisturbed buffer strip between all operations and the creek provides additional protection, keeping sediment from reaching Short Creek. Soils and overburden were salvaged, stockpiled and vegetated to prevent erosion in this high-rainfall area.

Over the years, several inspections by DOGAMI personnel noted problems with barren overburden and storm water management. The county responded quickly to address all concerns and to insure that protection of the creek was maintained. Several inspection reports from the 1980s and early 1990s commend the work accomplished by the county road department at this quarry.

In early 1998, Tillamook County decided to relinquish the Operating Permit for this quarry, and the landowner assumed the DOGAMI permit. Because the quarry had been developed in an orderly manner, Tillamook County was able to complete reclamation in those areas that had been mined out. Complex final slopes, 2:1 and flatter, were formed and revegetated. Terraces were built across the face of the remaining overburden dump to trap sediments and to break up the flow of surface water down the face. Because of the amount of rock in the overburden pile the slope configuration is stable and will create a suitable timber ground after revegetation.

The Tillamook County Road Department was nominated for this award due to their long-term diligence to operate and reclaim this quarry without impacting adjacent natural resources, which includes the water supply for Oceanside.

RECLAMATIONIST OF THE YEAR

John Jordan
Exploration Services, Inc.
Carson City, Nevada

John Jordan, originally of Vale, has performed reclamation at numerous precious-metal exploration sites in eastern Oregon. He has been involved in such projects at Hope Butte (see cover photos), Quartz Mountain, Bully Creek, and Grassy Mountain.

Jordan has embraced the latest technology and techniques in the field of reclamation to the benefit of the exploration companies and the environment. When he is involved in the earliest planning stages of a project, he is able to evaluate the disturbance he will be making and calculate how to minimize the impact before the project starts.

Although recent times have seen an overall decline in the mineral exploration business in Oregon, Jordan continues to refine and develop innovative reclamation methods.

Intrinsic permeability, porosity, and microstructure of Holocene vesicular basaltic andesites in the Oregon Cascades

by Martin O. Saar and Michael Manga, Department of Geological Sciences, University of Oregon, Eugene, OR 97403

Note: This is a modified abstract of the master's thesis by M.O. Saar (Saar, 1998). Coauthor M. Manga also collaborated on a related paper published recently in Geophysical Research Letters (Saar and Manga, 1999). The subject matter addresses issues in water-resource and water-quality research. —ed.

Vesicular basalts can serve as aquifers, as has been shown for Hawaii by Ingebritsen and others (1993) or for the Pacific Northwest by Manga (1996). These aquifers typically show dual porosities and permeabilities (Sanford, 1997). The overall aquifer permeability is probably governed by the fracture network, whereas contaminant storage and release (by diffusion) may depend on the interfracture permeability and porosity. Here, we discuss laboratory measurements of interfracture permeability, porosity, and microstructure (shape, size, and orientation of small features such as crystals and bubbles).

Samples were taken from blocks of Holocene and Pleistocene vesicular basaltic andesite flows and cinder cones in the Oregon Cascade Range (Figure 1). From these blocks, cores were drilled with a diameter of 7.2 cm and lengths between 2 and 23 cm, such that length always greatly exceeds bubble radius. Permeability measurements were made with a steady-state gas permeameter. Connected porosity was measured with a gas-expansion technique, and total porosity was obtained from a determination of rock matrix density and mass of the cylindrical cores. A comparison of total and connected porosity showed that virtually all pores were connected. The microstructure was investigated through thin section observations and image analysis on images scanned at high resolution (1,200 dpi) from discs representing cross sections of the cores.

Based on bubble shape and microstructure, samples can be grouped into five categories (four are shown in Figure 2): (1) Scoria samples, from cinder cones, contain a very fine-grained, partly glassy matrix, no micropores, and a wide range in the size of its subspherical bubbles. (2) Flow-1 samples, which probably cooled relatively close to the vent, have a fine-grained matrix with some glass and few plagioclase crystals; micropores are usually not abundant, and bubbles are elongated to an ellipsoidal shape. (3) Flow-2 samples, which are believed to have

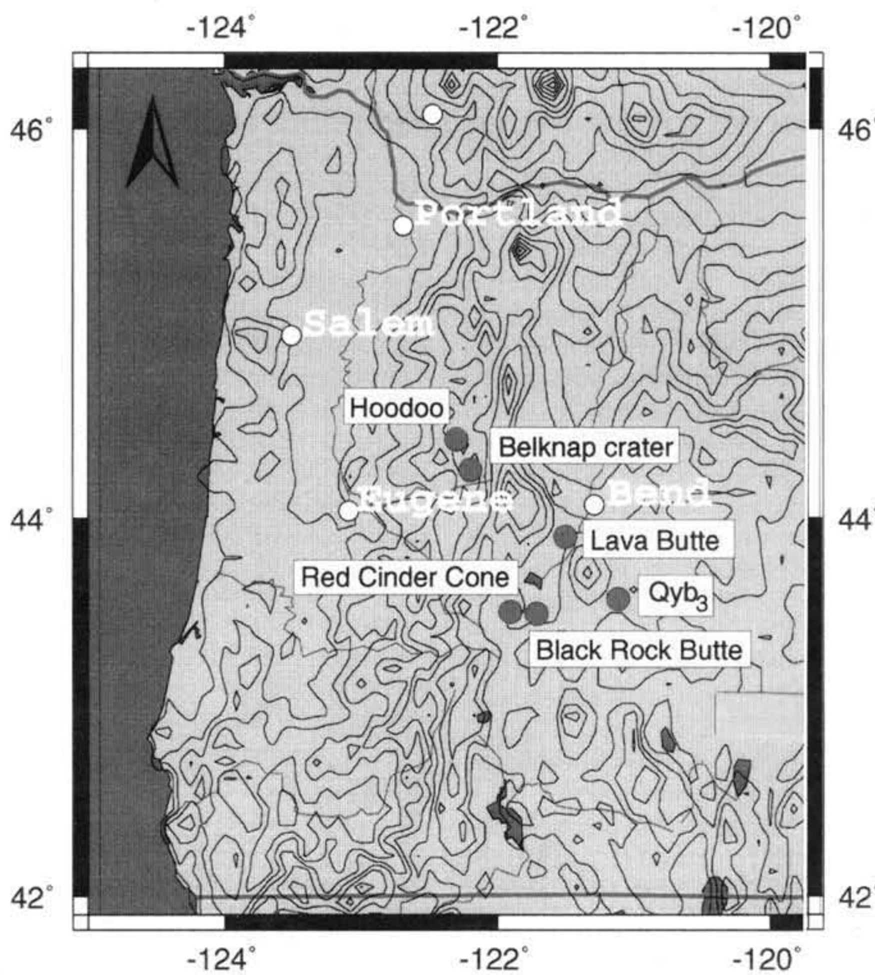


Figure 1. Map of western Oregon showing locations (filled circles) of basaltic andesite flows from which samples were taken. Qyb_3 = Mokst Butte flows at Newberry volcano, from MacLeod and others (1995).

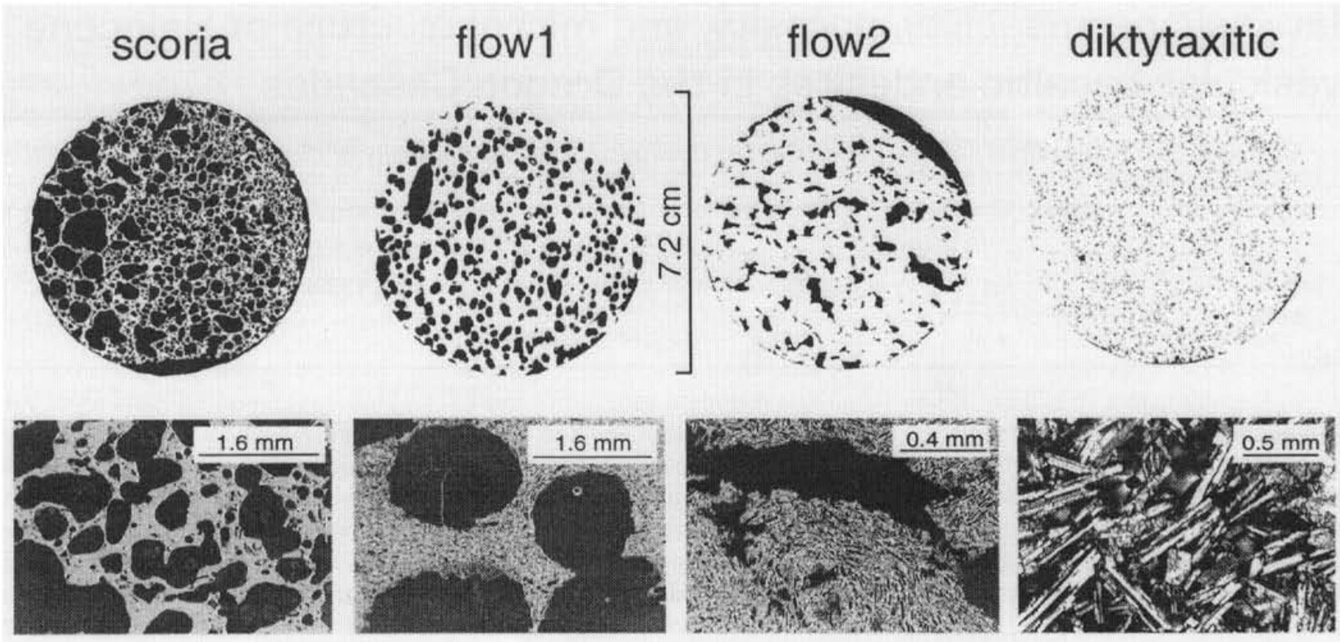


Figure 2. Images of scanned cores (upper row) and respective thin-sections (lower row). Bubbles are black, solids are white.

formed farther away from the vent than the Flow-1 samples, contain densely packed plagioclase crystals (size ~0.2 mm) with subparallel orientation, few micropores, and highly deformed, partially "collapsed" bubbles. (4) Diktytaxitic samples show randomly oriented, larger plagioclase crystals (size ~0.7 mm) and intercrystalline micropores (Chitwood, 1994). (5) Finally, some samples contain micropores only but do not have a diktytaxitic texture.

Typical permeability (k) of samples containing bubbles is in the range between 10^{-14} and 10^{-11} m^2 and agrees well with values of 10^{-14} -10^{-9} m^2 for unfractured vesicular basalts reported by Freeze and Cherry (1979, p. 29). Ditkytaxitic samples show a similar permeability range. Samples containing micropores only, representing the dense middle part of lava flows, have very low permeabilities of approximately 10^{-17} m^2.

Our results show that similar permeabilities for a wide range of porosities can be expected if different microstructures are present (Figure 3). However, the five sample types plot in distinct clusters, depending on their microstructural characteristics. During a possible evolution of samples from scoria to Flow-1 samples and finally to Flow-2 samples, the porosity may decrease, whereas the permeability could stay approximately constant or even increase. An explanation involving degassing processes is presented in Saar (1998) and Saar and Manga (1999).

Only the scoria samples show a characteristic permeability-porosity relationship, possibly as a result of a lack of degassing. Diktytaxitic samples show textures that are more similar to those of granular materials with respect to fluid pathways; these structures result in relatively high permeabilities (10^{-14}–10^{-12} m^2) for low porosities (~2–5 percent).

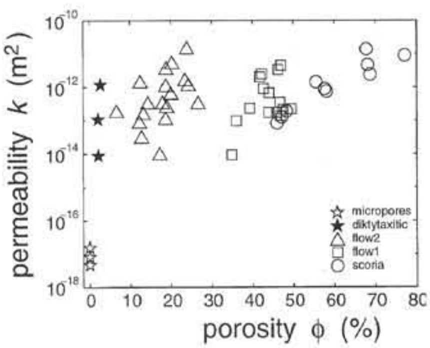


Figure 3. Measured permeabilities (k) versus porosity (ϕ) for the five sample types.

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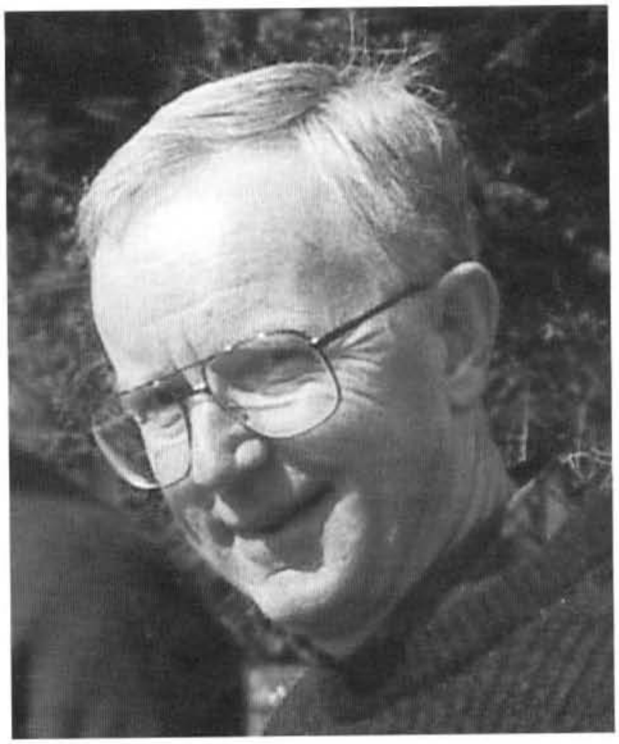
Donald A. Hull retires from DOGAMI

After 21 years as State Geologist, Donald A. Hull retired in June. Hull's background was in mining, but he broadened the focus of the Department of Geology and Mineral Industries (DOGAMI) to include research and mitigation of geologic hazards, along with the more traditional mineral regulation and mapping activities.

Hull was a tireless advocate to increase resources available for earthquake and tsunami preparation. One of his legacies is the construction of signs up and down the Oregon coast, teaching residents and tourists about the dangers of coastal earthquakes and tsunamis.

It is difficult to summarize such a long and impressive career, but here are some of the most important activities of the department under Hull's direction.



DOGAMI MILESTONES 1977–1999

1977 Intensive investigation of geothermal resources of Oregon initiated.

1978 First multi-year (1978-1985) Mission and Goals Plan adopted to guide Department activities.

1979 Charged with coordinating federal and state mapping through chairmanship of State Map Advisory Committee.

1979 Oregon's first commercial gas well near Mist.

1981 Surface mining regulatory authority expanded for metal mining.

1983 Dormant mineral interest legislation passed.

1984 Partnership formed with Minerals Management Service to jointly study mineral deposits and environment of Gorda Ridge.

1985 Plugged mined land reclamation loophole for "valid contract" grandfather rights.

1985 Added underground mining to Mined Land Reclamation Program authority.

1987 Co-hosted with Oregon State University Geology Department a landmark professional gathering of earth scientists to discuss the potential of a Cascadia subduction zone earthquake.

1987 Hosted a "cluster" meeting of regional state surveys with U.S. Geological Survey scientists to discuss the earthquake potential of the Pacific Northwest.

1987 Chemical heap leach regulatory authority added to Department responsibilities.

1987 Bonding authority increased for mined land reclamation to full cost of reclamation.

1987 Oregon sunstone became the official state gemstone.

1989 Regulation of mineral exploration authority added to Department responsibilities.

1989 Enabling legislation expanded to include various hazard and earthquake assessment, public education, and risk reduction.

1989 Sponsored national meeting of the Industrial Minerals Forum.

1993 Opened the Nature of Oregon Information Center (now the Nature of the Northwest).

1995 Tsunami legislation passed to regulate construction of certain buildings in tsunami inundation zone and to map the tsunami inundation zone. Other legislation mandated tsunami training in coastal schools.

1995 Earmarked Federal mining royalties to the Department.

1996 Seismic Rehabilitation Task Force appointed and legislation developed.

1997 Oregon Seismic Safety Policy Advisory Commission membership revised to include private sector representation.

HIGHLIGHTED ACTIVITIES

Treasurer and member of Executive Committee of American Geological Institute; member of Federal Emergency Management Agency Technical Floodplain Mapping Advisory Council; member, Western States Seismic Policy Advisory Commission Executive Board; Treasurer, Vice-President, President-Elect, and President of Association of American State Geologists; member, National Research Council Committee on offshore geologic information; State Co-chair, Federal-State Placer Minerals Task Force; State Co-Chair, Federal-State Gorda Ridge Technical Task Force; chaired the legislative State Flood Control Plan Task Force; served as ex-officio member of the State Board of Geologist Examiners and as member of the Oregon Geographic Names Board. In addition, served on numerous other State and Federal committees and task forces.

What you know about tsunamis could save your life

Results of a recently repeated poll by the Oregon Department of Geology and Mineral Industries (DOGAMI) suggest that Oregon coastal residents still need to be better informed to protect themselves from these giant waves. Tsunamis can be generated by earthquakes off the Oregon coast or elsewhere in the Pacific Ocean. Along the coast, their waves are generally expected to be up to 25 ft high, but might be up to 50 ft high.

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 39% of coastal residents correctly answered 30 minutes or less, but this is an improvement over the 31% who correctly answered the question a year ago. About a third (38%) said they didn't know.

A third of those questioned (32%) knew that after a distant earthquake, they would have 1–8 hours before the first tsunami wave hit the Oregon coast. That is an increase over the 27% who correctly answered the question earlier.

More than a third of respondents (36%) knew when it's safe to return to low-lying areas after a tsunami has struck (only after given approval by appropriate authorities, because tsunamis are a series of waves), but another third (32%) said they didn't know.

About half the respondents had seen tsunami information signs along the beach (45%) or seen a video or brochure about tsunamis (55%). Three-quarters read about tsunamis in a newspaper (77%) or saw a story on TV (75%).

Most people (85%) say they know what to do in an earthquake or tsunami, and more than half (51%) know their local evacuation route. Only 24% of coastal residents said they had earthquake insurance.

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%.

To get information about how to protect yourself in an earthquake or tsunami or to purchase tsunami inundation maps, contact the Nature of the Northwest Information Center, 800 NE Oregon St. #5, Portland, phone (503) 872-2750, http://www.naturenw.org.

Survey results broken down by coastal region

North	Central	South
Respondents: 128	Respondents: 165	Respondents: 107
Margin of error 9%	Margin of error 8%	Margin of error 10%
Astoria	Pacific City	Reedsport
Seaside	Lincoln City	Coos Bay
Cannon Beach	Newport	North Bend
Rockaway Beach	Waldport	Brookings
Tillamook	Yachats	Bandon
	Florence	Gold Beach
		Port Orford

1. How much time before the first tsunami wave after an Oregon coastal earthquake?

	Correct (30 minutes or less)	Don't know
North	45	29
Central	44	36
South	22	52

2. How much time before the first tsunami wave after a distant earthquake?

	Correct (1-8 hours)	Don't know
North	34	30
Central	30	30
South	33	43

3. When is it safe to return to low-lying areas?

	Correct (after authorities OK)	Don't know
North	45	29
Central	33	32
South	31	36

4. Seen tsunami information signs on beach?

	Yes	No
North	53	47
Central	42	58
South	39	61

5. Seen tsunami video or brochure?

	Yes	No
North	63	37
Central	54	46
South	45	55

6. Do you know what to do in an earthquake or tsunami?

	Yes	No
North	88	12
Central	84	16
South	83	17

7. Do you have earthquake insurance?

	Yes	No
North	23	71
Central	21	76
South	27	66

PLEASE SEND US YOUR PHOTOS

Since we have started printing color pictures on the front cover of *Oregon Geology*, we are finding ourselves woefully short of good color photographs showing geologic motifs in Oregon.

We also want to make recommendations for scenery well worth looking at in a new series of black-and-white photos on the back cover of *Oregon Geology*. For that, too, your contributions are invited.

Good glossy prints or transparencies will be the best "hard copy," while digital versions are best in TIFF or EPS format, on the PC or Mac platform.

If you have any photos that you would like to share with other readers of this magazine, please send them to us (you know, "Editor, etc."). If they are used, the printing and credit to you and a one-year free subscription to *Oregon Geology* is all the compensation we can offer. If you wish to have us return your materials, please include a self-addressed envelope.

Information for Contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Color photos for publication on the front cover are highly welcome, as are letters or notes in response to materials published in the magazine and notices of meetings that may be of interest to our readers.

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). Hard-copy graphics should be camera ready; photographs should be glossies. All illustrations should be clearly marked; 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.

Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

Authors will receive 20 complimentary copies of the issue containing their contribution.

Manuscripts, letters, notices, and photographs should be sent to Klaus Neuendorf, Editor, at the Portland office (address in masthead on first inside page).

Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated.

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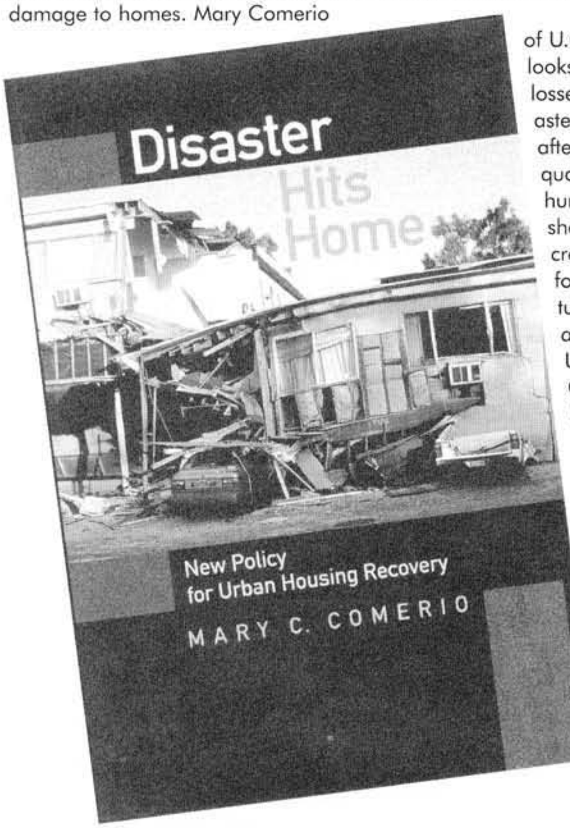
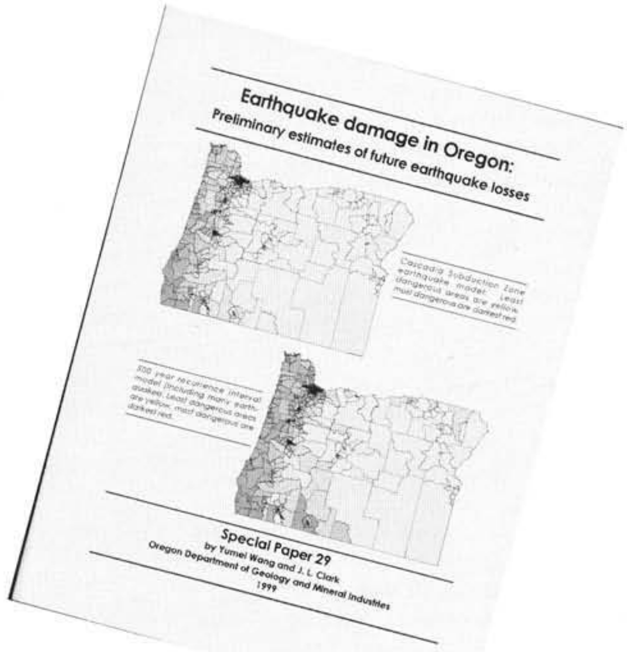
Allow two weeks for delivery on all maps plotted on demand.

Highlighting Recent Publications

now available from The Nature of the Northwest Information Center

Most injuries and damages in earthquakes are caused by buildings. If we can improve our buildings, we can reduce future danger. Between 1989 and 1994, the five largest disasters in the U.S. caused almost $40 billion in damage to homes. Mary Comerio of U.C Berkeley looks at housing losses and post-disaster rebuilding after four earthquakes and two hurricanes, and she suggests concrete measures for reducing future losses. *Disaster Hits Home*, University of California Press, 300 pages, $39.95; add $3.00 for shipping.





How much damage can earthquakes cause in Oregon? This eye-opening report estimates the damage from a single Cascadia subduction zone quake at more than $13 billion, with 7,000 casualties. It also breaks down damage forecasts by county so you can see how your area would fare: ***Earthquake damage in Oregon: Preliminary estimates of future earthquake losses***, DOGAMI Special Paper 29, 59 pages, $10.

Although you may think of 1996 as the year of floods, there were also hundreds of landslides. Portland State University Professor Scott Burns has documented more than 700 of them in the Portland area, as shown on this map. Find out why they occurred and learn about the geologic formations that are most at risk. As we head into landslide season, it's time to prepare for another round. The map, the data behind it, and the illustrated report prepared for the Portland Region Metro are assembled on a CD-ROM disk: ***Landslides in the Portland, Oregon, metropolitan area resulting from the storm of February 1996: Inventory map, database, and evaluation***. ($25)

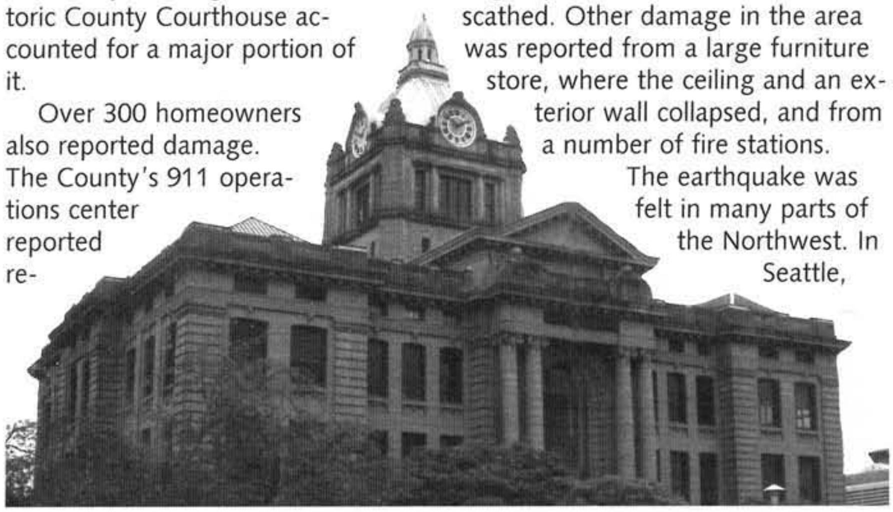
Washington earthquake hypocenter deepest since 1965

A powerful earthquake (magnitude 5.9) shook the Pacific Northwest on July 2, 1999, at 6:44 p.m., snapping utility lines, crumbling chimneys, and severely damaging the historic Grays Harbor County Courthouse in Montesano, Wash.

The quake originated at a depth of 25 mi beneath Satsop, Wash., about 68 mi southwest of Seattle. It is the deepest quake to hit the region in almost 35 years. The earthquake was similar to those that struck Washington near Olympia in 1949 (magnitude 7.1) and Renton (magnitude 6.5) in 1965. "The only historical earthquakes that have done significant damage were ones that occurred like this one, deep down in the subducted plate. These quakes can kill people," Steve Malone, a University of Washington seismologist, said.

Gas leaks, toppled chimneys, and power outages were reported all over Grays Harbor County after the earthquake, according to Rob Harper of Washington State Emergency Management, particularly in Hoquiam, Aberdeen, Brady, Satsop, and Montesano. Karin Frinell-Hanrahan of Grays Harbor County Emergency Management reported initial damage estimates at ten milion dollars for county buildings alone. The historic County Courthouse accounted for a major portion of it.

Over 300 homeowners also reported damage. The County's 911 operations center reported re-



Grays Harbor County Courthouse in Montesano, Washington. This historic building suffered several million dollars' worth of damage during the July 2 earthquake whose epicenter was about 7 mi away.

ceiving over 2,700 phone calls the night of the quake. Many callers asked about the danger of a tsunami following the tremor. No tsunami warning system exists in the area.

In Montesano, Dennis Selberg, Facilities Director for Grays Harbor County, said that the County Courthouse, built in 1910, sustained "very scary, substantial damage," and will remain closed until a team of structural engineers can assess the damage. The courthouse survived the larger quakes in 1949 and 1965 unscathed. Other damage in the area was reported from a large furniture store, where the ceiling and an exterior wall collapsed, and from a number of fire stations.

The earthquake was felt in many parts of the Northwest. In Seattle, diners in the Space Needle restaurant felt the floor jump; and in the Portland offices of the Oregon Department of Geology and Mineral Industries, employees felt the building shake for about 30 seconds.

Early reports pegged the earthquake at magnitudes of 3.5, 5.1, and 5.5, but the U.S. Geological Survey most recently determined that the earthquake had a "moment" magnitude of 5.9, based on a more elaborate measurement system.

Reprinted with permission from John Hughes' "Letter from the Editor" column in *The Daily World*, Aberdeen, Washington, July 4, 1999, page A4.

Do we really need another wake-up call?

Dear Reader: That got my attention. By eerie coincidence, reporter Ryan Teague Beckwith and I were discussing the major natural disasters of the 20th century on Grays Harbor—the Columbus Day Storm of 1963, the blizzard of 1950, the rainfall record of 113.49 inches in 1933 —when two tectonic plates did a bump and grind that stopped short of cataclysmic. A Richter here and a Richter there, and we could have had a front row seat for the No. 1 headline of the fast-ebbing old millennium and never lived to write about it.

