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WHAT'S HAPPENING WITH OUR PUBLICATIONS

We're trying hard to get *Washington Geology* back on a quarterly schedule—to be published every March, June, September, and December. Toward that end, this volume will consist of two double issues: v. 29, no. 1/2 (this issue) and v. 29, no. 3/4 (December 2001 issue). This will put us back on track for quarterly issues for next year, starting in March 2002. From then on, the issues will probably be shorter then they have been recently—most likely around 24 pages. During the year 2000, we tried a three issues per year schedule, but were not able to meet it. There will be no issue no. 4 for v. 28.

We have posted PDF files of *Washington Geology* back to v. 26, no. 4, December 1998, on our website (http://www.wa.gov/dnr/htdocs/ger/washgeol. htm) with some of the figures in color. (PDF files are viewable with Adobe Acrobat Reader, which can be downloaded free from http://www.adobe.com/products/acrobat/readstep.html.) Also, to reduce the size of issues, we have moved some items to our website only. For example, the sometimes-extensive list of new materials added to our library, which was formerly a regular feature in *Washington Geology*, will now be found on our website alongside our new, online searchable *Bibliography of the Geology and Mineral Resources of Washington State*, which used to be available only in printed form and on CD-ROM. We have also moved the calendar of upcoming events to our website.

The Division pays for *Washington Geology* from an ever-tightening budget. Help us use our resources well by letting us know if you have moved or no longer wish to receive this journal by mail. If you move and do not notify us, we will have to take your name off our mailing list. We pay $1 to the post office for each copy that comes back. In the past, we have corrected the address in our database and re-mailed the copy first class in an envelope at five times what it cost to mail it initially. We can no longer afford to do this. We had more than 300 copies of the last issue returned as undeliverable. So contact us and we will do an address change or take your name off the list immediately. (If you supply your +4 digit zip extension with your new address, it saves our staff time and makes the job of maintaining an accurate mailing list easier.)

Other new publications—those that do not contain large maps—are also posted on our website (http://www.wa.gov/dnr/htdocs/ger/pubs_ol.htm). We are looking at the best way to make maps available as well. We may gradually move toward a print-on-demand service for those customers who cannot access or print our electronic documents and maps, rather than keeping a large inventory of printed publications in our offices as we have in the past.

Digital distribution has its own set of challenges relating to longevity and continued access in the ever-changing landscape of electronic media and the Internet. An article by our senior librarian Connie Manson, "Insuring Future Access to Geoscience Reports" (p. 43), points out some of the issues we must consider as we contemplate our move towards digital distribution of publications.

We welcome your input on any of the above issues. Please contact us at geology@wadnr.gov with your comments and concerns. ■

Cover photo: George Mustoe emerges from a horizontal mold created two thousand years ago when a lava flow from Mount St. Helens inundated a conifer forest. See article on page 10.

The Metallic, Nonmetallic, and Industrial Mineral Industry of Washington in 2000

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INTRODUCTION

Production of nonfuel mineral commodities in Washington in 1999 was valued at $631,000,000 (U.S. Geological Survey, Mineral Industry Surveys, oral commun., 2001). This represents a 4 percent increase from 1998. Firm numbers for value of production in 2000 are not yet available.

This article summarizes company activities in 2000 based on results of a telephone survey by the Department of Natural Resources in January and February of 2001. Summary tables and location maps are provided for both metallic and nonmetallic mineral operations. All of the larger, known mining operations were contacted, but because some, especially small operations, were not contacted, this report does not contain a complete listing of mineral industry activities in the state. The known major mining operations contribute the majority of the value of the state's nonfuel mineral production.

Additional details about the geology of metallic mineral deposits and earlier industry activities in the state are available in prior reviews of Washington's mineral industry published in the first issue of *Washington Geology* each year (for example, Derkey, 1996, 1997, 1998, 1999; Derkey and Hamilton, 2000). Questions about metallic and nonmetallic mining activities and exploration should be referred to Bob Derkey in the Division's Spokane office. Information about the sand and gravel industry and mine reclamation can be obtained from Dave Norman in the Olympia office. *(See p. 2 for addresses and phone numbers.)*

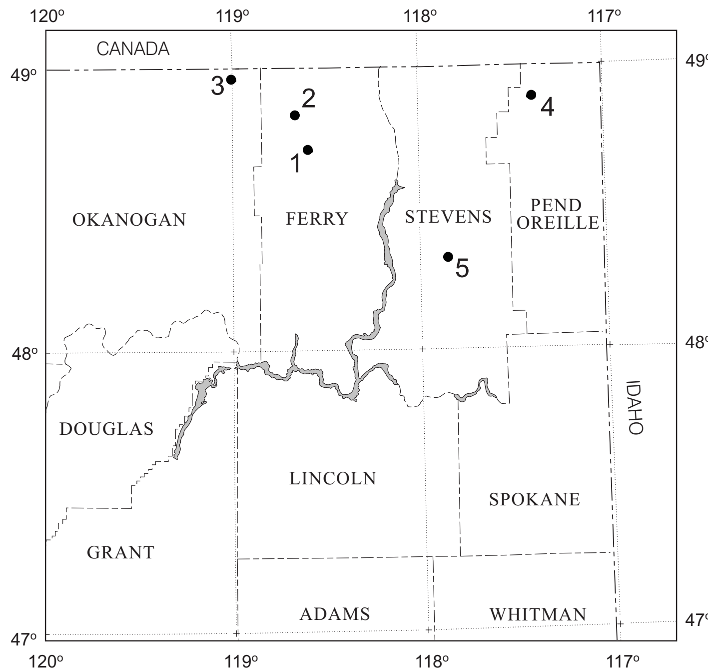

Figure 1. Location of major metal mining and exploration projects in northeastern Washington in 2000. Table 1 below identifies mines numbered on the map.

Table 1. Operator and brief description of the activity and geology at major metal mining and exploration projects in Washington in 2000 *(companion to Fig. 1)*

No.	Property	Location	County	Commodities	Company	Activity	Area geology
1	Lamefoot	secs. 4, 8, T37N R33E	Ferry	Au, Ag	Echo Bay Minerals Co.	Milled 331,131 tons of ore from the Lamefoot deposit and recovered ~60,000 oz of gold; reserves depleted except for small amount to be recovered in summer of 2001	Gold mineralization in massive iron exhalative/replacement mineralization in Triassic sedimentary rocks
2	K-2	sec. 20, T39N R33E	Ferry	Au, Ag	Echo Bay Minerals Co.	Milled 200,063 tons of ore from the K-2 deposit that contained ~33,900 oz of gold; developing East vein from K-2 adit	Epithermal deposit in Eocene Sanpoil Volcanics
3	Crown Jewel	sec. 24, T40N R30E	Okanogan	Au, Cu, Ag, Fe	Battle Mountain Gold Co./Crown Resources Corp.	Appealing revocation of water rights and discharge permits	Gold skarn mineralization in Permian–Triassic(?) metasedimentary rocks adjacent to the Jurassic–Cretaceous(?) Buckhorn Mountain pluton
4	Pend Oreille mine	secs. 10-11, 14-15, T39N R43E	Pend Oreille	Zn, Pb, Ag, Cd	Cominco American Inc.	Proceeding with permitting process and initiating site and facilities preparation to begin mining in 2002	Mississippi Valley–type mineralization in Yellowhead zone of Cambrian–Ordovician Metaline Formation
5	Addy magnesium mine	secs. 13-14, T33N R39E	Stevens	Mg	Northwest Alloys, Inc.	Mined 634,000 tons of dolomite; smelting to produce magnesium metal; reject material used for road metal	Cambrian–Ordovician Metaline Formation dolomite

METALLIC MINERAL INDUSTRY

The value of metallic mineral production accounted for approximately 23 percent of the $631,000,000 value of nonfuel mineral production for Washington in 1999, as it did in 1998. Major metal mining activities in Washington in the year 2000 included gold mining at the Lamefoot and K-2 gold deposits, development work to reopen the Pend Oreille lead-zinc mine, continuation of the appeals process concerning water rights at the Crown Jewel gold deposit, and magnesium metal production from dolomite mined at the Addy quarry. Major exploration projects for metallic minerals in Washington in 2000 include exploration for additional reserves in and adjacent to the Lamefoot and K-2 gold deposits and at the Pend Oreille mine. Activities for metallic commodities in 2000 are summarized in Figure 1 and Table 1 *(see p. 3)*.

The Kettle River Project of Echo Bay Minerals Co. continued gold production at two mines near Republic in Ferry County. The Lamefoot deposit (Fig. 1, no. 1), an exhalative/replacement-type deposit in Triassic rocks, produced approximately 60,000 ounces of gold from 331,131 tons of ore. Reserves at the Lamefoot deposit are depleted with the exception of a small tonnage, which the company will recover in the summer of 2001. The mine was closed in December. The K-2 deposit (Fig. 1, no. 2), an epithermal vein-type deposit in Eocene volcanic rocks of the Republic graben, produced approximately 33,900 ounces of gold from 200,063 tons of ore. Echo Bay also milled 3,835 tons of stockpiled, low-grade ore from the Overlook deposit and recovered approximately 190 ounces of gold from that ore. Total production from the Kettle River Project was 94,086 ounces of gold from 535,029 tons of ore; recovery was 84.1 percent.

Echo Bay continued to explore for mineralization to maintain their reserves in the Republic area. They obtained a 75 percent interest in the Golden Eagle Project, located in the Republic Mining District, just north of the Knob Hill shaft. The company also identified approximately 500,000 tons of additional gold resources in the East vein, just east of the K-2 vein. Echo Bay was developing this resource at the end of the year from the K-2 adit. Because access to the East vein and the K-2 vein is limited to the K-2 portal, the company expects production for their Kettle River Project to decrease to 60,000 ounces gold in 2001.

Cominco American conducted approximately 65,000 feet of core drilling, both underground and on the surface, at their Pend Oreille mine (Fig. 1, no. 4) in northern Pend Oreille County. The company has not announced any additional reserves; however, an announcement of increased reserves is expected in their annual report. Cominco had announced an ore reserve of 6.5 million tons containing 7.2 percent zinc and 1.3 percent lead. The deposit is a Mississippi Valley–type zinc-lead deposit. Most of the earlier mining was on the Josephine horizon (Fig. 2); however, this additional reserve is on a deeper ore zone referred to as the Yellowhead 1. A third horizon, referred to as the Yellowhead 2, has been identified below the Yellowhead 1. The company has applied for permits to mine the deposit and is planning to begin mining in 2002. They are rehabilitating the old mill on the property and will ship concentrates to their smelter in Trail, British Columbia, Canada, which is about 40 miles from the mine.

The Crown Jewel gold deposit (Fig. 1, no. 3) near Chesaw in Okanogan County is a skarn-type gold deposit in a sequence of Permian to Triassic(?) clastic and carbonate sedimentary rocks. Previously announced reserves for the deposit are 8.7 million tons of ore at a grade of 0.186 ounces of gold per ton.

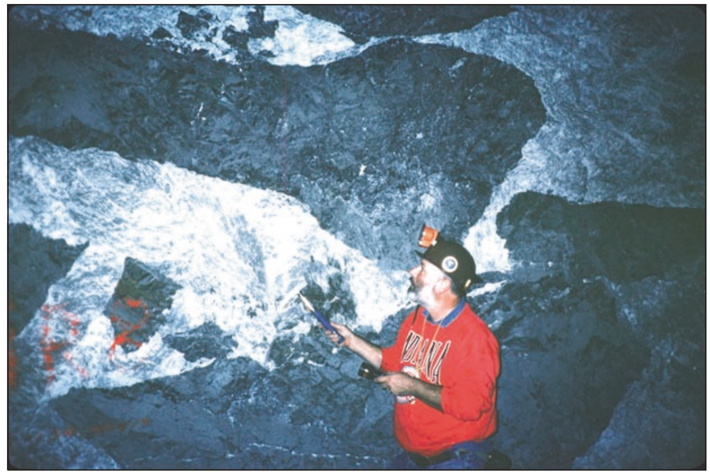

Figure 2. The Pend Oreille zinc-lead mine at Metaline Falls last operated in 1977. New reserves of zinc-lead ore have been identified and Cominco American has been exploring for additional reserves. The company has announced plans to reopen the mine in 2002 or 2003. Most of the ore produced in previous years came from the Josephine horizon ore bodies. In this view of the Josephine horizon, a block of dolomite host rock (dark) is seen surrounded by massive white calcite. The newer ore bodies identified are from the stratigraphically lower Yellowhead horizon.

Since the environmental impact statement was released in 1997, the operator, Battle Mountain Gold Company, has been working to obtain permits to mine the deposit and defending appeals to the proposed operation.

Northwest Alloys Inc. mined 634,000 tons of dolomite near Addy (Fig. 1, no. 5) in Stevens County for magnesium metal production and for road aggregate in 2000. They also were conducting research to find ways to utilize their several waste and reject materials.

NONMETALLIC MINERAL INDUSTRY

Nonmetallic mineral commodities (limestone, dolomite, shale, clay, diatomite, olivine, and silica) accounted for approximately 20 percent of the $631,000,000 value of nonfuel mineral production for Washington in 1999. Products included aggregate, soil conditioners, feed lime, landscape rock, paper filler, bricks, cement and fiber cement additives, filter material, casting sand, and glass. Activities for nonmetallic commodities in 2000 are summarized in Figure 3 and Table 2.

In 2000, two companies mined limestone (calcium carbonate) and dolomite (calcium magnesium carbonate) for use as a soil conditioner and feed lime. Pacific Calcium produced from the Tonasket (Fig. 3, no. 110) and Brown (Fig. 3, no. 111) quarries in Okanogan County, and Allied Minerals produced from the Gehrke quarry (Fig. 3, no. 116) in Stevens County. Northwest Alloys sold approximately 150,000 tons of dolomite waste rock from their magnesium metal operation at Addy (Fig. 1, no. 5) in Stevens County that was used for road aggregate. They also sold some of the byproducts from smelting for fertilizer and soil conditioner. Columbia River Carbonates continued to produce calcium carbonate from the Wauconda quarry (Fig. 3, no. 112) and shipped it to their processing plant in Longview, Cowlitz County; most is used as a coating agent to produce glossy paper. Northport Limestone mined limestone from the Sherve quarry (Fig. 3, no. 122) in Stevens County, and shipped most of it to Trail, BC, for use as a fluxing agent in smelting. Northwest Marble Products (Fig. 3, no. 119)

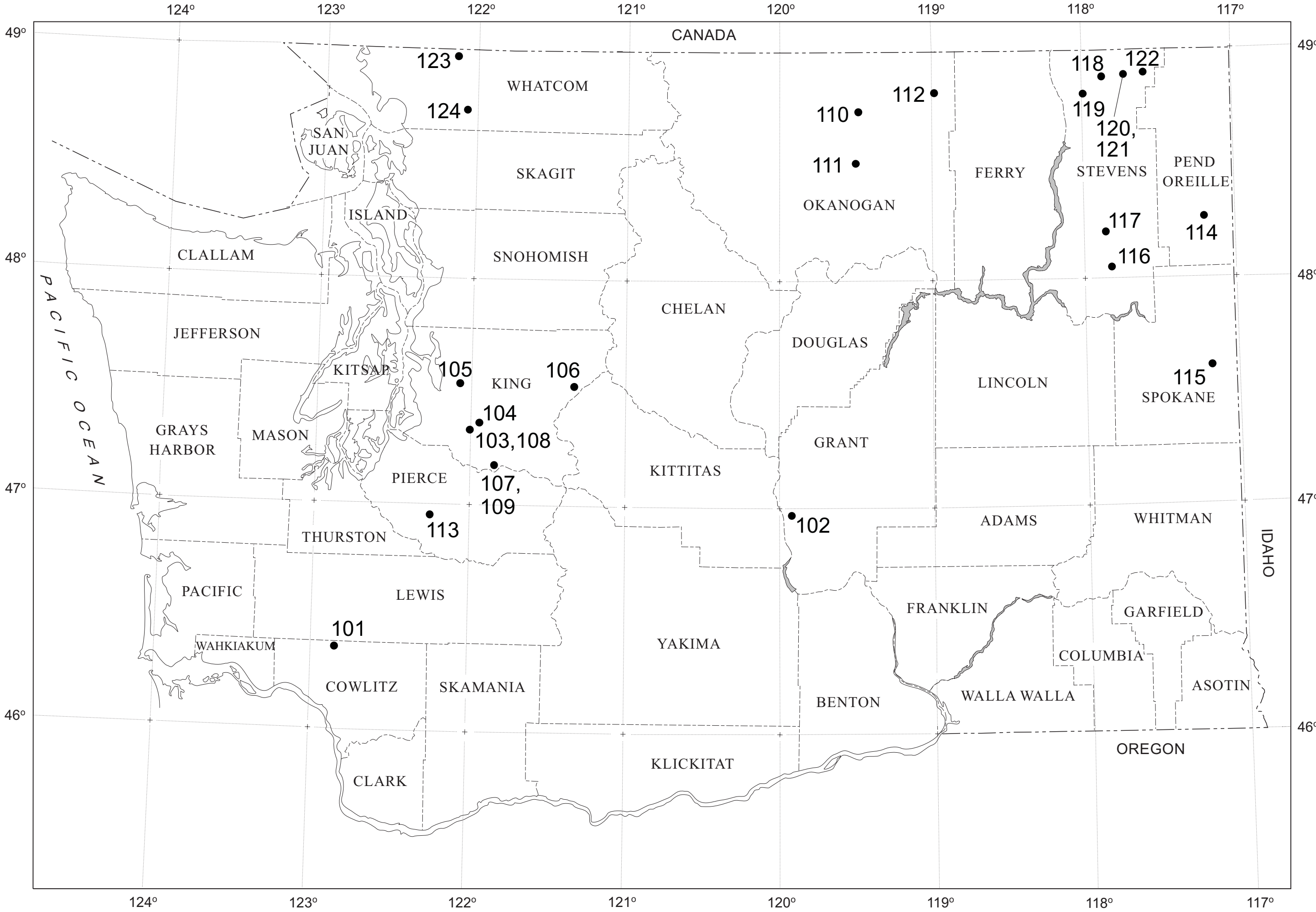

Figure 3. Location of nonmetallic mining operations in Washington in 2000. See Table 2 for additional details about each of these projects.

Table 2. Operator and brief description of the activity and geology of nonmetallic mining operations in Washington in 2000 *(companion to Fig. 3)*

No.	Property	Location	County	Commodities	Company	Activity	Area geology
101	Castle Rock quarry	sec. 18, T10N R1W	Cowlitz	clay	Ash Grove Cement Co.	No mining activity in 2000	Eocene–Oligocene sedimentary rocks
102	Celite diatomite pits	sec. 3, T17N R23E; sec. 7, T17N R24E	Grant	diatomite	Celite Corp.	Mined approximately 100,000 tons of ore and produced 65,000 tons of finished diatomite used primarily for filtration purposes	Miocene 'Quincy diatomite bed', local sedimentary interbed at the base of the Priest Rapids Member, Columbia River Basalt Group
103	Ravensdale pit	sec. 1, T21N R6E	King	silica	Reserve Silica Corp.	Mined and washed 132,100 tons and shipped 85,886 tons of silica sand; most used to manufacture glass in the Seattle area	Sandstone of the Eocene Puget Group
104	Elk pit	sec. 34, T22N R7E	King	shale	Mutual Materials Co.	Mined 26,000 tons of shale (clay); used 15,500 tons to manufacture bricks	Illite- and kaolinite-bearing shales of the Eocene Puget Group
105	Section 31 pit	sec. 31, T24N R6E	King	shale	Mutual Materials Co.	Mined 54,000 tons of shale; used 53,000 to produce bricks	Shale of the Eocene Puget Group
106	Spruce claim	secs. 29-30, T24N R11E	King	crystals	Robert Jackson	Extracted mineral and crystal specimens from the Spruce 16 claim	Quartz and pyrite crystals in a breccia pipe and open voids along faulted megabreccia in the northern phase granodiorite and tonalite (25 Ma) of the Snoqualmie batholith
107	Superior quarry	sec. 1, T19N R7E	King	silica	Ash Grove Cement Co.	Did not mine any products in 2000; shipped 67,552 tons from stockpile as cement additive; conducted a limited exploration program	Silica cap in hydrothermally altered Miocene andesites on a caldera margin

Table 2. Operator and brief description of the activity and geology of nonmetallic mining operations in Washington in 2000 *(continued)*

No.	Property	Location	County	Commodities	Company	Activity	Area geology
108	John Henry No. 1	sec. 12, T21N R6E	King	clay	Pacific Coast Coal Co.	Mined about 1,000 tons of clay; shipped only 50 tons	Upper middle Eocene silty clay near the base of the Puget Group comprising a 30 ft thick zone above the Franklin No. 9 coal seam
109	Scatter Creek mine	secs. 5-6, T19N R8E	King	silica	James Hardie Building Products, Inc.	Mined 100,000 tons of silicified andesite for manufacture of fiber cement and Hardie board	Cap rock material from hydrothermally altered and silicified andesite of an igneous complex
110	Tonasket limestone quarry	sec. 25, T38N R26E	Okanogan	limestone	Pacific Calcium, Inc.	Mined 11,879 tons of limestone for soil conditioner and feed lime	Metacarbonate rocks in the conglomerate-bearing member of the Permian Spectacle Formation (Anarchist Group)
111	Brown quarry	sec. 26, T35N R26E	Okanogan	dolomite	Pacific Calcium, Inc.	Mined 6,799 tons of dolomite for soil conditioner	Metadolomite member of the Triassic Cave Mountain Formation
112	Wauconda quarry	sec. 13, T38N R30E	Okanogan	limestone	Columbia River Carbonates	Mined high-brightness calcium carbonate and shipped it to their processing plant near Longview; used as filler in paper	High-calcium, pre-Tertiary white marble lenses in mica schist, calc-silicate rocks, and hornfels
113	Clay City pit	sec. 30, T17N R5E	Pierce	clay	Mutual Materials Co.	Mined 5,150 tons and used 4,860 to produce bricks	Tertiary kaolin-bearing, altered andesite
114	Usk pit	sec. 7, T32N R44E	Pend Oreille	clay	Mutual Materials Co.	No mining in 2000; used 4,350 tons from stockpile	Holocene lacustrine clay, silt, and sand; light gray clay fires dark red
115	Mica pit	sec. 14, T24N R44E	Spokane	clay	Mutual Materials Co.	Processed 51,500 tons of clay for making bricks, including some stockpiled material	Lacustrine clay of Miocene Latah Formation overlying saprolitic, pre-Tertiary felsic gneiss
116	Gehrke quarry	sec. 2, T29N R39E	Stevens	dolomite	Allied Minerals, Inc.	Mined approximately 5,000 tons; marketed as soil conditioner	Isolated pod of Proterozoic Y Stensgar Dolomite(?) (Deer Trail Group)
117	Lane Mountain quarry	secs. 22, 34, T31N R39E	Stevens	silica	Lane Mountain Silica Co. (*divn. of* Hemphill Brothers, Inc.)	Mined 218,289 tons and shipped 171,289 tons of silica for glass manufacture; also shipped 51,313 tons of byproduct to cement plant in Richmond, BC	Cambrian Addy Quartzite
118	Whitestone quarry	sec. 34, T39N R38E	Stevens	marble	Whitestone Co.	Mined dolomite for terrazzo tile and other uses	Recrystallized limestone (marble) in Cambrian Maitlen Phyllite
119	Northwest marble mine; other quarries	sec. 19, T38N R38E	Stevens	dolomite	Northwest Marble Products Co.	Mined and milled 3,000 tons of 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
120	Joe Janni limestone deposit	sec. 13, T39N R39E	Stevens	limestone	Joeseph A. & Jeanne F. Janni limestone deposits	Leased to Columbia River Carbonates; samples collected and submitted for analysis	Deposit is in Cambrian Maitlen Phyllite, Reeves Limestone Member
121	Janni limestone quarry	sec. 13, T39N R39E	Stevens	limestone	Peter Janni and Sons	Leased to Columbia River Carbonates; samples collected and submitted for analysis	Deposit is in Cambrian Maitlen Phyllite, Reeves Limestone Member
122	Sherve quarry	sec. 8, T39N R40E	Stevens	limestone	Northport Limestone Co. (*divn. of* Hemphill Brothers, Inc.)	Mined 60,000 tons of fluxing grade limestone; shipped to the Cominco smelter at Trail, BC; also used for road metal	Limestone in the upper unit of Cambrian–Ordovician Metaline Formation
123	Clausen quarry	secs. 7, 18, T40N R6E	Whatcom	limestone	Clauson Quarry LLC	Mined approximately 90,000 tons used for riprap, crushed rock, and landscape rock	Sheared, jointed Lower Pennsylvanian limestone overlain by sheared argillite and underlain by argillite, graywacke, and volcanic breccia of the Chilliwack Group
124	Swen Larsen quarry	sec. 34, T38N R6E	Whatcom	olivine	Olivine Corp.	Mined and milled 40,000 tons of olivine; most production used for casting sand	Dunite from the Twin Sisters Dunite (outcrop area more than 36 mi^2) in Whatcom and Skagit Counties

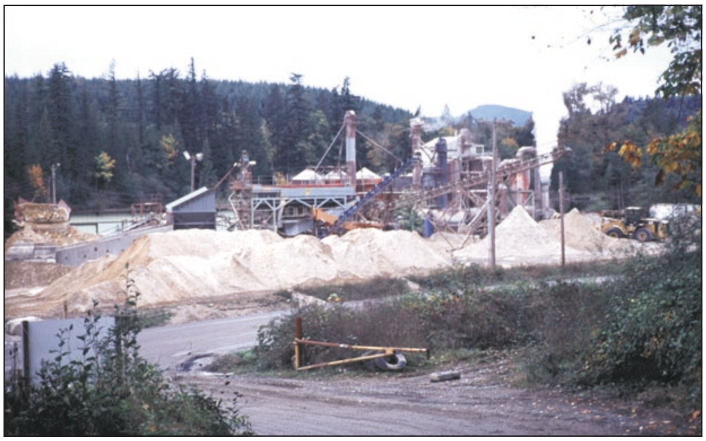

Figure 4. *(top photo)* Reserve Silica Corporation mines Puget Group sand beds adjacent to already mined coal seams in the Ravensdale area. The loader and dozer are preparing a new pit for mining. The removed coal seam is just to the left of center in the picture. *(bottom photo)* Reserve Silica Corporation's silica processing plant at Ravensdale. Puget Group sandstone is mined nearby and transported to this plant for processing. The sandstone is disaggregated, washed, and cleaned for use by the glass industry. Iron content is reduced after the sand is dried and sent past a magnet to remove iron-rich heavy minerals.

