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Cover Photo: The front wall of this boating supply store on Harbor Ave SE in Seattle was pushed out by one lobe of a debris flow that initiated on the bluff behind the store and broke through the rear wall. (Also see Figure 3, p. 18.) The other lobe flowed around the north side of the building and came to rest next to the truck (right side of photo).

Major Events Bring in 1997

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Winter weather systems dumped snow on Puget Sound communities. The snow, in combination with the subsequent rain, caused numerous landslides. These landslides resulted in fatalities and extensive property damage. Even larger landslides seem possible from information about the potential for devastating earthquakes and the threat of massive mud flows from Mount Rainier that has been featured in recent newspapers. These kinds of real and potential events remind us all that awareness of a threat from nature is not sufficient by itself. Understanding the geologic conditions, selecting mitigation measures, and implementing emergency preparation plans can reduce future losses.

In this issue of *Washington Geology* is an article by the staff of the Department of Natural Resources and the Department of Ecology about the late December 1996 rain-on-snow events. The article documents the various combinations of topography, geology, and hydrology that, combined with poor land-management practices, have created situations leading to property loss and fatalities.

In the regulatory arena, the final Environmental Impact Statement (FEIS) was issued for the Crown Jewel mine in Okanogan County. When permitted, this mine will counter the economic losses in northeast Washington caused by the closure of the Hecla operations at Republic, Ferry County, and of the Cannon gold mine and mill at Wenatchee, Chelan County. The Notice of Availability was published in the Federal Register on February 7, 1997. In the Record of Decision by the Forest Service and the Bureau of Land Management, Alternative B has been selected. This alternative is for an open-pit mine to operate around the clock to produce 3,000 tons of gold ore per 24-hr period. The ore will be treated in a mill using on-site tank cyanidation. Ore reserves have been calculated at 8.7 million tons with an average grade of 0.186 oz of gold per ton, using a cutoff grade of 0.034 oz gold per ton. A recent upswing in the price of gold has increased the reserve to 9.1 million tons of ore. The appeal period for the Record of Decision for the Forest Service is 45 days from the date of publication (Feb. 3, 1997) and the Bureau of Land Management 30 days from the date of the notice in the Federal Register (Feb. 7, 1997). ■

Recently Released

Assessing earthquake hazards and reducing risk in the Pacific Northwest, volume 1 of U.S. Geological Survey Professional Paper 1560. The volume editors are A. M. Rogers, T. J. Walsh, W. J. Kockelman, and G. R. Priest. Included are articles about earthquake sources, paleoseismicity, evolution of the continental margin, and earthquake focal mechanisms in western Washington. Plate 1 is a map showing known or suspected faults with Quaternary displacement in northern California, Oregon, and Washington at a scale of 1:2,000,000.

The Metallic, Nonmetallic, and Industrial Mineral Industry of Washington in 1996

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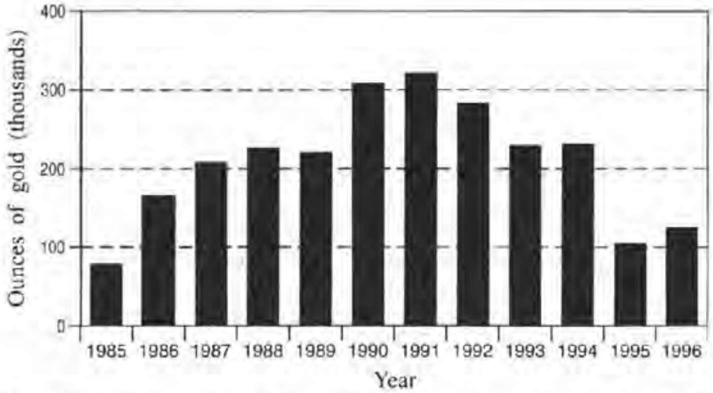

Figure 1. Gold production in Washington, 1985–1996. The decline in gold production reversed in 1996 because of a 24,000-oz increase from Echo Bay Minerals Co., the only known producer in the state. Hecla Mining Co.'s Republic unit and Asamera Minerals (U.S.) Inc. Cannon mine produced only a small amount in the final stages of operations in 1995. The Lone Jack mine did not produce in 1996 due to subeconomic grade ore.

INTRODUCTION

Washington ranked 20th in the nation in total value of nonfuel mineral production in 1995, the last year for which production figures are available. This value, $582,447,000, represents a 5 percent increase over 1994, which occurred for most commodities with the notable exceptions of gold and sand and gravel. The value of gold production decreased by 42 percent in 1995 (Fig. 1) due to closing of mines at Wenatchee and Republic (Derkey, 1996). It increased slightly in 1996.

This article reviews 1996 activities in the nonfuel mineral industry of Washington. Firm production values are not yet available from the U.S. Geological Survey for 1996. Volunteered information obtained from an annual survey of mining companies and individuals provided data for this preliminary update. In addition, several companies and individuals were contacted directly because they were known to be operating in the state. The tables in this article should not be considered a complete listing of mineral industry activities.

Additional details about the geology of the metallic mineral deposits and earlier industry activities in the state are available in the reviews of Washington's mineral industry published in the first issue of *Washington Geology* each year (for example, Derkey and Gulick, 1992; Derkey, 1993, 1994, 1995, 1996; Gulick, 1994, 1995; and Gulick and Lingley, 1993). Questions about metal mining activities and exploration should be referred to Bob Derkey in the Division's Spokane office. Information about the sand and gravel industry and reclamation can be obtained from Dave Norman in the Olympia office. See p. 2 for addresses and phone numbers.

METALLIC MINERAL INDUSTRY ACTIVITIES

About 32 percent of the total value (nearly $582,500,000) of all nonfuel mineral commodities produced in Washington in 1995 came from metal production. When figures become available, the overall value of metal production will probably be lower in 1996.

In this report, activities in the metallic mineral industry are divided into three categories: major mining and exploration projects, small-scale mining and exploration projects, and properties at which the principal activity was maintenance. Location maps are included for the first two categories, and tables are presented for each of the three categories.

Major Metal Mining and Exploration Projects

The locations of the six major metal mines or exploration projects in Washington in 1996 are shown on Figure 2. Table 1 lists the mines and the activity in 1996 and briefly describes the geology of the deposits.

All known precious metal production in Washington in 1996 was by Echo Bay Minerals Co. at their Kettle River Project near Republic in Ferry County. Their gold production increased by 24,000 oz (Fig. 1).

As in 1995, the Kettle River Project was the only major gold mining operation in Washington in 1996. It produced 124,910 oz of gold, up from the 100,419 oz produced in 1995. The head grade increased from 0.212 oz of gold per ton to 0.240 oz of gold per ton. Recovery in 1996 was almost the same as in 1995, 86.5 percent. A total of 601,468 tons of ore was processed at the company's mill near Republic, compared to 547,597 tons in 1995.

Ore for the Kettle River operations was mined from the exhalative/replacement-type Lamefoot deposit (87 percent) and from the epithermal vein-type K-2 deposit (10 percent). The remaining 3 percent of ore processed at the mill came from stockpiled ore of the Overlook deposit, which was mined out in 1995. The nearly 25 percent increased gold production is attributed to higher grade ore from the Lamefoot deposit and increased tonnage at the mill.

Lamefoot (Fig. 2, no. 1; Fig. 3) and K-2 (Fig. 2, no. 2) are expected to be the mainstays of Kettle River operations for several years. The company reports that proven and probable ore reserves at Lamefoot are 1,246,400 tons at 0.185 oz of gold per ton (231,000 oz of contained gold). An additional possible ore reserve includes 108,700 tons at 0.189 oz of gold per ton (20,500 oz of contained gold). The company is conducting an extensive underground exploration program at the mine in an attempt to prove known mineralization can be profitably mined.

The K-2 deposit (Fig. 4), an epithermal vein-type deposit in Eocene volcanic rocks of the Republic graben, was being developed in 1996. The development also determined the reliability of surface drilling. The company reports proven and probable reserves at the mine are 741,000 tons at a grade of 0.188 oz of gold per ton (139,000 oz of contained gold). An additional possible ore reserve includes 173,300 tons at

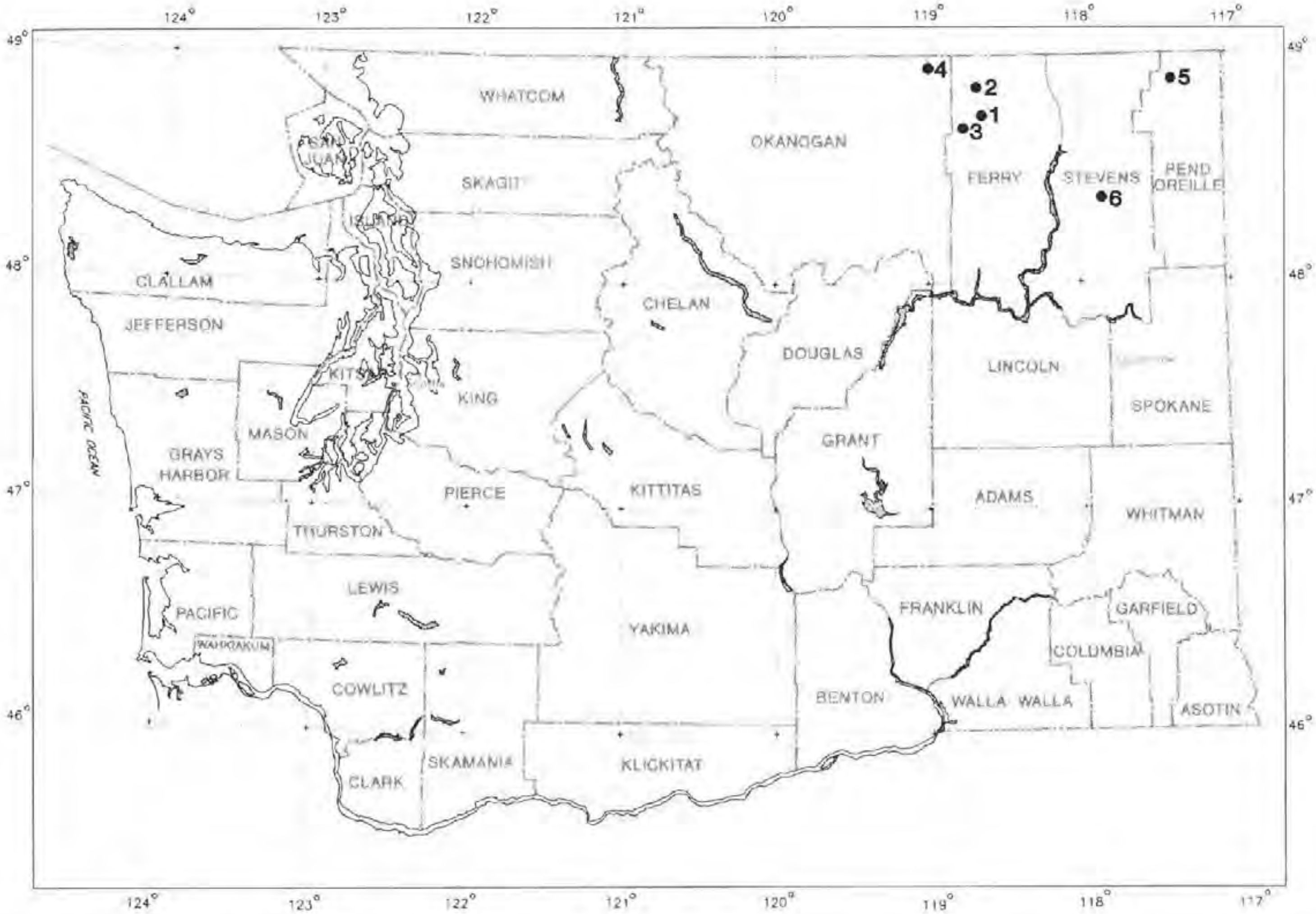

Figure 2. Location of major metal mining and exploration projects in Washington in 1996. Table at right identifies mines from numbers on the map.

No.	Property	Commodities	Location	County
1	Lamefoot mine	Au, Ag	secs. 4, 8, 37N, 33E	Ferry
2	K-2 mine	Au, Ag	sec. 20, 39N, 33E	Ferry
3	Golden Eagle	Au, Ag	sec. 27, 37N, 32E	Ferry
4	Crown Jewel	Au, Cu, Ag, Fe	sec. 24, 40N, 30E	Okanogan
5	Pend Oreille mine	Zn, Pb, Ag, Cd	secs. 10-11, 14-15, 39N, 43E	Pend Oreille
6	Addy Magnesium mine	Mg	secs. 13-14, 33N, 39E	Stevens

Table 1. *(below)* Operator and brief description of the activity and geology at major metal mining and exploration projects in Washington in 1996

Property	Company	Activity	Area geology
Lamefoot mine	Echo Bay Minerals Co., Kettle River Project	Produced 522,300 tons of ore that was processed at the mill near the Overlook mine site	Gold mineralization in massive iron exhalative/replacement mineralization in Permian sedimentary rocks
K-2 mine	Echo Bay Minerals Co., Kettle River Project	Underground development, shipped about 62,500 tons of ore to the mill near the Overlook mine site. Exploration around mine site included 20,000 feet of drilling.	Epithermal deposit in Eocene Sanpoil Volcanics
Golden Eagle	Santa Fe Pacific Gold Corp./Hecla Mining Co.	Santa Fe Pacific Gold Corp. continued drilling of this deposit until February; they then exercised their option and purchased the Golden Eagle portion of Hecla Mining Company's Republic holdings; exploration included leasing of the South Penn property	Epithermal mineralization in Eocene bedded tuff
Crown Jewel	Battle Mountain Gold Corp./Crown Resources Corp.	EIS was released in February 1997	Gold skarn mineralization in Permian or Triassic metasedimentary rocks adjacent to the Jurassic–Cretaceous(?) Buckhorn Mountain pluton
Pend Oreille mine	Cominco American Incorporated	Conducted exploration drilling from the surface and underground exploration drifting and drilling from underground workings	Mississippi Valley-type mineralization in Yellowhead zone of Cambrian–Ordovician Metaline Formation
Addy Magnesium mine	Northwest Alloys, Inc.	Mining dolomite, smelting to produce magnesium metal	Cambrian–Ordovician Metaline Formation dolomite

Figure 3. *(top right)* Almost 90 percent of the 2,000 tons of gold ore processed daily at Echo Bay Mineral Company's Kettle River Operations is from the Lamefoot deposit, an underground gold mine northeast of Republic in Ferry County. The portal to the mine is shown here. Miners remove alternate blocks of ore; the remaining blocks support the overlying rock. Cement is mixed with waste materials to backfill the mined-out areas. After the cement sets, it provides the essential support to allow mining of the remaining block of ore. The truck on the right is unloading cement into the large vertical tank. The vehicle at the center is headed into the mine; it will haul 20 to 25 tons of ore to the surface. At the left is a scale where each load of ore is weighed. Because owners of this deposit receive royalties for the gold produced from their portion of the deposit, the company must record the tons of ore extracted.

Figure 4. *(right)* Portal of the new K-2 gold deposit of Echo Bay Minerals Co. The mine operated as a development/exploration project in 1995. In 1996, development continued with development ore being shipped to the company's mill northeast of Republic.

Figure 5. *(bottom left)* One of the few drills operating for mineral exploration in Washington in 1996. This one, adjacent to the K-2 deposit of Echo Bay Minerals Company, was drilling to extend reserves at the mine.

Figure 6. *(bottom right)* Portal of the Pend Oreille mine near Metaline Falls. This mine has been the focus of an extensive program to identify zinc and lead resources. The big change in 1996 was the announcement that Cominco American Incorporated had acquired the property. If sufficient resources can be identified, the company would reopen the Pend Oreille mine when their giant lead-zinc Sultan deposit in British Columbia is mined out in about 4 years.