Although we're joking about the emotional fallout—the brain's way of coping—most of us now have a better understanding of post-traumatic stress. When I think of the what-ifs, I really get scared. And I was scared at 6:43 p.m. Friday, July 2, 1999. So scared that I stood for several seconds in front of a seven-foot-tall bookcase instead of diving under my desk, an antique so substantial that it likely could withstand a direct hit by an ICBM.

(Would I have shared my space with Ryan? He has his whole life ahead of him. I'm 55. I've lived in Bermuda, owned two Porsches and have a personal letter from Annette Funicello. Although he sometimes looks at me with the secret glint of youthful contempt, as if I'm just another worn-out Boomer worried about prostate trouble and glued to a 401(k) hotline, it would have been the right thing to say, "Quick, Ryan! Under here!" But naaaaa! Crawl under your own desk, cheeky twirp!)

Beckwith, given often to ironic understatement, stood frozen in the doorway and declared, "I think this is an earthquake." And I said, "Holy #@$*!" Or words to that effect.

The newsroom emptied into the parking lot fronting historic State Street, which sits atop several jillion cubic yards of sawdust spaltz. In fact, this whole end of town was a salmonberry marsh a century ago.

We rode the wave for 40 seconds. It seemed like an eternity. Streetlight poles shook, my Volksvagen Beetle did the Macarena while Dee Anne Shaw's Chrysler coupe was undulating. There were a half-dozen of us looking at one another like deer caught in the headlights of an oncoming car. Then the shaking stopped. Seconds later, the first siren.

I've been in bigger quakes—a lot bigger quakes—but this one lasted longer and felt stronger.

A RUDE AWAKENING

In June of 1992, I was finishing up a month-long stint as acting editor of our company's newspaper at Hemet, Calif., east of L.A., when I endured the longest 30 seconds of my life. Then it happened all over again three hours later.

It was the definitive rude awakening at 4:58 a.m., when the bright-red Mickey Mouse alarm clock my daughter Sarah had loaned me for the trip rocketed off the nightstand. The four heavy drawers in the bureau slid open with a whoosh and everything in the bathroom medicine cabinet crashed onto the tile floor. The room was rolling. I was riding the bed and saying Hail Marys.

It was California's strongest earthquake in 40 years—7.4 on the Richter, infinitely stronger than the 5.5 we experienced Friday night.

The aftershocks were relentless. I couldn't get back to sleep, so I actually read the Gideons' Bible.

I was brushing my teeth at 8:07, when the second one hit. It was only a 6.5, but the jolt was even stronger—a violent side-to-side motion.

As a rule, I only need one wake-up call, literally and figuratively. I had to go to the bathroom, but the thought crossed my mind that I didn't want to be found dead on the toilet a thousand miles from home, so I threw everything in the suitcase and headed for the stairs.

I waited for an hour in the hotel parking lot, bags at my side. The sky was alive with arcing bolts of light, as transformers exploded for miles around.

Dave Caffoe, who was general manager at The Daily World in the early '70s, was the publisher at Hemet. I was there as a favor to him.

He was laughing, as he pulled into the portico of the Doubletree and popped the trunk lid on his white Oldsmobile.

"I gather you'd like to go home," he said.

I declined his offer of a Bloody Mary with celery stalk, opting for black coffee and a boarding pass.

NOT IN MY BACKYARD

That was then; this is a more sobering now. This is home. Despite the absolute consensus by scientists that The Big One is coming to the Northwest—not if, but WHEN—I've always kidded my friends in California about their precarious existence.

Sure, it could happen here, I thought, but it probably won't. It's gonna be -Seattle or, better yet, Bellevue. Not in my backyard.

I've been in denial. You too?

I lost a lovely Tiffany-style lamp Friday night. A thousand-dollar lamp that I got for a song 30 years ago. It tumbled off the rolltop desk in the hallway. There's plaster damage in the kitchen and dining room, and a beam in the garage is askew.

But I'm counting my blessings. The lamp, with its heavy leaded-glass shade, could have hit Sarah, who was scrambling for cover. If those tectonic plates had shifted just a little bit more, the ground could have turned to goo and swallowed my family—maybe yours too. Forget the lamp.

The tsunami that followed could have killed thousands.

As I made a quick reconnaissance of the area around the newspaper, I imagined the center span of the Chehalis River Bridge upright in the water, like the arm from the Statue of Liberty in the climactic scene of "Planet of the Apes."

I imagined the Becker Building a pile of smoking rubble and the parking lot of Wal-Mart as one giant field hospital.

I saw the remains of Community Hospital half-way down the hill. Dee Anne's house, with husband John and 9-month-old Gordon, the cutest baby in the world, is just below the hospital.

Driving home to Hoquiam through the pitch-black along Sumner Avenue at 2:30 a.m. Saturday after the presses rolled, I imagined no lights anywhere, no water, fires out of control in a hundred homes and businesses, gas lines ruptured. Chaos.

Survival could require a blend of luck, pluck, and smarts.

I, for one, as the letter writers always say, am going to start paying attention to those emergency checklists of do's and don'ts.

And if you think the best thing to do in an earthquake is call 911, you might as well hang up and kiss your silly derriere goodbye.

Be prepared.

There will be another earthquake. Earthquakes. One is bound to be bigger. Maybe a whole lot bigger.

I don't need another wake-up call, but if you can repair leaded glass I'd like to hear from you.

John Hughes can be reached at [360] 532-4000, ext.112, or editor@thedailyworld.com

Intensities for the February 1999 Molalla earthquake

by Gerald L. Black, Oregon Department of Geology and Mineral Industries

INTRODUCTION

On February 24, 1999, a small (M_L 2.7) earthquake occurred approximately 14.6 km (9.1 mi) south of Canby, Oregon (Figure 1). The earthquake occurred at 08:45 a.m. PST and was located at lat 45.11°N., long 122.66°W. The location quality was rated as B by the Pacific Northwest Seismograph Network (with "A" rated as "good" and "D" rated as "bad" location qualities).

The earthquake was unusual for two reasons. First, its hypocenter was quite deep, nearly 35.7 km (22.2 mi). Second, given its small size, it was felt over an extremely large area. Because of the large felt area, the Oregon Department of Geology and Mineral Industries (DOGAMI) placed a questionnaire on the DOGAMI web page (**http://sarvis.dogami.state.or.us/**) and in local newspapers in the northern Willamette Valley, asking people to describe what they felt during the earthquake.

DOGAMI received a total of 250 responses. These responses indicated that the earthquake was felt in Vancouver, Wash., 53.3 km (33.8 mi) north of the epicenter; in Sweethome, Oreg., 84.7 km (52.7 mi) south of the epicenter; and in Sheridan, Oreg., 57.1 km (35.5 mi) west of the epicenter. The earthquake was felt only 24.6 km (15.3 mi) east of the epicenter, a lesser distance which probably reflects the lower population density in the foothills of the Cascade Range.

Figure 1. Earthquake intensities for the February 24, 1999, ML 2.7 earthquake. Star is epicenter. Isoseismal contours outline the (larger) felt area and the area with Intensity III or greater effects. Responses were grouped by zip code and plotted at the zip-code centroids.

A M_L 2.7 earthquake is typically felt only by people located very close to the epicenter and does little or no damage. While this particular earthquake was felt over an unusually large area, the only damage reported was that minor cracks were opened in walls and ceilings in the Oregon City High School, and an 83-year-old home was shifted off its foundation in West Linn (Oregon Geology, 1999). Despite its small size and relatively minor effects, DOGAMI decided to do an intensity study of this earthquake because we wanted to document the size of the felt area and determine why it was so widely felt.

METHODS

The intensity is a number that describes the effects of an earthquake on people, manmade structures, and the Earth's surface. The intensity scale most commonly used in the United States is the Modified Mercalli (MMI) scale of 1931 (Wood and Neumann, 1931). For a small earthquake such as the one in question, only the lower intensity values are encountered. The effects of intensities I–V are listed in Table 1.

It should be noted that the assignment of intensities is subjective, particularly so at the lower intensity values. Ideally, a random telephone survey is completed after a significant earthquake. The number of people who "felt" the earthquake is tabulated and used to assign intensities of II to IV. For example, Dengler and Dewey (1998) conducted a telephone survey after the 1994 Northridge, California, earthquake. They assigned an intensity II to a community if fewer than 10 percent of respondents felt the earthquake, intensity III if it was felt by 20–40 percent of respondents, and intensity IV if felt by more than 50 percent of respondents. The M_L 2.7 earthquake under discussion did not warrant that degree of effort. Therefore, we read each of the 250 responses and assigned an intensity on the basis of Table 1. Once intensities were assigned, they were grouped by zip code and plotted (Figure 1). For those zip codes with fewer than three responses an intensity I was assigned. For zip codes with more responses, likewise an intensity I was assigned, if 50 percent or more of the responses received indicated "not felt."

Table 1. Modified Mercalli intensity scale of 1931 (abridged)

I	Not felt except by a very few under especially favorable circumstances.
II	Felt by only a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.
IV	During the day, felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls heard to make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

The grouping by zip code enabled us to outline the felt area and draw general isoseismal contours, but it does not provide information that can be related to local soil conditions. Therefore all intensities of III or greater (122 of 250 or 49 percent of the responses) were plotted at their exact location.

RESULTS

The earthquake was felt over a very large area. Responses received by DOGAMI indicate that it was felt 54.3 km north, 84.7km south, 24.6 km east, and 57.1 km west of the epicenter. Assuming these responses represent the true maximum extent of the felt area, the area over which the earthquake was felt is 9,412 km^2. (Areas were determined with MapInfo, a commercial desktop GIS software). It is quite likely, however, that the true maximum extent of the felt area is larger than that indicated by survey responses. Felt reports to the east are probably lacking because of low population densities in the foothills of the Cascade Range, and felt reports to the north are missing because questionnaires were not placed in papers published farther north than the Portland *Oregonian*.

If it is assumed that the felt area is roughly symmetric around the epicenter, the felt area is 15,240 km^2. Are these felt areas exceptionally large? Yes, Toppozada (1979) did a study of shallow California and western Nevada earthquakes that related felt area to earthquake magnitude. The expected felt area for a M_L 2.7 earthquake is 977 km^2. Thus, the reported felt area is more than nine times larger than expected. When it is assumed that the felt area is symmetric around the epicenter, it is over fifteen times larger than expected. On the basis of the empirical relationships developed by Toppozada (1979), the earthquake magnitude as represented by the reported felt area would be M_L 4.2. In the case of a symmetric felt area, it would be M_L 4.5.

Magnitudes calculated from the area enclosed by isoseismal contours are generally within 0.5 units of the true magnitude (Toppozada, 1979). For example, for the March 1993 Scotts Mills ("Spring Break") earthquake, the magnitude calculated using the area enclosed by the Intensity V isoseismal is M_L 5.3 (Black, 1996). The true magnitude was 5.6. Thus, for this particular M_L 2.7 earthquake of February, magnitudes calculated using the area enclosed by isoseismal lines are much too large. This does not mean that the relationships developed by Toppozada (1979) are wrong, merely that they were developed for shallow crustal earthquakes and do not apply to deeper earthquakes like the one under discussion.

Since the felt area is larger than expected, why is it so large and why is the large area significant? The felt area is large because the focus is unusually deep, nearly 36 km (The focal depth of the Scotts Mills earthquake was 15.1 km; Thomas and others, 1996). From a deep-focus earthquake, the seismic waves travel to the surface through materials that are more homogenous and of higher velocity than near-surface materials. Thus there is less attenuation, and the waves arrive at the surface with more of their initial energy preserved. This is significant because, should a stronger earthquake occur with a similarly deep focus, damaging effects will not only be greater but also occur over a much larger area than expected.

The deep focus is important for another reason. Throughout the western United States, the thickness of the seismogenic crust varies from 15 to 20 km. In western Oregon (west of the Cascade Range), based on observed seismicity (Ludwin and others, 1991), the seismogenic crust is 25–30 km thick. Earthquakes occasionally occur on faults that have no surface expression. The 1994 Northridge earthquake (M_L 6.8), which occurred on a previously unknown, "blind" thrust fault, is an example. Previous studies have shown that for typical crustal thicknesses of 15–20 km, earthquakes larger than M_L 6.5 will be accompanied by surface rupture and that continued earthquakes on the fault will develop recognizable surface features (Wong, 1997). Because the magnitude of an earthquake is a function of the rupture *area*, the thicker crust in western Oregon gives us more "room" to hide a fault that has no surface expression. In western Oregon, faults capable of a magnitude 7 earthquake may not rupture the surface (Wong, 1997). Thus a deep-focus earthquake in western Oregon could be quite large and could result in damage over a much larger area than expected.

SUMMARY

The (M_L 2.7) earthquake on February 24, 1999, was felt over at least 9,412 km^2, even though the expected felt area for an earthquake that size is 977 km^2. A M_L 2.7 earthquake is typically felt only by people located very close to the epicenter and does little or no damage. This event was felt so widely because its hypocenter was quite deep, nearly 35.7 km (22.2 mi). A deep-focus earthquake in western Oregon could be quite large and could result in damage over a much larger area than expected.

ACKNOWLEDGMENTS

Thanks to the many people who sent in responses, including the classes of Dr. Scott Burns at Portland State University! The task of processing the data was made much easier by the help of Robert Schumacher; and the intensity map could not have been completed without Kate Halstead of DOGAMI.

REFERENCES CITED

Black, G.L., 1996, Earthquake intensity maps for the March 25, 1993, Scotts Mills, Oregon, earthquake: Oregon Geology, v. 58, no. 2, p. 35–41.

Dengler, L.S., and Dewey, J.W., 1998, An intensity survey of households affected by the Northridge, California, earthquake of 17 January, 1994: Bulletin of the Seismo-

(Continued on page 102)

BOOK REVIEW

Reprinted with permission from California Geology, *v. 52, no. 4, p. 26.*

The Earth in Turmoil, by Kerry Sieh and Simon LeVay. New York, NY, W.H. Freeman and Company, 1998. ISBN 0716731517, 324 p., hard cover, $24.95.

Sieh and LeVay's first popular science title should be required reading for anyone interested in how earthquakes and volcanoes work and how these natural phenomena have affected our world and society. In *The Earth in Turmoil*, Sieh and LeVay have written a very readable book about the science behind earthquakes and volcanic eruptions, and the destruction these events have had and the hazards they still pose. Except they go beyond that. The book gives many first-hand accounts (including the authors') from people who experienced some of the more catastrophic earthquakes in U.S. history. The volcanic histories of North America and Hawaii are also introduced with a human viewpoint. Some of these accounts are compelling, and all illustrate the potential destruction these events can have on our lives. The authors describe the science in well-written and very understandable terms. Some of the more technical terms used in the book are included in a glossary. An appendix is also added for those who want a better understanding about how earthquake magnitudes are obtained, the Global Positioning System, and the method of radiocarbon dating.

Although the information mostly covers the U.S., the book is sprinkled with comparisons to events or examples from other parts of the world. It is organized into chapters that start with the Pacific Northwest to California, then across to the Mississippi Valley and the east coast, and finally, in chapter 12, "Peles Wrath: The Volcanoes of Hawaii," an absorbing description of the Hawaiian volcanic chain. The book ends with a chapter primarily on earthquake hazard mitigation issues that have arisen in California. In this last chapter, as with some of the others, the authors are not shy about presenting their opinions.

Three chapters are devoted to the San Andreas Fault, The reason for this emphasis has more to do with, as they state, "The San Andreas Fault [being] a star among faults, a seismological celebrity," than the fact that Kerry Sieh, a Caltech geologist, has spent years working on the San Andreas Fault. His paleoseismic background does, however, explain why such relatively detailed descriptions of trench studies are included —more perhaps than many would be willing to read through. However, there are few publications that contain such detail for the lay reader, and the book is invaluable in that regard. Throughout the book, historical perspective is included, and the authors cite the work of many geologists who have made important contributions. There are over 60 clearly constructed figures, photos, and satellite images; 23 are included as color plates in the center portion. The book is well indexed, and references are listed by chapter. Some chapter titles—*1. When Push Comes to Shove: Giant Earthquakes in the Pacific Northwest; 2. Blasts from the Past: Mount St. Helens and her Sleeping Sisters; 3. The Great Divide: Discovering the San Andreas Fault; 6. The Enemy within the Gates: Earthquakes on Urban Faults;* and *7. The Little Volcano that Couldn't: Fear and Trembling at Mammoth Lakes*—hint at the authors' sense of irony and humor that is cleverly intertwined throughout the text. Along with this, they offer their own philosophical views about dealing with a future that will undeniably contain a catastrophic volcanic eruption and earthquake.

—Review by Graben Horst

New poster highlights Earth Science Week '99

In anticipation of Earth Science Week'99 (Oct. 10–16), the American Geological Institute (AGI) has produced another vibrant poster.

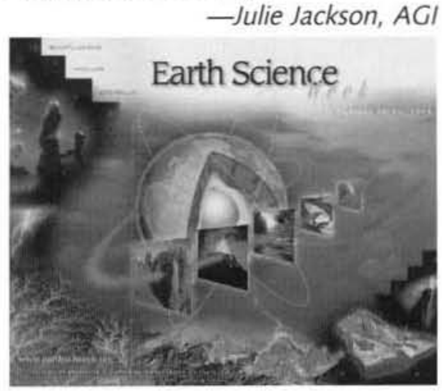
Eighteen AGI member societies and a number of other organizations are distributing the new Earth Science Week poster to more than 200,000 geoscientists and educators along with their societies' journals or newsletters.

The front of the poster features a model of Earth's interior structure. The investigation on the back, "Modeling from Evidence," is a "mystery bag" activity that will help students develop scientific inquiry skills as they gather evidence, propose models based on evidence, and debate and discuss their observations and inferences. In the process, they also learn to revise and improve their models by gathering new evidence and by reevaluating and modifying their interpretations.

The Earth Science Week poster is the newest addition to AGI's Earth Science Week'99 information kit. The kit includes four posters, a 32-page booklet filled with ideas and activities for Earth Science Week and other useful materials and is available from AGI at no charge.

To learn more about Earth Science Week or to request an Earth Science Week information kit, visit the Earth Science Week web site, http://www.earthsciweek.org or send your request to Earth Science Week, AGI, 4220 King St., Alexandria, VA 22302.

—Julie Jackson, AGI



Site-specific seismic reports in DOGAMI library nearing 200

On May 1, 1994, the Oregon Structural Specialty Code, a part of the Oregon Administrative Rules, was changed to order that a copy of each legally required "seismic site hazard report" should be deposited with the DOGAMI library and accessible to the public for inspection. This growing collection now holds nearly 200 reports. The following list is derived from the records in the library's bibliographic database. It is organized by county and USGS 7½-minute topographic quadrangle.

This list covers a first portion of the quadrangles in counties outside the Portland metropolitan area. The remaining counties as well as the Portland metropolitan area will be included in subsequent issues of *Oregon Geology*. A few reports are associated with more than one quadrangle.

BAKER COUNTY QUADRANGLES

Baker City

15296. Kleinfelder, Inc. (1996): Phase I geotechnical study, Oregon Department of Corrections, Bootsma site, Baker City, Oregon, ODC #BK-BC-1. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-14), 4 pages, 1 fig., 3 tables.

BENTON COUNTY QUADRANGLES

Corvallis

15919. AGRA Earth & Environmental (1998): Geotechnical engineering investigation, Weatherford Hall renovation, Oregon State University, Corvallis, Oregon. (Report prepared for Oregon State University Facilities Services, Job No. 8-61M-09710-0), 25 pages, 7 figs., 19 p. app.

15616. CH2M Hill,Joe Lukas (1996): Geotechnical recommendations [with Addendum], Oregon State University Alumni Center. (Report for Industrial Design Corporation (Ken Lundgren), Project No. 132132.A0.ZZ, submitted by City of Corvallis, Development Services Division), 15 pages, 10 p. app., 4 p. add.; 2d copy submitted by CH2M Hill.

15617. Fujitani Hilts and Associates, Inc. (1995): Site-specific seismic hazard evaluation and geotechnical design addendum, Central Library expansion, Oregon State University. (Report prepared for OSU Dept. of Facilities Services, Project No. 2749-01), 18 pages, 4 figs., 8 p. app.

15658. GeoEngineers, Inc. (1996): Report of geotechnical engineering services, proposed replacement fire station, Corvallis, Oregon. (Report prepared for City of Corvallis, File No. 4635-001-00-2130), 13 pages, 2 figs., 13 p. app.

Riverside

14882. CH2M Hill (1996): Hewlett-Packard Building 9 seismic site hazard report. (Report for Hewlett Packard, Project No. 117161.A0.02, submitted by City of Corvallis, Development Services Division), 12 pages, 4 figs., 19 p. attachments.

CLACKAMAS COUNTY QUADRANGLES

Bull Run

15630. Kleinfelder, Inc. (1997): Smejkal site #CK-SD-1, Clackamas County, Sandy. Final report, prison site location analysis, State of Oregon, Department of Corrections. (Report for KPFF Consulting Engineers/ODC), var. pages.

Estacada

15659. Braun Intertec Corporation (1997): Site-specific seismic evaluation, proposed Eagle Creek fire station, Hwy 211 and Judd Road, Clackamas County, Oregon. (Report for Boring Fire Protection District No. 59, Project No. EAAX-97-0143), 13 pages, 4 figs., 26 p. app.

Molalla

13384. HongWest & Associates (1995): Seismic evaluation, Molalla United Methodist Church, Molalla, Oregon. (Report for Molalla United Methodist Church, Project No. 95040-01, incl. geotechnical exploration, Project No. 95040), 9 pages; geotech. exploration 15 p., 1 fig.

15634. Kleinfelder, Inc. (1997): Sharp site #CK-SAFETY-12A, Clackamas County, Molalla. Final report, prison site location analysis, State of Oregon, Department of Corrections. (Report for KPFF Consulting Engineers/ODC), var. pages.

Wilhoit

12603. Carlson Testing,Tigard (1995): Seismic hazards report, Butte Creek Scout Ranch, 13462 South Butte Creek Road, Clackamas County, Oregon. (Report prepared for Cascade Pacific Council, 2145 SW Front Ave., Portland, Oregon, CTI Job No. 95-4282), 12 pages, 2 figs., 2 p. App.

CLATSOP COUNTY QUADRANGLES

Astoria

15886. Braun Intertec Corporation (1997): Site-specific seismic evaluation, proposed 73-unit motel, Hwy 30 and East of 34th Avenue, Astoria, Oregon. (Report for Super One, Inc., Beaverton, Oregon, Project No. EAAX-97-0624, Report No. 09-127-3457), 14 pages, 3 figs., 13 p. app.

Tillamook Head

4942. David J. Newton Associates (1996): Seismic hazards report and preliminary geotechnical investigation for the impact site for proposed new elementary school, N.E.C. of Monroe and Spruce Street, Cannon Beach, Oregon. (Report for City of Cannon Beach, Project No. 628 101), 19 pages, 1 table, 3 figs., 14 p. app.

14869. David J. Newton Associates (1996): Seismic hazards report and preliminary geotechnical investigation for the RV site for proposed new elementary school, 345 Elk Creek Road, Cannon Beach, Oregon. (Report for City of Cannon Beach, Project No. 628 101), 20 pages, 1 table, 3 figs., 20 p. app.

12583. Kelly,Patrick B (1995): Seismic site hazard study, proposed new fire station, NE corner of Sunset and Spruce Streets, Cannon Beach, Oregon. (Report for Cannon Beach Rural Fire District, Project No. K128.01)), 11 pages, 1 fig., 2 tables, 8 p. app.

15642. Wright/Deacon and Associates (1994): Geologic, tectonic, and seismic studies and geologic hazards report for Clatsop County Department of Planning and Development [Peterson Point Dam and Reservoir project]. (Report submitted to Foundation Engineering, Inc., Project No. J94-298), 9 pages, 2 figs.

COLUMBIA COUNTY QUADRANGLES

Birkenfeld–Marshland–Pittsburg–Vernonia

15625. Northwest Natural Gas Company (1997): Application to amend site certificate for Mist underground natural gas storage facility. (Submitted to the Oregon Energy Facility Siting Council, March 20, 1997), var. pages.

16005. Northwest Natural Gas Company,NW Natural (1998): Application to amend the site certificates for Mist underground natural gas storage and the South Mist feeder pipeline. (Report for Oregon Energy Facility Siting Council) (Gray Literature Collection, Siting studies, energy.), 140 pages (at least as many pages app.; second volume contains exhibits).

COOS COUNTY QUADRANGLES

Bandon

16546. Terra Firma Geologic Services (1999): Seismic hazard investigation, Bandon's Little Theater in the Park, Bandon City Park, Bandon, Oregon. (Report prepared for Richard P.Turi Architecture and Planning, North Bend, Oregon), 18 p., incl. 4 figs. and 3 p. app.

DESCHUTES COUNTY QUADRANGLES

Bend

15611. Mark V. Herbert and Associates, Inc. (1996): Geotechnical investigation, Deschutes County Public Safety Center, North Highway 97 adjacent to existing Criminal Justice Center, Bend, Oregon. (Report for Deschutes County Sheriff, Project No. 96-051. Submitted by Lombard-Conrad Architects, Bend, Oregon), 26 pages, 1 table (7 p.), 21 figs., 7 p. app.

La Pine

12590. Siemens & Associates (1995): Results of geotechnical and seismic site hazard investigation, La Pine Fire Station, La Pine, Oregon. (Report for La Pine Fire Department, Project No. 951008), var. pag.

DOUGLAS COUNTY QUADRANGLES

Sutherlin

16538. Professional Service Industries,Inc. (1999): Site-specific seismic evaluation for the proposed remodels and additions, East Primary School, 301 East Third Avenue, Sutherlin, Oregon. (Report for Sutherlin School District, PSI Project no. 704-95113, Braun Intertec Report no. 3974-069-001), 10 pages, 4 figs., 12 p. app.

HOOD RIVER COUNTY QUADRANGLES

White Salmon

12591. Dames & Moore (1995): Seismic hazard investigation, Pine Grove Fire Station addition, Hood River, Oregon. (Report prepared for Pine Grove Fire Department, Job No. 31566-001-016), 6 pages, 1 site plan.

JACKSON COUNTY QUADRANGLES

Ashland

12597. Marquess and Associates, Inc. (1995): Seismic hazard investigation report, Ashland Community Hospital additions, Ashland, Oregon. (Report for Ashland Community Hospital, Job No. 1-5743, deposited by McNamara Engineering & Construction, Ashland, Oreg.), 5 pages, 5 figs.

Eagle Point

15288. Kleinfelder, Inc. (1996): Phase I geotechnical study, Oregon Department of Corrections, Orchard site, Medford, Oregon, ODC #JK-MD-2. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-15), 5 pages, 1 fig., 3 tables.

Sams Valley

15287. Kleinfelder, Inc. (1996): Phase I geotechnical study, Oregon Department of Corrections, Roseburg Resources site, Medford, Oregon, ODC #JK-MD-1. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-07), 5 pages, 1 fig., 3 tables.

Medford East/Medford West

14897. Marquess and Associates, Inc. (1995): Soil investigation report, additions to Hedrick and McLoughlin Middle Schools, Medford 549C School District. (Report for Medford 549C School District, Job No. 1-5655), 14 pages, 21 figs.

JEFFERSON COUNTY QUADRANGLES

Buck Butte

15284. Kleinfelder, Inc. (1996): Phase I geotechnical study, Oregon Department of Corrections, Zemke site, Madras, Oregon, ODC #JF-MA-6. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-20), 4 pages, 1 fig., 3 tables.

Culver

15285. Kleinfelder, Inc. (1996): Phase I geotechnical study, Oregon Department of Corrections, Dover Lane site, Madras, Oregon, ODC #JF-MA-3. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-02), 4 pages, 1 fig., 7 tables.

Madras West

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Klamath Falls

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Lost River

15303. Kleinfelder, Inc. (1996): Phase I geotechnical study, Oregon Department of Corrections, Klamath Hills site, Klamath Falls, Oregon, ODC #KL-KF-4. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-16), 3 tables (text missing?)

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Penrose Conference to focus on Great Cascadia Earthquake Tricentennial

The year 2000 marks the tricentennial of the last great earthquake at the Cascadia subduction zone. Coastal and offshore geological work has confirmed that many great subduction earthquakes have struck this region in the last several thousand years. In addition, geodetic studies have shown that the subduction zone is accumulating strain that will be released in one or more future earthquakes.

This will be background and focus of the Geological Society of America (GSA) Penrose Conference in the tricentennial year of the A.D. 1700 Cascadia earthquake.

The GSA Penrose Conference of the year 2000 will be held at Seaside, Oregon, June 4–8, 2000. It will bring together 75 earth scientists,

(Continued on page 103)

New State Geologist to guide Oregon activities

Earthquakes—Ecosystems—Landslides—Floods—Tsunamis—Volcanic Eruptions—

Oregon's new chief geologist wants to provide information Oregonians need about these events and processes. "It's simple," says Dr. John Beaulieu, "the more we know about areas at risk and the mechanisms of these geologic processes, the safer we can be and the better managers we can be of natural systems."