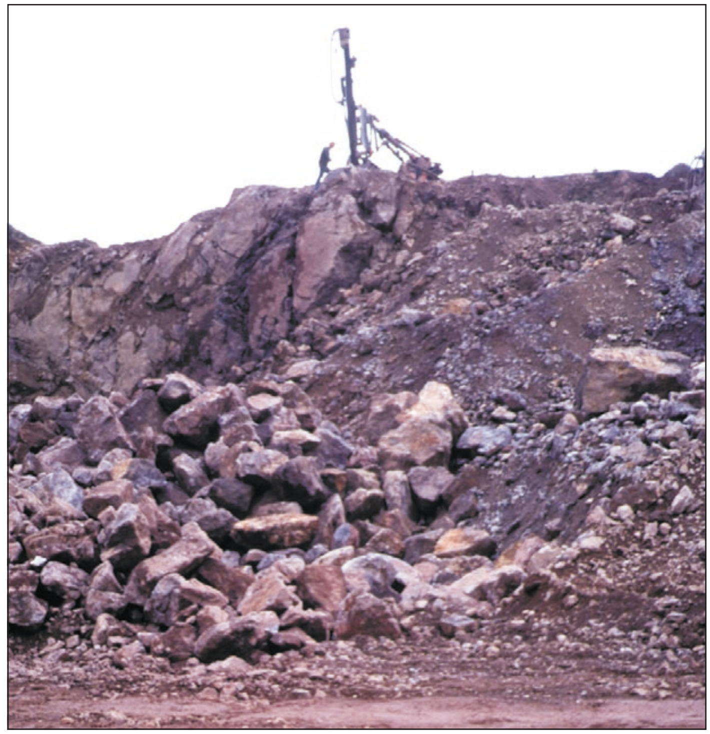

Figure 5. *(top photo)* Silhouette of a drill and driller on a bench of silicified andesite at James Hardie Building Products silica quarry near Enumclaw. The silicified andesite is drilled and blasted on 30-foot-high benches. *(bottom photo)* Following blasting, the blasted material is loaded on trucks and transported to their plant between Puyallup and Tacoma. Most of the silicified andesite is used directly to make Hardie building products; however, about 20 percent mined contains excessive iron. The high-iron material is shipped to Lafarge Corporation's cement plant in Seattle.

and the Whitestone Co. (Fig. 3, no. 118), both in Stevens County, continued to produce terrazzo tile products and building aggregates, as they have for a number of years.

Olivine Corp. mined 40,000 tons of refractory-grade olivine from its Swen Larsen quarry (Fig. 3, no. 124) in Whatcom County in 2000. Most of that production was shipped to Unimin, a Belgian company that produces casting sands and other refractory products at Hamilton in Skagit County.

Silica stockpiles at Ash Grove Cement's Superior quarry (Fig. 3, no. 107) in King County supplied 67,552 tons of ore that was used for portland cement production in Seattle. Lafarge Corp., which formerly mined clay from the Twin River quarry in Clallam County, reported that the company was obtaining an alternate source for clay from Canada. Pacific Coast Coal Co. mined 1,000 tons of clay interbeds from the John Henry No. 1 coal mine (Fig. 3, no. 108) but shipped only 50 tons to Ash Grove Cement.

Mutual Materials mined about 137,000 tons of clay for the manufacture of bricks and related products at their plants in Seattle and Spokane. The company produced from the Mica pit (Fig. 3, no. 115) in Spokane County and used stockpiled material from the Usk pit (Fig. 3, no. 114) in Pend Oreille County. For their Seattle plant, the company obtained clay from the Elk (Fig. 3, no. 104) and Section 31 (Fig. 3, no. 105) pits in King County, and shipped stockpiled clay from the Clay City pit (Fig. 3, no. 113) in Pierce County.

Celite Corp. mined and processed approximately 100,000 tons from the diatomite pits (Fig. 3, no. 102) in Grant County. The company shipped approximately 65,000 tons of finished diatomite; most is used as a filter media.

Lane Mountain Silica mined 218,289 tons of Addy Quartzite from the Lane Mountain quarry (Fig. 3, no. 117) in Stevens County. Following processing, the company shipped 171,289 tons of high-purity quartz, most of which was used to manufacture glass bottles and jars. Lane Mountain also shipped 51,313 tons of clay/silica byproduct, recovered during processing, to make cement at a plant in Richmond, BC.

Reserve Silica Corp. mined 132,100 tons of quartz-rich Puget Group sands from the Ravensdale pit (Fig. 3, no. 103) in King County (Fig. 4). Most of Reserve's production is used for the manufacture of bottle glass; some is used for sand traps at golf courses.

James Hardie Building Products, as in 1999, mined 100,000 tons of silica in 2000 from their Scatter Creek mine (Fig. 3, no. 109) in King County (Fig. 5), which they used for the manufacture of fiber cement for Hardie building products.

Historical Mining Photo. The magnesite industry in the state of Washington goes back to the early part of the 20th century when the onset of World War I created a demand for magnesium. This photograph, taken in 1918, shows mining at Northwest Magnesite's Finch quarry located southwest of Chewelah, which operated between 1916 and 1954. The deposit produced over 3 million tons of magnesite and provided the bulk of our domestic needs for refractory magnesia through two World Wars (Campbell and Loofbourow, 1962). The scene demonstrates the adaption of underground mining techniques to early open pit operations with the use of track, ore cars, and hand tools to move the rock. *Photo courtesy of Cheney Cowles Museum, Spokane, Wash.*

AGGREGATE INDUSTRY

Aggregate (sand and gravel and crushed stone) produced for the construction industry, in terms of value and amount produced, accounted for approximately 57 percent of the $631,000,000 total value in 1999. The construction and paving industries are the principal consumers of aggregate. Large sand and gravel operations are common near heavily populated areas where the need for aggregate is greatest. High ground transportation costs generally preclude large aggregate operations any great distance from where the aggregate is to be used. Small seasonal or project-dependent operations can be found throughout the state. The small pits are operated by city, county, and state road departments and small companies for smaller-scale needs.

Activities at most large aggregate mining operations in Washington continued at a rate similar to that in previous years. A major issue on the horizon for the aggregate industry in the Pacific Northwest is locating an adequate aggregate source for the city of Portland, Oregon. The present source is nearly depleted, and the city is looking at glacial flood gravels in Klickitat County, Washington, as a possible new source of aggregate. Despite the great distance from Portland, transportation costs for Klickitat County aggregate are low because it can be shipped by barge on the Columbia River.

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'Selected Additions to the Library of the Division of Geology and Earth Resources', a feature formerly found in *Washington Geology*, is now on our website. Find it at http://www.wa.gov/dnr/htdocs/ger/libadd.htm.

MAP AVAILABLE FREE TO TEACHERS

Free copies of U.S. Geological Survey Mineral Investigations Field Studies Map MF-135, *Preliminary geologic map of part of the Turtle Lake quadrangle, Lincoln and Stevens Counties, Washington*, by George E. Becraft and Paul L. Weis, 1957, are available to teachers. First preference will go to teachers in Lincoln and Stevens Counties; we'll fill other orders as supply lasts. Each teacher may order up to 20 copies.

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Washington's Coal Industry—2000

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In 2000, coal production from Washington's two coal mines was slightly up from the previous year. The Centralia mine in north-central Lewis County and the John Henry No. 1 mine in south-central King County produced a total of 4,270,364 short clean tons of coal. Total production was up by 192,765 tons from the previous year.

The state's largest coal mine, the Centralia Coal mine, was purchased in May 2000 by TransAlta Centralia Mining LLC, a Canadian company, from the Centralia Mining Company, a division of PacifiCorp. The mine is located 5 miles northeast of Centralia (Fig. 1). The mine is totally dedicated to supplying coal to the Centralia Steam Plant, located a mile from the coal mine, now operated by TransAlta Centralia Generation LLC.

The Centralia mine completed its 30th year of production in 2000, producing 4,269,764 short tons of subbituminous coal, 195,364 tons more than it produced in 1999. The mine's average annual production over the last 5 years has been 4.4 million tons per year; average annual production over the life of the mine is 4.3 million tons per year. Officials of TransAlta Centralia are planning on increasing annual production at the mine to more than 5 million tons per year and are looking at another 25 years of production from the mine.

Coal production at the Centralia mine in 2000 came from four open pits. Coalbeds mined were the Tono No. 1 and No. 2, the Upper and Lower Thompson, the Big Dirty and the Little Dirty seams and their splits, and the Smith seam and its splits. These coalbeds are part of the Skookumchuck Formation, which is comprised of nearshore marine and nonmarine sedimentary rocks. The Skookumchuck is the upper member of the Eocene Puget Group.

Washington's other producing coal mine, the John Henry No. 1, is located 2 miles northeast of the town of Black Diamond (Fig. 1). The mine is operated by the Pacific Coast Coal Company (PCCC), which completed its 14th full year of production in 2000. Production in 2000 was a mere 600 short tons of bituminous coal, a reduction of 2,599 tons from its 1999 production. PCCC continues to suffer from losing most of its customers due to a large landslide in the mine in January 1997 that significantly affected the mine's ability to supply its then-current customers. A sluggish Pacific Rim economy has not allowed a return demand for steam coal, which PCCC had previously supplied to that sector.

Nearly all the coal sold by PCCC in 2000 went to supplying a new market, which is coal used as a filter medium for large industrial and municipal water filtration systems. Although currently small, PCCC is hopeful that the new market will continue to grow. The remaining production consisted of coal sold to residential customers for space heating.

All coal mined from the John Henry No. 1 mine in 2000 came from the Franklin No. 12 coalbed in Pit No. 2. The Franklin coalbeds are stratigraphically near the base of the undivided Eocene Puget Group in nonmarine deltaic sedimentary rocks.

PCCC continues to mine a 30-foot-thick clay bed that lies stratigraphically between the Franklin No. 9 and No. 10 coalbeds. In 2000, the company mined 1,000 short tons of clay. The clay is blended with high-alumina clay from another source for the manufacture of portland cement. ■

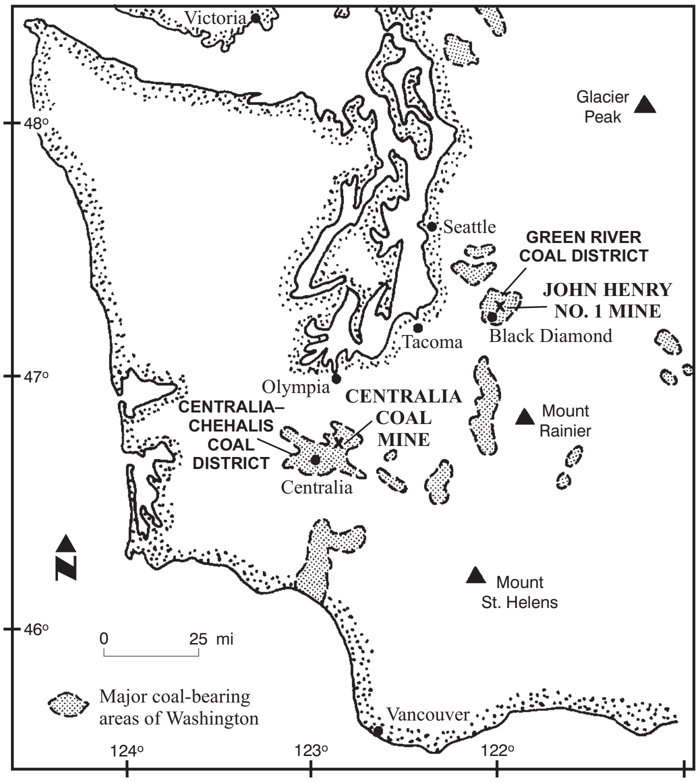

Figure 1. Coal-producing areas and districts of western Washington.

Event to Mark Closure of Sullivan Mine

The Sullivan lead-zinc mine at Kimberley, B.C., will close at the end of this year, after roughly a century since first production. To commemorate the occasion, Teck Cominco is hosting a geological meeting in Kimberley on November 9th and 10th, 2001. The first day of the meeting will consist of talks organized by two well-known former employees of the Sullivan mine, including reminiscences and current synopses of the science resulting from work at the mine. The second day will consist of underground and surface tours of the mine and a poster and chat session in downtown Kimberley. For the underground tour, fresh material will have been blasted from the bedded ore in one of the drifts and left on the floor for collecting.

There is no registration fee for the meeting. The full event announcement can be found at http://www.teckcominco.com/operations/sullivan/articles/sullivan-geological.htm. For more information and a registration form, contact Helen Augustin at Teck Cominco Metals Ltd., #500–200 Burrard Street, Vancouver, BC, Canada V6C 3L7; info@teckcominco.com.

Washington's Fossil Forests

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INTRODUCTION

Tracing the botanical evolution of the Pacific Northwest is challenging because of the region's complex geologic history. The simple layer-cake sequence of sedimentary rocks described in beginning geology classes bears little resemblance to the intricate structural patterns observed in the western and central areas of our state where interleaved scraps of rock of diverse age and origin have been transported from distant locations and welded to the western edge of North America by the forces of plate tectonics. These 'exotic terranes' mostly originated as marine sediments, submarine basalts, or volcanic islands—three geologic environments that are unlikely to preserve terrestrial plant remains. Despite these complexities, Washington rocks contain a diverse variety of plant fossils (Fig. 1). Two sites have gained international fame—the Stonerose fossil beds at Republic in Ferry County and Ginkgo Petrified Forest State Park near Vantage.

MESOZOIC PALEOFLORAS

Although land plants first appeared 350 million years ago during the Silurian Era, Washington's oldest known plant fossils date back only 130 million years to the Jurassic. Nooksack Group siltstone, exposed on Church Mountain north of Mount Baker, has produced mineralized shells of belemnites and pelecypods and a few specimens of fossilized driftwood. On the east side of the Cascade Range, the Twisp Formation has yielded a single specimen of fossil cycad leaves (McGroder and others, 1990). Neither of these sites reveals a true record of Mesozoic flora native to the Pacific Northwest. Instead, these

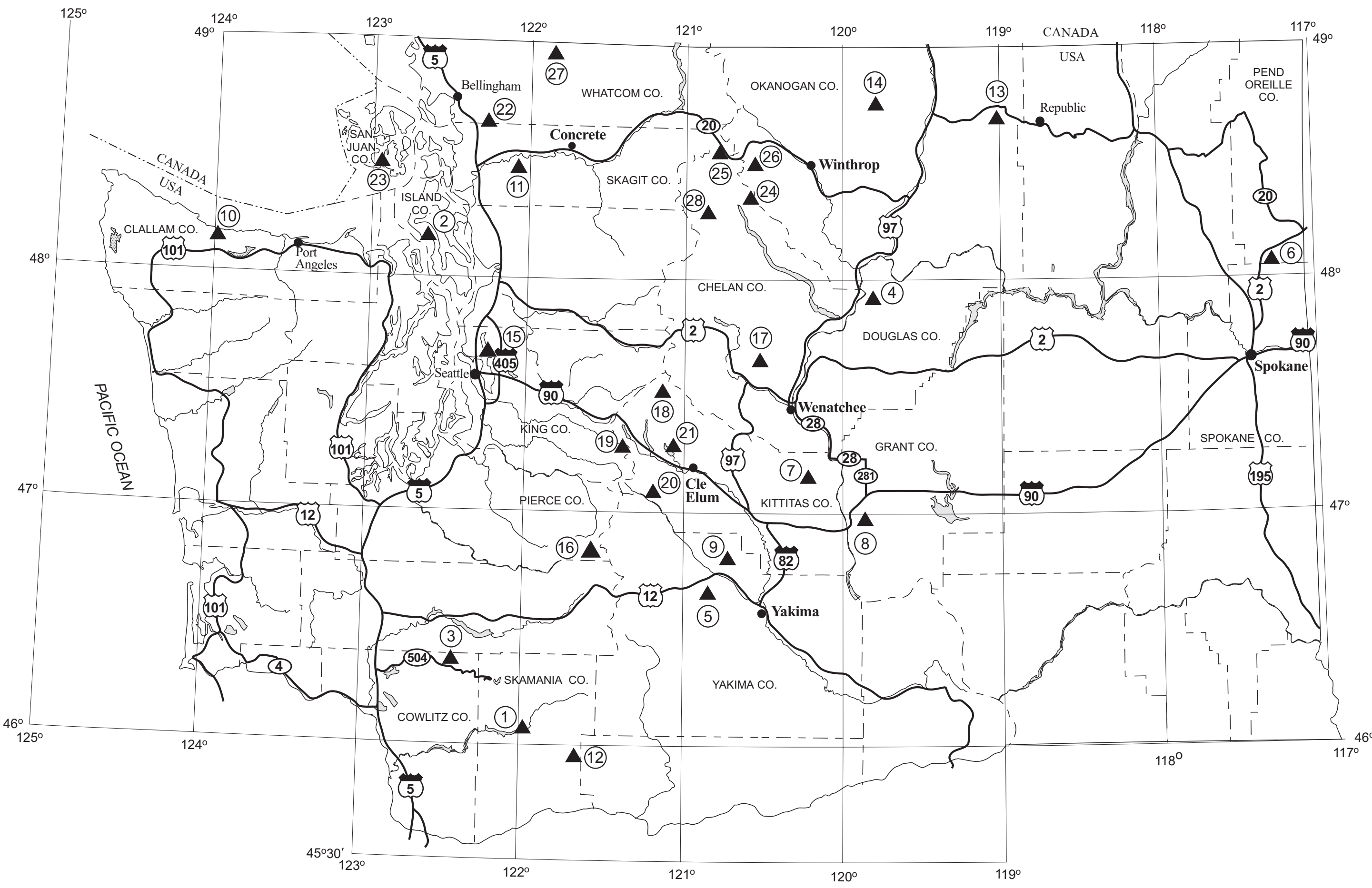


Figure 1A. Location of fossil plant sites (numbered triangles) in Washington. Age of sites from youngest to oldest: RECENT: 1, Mount St. Helens lava cast forest. PLEISTOCENE: 2, Puget Sound glacial deposits. MIOCENE: 3, Wilkes Formation; 4, Grand Coulee flora; 5, Ellensburg flora; 6, Latah Formation; 7, Ginkgo Petrified Forest State Park; 8, Saddle Mountain; 9, Yakima Canyon. OLIGOCENE: 10, Twin Rivers Group; 11, rocks of Bulson Creek; 12, Gumboot Mountain. EOCENE: 13, Republic flora; 14, Similkameen Dam flora; 15, Puget Group; 16, Naches Formation; 17, Wenatchee Formation; 18, Chumstick Formation; 19. Roslyn and Cle Elum Formations; 20, Manastash Formation; 21, Swauk Formation; 22, Chuckanut Formation. LATE CRETACEOUS: 23, Nanaimo Group; 24, Pipestone Canyon Formation; 25, Winthrop and Virginian Ridge Formations. EARLY CRETACEOUS: 26, Buck Mountain Formation. JURASSIC/CRETACEOUS: 27, Nooksack Group. JURASSIC: 28, Twisp Formation.

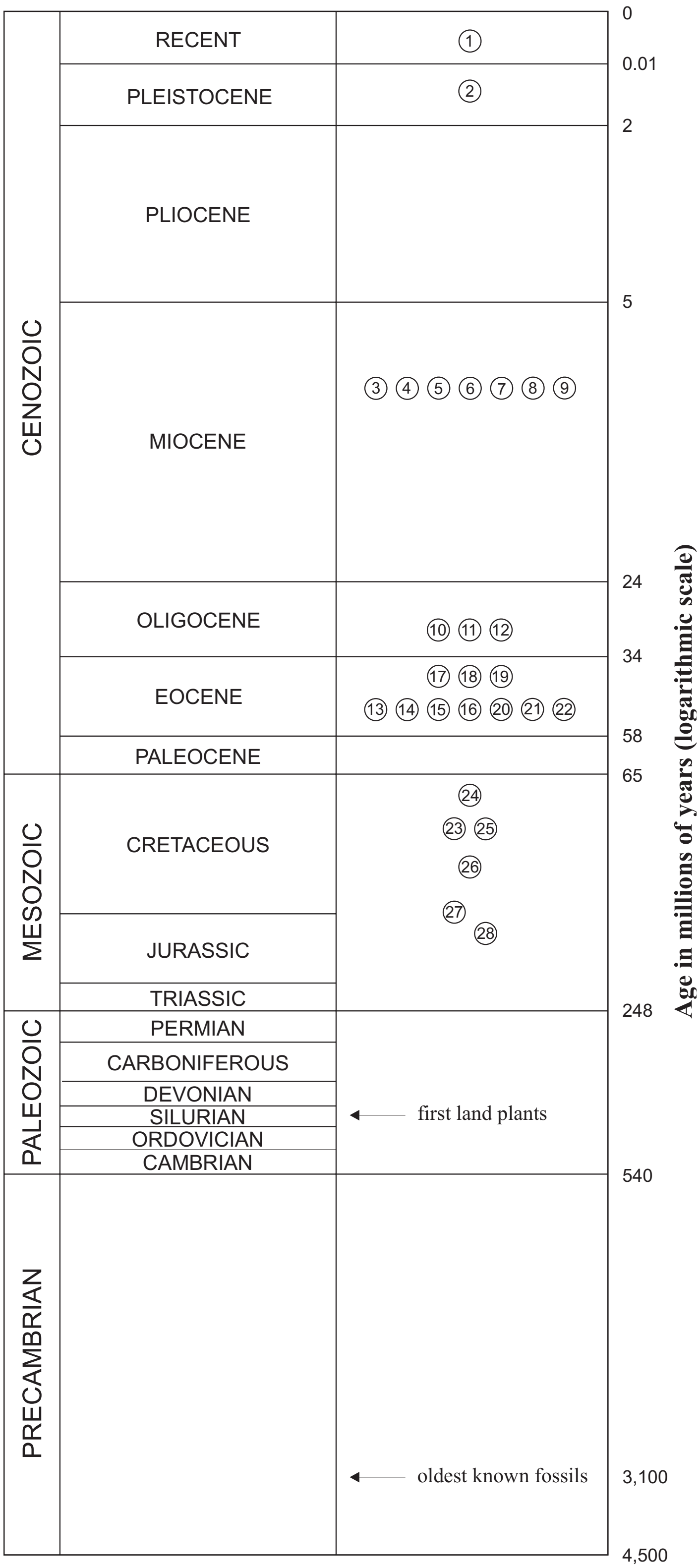
formations preserve remains of plants that inhabited islands or microcontinents originally located far to the south or west.