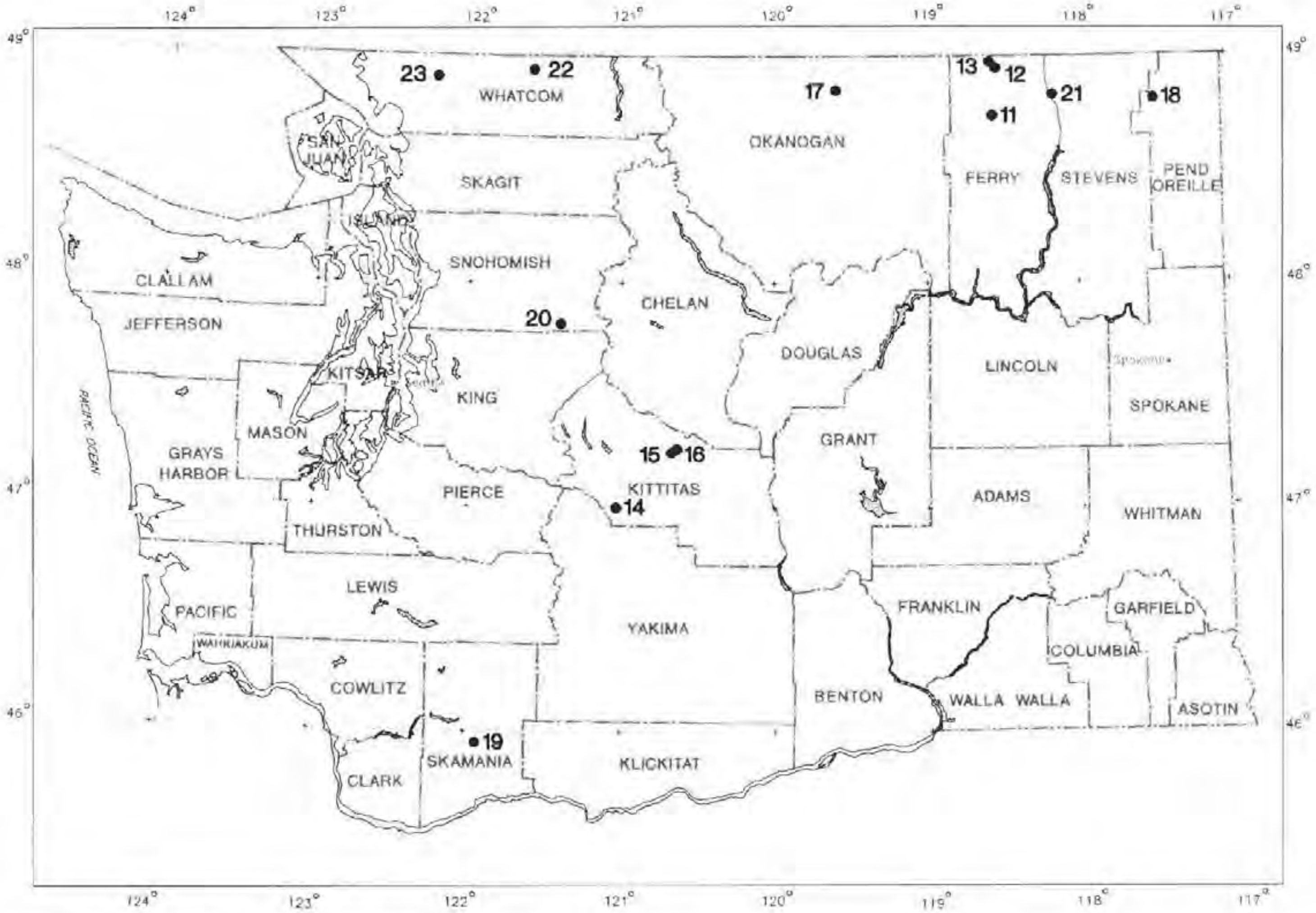

Figure 7. *(above)* Location of small-scale metal mining and exploration projects in Washington in 1996. The table at right identifies mines from numbers on the map. See Table 2 *(next page)* for additional details for each of these projects.

No.	Property	Commodities	Location	County
11	Black Hawk	Au, Ag, Cu, Fe	sec. 6, 37N, 34E; sec. 31, 38N, 34E	Ferry
12	Morning Star	Au, Ag, Cu, W	sec. 16, 40N, 34E	Ferry
13	Gold Mountain	Au, Ag, Cu	secs. 7-8, 40N, 34E	Ferry
14	Three Crosses	Cu, Au, Ag	sec. 25-26, 23N, 14E	Kittitas
15	Williams Creek	Au, Ag	secs. 1-2, 20N, 17E	Kittitas
16	September Morn	Au, Ag	sec. 10, 20N, 17E	Kittitas
17	Palmer Mountain	Cu, Au, Ag, Zn,	secs. 20, 29, 39N, 26E	Okanogan
18	Jim Creek	Zn, Ag, Pb, Cu, Mo, Au, W	secs. 8-9, 16-17, 38N, 42E	Pend Oreille
19	Wind River	Au, Ag	sec. 9, 5N, 7E	Skamania
20	Trout Creek property	Cu, Au, Ag, Zn, Pb, W, Sn, Pt	sec. 20, 27N, 11E	Snohomish
21	Toulou Mountain	Zn, Pb, Cu, Ag, Au	secs. 6, 30-31, 39N, 37E	Stevens
22	Lone Jack	Au, Ag	secs. 22-23, 40N, 9E	Whatcom
23	South Pass Nickel	Sc, Ni, Co	sec. 2, 39N, 4E; sec. 35, 40N, 4E	Whatcom

0.176 oz of gold per ton (30,500 oz of contained gold.) The company is continuing an extensive drilling program both around the mine (Fig. 5) and underground to locate additional reserves for the K-2 deposit.

The environmental impact statement for Battle Mountain Gold Company's Crown Jewel gold deposit (Fig. 2, no. 4) at Chesaw in Okanogan County was released in early February 1997. The company will be completing permit applications for the operation in 1997. This process is expected to take about a year.

Magnesium metal is the dominant value-added nonfuel mineral commodity produced in Washington. Because the magnesium metal market has been soft, dolomite mined for magnesium metal production at Northwest Alloys Inc. (a subsidiary of ALCOA) decreased from 850,000 tons of dolomite in 1995 to about 700,000 tons mined in 1996. The company expects demand to pick up in 1997, and production should increase also.

Cominco American Incorporated, through its parent company Cominco Limited, acquired the Pend Oreille Mine (Fig. 2, no. 5) in the northeast corner of the state. The company assisted in an extensive, ongoing surface and underground exploration program (Fig. 6) at the mine with hopes of identifying additional reserves of zinc and lead ore on which to base a production decision.

Santa Fe Pacific Gold Corp. completed their exploration drilling program to evaluate the Golden Eagle deposit (Fig. 2,

Table 2. Operator and a brief description of the activity and geology of small-scale mining and exploration projects in Washington in 1996

Property	Company	Activity	Area geology
Black Hawk	Echo Bay Exploration Inc.	Drilled 2 holes	Gold mineralization in massive iron replacement/ skarn in Permian sedimentary rocks
Morning Star	Echo Bay Minerals Co. lease	Drilled 3 core holes	Volcanogenic massive sulfide mineralization in Mesozoic accreted terrane rocks
Gold Mountain	Globex Nevada, Inc.	Geologic mapping, geophysics, drilled 14 holes	Gold-pyrite mineralization in an alkalic dike of the Jurassic Shasket Creek complex
Three Crosses	Art Baydo	Drilling	Mineralization in diabase and gabbro of the Ingalls Complex
Williams Creek	Goodfellow Construction	Seeking new permits	Placer deposit along Williams Creek
September Morn	Ron Kilmer	Seeking permits to placer mine	Placer deposit along Williams Creek
Palmer Mountain	Wilbur Hallauer	Geophysics, geologic mapping, opened old adit	Ore lenses in altered andesite of Permian–Triassic Palmer Mountain Greenstone
Jim Creek	Northwest Minerals Ltd.	Property acquisition, reconnaissance, sampling	Contact metamorphic Zn, Ag, Pb mineralization in lower Paleozoic carbonate and shale intruded by Cretaceous granitic rocks with porphyry type mineralization
Wind River	DeLano Wind River Mining Co.	Mined and stockpiled approximately 2,000 tons of ore	Epithermal mineralization in Oligocene–Miocene volcanic rocks
Trout Creek property	Ariel Resources Ltd.	Geophysics	VMS/contact metamorphic mineralization adjacent to the Tertiary Grotto batholith
Toulou Mountain	Northwest Minerals Ltd.	Obtained property, reconnaissance exploration	Exhalative/contact metamorphic mineralization in Permian volcaniclastic and sedimentary rocks
Lone Jack	Diversified Development Co.	Mining, but ore grade dropped to ~3/4 ounce, precluding profitable shipping to East Helena; re-evaluating for 1997	Quartz veins in metasedimentary rocks
South Pass Nickel	Consolidated Viscount Resources, Ltd.	Obtained property, planning winter exploration program	Testing feasibility of extracting nickel and scandium in Eocene, resedimented laterite

no. 3) in mid-February 1996. They exercised their option and purchased the property. Santa Fe has, however, put on hold any decision to develop the property pending takeover offers for the company. They continue to hold their earn-in agreement on the remainder of Hecla Mining Co.'s holdings at Republic in Ferry County.

Small-Scale Mining and Exploration Projects

A number of smaller scale mining and exploration projects were ongoing in 1996. Figure 7 shows the locations of these projects; Table 2 lists the mines and their activities and includes a brief comment about the geology of the deposit. The majority of those companies and individuals were looking for gold. As in 1995, the Lone Jack mine (Fig. 7, no. 22) in Whatcom County was in operation in 1996. However, the vein that the company had intercepted at depth in 1995 proved to be of lower than expected grade, and the company did not ship any ore in 1996. DeLano Wind River Mining Co. mined and stockpiled approximately 2,000 tons of ore at the Wind River gold deposit (Fig. 7, no. 19) in Skamania County. The company also continued to seek permits to establish a milling operation. Globex Nevada Inc. conducted mapping and geophysical studies before it drilled 14 deep holes on the Gold Mountain deposit (Fig. 7, no. 13) in rocks of the Shasket Creek alkalic complex at the north end of the Republic Graben in northern Ferry County. Echo Bay Minerals Co. explored at the Black Hawk property (Fig. 7, no. 11), seeking mineralization similar to that at the Lamefoot deposit in Ferry County. The owner of the Three Crosses property near Cle Elum in Kittitas County completed some exploratory drilling in 1996. Owners of placer properties on Williams Creek (Fig. 7, nos. 15, 16) near Liberty in Kittitas County were seeking permits to operate.

The most active 1996 exploration target for base metals was deposits that have potential volcanogenic massive sulfide (VMS) mineralization. Echo Bay Exploration drilled three holes at the Morning Star (Fig. 7, no. 12) deposit in northern Ferry County. Ariel Resources conducted geophysical studies on possible VMS mineralization at the Trout Creek property (Fig. 7, no. 20) in Snohomish County. Northwest Mineral Ltd. explored Toulou Mountain (Fig. 7, no. 21) in Stevens County, a property with potential for VMS and contact metamorphic mineralization, and Jim Creek (Fig. 7, no. 18) in Pend Oreille County, which has potential for base metal mineralization. Consolidated Viscount Resources, Ltd. was investigating methods of recovering nickel and scandium from the South Pass laterite deposit (Fig. 7, no. 23) in Whatcom County.

Maintained Property

A number of companies and individuals maintained their properties in 1996, either through payment of claim lease fees or completion of assessment work on unpatented claims. Table 3 lists those properties.

NONMETALLIC MINERAL INDUSTRY ACTIVITIES

The combined production of nonmetallic mineral commodities (carbonates, clays, diatomite, olivine, and silica) accounted for about $163 million, or approximately 28 percent of the approximately $582 million total value of nonfuel mineral production for Washington in 1995, the last year for which figures are available. Figure 8 and Table 4 summarize activities for nonmetallic commodities in 1996. Information covering previous years' activities for nonmetallic commodities can be found in articles by Gulick (1994, 1995), Gulick and Lingley (1993), and Derkey (1996).

Table 3. Properties known to be maintained or undergoing reclamation activities but where no active mining or exploration was associated with the property

Property	Location	Company	Commodities	Area geology	County
Wenatchee Gold Belt project	sec. 35, 22N, 20E	Quest International	Au, Ag	Mineralization in altered (commonly silicified) horizons in Eocene arkosic sandstone.	Chelan
Gold Bond	secs. 2-3, 22N, 17E	Gold Bond Mining Co./Gold Bond Resources	Au	Vein mineralization in rocks of the Ingalls ophiolite complex	Chelan
Irish	sec. 15, 40N, 34E	Johnson Explosives	Au	Gold mineralization in alkalic rocks of the Jurassic Shasket Creek complex	Ferry
Ape & Damon	sec. 34, 26N, 10E	CSS Management Corp.	Au, Ag, Cu, Pb	Quartz vein in granodiorite of the Miocene Snoqualmie batholith	King
Weyerhaeuser properties	Cascades area	Weyerhaeuser Co.	Au, Ag, Cu, Mo, Pb, Zn, clay, silica	Cascades province and adjacent volcanic, volcaniclastic, and intrusive rocks	King, Pierce, Thurston
Maverick	sec. 30, 21N, 17E	Wallace Corbley	Au, Ag	Gold-quartz veins in Eocene Swauk Formation	Kittitas
Starr Molybdenum	secs. 8, 16, 37N, 26E	Wilbur Hallauer	Mo, Cu, W	Porphyry-type mineralization in Cretaceous Aeneas Creek quartz monzonite and granodiorite; gold in secondary enriched zone	Okanogan
Aeneas Valley property	sec. 8, 35N, 31E	Sunshine Valley Minerals, Inc.	Au, Ag, Cu, silica	Possible gold mineralization associated with large quartz (high-grade quartz) bodies in probable Permian rocks	Okanogan
Silver Belle	sec. 25, 38N, 31E	Lovejoy Mining	Au, Ag	Epithermal mineralization in Eocene felsic volcanic rocks of Toroda Creek graben	Okanogan
Ida	secs. 16, 21, 39N, 31E	Crown Resources Corp.	Au, Ag, Cu	Epithermal veins in Eocene Sanpoil Volcanics and Klondike Mountain Formation of the Toroda Creek graben	Okanogan
Crystal Butte	sec. 35, 40N, 30E	Keystone Gold, Inc., leased to Battle Mountain Gold Corp.	Au, Ag, Pb, Zn, Cu	Skarn type mineralization in Permian Spectacle Formation intruded by Mesozoic rocks	Okanogan
Lucky Knock	sec. 19, 38N, 27E	Magill & Associates	Au, Sb	Stibnite veinlets and disseminations in fractured and silicified limestone of the Permian Spectacle Formation	Okanogan
Billy Goat	sec. 15, 38N, 20E	Sunshine Valley Minerals, Inc.	Au, Cu, Ag	Stockwork in Cretaceous? andesite tuff and breccia	Okanogan
Kelsey	secs. 5-8, 40N, 27E	Wilbur Hallauer	Cu, Mo, Ag, Au	Porphyry-type mineralization in Jurassic–Cretaceous Silver Nail quartz diorite	Okanogan
Silver Star	secs. 3-5, 8-9, 3N, 5E	Kinross Gold USA, Inc.	Cu, Ag, Au, Mo	Tourmaline-bearing breccia pipe associated with porphyritic phases of the Miocene Silver Star pluton	Skamania
Lockwood	secs. 25, 30-32, 29N, 9E	Island Arc Resources Corp./ Formosa Resources Corp.	Cu, Au, Zn, Ag	Kuroko-type volcanogenic massive sulfide mineralization in Jurassic volcanic rocks of the Western melange belt	Snohomish
Van Stone mine	sec. 33, 38N, 40E	Zicor Mining Inc.	Zn, Pb, Cd	Mississippi Valley-type mineralization in the Cambrian–Ordovician Metaline Formation	Stevens
Uranwash 1-4 & New Indian Henry claims	sec. 13, 40N, 36E	Loudon & Sanstrom partnership	Au, Ag, Cu, Pb, Zn	Vein-type mineralization in Jurassic metavolcanic rocks	Stevens
Cleta Group	secs. 22, 27, 40N, 37E	David Robbins and Associates	Au, Ag, Cu	Vein and replacement mineralization in sheared and contact-metamorphosed Permian Mount Roberts Formation	Stevens
Iroquois	secs. 1, 19-20, 29-30, 40N, 42E	Mines Management, Inc.	Zn, Pb, Ag, Au	Mineralization in a breccia zone in Cambrian–Ordovician Metaline Formation	Stevens
New Light	sec. 27, 38N, 17E	Lion Mines Ltd.	Au, Ag	Quartz-carbonate-cemented slate-argillite breccia in the Lower Cretaceous Harts Pass Formation	Whatcom
Minnesota	sec. 2, 37N, 16E	Seattle-St. Louis Mining Co.	Au, Ag, Cu	Quartz veins in argillite and feldspathic sandstone of Lower Cretaceous Harts Pass Formation	Whatcom
Azurite	sec. 30, 37N, 17E	Double Dragon Exploration Inc.	Au, Ag, Cu, Pb	Veins in sedimentary rocks of the Cretaceous Virginian Ridge Formation	Whatcom
Morse Creek	sec. 31, 17N, 11E	Ardic Exploration & Development, Ltd.	Au, Ag	Tuffs of the Oligocene Ohanapecosh Formation	Yakima

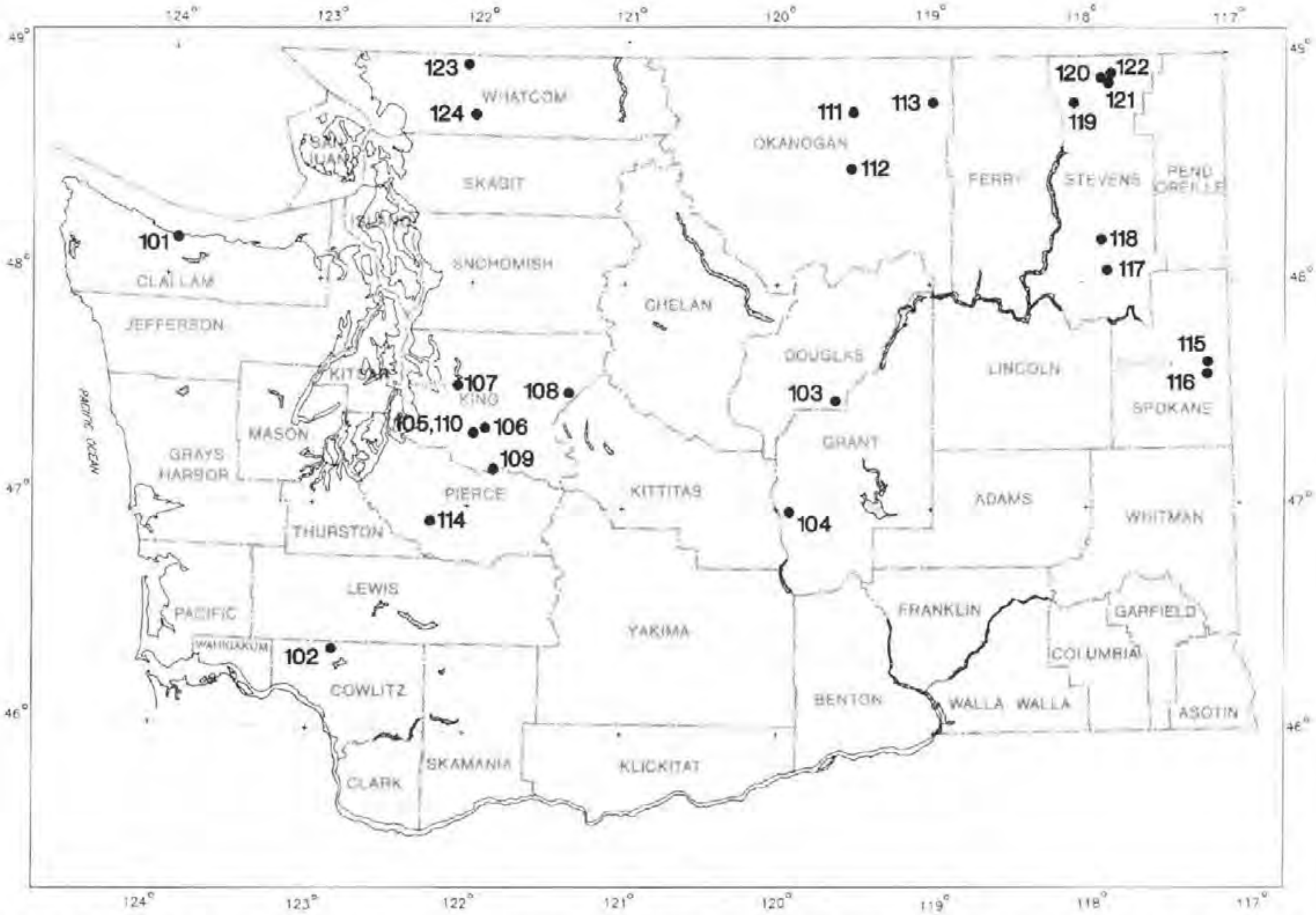

Figure 8. Location of nonmetallic mining operations in Washington in 1996. Table below identifies mines from numbers on the map. See Table 4 *(next page)* for additional details on each of these projects.