Beaulieu also wants to provide more and better information aimed at other problems in Oregon's future, including groundwater supply, watershed health, and resource development.

Beaulieu is uniquely qualified to be the new State Geologist and director of the state's Department of Geology and Mineral Industries. Since becoming Deputy Director in 1977, he has helped fashion the department's current programs but knows where he'd like to make a few changes. "We're the people who gather the information. We need to make sure that local governments, other state agencies, businesses, volunteer assistance organizations like the Red Cross, and everybody else has the balanced information they need to solve geology-related problems in Oregon. That should result in keeping Oregonians reasonably safe."

Years of researching Oregon's geology, lobbying the Legislature, working with other state and federal agencies, and developing the current staff give him the tools he needs to be effective. "Twenty years ago we didn't really appreciate how geologically active Oregon was; we didn't know, for example, that part of Oregon was at risk of a magnitude 9 earthquake. Now that we know that it's a huge potential problem, we're able to work with a variety of public and private organizations to get ready for it.

"The purposes of the department are clear," says Beaulieu. "We're the centralized source of geology information for Oregon that people need to make wise decisions. In addition, we're expected to provide informed and creative regulation and voluntary problem-solving for earth resources like aggregate and natural gas."

With a world-class reputation and dozens of maps and research papers bearing his name, Beaulieu has been invited to speak at conferences in Paris, Kobe, and Cyprus as well as various places in the United States. He is one of the authors of a recent United Nations publication describing the use of geologic data to prepare for earthquakes.

Much of his earlier research has involved landslides, an especially important topic to Oregonians these days. "We're building in riskier places in much higher densities than we ever have before. Put that together with wetter winters than we're used to, and a lot of places are seeing landslides," he explains. "Unfortunately, the loss of an entire neighborhood to a landslide, as recently in places like Kelso, Washington, has happened in the past in Oregon and could happen again."

Along with developing applied geologic information and partnering to reduce the risk from natural hazards, Beaulieu will guide regulatory functions in mining and energy resources. "We have an exceptional staff here; that's one of the great benefits of this job. For example, one of our staff members was named the Best Reclamationist in the nation a couple of years ago. With that level of commitment and creativity of the staff, we will continue to improve our research and application of geologic information in serving Oregonians."

Family life is also important to Beaulieu. He and Kathy, his wife for 32 years, have raised three sons: Mike, Pat, and Matt. "You're a better worker and a better person when you have a challenging job and a rewarding life outside the office. I'm fortunate to have both," he said.

Beaulieu became State Geologist on August 1.

(Continued from page 98)

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Call for papers

The Geological Society of Nevada (GSN) will hold a symposium, ***Geology and Ore Deposits 2000: The Great Basin and Beyond***, May 15–18, 2000, in Reno-Sparks, Nevada. Information can be found on the GSN web site (http://www.seismo.unr.edu/GSN) or from the GSN office, P.O. Box 12021, Reno, NV 89510-2021, phone (775) 323-4569.

New geologist joins DOGAMI staff in Baker City

Vicki S. McConnell has joined the Oregon Department of Geology and Mineral Industries (DOGAMI) as a Natural Resource Geologist in the Baker City Field Office. She will be primarily involved in field work, mapping the volcanic terrain of northeastern Oregon.

McConnell comes to DOGAMI from positions as research associate in stable isotope geochemistry at the University of Wisconsin-Madison and, before that, as research fellow with he Alaska Volcano Observatory, where she conducted mapping work in the Aleutians.

Before her graduate studies which she concluded with earning a Ph.D. degree from the University of Alaska Fairbanks, McConnell worked for Sandia National Laboratories in Albuquerque, N.Mex. There she had the opportunity to work on a myriad of research projects in the geosciences, including magma energy research, basic research for the nuclear waste isolation projects in Yucca Flats, Nev., and Carlsbad, N.Mex., and scientific drilling research in volcanic areas. She brings with her 13 years of experience in the study of volcanoes and hydrothermal systems in Alaska, California, and New Mexico.

Vicki S. McConnell, Ph.D.

"In addition to my duties as a field geologist I have a strong commitment to improving the understanding of science within the local community through relevant outreach activities," McConnell said. "Science in general and geology in particular should not be perceived as mysterious or threatening, and the best way to dispel these perceptions is through grassroots activities and involvement with the community by scientists and professionals."

McConnell has worked in the past as a geology instructor with Elderhostel groups and as a volunteer science instructor with local primary schools.

Although McConnell grew up in West Virginia, she has spent so many years in "really western" states that Baker City and northeastern Oregon feel like home to her. "Yet," she confessed, "I can't wait to explore the whole state."

(Continued from page 101)

engineers, public officials, and hazard-mitigation professionals, who will critically review current knowledge about great Cascadia earthquakes and hazards posed by future earthquakes, discuss appropriate strategies for reducing losses from these earthquakes, and identify new research directions.

The conference will consist of three days of discussions, prompted by talks and posters, and a one-day field trip. Sessions will deal with hazards posed by great Cascadia earthquakes and the mitigation of these hazards; past earthquakes and tsunamis; tectonics; and present-day seismicity and strain accumulation. Evidence of past Cascadia earthquakes and tsunamis will be examined and discussed during a canoe trip along nearby Lewis River, Washington. The field trip will also include a visit to historic Fort Clatsop and examination of cores from Bradley Lake, Oregon, which contain a 7,000-year record of tsunamis produced by great Cascadia earthquakes. A public forum will be held just before of during the conference to give participants an opportunity to hear concerns of coastal residents.

The format of the conference is designed to ensure critical thought and interaction among participants. Formal lectures will be limited in favor of group discussions and poster sessions.

The conference is limited to 75 participants. Interested scientists, engineers, public officials, hazard-mitigation professionals, and graduate students are invited to apply. Application deadline is December 1, 1999. Invitations will be mailed to participants at the end of January 2000. Letters of application should be sent to John Clague, Department of Earth Sciences, Simon Frasier University, Burnaby, BC V5A 1S6, Canada. They should include a brief abstract of the poster or talk the applicant would like to present at the conference.

Graduate students working on Cascadia great earthquake topics are particularly encouraged to apply. Limited subsidies will be provided to selected students. The registration fee, which will cover lodging, meals, the field trip, and all other conference expenses except personal incidentals, is not expected to exceed U.S. $700. Participants will be responsible for transportation to and from Seaside.

Co-conveners are John J. Clague, Simon Fraser University and Geological Survey of Canada, jclague@sfu.ca; Brian F. Atwater, U.S. Geological Survey at University of Washington, atwater@u.washington.edu; Kelin Wang, Pacific Geoscience Centre, Geological Survey of Canada, wang@pcg.nrcan.gc.ca; Yumei Wang, Oregon Department of Geology and Mineral Industries, meimei.wang@state.or.us; and Ivan G. Wong, URS Greiner Woodward-Clyde Federal Services, Ivan_Wong@urscorp.com.

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Places to see—Recomended by the Oregon Department of Geology and Mineral Industries:

Kiger Gorge in the Steens Mountain Recreation Lands, Harney County

Kiger Gorge is one of several glacial valleys on Steens Mountain in southeastern Oregon. It is here seen from the rim rock at the head of its broad, U-shaped valley. The U shape is typical of a valley carved by a glacier, while river valleys have a V shape. Glaciers advanced during the Pleistocene (less than 2 million years ago), when the climate was colder and wetter than today. At that time, the present-day Alvord Desert (15 mi to the southeast of Kiger Gorge) was part of lake that was 70 mi long and 12 mi wide. Access: Loop Road from State Highway 205 to the east between Frenchglen and Roaring Springs Ranch. Geologic guide: Lund and Bentley, "Steens Mountain, Oregon," Oregon Department of Geology and Mineral Industries, Ore Bin, v. 38, no. 4 (April 1976), p. 51–66. (Photo by Oregon Department of Transportation)

OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries
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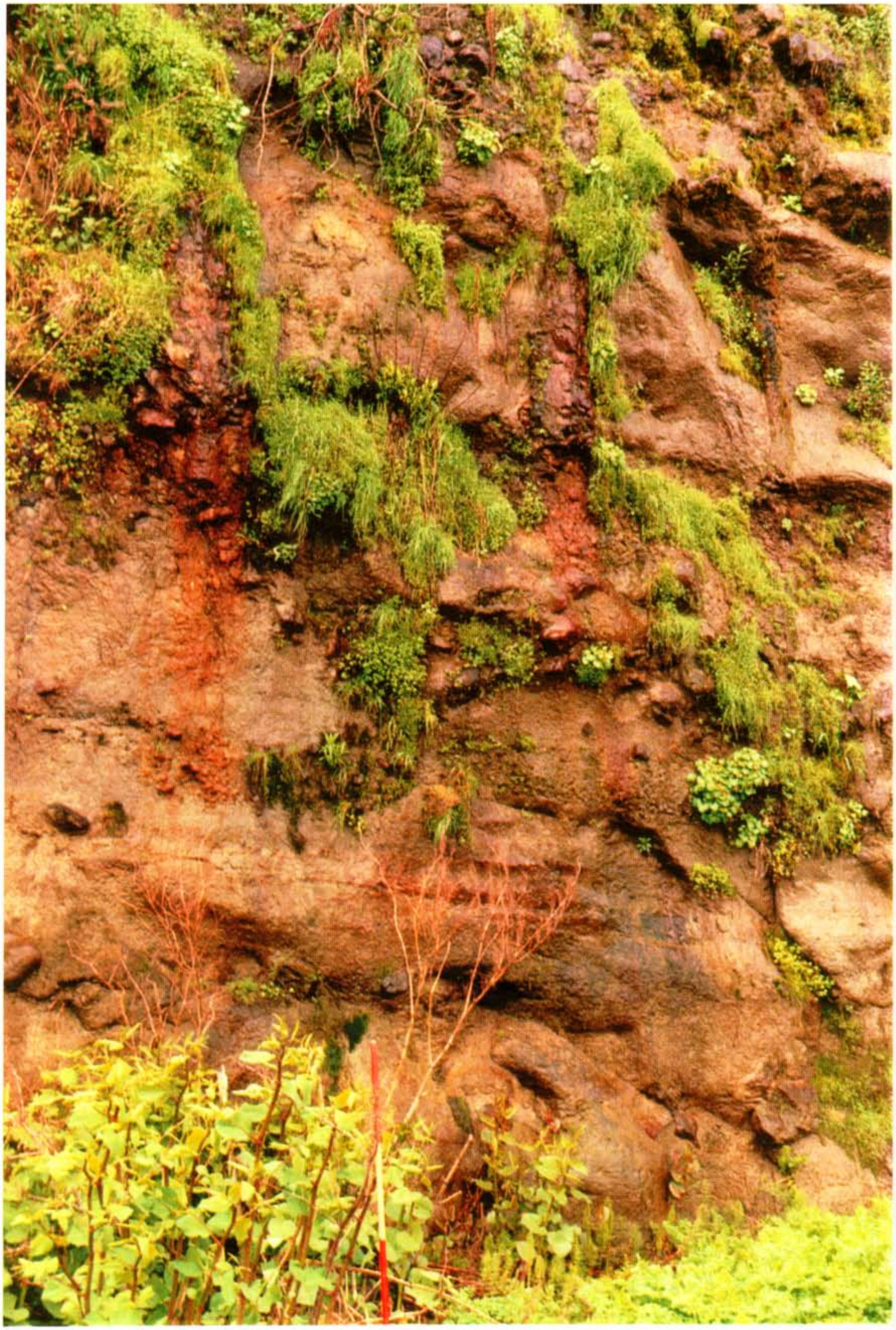

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How many earthquakes occur in Oregon over a year, and where?

Abstracts of theses

THROUGH THE EYES OF THE STATE GEOLOGIST

After discovering parts of the West, John Wesley Powell proposed in the late 1800s that governmental entities be structured around watersheds. But with rail lines, various Homestead Acts, Mining Districts, post-Civil War politics, and the rush to make a living off the land, settlers soon developed other patterns—more attuned to "progress" than to ecosystems. Today, however, ecosystems, including watersheds, have become keys for our survival.

Effectively working with ecosystems requires that diverse sciences and interests develop new ways of working together to solve regional problems. While each organization is used to approaching issues according to its own mandate, history, and resources, we had better find ways to integrate those approaches into comprehensive goals. This calls for nonregulatory as well as regulatory efforts. And while today the emphasis is on individual endangered species, primarily fish, future years may see a balancing towards broader concerns as well.

In the Department of Geology and Mineral Industries (DOGAMI), many of our current successes with ecosystem health are in the Mined Land Reclamation (MLR) Program, located in our Albany field office. Many disciplines come together there to provide for additional beneficial uses of mined land. MLR staff work with government agencies, the private sector, and environmental groups on projects that affect ecosystems, such as sediment management at mine sites, creation of a "Best Management Practices" manual with our neighboring states of Idaho and Washington, and participation in river initiatives and other stream channel morphology efforts.

More new efforts are emerging in the agency, as we focus on sustainability for both economic progress and ecosystem health. We are, for example, beginning to focus our mapping efforts to produce detailed geologic mapping in key areas of groundwater concern. In the future, we also hope to make appropriate enhancements to geologic maps, so that they better meet the needs of ecosystem and watershed managers.

By itself, this agency certainly is not going to solve boundary problems as they relate to governance of watersheds. And DOGAMI alone can not produce answers where current government structures are trying to relate to ecosystem structures. However, DOGAMI can help with focused efforts on the ground to put good information in the hands of watershed and ecosystem managers when they need it.

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Cover photo

Eagle Creek Formation outcrop at Tanner Creek in Multnomah County, near the Columbia River and Bonneville Dam. In the upper half of the picture, three upright petrified trees can be seen, which are, in this formation, typically accompanied by orange-colored staining below. Article beginning on page 111 by William Krause reports on a fossil location in what appears to be a low section of the Eagle Creek Formation, on the south shore of the Columbia River and about 2 mi west of Bonneville Dam. Photo by Rachel A. Carlin (see reference list at end of Krause's article).

The 1997 Vida, Oregon earthquake swarm

by Sue Perry and Ray Weldon II, University of Oregon, Eugene, Oregon

ABSTRACT

Three small earthquakes (magnitudes 2.1–2.6) occurred near Vida, Oregon, in May, 1997. We have redetermined their locations with a one-dimensional velocity model and constructed focal mechanisms and a net moment tensor. Earthquake locations, focal mechanisms, and moment tensor all indicate that the preferred slip plane is steeply dipping and trends north-northwest. The net sense of motion is right lateral with a reverse component, similar to that of the Scotts Mills earthquake (1993, magnitude 5.7), which had a more pronounced reverse component. The Vida focal mechanisms and moment tensor are consistent with regional maximum horizontal stress that is essentially north-south, as has been documented by several other workers.

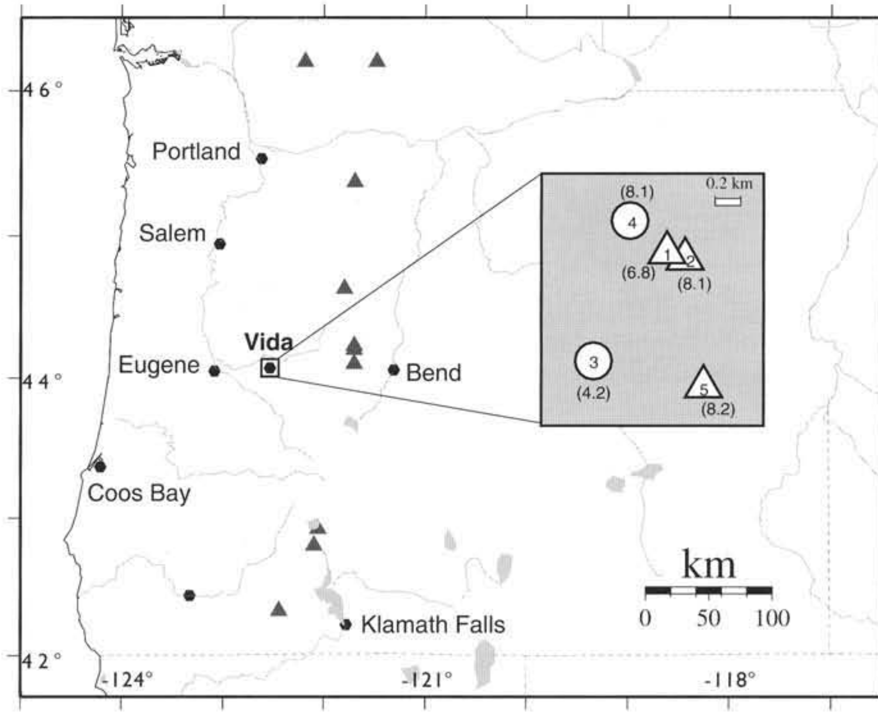

Figure 1. Map of Oregon showing locations of principal rivers, Cascade volcanoes (triangles), towns (dots), and 1997 Vida earthquake swarm (boxed circle). Inset: Epicenters of the five largest earthquakes, with event numbers keyed to Table 1 and depths (km) in parentheses. Triangles represent epicenters newly redetermined for this study. Other data are from catalog of Pacific Northwest Seismic Network (PNSN).

INTRODUCTION

In May 1997, five small earthquakes (magnitudes 1.5–2.6) occurred in the western Cascades. The Pacific Northwest Seismic Network (PNSN) located them near Vida, Oregon, about 45 km (28 mi) east of Eugene (Figure 1, Table I). Although small, the earthquakes were felt locally. Further, ground shaking triggered a landslide on a steep, logged slope that had become unstable during the previous winter's rains (Mortenson, 1997).

Staff at the Department of Geological Sciences, University of Oregon (UO), deployed three available Sprengnether S-6000 seismometers, and got usable results from one (site DHN, Figure 2). Analyzing these, we discovered that the five earthquakes were the biggest in a vigorous swarm. That is, the Vida earthquakes occurred quite close to one another in time and space and had magnitudes similar enough that no event was clearly the main shock. During nearly twelve days of continuous operation, DHN recorded as many as 80 earthquakes per day. Only five were large enough to be located by the PNSN and thus preserved in the network catalog.

To adequately determine an earthquake epicenter (the point on the Earth's surface that is directly above the earthquake's origin), it takes three seismometers surrounding the event. To determine the event's depth, at least four seismometers are required. Earthquakes of small magnitudes do not radiate enough energy to be clearly located by distant seismometer stations. PNSN collects data from fewer than 40 seismometers in Oregon (Figure 2). In northern and western Oregon, they provide a complete record of earthquakes of magnitudes 2.5 and above (R. Ludwin, PNSN geophysicist, written communication, 1998). The level of small-magnitude, background seismicity is well known only near Portland, where instrumentation is densest.

The Vida swarm is not the only recent swarm near Eugene. In June 1998, PNSN located magnitude 2 earthquakes northwest and southeast of Eugene. Our staff was testing seismometers in Eugene and recorded two distinctive groups of waveforms that suggest swarms in different locales. Additionally, in early 1996, while we deployed seismometers in Eugene and Springfield to assess seismic hazard, we recorded a series of small earthquakes with virtually identical waveforms. These events appeared to be part of a swarm located about 15 km (10 mi)

Table I. Source parameters of the five largest 1997 Vida earthquakes, determined by the Pacific Northwest Seismic Network (PNSN)

Event no.	Date	Time (UTC)	Lat N.	Long W.	Depth (km)	Magnitude
EV 1	5/22/97	10:35	44.066	122.517	6.8	2.3
EV 2	5/22/97	13:57	44.066	122.520	8.1	2.6
EV 3	5/22/97	14:07	44.061	122.529	4.2	1.8
EV 4	5/22/97	17:17	44.072	122.525	8.1	1.5
EV 5	5/24/97	09:00	44.062	122.515	8.2	2.1

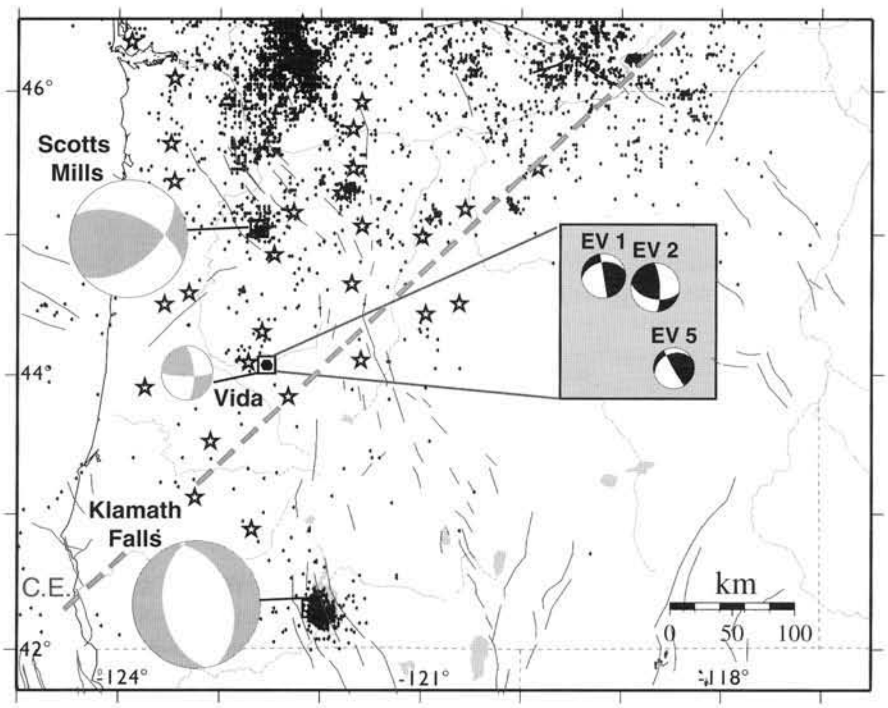

Figure 2. Map of Oregon locating active faults (dark lines) compiled by Pezzopane and Weldon (1993); PNSN earthquake epicenters 1970-1998 (black dots); the 1997 Vida swarm (boxed circle); and seismometer sites (stars) used in this study. The site west of the swarm, and closest to it, is site DHN, deployed by the University of Oregon. Other sites are PNSN stations. The gray-and-white "beach balls" are moment tensors for the 1997 Vida swarm (central ball), the M 5.7 Scotts Mills earthquake of 1993 (northern ball), and the M 5.9 and 6.0 Klamath Falls main shocks of 1993 (southern ball). The dashed gray line labeled "C.E." indicates the southern edge of the Columbia Embayment (Riddihough and others, 1986). Inset: Individual focal mechanisms for the three largest earthquakes in the 1997 Vida swarm, arranged according to relative epicenters. For these focal mechanisms, we used a PNSN crustal model; the other models gave quite similar results.

east of Eugene (D. Toomey, UO seismologist, oral communication, 1996). None of the 1996 earthquakes were large enough to be well-located by PNSN.

DATA AND ANALYSIS

For the three largest earthquakes in the 1997 Vida swarm, we have made focal mechanisms and a summed seismic moment tensor (Figure 2). A focal mechanism uses seismic energy radiation patterns to identify nodal planes, the two most likely orientations of the fault plane on which earthquake slip occurred. Two orientations are possible because the energy radiates symmetrically. Other geologic or seismologic evidence is then required to determine which nodal plane represents the fault plane. Summed moment tensors use nodal planes and earthquake sizes to calculate net deformation (strain) and can be represented as focal mechanisms. Focal mechanisms and moment tensors both allow inferences about regional tectonic stresses.

The making of our focal mechanisms required (1) knowledge of first-motion polarities at our seismometer sites (did the first seismic energy move the ground up or down?) and (2) a model of crustal structure in order to estimate the velocities of the seismic waves as they traveled from the fault plane to seismometers. We used P-wave polarity data from PNSN phase files, and we made additional first-motion picks (determinations) (Figure 3) after scrutinizing PNSN seismometer recordings of the events. We had from 15 to 26 picks per earthquake, and our results were all reasonably well constrained.

We tested three one-dimensional models of crustal structure. Two models assumed horizontal layers with unchanging velocities within layers: the model of northern and central Oregon used by PNSN in routine earthquake processing (R. Ludwin, written communication, 1998) and an amendment of a model used in Scotts Mills, Oreg. (Thomas and others, 1996), and Puget Sound, Wash. (Crosson, 1976). Our third model assumed linear increase of velocity with depth, with increases at a rate that best fit the layers of our two other models.

We employed widely used applications throughout our analysis: We made our polarity and arrival picks in SAC (Seismic Analysis Code, Tapley and others, 1990), redetermined event locations with HYPOINVERSE (Klein, 1989), and constructed focal mechanisms with FPFIT (Reasonberg and Oppenheimer, 1985). We calculated moment tensors using the equations of Aki and Richards (1980) and displayed results with Generic Mapping Tools (see Wessel and Smith, 1995).

RESULTS AND DISCUSSION

Our best constrained focal mechanisms and moment tensors are predominantly strike slip, with a component of reverse motion (Figure 2). All are consistent with regional maximum compressive stress that is roughly north-south, as has been found by many other workers (Thomas and others, 1996). Given the small, brief earthquake sequence and the forested epicentral area, we lack outside evidence to confirm a nodal plane; but the planes with right-oblique reverse slip are in best accord with other Oregon earthquakes (Pezzopane and Weldon, 1993). Right-lateral slip is consistent with the relative plate motion in this region of oblique subduction (Wells and others, 1998), where the Juan de Fuca and North American plates do not collide head-on.

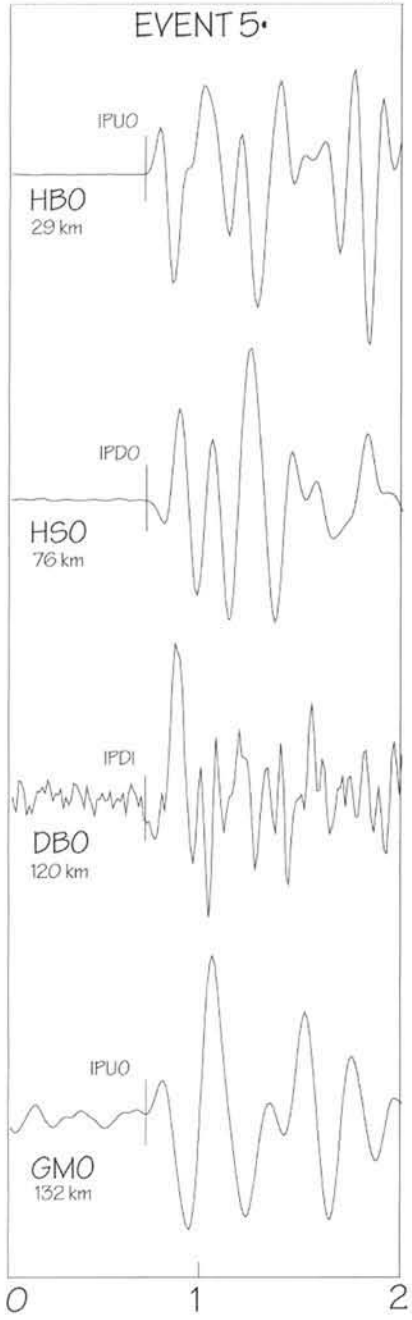

Figure 3. Representative first-motion P-wave picks for earthquake 5 of this study. PNSN station names and source distances are listed with each time domain trace. All are vertical components.

The most likely nodal plane is steeply dipping and trends north-northwest. All our focal mechanisms and summed tensors for all three of our crustal models had this plane in common. However, the dip is not unique: Some places dip steeply west and some dip steeply east. Additionally, the epicenters of the five largest swarm events (Table I and inset of Figure 1) delineate a north-northwest trend. If we assume they ruptured the same fault, then, because the event locations deepen to the east, they imply a fault plane dipping steeply to the east. Location uncertainties are greater than the distances among the events, so their absolute locations may differ from our results. However, the relative locations of the events are likely to be preserved.

It is doubtful that any one-dimensional model could fully represent the Oregon crust throughout the wide area covered by seismometers in this study. Given the two plates and the volcanic arc, modeling the crust with horizontal, homogeneous layers and linear increase of velocity with depth is clearly a simplification. However, the three models we tested gave generally quite similar results.

The Vida moment tensor is similar to that of the M 5.7 Scotts Mills earthquake of 1993, which was right-lateral with a much larger reverse component (Figure 2; Thomas and others, 1996). Both stand in contrast to the normal motion of the M 5.9 and 6.0 Klamath Falls earthquakes of 1993 (Figure 2; Braunmiller and others, 1995). In the Pacific Northwest, the sense of fault motion and stress regime changes as one moves from north to south (Pezzopane and Weldon, 1993; Blakely and others, 1995). It is not known where the change occurs. In Washington (Wells and others, 1998) and northwestern Oregon (Thomas and others, 1996), maximum compressive stress is approximately north-south, minimum compressive stress is vertical, and principal faulting style is reverse. In south-central Oregon, maximum compressive stress is vertical, minimum compressive stress (i.e., maximum extension) is roughly east-west, and faulting is primarily normal (Pezzopane and Weldon, 1993).