Several Cretaceous formations contain plant fossils, but these rocks have likewise been transported. Newberry (1898) described leaf impressions from the Nanaimo Group at Point Doughty on Orcas Island, and plant fossils have been collected in much greater quantity from Nanaimo Group strata on Vancouver Island (Bell, 1957).

Mesozoic leaf imprints can be found in the Methow Valley of north-central Washington. These fossils occur in sedimentary rocks located within a fault-bounded structural basin that represents only a small portion of the original deposits. Most of these sedimentary rocks are of marine origin. Fossil sea shells from these deposits are now exposed in siltstone beds along the summit ridge of 7440 ft (2268 m) Slate Peak—evidence of the power of the tectonic collision between the North America plate and the Pacific Ocean crust.

Several Methow Valley formations include nonmarine deposits that preserve plant remains. The Lower Cretaceous Buck Mountain Formation is an assemblage of volcanic and volcaniclastic rocks that crop out north of Winthrop. The most common fossils are marine mollusks, but the Burke Museum collection includes a few cycadeoid leaf fossils collected from a terrestrial interbed (McGroder and others, 1990). Leaf imprints are abundant in parts of the Upper Cretaceous Winthrop Sandstone and at a few sites in the adjacent Virginian Ridge Formation. Both units are comprised of arkosic sandstone with interbeds of fossiliferous shale (Rau, 1987; McGroder and others, 1990). Crabtree (1987) listed approximately 20 species of fern, conifer, and dicotyledonous plant remains from the Winthrop Formation type section near Boesel Canyon (Fig. 2), east of Highway 20 near Winthrop. Many specimens were collected from this site for the Burke Museum in 1998 by a University of Washington paleontology student, Sam Girouard, Jr. (Fig. 3).

Plant fossils from the Pipestone Canyon Formation near Twisp were once thought to be Paleocene (Royse, 1965), but new evidence indicates that their age is Late Cretaceous (Peterson, 1999). Unlike other plant-bearing beds of the Methow Valley, the Pipestone Canyon strata appear to have been deposited near their present location as evidenced by basal conglomerate beds that contain granite boulders eroded from the nearby Okanogan highlands. The type locality consists of 440 m of gently dipping sedimentary rock exposed in the walls of Pipestone Canyon, an Ice Age meltwater channel. The sediments originated as debris flow and alluvial fan deposits along an ancient mountain front, producing coarse sandstone and conglomerate beds that seldom preserve fossilized remains. But shale interbeds in the upper part of the stratigraphic section contain foliage and cones of dawn redwood (*Metasequoia*, Fig. 3) and leaf imprints from a few species of flowering plants. Steep slopes and a repu-



Age of sites from youngest to oldest

RECENT:
1. Mount St. Helens lava cast forest

PLEISTOCENE:
2. Puget Sound glacial deposits

MIOCENE:
3. Wilkes Formation
4. Grand Coulee flora
5. Ellensburg flora
6. Latah Formation
7. Ginkgo Petrified Forest State Park
8. Saddle Mountain
9. Yakima Canyon

OLIGOCENE:
10. Twin Rivers Group
11. rocks of Bulson Creek
12. Gumboot Mountain

EOCENE:
13. Republic flora
14. Similkameen Dam flora
15. Puget Group
16. Naches Formation
17. Wenatchee Formation
18. Chumstick Formation
19. Roslyn and Cle Elum Formations
20. Manastash Formation
21. Swauk Formation
22. Chuckanut Formation

LATE CRETACEOUS:
23. Nanaimo Group
24. Pipestone Canyon Formation
25. Winthrop and Virginian Ridge Formations

EARLY CRETACEOUS:
26. Buck Mountain Formation

JURASSIC/CRETACEOUS:
27. Nooksack Group

JURASSIC:
28. Twisp Formation

Figure 1B. Age range of Washington fossil plant sites. Relative stratigraphic positions of individual sites are only approximate.

tation for rattlesnakes combine to make Pipestone Canyon a less than ideal place for collecting specimens, but the site deserves merit for being one of the most scenic fossil localities in the Pacific Northwest (Fig. 4).

EARLY TERTIARY PLANT FOSSILS

Pipestone Canyon fossils date from approximately 70 million years ago, but to the great regret of geoscientists, our state appears to contain no sedimentary rocks deposited at the time of the Cretaceous/Tertiary transition that took place 5 million years later. The oldest known Cenozoic plant fossils in the Pacific Northwest are from the basal parts of the Swauk and Chuckanut Formations in strata that may date from the Late Paleocene (Johnson, 1984).

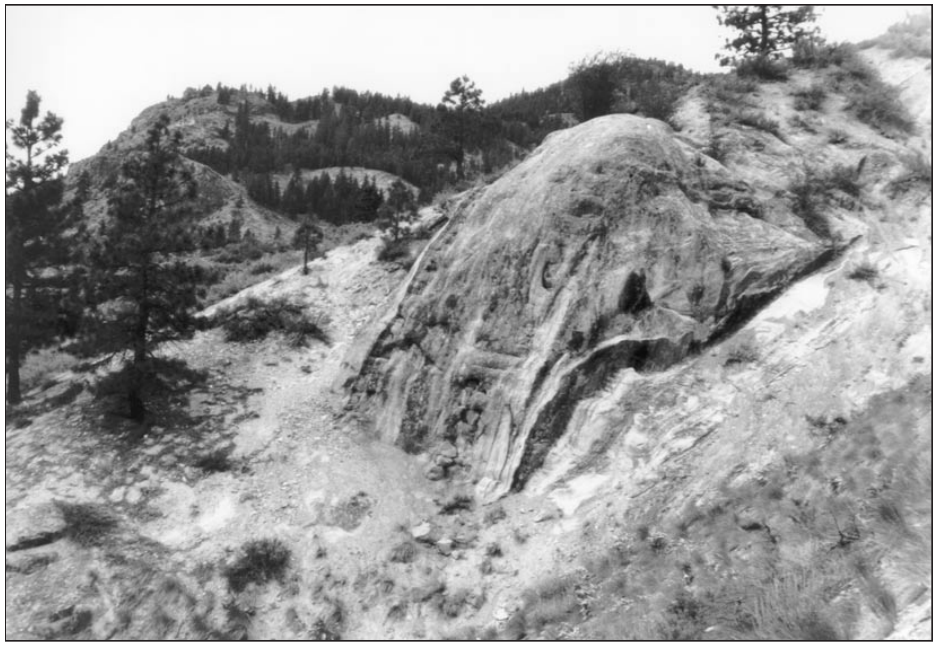


Figure 2. Type locality of the Late Cretaceous Winthrop Formation at Boesel Canyon, north of Winthrop, showing dome-shaped outcrop of steeply dipping sandstone.

Eocene nonmarine rocks form extensive deposits on both sides of the Cascade Range. Arkosic sandstone, conglomerate, siltstone, and coal were deposited by meandering rivers that flowed westward across a broad coastal plain that existed prior to the uplift of the Cascade Range. The Chuckanut and Swauk Formations rank among the thickest sequences of nonmarine sedimentary rocks in North America, with 6,000 m of Chuckanut strata mapped near Bellingham in an outcrop belt that extends from Puget Sound to the Mount Baker foothills (Johnson, 1984). Scattered arkosic outcrops extend across the North Cascades along a radial splay of faults that connects the type localities of the Swauk and Chuckanut Formations. This pattern suggests that both units may have originated in a single depositional basin. The Manastash Formation, southwest of Ellensburg, may be another fault-bounded remnant of this basin (Mustoe and Gannaway, 1997). Another Eocene formation, the Puget Group, is exposed in the walls of the Green River gorge and at several other sites in

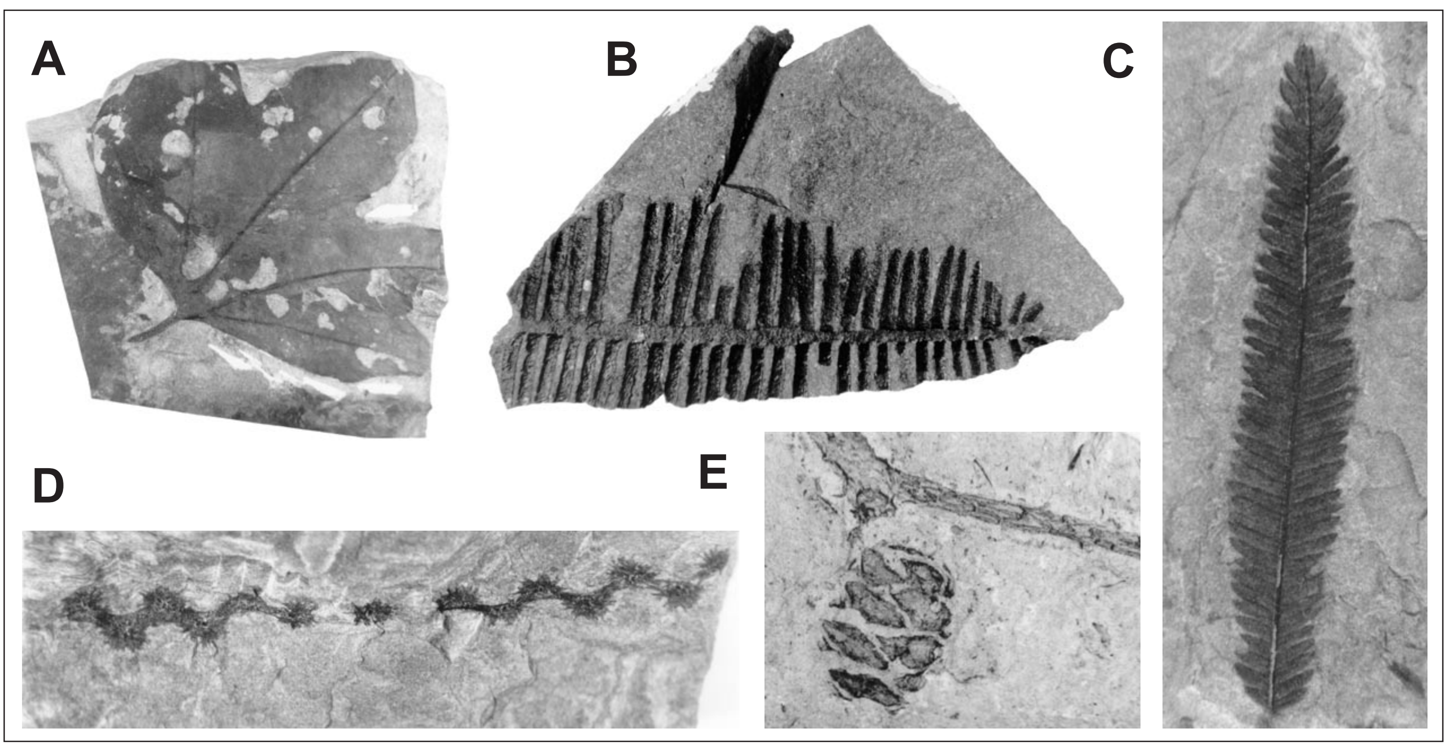


Figure 3. Cretaceous plant fossils. **A**, *Araliophyllum* sp., showing insect damage, 0.5X, Upper Cretaceous Winthrop Sandstone. **B**, *Pterophyllum* sp. (cycadeoid), 0.5X, Lower Cretaceous Buck Mountain Formation, Burke Museum collection, UWBM #66245. **C**, taxodiacious conifer, 0.8X, Upper Cretaceous Winthrop Sandstone. **D**, "*Sparganium*" sp. (monocot), 0.8X, Upper Cretaceous Winthrop Sandstone. **E**, *Metasequoia* (dawn redwood) cone, 1X, Upper Cretaceous Pipestone Canyon Formation; collected by Jim Peterson, 1996. Winthrop Formation fossils collected by Sam Girouard, Jr., 1998.

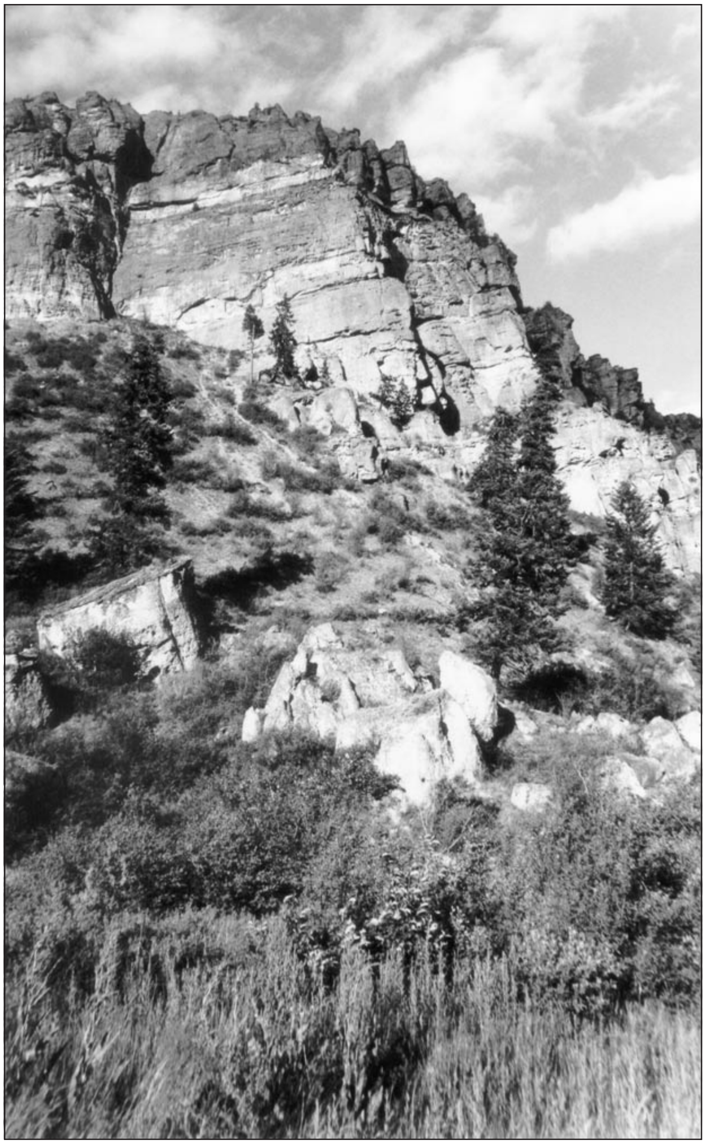


Figure 4. Pipestone Canyon, near Twisp.

western King County. Correlative strata extend as far south as Centralia.

Plant fossils from these formations provide abundant evidence of a subtropical climate during the early and middle Eocene. Remains of fan palms, tree ferns, and swamp-dwelling conifers are very common (Fig. 5). Climatic cooling during the late Eocene explains the absence of these taxa in the upper Chuckanut Formation (Mustoe and Gannaway, 1997). East of the Cascade crest, the Roslyn and Chumstick Formations are late Eocene deposits that also lack palm fossils (Gresens, 1982).

Paleobotanists have published few comprehensive studies of these lowland Eocene paleofloras. The Puget Group has been described by Wolfe (1968) and Burnham (1990), and preliminary analyses of Chuckanut fossils were made by Pabst (1968) and Mustoe and Gannaway (1995, 1997). Evans (1991a, 1991b) reviewed the paleobotany and paleogeography of the Chumstick Formation of central Washington, but description of leaf fossils from the nearby Swauk Formation is limited to the brief report by Duror (1916). Newman (1981) and Griggs (1970) described fossil pollen from several of these formations, including the Swauk and Chuckanut.

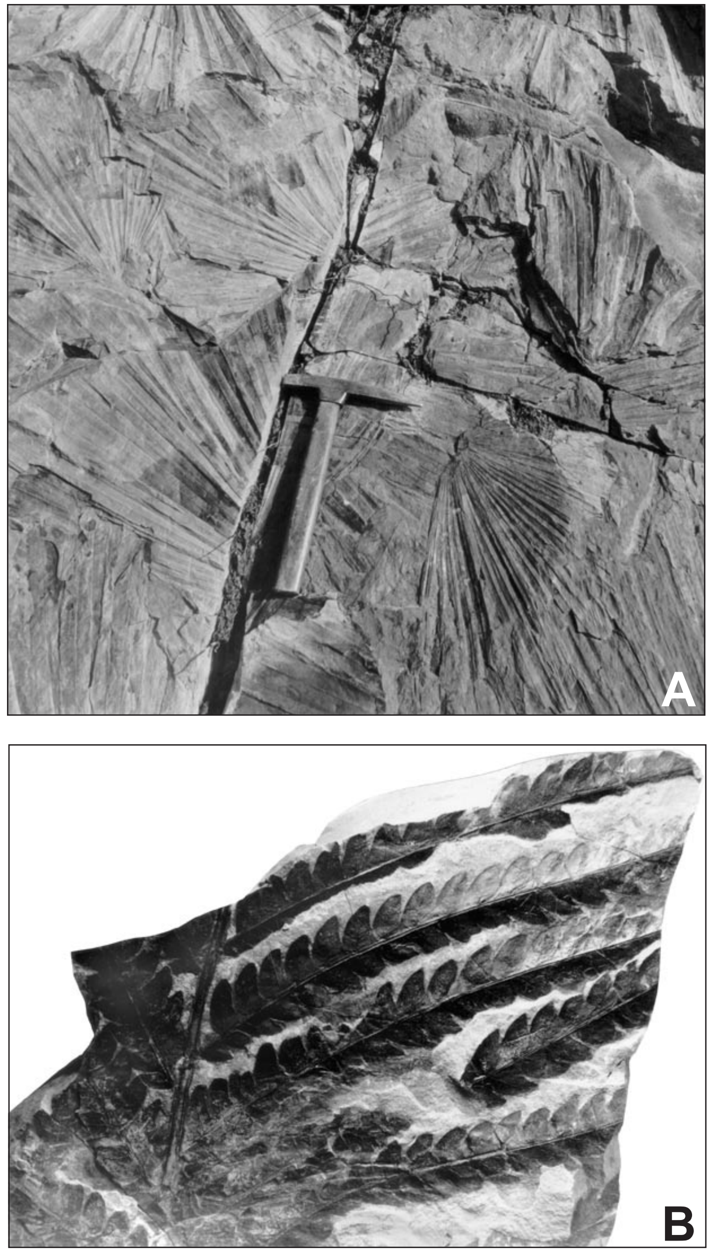


Figure 5. A. Palm fronds preserved on a bedding plane of the Eocene Chuckanut Formation east of Deming, Whatcom County, WA. B. Tree fern *Cyathea pinnata* (MacGinitie) LaMotte from the Chuckanut Formation, 0.4X.

Early Tertiary plant communities that flourished on low-elevation flood plains were quite different from contemporaneous floras at higher altitudes. Our knowledge of upland sites comes largely from fossils found at Republic in Ferry County, where shale beds contain remains of plants that bordered a shallow lake (Figs. 6, 7). These rocks also contain fish and insect fossils, typically preserved in exquisite detail. The international attention that has been given to the Republic site is in no small part the result of years of dedicated effort by Burke Museum paleobotanist Wes Wehr, who played a leading role in uniting a group of professional scientists, amateur collectors, and local residents to establish the Stonerose Interpretive Center. Researchers are continuing to compile a documentary record of these important fossils. (For a detailed synopsis, see the *Washington Geology* Republic Centennial Issue, v. 24, no. 2, June 1996.)

Republic fossils tell the story of an Eocene upland environment that provided a refuge for plants that were unable thrive in the subtropical climate of the lowland flood plain. These uplands were the scene of much diversification, resulting in plant communities that were a complex botanical mixture (Wolfe and Wehr, 1987, 1991). The flora included members of the pine family and deciduous trees, such as alder, sassafras, sycamore, and maple—all plants that continue to grow in North America. *Ginkgo*, *Cercidiphyllum* (katsura), and *Metasequoia* (dawn redwood) are presently native only to Asia. Many taxa have no close modern relatives, evidence of evolutionary transition in early Tertiary forests. Palms, tree ferns, and tropical vines are rare or absent in these upland paleofloras, in marked contrast to the abundance of these plants in lowland habitats that existed during the same time period. Although Stonerose is by far the most studied of the Eocene fossil plant sites in the Pacific Northwest, similar fossils occur along the Similkameen River west of Oroville and at Princeton and several other locations in British Columbia.

Figure 6. Fossil beds at Republic, Ferry County, WA. Stonerose Interpretive Center director Lisa Barksdale in foreground.

Cenozoic plant fossils offer a powerful tool for reconstructing past climates because leaf morphology provides evidence for calculating parameters such as mean annual temperature, rainfall, and the temperature range between winter and summer. Several statistical methods have been employed, the most well-established method being CLAMP (Climate Leaf Analysis Multivariate Program) pioneered by paleobotanist Jack Wolfe (1993, 1995). Humid subtropical rain forests extended as far north as arctic Alaska during the Paleocene and Eocene, and the onset of global cooling near the close of the Eocene was an important factor in the emergence of coniferous forests as a dominant floral element during the Oligocene and Miocene. Early Tertiary plant fossils from Washington are particularly significant because they provide a detailed record of climatic changes during this transitional period. Equally important, these paleofloras provide a powerful tool for determining rates of elevation change during a time when major tectonic events were affecting the region.

Paleobotanists initially estimated paleoaltitude from mean annual temperatures calculated from leaf fossils. They based their calculations on the inverse relationship between temperature and elevation, a phenomenon that explains why vacationers head for the mountains to escape sultry summer weather. One of the first examples came from Republic, where the paleoflora represents a mean annual temperature of 10°C (50°F), in contrast to 17°C (63°F) for Eocene coastal forests. Wolfe and Wehr (1991) concluded that the Republic fossils represent plants that inhabited an elevation of approximately 5,500 ft (2,300 m), about 5,000 ft (1,500 m) higher than the modern altitude. Paleoaltitude can now be determined with even better accuracy thanks to a method that combines CLAMP analysis with equations that describe atmospheric

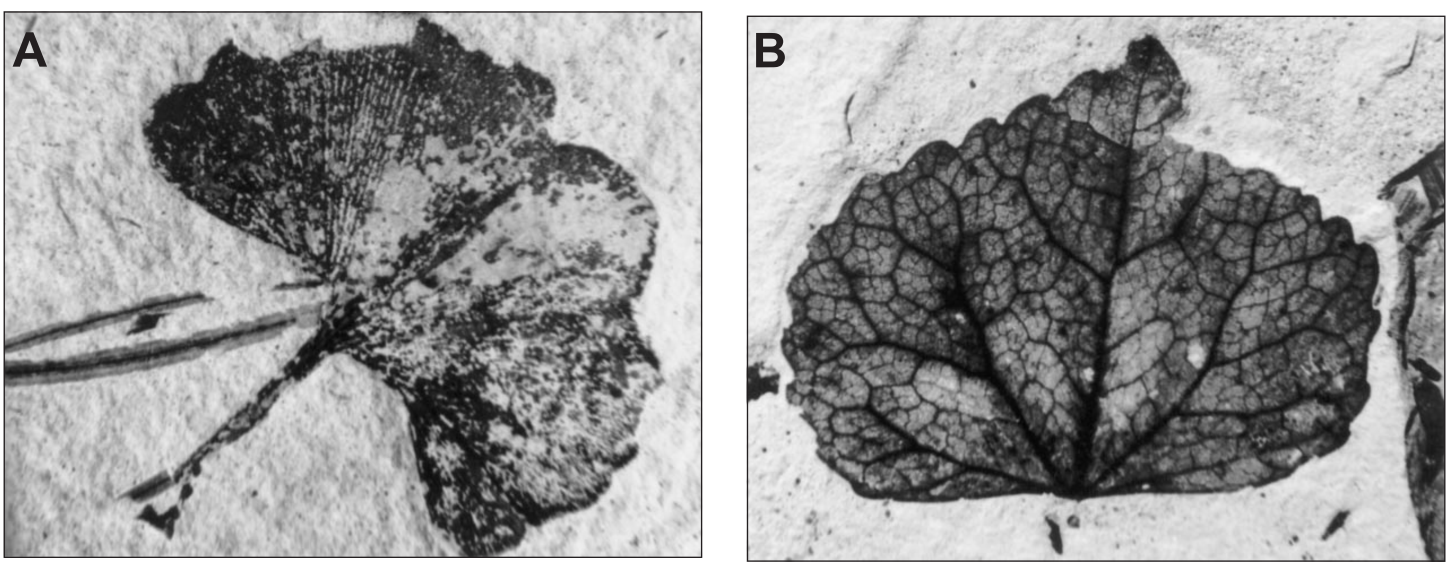


Figure 7. Eocene fossil leaves from Republic. **A**, *Ginkgo adiantoides* (Unger) Heer, 1.4X, photo by Sandra Sweetman. **B**, *Cercidiphyllum obtritum* (Dawson) Wolfe and Wehr (katsura), 1.6X, photo by Lisa Barksdale.