Carbonates

Northwest Alloys continued to market agricultural soil conditioners, mainly carbonate byproducts they obtain during production of magnesium metal at Addy (Fig. 2, no. 6) in Stevens County. Other companies producing calcium or calcium-magnesium carbonate products from limestone or dolomite, respectively, include Columbia River Carbonates from the Wauconda quarry (Fig. 8, no. 113) and Pacific Calcium Inc. from the Tonasket (Fig. 8, no. 111) and Brown (Fig. 8, no. 112) quarries in Okanogan County. The Gehrke (Fig. 8, no. 117), Northwest Marble Products (Fig. 8, no. 119), Joe Janni (Fig. 8, no. 120), and Janni Limestone (Fig. 8, no. 121) quarries in Stevens County were also in operation in 1996. The only known carbonate deposit operation in western Washington was the Maple Falls quarry (Fig. 8, no. 123) in Whatcom County.

No.	Property	Commodity	Location	County
101	Twin River quarry	clay	secs. 22-23, 31N, 10W	Clallam
102	Castle Rock quarry	clay	sec. 18, 10N, 1W	Cowlitz
103	Volcanic and Rock Top deposits	clay	sec. 13, 23N, 25E and sec. 20, 22N, 26E respectively	Douglas/ Grant
104	Celite Corp. diatomite pits	diatomite	sec. 3, 17N, 23E; sec. 7, 17N, 24E	Grant
105	Ravensdale pit	silica	sec. 1, 21N, 6E	King
106	Elk pit	shale	sec. 34, 22N, 7E	King
107	Sec. 31 pit	shale	sec. 31, 24N, 6E	King
108	Spruce claim	crystals	secs. 29, 30, 24N, 11E	King
109	Superior quarry	silica	sec. 1, 19N, 7E	King
110	John Henry #1	clay	sec. 12, 21N, 6E	King
111	Tonasket limestone quarry	limestone	sec. 25, 38N, 26E	Okanogan
112	Brown quarry	dolomite	sec. 26, 35N, 26E	Okanogan
113	Wauconda quarry	limestone	sec. 13, 38N, 30E	Okanogan
114	Clay City pit	clay	sec. 30, 17N, 5E	Pierce
115	Somers clay pit	clay	sec. 35, 25N, 44E	Spokane
116	Mica mine	clay	sec. 14, 24N, 44E	Spokane
117	Gehrke quarry	dolomite	sec. 2, 29N, 39E	Stevens
118	Lane Mountain quarry	silica	secs. 22, 34, 31N, 39E	Stevens
119	Northwest marble mine; other quarries	dolomite	sec. 19, 38N, 38E	Stevens
120	Joe Janni limestone deposit	limestone	sec. 13, 39N, 39N	Stevens
121	Janni limestone quarry	limestone	sec. 13, 39N, 39E	Stevens
122	Sherve quarry	limestone	sec. 8, 39N, 40E	Stevens
123	Maple Falls quarry	limestone	sec. 7, 18, 40N, 6E	Whatcom
124	Swen Larsen quarry	olivine	sec. 34, 38N, 6E	Whatcom

Table 4. Operator and a brief description of the activity and geology of nonmetallic mining operations in Washington in 1996

Property	Company	Activity	Area geology
Twin River quarry	Holnam Inc.	Mined 60,000 tons, development	Mudstone(?) in three members of the upper Eocene to lower Miocene Twin Rivers Formation
Castle Rock quarry	Ash Grove Cement Co.	Mined 40,400 tons	Eocene–Oligocene nearshore sedimentary rocks
Volcanic and Rock Top deposits	Basic Resources Corp.	Permitting is nearly completed, target is for 40,000 tons production in the first year	Calcium bentonite (clay) interbeds in Miocene Columbia River Basalt Group near Moses Coulee
Celite Diatomite pits	Celite Corp.	Mined over 100,000 tons of ore and produced about 65,000 tons of finished diatomite	Miocene "Quincy diatomite bed", a locally occurring sedimentary interbed at the base of the Priest Rapids Member, Columbia River Basalt Group
Ravensdale pit	Reserve Silica Corp.	Mined and washed 70,000 tons	Sandstone of the Eocene Puget Group
Elk pit	Mutual Materials Co.	Mined 13,000 tons to produce bricks	Illite- and kaolinite-bearing shales of the Eocene Puget Group
Sec. 31 pit	Mutual Materials Co.	Mined 65,000 tons to produce bricks	Shale of the Eocene Puget Group
Spruce claim	Robert Jackson	Extracting mineral and crystal specimens	Quartz and pyrite crystals in large, open voids along faulted megabreccia in the northern phase granodiorite and tonalite (25 Ma) of the Snoqualmie batholith
Superior quarry	Ash Grove Cement Co.	Exploration drilling and development, no production	Silica cap in hydrothermally altered Miocene andesites on a caldera margin
John Henry #1	Pacific Coast Coal Co.	Mined over 60,000 tons of clay that was shipped to Ash Grove Cement Co.	Upper middle Eocene silty clay near the base of the Puget Group comprising a 30-ft-thick zone above the Franklin #9 coal seam
Tonasket limestone quarry	Pacific Calcium, Inc.	Mined 16,000 tons of limestone for soil conditioner and feed lime	Metacarbonate rocks in the conglomerate-bearing member of the Permian Spectacle Formation (Anarchist Group)
Brown quarry	Pacific Calcium, Inc.	Mined 4,000 tons for soil conditioner	Metadolomite member of the Triassic Cave Mountain Formation
Wauconda quarry	Columbia River Carbonates	Mined 105,000 tons with net production of 78,000 tons	High-calcium, pre-Tertiary white marble lenses in mica schist, calc-silicate rocks, and hornfels
Clay City pit	Mutual Materials Co.	Mined 6,500 tons to produce bricks	Tertiary kaolin-bearing, altered andesite
Somers clay pit	Quarry Tile Co.	Produced ceramic tile from 1,545 tons of stockpiled ore	Lacustrine clay of the Miocene Latah Formation overlain by silty clay of the Pleistocene Palouse Formation
Mica mine	Mutual Materials Co.	Mined 42,000 tons, stockpiled to produce bricks	Lacustrine clay of Miocene Latah Formation overlying saprolitic, pre-Tertiary felsic gneiss.
Gehrke quarry	Allied Minerals, Inc.	Mined about 3,000 tons	Isolated pod of Proterozoic Y Stensgar Dolomite(?) (Deer Trail Group)
Lane Mountain quarry	Lane Mountain Silica Co. (division of Hemphill Brothers, Inc.)	Mined 300,000 tons, milled at plant near Valley	Cambrian Addy Quartzite
Northwest marble mine; other quarries	Northwest Marble Products Co.	Mining, milling, color/site specific aggregate materials for building and industrial applications	Dolomite of the Cambrian–Ordovician Metaline Formation; additional colored dolomite products are quarried at several locations
Joe Janni limestone deposit	Joseph A. & Jeanne F. Janni limestone deposits	Leased to Columbia River Carbonates	Deposit is in the Reeves Limestone Member of the Cambrian Maitlen Phyllite
Janni limestone quarry	Peter Janni and Sons	Columbia River Carbonates shipped some limestone to their plant in Woodland, WA	Deposit is in the Reeves Limestone Member of the Cambrian Maitlen Phyllite
Sherve quarry	Northport Limestone Co. (division of Hemphill Brothers, Inc.)	Mined 40,000 tons, processed on site	Limestone in the upper unit of Cambrian–Ordovician Metaline Formation
Maple Falls quarry	Clauson Lime Co.	Mined about 60,000 tons, used for rip rap and some aggregate and landscape rock	Sheared, jointed Lower Pennsylvanian limestone overlain by sheared argillite and underlain by argillite, graywacke, and volcanic breccia of the Chilliwack Group
Swen Larsen quarry	Olivine Corp.	Mined and milled 41,000 tons for refractory/incinerator uses; majority of production used by UNIMIN Corp.	Dunite is mined from the Twin Sisters Dunite (outcrop area more than 36 mi^2) in Whatcom and Skagit Counties

Olivine

Olivine Corp. mined olivine in 1996 from its Swen Larsen quarry (Fig. 8, no. 124) in the Twin Sisters dunite body in Whatcom County. The company uses some of its production to construct wood and municipal waste incinerators for international customers and supplies crushed olivine to UNIMIN, a Belgian company that produces casting sands and other refractory products at Hamilton.

Clays

Mutual Materials mined clay for making bricks in Spokane County at its Mica mine (Fig. 8, no. 116), in King County at its Elk (Fig. 8, no. 106) and Section 31 (Fig. 8, no. 107) pits, and from its Clay City (Fig. 8, no. 114) pit in Pierce County. Quarry Tile Company produced ceramic tile from clay mined from the Somers pit (Fig. 8, no. 115) in Spokane County. Much of the clay produced in western Washington (Fig. 8, nos. 101, 102, 110) was mined by or for Holnam Inc. or Ash Grove Cement Co. to produce cement. Basic Resources Corp. is progressing toward production of bentonitic clay (Fig 8, no. 103) in Douglas and Grant Counties to line irrigation canals and for other possible markets.

Diatomite

Celite Corp. mined more than 100,000 tons of diatomite at its pits (Fig. 8, no. 104) in Grant County. Following processing, this amount of ore was reduced to 65,000 tons of finished diatomite.

Silica

Lane Mountain Silica Co. (Fig. 8, no. 118) mined 300,000 tons of Addy quartzite in Stevens County, and Reserve Silica Corp. (Fig. 8, no. 105) mined 70,000 tons of quartz-rich Puget Group sands in King County. The majority of both companies' production is used for the manufacture of bottle glass. Ash Grove Cement Co. had previously mined silica (for use in making cement) from its Superior quarry (Fig. 8, no. 109) in King County. However, in 1996 they only conducted exploration drilling and development at the deposit.

INDUSTRIAL MINERAL INDUSTRY ACTIVITIES

Industrial mineral commodities, construction sand and gravel, and construction stone accounted for approximately 42 percent of the $582 million total value of nonfuel mineral production for Washington in 1995, the last year for which figures are available. The overall production volume and value of construction sand and gravel, the single most valuable nonfuel mineral commodity in Washington, was $154 million, a $10 million decrease from value of 1994 production.

Sand and gravel operations consist of many small and several large pits throughout the state. Most large operations are concentrated around population centers. The most encouraging news is that pits that were in the advanced permitting stage at the beginning of the 1996 are or will soon be permitted to mine. The Dupont deposit operated by Lone Star Northwest went into production, and permitting for a deposit near Shelton owned by Manke Family Resources Ltd. is nearly completed. Both deposits are accessible from the water, which allows barging the aggregate; this lowers transportation costs to markets in nearby communities and the greater Seattle area. Other deposits near Monroe in Snohomish County are in the permitting stage.

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NEW DIRECTOR FOR NORTHWEST MINING ASSOCIATION

Late last fall, the Northwest Mining Association named Laura E. Skaer its new director. Ms. Skaer was vice president and general counsel for a mining company in Reno, Nevada. She also brings 14 years of management, operations, and legal experience in the oil and gas industry, with a focus on land-use, reclamation, development, and tax issues. She served as chair of the Colorado Department of Natural Resources, Minerals, Energy, and Geology Policy Advisory Board, as Regional Vice President of the Independent Petroleum Association of America, and as president of the Independent Petroleum Association, Mountain States. She has authored legislation dealing with oil, gas, and mining tax reform, economic development, and deregulation of natural resource industries. She has long been an industry advocate on federal, state, and local levels.

Ms. Skaer has graduate degrees in Business Administration and law and has won several awards. She replaces the former director, Tim Olson.

AGGREGATE FACTS

- Washington construction projects consume nearly 77 million tons of aggregates each year.
- Washingtonians consume about 12–14 tons of aggregates and use 1.3 yd^3 of concrete and 1.25 tons of asphalt each year.
- A typical county road uses about 4,600 tons of aggregates for each mile.
- The average 2,000-ft^2 house in western Washington uses about 210 tons of aggregates in its foundation, driveway, base materials, and streets.
- Because transportation is nearly 40 percent of the cost to produce aggregates, aggregate products are most commonly used within about 30 miles of their origin.

(Provided by Meridian Aggregate Co.)

From Clay to Bricks

Robert E. Derkey
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Clay is a term applied to both a group of minerals and a rock made up of clay-size particles (generally less than 1/256 of a millimeter). Of the several definitions for clay in the American Geological Institute's Dictionary of Geology (Bates and Jackson, 1987, p. 122), the following best fits clay for making bricks. It is (1) "a loose, earthy, extremely fine-grained sediment or soft rock"; (2) it commonly contains "subordinate amounts of finely divided quartz, decomposed feldspar", and other non-clay minerals; and (3) it "forms a plastic, moldable mass when mixed with water, retains its shape on drying, and is firm, rocklike, and permanently hard on heating and firing."

Mutual Materials operates several brick plants in eastern and western Washington. (See the industrial minerals section of the preceding article, p. 11) The Mica plant, located 15 miles southeast of Spokane, uses a deposit of the Latah Formation to make bricks and related materials. This Miocene formation contains a high proportion of clay. The company makes a wide variety of shapes, sizes, and colors of face bricks, that is bricks used to face a building. They also make fire bricks, mainly for wood stoves, and tile for chimney liners.

The following figures illustrate some of the steps of making bricks from clay.

Reference Cited

Bates, R. L.; Jackson, J. A., 1987, Glossary of geology (3d ed.): American Geological Institute, 788 p. ■

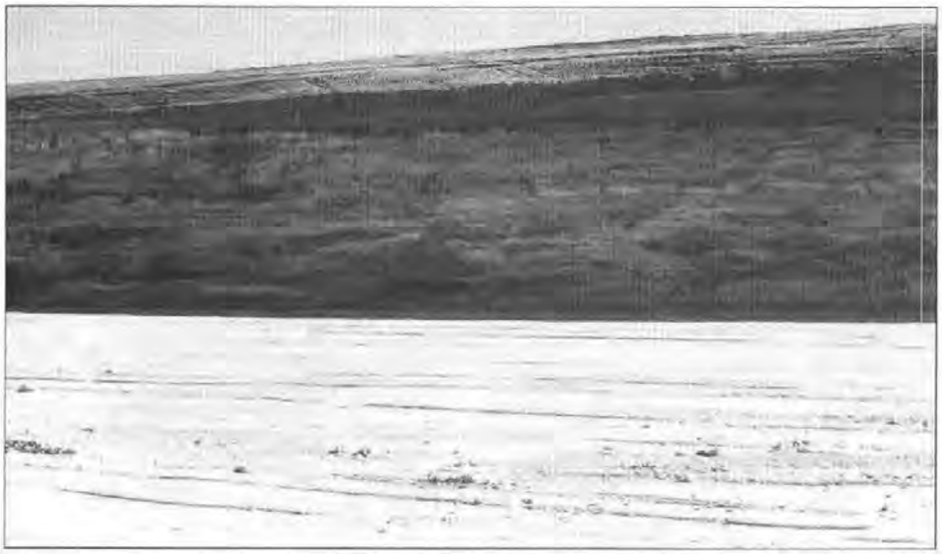

Figure 1. Highwall of clay pit. This is one of several pits where Mutual Materials Co. mines clay for making bricks at its plant in Mica, southeast of Spokane. The deposit contains about 65 percent clay, the remainder being quartz, feldspar, and mica. The non-clay fraction is about 65 percent quartz, 25–30 percent feldspar, and 5–10 percent mica. The pit highwall shown displays considerable color variation; the darker parts are stained by limonite, an iron mineral. By carefully controlling the mix of clays from this and several other pits, the Mica plant can produce a wide spectrum of brick colors.