We hypothesize that (1) the Vida sequence demarcates a strike-slip transition zone between these regimes; and (2) the boundary between regimes aligns with, and may be controlled by, the edge of the Columbia Embayment. The Columbia Embayment consists of accreted oceanic terranes underlying northwestern Oregon (Figure 2, Riddihough and others, 1986). To test these hypotheses, we are currently analyzing focal mechanisms of small earthquakes that have occurred throughout the region.

CONCLUSIONS

While it would be a mistake to infer too much from any trio of magnitude 2 earthquakes, these three are internally and regionally consistent. This is encouraging, because it suggests that a coherent and valuable story can be told through ongoing measurement and analysis of Oregon's limited background seismicity. Additionally, this seismicity can be used to test hypotheses about styles of deformation and movement in the region.

ACKNOWLEDGMENTS

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Earthquake updates

A small earthquake that occurred on Thanksgiving Day near Woodburn has been upgraded to a magnitude (M) 3.5 (from M 3.2). The earth movement was about 18 mi deep, which is somewhat unusual, and probably accounts for the widespread reports from people feeling the small earthquake.

"It's a very small earthquake and we get these frequently in Oregon," explains Lou Clark, the Earth Science Information Officer for the Oregon Department of Geology and Mineral Industries (DOGAMI).

In the Woodburn-Molalla-Mount Angel area, there have been 12 other earthquakes this year. The largest was the M 2.7 earthquake on February 24, which cracked plaster at Oregon City High School. Other events were between M 1.5 and M 2.3. None of these events were related to the 1993 Spring Break Quake (M 5.6), which was centered near Scotts Mills.

On Sunday, November 28, a small earthquake located near the epicenters of the devastating 1993 quakes was felt in the Klamath Falls area. The M 3.4 earthquake struck at 8:04 p.m., came from a depth (hypocenter) of about 5 mi and was located 13.9 mi WNW of Klamath Falls. There have been no reports of damage.

Three small aftershocks were registered in the same area on the following day. They had magnitudes between M 1.5 and 1.8 and were not felt except by the seismographs.

"Due to the amount of faulting in the area, this is not unexpected for such a geologically active region," explained James Roddey, the Community Education Coordinator for DOGAMI.

"At this point we don't know how it relates to the magnitude 5.9 and 6.0 earthquakes that hit the area on September 20th, 1993. But it was in the general vicinity of those two quakes. Hundreds of small aftershocks followed the 1993 quakes, some larger than Sunday's quake, but the area has been quiet for some time," noted Roddey.

DOGAMI geologists recently finished field work and technical review for relative earthquake hazard maps of the Klamath Falls area. These maps will combine the effects of ground shaking amplification, liquefaction, and earthquake-induced landsliding to show the earthquake hazards relative to the local geologic conditions. Individual maps for ground shaking amplification, liquefaction, and earthquake-induced landsliding will also be produced as part of the set. No date has been set for the release of these maps, but they should be available sometime in the summer of 2000.

New earthquake hazard maps for western Oregon communities, including Grants Pass and Ashland, will be released January 26, 2000, the 300th anniversary of the last great Cascadia subduction zone earthquake.

Earthquake magnitudes are logarithmic, so each higher number means 30 times more energy was released. For example, the M 5.6 Spring Break quake released 900 times more energy than this morning's M 3.5 earthquake.

The Oregon Department of Geology and Mineral Industries has prepared earthquake hazard maps of the Portland and Salem metro areas and coastal communities. Maps for about 40 other communities in western Oregon are scheduled to become available in January.

To get information about how to protect yourself in an earthquake or to purchase maps, contact the Nature of the Northwest Information Center, 800 NE Oregon St., Portland, phone (503) 872-2750, http://www.naturenw.org.

The Miocene Metasequoia Creek[1] flora on the Columbia River in northwestern Oregon

by William F. Krause, 8730 N. Chase Avenue, Portland, Oregon 97217

ABSTRACT

Fossil plants from an exposure on Metasequoia Creek are identified and discussed in relation to vegetational, climatic, and oceanographic interpretations of similar floral assemblages from the Eagle Creek, Lyons, and Rujada floras. These floras are thought to be contemporaneous with floras of the John Day Formation.

The floral assemblage includes species of eight probable genera and several species as yet unidentified. The exposure's flora was first dominated by species of the conifer *Metasequoia*, the dawn redwood, and then, in progressively higher levels, by a broadleaf flora. This flora appears to correspond to that of the Mixed Northern Hardwood forest of eastern Asia.

1 This name for the as yet unnamed creek has been formally submitted to the Oregon Board of Geographic Names, which is administered by the Oregon Historical Society.

INTRODUCTION

Metasequoia Creek (Figure 1) has been so named due to an abundance of Metasequoia needle and cone fossils found at the creek mouth on the south shore of the Columbia River, 37 mi east of Portland, Oregon, and 2 mi west of Bonneville Dam (lat 121°59'13", long 45°37'12"; sec. 30, T. 2 N., R. 7 E.; U.S. Geological Survey Tanner Butte 7½-minute quadrangle). The location is difficult to find, which could explain the lack of published information.

[Editor's note: The location has no public access and is dangerously close to both the Interstate Highway and the parallel railroad tracks; various private and public authorities control different portions of the area. We advise strongly not to attempt any unauthorized visits.]

The only earlier description of this fossil exposure was published by J. Le Conte (1874), who found, near the mouth of Moffett Creek, a layer of conglomerate "limited above by a very distinct irregular dark line, traceable for a mile or more along the river, which had all the characters of a dirt-bed or old ground surface." And "resting directly on this ground surface . . . a layer of stratified sandstone two or three feet thick, filled with beautiful impressions of leaves of several kinds of

(Continued on page 114)

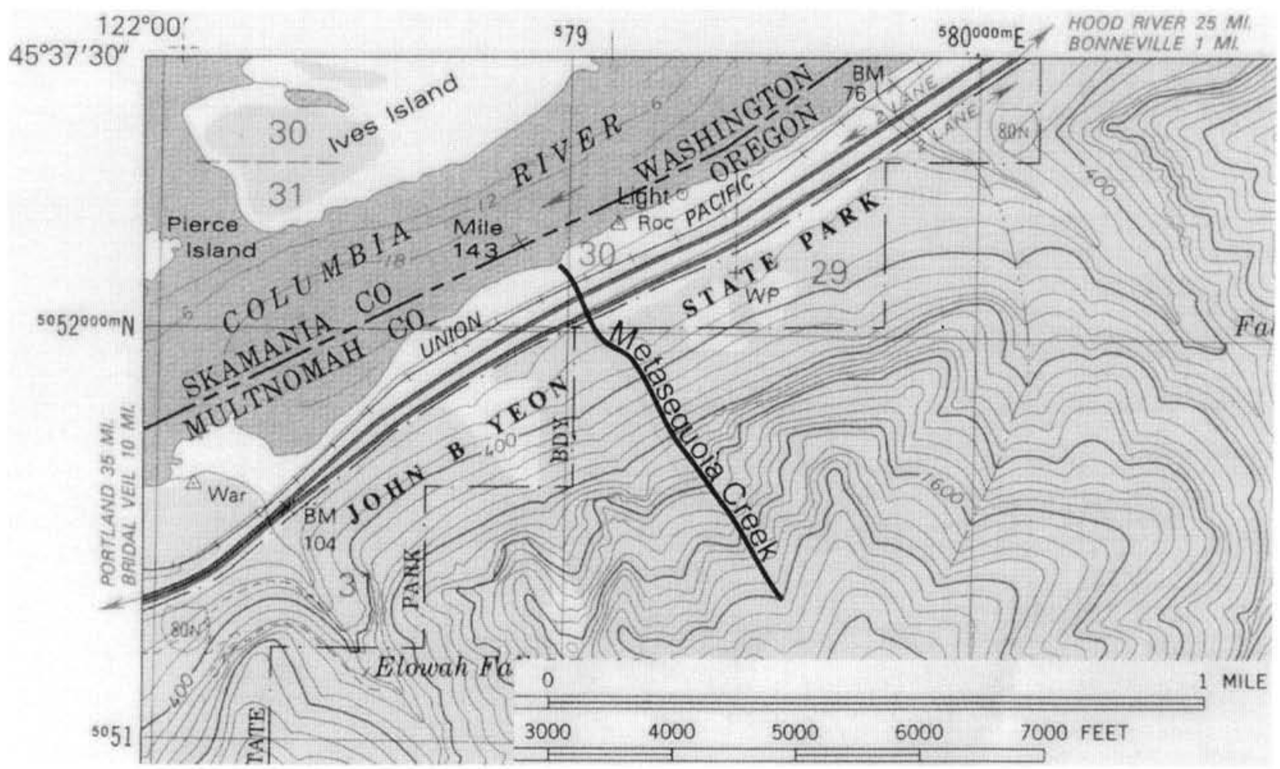

Figure 1. Map showing general area where fossils described in this paper were found. Metasequoia Creek runs between McCord Creek on the west and Moffett Creek on the east. It is as yet only informally named and here inserted by hand and approximately in the U.S. Geological Survey topographic map of the Tanner Butte quadrangle.

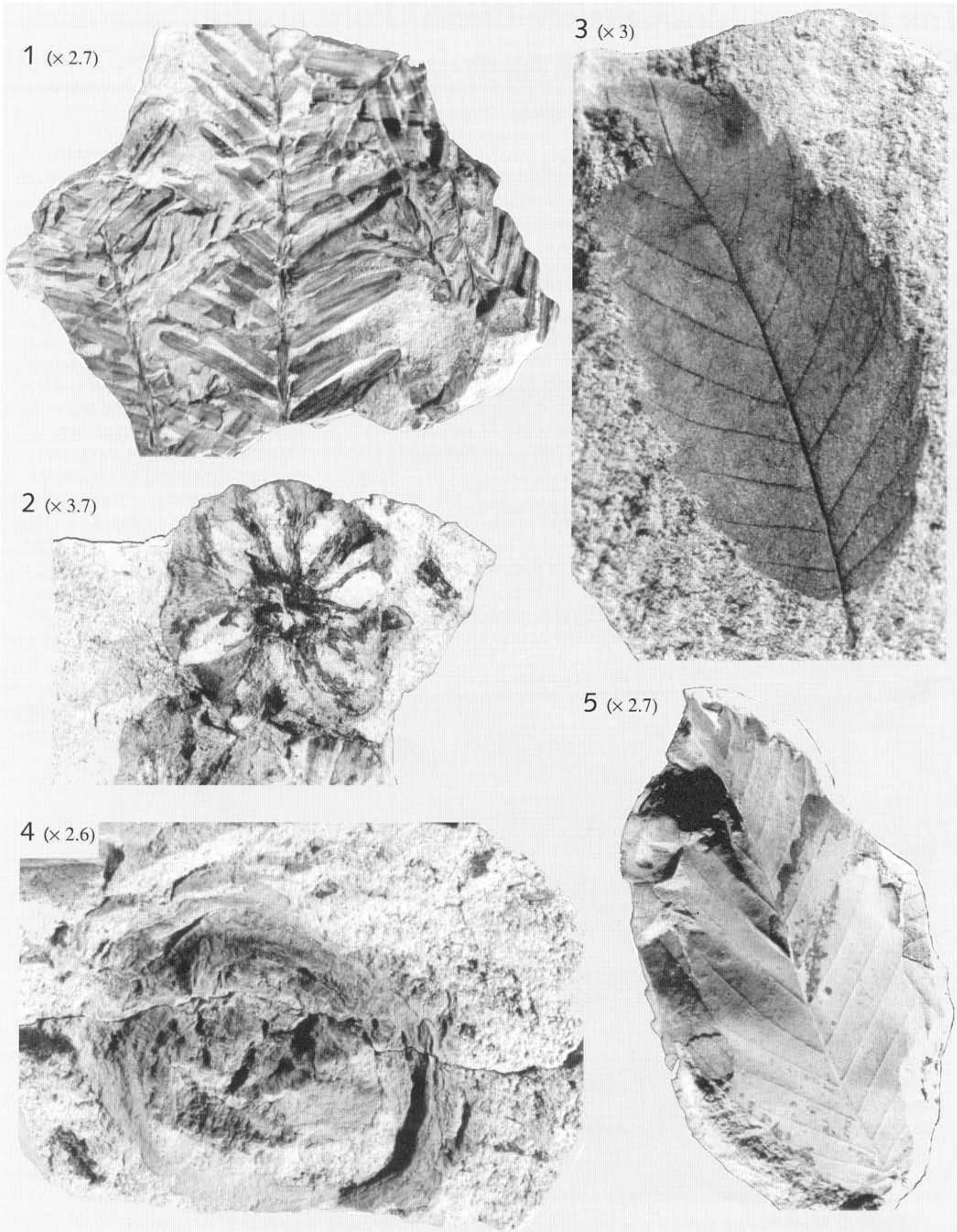

Plate 1. Plant fossils from Metasequoia Creek. 1–2. Conifers: *Metasequoia occidentalis* (leaves and seed cone); 3. *Incertae sedis* (*Fagus* sp.?); 4. Beech family: Nut of *Fagus pacifica* (beechnut); 5. Elm family: *Ulmus pseudoamericana* (elm).

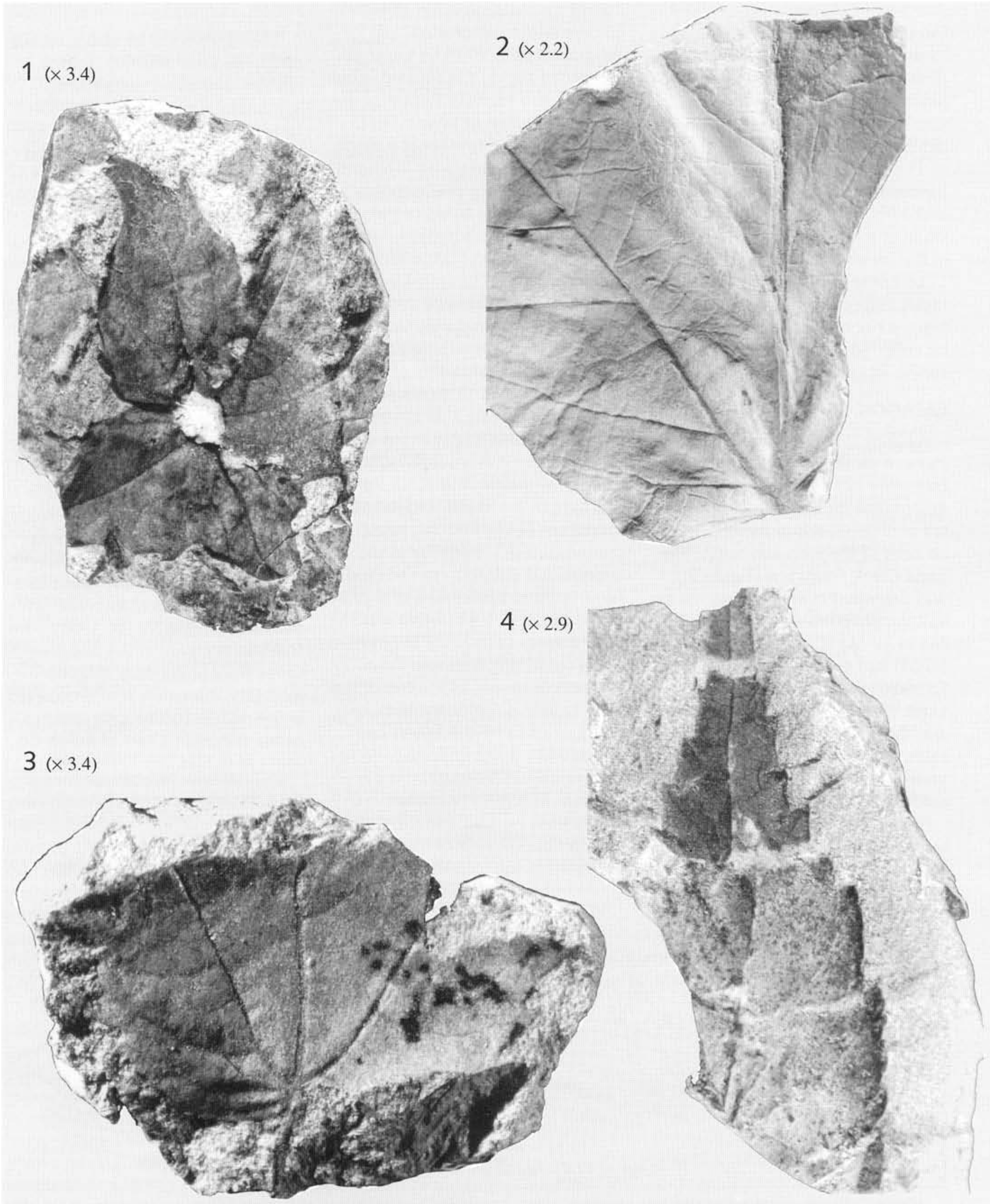

Plate 2. Plant fossils from Metasequoia Creek. 1–3. Sycamore family (Platanaceae): *Platanus* stipule and leaves; 4. Birch family (Betulaceae): *Alnus* leaf.

(Continued from page 111)
forest trees." Silicified tree stumps, "with their roots spread out and penetrating the boulder material beneath, and therefore evidently in situ," convinced him that it was "an old forest-ground surface."

This description matches the dark band containing carbonaceous fossils and overlain by several feet of siltstone at the fossil locality described in the present paper.

Le Conte also reported that the highly respected paleobotanist Leo Lesquereux had identified some of his collected specimens as oak and conifer of probable Miocene age.

GEOLOGIC SETTING

Chaney (1918) described 80 species in a nearby, younger, Eagle Creek Formation floral assemblage and suggested that the Eagle Creek flora resembled the fossils in the upper Clarno beds of the John Day basin. The Eagle Creek Formation (Figure 2) was deposited toward the end of the volcanically quiescent period from 38 Ma to 18 Ma (Carlin, 1988). Wise (1961) had divided the Eagle Creek Formation into the lower Miocene Eagle Creek Formation (24–18 Ma) and the upper Oligocene Weigle Formation (30–24 Ma), with the two units being separated by a slight unconformity and a saprolite layer.

The fossils occur in a 4-ft band of six fossiliferous siltstone layers. This band has a 3-in. base of dark, carbonaceous material that is interpreted here as the compressed "old forest-ground surface" of Le Conte as mentioned above. It is situated above the clay-rich saprolite surface of the Weigle formation of Wise (1961).

The dark base consists of a single compressed carbonaceous layer and contains exclusively *Metasequoia* fossils. The middle layers contain *Metasequoia* and broadleaf flora. The upper layers contain exclusively broadleaf flora.

About 23 silicified and carbonaceous log and stump sites occur in the ¾-mi fossil zone centered on Metasequoia Creek. Some of these were described by Le Conte (1874). Some contain agate and common opal. The largest tree stump is 15 ft tall and about 4 ft around and is held up by matrix on its back side. The base of this stump and its roots spread out below the "old forest-ground surface," evidently in situ. It appears that volcanic ash and mud flows covered the remains of a grove of *Metasequoia* trees, which were subsequently covered by progressive layers containing broadleaf flora.

The rediscovery, as it were, of this fossil locality is significant because this appears to be the lowest and perhaps oldest known locality within the Eagle Creek Formation. It has not been described previously and differs from typical Eagle Creek Formation flora because of the presence of *Metasequoia*.

FOSSIL PLANTS[1]

The fossils occur as carbonaceous compressions in siltstone. Leaves, needles, and cones were found. Specimens were recovered by surface examination of the laminated bedding planes that had separated from sandy layers of matrix.

Identification of the flora is based on comparison with photos and descriptions of similar specimens in the Lyons and John Day floras. The result is that the assemblage from the Metasequoia Creek area contains eight possible species, one conifer and seven broadleaf plants, and several specimens best assigned to *incertae sedis*.

Needles and cones of the conifer *Metasequoia occidentalis* (dawn redwood) are abundant in the lowermost layers of the exposure (Plate 1, nos. 1, 2). This conifer has deciduous rather than evergreen foliage and differs from other conifers in having opposite rather than alternative needles along the axis of its branchlets (Manchester and Meyer, 1987). This tree was common in the Bridge Creek flora of the early Oligocene John Day Formation. It also occurred in the middle Eocene peat swamps of the Princeton Chert of British Co-

[1] All specimens are still in the possession of the author, who is in contact with several possible repository institutions for a final disposition of the fossils.

(Continued on page 119)

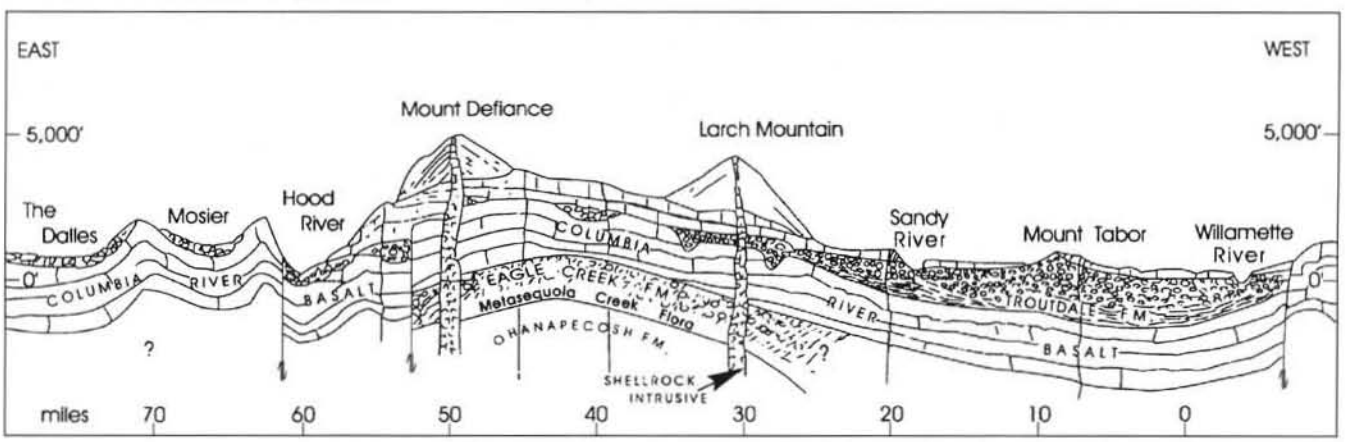

Figure 2. Diagrammatic cross section showing relative positions and attitudes of geologic formationson the south side of the Columbia River Gorge and including relative position of Metasequoia Creek flora. Vertical scale is exaggerated. Modified from Allen (1979).

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	GMS-68 Reston 7½' quad., Douglas County. 1990	6.00
	GMS-67 South Mountain 7½' quad., Malheur County. 1990	6.00
	GMS-66 Jonesboro 7½' quad., Malheur County. 1992	6.00
	GMS-65 Mahogany Gap 7½' quad., Malheur County. 1990	5.00
	GMS-64 Sheaville 7½' quad., Malheur County. 1990	5.00
	GMS-63 Vines Hill 7½' quad., Malheur County. 1991	5.00
	GMS-62 The Elbow 7½' quad., Malheur County. 1993	8.00
	GMS-61 Mitchell Butte 7½' quad., Malheur County. 1990	5.00
	GMS-60 Damascus 7½' quad., Clackamas/Multnomah C. 1994	8.00
	GMS-59 Lake Oswego 7½' quad. 1989	7.00
	GMS-58 Double Mountain 7½' quad., Malheur County. 1989	5.00
	GMS-57 Grassy Mountain 7½' quad., Malheur County. 1989	5.00
	GMS-56 Adrian 7½' quad., Malheur County. 1989	5.00
	GMS-55 Owyhee Dam 7½' quad., Malheur County. 1989	5.00
	GMS-54 Graveyard Point 7½' quad., Malheur/Owyhee C. 1988	5.00
	GMS-53 Owyhee Ridge 7½' quad., Malheur County. 1988	5.00

Publication	Price*
GMS-52 Shady Cove 7½' quad., Jackson County. 1992	6.00
GMS-51 Elk Prairie 7½' quad., Marion/Clackamas C. 1986	5.00
GMS-50 Drake Crossing 7½' quad., Marion County. 1986	5.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	4.00
GMS-48 McKenzie Bridge 15' quad., Lane County. 1988	9.00
GMS-47 Crescent Mountain area, Linn County. 1987	7.00
GMS-46 Breitenbush River area, Linn/Marion Counties. 1987	7.00
GMS-45 Madras West/East 7½' quads., Jefferson County. 1987	5.00
as set with GMS-43 and GMS-44	11.00
GMS-44 Seekseequa Junction/Metolius Bench 7½' quads. 1987	5.00
as set with GMS-43 and GMS-45	11.00
GMS-43 Eagle Butte/Gateway 7½' quads. 1987	5.00
as set with GMS-44 and GMS-45	11.00
GMS-42 Ocean floor off Oregon & adj. cont. margin. 1986	9.00
GMS-41 Elkhorn Peak 7½' quad., Baker County. 1987	7.00
GMS-40 Aeromagnetic anomaly maps, north Cascades. 1985	5.00
GMS-39 Bibliogr. & index: Ocean floor, cont. margin. 1986	6.00
GMS-38 NW¼ Cave Junction 15' quad., Josephine County. 1986	7.00
GMS-37 Mineral resources, offshore Oregon. 1985	7.00
GMS-36 Mineral resources of Oregon. 1984	9.00
GMS-35 SW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-34 Stayton NE 7½' quad., Marion County. 1984	5.00
GMS-33 Scotts Mills 7½' quad., Clackamas/Marion C. 1984	5.00
GMS-32 Wilhoit 7½' quad., Clackamas/Marion Counties. 1984	5.00
GMS-31 NW¼ Bates 15' quad., Grant County. 1984	6.00
GMS-30 SE¼ Pearsoll Peak 15' qu., Curry/Josephine C. 1984	7.00
GMS-29 NE¼ Bates 15' quad., Baker/Grant Counties. 1983	6.00
GMS-28 Greenhorn 7½' quad., Baker/Grant Counties. 1983	6.00
GMS-27 The Dalles 1° ´ 2° quadrangle. 1982	7.00
GMS-26 Residual gravity, north/ctr./south Cascades. 1982	6.00
GMS-25 Granite 7½' quad., Grant County. 1982	6.00
GMS-24 Grand Ronde 7½' quad., Polk/Yamhill Counties. 1982	6.00
GMS-23 Sheridan 7½' quad., Polk and Yamhill Counties. 1982	6.00
GMS-22 Mount Ireland 7½' quad., Baker/Grant C. 1982	6.00
GMS-21 Vale East 7½' quad., Malheur County. 1982	6.00
GMS-20 S½ Burns 15' quad., Harney County. 1982	6.00
GMS-19 Bourne 7½' quad., Baker County. 1982	6.00
GMS-18 Rickreall, Salem W., Monmouth, Sidney 7½' quads. 1981	6.00
GMS-17 Aeromagnetic anomaly map, south Cascades. 1981	4.00
GMS-16 Gravity anomaly maps, south Cascades. 1981	4.00
GMS-15 Gravity anomaly maps, north Cascades. 1981	4.00
GMS-14 Index to published geol. mapping, 1898–1979. 1981	8.00
GMS-13 Huntington/Olds Ferry 15' quads., Baker/Malheur C. 1979	4.00
GMS-12 Oregon part, Mineral 15' quad., Baker County. 1978	4.00
GMS-10 Low- to intermediate-temp. thermal springs/wells. 1978	4.00
GMS-9 Aeromagnetic anomaly map, central Cascades. 1978	4.00
GMS-8 Bouguer gravity anom. map, central Cascades. 1978	4.00
GMS-6 Part of Snake River canyon. 1974	8.00
GMS-5 Powers 15' quadrangle, Coos and Curry C. 1971	4.00

INTERPRETIVE MAP SERIES

Publication	Price*	
IMS-12 Tsunami hazard map, Warrenton area. 1999	**10.00**	NEW!
IMS-11 Tsunami hazard map, Astoria area. 1999	**10.00**	NEW!
IMS-10 Rel. EQ hazard maps, coastal urban areas. 1999	**20.00**	NEW!
IMS-6 Water-induced landslide hazards, Salem Hills. 1998	10.00	
IMS-4 Geology/faults/sedim. thickness, Oregon City quad. 1997	10.00	

(Continued on next page)

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (continued)

IMS-3 Tsunami hazard map, Seaside area. 1998	6.00
IMS-2 Tsunami hazard map, Yaquina Bay area. 1997	6.00
IMS-1 Relative EQ hazards, Portland metro area. 1997	12.00

MINED LAND RECLAMATION PROGRAM STATUS MAPS

MLR-03 Clackamas County. 1998	10.00
MLR-10 Douglas County. 1998	10.00
MLR-17 Josephine County. 1998	10.00
MLR-24 Marion County. 1998	10.00

U.S. GEOLOGICAL SURVEY MAPS PLOTTED ON DEMAND

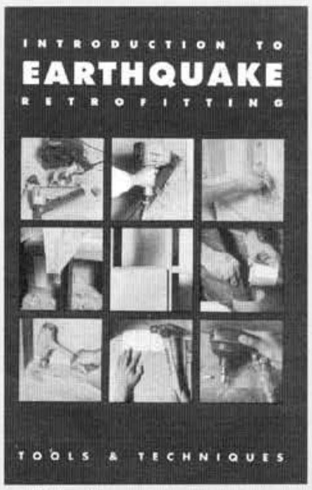
OFR 97-513 Volcano hazards at Newberry volcano	10.00
OFR 97-089 Volcano hazards in the Mount Hood region	10.00
OFR 94-021 Geologic map, Tillamook highlands (2 sheets)	20.00

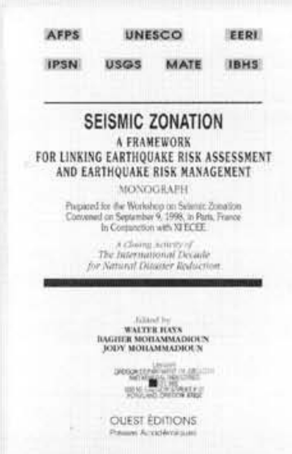
Allow two weeks for delivery on all maps plotted on demand.