Figure 8. Oligocene petrified wood showing teredo borings, collected near Port Angeles, Clallam County, WA., 0.4X.

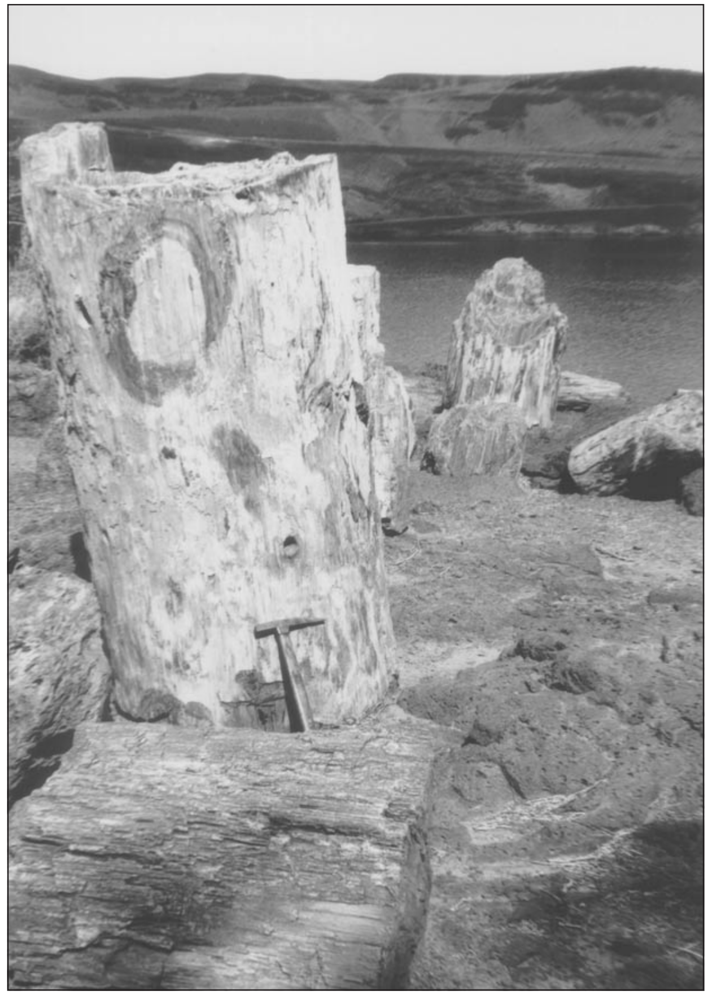


Figure 9. Agatized logs at Ginkgo Petrified Forest State Park near Vantage.

thermodynamics (Wolfe and others, 1998; Forest and others, 1999). Wolfe is presently heading a team of geoscientists that is studying early Tertiary plant fossils from Washington and British Columbia to document uplift rates for the region.

OLIGOCENE GEOGRAPHIC CHANGE

By the mid-Tertiary, the onset of Cascade Range mountain building disrupted the pattern of fluvial deposition, and lowland flood plains were uplifted, causing surface processes to be dominated by erosion rather than sediment accumulation. Oligocene plant fossils are known from only a few locations in Washington. Leaves and driftwood are preserved in the rocks of Bulson Creek (Cheney, 1987) exposed along Pilchuck Creek and the South Fork Stillaguamish River in Snohomish County (Marcus, 1991). Permineralized conifer cones (Miller and Crabtree, 1989; Miller, 1990) and teredo-bored wood fragments are found in marine sediments of the Twin Rivers Group on the northern Olympic Peninsula (Fig. 8). Small collections of fossil plant leaves have been collected from Gumboot Mountain south of Mount St. Helens. This paleoflora has not been described in detail, but Meyer and Manchester (1997) noted the presence of twelve genera of conifers and flowering plants that also occur in the early Oligocene Bridge Creek flora of north-central Oregon. East of the Cascades, the Wenatchee Formation locally contains small specks of amber but few other plant fossils.

MIOCENE WONDERS

During the Miocene, extensive plant-bearing beds were deposited as a result of unique environmental conditions that accompanied extrusion of the Columbia Plateau basalts. Agatized and opalized logs have been found at more than a dozen locations in central Washington, the best known is at Ginkgo Petrified Forest State Park near Vantage (Fig. 9). Collecting is not allowed in the park, but state lands at nearby Saddle Mountain and along the Yakima River canyon are popular destinations for rockhounds.

For many years paleontologists believed that these petrified logs represented fallen timber that was transported by streams to accumulate in a swamp (Beck, 1938, 1945a,b; Prakash and Barghoorn, 1961a,b; Prakash, 1968). The water-saturated logs were protected from combustion when the swamp was later inundated by lava flows, and silica-bearing ground water eventually caused the wood to be petrified. This explanation presumes that the fossils represent the intermingling of logs from several different plant communities. Tolan and others (1991) proposed that instead of being transported by streams, the tree trunks were ripped from their habitat and carried downvalley by a huge mudflow, suggesting that the mix of species represents genetic diversity within a single forest (Orsen, 1998). The 1980 eruption of Mount St. Helens provided spectacular evidence of the power of volcanic blasts and associated mudflows to decimate forests and transport some trees while preserving others in upright position in beds of ash or stream sediment. Early stages of the petrifaction process, where wood cells begin to be impregnated with silica, have been observed in trees buried by the 1980 cataclysm (Karowe and Jefferson, 1987).

Columbia Plateau basalt flows contain petrified trunks from broadleaf trees that include oak (*Quercus*), maple (*Acer*), elm (*Ulmus*), birch (*Betula*), sycamore (*Platanus*), and beech (*Fagus*). Conifers include yew (*Taxus*) and bald cypress (*Taxodium*), but ancestral varieties of fir, spruce, and Douglas fir comprise more than fifty percent of the fossils. The park's namesake, *Ginkgo*, is one of the rarest wood types. Sweetgum (*Liquidamber*), water tupelo (*Nyssa*), and bald cypress (*Taxodium*) are examples of tree genera that became restricted to the southeastern U.S. as a result of the late Cenozoic climatic cooling. This global temperature decline may have been related to changes in oceanic and atmospheric circulation triggered by expansion of the east Antarctic ice sheet (Flower and Kennett, 1993).

Leaf fossils preserved in shallow lake deposits interbedded with the basalt flows tell a similar story (Figs. 10, 11). Leaf-bearing Miocene sediments have been found in Washington at Spokane (Knowlton, 1926; Berry, 1929), Grand Coulee (Berry, 1931, 1938), Ellensburg (Smiley, 1963; Chaney and Axelrod, 1959), and at sites in Nevada, Oregon, and Idaho (Brown, 1935; Chaney, 1959, p. 1-34). Axelrod and Schorn (1994) noted that these paleofloras show major floristic changes at approximately 15 million years ago, evidenced by the abrupt disappearance of deciduous hardwoods whose descendants now inhabit the eastern U.S. and eastern Asia. They attributed this change to a 35 to 40 percent decrease in summer precipitation during the middle Miocene, a climatic shift that may have resulted when uplift of the Cascade Range and Rocky Mountains created rain shadows that increased the aridity of the inland Northwest.

Figure 10. Contact between Miocene lake bed deposits and basalt flow in roadcut between Ellensburg and Vantage.

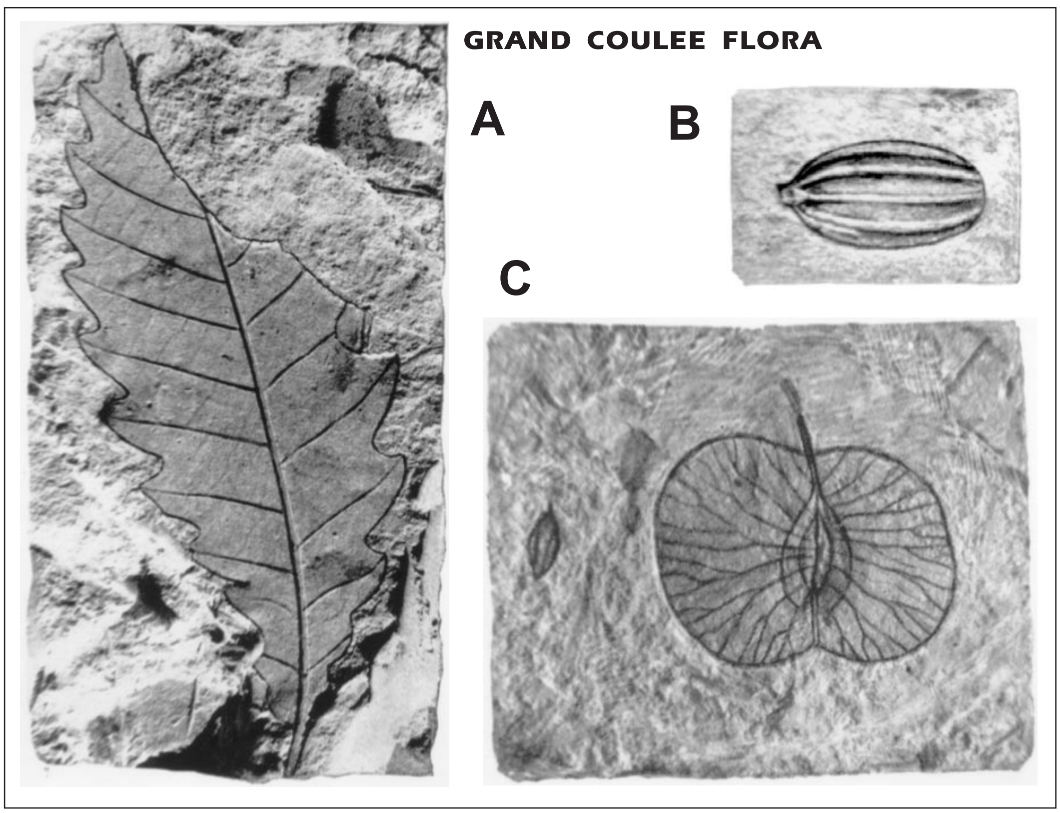
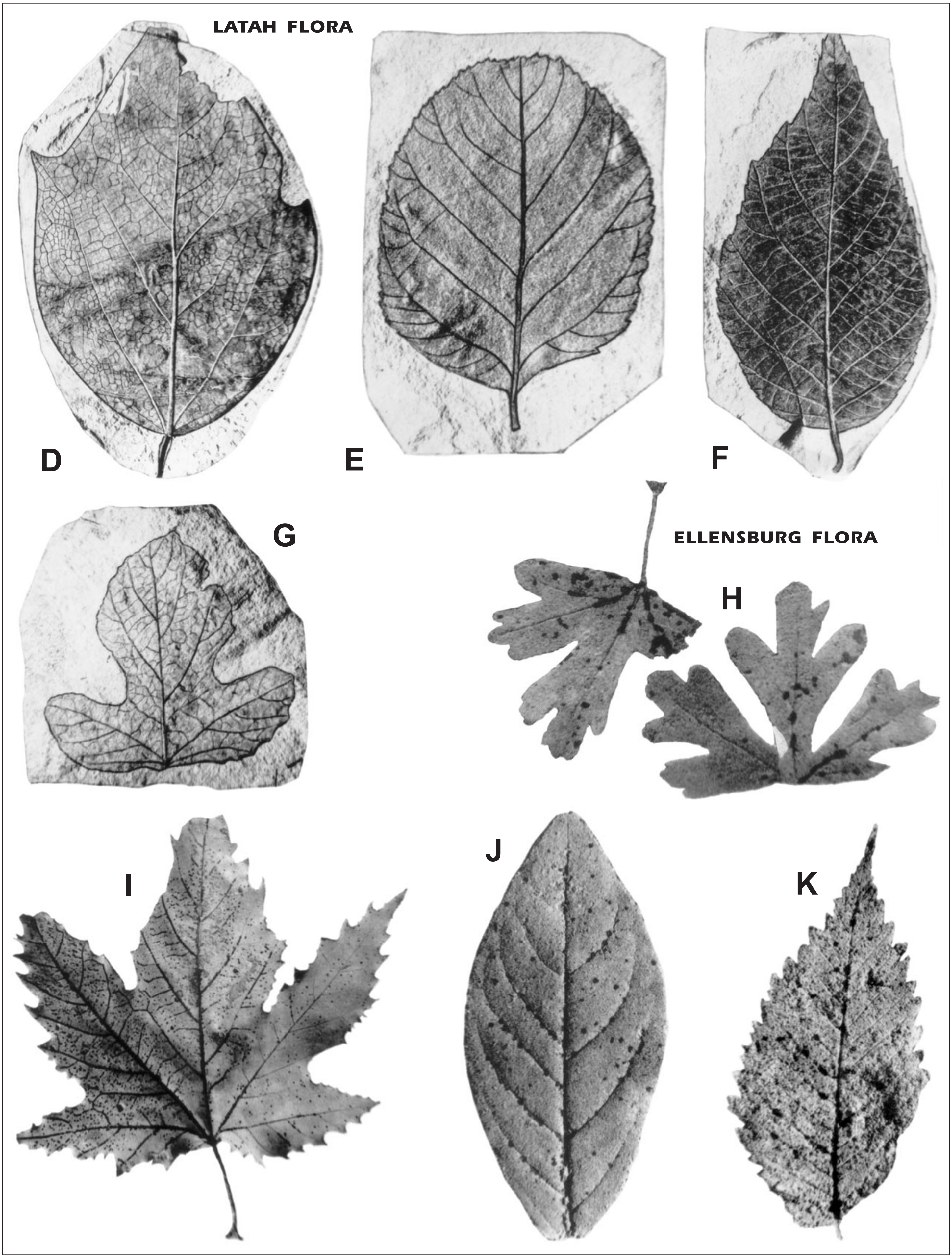


Figure 11. *(continued on next page)* Miocene leaf fossils. **Grand Coulee flora** (illustrations from Berry, 1931): **A**, *Quercus mccanni* Berry (oak family), 1.5X. **B**, *Nyssa hesparia* Berry (water tupelo seed), 1.7X. **C**, *Ptelea miocenica* Berry (seed), 1.7X. Seeds of this type are now assigned to the genus *Dipteronia*. **Latah flora** (illustrations from Berry, 1929): **D**, *Ficus*? *washingtonensis* Knowlton, 0.5X. Originally believed to be a fig leaf, this fossil probably represents an extinct genus. **E**, *Alnus prerhombifolia* Berry (alder), 1.2X. **F**, *Betula largei* Knowlton (birch), 0.9X. **G**, *Menispermites latahensis* Brown (an extinct vine?), 1X. **Ellensburg flora** (illustrations form Smiley, 1963): **H**, *Acer columbianum* Chaney and Axelrod (maple), 0.8X. **I**, *Platanus dissecta* Lesquereux (sycamore), 0.5X. **J**, *Celtis cheneyi* Sanborn, 1X. **K**, *Ulmus pancidentata* Smith (elm), 1X. Some of the photos have a diagonal-line or twill texture that does not belong to the fossils themselves but is the result of photographing halftone illustrations from the original books instead of the original fossils or photos, which were not available.


LATAH FLORA
D
E
F
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ELLENSBURG FLORA
H
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Miocene plant remains are scarce in western Washington, but the Wilkes Formation near Toledo in Lewis County contains beds that preserve unmineralized trunks of trees and shrubs that were buried by thick deposits of volcanic ash (Fig. 12). A few leaf fossils have been collected from other parts of the formation (Roberts, 1958).

Figure 12. Stems of shrubs and small trees preserved in growth position in clay beds of the Miocene Wilkes Formation along Salmon Creek east of Toledo, Lewis County, WA.

LATE CENOZOIC PLANT REMAINS

Paleobotanical evidence is lacking from the Pliocene, an 11 million year interval that produced few sedimentary deposits in our state (a notable exception being the vertebrate-bearing beds of the Ringold Formation in central Washington). Peat layers and wood fragments are common in some Puget Sound Pleistocene deposits, permitting geologists to date samples using carbon isotope ratios. The ^{14}C dating method is useful only for samples younger than 40,000 years, but spores and pollen can be used to determine chronological sequences in older deposits and to study ecological changes that affected prehistoric plant communities.

We usually consider fossils to be remains of organisms that lived during some dim dawn of time, a view that is challenged by the discovery of fresh-looking pieces of wood in Ice Age gravels that were deposited only 12,000 years ago. An even greater surprise awaits at the Trail of Two Forests interpretive site near Ape Cave on the south side of Mount St. Helens, where visitors can observe and even crawl through hollow tunnels left when a basalt flow buried living trees (cover photo, Fig. 13). These two-thousand-year-old tree molds are little more than twice the age of trees that still spread their limbs across the sky in our state's old growth forests.

Figure 13. Tree mold in 2,000-year-old basalt flow, Trail of Two Forests interpretive site, Mount St. Helens National Monument.

CONCLUSIONS

Washington sites teach us that fossilization is a dynamic process. Time is not the only factor that controls petrifaction—15-million-year-old wood weathering from the Wilkes Formation can be carved with a pocket knife and ignited with a match. Equally important, fossils tend to record only a tiny minority of species that once inhabited the landscape. Sedimentary deposits usually preserve remains of organisms that grew in or near wetlands, and we have only scant knowledge of ancient plants and animals that inhabited drier environments. Although an infinitesimally small percentage of ancient forest plants became fossilized, other members of these populations were immortalized another way. Each autumn the land is decorated with the fallen leaves from vast numbers of deciduous trees, and even evergreen species eventually lose their foliage. Nature long ago perfected the art of composting these materials so that carbon, nitrogen, and other elements are recycled into succeeding generations of plants and animals. Fossil collectors split slabs of rock in the hope of finding traces of cycads and ginkgoes, but we can observe biochemical descendants of these trees both in the living leaves that shade us while we work and in the hand that holds the rock hammer.

ACKNOWLEDGMENTS

Paleobotany curator Wes Wehr graciously allowed me to study plant fossils from the Burke Museum at the University of Washington, and Stonerose Interpretive Center director Lisa Barksdale provided photos and a tour of the Republic fossil beds. Ginkgo State Park staff member Debbie Hall contributed detailed information about the petrified forest, and Ellensburg geologist Jim Peterson donated fossils from Pipestone Canyon and shared preliminary data from his thesis research. Finally, I would like to commemorate Samuel P. Girouard, Jr., a young paleontologist who unexpectedly passed away in Bellingham in September of 1999. Sam's field work in the Chuckanut and Winthrop Formations and his enthusiastic discussions of paleobotany were important ingredients in the evolution of this project from a hazy notion to a completed manuscript.

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ON OUR WEBSITE:
Selected References on Washington Geology for Teachers and Students

Our website now contains a list of publications that may be of interest to teachers and students of the geology of Washington State. The list covers general works as well as works dealing with a specific geologic topic such as earthquakes, gold mining history, or paleontology. Find the list at http://www.wa.gov/dnr/htdocs/ger/selrefs.htm.

Where Am I Now, And Can I Take This Fossil With Me?

The rules governing the removal of fossils from a particular location vary according to the agency that controls the land where the fossil is found. Even if the fossiliferous find is only a broken bivalve, it might be illegal to pocket it and walk away. When traveling out West—where the checkerboard of private, state and federal lands seems endless—a fossil collector must be wary of the soil upon which he treads and, more to the point, digs for fossils.

Below is an outline of the regulations on fossil collecting and permit granting for federally managed lands, as well as an example of the management policies for the state of Wyoming.

FEDERAL LAND

Five federal agencies control virtually all public land in the United States. The different regulations reflect their diverse missions. The National Park Service maintains a preservational focus, while agencies such as the Bureau of Land Management establish their policies for multiple-use. In May 2000, Secretary of the Interior Bruce Babbitt sent a report to Congress on federal policies concerning fossils. The report can be found at www.doi.gov/fossil/fossilreport.htm.

Bureau of Land Management—Reasonable amounts of invertebrates, plants and petrified wood may be collected for personal use, but not for sale. No vertebrate fossils may be removed without a permit. Permits are granted for scientific purposes only.

National Park Service—Permits are required for the removal of any fossilized material. Permits are granted for scientific purposes only.

U.S. Forest Service—Same as BLM.

Bureau of Reclamation—Same as NPS.

U.S. Fish and Wildlife Service—Special-use permits are required for the removal of any fossilized material. Permits are granted for scientific purposes only. Obtaining a scientific permit for collecting on federal land generally requires a graduate degree in paleontology or a related field. Reports must be filed with the permitting agency annually and at the end of the project. Permits can vary from limited surface collection and surveying to the excavation of one square meter or more of sediment.

STATE LAND

Individual states have the power to grant permits for commercial fossil quarries. They are granted for a fee and royalties must be paid to the state in most cases. For the state of Wyoming, the Board of Land Commissioners lays out the rules and regulations for commercial and scientific permitting. Common invertebrates and five common species of fish can be quarried and sold without review by the Wyoming Geological Survey and without payment of royalties.

Continued on p. 27.

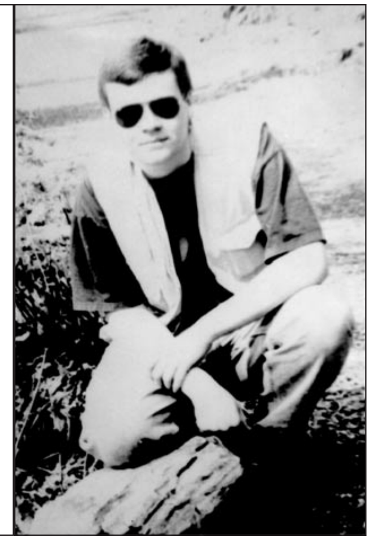
On the Trail of Washington Dinosaurs

Samuel P. Girouard, Jr.
University of Washington

Samuel P. Girouard, Jr.

This article originated as a draft written by Samuel Girouard, Jr., a University of Washington student whose eager preparation for a career as a vertebrate paleontologist was cut short by his death in September of 1999 at age 18. His loss is keenly felt by his family, friends, and scientific colleagues.

The manuscript was posthumously prepared for publication by George Mustoe, Geology Department, Western Washington University, Bellingham, WA 98225; e-mail: mustoeg@cc.wwu.edu. *Photo by George Mustoe, 1999.*



INTRODUCTION

Washington rocks have yielded a diverse variety of plant and animal fossils, but to the disappointment of school children and geologists alike, no dinosaur remains have yet been found. One explanation for this paucity is that Washington contains relatively few sedimentary rocks from the Mesozoic Era, the 120 million year period when dinosaurs roamed over much of the world.

Most deposits of this age in our state originated as fragments of sea floor and island chains that became welded to the western edge of North America as a result of the collision between the continent and the oceanic crustal plate. These submarine basalt flows, deep-ocean sediments, and island-arc volcanic rocks offered unfavorable environments for preserving fossils, and subsequent subduction zone metamorphism further decreased the likelihood that plant or animal remains would remain recognizable.

Because of these geologic factors, the probability of finding dinosaur fossils in the Pacific Northwest is slim. In comparison, the Great Plains region, extending from the Gulf of Mexico to Alberta, has yielded abundant vertebrate remains, which were preserved along the margin of the shallow midcontinental sea that existed prior to the uplift of the Rocky Mountains. But the search for dinosaur remains in Washington is not hopeless. Where might we expect to have the best chance of success? This paper explores several possibilities.