Figure 2. When the desired blend of source clay is reached, an appropriate amount of water is added. The clay is squeezed or forced into a mold from which it is extruded, in much the same way as toothpaste is squeezed out of its tube. The clay is extruded in a continuous stream onto a slowly moving conveyor belt. Different orifices are used to obtain the different sizes and shapes of bricks. If the design calls for holes in the brick, they are created at the orifice.

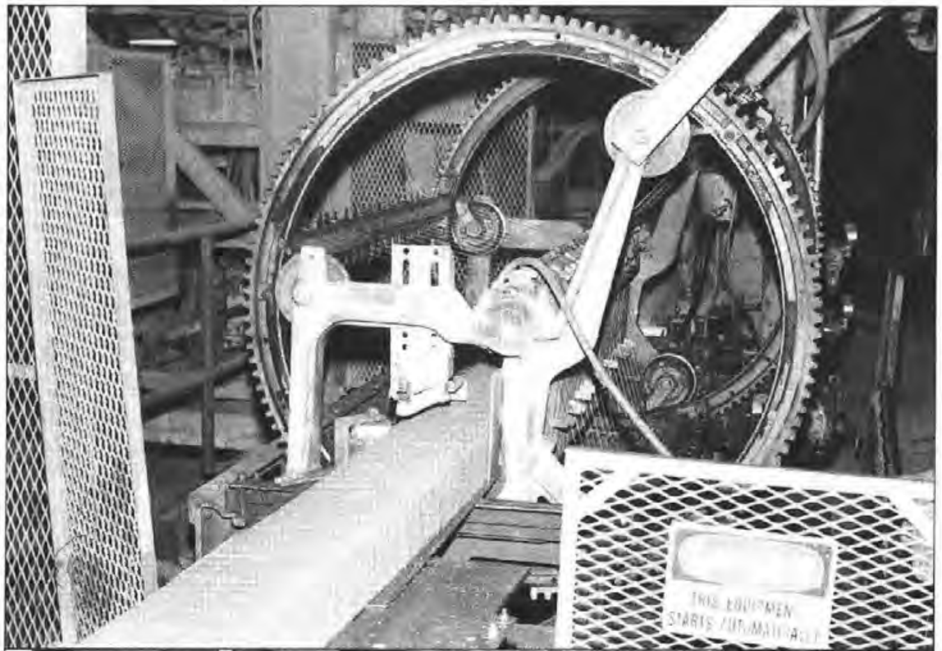

Figure 3. Cutting bricks. The conveyor belt carries the stream of clay through this cylinder-like apparatus, which periodically rotates one-third of a turn. The apparatus contains three sets of "piano" wires, and when it is turned by the cogs on the two wheels of the cylinder, the wires cut the clay into a brick shape. Because the extruded clay is moving at a steady pace, the cylinder also moves during the cut to ensure it is straight.

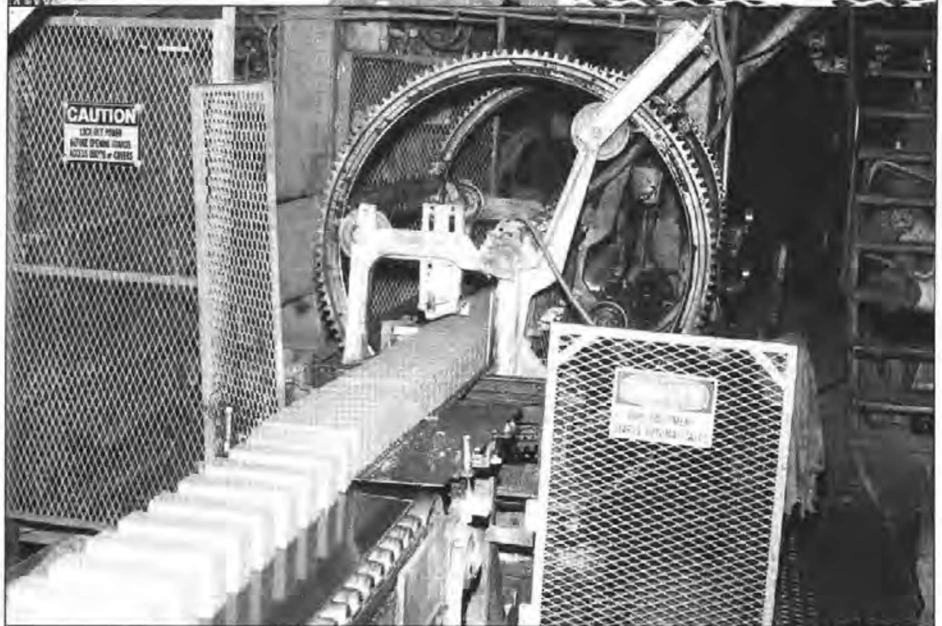

Figure 4. Moving right along....The freshly cut clay blocks now pass onto a belt that is moving slightly faster than the one that fed the clay to the cutter; this increases the space between the blocks. The bricks shown here are still soft, but of the typical size and have three holes.

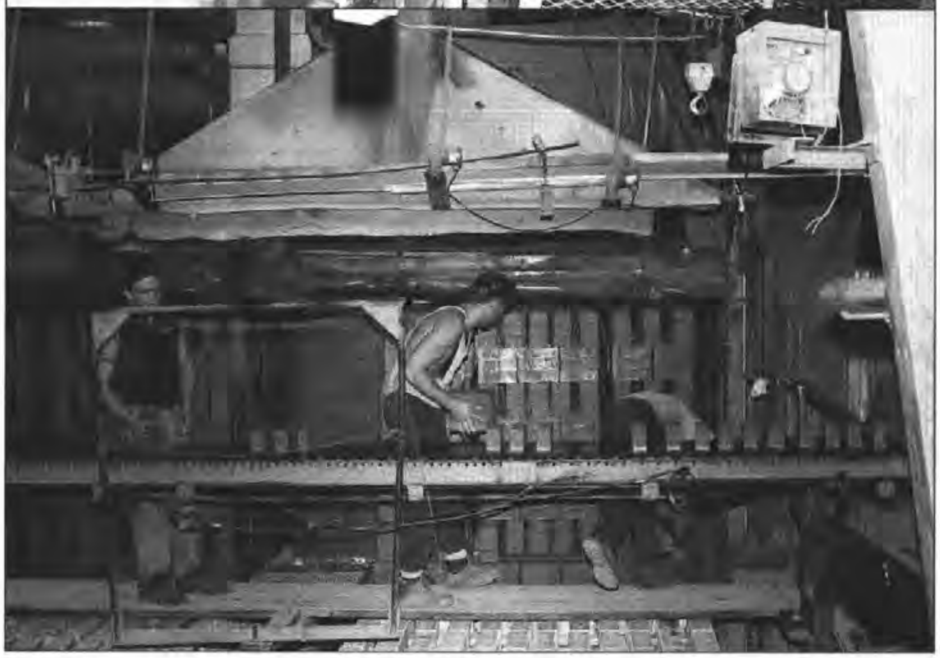

Figure 5. Stacking clay blocks to be sent to the dryer and kiln. The soft bricks move to where they are manually stacked on cars. This is the most labor-intensive part of the process. Once stacked on the cars, the clay blocks are moved along rails through the dryer and the kiln. The Mica plant can produce an unusual near-white brick from the Latah deposit. Because of this characteristic of the clay, the company can also make bricks in a number of light or pastel colors by adding colorants or small amounts of clay of another color.

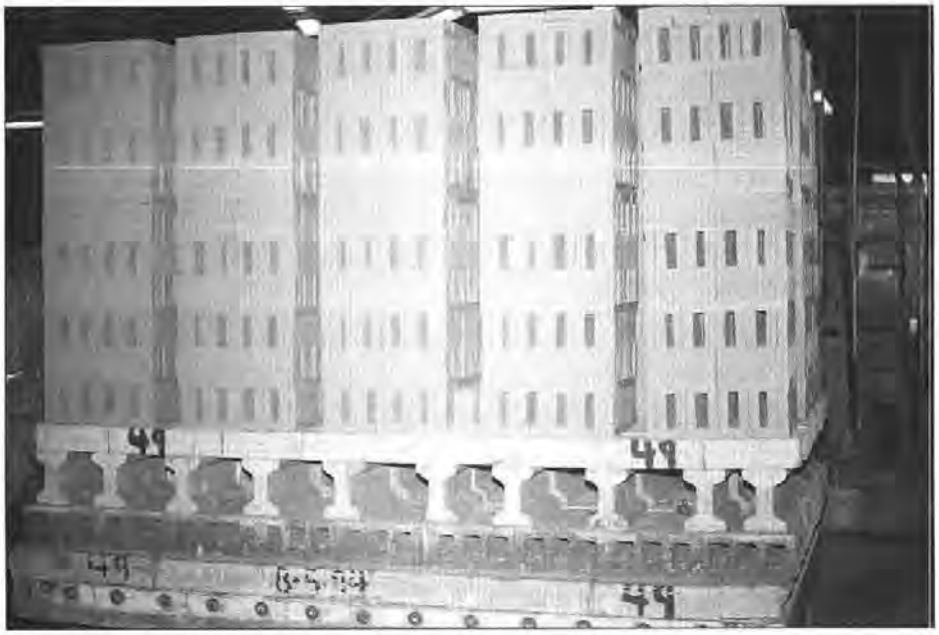

Figure 6. And finally, bricks. This car is loaded with bricks that were just removed from the kiln. Clay blocks spend 3 to 7 days in the dryer and kiln, the length of time depending on demand or production schedules. The average time is 5 days. In a 5-day cycle, the cars spend 3 days in the dryer and 2 days in the kiln. The temperature in the kiln is 2,125°F. The amount of available oxygen in the kiln is controlled to control brick color—excess oxygen will oxidize any iron and turn a near-white brick a rusty color.

DANTE'S PEAK, FACT OR FICTION?

Dante's Peak, a disaster thriller from Universal Studios, dramatizes the hazards faced by communities near active volcanoes. Set in the North Cascades of Washington, the movie portrays the roles of U.S. Geological Survey (USGS) scientists and local public officials during the re-awakening and eruption of a fictional volcano—one that resembles dozens of real volcanoes from northern California to Alaska. To separate fact from fiction, the USGS issued a release titled "Dante's Peak FAQ'S (frequently asked questions). Examples include:

- Hot springs may heat up before an eruption, but probably not in a matter of seconds as shown in the movie.
- If a town's water supply originates directly from a volcano's ground-water system, it could become contaminated, but probably not as quickly as shown in the movie.
- Earthquakes associated with eruptions rarely exceed magnitude 5, which are large enough to sway trees and damage buildings, but not to destroy them as shown in the movie.
- It's uncommon for a volcano to erupt different types of magma at the same time, that is, the fountains and flows characteristic of fluid magma *and* the explosive ash and pyroclastic flows characteristic of more viscous magma.
- Trying to drive over a hot lava flow (1,700°F) would result in melting tires and an exploding gas tank.
- Lakes near volcanoes *can* become acidic and cause burns to human skin but are unlikely to dissolve an aluminum boat in a matter of minutesy as shown in the movie.
- Hardly any vehicle can outrun a pyroclastic flow moving at speeds of up to 100+ mph.

For more information, contact C. Dan Miller, U.S. Geological Survey Cascades Volcano Observatory, 5400 MacArthur Blvd., Vancouver, WA 98661; (360) 696-7885 (office), (360) 696-7866 (fax), cdmiller@mailvan.wr.usgs.gov (e-mail), or visit the USGS website discussion about the movie at http://vulcan.wr.usgs.gov/News/DantesPeak.

EARTH GODDESSES OF THE PACIFIC NORTHWEST

Ahgishanakhou (Tlingit) – Chthonic goddess who protects the pillar-support of the earth.

Dah-ko-beed (Duwamish) – "Tacoma". Earth goddess of the Cascade mountains.

Hayicanako (Tlingit) – "The Old Woman Underneath". She supports the earth either by holding it or by tending the beaver leg post that holds it. She causes earthquakes, which her people believe means she is hungry. To appease her they throw grease on the fire so it will melt and run down to her. Alternate form: Hayicanak.

Klah Klahnee (Yakima, Klickitat) – Goddess of the "Three Sister" mountain in Oregon.

Loo-wit (Multnomah, Klickitat) – Fire goddess of Mount St. Helens.

Netcensta (Tahltan) – Earth mother. She supports the earth, and when she shifts she causes earthquakes.

Pahto (Yakima, Klickitat) – Goddess of Mount Adams.

Plash-plash (Yakima, Klickitat) – "White Spots." Goddess of Goat Rocks [near White Pass]. One of the five mountain wives of the sun. The others are the goddesses Wahkshum (Simcoe Mountain), Pahto (Mount Adams), Loo-wit (Mount St. Helens), and Tacoma (Mount Rainier).

Tacoma (Salish, Nisqually, Puyallup, Yakima) – Earth goddess of Mount Rainier. Alternate forms: Dah-ko-beed, Tacobud, Takkobad, Takobid, Tehoma.

Wahkshum (Yakima, Klickitat) – Goddess of Simcoe Mountain in southwestern Washington.

Wasco (Yakima) – Goddess of Mount Hood in Oregon. Alternate form: Wyeast.

Reference

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Washington's Coal Industry—1996

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In 1996, production at Washington's two coal mines was less than for 1995. The Centralia Mine in north central Lewis County and the John Henry No. 1 Mine in south-central King County together produced 4,565,323 short tons of coal, down 291,446 tons from 1995.

The Centralia Coal Mine, the state's largest coal producer, is operated by the Centralia Mining Company, a division of Pacificorp. Located 5 miles northeast of the city of Centralia (Fig. 1), the mine supplies the Centralia steam plant, which is about a mile from the mine.

The Centralia mine completed its twenty-sixth year of production in 1996, producing 4,392,516 short tons of subbituminous coal, about 234,000 tons less than in 1995. The mine's average annual production for the past 5 years has been 4.6 million tons; average annual production over the lifetime of the mine is 4.4 million tons.

In 1996, the mine produced coal from four open pits. Coalbeds mined were the Tono, Thompson, Big Dirty, Little Dirty, and Smith. These coals occur in the Skookumchuck Formation, composed of nearshore marine and nonmarine sedimentary rocks. The Skookumchuck is the upper formation of the Eocene Puget Group.

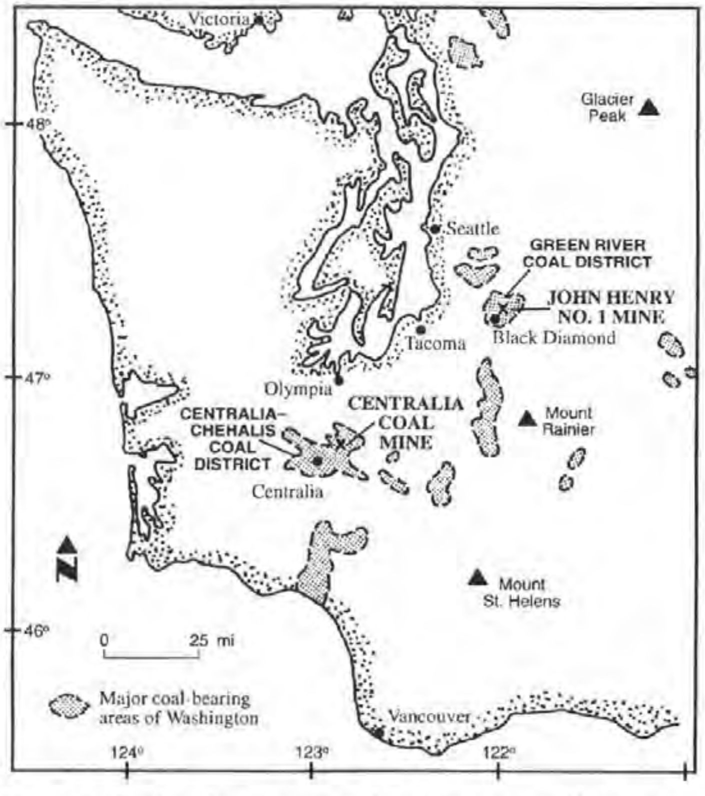

Figure 1. Coal-producing areas and districts, western Washington.

The John Henry No. 1, Washington's other producing coal mine, is located about 2 miles northeast of the town of Black Diamond (Fig. 1). The mine produced 172,807 short tons of bituminous coal in 1996, down about 57,000 tons from 1995. The mine completed its tenth full year of production in 1996. The mine, operated in partnership for the past seven years with a Japanese firm, a subsidiary of Mitsubishi Corporation, reverted to the original owner, Pacific Coast Coal Company, Inc. (PCCC), when the Japanese left the partnership about mid-year.

Figure 2. John Henry No 1 Mine, Pit No. 1, in January 1997. In this view to the southeast is the northwest limb of the anticlinal structure. Light-colored bare rock to the left of the pond forms the floor of the Franklin No. 7 coalbed. The Franklin Nos. 7, 8, and 9 coalbeds merge in this part of the mine. The excavator is alongside these three coalbeds (dark-colored material).

PCCC increased its sales share for the industrial sector to about 75 percent of its total sales in 1996 (up from 54 percent in 1995). The coal is used largely in the manufacture of cement and lime in the Puget Sound area. Actual sales increased by about 3,000 tons in 1996 for that sector. The greatest change accounting for the drop in total sales for this year was its sales share for the export market; the coal is sent to South Korea for steam generation. Export sales dropped by about 68,000 tons and accounted for about 24 percent of total sales in 1996 (down from 46 percent in 1995). The remaining sales (less than 1 percent) went to supply public and private institutions and residential customers for space heating.