Highlighting Recent Publications

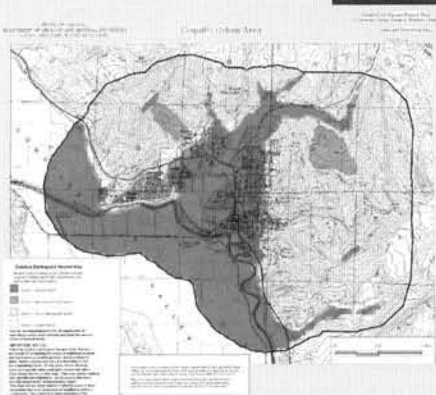
now available from The Nature of the Northwest Information Center

Are you handy around the house? There are some relatively simple steps homeowners can take to make their homes safer in an earthquake. If you have some familiarity with power tools but no particular expertise in home repair, this guide may be for you. A list of tools needed for each job is given, and each project includes photographs showing every step: **Introduction to Earthquake Retrofitting: Tools and Techniques** ($9.95, 77 pages)





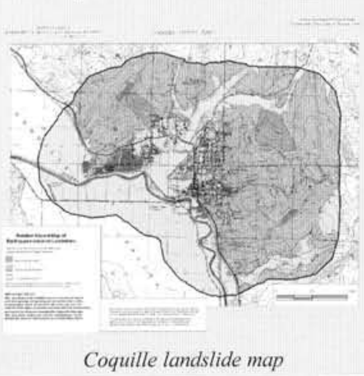
The United Nations recently published a monograph on using earthquake risk assessment as tool in reducing earthquake losses. Among the multinational list of authors are Oregon's State Geologist John Beaulieu and Earthquake Program Director Yumei Wang. Oregon is a leader in earthquake risk assessment; a preliminary report this year estimated more than $12 billion of damage and 5,000 deaths in the event of a magnitude 8.5 Cascadia subduction zone earthquake. The monograph is a summary of how other countries and states are dealing with earthquake hazards: **Seismic Zonation: A framework for linking earthquake risk assessment and earthquake risk management.** $40, 157 pages



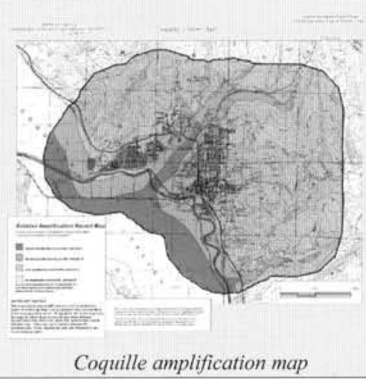
Coquille combined hazard map

Earthquake damage depends on a number of factors, including the rock and soil types that make up the ground in a given area. A new series of maps focuses on the relative ground response of coastal communities during an earthquake: Maps are available for Astoria-Warrenton, Brookings, Coquille, Florence-Dunes City, Lincoln City, Newport, Reedsport-Winchester Bay, Seaside-Gearhart-Cannon Beach, and Tillamook.

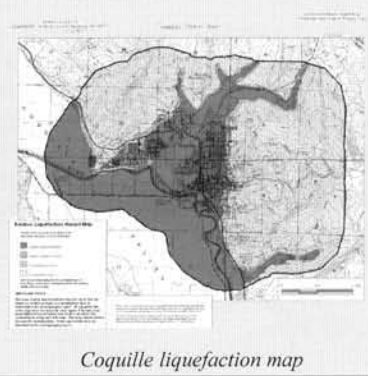
For each city, four maps are included, each showing a different hazard: amplification, liquefaction, landslides, and combined hazards. A CD with GIS information is included. The area mapped was slightly larger than the urban growth boundary of each city. These are relative ground response maps and should be used in conjunction with GMS 100, which shows where known faults are and what the extent of bedrock shaking may be. **Relative Earthquake Hazard Maps for Selected Urban Areas,** IMS–10, $20.



Coquille landslide map



Coquille amplification map



Coquille liquefaction map

(Continued from page 114)
lumbia. It was a peat-swamp plant like swamp cypreses today and may be of the same species as the living *M. glyptostroboides* (Retallack and others, 1996).

The Platanaceae (sycamore family) are represented by *Platanus* cf. *P. condoni*, with fan-shaped, five-lobed leaves (Plate 2, nos. 1–3). Some fruiting heads and a petiole were also found.

Two species of Ulmaceae (elm family) were found: *Ulmus* cf. *U. pseudo-americana* (Plate 1, no. 5) has compound teeth and an asymmetrical base; *Tremophyllum* cf. *T. hesperium* has leaves that are relatively narrow and have blunt teeth.

The Betulaceae (birch family) are represented by *Alnus* cf. *hollandiana* (Plate 2, no. 4). The leaves are ovate to elliptical with numerous small blunt teeth and have nonparallel, slightly concave secondary veins.

The Fagaceae (beech family) are represented by *Quercus* cf. *Q. consimilis* and *Fagus* cf. *pacifica* (Plate 1, nos. 3? and 4), whose leaves both have secondary veins that enter a tooth at the margin.

CONCLUSION

In comparison with floras of similar age in central and western Oregon, the Metasequoia Creek fossil flora appears to resemble the Lyons (Meyer, 1973) and Rujada (Lakhanpal, 1958) floras—closer to the Oregon coast and thus with a higher annual temperature than the inland area with floras in the John Day Formation (Wolfe, 1981; Manchester and Meyer, 1987).

The upper layer fossils at this locality are much like the present flora alive in the area. Elm, birch, and oak are quite common. Sycamores are no longer native. The lower layer's dominant fossils of *Metasequoia* have been replaced by western hemlock. Then and now, the assemblage is similar to temperate, hardwood, deciduous forests of eastern Asia (Wang, 1961). In general, the flora and vegetation would look similar but contrast in a few species changed due to cooling weather. At present, there are more shrubs than trees, which seems opposite the fossil record.

Table 1. Fossil plant list

Conifer:

TAXODIACEAE

Metasequoia cf. *M. occidentalis* [needles, cones, pollen cones]

Flowering plants:

DICOTYLEDONS

Platanus cf. *P. aspera* [leaves, stipules, fruiting heads)

Platanus cf. *P. condoni* [leaves, petiole, fruiting heads]

ULMACEAE

Ulmus cf. *U. pseudo-americana* [leaves]

Tremophyllum cf. *T. hesperium* [leaves]

FAGACEAE

Quercus cf. *Q. consimilis* [leaves, cupule]

Fagus cf. *F. pacifica* [leaves]

BETULACEAE

Alnus cf. *A. hollandiana* [leaves, catkin]

ACERACEAE

Acer cf. *A. ashwilli*

JUGLANDACEAE

Carya sp. [hickory nut]

ACKNOWLEDGMENTS

I would like to thank Melvin Ashwill of Madras, Oregon, for inspiration, Steven Manchester for helpful discussion; Jill Schatz for assistance at the Portland Hoyt Arboretum; and Dan Rokosz for taking photos of the specimens. Special thanks go to the Columbia River Gorge Rockhounds for granting me membership in a great club.

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Carlin, R.A., 1988, A geochemical study of the Eagle Creek Formation in the Columbia River Gorge, Oregon: Portland, Oreg., Portland State University master's thesis, 90 p.

Chaney, R.W., 1918, The ecological significance of the Eagle Creek flora of the Columbia River Gorge: Journal of Geology, v. 26, no. 7, p. 577–592.

Lakhanpal, R.N., 1958, The Rujada flora ot west-central Oregon: University of California Publications in Geological Sciences, v. 35, no. 1, 66 p.

Le Conte, J., 1874, On the great lava flood of the Northwest; and on the structure and age of the Cascade Mountains: American Journal of Science, 3d ser., v. 7, p. 167–180, p. 259–267.

Manchester, S.R., and Meyer, H.W., 1987, Oligocene fossil plants of the John Day Formation, Fossil, Oregon: Oregon Geology, v. 49, no. 10, p. 115--127.

Meyer, H.W., 1973, The Oligocene Lyons flora of northwestern Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 35, no. 3, p. 37–51.

Retallack, G.J., Bestland, E.A., and Fremd T.J., 1996, Reconstructions of Eocene and Oligocene plants and animals of central Oregon: Oregon Geology, v. 58, no. 3, p. 51–69.

Wang, C.W., 1961, The forests of China: Cambridge, Mass., Harvard University, Publication of the Maria Moors Cabot Foundation, 313 p.

Wise, W.S., 1961, The geology and mineralogy of the Wind River area, Washington, and the stability relations of celadonites: Baltimore, Md., John Hopkins University doctoral dissertation, 2 vols., 258 p.

Wolfe, J.A., 1981, Paleoclimatic significance of the Oligocene and Neogene floras of the northwestern United States, in Niklas, K.J., ed., Paleobotany, paleoecology, and evolution: New York, Praeger, p. 79–101.

New DOGAMI field office in Newport

The last Legislature approved funding for a new coastal field office of the Oregon Department of Geology and Mineral Industries (DOGAMI). DOGAMI will thus be able to offer coastal communities a wider range of geologic information services.

The office will be staffed with Dr. George Priest, already part of the DOGAMI staff, and a new coastal specialist. It will be located at the office of the Oregon Coastal Zone Management Association (OCZMA) on Highway 101 in Newport. OCZMA has offered some secretarial support and provides a link to local government and port districts.

The office will be opened early next spring. An open house at that time will celebrate our expanded capabilities for dealing with coastal geologic hazards and give interested people an opportunity for a first visit. More information will be distributed at a later date.

Site-specific seismic reports in DOGAMI library nearing 200

Part 2—Second half of Oregon counties outside Portland metropolitan area

On May 1, 1994, the Oregon Structural Specialty Code, a part of the Oregon Administrative Rules, was changed to order that a copy of each legally required "seismic site hazard report" should be deposited with the DOGAMI library and accessible to the public for inspection. This growing collection now holds nearly 200 reports. The following list is derived from the records in the library's bibliographic database. It is organized by county and USGS 7½-minute topographic quadrangle.

This list covers the second half of the quadrangles in counties outside the Portland metropolitan area. The Portland metropolitan area will be included in the next issue of Oregon Geology. A few reports are associated with more than one quadrangle.

LINCOLN COUNTY QUADRANGLES

Lincoln City

15660. Braun Intertec Corporation (1996): Site-specific seismic evaluation, proposed Taft-Nelscott-Delake fire station, 4500 block of SE Hwy. 101, Lincoln City, Oregon. (Report for Taft-Nelscott-Delake Rural Fire Protection District, Project No. EAAX-95-0459), 14 p., 3 figs., 11 p. app.

Newport North

15610. Fujitani Hilts and Associates,Inc (1997): Site-specific seismic site hazards evaluation, Ambulance Service Building, NW 6th and Coast Streets, Newport, Oregon. (Report prepared for Miller Consulting Engineers, Portland, Oregon, Project No. F-2893-01), 10 p., 2 figs.

Newport South

15641. Robert Deacon,Staff Consultant (1994): Geologic, tectonic, and seismic studies, proposed new addition, Hatfield Marine Science Center, Newport, Oregon. (Report by Foundation Engineering,Inc., Project No. 94200038), 11 p., 3 figs., 1 table.

Toledo North

962. David J. Newton Associates (1996): Geotechnical investigation and seismic hazard report for the Toledo High School additions, 1800 NE Sturdevant Road, Toledo, Oregon. (Report for Luey Architects, 11945 SW Pacific Hignway, Suite 301, Tigard, Oregon 97223; Project no. 644 111), 19 pages, 4 figs., 14 p. app.

Waldport

13350. David J. Newton Associates (1995): Geotechnical investigation and seismic hazards report, Waldport High School Gymnasium, Waldport, Oregon. (Report for Lincoln County School District, Facilities and Maintenance, South Beach, Oregon, Project No. 621 121), 18 pages, 12 p. app.

14880. David J. Newton Associates (1996): Geotechnical investigation and seismic hazards report, new Taft High School, High School Driveat SE Spyglass Ridge Drive, Lincoln City, Oregon. (Report for Lincoln County School District, Project No. 621 101), 19 pages, 5 figs., 15 p. app.

14886. David J. Newton Associates (1996): Geotechnical investigation and seismic hazards report, proposed new Newport Middle School, Newport, Oregon. (Report for Luey Architects, Portland, Project No. 644 101), 23 pages, 5 figs., 24 p. app.

14879. David J. Newton Associates (1996): Geotechnical investigation and seismic hazards report, proposed Waldport Elementary School, Crestline Drive, Waldport, Oregon. (Report for Lincoln County School District, Project No. 621 111), 19 pages, 5 figs., 7 p. app.

MALHEUR COUNTY QUADRANGLES

Malheur Butte

16551. Geocon Northwest (1999): Site-specific seismic hazard study, water reservoir, Ontario, Oregon. (Report for Keller Associates, Meridian, Idaho, Project No. P1016-05-01), 7 p., 2 figs.

MARION COUNTY QUADRANGLES

Mission Bottom

12582. Redmond & Associates (1995): Seismic site characterization and hazard evaluation, proposed Opengate Church of the Nazarene, Keizer (Marion County), Oregon. (Report for Multi/Tech Engineering Services, Inc., Salem, Oreg., Project No. 101.021.G), 6 pages, 8 figs.

Salem East

15302. Kleinfelder,Inc (1996): Phase I geotechnical study, Oregon Department of Corrections, Hay Field site, Salem, Oregon, ODC #MN-SM-3. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-13), 3 tables (text missing?)

Salem West

12588. AGRA Earth & Environmental (1995): Site-specific seismic study, proposed Siltec silicon facility, Fairview Industrial Park, Salem, Oregon. (Report prepared for Takenaka International (U.S.A), Ltd., Job No. 21-07612-02), 6 pages, 2 figs.

12070. Carlson Testing,Tigard (1994): Seismic hazards report, Far South Middle School site, Liberty and Davis Roads, Marion County, Oregon. (Report prepared for Salem/Keizer School District Facilities Planning, CTI Job No. 93-8867), 26 pages.

15640. Foundation Engineering,Inc (1996): Leslie Middle School replacement, site-specific seismic study, Salem, Oregon. (Report for Salem-Keizer School District, Salem, Oregon, Project No. 96100050), 6 pages, 2 figs.

Silverton

14871. David J. Newton Associates (1996): Geotechnical investigation and seismic hazard report for the Silverton Main Fire Station, 819 Railway Drive, Silverton, Oregon. (Report for Silverton Fire District, c/o Arbuckle Costic Architects, P.C., Salem; Project no. 634 101), 23 pages, 4 figs., 1 table, 16 p. app.

MORROW COUNTY QUADRANGLES

Boardman

12562. Ebasco (1994): Seismic hazards evaluation and dynamic analyses for Coyote Springs power generation project. (Report prepared for Portland General Electric Company) (Gray Literature Collection, Earthquakes-power plant siting.) Ebasco Division of Raytheon Engineers and Constructors, Bellevue, Wash. var. pages.

12563. Ebasco (1994): Site densification report for Coyote Springs power project, Boardman, Oregon. (Report prepared for Portland General Electric Company), var. p.

15297. Kleinfelder,Inc (1996): Phase I geotechnical study, Oregon Department of Corrections, Pasture (Kunze Road) site, Boardman, Oregon, ODC #MR-BD-2. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-11), 5 pages, 1 fig., 3 tables.

Crow Butte

15286. Kleinfelder,Inc (1996): Phase I geotechnical study, Oregon Department of Corrections, Boeing site, Boardman, Oregon, ODC #MR-BD-1. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-10), 5 pages, 1 fig., 3 tables.

POLK COUNTY QUADRANGLES

Dallas

16053. Braun Intertec Corporation (1999): Site-specific seismic evaluation, proposed Aquatic Center, SE La Creole Drive, Dallas, Oregon. (Report for City of Dallas, Project No. EAAX-99-0131), 14 pages, 3 figs., 10 p. app.

15831. David J. Newton Associates (1997): Preliminary geotechnical investigation and seismic hazards evaluation for the proposed Polk county jail facility, property bounded by Jefferson, Court, and Shelton Streets, Dallas, Oregon. (Report for Polk County, Project No. 764-101), 27 pages, 4 figs., 21 p. app.

13385. Foundation Engineering,Inc (1995): Geotechnical investigation, Dallas ambulance facility, Dallas, Oregon. (Report for City of Dallas, Oregon, Project No. 95100008), 8 pages, 4 p. app.

Grand Ronde

15638. Foundation Engineering,Inc (1994): Seismic hazard study, Gaming Center site development, Grand Ronde, Oregon. (Report for Spirit Mountain Development Corporation, c/o Mater Engineering, Ltd., Corvallis, Oregon, Project No. P93100052; fault map and tectonic map by Wright/ Deacon & Assoc., Inc.), 23 p., 9 figs., 14 p. app.

15290. Kleinfelder,Inc (1996): Phase I geotechnical study, Oregon Department of Corrections, Steel Bridge site, Willamina, Oregon, ODC #PK-WM-1. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-05), 5 pages, 1 fig., 3 tables.

Salem West

15639. Foundation Engineering,Inc (1994): Seismic study, Walker Middle School additions, Salem, Oregon. (Report for Salem-Keizer School District, Salem, Oregon, Project No. 94100105; fault map and tectonic map by Wright/Deacon & Associates, Inc.), 21 pages, 6 figs., 1 table, 12 p. app.

TILLAMOOK COUNTY QUADRANGLES

Tillamook

15292. Kleinfelder,Inc (1996): Phase I geotechnical study, Oregon Department of Corrections, Port of Tillamook site, Tillamook, Oregon, ODC #TL-TL-1. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-04), 5 pages, 1 fig., 3 tables.

UMATILLA COUNTY QUADRANGLES

Hermiston

12525. Bechtel Power Corporation (1994): Final subsurface investigation and foundation report for the Hermiston generating project, Hermiston, Oregon, var. pages, 10 figs., 84 p. app.

12579. Squier Associates (1994): Geology, slope stability, and seismicity. Exhibit G. in: Hermiston power project, application for site certificate. (Submitted to the Oregon Energy Facility Siting Council, Job No. 93804; revised version submitted April 1995 by Hermiston Power Partnership, Boise, Idaho, Job No. 93804.1), p. 1-23 (attachments 4 p., 3 tables, 6 figs.)

Pendleton

15751. Strata Geotechnical Engineering,Idaho (1997): Seismic site hazard evaluation, Umatilla Criminal Justice Center, Umatilla County, Oregon. (Report for Umatilla County, Pendleton, Oreg., submitted by Lombard-Conrad, Architects,P.A., Boise, Idaho, Project No. T9701B, 3 pages, 2 figs. (Accompanied by geotechnical engineering evaluation, job. no. T9701-C.)

Umatilla

15628. Geotechnical Resources,Inc (1997): Geotechnical investigation and site-specific seismic hazard study, Men's Medium-Security Corrections Institution, Umatilla, Oregon, for Oregon Department of Corrections. (Report for Oregon Department of Corrections, Job No. 2348), 11 pages, 3 figs., 34 p. app.

15298. Kleinfelder,Inc (1996): Phase I geotechnical study, Oregon Department of Corrections, Port of Umatilla site, Umatilla, Oregon, ODC #UT-UT-1. (Report for KPFF Consulting Engineers/ODC, Project No. 60-8080-12), 5 pages, 1 fig., 3 tables.

UNION COUNTY QUADRANGLES

La Grande

13379. AGI Technologies (1995): Site-specific seismic hazard evaluation, Grande Ronde Hospital, La Grande, Oregon. (Report prepared for Grande Ronde Hospital, Technical Services Dept., Project No. 30,166.005), 7 pages, 3 figs., 7 p. app.

15891. Foundation Engineering,Inc (1995): Geotechnical investigation, La Grande Armory, La Grande, Oregon. (Report for Carkin Arbuckle Costick Architects, Salem, Oregon, Project No. 95200087), 9 pages, 1 map, 14 p. app.

WASCO COUNTY QUADRANGLES

Dufur East

15557. Mark V. Herbert and Associates,Inc (1996): Seismic evaluation, New Gymnasium, Dufur School [Wasco County, Oregon]. (Report for Dufur School District, Project No. 96-050), 5 pages, 1 table, 2 figs.

The Dalles South

15620. Alder Geotechnical Services (1997): Seismic hazards report, proposed Calvary Baptist Church addition, 3350 Columbia View Drive, The Dalles, Oregon. (Report for FWL Architects (David D. Fisher), Portland, Oreg., Project No. 133-1), 12 pages, 26 p. app.

15957. Fujitani Hilts and Associates,Inc (1998): Seismic site hazard investigation, proposed new Armory, The Dalles, Oregon. (Report prepared for Architects Barrentine Bates Lee, Lake Oswego, Oregon, Project No. F-2970-02), 10 pages, 3 figs.

12592. H.G. Schlicker & Associates (1995): Seismic assessment, proposed theatre site, West 7th and Snipes, The Dalles, Oregon. (Report for Bruce Humphrey, The Dalles, Oreg., Project No. 951223), 7 pages, 5 figs., 8 p. app.

WASHINGTON COUNTY QUADRANGLES

Forest Grove

16005. Northwest Natural Gas Company,NW Natural (1998): Application to amend the site certificates for Mist underground natural gas storage and the South Mist feeder pipeline. (Report for Oregon Energy Facility Siting Council), 140 pages, at least as many pages app. (Second volume contains exhibits.)

Laurelwood

15283. Andrews,Desmond CA; Baez,Juan I; Martin,Geoffrey R (1996): Liquefaction mitigation: Use of vibro-stone columns for silty soils - Background and case histories [Fern Hill, Forest Grove, waste water treatment plant site], in: Ground stabilization and seismic mitigation. (Paper presented at seminar, Portland, Oregon, November 6-7, 1996, sponsored by American Society of Civil Engineers, Oregon Section Geotechnical Group, and Oregon Department of Geology and Mineral Industries), 18 p., 9 figs.)

Scholls

15633. Kleinfelder,Inc (1997): Butternut Orchard site #WA-SAFETY-222, Washington County, Hillsboro/Aloha. Final report, prison site location analysis, State of Oregon, Department of Corrections. (Report for KPFF Consulting Engineers/ODC), var. p.

15631. Kleinfelder,Inc (1997): Rood Bridge Rd. site #WA-HS-1, Washington County, Hillsboro. Final report, prison site location analysis, State of Oregon, Department of Corrections. (Report for KPFF Consulting Engineers/ODC), var. pages.

Vernonia

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Silicic volcanism in the Cascade Range: Evidence from Bear Creek and Antelope Creek valleys, southern Oregon

by Roy F. Torley, Department of Geological Sciences, 1272 University of Oregon, Eugene, OR 97403-1272; and Frank R. Hladky, Oregon Department of Geology and Mineral Industries, Grants Pass Field Office

Evidence of silicic volcanism exists in the soil profile of Bear Creek and Antelope Creek valleys, southern Oregon (Figure 1). Limpid medium- to coarse-sand-size (¼–½ mm and ½–1 mm) quartz crystals having a hexagonal dipyramidal form (Figure 2) were found in sediments collected from various creeks in the two valleys. Although crystals were commonly shattered to varying degrees, many complete crystals were also seen. These crystals were identified during a regional sedimentological study that was conducted between 1993 and 1996. The study involved Fourier grain-shape analysis of detrital quartz grains in Holocene sediments (Torley, 1998).

Quartz crystals with the hexagonal dipyramidal form are called beta quartz or high quartz (Figure 2). Beta quartz is known to form in high temperature conditions (^{3}573° C) (Deer, Howie, and Zussman, 1966). When beta quartz cools to below 573° C, it inverts to alpha quartz (or low quartz) but commonly retains its original dipyramidal shape. In the rock record, beta quartz occurs in quartz-rich tuffs and much more rarely in high-temperature geothermal deposits. Because ash from silicic volcanic eruptions can cover large areas, it is very likely that the region around Bear Creek has been episodically covered with a significant amount of quartz-rich ash throughout geologic time. Tertiary age ash beds occur in the region primarily as relatively thin beds of tuff sandwiched between thick sequences of lava. Some volcanic ash occurs in Holocene soil horizons, a portion of which is identified with the climactic eruption of Mt. Mazama that produced Crater Lake about 6,700 years ago. Ash is part of the soil profile in and around Bear Creek and Antelope Creek valleys.

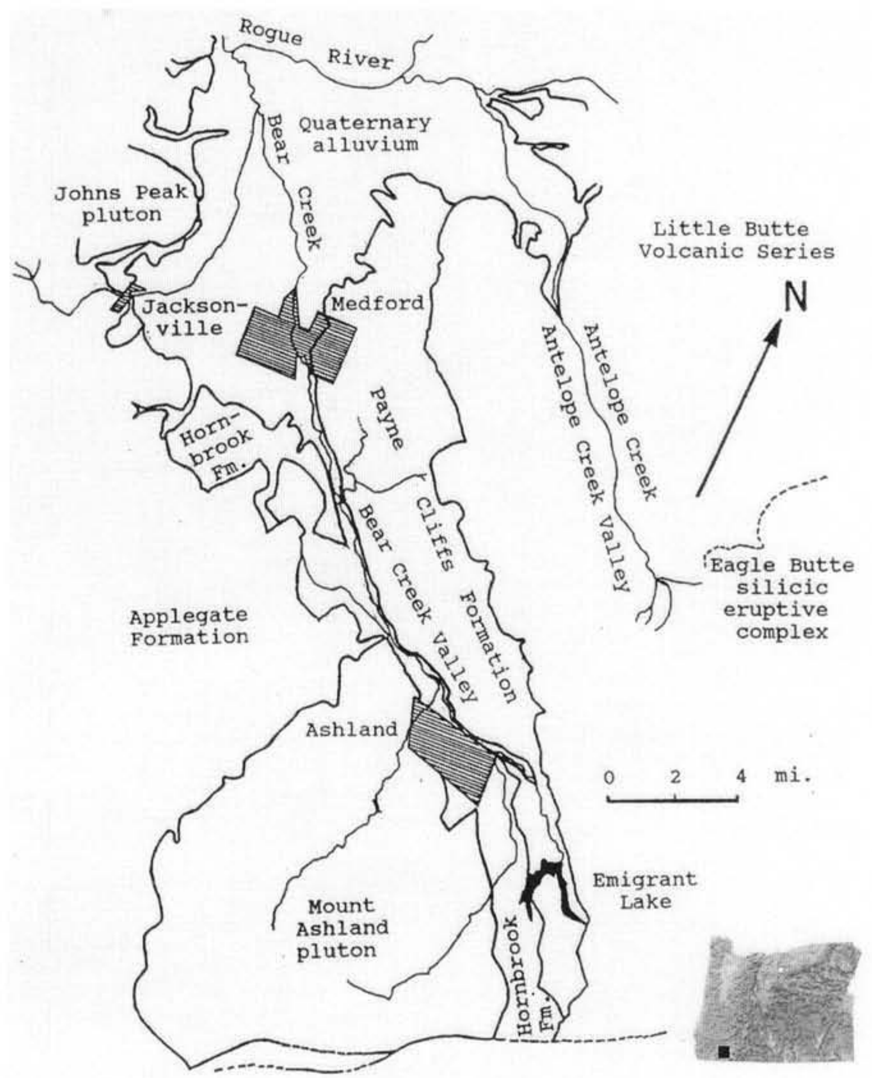

Figure 1. Generalized map of Bear Creek and Antelope Creek valleys, southern Oregon.

The creeks sampled in the sedimentological study include West Fork Ashland Creek and Neil Creek on the Mount Ashland pluton, Miller Gulch and South Fork Jackson Creek in the Siskiyou Mountains west of and flowing through Jacksonville, respectively, Payne Creek east of Phoenix, and Antelope Creek (Figure 2). Six to eight sediment samples were collected along the lengths of each creek in an effort to identify detrital quartz grain-shape populations that could be linked with certain source rock types, specifically volcanic, plutonic, metamorphic, and sedimentary rocks. Beta quartz pseudomorphs were found in all sediment samples.