REPTILE REMAINS FROM NEARBY REGIONS

Possible Washington occurrences of saurian bones or tracks are suggested by discoveries of Mesozoic vertebrate fossils elsewhere in the Pacific Northwest. Permineralized bones of the iguanodont ornithopod *Tenontosaurus* have been reported from the Lower Cretaceous (Albian) Wayan Formation of southwestern Idaho, along with numerous eggshell fragments and ankylosaur and possibly ceratopsian bones (Dorr, 1985). Stokes (1978) described probable dinosaur tracks from the Early Jurassic Nugget Sandstone at Indian Creek near the Idaho–Wyoming border. Oregon has yielded only a single dinosaur find, the sacrum of a hadrosaur that is currently undergoing preparation at the University of Oregon (Weishampel, 1990).

The only documented dinosaur discovery from the British Columbia mainland is a single toe bone from an ornithopod found at a coal mine at Fernie in the southeast corner of the province, but a few other ornithopod bones are rumored to have been collected along the Pine River in northeastern B.C. (Sampson and Currie, 1996). A single 1-cm long theropod tooth was found in 1992 during excavation of a natural gas pipeline in Late Cretaceous rocks at Trent River, south of Courtenay on southeast Vancouver Island (Ludvigsen, 1996; Girouard, 1997). Spectacular trackways were discovered in 1922 at Peace River canyon. These trackways comprised more than 400 individual imprints left by a diverse variety of bipedal (two-footed) and quadrupedal (four-footed) dinosaurs (Sternberg, 1932; Currie and Sarjeant, 1979; Mossman and Sarjeant, 1983). Other Cretaceous dinosaur tracks have since been found along the Narraway River in eastern B.C. (Sampson and Currie, 1996).

Although dinosaur remains are rare in the Pacific Northwest, fossilized teeth and bones from four types of Late Cretaceous marine reptiles have been discovered in the Comox Valley region of southeastern Vancouver Island. Nicholls (1992) described a limb bone and lower jaw of the sea turtle *Desmatochelys* found during excavation of a fish ladder on the Puntledge River near Courtenay. Two nearby sites have yielded permineralized mosasaur (Sea Lizard) vertebrae, and a mosasaur femur and an incomplete skull have been found inside sandstone concretions on Hornby Island. The most spectacular Puntledge River find is the nearly compete skeleton of an elasmosaur (Swan Lizard) on display at the Courtenay & District Museum. The fossil was discovered in 1988 and excavated over a two-month period by a team of volunteers in the spring of 1992 (Ludvigsen, 1996).

Mesozoic marine reptile fossils have been found at several other sites in the Northwest. Fragmental icthyosaur (Fish Lizard) remains were first noted in eastern Oregon in 1895 (Orr and Orr, 1999). Later discoveries included vertebrae, a few poorly preserved long bones, and skull and jaw fragments of a teleosaurid crocodilian from the early Middle Jurassic Weyberg Formation near Suplee (Buffetaut, 1979) and scores of ribs and articulated vertebrae from Triassic limestones of the Wallowa Mountains (Orr, 1986). A section of icthyosaur skull containing twelve teeth was collected in 1961 from Late Jurassic strata at Sisters Rocks on the Oregon coast south of Port Orford (Camp and Koch, 1966), and an icthyosaur vertebra of similar age was described from eastern Oregon by Merriam and Gilmore (1928). Paleontologists from the Royal Tyrrell Museum are presently excavating a newly discovered icthyosaur at Pink Mountain, B.C., near the Alaska Highway between Fort Saint John and Fort Nelson.

Evidence of these extinct marine reptiles (Fig. 1) provides a tantalizing clue that although dinosaurs are, by definition, terrestrial, a likely place to look for dinosaur remains in Washington is in Mesozoic marine deposits. No vertebrate fossils have been found in non-marine parts of the Cretaceous Nanaimo

Group that underlies southeast Vancouver Island and adjacent islands (Mustard, 1994), but these deposits are rich in plant fossils (Bell, 1957) that presumably would have supported herbivorous reptiles and the carnivorous dinosaurs that preyed on them, and beds of silt and fine sand would have provided favorable conditions for fossilization.

The reason dinosaur remains have escaped detection is that finding bones—even very big bones—in terrestrial deposits is akin to finding small needles in a very large and well lithified haystack. The odds of finding vertebrate fossils improve in marine deposits because skeletal materials are likely to be preserved in the fine mud of the sea floor where they are protected both from scavengers and from oxidation. Remains of terrestrial animals may be found in marine deposits because bones and teeth were sometimes carried to sea by streams and rivers. The Trent River theropod tooth may have had an even more complicated depositional history because its corroded surface suggests that the specimen may have been exposed to digestive acids in the alimentary tract of a carnivore and later excreted prior to burial (Girouard, 1997).

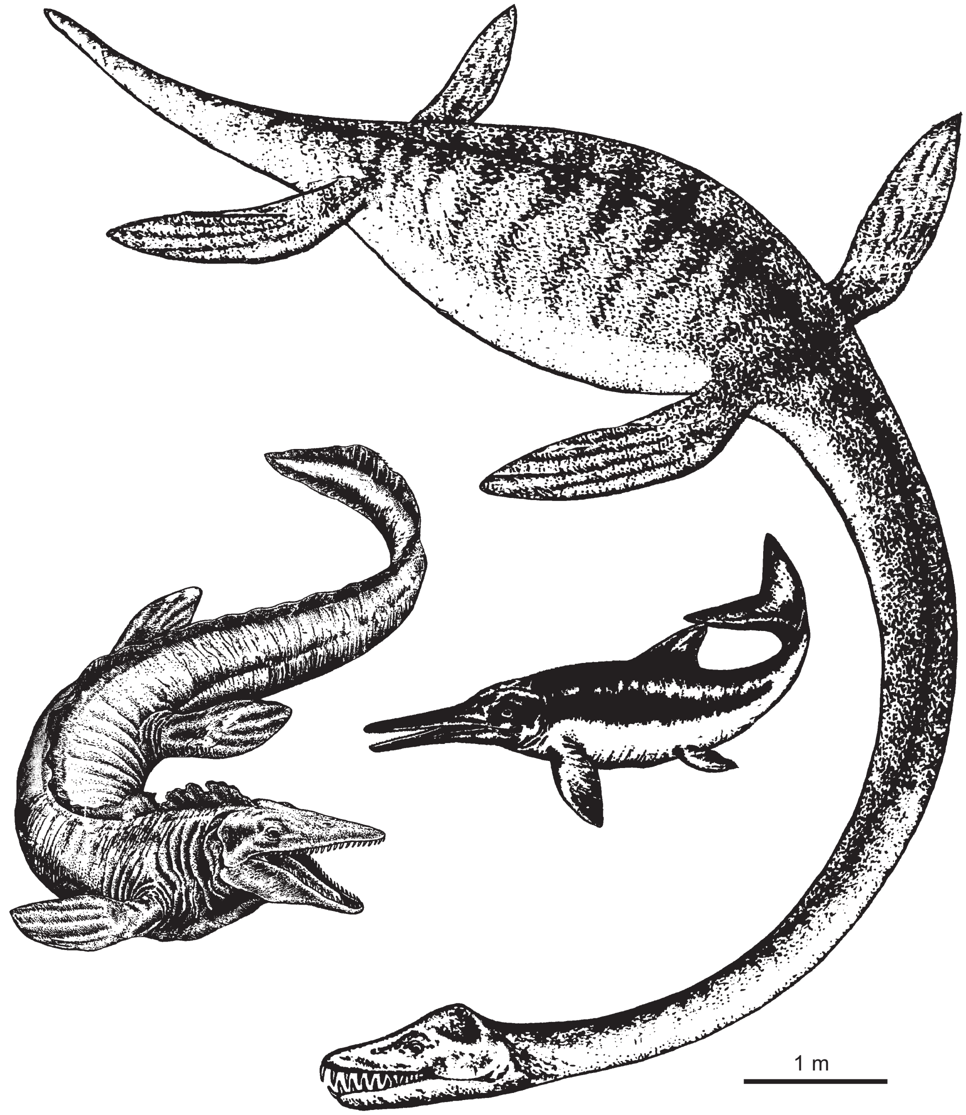


Figure 1. Extinct marine reptiles that are known to have inhabited the Pacific Northwest during the Mesozoic Era include mosasaurs *(left)*, icthyosaurs *(center)*, and elasmosaurs, a type of plesiosaur *(right)*. *Reconstructions from Rich and others, 1996*.

THE METHOW VALLEY

The greatest expanse of Mesozoic sedimentary rocks in Washington is found east of the Cascade crest in the Methow Valley, where both marine and terrestrial deposits span an age range of Late Jurassic to Late Cretaceous (Fig. 2). The Lower Cretaceous Buck Mountain Formation is an assemblage of volcanic and volcaniclastic rocks that outcrops near Winthrop. Barksdale (1975) divided the formation into three informal members. The basal unit is comprised mostly of andesite breccia with a few volcanic flows and fine-grained clastic interbeds. The middle member consists of thick beds of conglomerate, sandstone, siltstone, and shale and is overlain by a member that contains volcanic lithic sandstone and finer sediments but no conglomerate. Fossil ammonites and belemnites occur in all three units, and the pelecypods *Buchia* and *Inoceramus* are among the most common bivalves. The invertebrate fauna and the abundance of volcaniclastic sediment indicate deposition in a shallow near-shore marine basin, making the Buck Mountain Formation a possible candidate in the search for remains of marine reptiles.

The presence of plant fossils in rocks that also contain mineralized mollusks (McGroder and others, 1990) suggests that transported bones or teeth of terrestrial animals might someday be found in the same beds. The Burke Museum collection includes several specimens of foliage from the cycadeoid *Pterophyllum* (UWBM #66245, 66246, 66247), indicating that at least one non-marine siltstone interbed is present within the Buck Mountain Formation, increasing the odds that remains of land animals may have been preserved. South and east of Winthrop, the Buck Mountain Formation unconformably overlies argillites and volcanic lithic sandstones of the Twisp Formation, a Jurassic unit that has yielded a fish scale, cycadophyte leaves, and belemnites (McGroder and others, 1990). The overall scarcity of fossils in Twisp beds makes the chance of finding reptile remains very slim, but not impossible.

The Methow Valley region contains several other formations that are worthy of consideration. The Lower Cretaceous Panther Creek Formation predominantly consists of cobble-rich conglomerate, a poor host material for preservation of fossils, but pelecypods and ammonites have been collected from fine-grained interbeds at a few sites, sometimes in association with plant fragments. The formation is overlain by marine shale and sandstone of the Harts Pass Formation, believed to have been deposited approximately 100 million years ago near the midpoint of the Cretaceous Era. The 8,000 ft (2,400 m) thick formation extends over much of the western part of the Methow region, forming outcrops along high ridges between Slate Peak and Tatie Peak. Marine invertebrate fossils are very abundant at some of these localities.

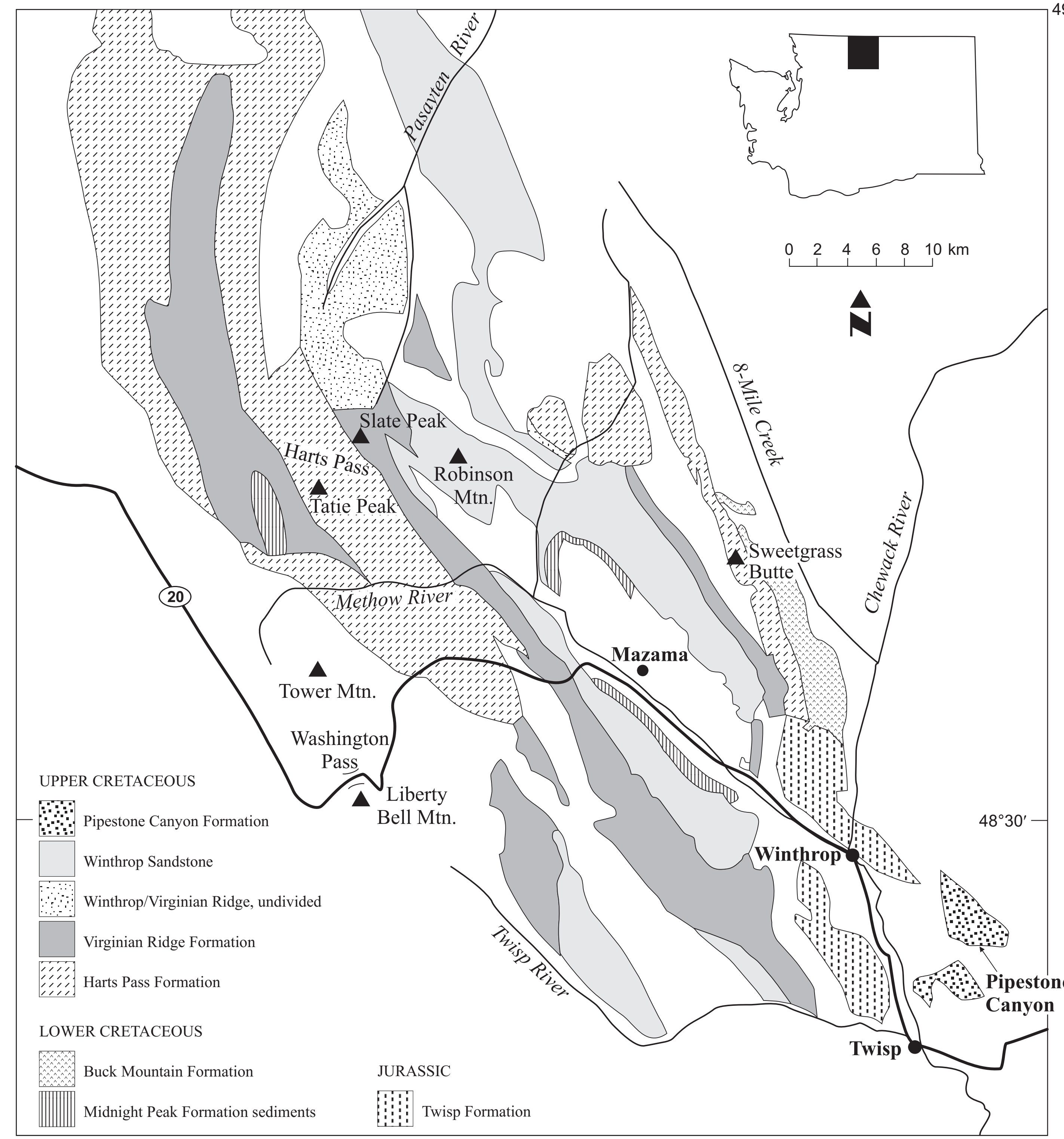


Figure 2. Distribution of Mesozoic sedimentary rocks in the Methow Valley region. *Redrawn from McGroder and others, 1990.*

Three Upper Cretaceous formations include terrestrial deposits. The Virginian Ridge Formation west and northwest of Winthrop contains chert-rich conglomerates and lithic sandstones and shale that contain marine invertebrates, as well as terrestrial interbeds that preserve plant fossils (R. A. Haugerud, personal commun., 1998). The Virginian Ridge Formation intergrades with the Winthrop Sandstone, a continental assemblage of massive arkosic sandstone and shale. These finer beds locally contain abundant leaf and wood fragments and minor coal seams. The Winthrop Sandstone outcrops as white sandstone beds on the east side of Highway 20 along the gentle slopes of Boesel Canyon, approximately 10 miles south of Mazama. The formation underlies much of the divide that separates the Pasayten and Chewack Rivers, but these forested and meadow-carpeted uplands display relatively few outcrops. Although most beds are composed of massive cross-bedded sandstone, shale interbeds contain abundant plant fossils. Crabtree (1987) listed approximately 20 species of fern, conifer, and dicotyledonous plant remains from the type locality near Boesel Canyon (Fig. 3), supplementing brief earlier reports (Russell, 1900; Daly, 1912; Bell, 1957, Barksdale, 1975; Rau, 1987). In the summer of 1998, I made a large collection of plant fossils from this site for the Burke Museum. The abundance and diversity of these fossils provide ample evidence that the Methow basin would have provided a favorable environment for herbivorous reptiles during the Late Cretaceous, and these herbivores in turn would have provided a food source for carnivorous dinosaurs. Winthrop Formation plant fossils include seeds, leaves, and stems. Angiosperm leaves commonly show insect damage (Fig. 4), evidence of a possible diet for small varieties of dinosaurs that are believed to have been insectivores (Dodson, 1997).

The great regional extent of the Winthrop Sandstone and the abundance and diversity of its plant fossils make this formation the most likely candidate for producing Washington's first dinosaur discovery, but the scarcity of outcrops poses a challenge. In contrast, the Pipestone Canyon Formation, 8 km northeast of Twisp, is a Late Cretaceous terrestrial deposit that is very well exposed (Fig. 5). Although the type locality reveals a continuous 440 m stratigraphic section, these rocks form vertical cliffs that make field work scenic but difficult. Most of the Pipestone Canyon beds are composed of coarse sandstone and conglomerate that originated as debris flows and alluvial fan deposits along an ancient mountain front. A few siltstone beds contain plant fossils that were originally interpreted as evidence of a Paleocene age (Royse, 1965), but the formation is now believed to be Late Cretaceous (Peterson, 1999). If vertebrate remains are preserved in Pipestone strata, they would probably be in the form of disarticulated bones sparsely scattered within the alluvial fan deposits.

Terrestrial sedimentary rocks of the Methow Valley may preserve dinosaur footprints, though none have yet been discovered. An individual animal has only one skeleton but it can leave behind an almost infinite number of footprints. In reality, tracks are likely to be preserved only under favorable environmental conditions when imprints are made in moist sediment that is soon buried by a new layer of protective

Figure 3. Dinosaur fodder? Outcrops of Winthrop Sandstone exposed along the south flank of Boesel Canyon *(top photo)* north of Winthrop contain shale interbeds that preserve Late Cretaceous plant fossils *(bottom photo)*. *Photos courtesy of George Mustoe, 1999.*

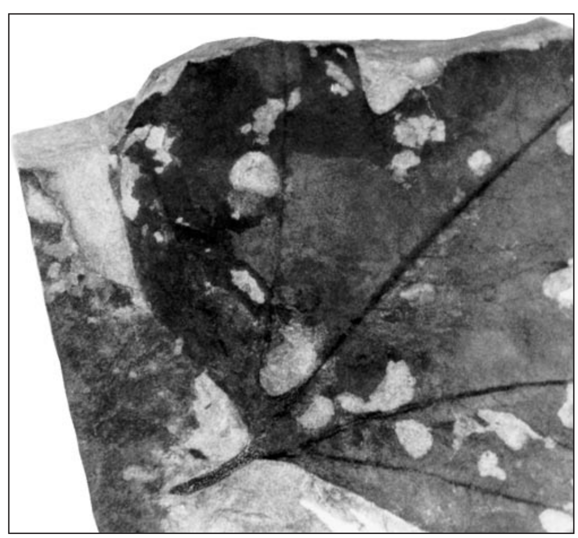


Figure 4. *(right) Araliophyllum* leaf from Boesel Canyon shows insect damage. This single fossil suggests possible dietary evidence for herbivores, insectivores, and carnivores. *Specimen collected by Sam Girouard, 1998.*

sand or silt. These trace fossils will only be discovered in rock that happens to split along that particular bedding plane. Odds of discovering tracks or trackways are greatly improved at locations where outcrops expose large expanses of bedding planes, a structural characteristic that is rare in sedimentary rocks of the Methow Valley. An analogous situation occurs in the early Tertiary Chuckanut Formation in northwest Washington. The formation contains abundant plant fossils, but for many years the only known vertebrate fossil was a carapace from an aquatic turtle (Mustoe and Pevear, 1983). Most Chuckanut Formation fossils come from steeply dipping outcrops of sandstone or siltstone that fail to display bedding plane surfaces, but road construction in the Mount Baker foothills has uncovered several areas of gently dipping bedrock that contain trackways from a diverse variety of birds and mammals (Mustoe, 1993; Mustoe and Gannaway, 1997). At sites within the Slide Mountain Member where we have had a chance to examine well-exposed Chuckanut Formation bedding planes, animal tracks were often discovered (Fig. 6). These observations should remind us that structural geology may play a crucial role in determining the success or failure of our search for evidence of ancient vertebrates in older deposits.

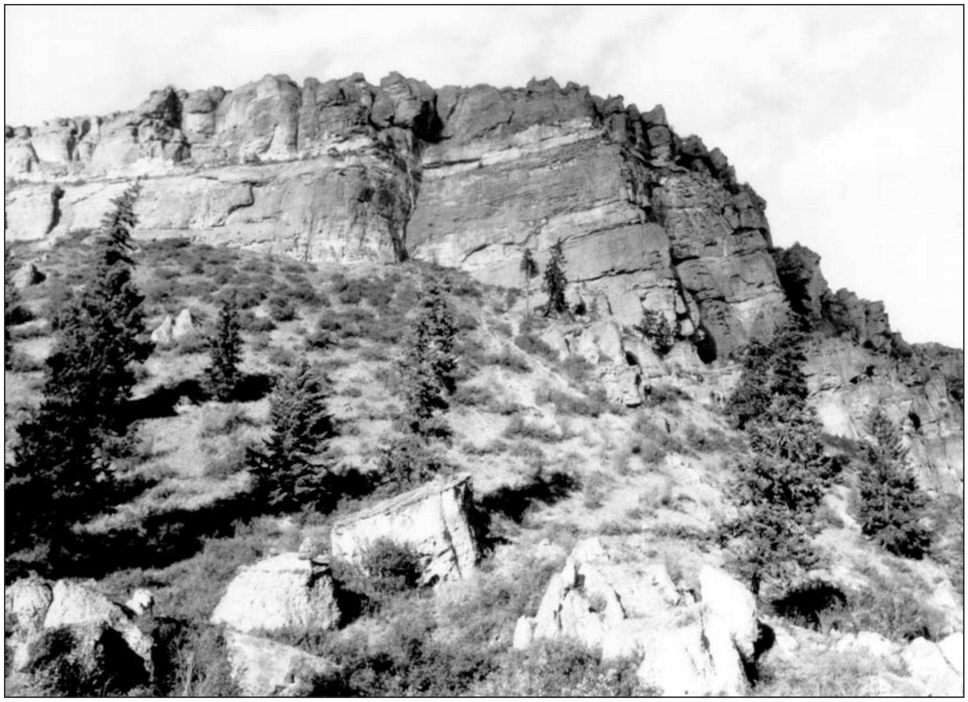


Figure 5. Late Cretaceous terrestrial sedimentary rocks of the Pipestone Canyon Formation form spectacular cliffs at Pipestone Canyon near Twisp. Plant remains are preserved in a few shale layers, but most of the strata are coarse sandstone and conglomerate beds that contain few fossils. *Photo by George Mustoe, 1999.*

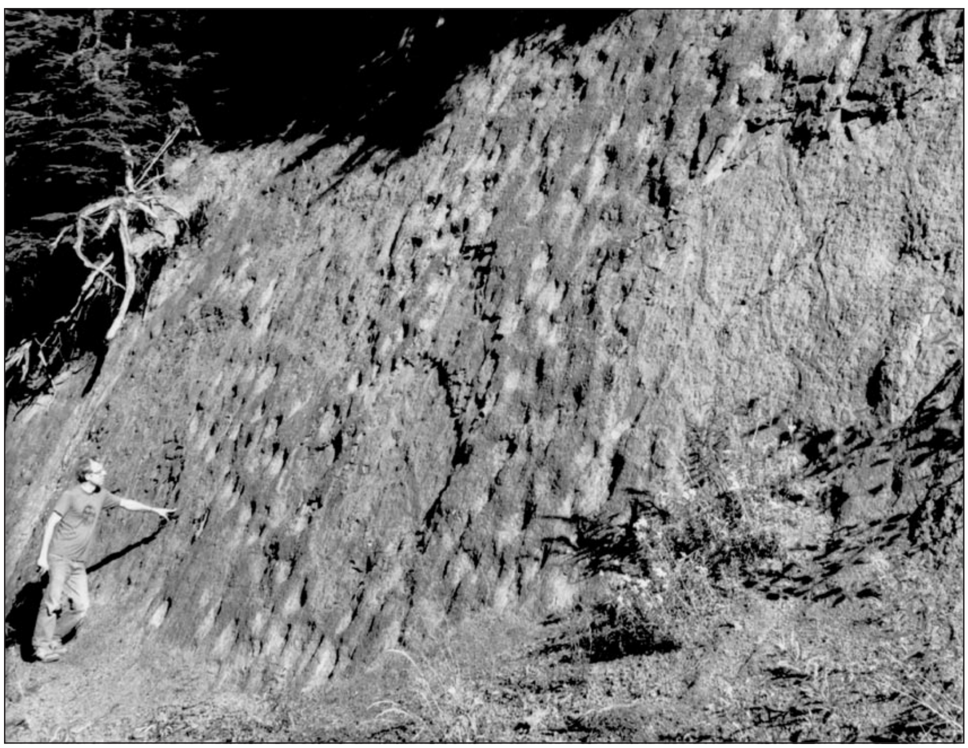


Figure 6. This bedding plane in the Mount Baker foothills east of Bellingham preserves hundreds of shallow circular tracks left by extinct Eocene animals that resembled a dwarf hippopotamus in body architecture. These tracks and others at nearby sites provide a spectacular rebuttal to the long-standing belief that the Chuckanut Formation contains no fossil evidence of large animals. The failure to find reptile remains in Mesozoic strata may mean that we have merely had poor luck or failed to look in the right places. *Photo by Elaine Mustoe, 1996.*

MESOZOIC SEDIMENTARY ROCKS WEST OF THE CASCADES

Pre-Tertiary rocks of the North Cascades and San Juan Islands consist of a complex mixture of exotic terranes. Subduction-zone metamorphism converted parent rocks into schist, phyllite, and gneiss, leaving few beds where fossils remain recognizable. The Late Jurassic–Early Cretaceous Nooksack Group siltstone that makes up Church Mountain and Chowder Ridge north of Mount Baker contains abundant pelecypod and cephalopod fossils (Fig. 7), suggesting that the formation may possibly preserve remains of marine vertebrates. The presence of both mollusk shells and driftwood impressions indicates that these sediments were deposited in a near-shore environment, and teeth or bones of terrestrial animals may have been transported into this basin by streams.