In 1996, PCCC mined coal at its Pit No. 1 (Figs. 2, 3), extending its mining deeper along the flanks of the anticlinal structure in the mine. Production comes from four coalbeds, the Franklin Nos. 7, 8, 9, and 10. These coals occur stratigraphically near the base of the undivided Eocene Puget Group in nonmarine deltaic sedimentary rocks. In late January 1997, PCCC was mining the Franklin Nos. 7, 8, and 9 coalbeds along the northwest limb where the three coalbeds stratigraphically merge (Fig. 2). PCCC also mines a clay bed between the Franklin Nos. 9 and 10 coalbeds. This clay is blended with high alumina clay for manufacturing portland cement. ■

Figure 3. John Henry No. 1 Mine, Pit No. 1, January 1997. In this view (to the southwest) the floor of the Franklin No. 7 coalbed forms the steeply dipping plane of bare rock to the left of the elongate pond. Here the southwest limb of the doubly plunging anticlinal structure is exposed. The Franklin Nos. 7, 8, and 9 coalbeds are exposed in the distance at road level (behind the mine truck), where they merge stratigraphically and occur near the crest of the plunging anticline where the dip has flattened.

Clarification of Information in "Geohydrologic Review of the Cedar River Ground-water Basin"

The following letter was sent January 23, 1997, to Kaleen Cottingham, Supervisor, DNR.

Dear Ms. Cottingham:

The December 1996 issue of the DNR publication "Washington Geology," contained an article entitled "Geohydrologic Review of the Cedar River Groundwater Basin" [v. 24, no. 4]. The article was written by Stephen H. Evans and Roy E. Jensen. A statement was made in the article with respect to the Department of Ecology and water rights that was not accurate, and I want to express some concern and provide you with some accurate information regarding water right decisions.

In the introduction section of the article, the statement is made that "the current Washington Department of Ecology moratorium on allocating and developing ground water demonstrates how critical it is to acquire comprehensive ground water information." My concern with this statement is two-fold:

1. DOE has instituted no moratorium on the allocation of water rights. It is true that the decision-making process for water right applications was drastically impaired in 1994 when the budget passed by the legislature resulted in massive cuts in the agency, and specifically the Shorelands and Water Resources Program, which handles water right applications.

Additionally, the recent Watershed Assessment done in the Cedar River Basin utilized existing information to show that water is in short supply in the critical summer months. The fact that the Cedar River does not meet required instream flows on the average of 81 days out of the year indicates that we cannot continue to issue water rights without adversely affecting existing water rights, instream uses, and our natural resources and habitat. This does not translate into a moratorium on the issuance of water rights. Rather it means that applicants need to look for alternatives to new water for their water supply. DOE is working with applicants who are proposing such alternatives. What these assessments point out is that the era of inexpensive, easy water supply is over.

2. The "development of ground water" is not something that is within the mission of DOE. It is the responsibility of the department to make a careful evaluation of water right application, but that it must act in the interests of the public as a whole. This may mean that denial of water right applications is necessary, as in the Cedar River Watershed. Again, [this] does not translate into a moratorium on the issuance of water rights. It is wrong to make the assumption that denial of water right applications in one area means denial in another area. Conditions and proposals are different in other areas, and we must address the issues specific to those areas.

I'm sure you can appreciate the need to have accurate information regarding agency policies and mandates, in this era of "distrust" of government. I know you must face some of these same issues working with a state agency. Thank you for your consideration of these issues. Please feel free to contact me with any questions or concerns at (206) 649-7096.

Sincerely,

[signature]

Raymond Hellwig
Shorelands and Water Resources Program

National Natural Landmarks

The 1995 "Section 8" annual report regarding the status of the landmarks indicates that the Drumheller Channels site in Washington is now considered threatened or damaged. For a copy of this report or a brochure about the 34 sites in the Cascades area, contact the National Park Service, Columbia Cascades System Support Office, 909 First Ave., Seattle, WA 98104-1060. See also their web page at http://www.nps.gov/ccso/nnl.htm.

Puget Sound Bluffs: The Where, Why, and When of Landslides Following the Holiday 1996/97 Storms

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From late December 1996 to early January 1997, a series of winter storms delivered snow, freezing rain, warm rain, and wind to the west coast, producing floods, snow and ice damage, and landslides from Washington to central California. Individual weather systems like these arrive almost annually; the consequences of their combination are somewhat more remarkable, but nonetheless occur every few years somewhere in the region. The region's long history of slope failure following heavy precipitation events is discussed in Tubbs (1974), Thorsen (1987), Miller (1991), and Evans (1994).

In the Pacific Northwest, the autumn months had above-normal precipitation, building high soil moisture and heavy snowpacks. In late December, a cold continental air mass sat over northwest Washington, while a series of warm wet storms began moving in from the Pacific Ocean. The incoming moisture first fell as snow north of the cold front and freezing rain south of it. In the southern Puget Sound region and the Columbia Gorge–Portland area, ice storms brought down trees and power lines, while snow accumulated from about Olympia northward, reaching depths of up to 3 ft in north King County.

Then on January 1 and 2, warm air, combined with locally heavy rains, quickly melted much of the low-elevation snow. This caused flooding in most streams in the Puget Lowland and in many of the rivers draining the Olympics and the Cascades.

The combination of pre-existing soil moisture, heavy rain, and rapid snowmelt brought soils to or near saturation. This had different effects, depending on the terrain. On the gentler drift plains, perching of water on tills and emergence of ground water from shallow aquifers caused lingering flooding of low-lying areas. But in the steep bluffs and ravines that border Puget Sound, Lake Washington, and the larger river valleys, lateral movement of ground water toward the free faces caused elevated pore-water pressures that triggered hundreds of landslides. A selection of these landslides are presented in this report.

Following a disaster declaration by President Clinton for most counties in Washington, the Federal Emergency Management Agency (FEMA) made funds available for identification, investigation, and remediation of the landslides, among other emergency needs. Division of Geology and Earth Resources geologists were asked by the Washington State Emergency Management Division to help the City of Seattle with damage assessment. Helicopter flights and several days of on-the-ground visits provided an overview of storm effects. The Division submitted oral and written reports to the City of Seattle and worked with other local geologists and landslide experts to examine new slides and slide-prone areas that threatened structures and transportation corridors. At the same time, private consultants assisted homeowners in repairing the damage and provided advice on slope stabilization techniques.

Figure 1. Map of the City of Seattle showing landslide critical areas (shading) and the location of some of the landslides that occurred during the December 1996–January 1997 storms (black dots). Compiled from City of Seattle information.

This article is a photographic essay that provides a geologic explanation for these landslides. In Seattle and to the north, the areas of Magnolia, West Seattle, and Whidbey Island were particularly hard hit (Figs. 1, 13). Captions for Figures 2–12 and 14–21 describe the setting of the landslides that

Figure 2. This house, which has been the subject of several news stories, is located on East Boston Terrace in the Capitol Hill area of Seattle. It hangs precariously over the headscarp of a reactivated old landslide. Careful construction engineering preserved the structure but not the front yard, leaving the driveway suspended. The failure of the front yard destroyed part of the road below. Note the exposed pipes, climbing ivy no longer rooted (below the tall window on the right), and tension cracks migrating into the neighbor's yard to the left in the photo. After this picture was taken, a retaining wall was built in front of the house (Seattle P-I, Feb. 6, 1997); a retaining wall behind the house was built during the original construction. This house is in the same drainage as, and a few hundred feet upslope of, a house destroyed by a landslide in 1942. That landslide killed one resident and seriously injured another.

Figure 3. This boating supply store on Harbor Avenue SW stands in a line of commercial and residential structures at the base of the bluff on the east side of Duwamish Head. Many debris flows were generated along the upper portions of the bluff as a result of the December storms. At this site, a fairly small debris flow (approx. 200 yd^3) hit the back of the building and split into two lobes, one flowing north around the outside of the building, the other pushing through and out the front of the building. (See also the cover photo.) The area without vegetation on the bluff behind the store is a layer of sand that failed when it became saturated by ground water perched on the underlying clay. An explanation of this common geologic situation is given in Figures 20 and 21.

Figure 4. The "Anderson house" (known by the name of its designer) is cantilevered over the slope above Ferry Avenue SW, north of the bluff shown in Figure 3. Below it, and about 15 feet above the street, a small debris flow initiated in saturated material (here colluvium) covering clay deposits. Clay layers can be seen in the lower part of the photo. Slides like this commonly increase in size through headward erosion.

Figure 5. This view to the east shows three homes along Alki Avenue SW in West Seattle that were affected by a growing deep-seated landslide. The largest displacement occurred west (toward the viewer) of the low house on the left. Note the person (circled) standing on the down-dropped portion of the slide in front of the headscarp. Also visible is the displacement of the deck of the large house in the center. The tension crack delineating the headscarp continues through the deck area in the center house and into the backyard of the house to the right (south). The dark line extending from the house on the left is a tightline for drainage (see p. 29). Another segment of the headscarp is visible to the left of the tightline.

Figure 6. This photo shows one of the larger Seattle landslides along Perkins Lane on the southwest side of the Magnolia neighborhood. This is an area of continuing large-scale instability. Immediately following the February 1996 storms, a 1,500-yd^3 landslide (Harp and others, 1997) slid from the upper portion of the bluff into the back yard of the home on the right. Seattle engineers attempted to mitigate the problem by regrading and revegetating the upper slope. However, the February landslide was a shallow manifestation of a deep-seated rotational failure that formed, or might have already existed, in the sand, gravel, and silt deposits of the bluff at this site. This deep-seated slide was reactivated in December 1996, damaging at least five houses. These three are now uninhabitable. The white plastic sheeting on the slope was probably placed there in an attempt to prevent water from infiltrating the soil. This site is representative of the geologic conditions shown in Figures 20 and 21C.

Figure 7. This house in West Seattle (lower right), and a portion of the road that runs behind it, are built on fill, commonly failure-prone when saturated. Note the down-dropped (and previously patched) section of the road between the white signs. Tension cracks start to the left of this area and extend to the right, under the house. Fill material at the lower right corner of the house appears to be displaced. Also note the recent debris flows in the drainage below the road (lower left center of this photo). These may have been caused by excessive runoff onto colluvium and fill.

Figures 8A & B. *(this and facing photo)* This landslide at the intersection of Ferry Avenue SW and California Way SW, just to the north of the "Anderson house" (Fig. 4), illustrates geologic conditions that contribute to many Seattle landslides. Sand exposed in the upper bluff (barely visible in the upper left corner of B) has been sloughing onto the bench (visible in the upper portion of both photos) and then sliding along that bench to the lower bluff's edge (see Figs. 20, 21). These photos were taken several days after the initial landslide. Sand was still slowly creeping out over the clay toward the face of the slope. Despite the large amount of recent precipitation, much of the upper part of the sand unit remained well drained and dry. Roots exposed above the person (circled) in B are being stretched and torn because they are at the contact (dashed line) between the sand and the impermeable clay, from which ground water is seeping (more visible in A). The clay layers just above the fallen tree in A remain intact. This landslide blocked the intersection and forced its closure for more than a week.

Figures 9A & B. This shallow landslide, just north of the intersection of Ferry Avenue and California Way SW (Fig. 8), occurred following the storm of February 1996. Subsequent regrading and covering with plastic sheeting stabilized this portion of the slope enough to prevent shallow failure during the December 1996 storms. However, disruption of the pavement and sidewalk at the base of the slide (B) suggests that the slope may be moving along a deeper failure surface and may still (or again) be active. Notice the tilted street lamp. Although the plastic serves to prevent shallow failures, it does little to prevent a deep-seated failure, such as that shown in Figure 6. Just below California Way are several homes and businesses; at the time of the inspection, a sign indicated that more building is proposed. In A, snow, more than a week old, is still lying at the base of the plastic.

Figure 10. This view to the west over the Magnolia Bridge, a major artery into downtown Seattle, shows the landslide that forced the closure of the bridge and the "red-tagging" (condemning or declaring uninhabitable) of at least five homes along the headscarp of the slide. This slide occurred after the rains had ceased. Notice the displaced bridge trusses, the debris on the house at the base of the slope, and the broken water main just below the fallen truss and above the house.

Figure 11. The owners of the house under construction in the center of this photo recognized the potential for instability at the site. The "shotcrete" (concrete sprayed on the slope) on the face of the slope was intended to protect the sandy upper part of the slope from surface erosion, but failed, probably due to excessive hydrostatic pressure. The shotcrete seems to hang like a curtain over the bluff face, with the left portion having fallen away.

Figure 12. This slide, one of many that occurred along a stretch of railroad tracks north of Carkeek Park, lies within an older, larger slide scar. Past slides along these tracks have temporarily halted train traffic many times. Such slides have knocked railroad cars into Puget Sound, at times resulting in injuries or hazardous spills. Trip wires are strung just above the retaining wall along the tracks. An interrupted circuit signals when (but not precisely where) landslides occur. Figures 21 through 26 illustrate the different mechanisms responsible for landsliding along this stretch of bluff. Development at the top of the bluff can contribute to and is affected by the slides. Coastline modifications such as the bulkhead (built in the 1890s to support the railroad bed) also affect slope and near-shore processes. The bulkhead does not prevent landslides, but does control the rate and nature of redistribution of slide debris in the near-shore zone. Material dumped into the Sound by railroad crews cleaning the tracks is rapidly redistributed out of the narrow and steep intertidal zone and offshore by wave energy reflected off the bulkhead.

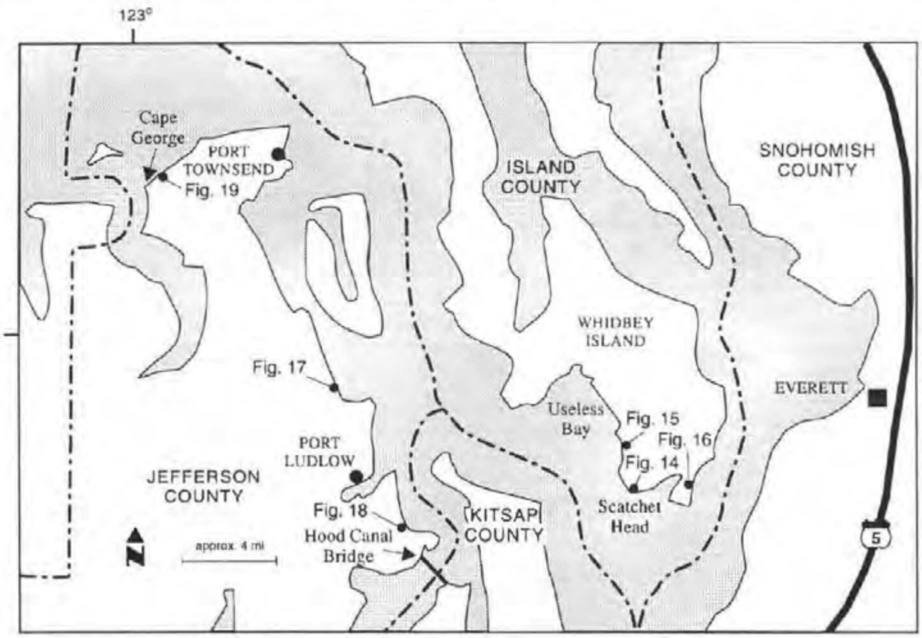


Figure 13. Locations of landslide damage shown in Figures 14 through 19.

Figure 14. At Scatchet Head at the southern end of Whidbey Island, mudflows temporarily block access to these beach-level homes during wet winters. The upper bluff is porous glacial outwash sand that dries out in summer. The silt that forms the lower bluff (below dashed line) and perches ground water is damp and green year round. The top of the silt is approximately at the position of the dashed line. The scarp in the background and the partially forested bench are characteristic of such slide areas where percolating ground water is perched above the less permeable silts. The sands are weaker than the silts and slide readily when saturated. Similar situations are present north of Carkeek Park and in the Golden Gardens area of Seattle, among other places. (See Figs. 20, 21.)

Figure 15. Slide activity such as this in the Useless Bay area of Whidbey Island can cause periodic retreat of the bluff edge by as much as 20 feet or so in seconds. During this recent slide, a portion of the fence in front of the large house was lost. Such episodes commonly are preceded and followed by decades of little erosion, making estimates of average bluff retreat rates potentially meaningless. In this location there are multiple impermeable silt layers that perch water, in contrast to conditions like those at Scatchet Head (Fig. 14), where water is concentrated above one impermeable "perching" layer. Slides here can be triggered by an abundance of water (as in the December/January storms) or by wave erosion at the base of the bluff. A rainstorm may simply be the "last straw". In many locations around the sound, water from winter rains is accumulated inland of bluffs and may cause landslides to occur months later as it slowly migrates toward the bluff. In the mid-1970s in the Golden Gardens area of Seattle, slides occurred well into summer after a series of exceptionally wet winters.

Figure 16. Several beach homes on the east side of southern Whidbey Island had close calls from debris avalanches. Debris avalanche tracks and deposits here will soon be colonized by alders. Stripes or patches of alder trees that are all of the same age can indicate areas where slide activity occurred in the past; the age of the trees indicates approximately when the slide(s) occurred. In the 1950s and '60s, many beach-level developments like this were constructed on fill behind bulkheads. Material for the fill was commonly hosed off the slopes or bulldozed from the bluffs. This may have contributed to continuing slope instability by destabilizing the toe of the slope.