Sediments collected around the

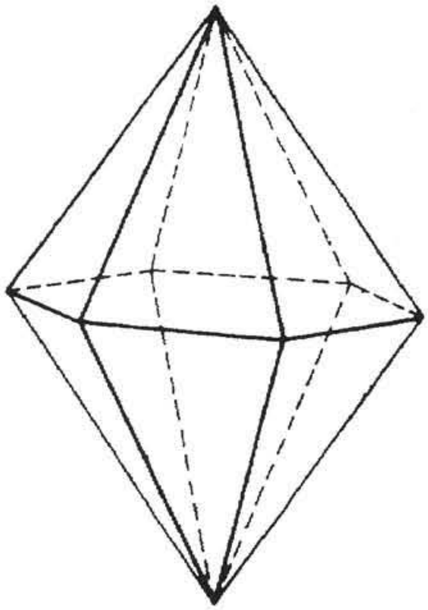

Figure 2. Schematic representation of hexagonal dipyra midal form typical of so-called "beta quartz" or "high quartz" (high-temperature quartz).

summit and on the sides of Mount Ashland contain identifiable hexagonal dipyramidal quartz crystals commonly amounting to five percent of quartz grains hand-picked for shape analysis (Figure 3). Samples collected from Miller Gulch have about the same proportion of crystals but proportions vary wildly along South Fork Jackson Creek from very few grains seen to about forty percent of hand-picked quartz grains.

Many beta quartz pseudomorphs were identified in Payne Creek and Antelope Creek sediments. Because Antelope Creek incises only the Little Butte Volcanic Series along its upper length, it is reasonable to hypothesize that all the detrital quartz in its sediments is volcanic in origin. This hypothesis is supported in that the head of Antelope Creek is located at the remains of the Eagle Butte silicic eruptive center where bodies of quartz-rich tuff are located (Hladky, 1997) (Figure 2).

The Eagle Butte silicic eruptive center is a possible source of the region-wide ashfall. It was active from 23 to 21 Ma before becoming extinct. Located 19 miles to the west southwest of Mount Ashland's summit, it erupted more than once during this period and with enough force and volume of ash to blanket the region that is now incised by Bear Creek and Antelope Creek, including Mount Ashland. The fact that Mount Ashland received ash on its summit corroborates the view that the pluton was already exhumed by the time Eocene volcanism commenced in the Western Cascades. The extent and volume of this ashfall has not been determined and it is doubtful that it ever will be because much of it has been removed from the valley by fluvial erosional and transport processes during Tertiary and Quaternary time.

Another possible source of ash is a caldera complex located about 30 miles north of Medford in the Western Cascades (Hladky and Wiley, 1993). During the late Oligocene (28 to 25 Ma), it produced extensive sheets of ashfall tuff (Hladky and Wiley, 1993; Frank Hladky, pers. comm. 1996; Jim Smith, pers. comm. 1996). If it did contribute quartz-rich ash to Bear Creek and Antelope Creek valleys, it may be difficult, if not impossible, to distinguish between beta quartz crystals originating from the two eruptive centers in Holocene sediments. Additionally, silicic eruptions during Holocene time from Mt. Mazama (now Crater Lake) and Mt. Shasta are possible, indeed probable, contributive sources for volcanically derived beta quartz in the Holocene soils of the Antelope Creek and Bear Creek Valleys.

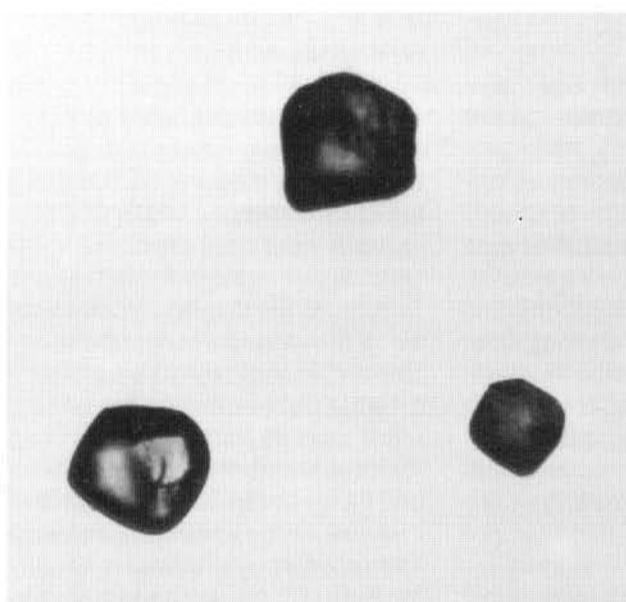

Figure 3. Beta quartz pseudomorphs found in creek sediment near the summit of the Mount Ashland pluton. The two larger grains are about 0.5 mm in size, the smaller grain about 0.25 mm in size.

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THESIS ABSTRACTS

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

Geochemistry of the Boring Lava along the west side of the Tualatin Mountains and of sediments from drill holes in the Portland and Tualatin basins, Portland, Oregon, by Michelle L. Barnes (M.S., Portland State University, 1995), 182 p.

Instrumental Neutron Activation Analysis (INAA) was used to identify geochemical groups in Boring Lava along the west side of the Tualatin Mountains, and in sediments of the Portland and Tualatin basins.

Samples of Boring Lava were obtained from TriMet drill core collected during planning of the tunnel alignment for the Westside Light Rail line. Additional samples of Boring Lava were collected from outcrops along the west side of the Tualatin Mountains. Samples of sediment from the Tualatin and Portland basins were obtained from drill core collected during an Oregon Department of Geology and Mineral Industries (DOGAMI) Earthquake Hazards Mapping project.

INAA of Boring Lava samples resulted in the identification of three geochemical groups. Additional data sets, including x-ray fluorescence geochemistry, magnetic polarity, and age dates, allowed for the distinction of three Boring Lava units. The Boring Lava of Barnes Road is a young, normal unit, the Boring Lava of Sylvan Hill is an older normal unit, and the Boring Lava of Cornell Mountain is the oldest, reversed unit. The surface distribution, identified using topography and outcrop geochemistry, is consistent with the subsurface distribution, identified using boring logs and core geochemistry. Volcanic vent locations are proposed at topographic highs within the identified surface distribution of the Boring Lava of Barnes Road.

INAA of sediment samples resulted in the identification of seven groups:

(1) Columbia River source sediments, (2) lower Troutdale Formation, (3) Reed Island ashes, (4) young Columbia River sediments, (5) high- alumina basalt sediments, (6) episodic Cascadian volcanic sediments, and (7) Columbia River Basalt Group (CRBG) sediments.

Only the CRBG sediments group was identified in the Tualatin basin, while all seven groups were identified in the Portland basin. This appears to demonstrate that the sediment packages in the two basins are different.

Finally, each sediment group can be placed into one of three broad geochemical categories:

Columbia River source sediments and lower Troutdale Formation represent a Columbia River or continental source; Reed Island ashes, young Columbia River sediments, high-alumina basalt sediments, and episodic Cascadian volcanic sediments represent a Cascadian or local source; and CRBG sediments represent residual soils or sediments overlying Columbia River basalt flows.

The volcanic stratigraphy of the Juntura region, eastern Oregon, by George B. Binger (M.S., Washington State University, 1997), 206 p.

Major- and trace-element concentrations were determined on 433 samples of the diverse volcanic units along the western margin of the Vale and Mahogany Mountain 1:100,000 sheets in an attempt to refine stratigraphic correlations in a structurally complex area of Basin and Range extension in east-central Oregon. Analyzed samples included 197 collected by J. Evans, H. Brooks, M. Ferns, M. Francis, and J. Johnson from 12 7½-minute quadrangles and 73 collected from a continuous section of Steens Basalt by J. Johnson and C.J. Hawkesworth. These were supplemented by 138 samples collected for this study and compared to earlier analyses of samples mainly collected from the north and northeast of the study area by K. Lees (24 samples).

The data are used to more fully characterize units identified in the original mapping and to recognize 12 additional units. Significant modifications of the stratigraphic framework are suggested and related to the chronology established by Lees (1994). Detailed correlations between basalt sections have established the relationship between the Steens Basalt and tholeiitic basalts progressively farther north, which can be correlated with the Imnaha and Grande Ronde basalts of the Columbia River Basalt Group. The stratigraphy of the volcanic units demonstrates the change from the mantle-plume-related lower tholeiites, through calc-alkaline sequences and finally alkali basalts related to the active extension. The extension-related younger units are low volume, geographically and chemically distinct flows, unlike the higher volume, relatively homogeneous lower tholeiites.

Paleoseismic deformation in behind-arc lacustrine settings: Acambay, Mexico, and Ana River, Oregon, by Robert M. Langridge (Ph.D., University of Oregon, 1998), 188 p.

Paleoseismic techniques offer the means to study fault activity in "behind-arc" tectonic settings where rates of deformation and historic seismicity are low. This dissertation presents geologic evidence of large earthquakes in the behind-arc, and establishes this setting as one that generates large (M~7) and damaging earthquakes. Developing criteria for the recognition and characterization of subaqueous paleoseismic events is central to this study.

The 1912 MW 7.0 Acambay earthquake in Mexico is used as a model for behind-arc extensional faulting. This event's rupture is ana-

(Continued on next page)

Simonton appointed as new Governing Board member

Vera E. Simonton of Pendleton has been appointed by Governor John Kitzhaber and confirmed by the Oregon Senate for a four-year term as member of the Governing Board of the Oregon Department of Geology and Mineral Industries. She succeeds Jacki Hagerty of Enterprise, whose term expired in July.

Ms. Simonton is a real-estate agent with Garton and Associates Realtors in Pendleton and has a 20-year history as an educator with community colleges in eastern Washington and Oregon. She has long been involved in civic organizations in the Pendleton area and in 1993 was inducted into the Pendleton Round-Up Hall of Fame. In 1995, she was appointed to the site selection committee for the Pendleton County Jail and Work Release Center. Most recently, Simonton has been volunteering with the local Cancer Society, Festival of Trees, and St. Anthony Hospital Hospice.

Serving with Simonton on the three-member board are Don Christensen of Depoe Bay, Chair, and Arleen Barnett of Portland.

(Continued from previous page)
lyzed to assess the prehistoric record of earthquakes on the Acambay-Tixmadejé fault, and to test whether the size and geology of this earthquake are typical for this setting. Trenches at four sites along the 1912 ground rupture revealed evidence of repeated latest Pleistocene and Holocene earthquakes with equivalent offset, and by inference magnitude, to the 1912 event. The recurrence interval for events is 3-5,000 years and the slip rate across the Acambay graben totals ~0.25 mm/year. These results probably apply to geomorphically similar deformation along active faults in both central Mexico and Oregon and therefore have implications for the contemporary seismicity predicted for these regions.

Trenches and exposures across and near the Ana River fault, Oregon, reveal evidence of multiple late Pleistocene and Holocene earthquakes from a well-exposed and dated sequence of tephra-bearing lacustrine sediments of pluvial Lake Chewaucan. Near- to far-field correlation of event horizons has helped establish a long paleoseismic record for the Ana River fault. Large earthquakes recur every 10–20,000 years on this structure, with a slip rate of ~0.1 mm/year.

Many of the paleoseismic events on the Huapango Plain, Mexico, and at the Ana River occurred underwater during Pleistocene pluvial periods. Seismically-deformed thizotropic sedimentary packages are defined by the presence of low-angle faulting, folding, slumping with section stacking, subtle bevel unconformities, addition or removal of section, liquefaction, and boudinage structures. Detailed mapping of seismites has resulted in a tectonic model for submerged normal faults, based on shaking-related failure and gravity-driven block transport on gentle slopes.

Structure and seismic hazards evolution of the of the offshore Cascadia forearc and Neogene forearc basin, by Lisa C. McNeill (Ph.D., Oregon State University, 1998), 178 p.

The Cascadia subduction zone has been characterized as a typical Chilean-type subduction zone based on qualitative comparisons of plate age and convergence rate, with simple forearc structure. However, the discovery of unusual structural styles of deformation, variations in the morphology of the forearc, and its absence of seismic activity suggest differences from the Chilean analog. The manuscripts presented here illustrate this complexity and provide examples of contrasting deformation throughout the offshore forearc. The Washington and northern Oregon shelf and upper slope are characterized by extension in the form of listric normal faults. These faults have been active since the late Miocene and are driven by detachment and extension of the underlying overpressured melange and broken formation. This region of the forearc is partly to wholly decoupled from convergence-driven compression which dominates deformation elsewhere in the forearc. One exception to convergence-driven compression is a region of N-S compression of the inner shelf and coastal region, which reflects the regional stress field. N-S compressional structures apparently influence the positions of coastal lowlands and uplands and may contribute to the record of coastal marsh burials interepreted as the result of coseismic subsidence during subduction zone earthquakes. Modeling of subduction zone earthquake characteristics based on marsh stratigraphy is likely to be inaccurate in terms of rupture zone position, magnitude, and recurrence interval. The Cascadia shelf and upper slope are underlain by a sequence of deformed basinal strata which reflects the tectonic evolution of the margin. The surface of a regional late Miocene angular unconformity (7.5-6 Ma: a global hiatus) indicates deformation by uplifted submarine banks and subsided synclines (coincident with low recent uplift onshore), which control the current shelf break position. The basin is currently filled behind a N-S-trending outer-arc high, which uplifted in the early-middle Pliocene following truncation and erosion of the seaward edge of the basin. Breaching of the outer-arc high occurred in the early Pleistocene leading to the formation of the Astoria Submarine Fan and increased growth rates of the accretion ary wedge.

DOGAMI PUBLICATIONS

Released October 21, 1999:

Tsunami Hazard Map of the Astoria Area, Clatsop County, Oregon, by George R. Priest, Edward Myers, Antonio Baptista, Garnet Erdakos, and Robert A. Kamphaus. Interpretive Map Series map IMS-11, scale 1:24,000, 4 p. text, $10.

Tsunami Hazard Map of the Warrenton Area, Clatsop County, Oregon, by George R. Priest, Edward Myers, Antonio Baptista, Garnet Erdakos, and Robert A. Kamphaus. Interpretive Map Series map IMS-12, scale 1:24,000, 5 p. text, $10.

These map shows how three different tsunamis might affect the area. A tsunami is a series of waves generated by undersea earthquakes, so the authors used computers to simulate three different local earthquakes and the tsunamis they might cause. The simulations were used in conjunction with field observations to produce the maps.

Great (magnitude 8 to 9) undersea earthquakes off the Oregon coast cause devastating tsunamis to strike every 300–600 years. The earthquake itself might last up to four minutes; then, within about 30 minutes after the start of the earthquake, the first of several large high-velocity tsunami waves hits this part of the coast. It is important that people know the safest way to go to high ground or at least go as far inland as possible. The new maps and similar maps will help find evacuation routes that will be least affected by tsunamis.

The maps, which show city streets and tsunami flooding areas, were produced by DOGAMI in partnership with a community advisory committee. The Oregon Graduate Institute of Science and Technology and the National Oceanic and Atmospheric Administration (NOAA) provided scientific research to produce the maps. NOAA and the Federal Emergency Management Agency (FEMA) funded the project.

Released October 25, 1999:

Relative Earthquake Hazard Maps for Selected Urban Areas in Western Oregon, by Ian P. Madin and Zhenming Wang. Interpretive Map Series map IMS-10, 9 maps on 2 sheets (scale 1:24,000), 4 p. text, one CD-ROM disk, $20.

The relative earthquake hazard maps for nine coastal communities—Astoria-Warrenton, Brookings, Coquille, Florence-Dunes City, Lincoln City, Newport, Reedsport-Winchester Bay, Seaside-Gearhart-Cannon Beach, and Tillamook—combine the effects of ground shaking amplification, liquefaction, and earthquake-induced landsliding (included on CD-ROM) to show the earthquake hazards relative to the geologic conditions.

The maps were produced with funding by the State of Oregon and the U.S. Geological Survey.

Important uses of these new maps include the following:

- Emergency response and hazard mitigation

Planning for disaster response will be enhanced by the use of these maps to identify which resources and transportation routes are likely to be damaged.

- Land use planning and seismic retrofit

Efforts and funds for both urban renewal and strengthening or replacing older and weaker buildings can be focused on the areas where the effects of earthquakes will be the greatest. Requirements placed on a development could be based on the hazard zone in which it lies.

- Lifelines

Lifelines include road and access systems including railroads, airports and runways, bridges, and over- and underpasses, as well as utilities and distribution systems. These hazard maps allow assessing vulnerability and setting priorities for mitigation.

Additional earthquake hazard maps for western Oregon communities will be released January 26, 2000, the 300th anniversary of the last great Cascadia subduction zone earthquake.

Released September 7, 1999:

Geology and Mineral Resources Map of the Brownsboro Quadrangle, Jackson County, Oregon, by Frank R. Hladky. Geological Map Series map GMS-109, scale 1:24,000, 12 p. text, $10.

The Brownsboro quadrangle, is located northeast of Medford and just east of Eagle Point in Jackson County. The new map includes areas around Antelope Creek and Little Butte Creek in the foothills of the Cascade Range. The accompanying text outlines groundwater and mineral resources and the geologic history of the area.

The oldest rocks identified in the area were erupted about 30 million years ago. On top of this bedrock, the dominant factor in shaping the landscape has been landsliding. Large-scale landslides may have been induced by earthquakes. As streams have drained the area and changed their channels, gravel terraces have been preserved. These gravels reach a maximum thickness in the quadrangle of 50 ft.

Crushed rock is the primary mineral resource of the quadrangle. Clay, mercury, and copper have been prospected, but there has been little or no production.

Groundwater resources are affected by the variety among volcanic rocks. Volcanic lava flows tend to produce large quantities of water , often of good quality. Tuffaceous rocks tend to restrict ground water movement. Areas of silicic rocks, especially near old volcanic vents, often produce water with high levels of metals, including arsenic and mercury, so these resources must be carefully analyzed before use.

The publications are available from the Nature of the Northwest Information Center, 800 NE Oregon Street #5, Portland, 97232, (503) 872-2750; and the DOGAMI field offices: 1831 First Street, Baker City, 97814, (541) 523-3133; and 5375 Monument Drive, Grants Pass, 97526, (541) 476-2496.

How many earthquakes occur in Oregon over a year, and where?

The answers to both questions might surprise you.

by Lou Clark, DOGAMI Earth Science Information Officer

The Pacific Northwest Seismograph Network at the University of Washington tracks earthquakes in the Pacific Northwest and notifies DOGAMI through RACE, Rapid Alert for Cascadia Earthquakes. The following earthquake highlights come from that system.

These are only earthquakes over magnitude (M) 1.5, but thousands of smaller quakes happen throughout the year that we cannot measure and record. In much of Oregon, population density is so low, and damaging earthquakes happen so infrequently that seismometers are not installed in many places. While they give us valuable data, seismic instruments are so expensive to place and maintain that we can't afford and justify enough of them to truly understand Oregon's earthquake context.

In 1999, RACE registered 124 earthquakes between January 1 and October 31—centered in or near Oregon. Few of them were felt: Typically, you don't feel earthquakes below M 3 unless they are very close or you are in a special situation—for example, being in a tall building.

Did you feel the small earthquake on February 24? Thousands of people did. This M 2.7 event was centered between Molalla and Woodburn and cracked plaster at Oregon City High School buildings. What you probably don't know is that within a few miles of that quake, 12 other earthquakes occurred through the year, between M 1.5 and M 2.3!

Another earthquake that people felt was the M 2.1 quake on Sauvie Island in February. That one didn't cause any damage, but was felt by enough people to get some media coverage. There were four other earthquakes around the same spot, (M 2.3 to M 3.2), but they happened in the middle of the night and were not felt.

Of course, the most damaging and widely felt earthquake of 1999 was in July, centered just east of Aberdeen, Washington, and felt throughout northwestern Oregon. The main shock was M 5.7 and caused millions of dollars of damage. There were three small aftershocks within a week (M 1.6 to 2.5).

Several small events were centered in the Coast Range, from south of Astoria to west of Grants Pass.

Occasionally, there are offshore earthquakes. This year, two of these occurred, both in January: a M 2.5 off Rockaway Beach and a M 2.6 off Port Orford.

The Cascade Range had far more earthquakes. In a highly publicized swarm, there were 12 quakes on January 11 on Mount Hood. An additional 11 small quakes shook the mountain in the following months, with only one over M 3. Compare that to Mount St. Helens, which had 13 small earthquakes, with two of them over M 3. This is a very common pattern of small movements on our neighboring volcanoes and does not indicate any movement of magma. There were a few other isolated, very small events in the Cascades.

Northeastern Oregon had a number of quakes. RACE reported nine events north of Umatilla, including a M 3.0 and a M 3.2 in September. Several were located east of Pendleton, the largest being a M 2.6 in March. Two small events were centered near Enterprise.

The area near Condon experienced a number of earthquakes. The largest was a M 3.5 quake on August 31, followed by five more in September.

By far the area with the most earthquakes this year was Christmas Valley: 27 events between April and June (and an "afterthought" in October). One was a M 3.8, but the others were M 1.6 to M 2.4. Fortunately, they were so small that they did not cause damage, and most were not even felt. Even for a geologist, three months of earthquakes might be a little much.

If you're in an area not shaken by an earthquake on this list, don't feel left out. Quakes happen every day, and happen all over the state. For example, in 1993, there were hundreds of aftershocks around Scotts Mills (after a M 5.6 shock) and Klamath Falls (after main shocks of M 5.9 and M 6.0).Last year, there were temblors in various parts of the state where no shaking occurred this year, for instance, two quakes that exceeded M 3 near Halfway in Baker County and a M 2.5 near St. Helens. The two largest quakes of 1998 were offshore: a M 5.1 off Coos Bay and a M 4.1 off Gold Beach.

According to this list, Oregon has experienced one earthquake every other day, on average; however, a great many more earthquakes did actually occur, even if they were not registered by these instruments. We've been fortunate in having little earthquake damage since 1993. But while you're waiting for the earthquake that will make the big headlines, remember that, wherever you are, there's probably an earthquake happening near you today.

Correction

In the last issue (July/August), on page 87, we printed a map that showed the location of Salem a lot closer to the coast than it really is. We apologize for the oversight—as well as for placing an unintended and nameless spot for a town into the state of Washington.

We also thank reader Allen Agnew of Corvallis for letting us know what his sharp eyes had spotted right away!

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at Portland, OR

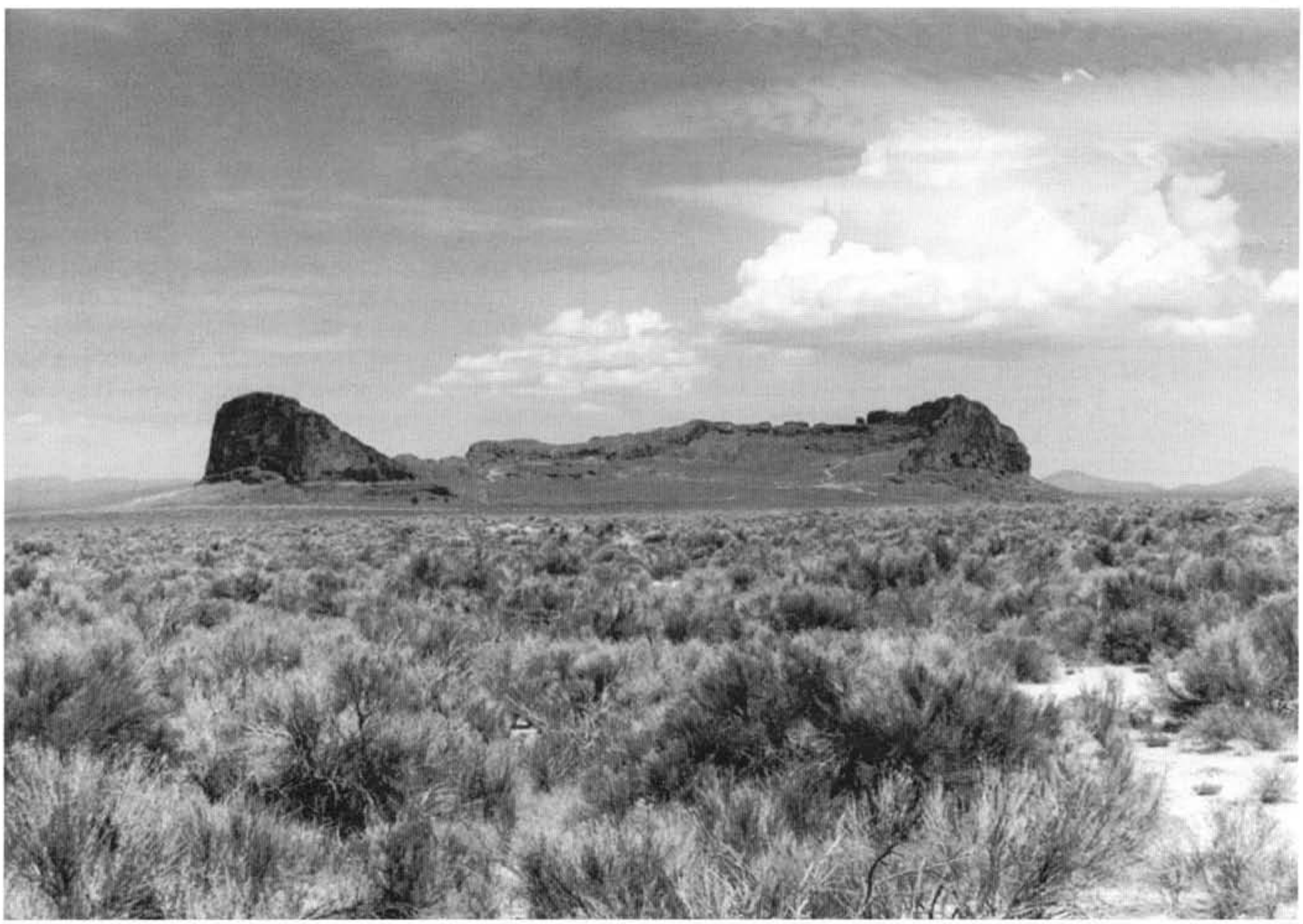
Places to see—Recommended by the Oregon Department of Geology and Mineral Industries:

Fort Rock State Monument in Lake County, one of six National Natural Landmarks in Oregon

Fort Rock with its steep rock sides is the most striking example of the maars and tuff rings in the young volcanic landscape of the High Lava Plains province. It was formed by a shattering explosion in early Pleistocene time, when rising magma met a shallow lake that covered the Fort Rock and Christmas valleys. The lake water eroded part of the crater ring and left wave-cut benches that can be seen especially near the tips of the horseshoe-shaped "fort."

In the caves cut along the edge of the lake in this vicinity, evidence of early human habitation has been found, including the 10,000-year-old woven sandals that are now thought to be the oldest shoes on record.

Access: From State Highway 31 (Designated Scenic Byway), about 60 mi south of Bend or 100 mi north of Lakeview. The 7-mi side road to Fort Rock is part of the scenic route. Photo contributed by reader Steve Fritz of Portland.



OREGON GEOLOGY

Oregon Department of Geology and Mineral Industries

Volume 61, Number 6, November/December 1999

IN THIS ISSUE:

The other face of Oregon: The geologic processes that shape our state

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Index for volume 61, 1999

THROUGH THE EYES OF THE STATE GEOLOGIST

John D. Beaulieu
Oregon State Geologist

Oregon has the "privilege" of being home to many geologic processes that become hazards when they interfere with human activity. We have the "privilege" of experiencing landslide slumps, debris flows, floods, shrink-swell soil, coastal erosion, local tsunamis, distant tsunamis, volcanism, crustal earthquakes, subduction earthquakes, land subsidence, and others. These hazards give us our mountainous scenery, valleys, picturesque coastline, fertile fields, and, to some extent, our economy and livelihood. Things are said to "Look different here".

Although it is a privilege that "Things look different here," there are responsibilities, too. It is our responsibility to manage the hazards to assure the health, safety, and well-being of the public.

Worldwide, nationwide, and statewide, losses from geologic hazards are increasing rapidly each year. The losses from geologic hazards in Oregon can easily amount to many lives and many tens of millions of dollars annually. Yet we learn from experiences in other states that proper management can greatly reduce losses. Well-managed development of hillsides, for example, has been shown to reduce losses by more than 95 percent in test areas in California.

Good management depends on the ready availability of good, reliable, and well-designed information. Good management also requires effective partnerships. In such partnerships, each member agency must know its unique role clearly, must perform it well, and must perform it in concert with others.

The Oregon Department of Geology and Mineral Industries is the leading source for much of the general information about geologic hazards in Oregon. To reduce risk, we are partnering with many entities, including the Office of Emergency Management, the Department of Land Conservation and Development, and the Progress Board, as well as other state agencies, the private sector, local government, and others.

We are seeking an information-based, disaster-resilient state from border to border. The broad diversity of hazards poses challenges but does not necessarily lead to disasters. We at DOGAMI would like to do our part. We would like to cultivate understanding of the finely tuned balances that have produced and are producing the landscapes and the resources we all enjoy. We would like to further the use of this information to reduce risks from geologic hazards in Oregon.

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Cover photo

The massive Bonneville slide into the Columbia Gorge has been recently dated at 300 years in the past. This places the slide at the same time as the last big subduction earthquake, suggesting that this seismic event may have triggered the landslide.

The article beginning on the next page discusses this and other hazards that have shaped "The other face of Oregon."