The Upper Cretaceous Nanaimo Group underlies Orcas, Waldron, Stuart, Johns, and several lesser islands of the San Juan group. Fossil Bay on Sucia Island was named for the abundance of mineralized mollusk shells in coastal bluffs of Nanaimo strata, and the only known Mesozoic vertebrate fossils from Washington are shark teeth described from this locality (Weymouth, 1928). Newberry (1898) illustrated several types of leaf fossils from Point Doughty, Orcas Island, suggesting a slim possibility of finding animal remains in these fossiliferous terrestrial sediments.

The discoveries of reptile remains in Nanaimo Group strata on Vancouver Island described earlier provide the best reasons for hope that correlative rocks south of the 49th parallel may contain similar fossils. These Canadian discoveries came from formations that were well known to local collectors who had long searched the banks of the Puntledge River near downtown Courtenay in pursuit of fossilized ammonites and bivalves, but no bones were observed prior to 1988. It is significant that all of these vertebrate remains were found by amateurs, and both the elasmosaur skeleton and the theropod dinosaur tooth were found by parents on outings with their young children. These precedents suggest that vertebrate fossils may eventually be found in Mesozoic rocks in Washington, and that it will most likely be a rockhound and not a professional geologist who makes the discovery.

Figure 7. This polished siltstone slab from the Late Jurassic–Early Cretaceous Nooksack Group of the northwestern Cascades reveals numerous belemnites. Also present in the deposit are ammonites, oysters, and wood fragments, evidence of a shallow marine basin that may have also preserved bones or teeth of reptiles. Scale: 0.53X. *Photo by George Mustoe, 1999.*

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MAXIMUM MINERALS

Mineralogy Database at http://webmineral.com/ contains information on over 4,205 mineral species and a variety of other things too.

You can get to the mineral listing at http://webmineral.com/Alphabetical_Listing.shtml. You can browse by letter of the alphabet. You'll get a list of hyperlinked mineral names. Some names have a red dot beside them; click on the red dot to get a pronunciation of the name. (So if your education was less than complete and you never learned how to pronounce "naujakasite," you're in luck...)

Click on the name of a mineral to get more information about it. You'll get a page with lots of details, including chemical composition, classification, crystallography, physical and optical properties, and references. There are also several search engine links set up to search for the mineral in which you're interested.

This isn't all that's available on this site. There are several other items, including a list of mineral species by crystal system, mineral species by chemical composition, and a gallery of mineral photographs. Worth a look.

Where Am I Now, And Can I Take This Fossil With Me? *(Continued from p. 20.)*

Species such as gar fish, rays, bowfins and paddlefish can be sold without review, but the state requires that they be reported and that royalties be paid on those specimens. All rare and unusual specimens must be presented to the Office of State Lands and Investments within 30 days of discovery for review by the Wyoming Geological Survey.

PRIVATE LAND

If you own the land, the fossils are yours to do with as you please. That means you can lease the land to others who wish to establish commercial fossil quarries or you can head out and split some rocks on your own. Whatever is found can be sold.

Laura Wright

FOSSIL AND MINERAL COLLECTING ON WASHINGTON STATE LANDS

A map of major Public Lands in Washington is available free from the Division of Geology and Earth Resources (address on p. 2) showing state, federal and other publicly owned lands in Washington. Washington State law prohibits removal of petrified wood, minerals, fossils, wood products or artifacts from state lands unless you have a permit (WAC 232-12-251).

How to Get Permits

Department of Natural Resources

Small amounts of invertebrates, plants, and petrified wood may be collected for personal use, but not for sale. If a significant number of fossils are being gathered, particularly if ground is being disturbed, you definitely must have a permit. No vertebrate fossils may be removed without permission from the State Geologist. Permits may be obtained from the DNR Region office nearest you (1-800-527-3305 or http://www.wa.gov/dnr/base/regions.html).

State Parks & Recreation Commission

Public Programs, Permits and Passes
Washington State Parks and Recreation Commission
PO Box 42650; Olympia, WA 98504-2669
Internet: http//www.parks.wa.gov
Phone: (360) 902-8608
E-mail: permits@parks.wa.gov

Department of Fish and Wildlife

WDFW Main Office
600 Capitol Way N; Olympia, WA 98501-1091
Phone: (360) 902-2200
Fax: (360) 902-2230
Internet: http://www.wa.gov/wdfw/reg/regions.htm

Another Whale of a Tale

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The Makah Indian Tribe has seemingly become forever associated with the controversial practice of whale hunting. Now that the gray whale population has successfully recovered (to the point of having the species removed from the endangered list), the Makah elders have deemed it time to reunite with this significant aspect of their cultural heritage. Animal rights activists, on the other hand, have deemed it cruel and unnecessary and have protested renewed Makah whale hunting from the outset. Considering all this, there was some irony when a number of us became quietly involved in our own whale hunt so close to the Makah Indian Reservation (Fig. 1). Our quarry, however, was already dead and had been for over 30 million years.

The expedition came about after Jim Goedert, affiliate curator of fossil marine vertebrates at the Burke Museum, announced at the July [2000] meeting of the Northwest Paleontological Association that he could use some assistance in retrieving whale fossils from a site on the northern coast of the Olympic Peninsula. The fossils were within concretions, those hard rounded nodules found in sedimentary rock that form when water-borne minerals aggregate around a nucleus, in the process producing a dense cement that's harder and more compact than the surrounding rock. Sometimes the nucleus is nothing other than a sand grain, but other times it's the organic remains of a once living organism. Concretions look like balls of concrete (hence the name). Small to medium-sized ones sometimes have at their core a preserved crab or snail. Large concretions may contain something as dramatic as a dolphin skull.

In any event, a few NPA members (jokingly referred to as the "young, dumb, and strong") volunteered to help in the backbreaking task of hoisting and carrying the large concretions that the fossilized bones were encased in. Once the team was assembled, the timing of the excursion could be decided. This was dependent on two things—a low tide and the availability of Tom Paulson, a reporter for the *Seattle Post-Intelligencer* who had previously written about Jim's paleontologic adventures and wanted to report on Jim's latest find.

We arrived at our rendezvous spot bright and early at five in the morning. I had been up since two in order to make the journey from Kent, but was surprisingly quite awake. Once we had all arrived (Jim and Gail Goedert, Tom and his brother Ken, PI photographer Dan DeLong, Rob and Lori Healy, Casey Burns, and myself), we departed for our destination on the coast. A convoy of vehicles followed a dusty gravel road down to where it terminated at the shore among a little shanty campsite with various vehicles and makeshift shelters.

The bedrock of this shore on the north coast of the Olympic Peninsula is part of the lower Pysht Formation, which is Oligocene in age. It is paleontologically very significant and has yielded a number of important and unusual marine mammal finds. Among these are the world's most primitive odontocete (toothed whale) and several toothed mysticetes. Modern mysticetes (baleen whales) are unique among mammals in having no teeth at all, but rather a mouthful of keratinous plates, each one bearing a series of slender fibers that are used collectively to filter planktonic food from the water. This baleen is modified epidermal tissue, but embryo-

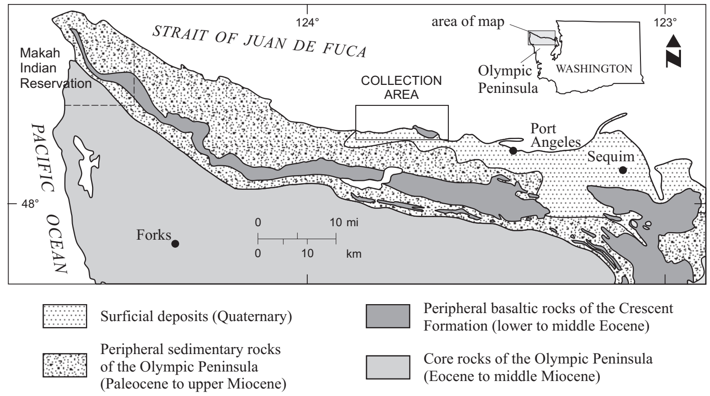

Figure 1. Map of the northern part of the Olympic Peninsula showing rock types and approximate collection area.

Figure 2. *Seattle Post-Intelligencer* photographer Dan DeLong sets his camera to photograph the fossil-bearing concretions. We had just removed them from a hiding place in the surrounding foliage.

Figure 3. Paleontologist James Goedert dons workmen's gloves as he prepares to move the heavy concretions. Dan DeLong looks on, satisfied with his role as the photographer.

Bryan Robles teaches biology and physical science at Issaquah High School. This article originally appeared in *The Aturian, v. 7, no. 5*, September 2000. *The Aturian* is the newsletter of the Northwest Paleontological Association, http://www.cnw.com/~mstern/npa/npa.html.

logical studies of mysticetes, in which it was observed that teeth temporarily erupt from the jaw and then reabsorb, indicate that their chromosomes must contain some genetic information for tooth production. This makes sense if mysticetes evolved from toothed whales, and, in fact, several toothed mysticetes, demonstrating the development of baleen while at the same time retaining the ancestral toothed condition, have been found at this site.

When I stepped out onto the beach, the tide was at its lowest ebb and the sun was just rising. Brilliant hues of orange and yellow reflected beautifully off the still water. Herons silently stalked in the shallows, campers slumbered peacefully, and the only audible sound was the gentle staccato of thousands of sand fleas hopping and dropping on beds of dry seaweed. We unloaded our gear as we readied for our trek across the bay. Our carrying equipment consisted of backpacks, a large two-wheeled garden cart that Casey brought, along with 50 feet of climbing rope and Rob's now famous two (or four) man sling. This device is comprised of two thick aluminum bars connected by a strong nylon net. The undersides of the bars are nicely equipped with padded shoulder rests, mercifully added to lend a modicum of relief to the toiling slaves under the sling. All that is missing from this device are the coffee cup holders.

We began our quarter mile trek across the bay, stepping around boulders and on terrain that would shift from slippery seaweed-covered stones to soft squishy mud and then back again. We quickly resigned ourselves to the fact that our boots would not remain dry. The brown goop we were mucking our way through part of the time was derived from the cliff sides facing the Strait of Juan de Fuca. These cliffs are composed of Oligocene mudstones that at one time accumulated in mid-bathyal depths. Outward from the cliffs and out into the bay are terraces of sandstone that represent ancient turbidite flows in which underwater landslides carried sediment down into old offshore basins. It was in these deep basins where sunken animal carcasses, including our whale, would come to rest, get buried in sediments, and eventually fossilize.

When we finally arrived on the scene (Fig. 2), we removed the whale stones from their hiding place behind some foliage where Jim had stashed them earlier. We laid them out on the beach so Dan could get pictures of the somewhat oblong specimens (Fig. 3). They looked like enormous stone eggs, each at least two feet long. Jim had spotted them on an earlier visit, his well-trained eyes noticing small protrusions of bone jutting out from the rock, hinting at the possibility of paleontological treasures inside.

We carefully set the big stones in the sling (Fig. 4) and garden cart, and commenced with a grisly series of marches, ferrying our load for a distance, pausing to rest when the four hoisting the sling were man enough to admit they were tired (Fig. 5) or when the skull slipped out of the rope harness in the garden cart, narrowly missing Tom's toes, and then going back for more. We were in Tertiary boot camp, pallbearers of a long-deceased mystery whale, beasts of burden to a silent cetacean. Dan scurried about us, continually snapping pictures from every angle, and Jim assured us that traversing this bay is actually easier in the winter. This is because the lack of sunlight reduces the treacherous seaweed growth, and the stormier wave action washes away the mud. (The only problem is that in winter the bay is only exposed at 3:00 a.m.!) I just kept hoping that my ankle, which I had completely turned in a volleyball game two months earlier, would hold out.

At last we got all our burdensome specimens into Jim's truck. An aggressively curious rockhound who had been scoping out our every move commented "I know what you got, those are Precambrian worm burrows!"

Figure 4. *From the left:* Dan DeLong, Rob Healy, Jim Goedert, and Carmen the dog. NPA member Rob Healy is ready to assist Goedert in loading the concretions onto the conveying harness, lying to the right, which he had built for this operation.

Figure 5. *From the left:* Ken Paulson, Jim Goedert, Bryan Robles, Rob Healy, Lori Healy. We pause for a breather (author is third from left) as Lori Healy encourages us from a safe distance. Note the seaweed-covered landscape we were forced to negotiate. *Photo by Gail Goedert.*

Tom's article appeared in the *Seattle Post-Intelligencer* on August 2, 2000, and it lamented the fact that the Puget Sound region does not have a large enough natural history museum with adequate space to store these specimens, nor enough people to work on them. Indeed, Jim mentioned that these particular specimens we were removing may not be processed and studied within our life times. On the other hand, it was invigorating to be part of the ongoing work (even if just the grunt labor stage of the game) to understand cetacean evolution, to try to fill in the blanks of the whale family tree. As I overheard Casey tell the newspaper men, "What we have are amateurs doing cutting edge science." ■

Tom Paulson's story, "Local Fossils Lack a Northwest Home", was published in the August 2, 2000, Seattle Post-Intelligencer and may be found on the Web at http://www.seattlep-i.com/local/muse02.shtml under the title: Local fossils lack a Northwest home—Important ancient whale bones unearthed by a Gig Harbor paleontologist are in Los Angeles.

Landslide Hazard Mapping in Cowlitz County—A Progress Report

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INTRODUCTION

The need for mapping of potential geologic hazards such as landslides, volcanic lahar inundation zones, and areas of earthquake-induced liquefaction susceptibility is increasing in step with regional population growth and expansion of the urban fringe into once sparsely populated rural forest and agricultural lands. This article discusses in-progress landslide hazard mapping for the urban growth areas of Cowlitz County (Fig. 1).

With passage of the Washington Growth Management Act (GMA) and amendments in 1990 and 1991, counties and cities were directed to delineate critical areas (including those subject to geologic and hydrologic hazards) to aid in formulating regulations governing development in such areas (Brunengo, 1994). Although Cowlitz County did not meet the population threshold for inclusion in the GMA and therefore was not required to develop a comprehensive plan of action, the county was required to establish a critical areas protection ordinance (CAO), which was adopted in 1996 (Cowlitz Co. Ordinance 96-104). Section 19.15.150 of this CAO pertains to geologic hazard areas, including landslide hazard areas. Identification of potential slope-stability hazard areas within the rapidly urbanizing areas of Cowlitz County is an important first step toward effective implementation of the geologic hazards section of the county's CAO.

The purpose of the current landslide hazard mapping project in Cowlitz County is to update and expand previous slope stability studies for the Longview–Kelso urban area (Fiksdal, 1973) and to extend slope-stability mapping to include the high-growth areas adjacent to the Interstate 5 corridor from the Clark County line in the south to the Toutle River in the north (Fig. 1). The intended outcome of this mapping project is the production of landslide hazard maps and an associated database delineating the distribution of identified deep-seated landslides (landslides that fail below the rooting depth of vegetation) as well as areas in which the combination of geologic and topographic factors favor the likelihood of future slope instability. Deep-seated landslides are often large in areal extent and once reactivated, by either natural causes or land management practices, often prove to be expensive and difficult (sometimes impossible) to mitigate. Updating and extending landslide hazard mapping for Cowlitz County will allow county officials to make better-informed decisions regarding implementation of slope-stability provisions in their CAO. Intended benefactors from this hazard mapping project include county and city governments, private citizens, state and federal agencies, geologic consultants, public and private utility corporations, and land developers.

PROJECT HISTORY

Significantly higher than normal annual precipitation was recorded for most of western Washington State, including Cowlitz County and the Longview–Kelso urban area, beginning in the 1995/96 water year (October 1 to September 30) and lasting through the 1998/99 water year. The several-year increase in annual precipitation resulted in elevated ground-water levels that, in turn, likely triggered reactivation of numerous dormant deep-seated landslides throughout southwestern Washington. In February of 1998, a deep-seated earth slide–earth flow reactivated in the Aldercrest neighborhood of Kelso (Figs. 2–4). In October of 1998, President Clinton issued a federal disaster declaration for the 138 homes affected by the landslide (Burns, 1999; Buss and others, 2000).

In response to the Aldercrest–Banyon landslide and numerous other recent landslides in Cowlitz County, geologists from the Washington Division of Geology and Earth Resources (DGER), Cowlitz County officials, and members of the state legislature representing southwestern Washington recognized the need for improved slope-stability mapping within the urbanizing Interstate 5 corridor. During the second half of 1998, in preparation for the 1999–2001 biennial state budget, the Washington Department of Natural Resources (DNR) requested and received funding from the state legislature for geo-

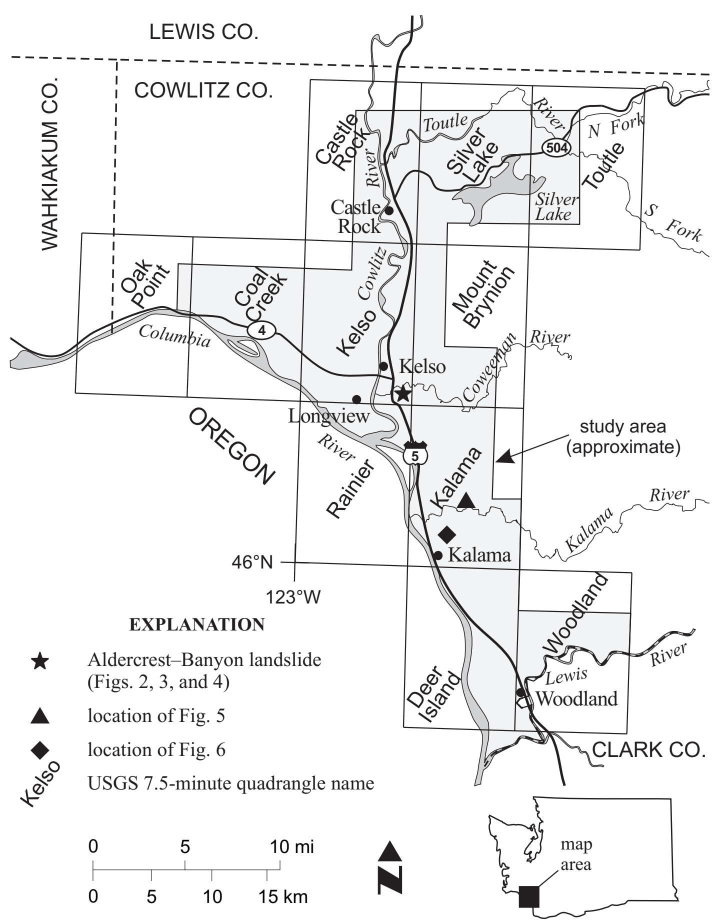

Figure 1. Location of the study area.

logic hazard mapping to evaluate ground stability in high-growth areas and to provide geologic expertise to small communities.

DGER began the Cowlitz County Landslide Hazard Mapping Project in February of 2000. Approximately 200 square miles were identified by Cowlitz County GIS Department staff as critical to the urban growth needs of the county and in need of improved slope-stability mapping (Fig. 1). Partnerships were established between geologists from Oregon State University and the U.S. Geological Survey to bring together various geologic mapping projects to provide coverage for the entire study area at a scale of 1:24,000. To fill gaps in the coverage at this scale, DGER geologists will also map portions of the Kalama and Mount Brynion 7.5-minute quadrangles.

PROJECT TIMELINE AND METHODS

The project timeline calls for all work to be completed within three years of initiation, by early 2003. During the winter and spring of 2000, potential deep-seated landslides were delineated using DNR 1993 (1:12,000, black & white) and 1999 (1:12,000, color) aerial photographs. Previous landslide inventories in western Washington State have shown that the combination of aerial photograph interpretation and in-the-field verification is an effective method for properly identifying deep-seated landslides (for example, Dragovich and Brunengo, 1995; Gerstel, 1999). Field verification of individual landslides identified during the initial aerial photographic analysis, as well as the mapping of geologic conditions conducive to slope instability, commenced in the summer of 2000 and is planned to continue through the fall of 2001. The compilation of geologic mapping and identified landslides and the construction of a landslide database will be completed in 2002, with publication and presentation of results in late 2002 to early 2003.

Landslides verified by field evidence will be digitized into ArcView coverages using 1:12,000 DNR digital orthophotos. Our goal is to release published maps as both digital (ArcView coverages) and paper products along with a landslide database in Microsoft Access. Database fields will include: a unique identification number, location, state of activity (active, recent, dormant, or ancient), certainty of geologist

Figure 2. Stereophoto pair of Aldercrest–Banyon Landslide from 1999 DNR aerial photographs. Note that the reactivated portion of the slide is interior to a larger landslide feature, as defined by the pre-existing dormant scarp. To view this photo in 3D, focus your eyes on the far distance and bring this figure up in front of your face at your normal reading distance.

Figure 3. View northwest along the main scarp of the deep-seated reactivated Aldercrest–Banyon (Kelso, WA) earth slide–earth flow as it appeared in August 2000. Landslide motion initiated in February of 1998 and by October of the same year had affected 138 homes, causing President Clinton to declare it a federal disaster area. Damage to public facilities and private property is estimated in excess of 30 million dollars (Buss and others, 2000). The landslide is about 3,000 feet wide by 1,500 feet in length, and the main scarp is over 100 feet high in places. Note the destroyed houses and tilting trees at the base of the scarp. Prior to the landslide, these houses were slightly above the elevation of the top of the scarp. This photo was taken in the former basement (light gray area on the left) of a house now at the bottom of the hill outside the photo area. The scarp exposes Pliocene to Pleistocene fluvial gravels and sands of the Troutdale Formation.

that feature is a landslide (definite, highly probable, probable, or questionable), cause of landslide if determinable (natural, human-influenced), landslide dimensions, geologic unit(s) involved in failure, type of impacted infrastructure, and previously reported identification and (or) mitigation work conducted on individual landslides if any.

LANDSLIDE TYPES IN THE STUDY AREA

Much of southwestern Washington, and the study area specifically, was not glaciated during the Pleistocene Epoch. The lack of glacial erosion in the recent geologic past means that, in places, the ground has been subjected to weathering processes for millions of years (Thorsen, 1989). This has resulted in deeply weathered clay-rich soils (saprolites) formed by the weathering of Tertiary sedimentary and volcanic rocks as well as unconsolidated upper Tertiary to Quaternary fluvial and eolian deposits. Extensive portions of the study area are underlain by Tertiary sedimentary and volcanic rocks containing inherent weaknesses, such as dipping bedding planes, joints, brecciation and shear zones, paleoweathering (paleosol) surfaces, and clay-rich interbeds. Many bedrock-dominated landslides initiate along such inhomogeneities. Upper Tertiary to Quaternary fluvial deposits of the ancestral Columbia River form dissected terraces along the lower slopes of the study area, filling in paleotopography developed upon the underlying Tertiary bedrock. Many of these surficial deposits have weathered almost entirely to high-plasticity clays.