Figure 17. Fortunately, homes here were built with adequate setback— for these failures. The depth of a failure surface can influence the rate of retreat of the edge of the upland surface. In this slide west of Port Townsend, shallow debris avalanching (far left) has caused no significant edge retreat yet. The mid-bluff bench on the right indicates a relatively deep-seated slide of upper-bluff sediments only. (See Fig. 21B.) The surface of failure for the middle slide is even deeper, "daylighting" at (or below?) beach level (Fig. 21B, C), and has caused the most retreat. At many sites along the coastal bluffs, sedimentary units are not laterally continuous, and conditions can be quite different over a distance of 100 feet or less.

Figure 18. This shoreline home between the Hood Canal Bridge and Port Ludlow lost its front yard during the December/January rainstorms and snowmelt. Bedrock exposed on the beach below the bluff shown in this photo was resistant to wave erosion. However, the glacially polished bedrock perched ground water in the gravelly sand above the steeply sloping contact here. Runoff from rapid snowmelt was apparently funneled down the driveway from upslope development. The area to the left of this landslide (out of view) was probably buttressed by a large maple stump kept alive by sprouts. (The area still farther left also failed.) Glacially compacted silts or bedrock form a barrier to roots and ground water. Where this condition exists in the Puget Lowland, shallow debris avalanches can be common. The overlying permeable saturated soil cannot be anchored to the substrate by the weak toehold of the roots of trees and other vegetation.

Figures 19A & B. Continuing slide activity has made this home near Cape George in Jefferson County uninhabitable. At this site, the perching layer is a small area of ancient lakebed silt that lies beneath the house at about mid-bluff level, now covered with grass dropped from the back lawn. This part of the bluff remains green year round. Note the old slide mass at beach level (lower left), now covered by alder trees that are all of approximately the same age (here, perhaps 25 years old). Also note the arcuate line of boulders seaward of these trees. Such a pattern of boulders, which are commonly accompanied by steeply tilted silt and clay beds, can indicate an old slide surface at or below beach level. **B.** *(right)* This closeup shows recent slide debris on the bench, as well as the exposed septic tank (the white rectangle below the right side of the house and drainfield pipe in A); the tank has since fallen to the beach. Poorly located septic systems often contribute to slope instability. The dark strata at the upper part of the bluff are gravels and are not saturated here. It is possible that drainfield effluent percolated downward and bluffward to destabilize this slope or that deeper ground water caused the problem at this location. Wave erosion has likely been a contributor at this site as well. Trying to maximize a view by building close to the bluff line can be a costly and potentially hazardous mistake.

occurred in these areas. We also discuss what area residents can do to avoid such serious consequences and prepare for the effects of future rains and snows. At the end of the article is a list of helpful books and articles.

GEOLOGY BY EXAMPLES

Seattle Area Stratigraphy

Several different mechanisms contribute to the instability of coastal bluffs in the Puget Sound region. The resulting landslides can range in size from small, shallow soil slips to large, deep-seated rotational slump-earthflows. Most of those resulting from the February 1996 and holiday 1996/97 storms were some variation of the ones shown earlier in this article and described in the following text and accompanying sketches.

The typical undisturbed stratigraphy in the central Puget Sound area consists (from the top down) of a thin soil layer overlying relatively impermeable till (hard pan), permeable sands, and/or nearly impermeable clays and silts (Fig. 20). However, in many areas, the stratigraphy can be more complicated (Figs. 15, 17).

Throughout much of the Seattle area, till of Vashon age (approximately 13,000 years old), approaching thicknesses of up to 30 ft, forms a relatively strong and resistant cap that covers much of the highlands and protects softer underlying layers from erosion. Although till is in many places impermeable to ground water, fractures and gullying in the till surface allow percolation into the lower sedimentary layers. Till commonly overlies advance outwash deposits locally known as the Esperance Sand.

The Esperance Sand was deposited by streams issuing from the ice sheet while it was located some distance to the north. It is highly permeable (well-drained) and poorly consolidated. In typical Esperance Sand deposits, the upper part may be dry, even in winter, whereas ground water flows rapidly through its basal zone, where the water is perched on underlying clays and silts. Water saturation builds pore pressure, which in turn reduces soil strength and allows the sand to mobilize and slide along the surface of the clay (Fig. 21). In some places, the sand is so poorly consolidated that it collapses on itself and flows like a fluid. Permeability within the Esperance Sand varies laterally and vertically, and ground water piping can occur along weak zones. Gullies form where piping intersects the surface.

The compact clays and silts underlying the Esperance Sand were deposited in a proglacial lake that existed before the ice advance into the Puget Sound area. The name "Lawton Clay" is applied to this thinly and parallel-bedded clay and silt unit. The Lawton Clay perches ground water, forming the slippery surface on which the Esperance Sand can slide (Fig. 21B, C). The clay unit, generally more competent, remains in place, with only minimal seasonal retreat. With each passing winter, the sand portion of the bluff retreats at a faster rate than the clay and the resulting landform is the characteristic stepped or benched bluff (Fig. 21C). Deep-seated failures can occur where a failure surface extends into the clay unit. (For discussions of these and other relations between ground water and landslides, see Tubbs, 1974; Dunne and Leopold, 1978; Freeze and Cherry, 1979; Thorsen, 1987; and Evans, 1994.)

Any of these Pleistocene units may overlie knobs and fault blocks of impermeable Tertiary bedrock. The upper surfaces of these bedrock protrusions may also perch water and act as glide planes for landslides (Fig. 18).

Processes along the Burlington Northern–Santa Fe (BNSF) Railroad North of Carkeek Park

The landslides that occurred along the BNSF Railroad tracks (Figs. 12–26) provide excellent examples of the different types of failures and the different slope retreat rates discussed above and seen throughout the storm-damaged areas (Fig. 21). It is important to understand and anticipate these landslides, as they have been and will continue to be responsible for damage along the Puget Sound shoreline.

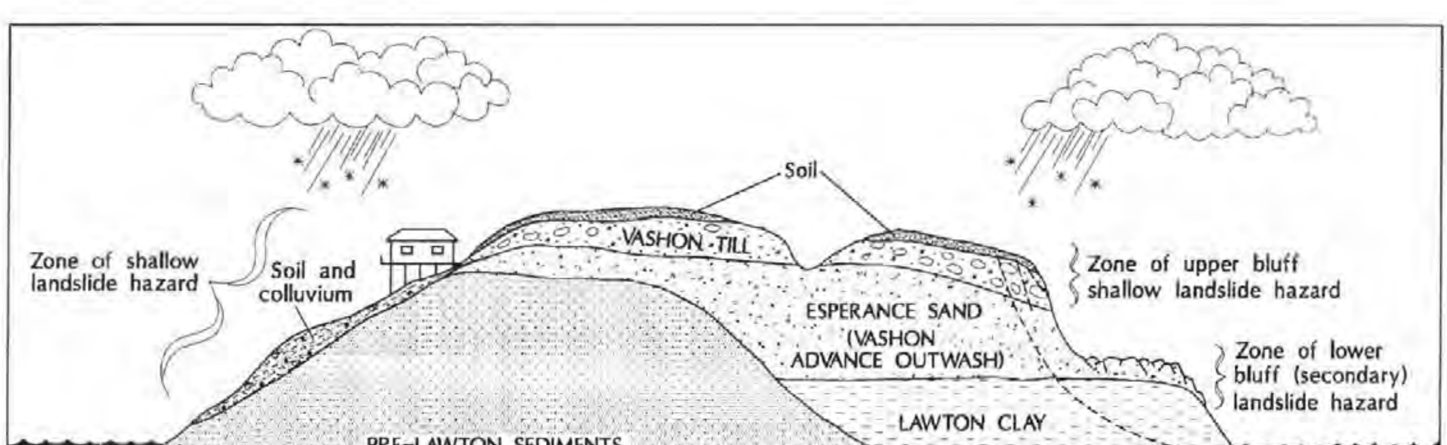
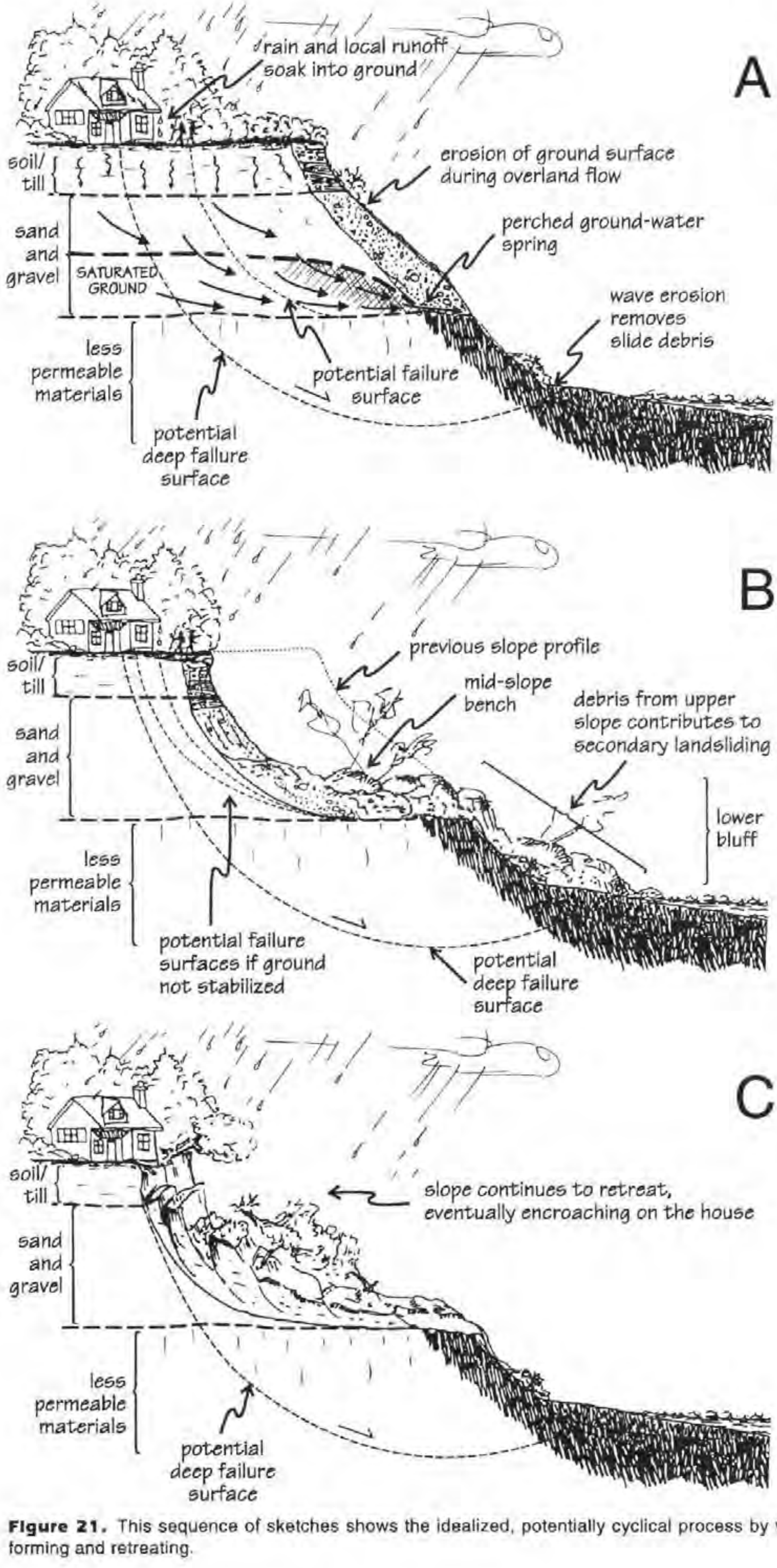


Figure 20. This is an idealized cross section of the characteristic stratigraphy in the Seattle area that is responsible for landsliding. These units are not necessarily laterally continuous over long distances, and they can be more complex, with several water-perching layers. However, the general geologic and hydrologic principles are similar. The Esperance Sand and Lawton Clay are unit names restricted to the Seattle area, but similar sequences are present elsewhere in the Puget Lowland. (Adapted from Tubbs, 1974.)



A At the beginning of an idealized cycle, the bluff has a uniform slope. Water infiltrates the surface soils and perches above the relatively impermeable materials at the base of this sandy sequence. Saturation creates pore-water pressures that reduce the effective strength of these materials.

B Runoff and precipitation introduced by the sources shown in **A** have infiltrated and weakened the sediments, causing failure of the unconsolidated upper sand unit. Once mobilized, the sand moves (sometimes episodically, sometimes continuously) along the contact with the underlying less permeable unit on the mid-slope bench, often cascading as a secondary landslide off the bluff formed by the lower unit. This migration of material across the bench decreases the buttressing of the upper bluff. Failure surfaces can be deep (those that project into the lower, less permeable materials) as well as shallow.

C Benched bluff retreat continues. Movement of slide debris toward the lower bluff further destabilizes the upper bluff, causing continued sloughing onto the bench. Either failure of the upper bluff onto the bench or failure of the slide debris off the lower bluff can trigger a cycle of movement. Movement along a deep-seated surface can reset this sequence of events.

Figure 21. This sequence of sketches shows the idealized, potentially cyclical process by which bluffs in the northern Puget Sound area are forming and retreating.

Figure 22. This view to the south shows a few of the many recent debris flows along the section of the railroad tracks north of Carkeek Park (Fig. 1). Exposed in the lower half of the bluff face are dense water-perching clays and clayey silts, which have not moved at this location. These maintain a steep bluff face that is often wet due to ground water seeping from the contact with the overlying sand. The weaker overlying sands have a much gentler slope. In the upper middle part of the photo, one can see the headscarps of older, vegetated landslides that have progressed farther back into the highlands. These features illustrate the continuing differential retreat rates of the upper and lower portions of the bluff (see Fig. 21C). The home in the left center of the photo sits in one of these landslide scars. This view shows the bulkhead that protects the toe of the slope from wave erosion (discussed in Fig. 12).

Figure 23. This view to the south (and Figs. 24–26) of the bluff along the railroad tracks (60–80 ft below) shows a fresh exposure in the Esperance Sand (Fig. 20). Shallow failures in this unit created a sand slurry (Fig. 25) that flowed onto the bench in the lower right of the photo. This location is just south of the area shown in Figure 22.

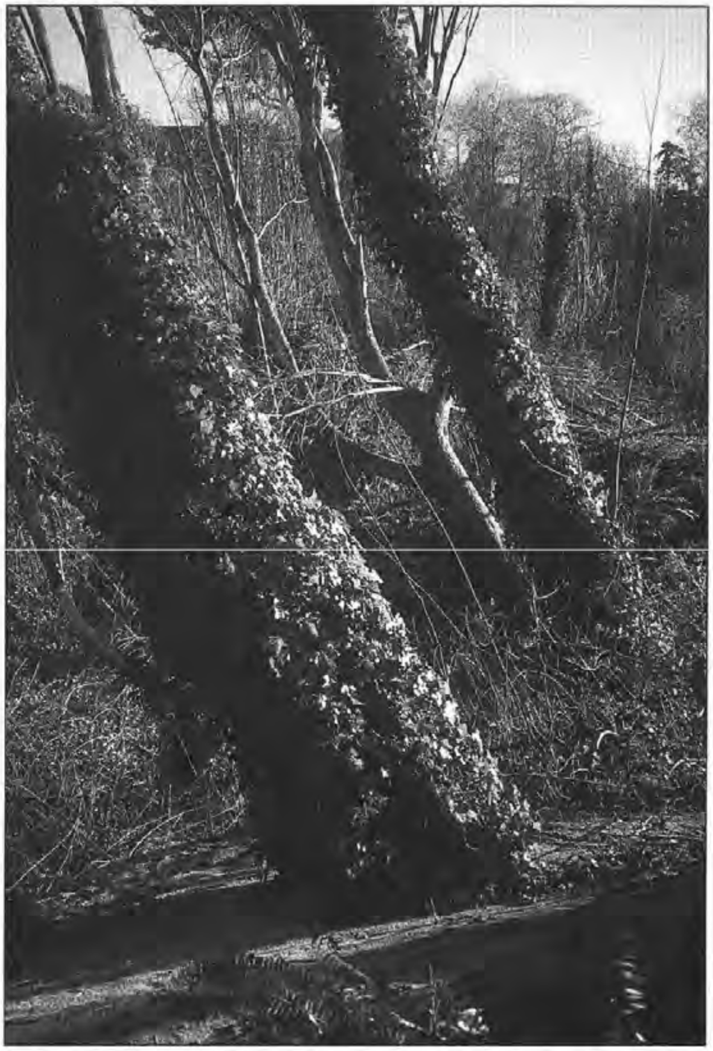


Figure 24. These tilted trees are those shown on the right in Figure 23. They indicate back rotation of the bench along a larger, deeper seated failure surface. Tension cracks in the sand surrounding the base of the trees (Fig. 25) show that this movement took place after the sand slurry was deposited.

Figure 25. This closeup of the sand slurry deposit (Fig. 24) shows that sand flowed onto the bench from left to right in the photo (now uphill). Partial drying of the sand and subsequent rotation of the bench resulted in the formation of these tension cracks parallel to the back edge of the bench (upper left of photo). Note footprints for scale.

Figure 26. In this view to the north, the large tension crack near the outer edge of the bench indicates active movement. The geologist in the foreground is standing in the crack; the other is at the north end of the crack. The railroad tracks are about 60 ft below and to the left.

WHAT CAN BE DONE TO IDENTIFY AND AVERT POTENTIAL LANDSLIDES?