The other face of Oregon: Geologic processes that shape our state

By Elizabeth L. Orr and William N. Orr, Department of Geological Sciences, University of Oregon, Eugene

Note: As we end the century and the millenium, it is an appropriate time to review the geologic processes that formed and continue to re-form Oregon. We enjoy, and even take for granted, Oregon's great outdoors. But the flip side of our scenic wonders are natural disasters—the geologic processes that wreak havoc when they intersect with people's lives. *–ed.*

INTRODUCTION

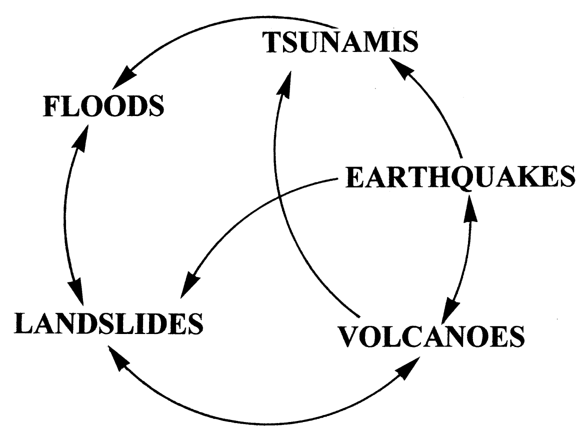
The Pacific Northwest is known for its wonderful diversity of natural landscapes including deserts, deep river canyons, high snow-covered mountains, flat well-watered fertile valleys, and a coastline with quiet coves and dramatic headlands. Unavoidably, however, the breathtaking scenery goes hand in hand with geologic processes that can be responsible for recurring and destructive hazards.

The long view of geology, or uniformitarianism, recognizes that most geologic processes shaping the topography are remarkably slow and that all of these features can be explained by ongoing natural events. Oregon's landscape is being continuously shaped by crustal plate movement, heavy winter rainfall, and ocean storms.

Are hazardous geologic occurrences increasing in frequency? There is a tendency to suggest that this is the case. In a headlong rush for news items, the media will often pump up any event to catastrophic levels—even when no deaths and only minimal property damage have occurred. Additionally, the wonder of modern communication is such that news stories are pulled in from remote corners of the globe, while 50 years ago they would have been missed or rated only a line in a newspaper.

On the other hand, it is true that the increase in population and the dispersal of populations into some areas previously considered marginal or unsafe dictate that more of these natural disasters will be witnessed than before.

Humans themselves often aggravate disastrous situations by placing themselves in harm's way, and activities such as redirecting rivers, oversteepening slopes, or clear-cutting may create problems. Moreover, development of dwellings and highways is so widespread and growing that natural disasters are much more likely to impact mankind and cause loss of life and property than at any time in the past.



The interrelationship of hazards

The 1964 flood at the confluence of the Pudding and Molalla rivers in the northern Willamette Valley near Canby.

In the Pacific Northwest, natural geologic catastrophes may be placed into five categories: floods, landslides, earthquakes, volcanic eruptions, and tsunamis. All five of these catastrophes have occurred in Oregon within the past century. Quite often the effect of two or more events occurring simultaneously greatly accentuates the destructiveness of the episode. Floods are nearly always accompanied by landslides, mudflows are often a significant part of volcanic activity, and a major quake following a flood results in a multitude of large and small landslides. Earthquakes in coastal areas frequently precede tsunamis.

SURFICIAL HAZARDS

Flooding and accompanying landslides should surprise no one living in the rainy Northwest. Of all the destructive natural phenomena that have taken place in Oregon, floods

At the height of the 1894 flood, the entire business district at The Dalles was under 10 ft of water.

and landslides have been the most costly to life and property. Receding slowly, flood waters can take days to disappear; cleanup of slides that block highways can take months; and buildings on slides can be completely destroyed.

FLOODS

Floods occur when rising waters spill over the established streambed. In western Oregon, the underlying causes are heavy rainfall, unseasonably warm spells, and ensuing snow melt. Rainfall is greatly accentuated by moisture-laden marine air encountering the Coast Range and Cascade Mountains. In eastern Oregon, flooding is directly related to rainfall amounts.

Flood waters rise quickly but retreat slowly. While the flow in stream channels is rapid, runoff on a flat landscape is gradual. Such wide avenues, flood plains, are natural safety valves for periodic flooding. As the looping meanders of a stream move progressively back and forth, water is dissipated across the flood plain. Unfortunately, the level surfaces of floodplains often appeal to those who build roads, highways, and housing tracts; however, this planar topography is deceptive because moving waters can gradually purge the surface of any structure.

Channels within the floodplain are remarkably ephemeral, and course-altering streams can pose problems for houses nearby. Evidence of ancient streambed patterns can be seen, for instance, where glacial debris, borne by Western Cascade fluvial systems, pushed the channel of the Willamette River well off to the west side of the valley. Ancient abandoned channels of the river along Mill Creek as it enters Salem, as well as at Lake Labish where it leaves Salem, show how profound channel displacement can be.

Human efforts to control stream flow often cause more difficulties than are solved. Straightening and deepening meander channels tends to focus stream energy into a narrow line, where previously it was dispersed along miles of meanders. Artificially smoothed channels also greatly speed up the flow, greatly enhancing erosion capacity. Although the placement of riprap along the outside of meander bends may work as a medium-term remedy, it often only delays the inevitable erosion and channel migration.

Prehistoric and historic floods

One of the most far-reaching prehistoric series of floods in the Northwest affected the entire Columbia River drainage from Montana through Idaho, Washington, and Oregon to the Pacific Ocean. A succession of Ice Age dams, between 15,000 to 12,000 years ago, blocked the Clark Fork River in Montana, creating glacial Lake Missoula. As the dams broke periodically, up to 400 cubic miles of water were suddenly released. With an estimated flow of 9 cubic miles per hour, two days would have been needed to empty the basin. From Montana, flood waters raced across the Idaho panhandle and into the Spokane River Valley before spreading into multiple channels throughout eastern Washington. Pouring into the Columbia River, the waters backed up into the Willamette Valley, turning the valley into glacial Lake Allison, before reaching the ocean. Over 40 similar floods took place, permanently molding the topography here. In the Willamette Valley only the tops of the buttes—Mount Tabor, Rocky Butte, Mount Scott, and others—would have been visible. Over 200 feet of water covered present-day Lake Oswego, while Beaverton, Hillsboro, and Forest Grove would have been under a mere 100 feet.

Even though no floods of this dimension have taken place in historic times, the state has been subjected to annual flooding problems since European settlement. Some of these were the Willamette River floods of 1861, 1890, 1964, and 1996, the Heppner flood of 1903, and the Vanport flood on the Columbia River in 1948. In each case, the floods were said to be one of a kind, never to recur. Governor John Whiteaker termed the December 1861 flood on the Willamette "a scourge . . . which has resulted in the loss of immense quantities of property . . . and seriously crippling . . . the agricultural interests of the state."

November 1861 was cold and wet, with snow on the hills of both ranges paralleling the Willamette valley. When this weather pattern occurs, subsequent flooding is frequent. On December 14, a combination of warm winds and temperatures along with copious rains brought up the level of the river, which drains over 11,000 square miles of the eastern Coast Range and Cascades. Since it flows through what has always been the most populous region of the state, the impact on human development was inevitable. Roads were closed and bridges washed out as the water rose steadily with continuing rain and snow melt. Towns situated near the river for the advantages to business suffered extensive damage, although Eugene and cities toward the southern end of the valley experienced less flooding. An estimated 500,000 acres was covered with water with $\frac{1}{3}$ billion dollars in damages, in current dollars.

By contrast, the tragedy that struck Heppner in Morrow County on Sunday, June 14, 1903, was caused by a sudden flash flood that resulted from a heavy storm. Dark clouds in late afternoon brought rain to Willow Creek, a mile or two above the town. The roaring wall of water, funneled down the narrow creek bed, was 200 yards wide. Property loss was placed at $400,000, and 247 lives were lost. Many were saved because a barrier of trees piled up against downtown buildings, catching debris and slowing the water enough to push it back into the Willow Creek bed.

Torrential rains and a rapidly melting deep snow pack on Sunday, May 30, 1948, combined to raise levels of the Columbia River at Portland more than 13 feet above flood stage, threatening people, homes, and businesses along its bank. The community of Vanport was most seriously affected. Built during World War II to house newly arriving workers at the Kaiser Company shipyards in Portland, it had quickly grown to be Oregon's second largest city.

In this view to the west at the business district, up to six feet of water from the Willamette River covered Oregon City during the 1964 flood.

Even though situated on low ground between old meanders of the Columbia, Vanport was thought to be protected by dikes. But a 10-foot-high wall of water broke through an earthen barrier that was 75 feet across at the top and 125 feet wide at the base. The low-lying slough was saturated, and residents had 30 to 40 minutes of warning to escape with whatever they could carry. Fifteen people were killed. Some of the housing was later reoccupied and used for a time. Today the Portland International Raceway and the Multnomah County Expo Center are on the site.

Tualatin shows water still standing five days after the rains of the 1996 flood. Photo courtesy of Scott Burns.

It is possible that these historic floods may never recur, but statements made in 1861 about "the greatest flood known" have been repeated more recently in reference to contemporary events. Memories of previous floods fade quickly, even though the combination of abundant rains, warm temperatures, and melting snow occur almost annually. In 1996, news media and state officials underestimated the flood potential, expressing surprise at how fast the water rose.

February 1996 was called "the winter from Hell" by many who experienced the flooding. Once again, dangerous weather conditions brought rivers up over their banks. The Cascades snow cover of 200 inches was reduced to 50 inches in two weeks by warm temperatures. After a succession of storm-weather systems, the Columbia and Willamette Rivers began to rise. As rain fell without letup, water from tributary streams overwhelmed main channels. At the height of the event, 29 rivers were above flood level in the Willamette Valley and coastal region. The Columbia crested at 27.6 feet and the Willamette at 35 feet.

The entire state was involved in the 1996 floods. In Portland, the Burnside and Steel bridges were closed. A number of sections of Interstate 5 as well as highways near Vancouver, Lake Oswego, and Canby were blocked by mud. In low-lying Tillamook County, there was a large loss of livestock. Six

Bent railroad tracks and blocked coastal road at Mapleton, Oregon, reflect the power of a mudflow there in 1964.

blocks of downtown Corvallis were under water, and 1,000 families were evacuated. The Mapleton highway was blocked by sliding debris. Homes and businesses at Oregon City were evacuated. Interstate 84 west of Cascade Locks was closed by two major landslides, one 300 yards wide. Even as cleanup was taking place, a third slide tumbled down the unstable slope. In eastern Oregon, rain-swollen streams washed out roads and isolated families and even entire communities as highways in Wallowa County were covered by mudslides.

A recurring hazard of the flooding was from sewage treatment plants located near waterways. As lines were broken or water rose over the tanks, vast amounts of raw sewage were discharged into streams. Disabled plants in Milwaukie and Oregon City sent over 30 million gallons of sewage daily into the Willamette. Similar situations took place at Salem, McMinnville, and The Dalles.

In all, 22,000 people were evacuated and six were killed. In Oregon, 18 counties were declared disaster areas, along with 13 in Washington, making them eligible for federal aid.

The question to be asked is with the placement of multiple dams altering stream-flow, why do destructive floods still occur? Historically, dams have been considered to be one of the "solutions" to flooding. In spite of a network of dams throughout the Northwest, flooding continues. It is informative to compare the flood levels of February, 1996, after dam construction, with those of the previous century, when there were fewer dams. Willamette River waters reached 35 feet above flood stage at Salem during the 1996 floods, 37.8 feet during the 1964 floods, and 37 feet in 1861. If the extensive dam construction projects of the past 135 years do not halt flood waters, perhaps it is time to reexamine the whole program for controlling streamflow.

LANDSLIDES

Landslides are the downslope movement of rock, soil, or related debris. Geologists use the term "mass movement" to describe a great variety of processes such as rock fall, creep, slump, mudflow, earth flow, debris flow, and debris avalanche. In most mass movement, water plays a pivotal role by assisting in the decomposition and loosening of rock, lubricating rock and soil surfaces to enhance the beginning of movement, adding weight to an incipient landslide, and imparting a buoyancy to the individual particles, which helps overcome the inertia to move. The composition of slides is also very important, and the proportions of rock, sand, clay, and water will dictate the initiation, speed, and areal extent of each slide.

Although landslides are propelled by gravity, they can be triggered by other natural geologic disasters or human activity. Volcanic eruptions and earthquakes can initiate earth movement on a grand scale. A variety of mudflows called a "lahar"—a mixture of volcanic ash and water—is specific to volcanic activity. Indeed, lahars are often the major hazard experienced in a volcanic episode. Although earthquakes can initiate mudflows, the major causes of landslides in the northwest are continuous rains that saturate soils.

There can be no doubt that mud and debris flows are frequently the direct consequence of human activity. Seemingly insignificant modifications of surface flow and drainage may induce landslides, and once the slide is established, it will continue to move over remarkable distances.

The placement of buildings, to capture a spectacular view, on slide-

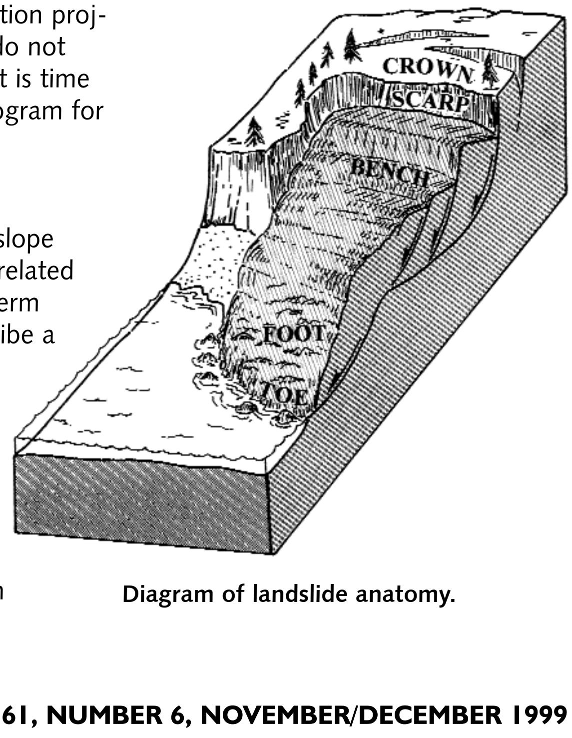


Diagram of landslide anatomy.

Both scenes in the southern Willamette Valley near Sweet Home show how clear-cutting initiates landslides. The rumpled appearance of the slope behind the house is a shallow earth-flow above bedrock that began to slide shortly after the trees were removed.

prone coastal dunes, eroding headlands and sand spits, or at the edge of a receding shoreline, may lead to the loss of the structure. It has been noted that in Portland, population pressure has pushed construction into many areas and sites previously rejected as landslide-prone. In an urban setting, improper drainage most often induces disastrous sliding.

Agricultural irrigation and forestry practices such as clear-cutting and stripping vegetation from naturally oversteepened slopes have been shown to be responsible for a spate of landslides. Highway construction on similar slope conditions awaits only the first good rain to provoke earth movement.

During the floods of 1996, most of the 250 landslides in the Clackamas River watershed and 75 percent of the slides in the Mount Hood National Forest were in logged-over lands or those criss-crossed by dirt logging roads.

Research on slides in relation to clear-cutting in the Pacific Northwest over the past 30 years documents a direct causal relationship. A 1996 Forest Service study of 244 slides found 91 instances of mass movement on logged-over lands, 93 in association with roads, but only 59 in undisturbed forests. The combination of both logging and road-building increases slide frequency five times over a twenty-year period when compared to undisturbed forested lands.

Forestry regulations, modified in 1997, address only those logging or road-construction operations where there might be a risk to human life from landslides or debris flows, as opposed to considering the overall environmental picture.

One characteristic of landslides is that virtually all unstable and movement-prone slopes can be recognized, so mass movement should not be totally unexpected. Tip-offs to incipient hazard-prone slopes include scarps, tilted and bent ("gunstocked") trees, wetlands and standing water, irregular and hummocky ground topography, and oversteepened slopes with a thick soil cover. The technology of spotting landslides by use of aerial photography has become so refined that NASA routinely recognizes and maps mass-movement features on several of the planets in our solar system as well as on our own moon.

Prehistoric and historic landslides

Even though landslides are not restricted to any one part of Oregon, most are triggered by erosion or water-saturated soil in the Coast Range, the Willamette Valley, and, to a lesser degree, along the Columbia River.

The geologic history of the Columbia Gorge is closely linked to the Missoula floods between 15,000 to 12,500 years ago. The raging torrents purged the lower canyon wall of soils and rock, leaving over-steepened slopes and erosion, conditions that contribute to landslides.

Historically, the Columbia River Gorge was the scene of massive slides that took place around 300 years ago—the same time as the last great subduction earthquake. Remnants of this immense earth flow can be seen today between Bonneville Dam and Cascade Locks. Before waters of the dam covered the debris flow, the rapids created by water flowing over the rock and soil of the landslide, were a noted feature to the Indians and a hindrance to early pioneers.

The Bonneville slide, which covers 14 square miles, flowed into the Co-

The Royce home still sits on its foundation, surrounded by a rock garden of flow debris. Looking out of a back window, Ms. Royce saw a line of huge rocks rolling toward the house at about five miles per hour. She and her husband barely escaped before mud from the flow poured into the house and filled most of the lower floor. Photo courtesy of Scott Burns.

lumbia channel from the north, pushing the river southward and creating a 200-foot-high obstruction that temporarily blocked the flow. That land bridge from present-day Oregon to Washington may have been the origin of the Indian legend of the Bridge of the Gods.

Today the distinctive hummocky surface of low, rounded mounds and shallow depressions is a hallmark of slides in the Gorge between Vancouver and Bonneville Dam. In this area, older ash and mudflow layers lying beneath the Columbia River basalts erode easily. Landslides are not uncommon, most flowing from north to south into the river.

Upriver at The Dalles, the clay-rich Dalles Formation atop the Columbia River basalt is responsible for most of the slides. Water accumulates between the two formations, and acts as a lubricant to send a thick soup of rock debris into valleys and streams. In addition, The Dalles has been disrupted by slides that are slow but ongoing. The wide meander of the Columbia River, where the town is presently situated, was eroded during the Missoula floods, predisposing the terrain to landsliding. Hazardous conditions were then accelerated by human activity such as housing, roads, increase in water runoff from paved areas, and irrigation of lawns and orchards.

Because it was moving so slowly, the ongoing landslide was not noticed until 1977, when a study by the Oregon Department of Geology and Mineral Industries (DOGAMI) reported bent water mains and sewer lines, distorted sidewalks and roads, as well as structural damage to houses. Several buildings were retrofitted for support, while others, as The Dalles Junior High School, had to be abandoned.

The Oregon coast is the scene of ongoing landslides, which can be directly correlated with erosion by high winter waves and increased rainfall during the major storms of January and February. Storm surges have caused considerable coastal damage by eroding sand and cutting away at headlands, which leads to sliding.

Once again, human intervention has been responsible for altering beach processes and changing patterns of deposition and erosion. Considerable money and effort have been expended to halt coastal erosion, which in places carries away as much as two feet per year. Much of the problem can be attributed to a poor understanding of coastal processes. Sea walls and riprap, as well as housing on sand spits and headlands, quite often result in effects opposite those desired.

Examples in the historic record are numerous. A jetty constructed on the northside of Tillamook Bay restricted the flow of sand down the coast to Tillamook Spit, where the community of Bay Ocean had been built in 1910. A post office, indoor pool, hotel, bowling alley, and 59 homes had been placed on the unconsolidated sand, which began to disappear in less than a decade. Retreating at around 50 feet per year, the spit was breached in 1939, and the community destroyed by 1940.

A large landslide in Tillamook County blocked 600 feet of Highway 6 on April 4, 1991, with 500,000 cubic yards of rock and soil partly damming the Wilson River. This highway has been closed annually by mudslides or rock-falls, and the 1991 episode took nearly two months for debris removal at a cost exceeding $2 million. The slide occurred when soils on the steep slope became saturated from nine inches of winter rain in two days. Cracks appeared along the upper planar slide and permitted infiltration of runoff to satu-

The community of Bay Ocean, constructed on a spit in Tillamook County, was completely destroyed by erosion.

rate soils. The soil liquefied immediately before movement. When the event took place, the slide was being monitored, and an attempt was being made to drain the slide block.

A similar long-standing problem exists in Curry County, where a section of coastal Highway 101 is periodically closed by landslides. Sliding began in 1938, when the roadway was newly constructed, and is still ongoing. In response to heavy rainfall, a debris flow took place on March 23, 1993, and blocked the highway for two weeks until a bypass was constructed. A number of measures had been tried over the years to control the slide, including drains and re-grading the surface, but none were effective. More recently, increased knowledge of landslide behavior prompted the installation of a horizontal drainage system, which was able to decrease dramatically the amount of movement during the stormy winter of 1996.

A currently active landslide at The Capes, in Tillamook County near Netarts, was first noticed in 1997 by local home owners. A small slope failure on the seaward side of a steep hill indicated that minor but steady movement was accelerating. The slide began with small problems when a stairway to the beach was damaged and had to be removed. Ground cracks opened, and lawns dropped vertically some 18 inches in January 1998. Five more feet of drop were added a few weeks later, and fresh slumping was visible downslope.

The main area of movement is presently 900 feet long and 500 feet wide, endangering 10 houses, with 10 more at risk. Because the slide is now moving so rapidly, assessment of hazards is ongoing.

The situation at The Capes could have been easily prevented if an existing geologic assessment had been used by planners and developers. The landslide is an old structure that cuts through a 100-foot-thick body of Holocene (less than 10,000 years old) dune sand lying over muddy debris and, together with it, filling an ancient valley. Groundwater saturated the valley lined by the impermeable muds, but a contributing factor to reactivation was the erosion of a high modern dune which had supported the toe of the landslide.

On the Wilson River in Tillamook County, a 1991 landslide completely covered Highway 6 and dammed the stream. Clean-up took two months. Photo courtesy of Oregon Dept. of Transportation.

South of Tillamook Bay, steep cliffs at Cape Meares, Ecola State Park, and Newport have been subject to continuous wave erosion and landsliding. Cape Meares in Tillamook County was cut back 350 feet between 1930 and 1960, and in 1961 a mass of 125 acres at Ecola State Park in Clatsop County was carried downslope at a rate of three feet per day. Over a two-week period, much of the debris entered the ocean. At Newport in Lincoln County, coastal sliding that began in the 1920s accelerated during the middle 1940s. Roadways, drain pipes, and 15 houses were moved seaward. At present, storm waves are carrying off the mass of debris, which will eventually disappear.

Erosion of dune sand at The Capes development led to landsliding which endangered homes.

In the Willamette Valley, landslides resulting from a combination of heavy rain, steep slopes, and thick soils are especially costly in this most populous region of Oregon. Portland in the northern valley, Salem in the central area, and Eugene to the south furnish good examples of ongoing sliding as well as the potential for hazardous future earth flows.

During the intense rains of February 1996, Portland officials estimated there were 168 slides, 90 percent of which were in the West Hills. Almost 40 homes were rendered uninhabitable, and total damage to public facilities alone was $33 million. Supersaturated soils, steep slopes, and natural water drainage diverted by streets and gutters, sent the soil downslope during the February storms. Most slides in the West Hills take place in the Portland Hills Silt, a wind-blown loess deposit dating from dry intervals of the Ice Ages.

Southwest of the Salem downtown area, large tracts of the Salem Hills, zoned for future development, are of concern because of slope instability. Hummocky topography, an indicator of slumping ground, as well as recent slides during heavy rains, are clear warning signs of conditions unfavorable to construction. A 1999 study of soil movement in the Salem Hills, carried out by DOGAMI, identified many areas of high risk. Both rainfall and earthquakes were considered as factors that could induce sliding. Slope topography—whether gentle, moderate, or steep—was indexed and compared to the rock/soil composition in order to identify and map localities where hazardous conditions might be present. In addition to assessing potential hazards, the study also developed mitigation plans.

Beginning in 1922, the Jump-off Joe landslide at Newport in Lincoln County moved dramatically in 1942. Despite its known instability, attempts to build houses here have been made as late as the 1960s and 1970s.

During 1997, work in the Eugene-Springfield area by DOGAMI and the U.S. Geological Survey showed that despite warnings, housing construction on unstable hillsides was increasing dramatically. After the 1996 rainfall, large earth and rock masses in the South Hills slumped off below dwellings placed on steep slopes. To avoid such hazardous situations, a map by the two agencies identifies soil and slope properties and possible earthquake scenarios for the area.

Remedies for landslides in urban areas are rarely easy or inexpensive. Most of the slides are shown to be

(Continued on page 143)

Both houses in Portland were damaged by the 1996 floods and subsequent landslides. The white house on Fairview Street is threatened by sliding on the adjacent vacant lot. The land movement here is due to runoff from the road above. A sheer wall of Portland Hills Silt can be seen at the top of the slide, while the toe has moved onto the road. The three-story house with the failing foundation has rotated as a result of sliding. Situated on the toe of an ancient landslide on Bull Mountain in Tigard, mass movement was reactivated by the 1996 floods. Incredibly, today new houses are being placed on the same slide surface. Photos courtesy of Scott Burns.

PLEASE SEND US YOUR PHOTOS

Since we have started printing color pictures on the front cover of *Oregon Geology*, we are finding ourselves woefully short of good color photographs showing geologic motifs in Oregon.

We also want to make recommendations for scenery well worth looking at in a new series of black-and-white photos on the back cover of *Oregon Geology*. For that, too, your contributions are invited.

Good glossy prints or transparencies will be the best “hard copy,” while digital versions are best in TIFF or EPS format, on the PC or Mac platform.

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Conclusions and opinions presented in articles are those of the authors and are not necessarily endorsed by the Oregon Department of Geology and Mineral Industries.

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(Continued on next page)

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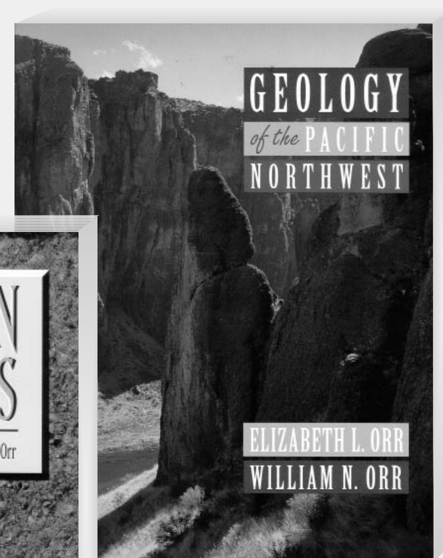
Allow 2 weeks for delivery on all maps plotted on demand.

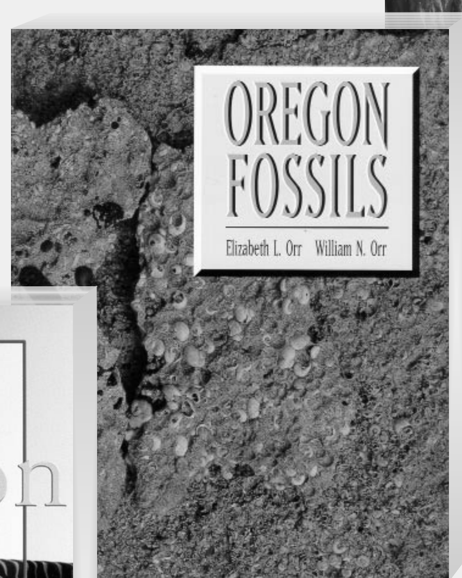
Highlighting Recent Publications

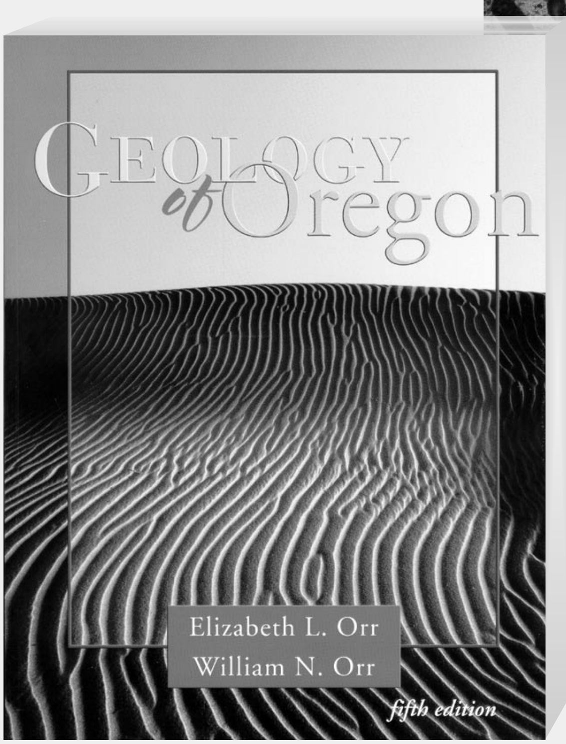
now available from The Nature of the Northwest Information Center

Elizabeth and William Orr, the authors of the article in this issue, have contributed much to our knowledge of the geology of Oregon and the Pacific Northwest. Their most current books are featured here.