Landslides within the study area occur within Tertiary sedimentary and volcanic units (Fig. 5), at the interface between Tertiary bedrock and overlying younger unconsolidated fluvial units (Fig. 3), and within the younger unconsolidated deposits (Fig. 6). The dominant form of landsliding within the study area is the rotational to translational earth and (or) rock slide, composed of extensively weathered bedrock and (or) surficial deposits (Figs. 3–6). Faster-moving rock falls and topples are limited to the steep bluffs along the Columbia River west of Longview, the inner gorges of the Kalama and Coweeman Rivers, and the rocky headscarps of some of the larger rock slide complexes. Many of the larger landslides appear to have multi-part movement histories (Fig. 7), as exhibited by recently active deep-seated failures such as the Aldercrest–Banyon slide that have reactivated only a portion of the larger overall landslide feature (Fig. 2). Also within the study area are gently to moderately sloping regions that are not distinct landslides, but rather areas of prominent slope creep. These areas are underlain by thick deposits of high-plasticity (and potentially swelling) clay derived from the weathering of both the underlying bedrock and surficial deposits. Such areas of accel-

Figure 4. View to the southeast across the middle section of the Aldercrest–Banyon landslide. Two uninhabitable houses are present in this view. Note the internal rotation within the landslide body as evidenced by the back-tilting of the distant house.

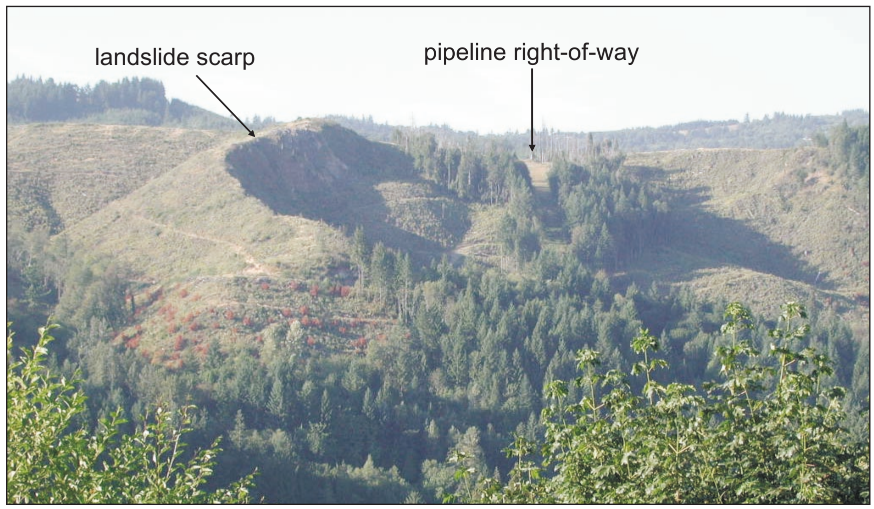

Figure 5. Large deep-seated rock slide along the north side of the Kalama River. View is to the north, across the Kalama River valley. This slow moving 90-acre landslide is failing in Tertiary volcanic and volcaniclastic rocks. In 1996, movement on this landslide ruptured and ignited a natural gas pipeline that is routed across the landslide.

Figure 6. Human-influenced, small deep-seated rotational earth slide–earth flow north of Kalama. The slide is about 75 feet wide by 40 feet long by 15 feet deep and is failing in a clay-rich diamicton (older landslide debris). This landslide initiated after a period of heavy rain in the spring of 2000. The slope had recently been cut back to enlarge a private yard, resulting in a lack of lateral support for the lower portion of the slope.

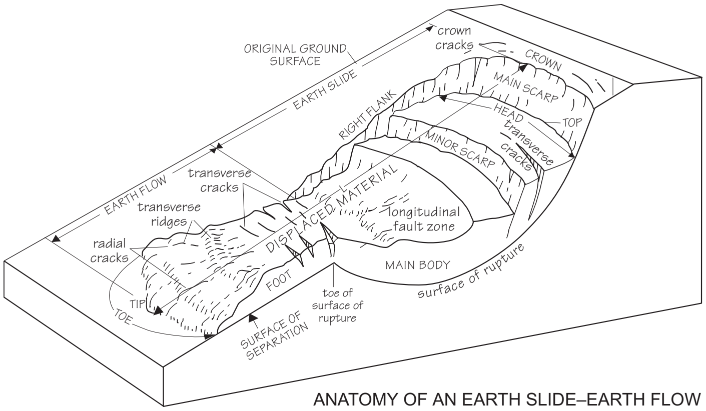

Figure 7. Anatomy of an idealized complex landslide, a deep-seated earth slide–earth flow. Labeled components apply to most landslides. From Cruden and Varnes (1996).

erated slope creep can be damaging to structures and utilities over time.

CAUSES OF LANDSLIDES

A majority of the deep-seated landslides so far identified in this study seem to have been triggered by natural causes. The primary initiating factor behind many of the landslides appears to have been climatically driven increases in ground-water levels and soil pore-water pressures. Some of the inactive deep-seated landslides may have been seismically induced. During the 1949 Olympia earthquake, for example, rock falls and earth slides were reported within the study area (Chleborad and Schuster, 1998). It stands to reason that if a moderate to large earthquake occurred close to the study area, especially during the wet season when ground-water and soil moisture levels are elevated, landsliding might result. A third triggering mechanism for landslides in lower elevations (below approximately 250 feet above mean sea level) may have been the rapid drawdown of late-Pleistocene glacial outburst floodwaters (Missoula floods) along the Columbia River and tributaries.

A significant minority of landslides appear to have been influenced by human activities (Fig. 6). Land-use modifications can alter the amount and flow direction of surface and ground water on slopes, which in turn may trigger slope failure. The undercutting of slopes for roads, building foundations, pipelines, and other construction projects has also been observed to contribute to slope failure. In a fair number of cases, it may be the combination of slope modification by humans and an increase in annual and regional precipitation levels (such as occurred during the late 1990s) that triggers slope failure.

RESULTS TO DATE

To date, approximately 350 individual deep-seated landslides have been field-verified in the southern half of the study area. Of these landslides, about 20 percent exhibit demonstrable evidence of movement within approximately the past 5 years. Field verification of landslides and areas of potential slope instability will continue throughout the summer and fall of 2001.

CONCLUSIONS

Landslides such as the Aldercrest–Banyon slide serve as stark reminders of the potentially devastating consequences of human development on unstable slopes. As our population increases outward from established urban areas, the need for new and updated geologic hazard mapping increases in step. It is with this in mind that the intended and ultimate goal of this project is to provide the citizens of Cowlitz County and Washington State with socially relevant slope-stability maps based upon the identification of areas of potential geologic instability and individual deep-seated landslides.

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IDENTIFYING UNSTABLE SLOPE CONDITIONS

Landslides can often be identified in the field through careful observation. Tension cracks, hummocky topography, springs and seeps, bowed and jackstrawed trees, abrupt scarps, and toe bulges are all readily observable indicators (Fig. 7, p. 33).

Tension Cracks—Tension cracks, also known as transverse cracks, are openings that can extend deep below the ground surface. Tension cracks near the crest of an embankment or hillside can indicate mass movement. However, cracks may occur anywhere on the slide. They are perpendicular to the direction of movement and are typically continuous in a pattern across the width of the landslide. Tension cracks can fill with water, which lubricates the slide mass and may cause additional movement.

Hummocky Ground—Hummocky ground can indicate past or active slide movement. A slide mass has an irregular, undulating surface.

Continued on next page.

Cutting Losses from Landslide Hazards

Paula Gori and Elliott C. Spiker, reprinted from *People, Land & Water*, April–May 2001, U.S. Department of the Interior

In communities across the United States, landslides cause human suffering, including 25 to 50 deaths annually, billions of dollars in economic losses, and environmental degradation. El Niño weather patterns of above-normal precipitation in communities in the Pacific Northwest and California, as well as the recent earthquake in Washington State, have resulted in an increased number of destructive landslides.

These events have caused unusually high financial losses to local governments, railroads, and other utilities, as well as private businesses and individuals who bear the burden of rebuilding or relocating. The extent of economic losses has raised public awareness of the impacts of landslides. With development expanding into more land that is susceptible to ground failure and with society becoming more interdependent, landslide hazards and resultant losses will increase unless and until the U.S. adopts a comprehensive strategy to mitigate landslide hazards at the federal, state, local, and private levels.

No such strategy exists today. States, local governments, and federal agencies, including the USGS, handle landslide hazards independently of each other. In 1999, the U.S. Congress, concerned over the lack of a comprehensive strategy, directed the USGS to address the widespread landslide hazards facing the nation, asking the Survey to prepare a strategy that would involve all the parties that have responsibility for dealing with landslides (P.L. 106-113). The USGS derives its leadership role in landslide hazard-related work from the Disaster Relief Act of 1974 (Stafford Act). (See 1974 Disaster Relief Act 42 U.S.C. 5201 et seq.)

The USGS recently completed a report that outlines a strategy built on the premise that no single agency, level of government, or program can independently reduce losses from landslide hazards. Titled National Landslide Hazards Mitigation Strategy: A Framework for Loss Reduction (USGS Open-File Report 00-450), the report is based on comments and suggestions from landslide experts, representatives of scientific and professional societies, as well as federal and state agencies.

The strategy outlines a new public–private partnership that encourages the use of scientific information, maps, and monitoring in emergency management, land-use planning, and public and private policy decisions to reduce losses from landslides. Drawing on 25 years of experiences and suggestions of scientists, public officials, and professionals, the strategy proposes a major, long-term effort and a commitment of all levels of government and the private sector to reduce losses from landslide hazards in the U.S.

The strategy calls on the federal government, in partnership with state and local governments, to provide leadership, coordination, research support, and incentives in the areas of landslide hazard mitigation. The objective is to encourage communities, businesses, and individuals to undertake mitigation measures to minimize potential losses prior to landslide events and to employ mitigation measures in the recovery.

The primary goal of the strategy in the next 10 years is to reduce the number of deaths, injuries, and economic costs caused by landslides. The strategy proposes nine major elements, spanning a continuum that ranges from research to the formulation and implementation of policy and mitigation. The elements are (1) *Research*—Developing a predictive understanding of landslide processes and triggering mechanisms; (2) *Hazard mapping and assessments*—Delineating susceptible areas and different types of landslide hazards at a scale useful for planning and decision-making; (3) *Real-time monitoring*—Monitoring active landslides that pose substantial risk; (4) *Loss assessment*—Compiling and evaluating information on the economic impacts of landslide hazards; (5) *Information collection, interpretation, and dissemination*—Establishing an effective system for information transfer; (6) *Guidelines and training*—Developing guidelines and training for scientists, engineers and other professionals, and decisionmakers; (7) *Public awareness and education*—Developing information and education for the user community; (8) *Implementation of loss reduction measures*—Encouraging mitigation actions; and (9) *Emergency preparedness, response, and recovery*—Building resilient communities.

Carrying out the strategy will require increased funding, better coordination among levels of government, and new partnerships between government, academia, and the private sector. The cooperation will encourage innovative programs and incentives for hazard mapping and assessment, adoption of loss reduction measures, and new technology. The USGS is currently distributing the open-file report and working with state geological surveys and scientific and professional societies to encourage implementation of the strategy.

For information about this new project, visit the American Planning Association website at http://www.planning.org/Landslides. For a copy of National Strategy to Reduce Losses from Landslide Hazards: A Framework for Loss Reduction (USGS Open-File Report 00-450), visit the USGS Landslide Hazards Program homepage at http://landslides.usgs.gov or write to USGS Information Services, Box 25286, Denver, CO 80225. ■

Identifying Unstable Slope Conditions *(Continued)*

Displaced and Distorted Trees—Vegetation, particularly trees, records the downslope movement of soil. Trees may be uprooted and lean in a variety of directions (jackstrawed trees) as their roots are broken or moved in a rapid slide movement (Fig. 3, p. 31). Bowed tree trunks may indicate soil creep; trees attempt to remain upright as the soil moves slowly downslope.

Springs and Seeps—Ground water that collects at the contact between permeable layers that overlie relatively impermeable layers or rock strata dipping with the slope can cause instability. Carefully investigate springs, seeps, and areas of lush vegetation. Alder, horsetail, devils club, cow parsnip, and skunk cabbage typically grow in wet sites.

Scarps—Fresh scarps are a clear sign of recent slope failure (Figs. 5 and 6, p. 32). Older scarps may be covered by vegetation and hard to identify. The presence of several scarps can indicate several active failure surfaces or movement downslope along a larger failure surface.

Toe Bulge—The toe of a slide commonly bulges out onto the more stable ground surface below the slide. A toe bulge often gives the appearance of a mud wave displacing trees and vegetation in its path. Removing the toe may reactivate the slide mass.

A New Look at an Old Landslide

Radiocarbon dates indicate the Bonneville Landslide may be far younger than thought

Wednesday, September 29, 1999
By Richard L. Hill of *The Oregonian* staff

Aerial-oblique photo of the Bonneville landslide. View is to the northeast with Mount Adams volcano in the distance. The Bonneville Dam and powerhouses (lower left) and the "Bridge of the Gods" (far right) flank the landslide. *Photo courtesy of Derek Cornforth, Landslide Technology.*

A long-dead tree may hold the clues for helping solve a few mysteries about one of the Northwest's most famous landslides. The Bonneville Landslide in the Columbia Gorge about 30 miles east of Portland covered more than 5½ square miles, producing a temporary dam and immense lake on the Columbia River that probably led to the Native American legend about the "Bridge of the Gods."

Despite it being one of the region's most studied landslides, questions about exactly when the catastrophic slide occurred—and its precise effect on the landscape and people—remain. Answers could help scientists understand the possible effects from future large landslides in the gorge.

Radiocarbon dates from the core of a Douglas fir buried 150 feet under the massive slide indicate it killed the fir about 400 years ago and perhaps as recently as 250 years ago. That would make the landslide half a millennium younger than a previous estimate, which said the slide occurred about A.D. 1100.

If future work supports the younger date, the slide would be in the same time frame as the last huge offshore earthquake, which rocked the Northwest coast in 1700. Although scientists are confident a quake caused the landslide, they say it's premature to link it with the magnitude 9 earthquake.

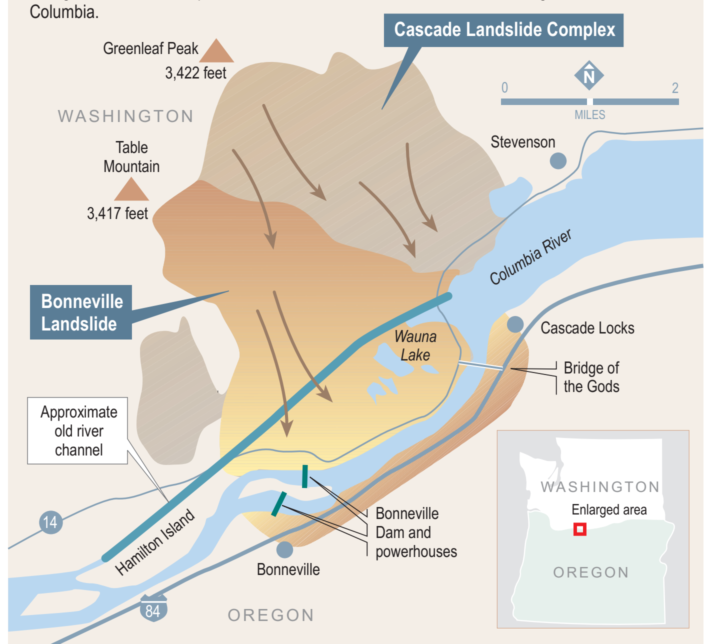
From analyzing the radiocarbon dates, "my feeling is that the landslide likely happened between 1550 and 1750," said Patrick T. Pringle, a geologist with the Washington Department of Natural Resources who has been conducting the study with Robert L. Schuster, a landslide expert with the U.S. Geological Survey. "I realize what a big window this is, but that's about all the data allow us to say."

Most Recent of Four Slides

The Bonneville Landslide, which tumbled from Table Mountain, has intrigued scientists for decades. It is the youngest and largest of four adjacent slides that make up the 14-square-mile Cascade Landslide Complex north of the Columbia near Cascade Locks and Stevenson, Wash. The area on the Columbia's north side is prone to landslides because of steep terrain made up of formations that tip toward the river. Columbia River basalt overlies the fragile, clay-filled Eagle Creek and Weigle Formations. The cliffs exposed when the mountain gave way easily can be seen north of Bonneville Dam.

ANCIENT LANDSLIDE

A series of large landslides struck the north shore of the Columbia River west of Cascade Locks and Stevenson, Wash., in the prehistoric past. The Bonneville Landslide, which researchers now say may have occurred about 400 years ago, temporarily blocked the Columbia River with a 200-foot-high wall of debris and shoved the river channel one mile south. The landslide dam is probably the source of the Native American legend about the "Bridge of the Gods." Deposits from the slide also can be found on the Oregon side of the Columbia.



Source: Division of Geology and Earth Resources, Washington State Department of Natural Resources

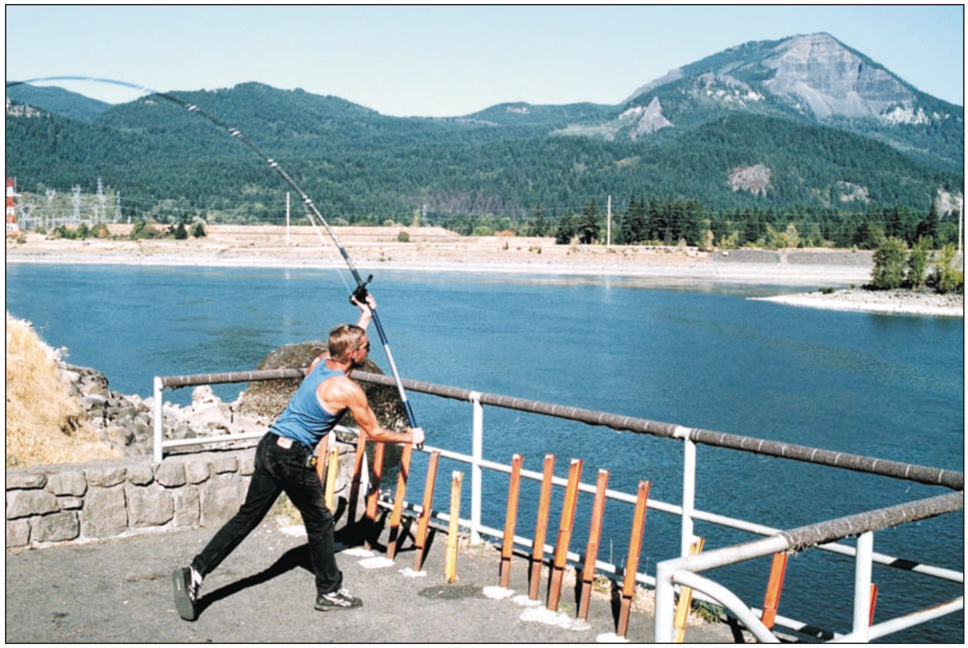
WERNER BITTNER/THE OREGONIAN

"What you've got is a deck of cards that is pointing and sliding toward the river," said Alex Bourdeau, an archaeologist with the U.S. Fish and Wildlife Service who is interested in the landslide's effect on the people who lived along the river. "I always said all you had to do is jump up and down on top of Table Mountain and you could have triggered this slide."

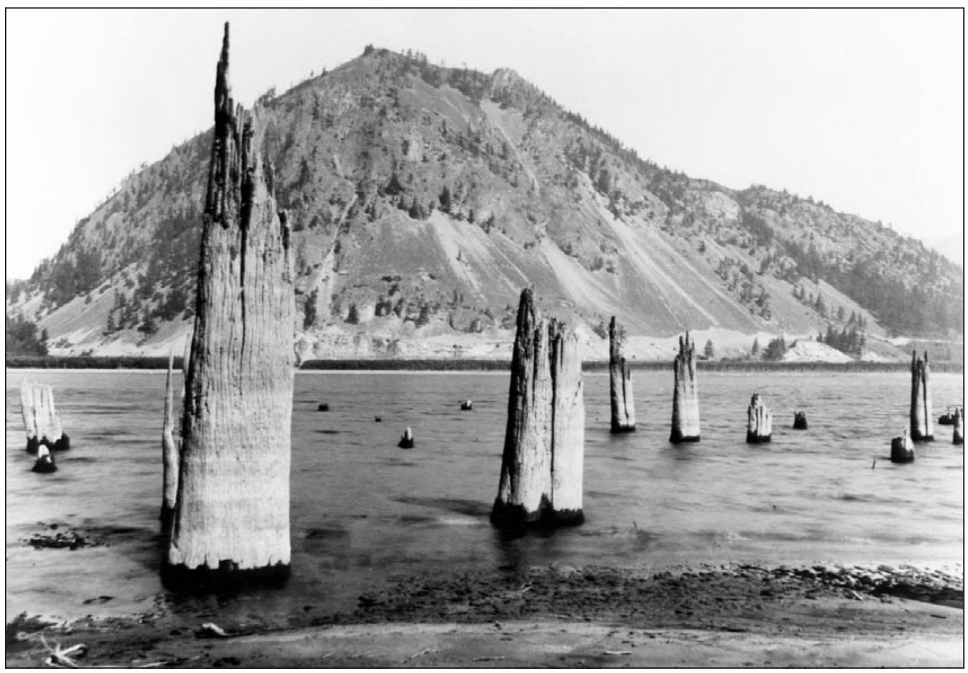
The landslide unleashed blocks of rock as large as 800 feet long and 200 feet thick down the mountain, creating a temporary earthen dam more than 200 feet high—three times the height of Bonneville Dam. The slide covered a 3½-mile stretch of the river, shoving it about a mile off its course.

No one knows exactly how long the river was blocked. One estimate is that it took about two years for the water to rise to the top of the dam, creating a huge lake that may have stretched 100 miles east to Arlington. The lake drowned a narrow forest of trees for 35 miles. About 1,800 of the stumps were visible in the river before they were again submerged in 1938 by the reservoir created by the Bonneville Dam.

Eventually, the lake rose high enough to cut through and spill over the barrier, unleashing a catastrophic flood that was nearly 100 feet deep at Troutdale and eroding much of the landslide. Ives, Hamilton, and Pierce Islands are remnants of the slide, while the uneroded portions produced the famous "Cascades of the Columbia." The cascades, or series of small waterfalls, produced by the slide provided the name for the Cascade Range—perhaps the only time a landslide indirectly led to the naming of a mountain range, said Scott Burns, a geology professor and landslide expert at Portland State University.



Ron Kowalski of Clackamas, Oregon, fishes for sturgeon near Bonneville Dam across the river from Table Mountain (upper right), the source of the landslide. *Photo courtesy of Brent Wojahn,* The Oregonian.



View of Wind Mountain to the north from Wyeth, Oregon. This 1936 photo, taken by researcher Donald Lawrence, shows snags of the "drowned forest of the Columbia" that he described in detail in a series of noteworthy papers. Lewis and Clark also described the forest in their journals. Both they and Lawrence believed the trees were drowned when a lake formed behind the Bonneville landslide, which completely dammed the Columbia River at one time. The reservoir behind Bonneville Dam covered the trees in the late 1930s. *Photo (no. 24256) courtesy of the Oregon Historical Society.*

Explorers Note Obstruction

Lewis and Clark were the first to document the landslide and its effects. Heading downstream in October 1805, the explorers described the river as being "obstructed by the projection of large rocks, which seem to have fallen promiscuously from the mountains into the bed of the river."

They added "that there are stumps of pine trees scattered for some distance in the river, which has the appearance of being dammed below and forced to encroach on the shore."

When the explorers returned upstream the following spring, they again mentioned the tree trunks standing in the water. They correctly stated that "the passage of the river through the narrow pass at the rapids has been obstructed by the rocks which have fallen from the hills into the channel," although they were off in their estimate that the landslide had occurred "within the last 20 years."

While the Columbia was dammed by the slide, area inhabitants might have been able to cross the river on foot, which probably gave rise to Native American stories about a bridge near Cascade Locks. One version relates how Wy'east (Mount Hood) and Pahto (Mount Adams) were powerful braves, the sons of Old Coyote. They both fell in love with a maiden (Mount St. Helens), and they frequently crossed a bridge over the Columbia to fight each other. Coyote caused the bridge to collapse in an effort to keep the feuding brothers apart.