As the Growth Management Act and its enabling regulations state, avoidance is the safest approach when it comes to land-use practices in areas of unstable slopes. However, in many places urban growth has already encroached on these slopes. If you live at the edge of a bluff or in an area that has experienced landslides in the past, there are some things you can do to reduce the rate of bluff retreat and improve the stability of the slope with respect to shallow failures and surface erosion. Deep-seated failures are more difficult to control, but it is clearly beneficial to reduce infiltration and surface runoff from roofs and driveways and to fix clogged or leaking storm drains.

Listed at the end of this article are several publications that provide useful information on amelioration of unstable bluff slopes. Figures 27 through 29 show examples of stabilization efforts in the Seattle area, not all of which were successful. The following lists offer landslide identification criteria and prevention and mitigation techniques.

Identification of Landslide Hazard Areas

These are some characteristics that may be indicative of a landslide hazard area:

- Active bluff retreat – Continuing sloughing or calving of bluff sediments, resulting in a vertical or steep bluff face with little to no vegetation.
- Pre-existing landslide – Landslide debris within an arcuate head scarp.
- Tension cracks – Ground fractures along and/or near the edge of the top of a bluff or ravine.
- Structural damage – Settling and cracking of building foundations near edge of a bluff or ravine; also separation of steps or porch from the main structure.
- Toppling, bowed, or jackstrawed trees – Disruption of the ground surface by active movement causes trees to lean and/or fall in different directions or to grow in a curve instead of straight.

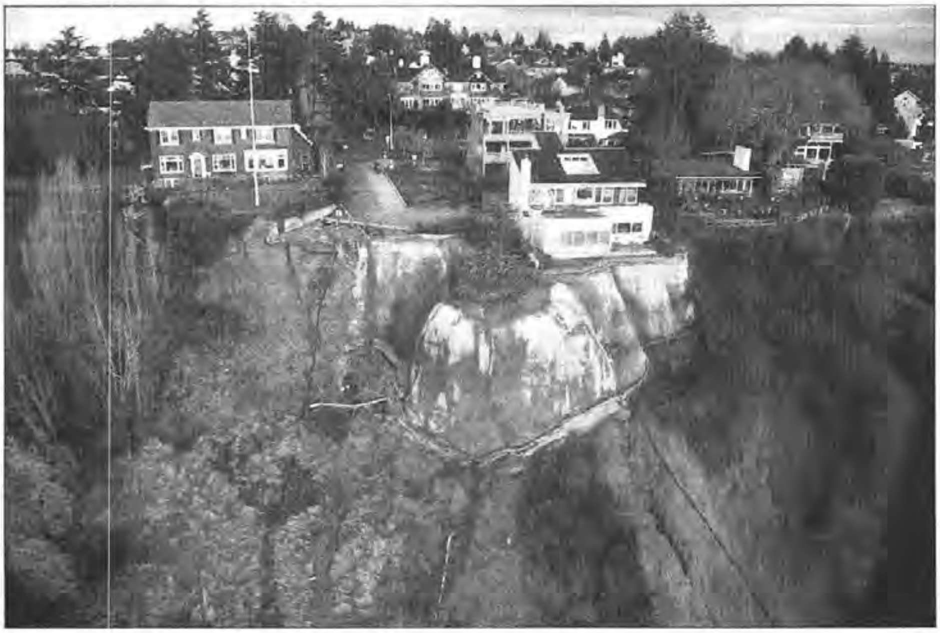


Figure 27. Shotcrete, shown here, has been used (not always successfully) to prevent surface erosion and headward migration of the bluff edge. The drainage must be directed away from the base of the cover so that the shotcrete will not be undermined by surface erosion. The drainage must also be continually maintained in order to be effective. In this location, there is extensive erosion occurring at the base of the shotcrete cover. If the material behind it is washed away, the shotcrete will fail, as seen in Figure 11.

Figure 28. These two apartment buildings in the Duwamish Head area of West Seattle, just south of the intersection of Ferry Avenue and California Way SW shown in Figures 4 and 8, are built at the head of a small ravine on unconsolidated sand deposits. The February 1996 storm resulted in a shallow debris slide in that ravine. As a result, drainage from all the roofs and balconies is now collected in nonperforated pipes and directed away from the steep slope. This is called tightlining, and it is also effective along beach bluffs. There were no slides directly below these buildings as a result of the December/January storms.

- Gullying and surface erosion – Dissection of the bluff edge by natural drainage or discharge from pipes, culverts, and ditches.
- Springs – Mid-slope ground-water seepage from the bluff face; particularly noteworthy are increases in flow.

Safeguarding Against Landslide Hazards

The following are some measures that can be taken to mitigate or avoid landslide hazards:

- Use setbacks – Expect natural slope processes to continue, and provide adequate construction setback for structures in landslide hazard areas.
- Reduce surface erosion – Keep drains and culverts clear. Avoid discharge onto the slope—direct surface water/runoff (especially from impermeable surfaces) to the base of the slope in nonperforated pipe. This is called tightlining.
- Reduce ponding and infiltration – Limit opportunities for water to pond on the surface by draining or regrading. Consider connecting to city sewers instead of installing or replacing septic systems.
- Maintain and improve vegetation – Trees and shrubs provide root strength to hold the soil in place and help dewater the slope. If they are removed, root strength will be gone within 2 to 12 years and will not be easily restored.
- Protect bluff from surface erosion – Apply erosion mats, plastic sheeting, or other erosion-control material where vegetation will not take hold.

DISCUSSION

The Puget Lowland bluffs have experienced landslides for thousands of years. Bluff retreat is a normal process. Some of the small-scale, but still potentially destructive, retreat occurs

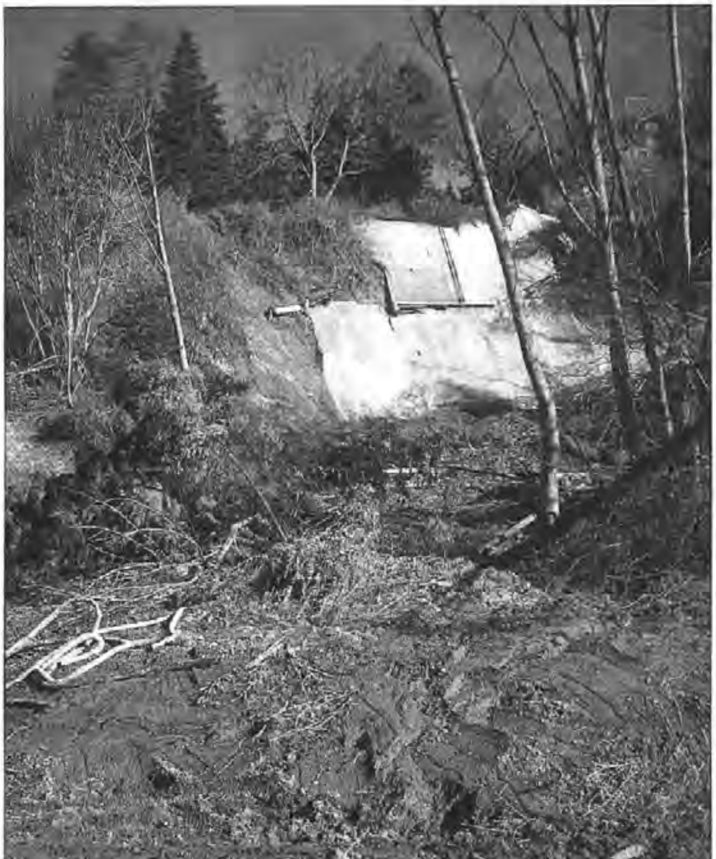


Figure 29. A resourceful homeowner in the area north of Carkeek Park, along the BNSF Railroad, used metal roofing material to cover the upper portion of the slope below his house. However, the lower part of the slope failed as a debris flow onto the railroad tracks during the December/January storms, probably because energy from runoff water was not properly dissipated, thereby causing erosion below the roofing material. Subsequently the lower slope was covered with strips from large rolls of plastic sheeting. Placing the plastic required the use of technical climbing equipment by skilled workers seen here to the left of the sheeting.

as continuous raveling and sloughing. The larger landslides tend to be more episodic. When heavy winter precipitation is added to bluff sediments, unstable parts of the slope tend to fail. (See, for example, Thorsen, 1987.) The frequency over time and space of these failures increases during and after particularly heavy precipitation. In some places, human activities (such as poor construction practices) have exacerbated the rate of bluff retreat by landsliding.

By learning to recognize old landslides and studying the effects of construction and landscaping near and on slide-prone areas, we may be able to plan for the slides to come.

In 1990, the legislature passed the Growth Management Act (amended 1991) requiring the enactment of local ordinances that govern the development of unstable coastal bluff areas. RCW 36.70A.170 requires that "on or before September 1, 1991, each county, and each city, shall designate where appropriate:...critical areas". These include "geologically hazardous areas", which are areas that "because of their susceptibility to erosion, sliding, earthquake, or other geological events, are not suited to the siting of commercial, residential, or industrial development consistent with public health or safety concerns" (RCW 36.70A.030).

The regulations (365-190-080 WAC) state that:

> "geologically hazardous areas...pose a threat to the health and safety of citizens when incompatible commercial, residential or industrial development is sited in areas of significant hazard. Some geological hazards can be reduced or mitigated by engineering, design, or modified construction practices so that risks to health and safety are acceptable. When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided. This distinction should be considered by counties and cities that do not now classify geological hazards as they develop their classification scheme.
>
> (b) Counties and cities should classify geologically hazardous area as either:
>
> (i) known or suspected risk.
>
> (ii) no risk.
>
> (iii) risk unknown – data are not available to determine the presence or absence of a geological hazard."

Ordinances identifying geologically hazardous areas are now in place in most cities and counties of Washington. Of the recent slides in Seattle, none occurred at a site developed solely under the new ordinances, suggesting that they may be providing a safeguard against slide hazards. Nevertheless, Seattle declared a 90-day moratorium on development in landslide hazard areas to assess the adequacy of the steep slopes ordinance. For information on designated steep-slope hazard areas in your community, contact your local planning agency or building department.

If you are uncertain about the conditions surrounding or underlying your home or property, consult the listed references or any of the many others available at your library or local jurisdictional offices. If you are still unsure, seek geotechnical advice from a professional geologist or geotechnical engineer.

ACKNOWLEDGMENTS

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(Although focused on Orange County, Calif., this book contains much information relevant to the Pacific Northwest. It is available from the International Conference of Building Officials, 5360 Workman Mill Rd., Whittier, CA 90601-2298.)

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Burke Museum Closes to Prepare New Exhibits

The Burke Museum will close its doors April 28 to renovate and install exhibits. It will reopen this coming November. "Life and times of Washington State—A trek through geologic time" and "Pacific voices—Worlds within our community" are two long-term exhibits being prepared for November.

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(Describes typical bluff retreat and slides in the Puget Lowland.)

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(Discusses 1972 landslides and includes a map showing slide locations and the "hazardous zone".)

See also: URL: www.geoengineers.com/ic52.htm

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(These volumes contain colored maps that show landslides and relative slope stability.)

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(Photocopies available through the Washington Division of Geology and Earth Resources.)

Wold, R. L., Jr.; Jochim, C. L., 1989, Landslide loss reduction—A guide for state and local government planning: Colorado Geological Survey Department of Natural Resources Special Publication 33, 50 p.

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Photo Credits

Wendy Gerstel – 3–5, 9B, 23–29
Leonard Palmer – 19B
Hugh Shipman – 2, 6, 7, 10–12, 22
Gerald W. Thorsen – 14–19A
Tim Walsh – 8A, 8B, 9A

Note added in proof: As this issue was going to press, another rainstorm hit the Puget Sound area and caused at least 30 more landslides.

Errata

- The price for Open File Report 96-6, Preliminary bibliography and index of the geology and mineral resources of Washington, 1991–1995, (announced in the previous issue) should indicate $1.03 tax.
- The cover photo and the photos on p. 22 in the previous issue were taken by Tim Walsh of our staff.
- In the previous issue, the article "A Field Guide to Washington State Achaeology" contains at the end of the last sentence "and also briefly discusses Ringold Formation correlatives throughout the region, setting the stage for future regional sedimentologic interpretations." This phrase wandered in from somewhere else and does not actually belong with the field guide.

Marshall Tower Huntting (1918 – 1996)

Former State Geologist and Supervisor of the Division of Mines and Geology (now Division of Geology and Earth Resources) Marshall T. Huntting died in a traffic accident near Morton, Washington, on December 21, 1996.

Marshall was born on October 3, 1918, in Silver Creek, Washington, where his family owned a farm. He graduated from Mossyrock High School in 1936. In the summer of 1936, he worked in the placer gold fields of Alaska and attended the University of Alaska, Fairbanks, during the 1936–1937 school year. He then attended Washington State College (WSC, now Washington State University) in Pullman and received a B.S. degree in Geology in 1941. He stayed at WSC for graduate work and received his M.S. degree in Geology in 1942.

At that time, the Division of Geology (the predecessor of the Division of Mines and Geology and the Division of Geology and Earth Resources) was headquartered at WSC, and the Geology Department Chairman, H. E. Culver, was also State Geologist and Division Supervisor. During his college years, Marshall worked for the Division during at least some of the summers, serving as a field assistant in 1939 and doing geologic mapping for the Division in the Horseshoe Basin area near Cascade Pass in the North Cascades in 1940. The 1940 mapping for the Division of Geology was combined with the Department of Geology's summer field camp class (Fig. 1). While at WSC, Marshall met and later married Martha E. Currie of Cashmere, WA. She died in 1990. They had no children.

Marshall served in the U.S. Army in the Philippines from 1943 to 1945. He began full-time work for the Division of Geology, still headquartered in Pullman, in May 1942. In 1945, the Division of Geology was combined with the Division of Mines and Mining and moved to Olympia, where Mines and Mining was already located. The combined division was called the Division of Mines and Geology.

Marshall served as a geologist with the Division under Supervisor and State Geologist Sheldon L. Glover and became Assistant Division Supervisor in 1956. When Glover retired in February 1957, Marshall was named Supervisor and State Geologist. During the earlier part of Marshall's tenure in Olympia, the Division's offices were on the top floor of the Transportation Building (now the John L. O'Brien Building) near the Legislative Building. In about 1956, the Division moved to the new General Administration Building and occupied a suite of offices, known as Room 335, on the west side of the building near the northwest corner, adjacent to the Division of Water Resources. Prior to 1967, the Division had been part of the Department of Conservation and Development. On July 1, 1967, that department was disbanded, and the Division was transferred to the Department of Natural Resources.

During his career with the Division, Marshall's major emphases were on development and conservation of mineral resources, geologic mapping, regulation of oil and gas drilling, and, later, surface mining reclamation. Marshall's two most important and lasting contributions were his Inventory of Washington minerals, Part II—Metallic minerals, published in 1956, and 1:500,000-scale geologic map of Washington published in 1961. The Inventory of Washington minerals has served the mineral industry well and still guides mineral exploration in this state.

Marshall was a member and officer of the North Pacific Section of the American Institute of Mining, Metallurgical, and Petroleum Engineers and the Northwest Geological Society. He was certified as a registered mining engineer in 1948.

Following his retirement on June 30, 1971, Marshall and Martha moved to their farm near Silver Creek in Lewis County. The effect of retirement on Marshall was wonderful. He had retired partly because of increasing regulatory responsibilities, and his duties sometimes left him rather harried. He visited the office a few months after his retirement, and the change was marvelous. He was tanned, smiling, and physically fit. He remained that way. He also remained very, very active, so much so that it is not really accurate to say he retired. He just changed jobs, from geologist to rancher, farmer, forester, and civic leader.

Marshall continued to do occasional geological consulting jobs, and he stayed in touch with the Division, but most of his energy went into public service and raising cattle, berries, filberts, and trees. At various times he was board member for Lewis County Conservation District, member of Lewis County Farm Bureau Association, American Farm Bureau advisory committee on forestry, Lewis County Planning Commission, Lewis County Farm Forestry Association, and Lewis County Search and Rescue. In 1992, his was the Lewis County Tree Farm of the Year, and in 1995, the Wildlife Farm of the Year. He served 14 years as secretary/treasurer of the Mossyrock Viking Scholarship Fund.

Figure 1. The Washington State College field camp in Horseshoe Basin at the headwaters of the Stehekin River near Cascade Pass, September 1940. Standing, left to right, Chuck Graham, Grant Valentine, Eugene Richardson, Arthur Ritchie, and Marshall T. Huntting. Kneeling or seated, left to right, Hank Wenden, Robert Stevenson, and Sherwood D. Tuttle. Photograph courtesy of Mrs. H. E. Culver. Some identifications courtesy of Grant Valentine.

Marshall was always ready to share his time and talent with others. He was interested in a great variety of natural resource-related issues and was always ready to talk about geology. Because Marshall was at his best when working with other people, Figures 1 and 2 picture him with colleagues rather than alone. Those who worked with him will remember and miss him.

by J. Eric Schuster

Figure 2. Staff of the Division of Mines and Geology sometime between 1958 and 1960. Standing, left to right, Bill Reichert, Ted Livingston, Jerry Thorsen. Seated, left to right, W. A. G. (Ben) Bennett, Gloria DeRossitt, Dorothy Rinkenberger, Mark Haun, Marshall T. Huntting, and Jean Preston (?). Not pictured: Wayne Moen. The photograph was taken in the Division library, third floor, General Administration Building. On the table is a large pantograph that was used to change the scales of source maps for the 1961 state geologic map.

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Centralia Chronicle, December 23, 1996, article entitled "Longtime forestry leader dies in crash".