Geology of the Pacific Northwest, published 1996 by McGraw-Hill, represents the first major update of Pacific Northwest geology since the 1972 book *Cascadia* by Bates McKee. It reflects the growing understanding of tectonic plate movements and particularly accretionary events and how they shaped our region. Expanding our view beyond the Geology of Oregon, it includes British Columbia, Washington, and Idaho.







Oregon Fossils, published 1999 by Kendall/Hunt, grew out of the Orrs' 1981 *Handbook of Oregon Plant and Animal Fossils* and a 1984 *Bibliography of Oregon Paleontology*. A comprehensive overview, which also tells of the major events and people involved.

Geology of Oregon, 5th edition, published 1999 by Kendall/Hunt, revises and updates the out-of-print 4th edition. The latter had been coauthored with Ewart Baldwin, sole author of the first three editions published between 1959 and 1976. The new edition adds color photos (13, on 8 pages), fills four previously blank pages or spaces with more black-and-white photos, and updates illustrations modeling the possible plate-tectonic history of the Cascade and Coast Ranges.

All three books are intended for both amateur and professional readers and are richly illustrated. You will find them listed on the previous pages under "Miscellaneous Publications."

(Continued from page 138)
ancient structures that have been reactivated by careless land use practices, and once a serious landslide has been activated, ten or more years of effort can go into arresting the flow.

TECTONIC HAZARDS

Earthquakes, volcanic eruptions, and tsunamis in the Pacific Northwest have recently had ample press coverage. Yet, they are relatively rare in modern times and therefore have not caused as much damage here as floods and landslides. In the public mind, however, the destructive power these tectonic hazards have occupies a position of major importance—and with good reason.

Earthquakes

Earthquakes are seismic shock waves generated by breaks in the earth's crust. Striking without warning, quakes are among the potentially most catastrophic of geologic processes, destroying property and killing on a vast scale. Deaths are primarily due to falling structures or landslides, while fires, started by the quake and fed by rubble, contribute to the devastation.

Most large quakes in the Pacific Northwest can be classified as either crustal shear, tensional, or subduction earthquakes. Crustal shear quakes are induced by stresses set up near the edges of large juxtaposed blocks moving in different directions. The magnitude (M) of crustal shear earthquakes may be up to M 7, and the duration is usually less than a minute. Tensional quakes relate to extreme stretching of the crust, and they can reach M 6.5.

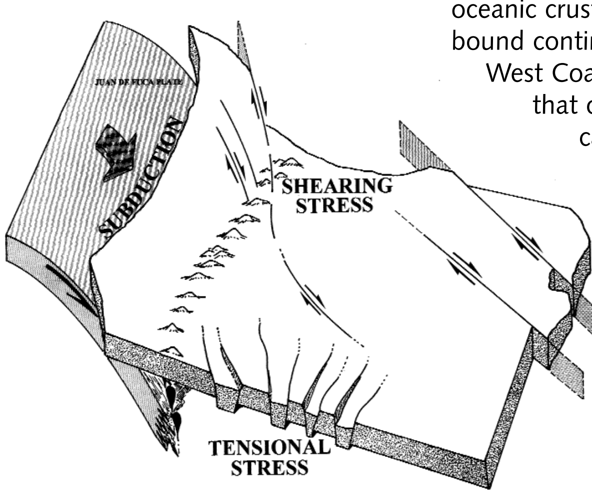


Diagram showing different types of stresses that characterize the main types of earthquakes in the Pacific Northwest.

Subduction quakes, where crustal slabs are overriding each other at collision boundaries between plates, are far more destructive with magnitudes reaching 8.0 or even 9.0 and a duration of three or more minutes. Major quakes of this nature fortunately take place centuries apart, and Oregon's geologic history suggests an irregular 300-year to 500-year cycle.

The recognition that the Pacific Northwest is subject to massive subduction quakes came only recently as the result of excellent scientific work. During the early 1980s, emerging evidence suggested that the subduction process along the Pacific Northwest margin—far from being gradual and benign—might be catastrophic in nature. Data from coastal soil and sediment profiles, liquefaction, large-scale landslides, and even deep-ocean drill cores showed a clear record of intermittent but devastating quakes.

When the Cascadia subduction system—young, warm, buoyant oceanic crust sliding beneath a westbound continental mass along the West Coast— was compared to that of Chile in South America, startling similarities emerged. In Chile, the configuration of a sediment-filled trench, an uplifted coast range, an interior valley, and a volcanic chain further to the east mirror that of Oregon's Coast Range, Willamette Valley, and Cascade Range. Most disturbing is, of course, the seismic history of Chile whose M 9.5 quake in 1960 was the largest of the 20th Century.

Prehistoric and historic earthquakes

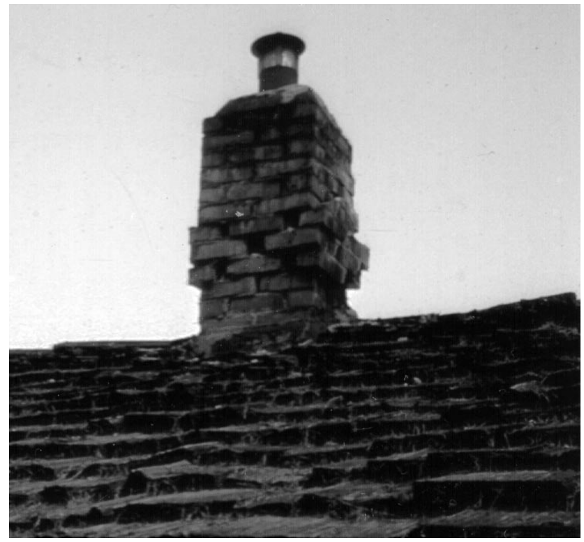
Compared to California and Washington, earthquakes in Oregon are infrequent. Of the approximately 33,000 historic quakes recorded in the Pacific Northwest, 26,000 took place in Washington and 7,000 in Oregon. Most were less than M 3.0.

The lack of historic records for quakes is misleading, due, in part, to the fact that Oregon's recorded seismic past goes back only about 175 years. No subduction earthquake has occurred since the European settlement of the Pacific Northwest.

Off the West Coast, the Juan de Fuca slab is subducting beneath the overriding North American plate. It is thought that the subduction process here is characterized by periodic binding of the two plates, causing the overlying slab to arch upward. When the plates release, the event is accompanied by a massive seismic shock and very rapid depression of large tracts of the coast.

By looking at the record of subsidence as seen in buried coastal marshes, earthquake events can be chronicled. Depth, stratigraphy, and radiocarbon dates of buried forests and peat layers at seven estuaries covering over 100 miles of the Oregon coast were compared, from Necanicum River in Clatsop County to South Slough in Coos County. The comparisons were then used to calculate the degree of subsidence produced by the quakes, the magnitude of the quakes, and the interval of time between events. Estimates are that Cascadia subduction margin quakes of at least M 8.0 took place over a time span from 2,400 to 300 years in the past, recurring at an average of 400-year intervals. Additional studies of late Pleistocene coastal terraces from Seaside to Gold Beach substantiate this record.

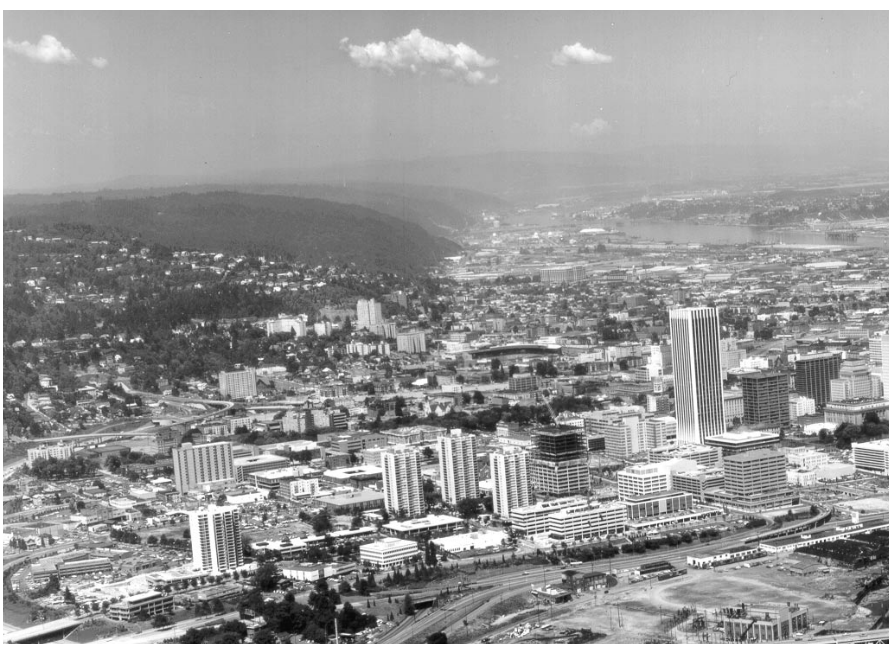
A similar record has been exposed at sites in the Columbia Gorge showing soil liquefaction from a 300-year-

Chimneys, usually built of unreinforced masonry, show the most common type of damage caused by the 1993 Scotts Mills earthquake. Photos show house near Molalla on left and roof of authors' home near Scotts Mills (right). Photos courtesy of Doug Eaton.

old earthquake. In contrast to other studies, these localities were plentiful but indicated a fairly low intensity for the event.

In historic times, the Port Orford-Crescent City earthquake of November 23, 1873, was the strongest to shake Oregon. The shaking from the M 8.0 event was felt from San Francisco to Portland. There were no aftershocks, which leads to the conclusion that the quake originated offshore either from a crustal fault or from the Cascadia subduction zone.



Two major north northwest-trending faults slice across Portland. The Portland Hills fault to the left is marked by the straight northeast margin of the foothills, while across the Willamette River, the parallel East Valley fault is buried beneath alluvium and fill. Photo courtesy of Delano Photographics.

The historic record on earthquakes in Portland and the Willamette Valley is far too brief for a complete seismic picture. However, from 1846 to 1993 there have been clusters of earth tremors roughly every five to 10 years. Most of these were moderate to slight and centered over a region from Woodburn northward to Vancouver.

Portland could be struck by either a shallow crustal shear earthquake along the north-northwest trending Portland Hills-Clackamas River fault zone or by a shock wave from the deeper Cascadia subduction system. In the case of either type of earthquake, the Portland metropolitan center will experience considerable ground shaking. Research aimed at specific sites here postulates that soils and unconsolidated sediments downtown would be more severely affected than deeper soil profiles at the Marquam Bridge and Portland Airport.

Coming as a complete surprise to most people, including geologists, the M 5.6 Scotts Mills quake of 1993 was one of the strongest events in Oregon's recorded history. Because it was so unexpected, it should be seen as a warning that fu-

The huge boulder above was dislodged and fell on Highway 140 west of Howard Bay at Upper Klamath Lake during the 1993 Klamath Falls earthquake, which also produced a rotational slump and its associated crescent-shaped cracks in the roadbed nearby (right).

ture seismic events could be equally unforeseen. It is probably fortunate, in this case, that the epicenter was in a remote area, approximately three miles east of the small community of Scotts Mills in Clackamas County.

The Scotts Mills quake originated at a depth of 12 miles, whereas the February 24, 1999, earthquake at Molalla in Clackamas County was almost twice that deep, at 22 miles. Although it only measured M 2.7, the Molalla quake was felt over an extremely wide area from Vancouver to southern Linn County.

Although no ground cracking, landsliding, or soil liquefaction was visible on the surface following these earthquakes, nearby population centers of Woodburn, Mount Angel, and Molalla, as well as Newberg and the State Capitol Building in Salem suffered considerable damage during the Scotts Mills event, while only minor loss resulted from the Molalla quake.

The Scotts Mills quake was caused by crustal movement along the Mount Angel fault which runs from west of Woodburn toward Scotts Mills. On the west side of the Willamette River, the Gales Creek fault is part of the same north-northwest trending structural zone near Newberg. An earlier series of small earthquakes in 1990 close to Woodburn as well as the Thanksgiving Day quake of 1999 indicate that the activity along the Mount Angel fault is ongoing. This zone, as in the case of the Portland Hills fault zone, consists of faults caused by right-lateral movement (i.e., looking across the break, a viewer would see the block on the far side move to the right).

By contrast, the earthquake that struck Klamath Falls on September 20, 1993, was the strongest so far measured in the state and the strongest since the 1873 Port Orford-Crescent City event. Two main shocks at Klamath Falls, centered near the Mountain Lake Wilderness southwest of Upper Klamath Lake, were followed by 16 smaller tremors and then the largest tremor at M 6.0. Surface evidence of the event included ground cracks, and landslides. Two people died, one whose car was struck by a boulder and another of a heart attack. Over 1,000 buildings were damaged, but because it was even further from a population center than the quake at Scotts Mills, overall property damage was less.

Dramatic north-northwest scarps mark a zone of tensional quakes in south-central Oregon where normal faults (i.e., the viewer would see one block move downward relative to the other)—are part of the Basin and Range system. In this province, the earth's crust was stretched as much as twice its original width, before failure produced faulting.

A similar tensional fault and quake in the Warner Valley in Lake County on June 4, 1968, registered M 4.7, but little damage was evident other than fallen chimneys and foundation cracks.

Seismic processes have been studied even east of the Cascades, away from the population density of the Willamette Valley. Numerous quakes in the range of M 2.0 to M 3.0 have shaken open cracks in plaster and chimneys in the Deschutes valley, near Baker City, and at Hermiston. Stronger shocks causing more damage measured M 4.8 northeast of Maupin in Wasco County on April 12, 1976, and M 7.0 near Milton-Freewater on July 15, 1936.

At Milton-Freewater, large ground cracks, some 300 feet long and six feet wide, along with marked changes in the flow of local well water were noted. In some cemeteries a number of the head stones moved, and many houses were badly damaged.

The Oregon Legislature passed a law in 1993, requiring that sites for public-use buildings such as hospitals and schools be evaluated for soil and slope stability, and building codes were subsequently revised. In 1999, DOGAMI released earthquake hazard maps for several coastal communities. These maps analyze potentially hazardous conditions that might increase damage and risks from earthquakes. In 2000, the department will release maps for many of the urban areas in western Oregon.

VOLCANOES

Volcanoes, like most earthquakes, are related to tectonic plate motion. Since the eruption of Mount Lassen in 1919 and Mount St. Helens in 1980, most Northwesterners have accepted intermittent volcanic events as part of life here.

Volcanoes bring about a diversity of hazards to human culture, including clouds of hot gasses carrying rock and sand, blast effects, ash falls, and mud flows. On the positive side, it can be said that, unlike earthquakes, volcanoes generally give plenty of warning that they are awakening, although the actual moment of eruption may come as an unpleasant surprise.

More than any other single event in this century, the May 18, 1980, eruption of Mount St. Helens brought the reality of geologic hazards to the public's awareness. Photo courtesy of U.S. Geological Survey.

Following an eruption, ash may take weeks to settle from the air. This fine powder is quite harmful to lungs and incredibly abrasive to moving parts of any machinery or engine. The weight of wet ash can collapse a building.

A most sensational aspect of a volcanic eruption is the *nuée ardente* or fiery ash flow. In this event, superhot, burning gas is suddenly pumped into the air to fall back to earth as a heavy cloud and move across the landscape at hundreds of miles per hour, immolating everything in its path. Even though these ash flows were known to geologists, they were only rarely witnessed and not filmed until the 1980s, when they were captured on videotape in Japan. In 1902 over 30,000 people in the village of St. Pierre on Martinique were incinerated by a *nuée ardente*, and more recently the island of Monserrat experienced the same phenomenon, fortunately without loss of life. In Oregon, deposits from ash flows are a frequent part of the geologic record east of the Cascades.

Mount St. Helens displays the debris avalanche and mudflow deposits that supplemented the blast effect of the eruption. Photo courtesy of U.S. Geological Survey.

Before the 1980 Mount St. Helens episode, the incidence and impact of lateral eruptions was poorly understood. During this event, the northeastward blast knocked down trees and increased the damage significantly. Since then, it has been found that lateral blasts are not uncommon in Cascade volcanoes. An urban center in the path of such a force would be totally devastated.

Prehistoric and historic volcanic eruptions

In the Cascade volcanic chain, that extends from Lassen Peak in northern California to Meager Mountain in British Columbia, over 3,000 large and small volcanoes have erupted during the past five million years. Within the vicinity of Portland alone, close to 50 volcanoes erupted more than half a million years ago. Between 1843 and 1860, a series of 21 eruptions took place in the Cascades, and there is speculation that the Northwest may be entering another period of volcanic activity.

The Cascade peaks in Washington and California have erupted more recently than those in our state. Mount Hood has erupted three times over the past 2,000 years. Flows of hot ash, rock, and mud poured down the southwest side of the mountain near Crater Rock about 1,400–800 years ago, 600–400 years ago, and between 1760 CE and 1800 CE. In each event, lava reached the surface through vents, accumulated, then collapsed, sending streams of the hot debris downslope. Melting snow combined with lahars of ash, lava, rock, and mud to travel along the Sandy, Zig-Zag, and White Rivers, burying forests upright.

Predictions about future eruptions of Mount Hood have been based on observations of volcanism elsewhere. Warning times from as little as a few hours to as long as one year have been suggested as needed; but a system of seismometers, located on the mountain and recording present-day tremors, should give adequate advance notification for civil evacuation. As during earlier eruptions, molten material and an ash cloud could be expected to affect the same river valleys, and the projected hazard zone could extend to the communities of Hood River, Sandy, and Zig-Zag.

Across the Columbia River in Washington, the eruption of Mount St. Helens on May 18, 1980, devastated a wide area of the Northwest. The destruction shocked people living here and made them realize that such a violent event could easily recur.

Mount St. Helens gave substantial warning that it was to erupt. About two months prior, small earthquakes were detected by a network of seismographs, and a minor eruption on March 27 opened a summit crater. These were followed by a M 5.1 earthquake that triggered massive landslides on the north slope and brought about the rapid release of pressure on the superheated interior of the cone. The ensuing eruption took off the upper 1,300 feet of the peak. Lahars of melted snow, ice, and hot rock combined to descend the side of the volcano, and a visible plume of airborne ash was carried as far east as Denver, Colorado. Powdery gray ash fell eastward to Spokane and later south to the Willamette Valley.

About 7,000 years earlier, the eruption of Mount Mazama—now Crater Lake—in southern Oregon was more violent and would have been spectacular to any one viewing it. During the Pleistocene Epoch, over 400,000 years ago, numerous early eruptions spread individual flows of lava up to 30 feet thick. After an extended period of cone building, the stratovolcano exploded with clouds of ash and fiery debris that would have covered the present-day city of Bend six inches deep. Ash layers would also have accumulated on what is now Portland and the Willamette Valley. After about six cubic miles of magma had drained from the subterranean chamber, the roof collapsed into the caldera, removing approximately 2,000 feet from the mountain top. Today the beautiful blue waters of Crater Lake occupy the collapsed volcano.

Warning signs of a possible volcanic eruption such as earthquakes, swelling, heat flow, tilting, and gas plumes need to be monitored. If a volcano shows signs of increased activity, people should be alerted and plans announced for evacuations, whenever necessary. Available maps of volcanic hazardous zones should be rated for potential danger so that local, state, and federal authorities can guide development in these regions.

This idyllic scene in the Hood River valley would be destroyed by a northward lateral blast from an erupting Mount Hood. Photo courtesy of Oregon Department of Transportation.

TSUNAMIS

Tsunamis, the first cousins to earthquakes, can arrive with only slight warning. A tsunami, also called a seismic sea wave, or incorrectly called a tidal wave, travels across the deep ocean at speeds up to 500 miles per hour. A tsunami generated offshore from Japan or Alaska might not hit the Oregon coast for several hours. A tsunami following a Cascadia earthquake may hit in less than 30 minutes.

On the open ocean, a fast moving tsunami might be a wave only three to four feet high, with 100 miles separating wave crests. Approaching the coast, however, the tsunami begins to slow in shallow water, and successive waves bunch up, increasing in height. As the ocean bottom shallows even more, the wave rapidly rises and may break several tens of feet high with incredible destructive power. It has been conjectured that the configuration of the Oregon and Washington continental shelf could produce tsunami waves that would appear to rise slowly out of the ocean but build up to 30 feet or more in height as water is cast shoreward.

If you throw a pebble into standing water, a succession of ripples or waves moves across the water. Similarly, tsunamis almost never come as single waves but arrive as multiple crests that are sometimes hours apart. Often the first tsunami is not even the largest or most destructive, and wave four or five may be the largest of all.

Tsunamis are caused by undersea volcanic eruptions, landslides, or faulting as slabs of the sea floor are displaced vertically. Most commonly, rapid uplift or subsidence of the sea floor along faults is transmitted to the surface of the ocean, forming unusually large waves. Coastal slides from land under the water, also triggered by earth movement, can intensify the effects of tsunamis.

The undersea subduction zone, paralleling the Oregon coast at a distance of about 75 miles, is the junction between the Juan de Fuca and the North American tectonic plates. The two plates lock together, but periodically the stress is released suddenly with a snapping motion, and the resulting shock may trigger a tsunami. Distinctive, thin deposits of shallow marine sands along the coast are physical evidence of these ancient waves.

Prehistoric and historic tsunamis

Most inhabitants of the Pacific Northwest have never experienced a tsunami—in contrast to experiences of flooding, landslides, earthquakes, and even volcanic eruptions.

The past occurrence of seismic sea waves in the Pacific Northwest has come to light with recent research that matches records from Japan with carbon-isotope-14 data from wood buried in tsunami sands on the West Coast. Because the Japanese data are so accurate, exact dates can be given for sea wave occurrences. The date of the last large tsunami, recorded in the sands and correlated with Japanese records, was January

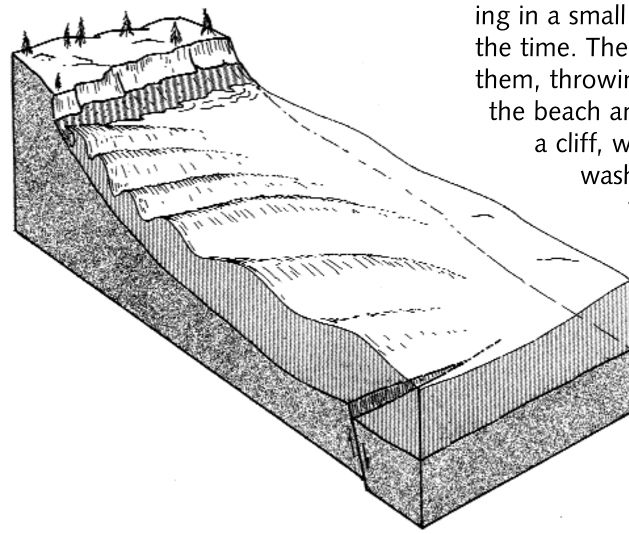


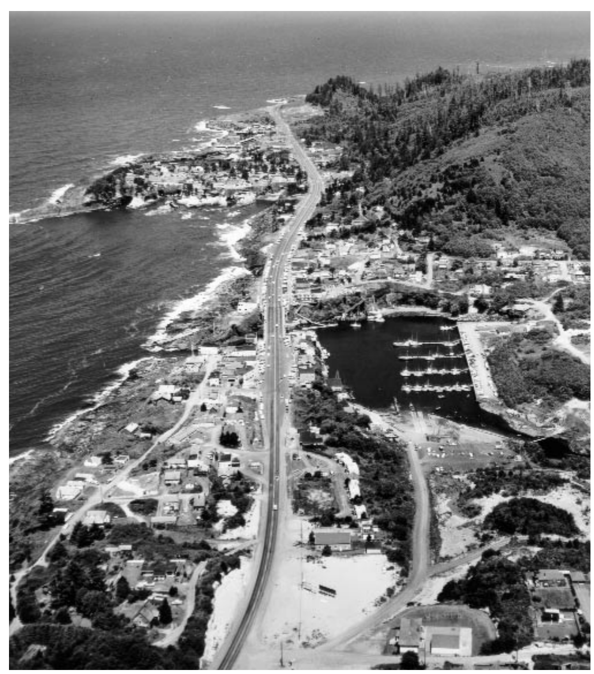
Diagram showing generation of tsunamis.

26, 1700. The earthquake that generated the wave registered M 9, and the ensuing tsunami destroyed coastal villages in Japan.

In Oregon, prehistoric runups (i.e., how high a tsunami wave reaches above mean sea level) can be deduced with numerical methods. From such models, it was concluded that a tsunami that struck Salishan Spit in Lincoln County between 300 and 800 years ago had a runup of up to 40 feet above sea level. It is likely that the same wave probably overtopped a 16-foot-high barrier ridge at Cannon Beach and breached a 20-foot ridge at Seaside.

One of the largest subduction zone earthquakes ever recorded was the M 9.2 quake on March 27, 1964, centered in Prince William Sound, Alaska. This generated a tsunami that struck the Oregon coast at 11:30 p.m. with waves as high as 10 feet, swamping houses, destroying bridges and sea walls, and tragically killing four children. A family was camping at Beverly Beach and sleeping in a small driftwood shelter at the time. The second wave reached them, throwing the mother out onto the beach and the father up against a cliff, while the children were washed out to sea. In March 1999, a plaque remembering the children and providing information about tsunamis was dedicated at Beverly Beach State Park.

A predicted tsunami on the Oregon coast in 1995 turned out to be a barely recognizable small wave, but the effect on local residents was revealing. Hysterical television and radio warnings led to panic as food and bottled water were emptied from grocery shelves and families were hastily thrown into automobiles that sped to higher ground. Other people, driving to the coast to view the event, caused traffic jams that were worse than the natural disaster which never materialized.



Clinging to the coastline, communities such as Depoe Bay, Oregon, would be devastated by a large-scale tsunami, which might give as little as 20 minutes of warning before reaching land. Photo courtesy of Oregon. Dept. of Transportation.

The recently hightened awareness of the potential for a seismic sea wave to inundate the western coastline has caused the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the Federal Emergency Management Administration to initiate a program to upgrade their seismic system in order to predict tsunamis more accurately. As a tsunami traverses the ocean, a network of sensitive recorders on the sea floor measures pressure changes in the overhead water, sending the information to sensors on buoys, which, in turn, relay the data to satellites for immediate transmission to warning centers.

Tsunami maps of the Oregon coast were produced by DOGAMI in response to a bill passed by the 1995 Legislature, limiting construction of new hospitals, schools, and other similar public-service buildings in tsunami flood zones. Additional mapping was begun in 1997 with the establishment of the Center for the Tsunami Inundation Mapping Effort at the Hatfield Marine Science Center in Newport. The maps, as well as offshore detection systems, public education, and evacuation planning, are part of a strategy to save lives and reduce loss from tsunamis. In order to educate and alert coastal residents and visitors to potential risks, interpretive signs have been installed to explain hazards. Blue-and-white reflective signs depicting high waves and a person running uphill are being placed at a variety of locations in coastal communities.

SUMMARY

It is ironic that building is still taking place on floodplains, ocean cliffs, landslide-prone slopes, and at other high-risk sites, in spite of increased knowledge of geologic hazards and a tightening of government regulations. The Oregon Department of Agriculture has even recommended placing a 200-foot-high earth-fill dam on Butte Creek in Clackamas County—on the epicenter of the 1993 Scotts Mills earthquake. On many of the known hazardous slopes in Portland, houses that were destroyed by landslides are being reconstructed or replaced. Most of the decisions pertaining to these practices seem to be made by individuals without any understanding of the hazards and certainly without benefit of trained geologists. The answer to avoiding potentially hazardous situations is research, public education, sensible planning, and rigid restrictions in problem areas.

Ongoing geologic processes that shape Oregon's scenic landscape can also set up hazardous conditions. Regardless of human efforts to the contrary, natural phenomena will have the final word.

ACKNOWLEDGMENTS

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Corvallis as seen from the east. During even minor floods the entire flatland between meanders is usually under water.

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Klaus K. Neuendorf, Editor

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Places to see—Recommended by the Oregon Department of Geology and Mineral Industries:

Shore Acres State Park near Cape Arago in Coos County

A marine terrace borders the Coos County shore for much of the distance between the entrance to Coos Bay and the Curry County line. Rocks on which the terrace was formed differ along the shore, and erosion along this terrace has produced a shore with varied and magnificent scenery. Different degrees of resistance to erosion have allowed the waves to sculpture the terrace into sharp points of land, reefs, islands, secluded coves, and a myriad of smaller forms. Here, near Cape Arago, the terrace is on a sequence of Tertiary sedimentary rocks that are inclined steeply toward the east and cut by numerous fractures. Erosion has shaped a shore that is distinctly different from that of any other part of the Oregon coast. (From E.H. Lund, "Landforms along the coast of southern Coos County, Oregon," a 1973 article in the *Ore Bin*, v. 35, no 12)

The predominant rock unit, the Coaledo Formation, contains an abundance of marine fossils. The park is also home to a famous formal garden and has, on the site of the former owner's mansion, an observation building that is popular for spectacular views and whale watching.

Access: On the Cape Arago Highway, 13 miles southwest of Coos Bay/North Bend and U.S. Highway 101.