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Washington Geologic Newsletter, 1974, What's Marshall doing these days?: Washington Division of Geology and Earth Resources, Washington Geologic Newsletter, v. 2, no. 3, p. 5-6.

Washington Department of Natural Resources, 1967, Mining industry to prosper, says Huntting: Washington Department of Natural Resources, The Totem, v. 9, no. 10, October, 1967, unpaginated.

Displays at Marshall T. Huntting memorial service, January 19, 1997 at Mossyrock High School.

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Huntting, M. T., 1956, Inventory of Washington minerals; Part II—Metallic minerals: Washington Division of Mines and Geology Bulletin 37, Part II, 2 v.

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Moen, W. S.; Huntting, M. T., 1979, Gold in Washington: Washington Geologic Newsletter, v. 7, no. 4, p. 1-6. ■

Charles Phillips Purdy, Jr. (1916–1997)

Phil Purdy, geologist with the Washington Division of Mines and Geology for several years, died in Spokane on February 24, 1997, at age 81. During his career as a mining geologist he worked for both federal and state governments and for several corporations in the western United States, Canada, Greenland, and Central America. He retired in 1985, settled in Spokane, and became active with the Mineral Information Institute.

He began working for the Division as a geologist on April 7, 1947, and resigned on October 15, 1954. The 1948–1950 biennial report of the Division of Mines and Geology (Glover, 1951) lists Purdy's education as S.B. in Geology, Harvard College, and postgraduate in mining geology, Massachusetts Institute of Technology. He was the author of several reports for the Division, listed below.

Division Publications

Purdy, C. P., Jr., 1951, Antimony occurrences of Washington: Washington Division of Mines and Geology Bulletin 39, 186 p.

Purdy, C. P., Jr., 1952, Directory of Washington mining operations: Washington Division of Mines and Geology Information Circular 20, 75 p.

Purdy, C. P., Jr., 1953, Directory of Washington mining operations: Washington Division of Mines and Geology Information Circular 21, 81 p.

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Purdy, C. P., Jr., 1954, Molybdenum occurrences of Washington: Washington Division of Mines and Geology Report of Investigations 18, 118 p., 13 pl.

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Charles Purdy Jr. obituary, The Spokesman-Review, Spokane, WA, February 28, 1997, p. B2.

Glover, S. L., 1951, Biennial report no. 3 of the Division of Mines and Geology, for the period commencing October 1, 1948 and ending September 30, 1950: Washington Division of Mines and Geology, 13 p.

Glover, S. L., 1956, Biennial report no. 6 of the Division of Mines and Geology, for the period commencing July 1, 1954 and ending June 30, 1956: Washington Division of Mines and Geology, 12 p. ■

NORTHWEST PALEONTOLOGICAL SOCIETY

- May 3 meeting at the Burke Museum: Showcase session for members' collections
- June: Trip being planned to Chuckanut Formation outcrops; Bill Smith, leader
- August: Trip to Olequah and Coal Creeks, Cowlitz Formation; Bill Smith, leader

For more information about these field trips, contact Bill Smith, 13332 Ridgeland Dr., Silverdale, WA 98383.

Membership is $15/yr, $25 for families, $10 student or senior, and $5 junior; send checks to Betty Jarosz, 17807 NE 102nd Ct., Redmond, WA 98073. (Although elections are slated for May, questions and applications will be forwarded to the appropriate officers.)

NORTHWEST GEOLOGICAL SOCIETY

At the April 8 meeting, John Delaney will discuss exploration of the Juan de Fuca Ridge. On May 13, Darrel Cowan will talk about the San Juan Islands, a prelude to the members-only field trip he will lead June 6–8. The Division of Geology and Earth Resources plans to bring to each meeting copies of important new publications, new Division releases, and papers related to the speaker's subject. These would be "for inspection only" as an effort to inform members of what is available.

Meetings are held at the University Plaza Hotel, just west of I-5 on 45th Ave. Anyone may attend these meetings.

Tom Bush is president of the society, David Knoblach is president-elect, Linda Schieber is Treasurer, Matt Mero is Director of Publications, and John Whitmer serves as editor. Board members are Emery Bayley, Brian Lowes, and Art Coulter. For membership information, write to Donn Charnley (NWGS Secretary), 19344 11th Ave NW, Seattle, WA 98177-2613. Dues are $20 a year, $5 for students.

Book Review: Geological History of the Wenatchee Valley

The Geological History of the Wenatchee Valley and Adjacent Vicinity, A Pictorial Essay
by Charles L. Mason. Price $29.95.
Pixie Publishing (1996). 172 p. Softcover.

Available from the author at Pixie Publishing, P.O. Box 97, Rock Island, WA 98850-0097

The author presents the geologic history of the Wenatchee area, with Wenatchee as the geographic center of the discussion, and describes geologic events more or less chronologically. His presentation is that of an advanced amateur, with college courses and much practical experience, but no four-year degree in geology. Chapter headings are: In the beginning; The formation of Washington State; The rock cycle; Igneous rock structures; Basalt flows of the Columbia Plateau; Volcanoes and earthquakes; Consolidated and unconsolidated sedimentary deposits; Metamorphic structures; Landslides; Bretz-Missoula floods; Moses Coulee; Erratics, Knapp and Navarre Coulees; Malaga slide; Metallic, industrial and carbonaceous activity in the Wenatchee area; and Conclusion.

The book has a number of strengths. Although the geologic events described center on Wenatchee, many are treated in a regional, statewide, or even larger context, so the book is meaningful to people living outside the Wenatchee area. There is enough informal cross-referencing in the text to tie concepts, localities, and geologic events together adequately. The author displays an obvious wide-ranging interest in geology, has read the geologic literature treating the Wenatchee area, understands the geologic concepts and interpretations of geologists who have published on the geology of the area, has observed the geology of the area extensively, and presents the information in an easy-to-read way. His discussion is quite broad ranging—he has attempted to cover the whole of the geologic history of the Wenatchee area, not just selected geologic events. Basic concepts needed to understand his discussion are explained, so the book can be read by a layperson without reference to other works.

The author adds historical sketches that tie the geology to human activities. He explains the significance of past geologic events such as earthquakes and volcanic eruptions and discusses potential dangers from future events. Most of the locations are described and located well enough so the reader could find them with the aid of good maps and a knowledge of the section, township, and range location system.

Mason does quite a nice job of describing the sedimentary units in the Wenatchee area—the Swauk, Chumstick, and Wenatchee Formations. He covers the various aspects of the Columbia River basalts nicely and at considerable length. His best treatment, perhaps, is of the events of the last glaciation, especially the glacial Lake Missoula outburst floods and how they and related events shaped the topography and unconsolidated deposits found in the Wenatchee area today.

I think the most impressive feature of the book is the 198 color photographs, all taken by the author and his wife. Most illustrate the chosen feature well and have reproduced well.

The book also has a number of weaknesses. These include random capitalization, frequent misspellings, choice of wrong homonyms (roll for role, brakes for breaks, vain for vein, sheer for shear, mixed usage of terrain and terrane), careless and inconsistent use of the names of geologic units, lack of location maps, and use of "strata" and "stratum" without regard to the number of strata being discussed. Mason uses the term "structure" as a catchall term that includes, in different places, folds, faults, outcrops, peperite, hyaloclastite, hills, and igneous intrusions. This is quite irritating to a geologist who is accustomed to the word having a specific and much narrower meaning.

The author simplifies the plate tectonic history of Washington to only three accretionary packages, which he calls the Okanogan micro-island continent, Cascade micro- island continent, and Crescent terrane. For the non-geologist reader, this simplification is probably acceptable, even desirable.

There are a few outright mistakes and garbled definitions, for example, from page 58, "The oldest sedimentary formation within our state may be the Swauk."; from page 18, "An unconsolidated sedimentary material is rather self explanatory. The sediment is loose and 'unstratified.'"; and, from page 131, "An erratic is defined as a 'rock' of indeterminable size, transported by ice, from its 'in stiu' [sic] position, to some other indiscriminate location."

Overall, the book is a worthwhile effort and has much to offer both amateur and professional geologists. It would have been an outstanding book if the manuscript had been reviewed by a geologist and if misspellings, wrong homonyms, and English usage had been corrected.

by J. Eric Schuster

New Book on the Paleontology of British Columbia

"Life in Stone", a book about the paleontology, fossils, and fossil collectors of British Columbia has just been printed by the University of British Columbia Press. Rolf Ludvigsen has compiled and edited the contributions of numerous scientists and produced a comprehensive introduction to ancient life in our neighboring province. If not available locally, it can be ordered from Duthie Books, 919 Robson St., Vancouver, BC V6Z 1A5; (604) 684-4496. The price is about $65.00 Canadian or $45.50 U.S.

Ginkgo Petrified Forest Museum

Ginkgo Petrified Forest Museum in Vantage 1997 hours are 10 am–6 pm, weekends only in April; Friday–Sunday, May 1–12; and Thursday–Monday, May 16–Labor Day, when the schedule is reduced to Friday–Sunday. Groups tours (for a fee) of the facility are available year-round and can be arranged by calling (509) 856-2700. New events this year:

- The museum will be showing and selling the video "The Great Floods", depicting the Pleistocene outburst floods from glacial Lake Missoula.
- Ecology class: Wild Plants of the Desert, a 4-hr seminar describing native plants and their uses. By appointment, 12 person minimum, $3 per person. Led by Debbie Hall. Begins in April, weekdays only; schools will get reduced rates. Reserve time by calling the museum.
- Ginkgo seedlings will be sold to raise fund for the museum.

Selected Additions to the Library of the Division of Geology and Earth Resources

November 1996 through February 1997

THESES

Ahrens, R. J., 1995, Pedogenesis in soils derived from the tephras of Mount St. Helens: University of Nebraska Doctor of Philosophy thesis, 233 p.

Aziz, N. M., 1995, A baseline water quantity investigation of the west Medical Lake drainage basin, Spokane County, Washington: Eastern Washington University Master of Science thesis, 90 p.

Boese, R. M., 1996, Aquifer delineation and baseline groundwater quality investigation of a portion of north Spokane County, Washington: Eastern Washington University Master of Science thesis, 224 p.

Gough, Stan, 1995, Description and interpretation of late Quaternary sediments in the Rocky Reach of the Columbia River valley, Douglas County, Washington: Eastern Washington University Master of Science thesis, 112 p., 3 plates.

Johnson, E. A., 1995, Soil-gas radon mapping and seasonal variability, Spokane area, Washington: Eastern Washington University Master of Science thesis, 101 p.

May, M. T., 1991, Reanalysis of COCORP seismic reflection data from the Priest River metamorphic core complex of northeastern Washington: University of Wyoming Master of Science thesis, 89 p.

Morris, G. A., 1996, Petrogenesis of calc-alkaline rocks in an extensional environment—The Eocene Colville batholith of northeast Washington, USA: Washington State University Doctor of Philosophy thesis, 139 p.

Olson, D. F., 1995, Geology and geochemistry of the Lockwood volcanogenic massive sulfide deposit, Snohomish County, Washington: Western Washington University Master of Science thesis, 118 p., 8 plates.

Tucker, A. B., 1995, A systematic evaluation of fossil Raninidae from the Twin River Group, Olympic Peninsula, Washington, and a reexamination of the Raninidae: Kent State University Doctor of Philosophy thesis, 2 v.

Zheng, Yi, 1995, Distribution of major and trace metals in groundwater of the Spokane aquifer, northeastern Washington—Water quality and river/aquifer interaction: Eastern Washington University Master of Science thesis, 123 p.

U.S. GEOLOGICAL SURVEY

Published reports

Rogers, A. M.; Walsh, T. J.; Kockelman, W. J.; Priest, G. R., editors, 1996, Assessing earthquake hazards and reducing risk in the Pacific Northwest: U.S. Geological Survey Professional Paper 1560, 306 p., 5 plates.

Includes:

Adams, John, Great earthquakes recorded by turbidites off the Oregon–Washington coast. p. 147-158.

Atwater, B. F., 1996, Coastal evidence for great earthquakes in western Washington. p. 77-90.

Goldfinger, Chris; Kulm, L. D.; Yeats, R. S.; Appelgate, T. B., Jr.; MacKay, M. E.; Cochrane, G. R., Active strike-slip faulting and folding of the Cascadia subduction zone plate boundary and forearc in central and northern Oregon. p. 223-256.

Ma, Li; Crosson, R. S.; Ludwin, R. S., Western Washington earthquake focal mechanisms and their relationship to regional tectonic stress. p. 257-283.

Nelson, A. R.; Personius, S. F., Great-earthquake potential in Oregon and Washington—An overview of recent coastal geologic studies and their bearing on segmentation of Holocene ruptures, central Cascadia subduction zone. p. 91-114.

Peterson, C. D.; Darienzo, M. E., Discrimination of climatic, oceanic, and tectonic mechanisms of cyclic marsh burial. p. 115-146.

Rogers, A. M.; Walsh, T. J.; Kockelman, W. J.; Priest, G. R., Earthquake hazards in the Pacific Northwest—An overview. p. 1-54.

Rogers, A. M.; Walsh, T. J.; Kockelman, W. J.; Priest, G. R., Map showing known or suspected faults with Quaternary displacement in the Pacific Northwest. Plate 1, scale 1:2,000,000.

Snavely, P. D., Jr.; Wells, R. E., Cenozoic evolution of the continental margin of Oregon and Washington. p. 161-182.

Walsh, T. J., An introduction to earthquake sources of the Pacific Northwest. p. 71-74.

Weaver, C. S.; Shedlock, K. M., Estimates of seismic source regions from the earthquake distribution and regional tectonics in the Pacific Northwest. p. 285-306.

Yeats, R. S.; Graven, E. P.; Goldfinger, Chris, Map showing structure contours on top of bedrock, Benton, Lane, Linn, Marion, and Polk Counties, Oregon. Plate 3, scale 1:100,000.

Yeats, R. S.; Graven, E. P.; Werner, K. S.; Goldfinger, Chris; Popowski, T. A., Cross sections and selected residual gravity anomaly profiles of the Willamette Valley, Oregon. Plate 2C.

Yeats, R. S.; Graven, E. P.; Werner, K. S.; Goldfinger, Chris; Popowski, T. A., Geologic map of the central and southern Willamette Valley, Benton, Lane, Linn, Marion, and Polk Counties, Oregon. Plate 2B, scale 1:100,000.

Yeats, R. S.; Graven, E. P.; Werner, K. S.; Goldfinger, Chris; Popowski, T. A., Tectonics of the Willamette Valley, Oregon. p. 183-222.

Yeats, R. S.; Werner, K. S.; Popowski, T. A., Geologic map of the northern Willamette Valley, Clackamas, Marion, Multnomah, Polk, Tillamook, Washington, and Yamhill Counties, Oregon. Plate 2A, scale 1:100,000.

Miller, F. K., 1996, Geologic map of the Addy area, Stevens County, Washington: U.S. Geological Survey Miscellaneous Investigations Series Map I-2492, 1 sheet, scale 1:48,000.

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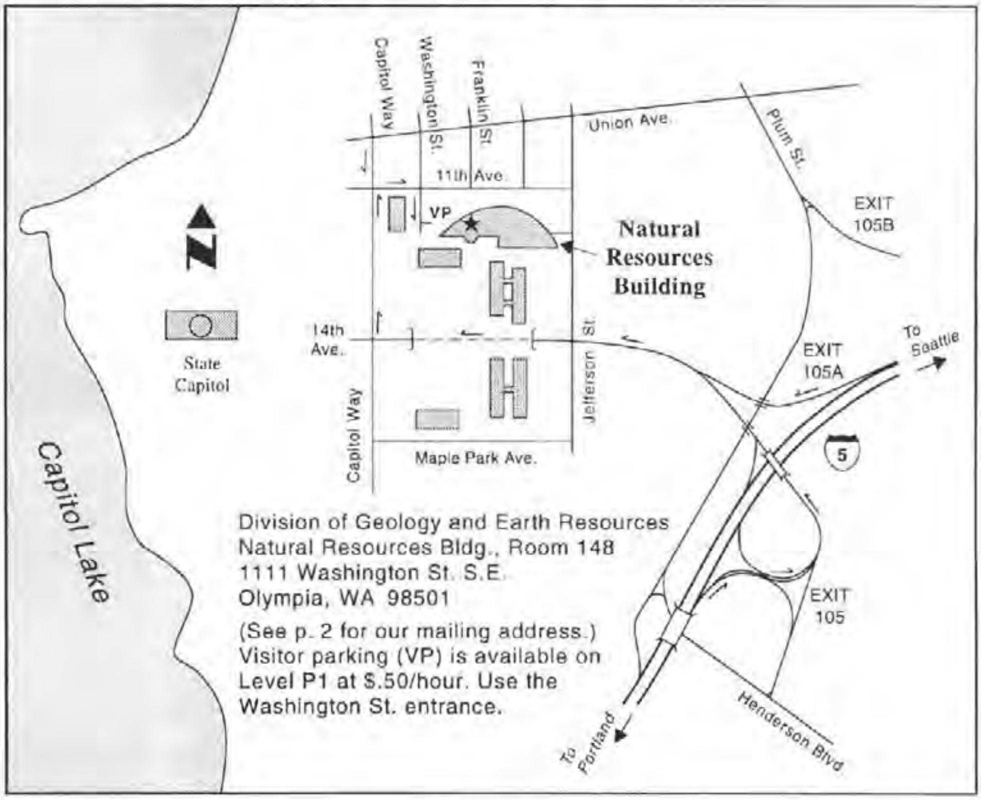

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