In the late 1830s, Daniel Lee wrote in an account of the region's geology that "the Indians say these falls were not ancient and that their fathers voyaged without obstruction in their canoes as far as The Dalles. They also assert that the river was dammed up at this place, which caused the water to rise to a great height far above, and that after cutting a passage through the impending mass to its present bed, these rapids first made their appearance."

Signs Of Flooding

Researchers with the U.S. Geological Survey have been examining sites downstream from the slide area to determine the effects of the flood unleashed by the river's breakthrough of the natural dam. "We've been looking at backwater deposits in the Sandy River from a big flood that dumped a lot of Columbia River sand," said Thomas C. Pierson, a hydrologist at the agency's Cascades Volcano Observatory in Vancouver, Wash. "The sand is nearly 100 feet above sea level, which would make it a flood of about 80 feet deep at the mouth of the Sandy River." Pierson said research suggests that two floods caused by the breaching of landslide-dammed lakes have occurred—one about 450 years ago and the other 1,600 years ago. Pringle said the emerging evidence and concerns about future slides make it important to study other large slides in the Columbia. "There is plenty of material still present in the gorge to pose future threats," he said. "In fact, these types of landslides commonly leave steep scarps that may themselves be susceptible to failure."

Research on the landslide intensified in the 1930s when the Bonneville Dam was being built and in the 1970s with the construction of the second Bonneville powerhouse, which was completed in 1978.

Robert L. Schuster cuts a sample of a Douglas fir that was found about 150 feet deep in the Bonneville landslide during construction of the second Bonneville Dam powerhouse in 1978. Radiocarbon dates show the tree was killed by the massive slide about 250 to 400 years ago. *Photo courtesy of Patrick T. Pringle, Washington Department of Natural Resources.*

Looking Upstream

Archaeologists say the landslide had a significant impact on the native inhabitants. No evidence exists that a village or seasonal camp site was destroyed by the slide itself, although the filling of the lake and the later "outburst" flood would have inundated any dwellings.

"One of the problems has been that everyone's attention primarily has been focused downstream from the event," said Bourdeau, who has been studying the slide for 20 years. "What people haven't done is go upstream and look for villages that would have been drowned by this big lake filling behind the landslide. They probably exist, but unfortunately they're now all drowned again by all the dams, so it makes them difficult to look for."

Bourdeau said the slide would have had a serious effect on migrating salmon if the earthen dam had been there a couple of years. The eventual erosion of the dam and the creation of the rapids, however, led to a boom in the native population along the river. The cascades formed the narrowest constriction in the gorge, obstructing anadromous fish runs and providing an ideal place to harvest the fish.

In addition, because the rapids formed an obstruction to river transportation, travelers had to portage around the barrier. Bourdeau said the Chinook placed villages on each end and at the center of a 4-mile-long trail that went around the rapids, enabling them to control river trade and travel. By collecting tolls, they were able to increase their wealth and power.

A report in 1984 by Rick Minor, an archaeologist with Heritage Research Associates in Eugene, for the U.S. Army Corps of Engineers said about a half-dozen village and fishing-camp sites on or at the edge of the landslide deposits had been studied in previous years.

Radiocarbon dates from drowned trees reported in 1958 indicated that the landslide occurred between A.D. 1250 and 1280. Minor compared radiocarbon dates of wood samples taken in 1978 from within and below landslide deposits with radiocarbon dates obtained from archaeological sites in the landslide and flood area. He determined that the landslide took place about A.D. 1100 and that the earliest occupation of a village on the site occurred about 100 years later.

The date puzzled Pringle and Schuster, however, because they thought the submerged trees visible in the Columbia until the 1930s would have rotted away had they been that old. "There should have been nothing left of those trees if they were 800 or 900 years old," Pringle said. "And that kept bugging me."

Pursuing The Old Tree

Schuster recalled that a Douglas fir buried by the landslide had been recovered during the building of the second powerhouse in 1978. Pringle tracked down the tree—which died when it was about 140 years old—in a storage area at the Columbia Gorge Interpretive Center near Stevenson.

They had radiocarbon tests conducted on two small segments of the tree, one about 120 annual growth rings from the bark and the other 20 rings from the bark. The deeper segment had a radiocarbon date of 410 years, and the portion closer to the bark had a date of 360 years. Both dates have a margin of error of 80 years.

Pringle is hoping a tree-ring study will help pinpoint a more precise date. "I'm confident we'll nail it with more work," he said. "We are exploring more options and may try to get a higher precision radiocarbon date to help us narrow the gap a bit.

Bourdeau said the new dates pose a challenge for archaeologists who have been using the older dates in studying the effects of the landslide and flood downstream. "You have to start over on your analysis if indeed the younger dates turn out to be right.

"I'm pushing to get the archaeologists and the geologists out in the field together to look at the same things," Bourdeau said. "They can learn from us, and we can learn from them. Landslides in the Northwest have become a big topic in the past few years, and this event can teach us a lot about what effects it had on people, the geology, the river and the wildlife." ■

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Note: Figure captions have been altered from the original and the tree-ring photo opposite added to provide more detailed information to our readers.

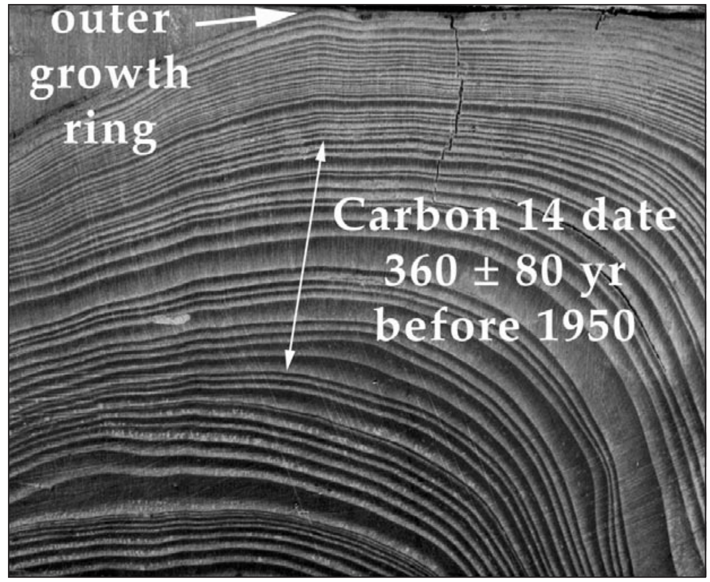

Photo of a sanded cross section of a root from a tree buried in the Bonneville landslide and recovered in the 1978 excavations for the second powerhouse. Doubleheaded arrow shows the extent of the first ring sample of this tree submitted for radiocarbon dating by Pringle and Schuster. *Photo courtesy of Patrick T. Pringle, Washington Department of Natural Resources*

Mount Rainier Volcano Evacuation Plans

Pierce County is unveiling volcano evacuation signs, similar to tsunami evacuation signs seen on our coast, in an effort to educate and prepare its citizens for potential volcanic hazards in the Puyallup and Carbon River valleys. According to scientists at the U.S. Geological Survey (USGS), lahars (mudflows) from Mount Rainier are the primary hazard to developed areas in the Puyallup Valley, including the towns of Orting, Sumner, Puyallup, and Fife.

"Addition of the evacuation signs in the Puyallup Valley will provide important emergency information and a critical reminder to residents and visitors alike that the valley is potentially at risk should Mount Rainier become restless again," said Emergency Management Director Steve Bailey.

Mount Rainier remains quiet, with no signs of renewed volcanic unrest. The timing of lahars is unpredictable, but chances of their occurrence are enhanced when the volcano becomes restless. Monitoring instruments deployed on the volcano should detect its reawakening.

Our understanding of the mountain's geologic history and potential has vastly improved in the past several years. Scientists have found that some very large lahars are caused by landslides and may not be accompanied by such precursory warning. The 500-year-old Electron lahar, for example, has no associated evidence of eruptive activity and is thought to have been caused by the collapse of weakened rock in the Sunset Amphitheater area. "A recent USGS study showed that enough potentially weakened rock exists on the upper west side of the volcano to produce future large landslides and lahars in the Puyallup Valley," said William Scott, the scientist in charge at the USGS Cascades Volcano Observatory.

The evacuation sign installation is a culmination of more than 6 years of hard work by emergency managers, community leaders, scientists, and planners. Together, they assembled emergency response and education plans. A joint project between Pierce County Emergency Management and the USGS to develop and install a lahar warning system nears operational status. Stations in the upper Puyallup and Carbon River valleys will detect lahars and send warnings to the 911 system (to police and fire), which in turn will notify emergency management agencies and residents.

Much of this action was motivated by a disaster in Colombia during 1985, where Nevado del Ruiz, a volcano similar to Mount Rainier in lahar hazard, size, and distance from populated communities, took more than 20,000 lives. A small eruption caused a lahar that reached the city of Armero in about 2.5 hours, overrunning it with mud and debris. Those who perished could easily have been spared if only they'd known the lahar was coming and that safety was within an easy walk, only a few hundred yards away. Public education and signage may have prevented this tragedy. The disaster, so similar to potential events at Mount Rainier, spurred scientists to work more closely with public officials to ensure effective education, communication, and planning.

The lahar warning system and evacuation signs are the first step in helping citizens prepare themselves for this potential hazard. A public education campaign will begin in the fall, following the completion of detailed city evacuation plans, to help prepare citizens to rely on their own resources. During a lahar, emergency responders will not be in the valley communities to assist with evacuations. Citizens must recognize the warning sirens, know their evacuation routes, and prepare to be on their own for 72 hours.

USGS maps of volcano hazards can be purchased through USGS Map Sales, Building 810, Denver Federal Center, 303-202-4700.

From a June 15, 2001, news release by Pierce County Emergency Management

EARTH CONNECTIONS

Resources For Teaching Earth Science

BACK TO SCHOOL— TIPS FOR CLASSROOM SPEAKERS

At this time of year, teachers are preparing for the new school year, but they aren't the only ones. More and more, parents and professionals are being invited into classrooms to talk to students about their area of expertise. While these professionals know their subjects well, they haven't been trained as educators. Talking to a third-grade class is much different from making a corporate presentation or a report to colleagues. The following tips from the Mineral Information Institute can help speakers prepare for their visit to the classroom.

YOU'VE BEEN ASKED TO TALK TO A CLASS— NOW WHAT DO YOU DO?

- ✓ What is your topic? Is it relevant to what the students are studying? Find out what the students have been studying and how much they know about you and your topic. Sometimes you can't make the 'speech' you want because it doesn't fit. You can ask the teacher anything—they want you to be successful.
- ✓ Teachers are now specialists in a subject area. You'd better know the opinion of the teacher about your subject and your industry.
- ✓ Don't try to run a one-man show. You can't do that at work, so don't try it in the classroom. Contact your company's head office or your industry's trade association. Their job is to help you look good.
- ✓ Look at the size of the textbook the class is using. More often than not, the students feel as if they are being fed with a fire hose. And they're right. Remember, the class you are in is only one of 4 or 5 they take, every day.
- ✓ If you're not prepared, or think you can bluff, these kids will put you on the spot. Don't go to a government class to discuss your community's land-use laws or the revision of the 1872 Mining Law unless you've read and understand them. The kids will have read and analyzed the regulations and the law in preparing for your visit.
- ✓ Don't do more damage than good. Practice, practice, practice.
- ✓ Come bearing gifts—handouts, samples, etc. If you can, leave everything with the teacher.
- ✓ If you want to involve the students in an activity, always check with the teacher first to make sure they can handle it.
- ✓ Never start a lesson, activity, or program that takes more than your allotted time.
- ✓ Never talk down or up to students.

CAREERS AND JOBS ARE THE SECRET TO BEING A SUCCESSFUL CLASSROOM SPEAKER

The new national standards emphasize jobs after school. This is the area in which you are the supreme expert—the students know it and so does the teacher. If you want instant attention:

- ✓ Tell them how much money the different skilled jobs pay at your company. It might be best to compare wages rather than give out specific figures. Students are used to minimum wage jobs, because that's all they've had.
- ✓ Tell them about the special skills, training, and education it takes to get a job like yours, trying to spur them on to more education and training. Make the point that education never ends; it's an ongoing process to upgrade skills and learn new techniques.
- ✓ Relate your job, your company, your industry to the economy of your community, the state, the nation, and the world.

MINERAL INFORMATION INSTITUTE

Mineral Information Institute is a nonprofit educational organization providing minerals and energy information at no cost to teachers (cost involved to others). Materials include posters, lessons, activities, and referrals to other sources providing free or highly subsidized educational information. The purpose of all materials is to increase awareness that "everything we have and everything we use comes from our natural resources". MII also provides technical support to new and established earth science programs. MII sponsored and continues to support revisions of the high school science textbook *Global Science: Energy, Resources, Environment*.

IF THE CHILDREN ARE UNTAUGHT, THEIR IGNORANCE AND VICES WILL IN FUTURE LIFE COST US MUCH DEARER IN THEIR CONSEQUENCES THAN IT WOULD HAVE DONE IN THEIR CORRECTION BY A GOOD EDUCATION.

Thomas Jefferson

Lesson modified from information provided by:

Mineral Information Institute
501 Violet Street
Golden, CO 80401
phone: (303) 277-9190
fax: (303) 277-9198
website: http://www.mii.org/

Earth Connections No. 5

GRADES K–6—WHAT IS TAUGHT WHEN AND HOW MUCH CAN THEY UNDERSTAND?

	KINDERGARTEN AGE 5–6	1ST GRADE AGE 6–7	2ND GRADE AGE 7–8	3RD GRADE AGE 8–9	4TH GRADE AGE 9–10	5TH GRADE AGE 10–11	6TH GRADE AGE 11–12
HINTS	Students are learning to use scissors, crayons, pencil; learning to tie shoes and work buckles. Use big, colorful pictures.	Students like to do, not listen; can share and work in groups; can follow short verbal directions; 10–15 minutes maximum attention span.	Students can listen to and follow directions; like to listen, then do. Expect many questions. Use variety.	Students begin to learn abstract concepts; like group activity and can follow directions.	A fascinating age. Analytical thought process begins. Students have sense of humor; enjoy everything.	Students are independent learners; are socially conscious; enjoy outside experts; ask many questions; like to be read to.	Students are more abstract thinkers; are easily bored; question everything; enjoy a challenge.
	STUDENTS DON'T READ OR WRITE IN CURSIVE, SO DON'T USE IT. PRINT EVERYTHING.				REGIMENT-ORIENTED—DON'T GO OVER YOUR TIME.		
LANGUAGE ARTS	Students are pre-reading—use pictures, puppets. Students learn colors, alphabet; learn to identify color and sounds; can read own name.	Students can use upper- and lower-case letters; can read words like *cat*, *run*, *the*; can follow two-step directions.	Students are introduced to cursive; can recognize some abbreviations; learn simple report writing and research; are very imaginative.	Students use dictionary, encyclopedia; can recall details of who, what, when, why, where; read news and non-fiction.	Students begin short novels; read more detailed texts, references; are able to recall verbal information; use cursive writing.	Students know difference between fact and fiction; can summarize; can draw conclusions and predict the outcome.	Students do more sophisticated reading; can read 'between the lines'; have strong opinions; know and can identify propaganda.
MATH	Students learn to count from 1 to 20 and identify numbers 1 to 10; learn 'more' and 'less', 'right' and 'left', 'top' and 'bottom'.	*First of year:* Students read and write numbers to 50; count to 100. *End of year:* Students add and subtract numbers 1 to 10; learn to measure.	*First of year:* Students add and subtract double-digit numbers; count coins; know square, cube, cylinder. *End of year:* Students learn 3-digit addition and subtraction; begin to multiply.	*First of year:* Students know numbers to 1000; know rounding; add and subtract money. *End of year:* Students multiply and divide 1 thru 6; learn charts and tables.	*First of year:* Students begin addition and subtraction with decimals. *End of year:* Students learn double-digit multiplication and division; read bar and line graphs; know geometric shapes.	*First of year:* Students learn 4-digit math, 3-number addition and subtraction. *End of year:* Students learn 2- and 3-place multiplication; learn to add, subtract, multiply, and divide with decimals; know fractions.	*First of year:* Students use order of operation to solve equations. *End of year:* Students find variables; learn simple geometry, algebra.
	ALL MATH INCLUDES CONCEPTS OF ESTIMATING AND PROBLEM-SOLVING.						
SCIENCE	Students observe through touch and feel; compare and sort different sizes, shapes, colors, etc.	Students know day, night, sun, moon; know living from non-living; like touch-and-feel activities.	Students learn how things grow; learn about dinosaurs; work with magnets; like observing, manipulating.	Students learn uses and misuses of resources; learn about changes in the Earth; learn about the use of machines, force, energy.	Students learn about rocks and minerals, classification systems, properties and states of matter; do experiments.	Students like use of science equipment; learn about atoms and molecules, source of electricity and energy; see relationships.	Students learn about Moh's scale, chemical changes; learn relationships of plants, animals, and Earth; like hands-on.
	COVERS ALL OF THE GENERAL SCIENCES EACH YEAR: LIFE, PHYSICAL, EARTH, AND HEALTH (HUMAN BODY).						
SOCIAL STUDIES	Students focus on their world, things they know: home, school, library.	Focus is on home and school. Students believe what they see and hear.	Focus is on neighborhoods. Students recognize likeness and difference in people.	Focus is on community citizenship, interdependence among people.	Focus is on world regions. Students learn interdependence among nations.	Focus is on U.S. history, maps, people. Students learn states and capitals.	Focus is on the world and specific countries, comparison of cultures.
MAP-READING SKILLS	Students like maps and globe; know blue is water, brown is land; see parts, not whole.	Students use symbols and color to represent things; can compare map and globe.	Students can use a key or legend, abstract symbols; learn to measure distances.	Students use cardinal directions on grids and to locate places; learn scale and distance.	Students examine world maps by region; recognize northern and southern hemispheres.	Students begin learning latitude and longitude; begin interpreting relationships between countries.	Students can combine information from different maps to analyze or draw conclusions.

SURVIVAL TIPS FOR THE UPPER GRADES

Grades 7 to 9 include students age 12 to 15—life is changing for them. These students:

- ✓ Are emotional and eager to get moving
- ✓ Don't really think ahead
- ✓ Like to work in small groups
- ✓ Like 'doing' activities
- ✓ Haven't had extensive work in the sciences
- ✓ Have basic math skills, are beginning algebra and geometry
- ✓ Are easily bored and have vulnerable egos, tend to embarrass easily

Grades 10 to 12 include students age 15 and older, some of whom are able to drive, vote, and go to war—respect them. These students:

- ✓ Are mature learners
- ✓ Are beginning to plan for career choices and training beyond high school
- ✓ Are able to understand abstract concepts, but still like hands-on activities
- ✓ Are expanding their understanding of ethical principles but do not yet realize the full impact of their words and actions ■

REFERENCES AND RESOURCES, RELATING TO THE LESSON PLANS AND OTHER ARTICLES IN THIS ISSUE

DINOSAURS

Correlation and Strata—Findasaurus, by Craig A. Munsart and Karen Alonzi-Van Gundy. *Good basic explanation of sedimentation, strata and index fossils.*[http://www.ucmp.berkeley.edu/fosrec/MunGun3.html] [lesson plan]

See also: Dinosaur-hunting resources list elsewhere in this issue

FOSSIL FORESTS

Learning from the Fossil Record [lesson plan] http://www.ucmp.berkeley.edu/fosrec/Learning.htm

Simple Home Experiments for Bringing Geology to Life; Experiment 2—Condensing Geologic Time or the Art and Science of Making Fossils, by Wendy Gerstel and Kitty Reed: Washington Geology, v. 27, no. 2-4, p. 31, 1999. [lesson plan]

Significance of the Republic Eocene Fossil Plants, by Jack Wolfe and Wes Wehr: Stonerose Interpretive Center [Republic, Wash.], 16 p., 1991 repr. 1992.

Mammoth Is Now State Fossil: Washington Geology, v. 26, no. 1, p. 42, 1998. [article]

Discovering Fossils: How to Find and Identify Remains of the Prehistoric Past, by Frank Garcia, Don Miller, Jasper Burns (illustrator): Stackpole Books, 176 p., 1998.

The Audubon Society Field Guide to North American Fossils, by Ida Thompson: Alfred A. Knopf [New York], 846 p., 1982.

Collecting Fossils—Hold Prehistory in the Palm of Your Hand, by Steve Parker, Murray Weston, and Jane Parker: Sterling Publications, 80 p., 1998.

Ginkgo Petrified Forest, by Mark Orsen: Ginkgo Gem Shop [Vantage, Wash.], 24 p., 1998.

FOSSIL SITES

Stonerose Interpretive Center, Republic, Wash. *Interpretive center has excellent collection of fossils, and visitors are allowed to collect fossils on site.* http://www.stonerosefossil.org/

Ginkgo Petrified Forest State Park, Vantage, Washington. *Has an interpretive center with a fabulous collection of petrified wood and interpretive hiking trails* (no collecting). http://www.tcfn.org/tctour/parks/Ginkgo.html ■

New Monitoring Tools Help Reduce Earthquake Risks

Shake Maps Pinpoint Hardest Hit Areas

Pat Jorgenson

reprinted from People, Land & Water
April–May 2001, U.S. Department of the Interior

The most common information available immediately after an earthquake is the location and magnitude. However, what scientists really want to know is where the shaking was felt, and in the case of emergency response, where it shook the most. Two new, near-realtime systems—ShakeMap and Community Internet Intensity Maps—can now depict within minutes which areas in the vicinity of the quake were hardest hit. ShakeMap shows the distribution of earthquake shaking as measured by seismic instruments. Immediately after an earthquake, emergency managers must make response decisions using limited information. Automatically and rapidly generated computer maps of the intensity of ground shaking, known as ShakeMaps, are now available within about 5 to 10 minutes of an earthquake. This quick, accurate, and important information can aid in making the most effective use of emergency response resources.

While this system has only been in place for about three years in Southern California, and only a few months in northern California and the Seattle region, it has already proved useful for several recent quakes. Decision-makers used the system to rapidly assess the situation after the Oct. 16, 1999, magnitude 7.1 Hector Mine earthquake in Southern California. Rapid loss estimates also were made with information provided by ShakeMap after the magnitude 5.2 Yountville (Napa Valley) quake in September 2000 and the magnitude 6.8 Nisqually/Seattle) earthquake on Feb. 28, 2001. Based on the success of the ShakeMap project in California, the USGS, in cooperation with other scientific institutions and emergency agencies, is developing a ShakeMap system for the other seismically active regions of the United States.

The Community Internet Intensity Map, commonly referred to as Did You Feel It?, also shows the areas of greatest shaking and damage, but requires the contributions of Internet users to show where the earthquake was felt and how strongly it shook. After any quake, almost everyone wants to tell someone what it felt like, how long it lasted, and the damage it did to their home or business. Building on that universal human trait of wanting to describe such an experience, or at least confirm that you were affected by it, USGS scientists developed a system that instantly converts responses to web-based questionnaires about earthquake experiences and/or damage into colorful maps depicting which areas were hardest hit and which areas were spared.

Since this map system was launched in 1998, the USGS has recorded and compiled more than 100,000 individual reports to develop maps showing areas where the ground shook the hardest. In the wake of the 1999 Hector Mine earthquake, for example, more than 25,000 people contributed to Community Intensity Maps, which showed that the quake was felt over a 90,000-square-mile area.

Over 7,000 responses to the Sept. 3, 2000, earthquake that damaged parts of Napa County, California, show a strong correlation between human reactions to the earthquake, intensities of ground shaking recorded on instruments, and patterns of structural damage. That experience was repeated in the Puget Sound area, after the Feb. 28 quake, when over 12,000 citizen reports allowed mapping of the overall affected area. The maps coincided well with later official damage reports. The maps are at http://pasadena.wr.usgs.gov/latest/shakingmaps.html. ■

Spokane Earthquakes Point to Latah Fault?

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On June 25 at 7:15 a.m., a magnitude 3.7 earthquake struck the downtown Spokane area. This quake was followed by a number of smaller aftershocks that continued until early August. Many of these quakes were felt by local residents, but some were not recorded by the Pacific Northwest Seismograph Network. These unrecorded events likely occurred very close to ground surface and were felt only very near their epicenter. The earthquakes were located near a suspected northwest-trending fault that roughly parallels the Hangman Valley, a distinct lineament feature in the local landscape that is occupied by Latah (Hangman) Creek (Fig. 1).

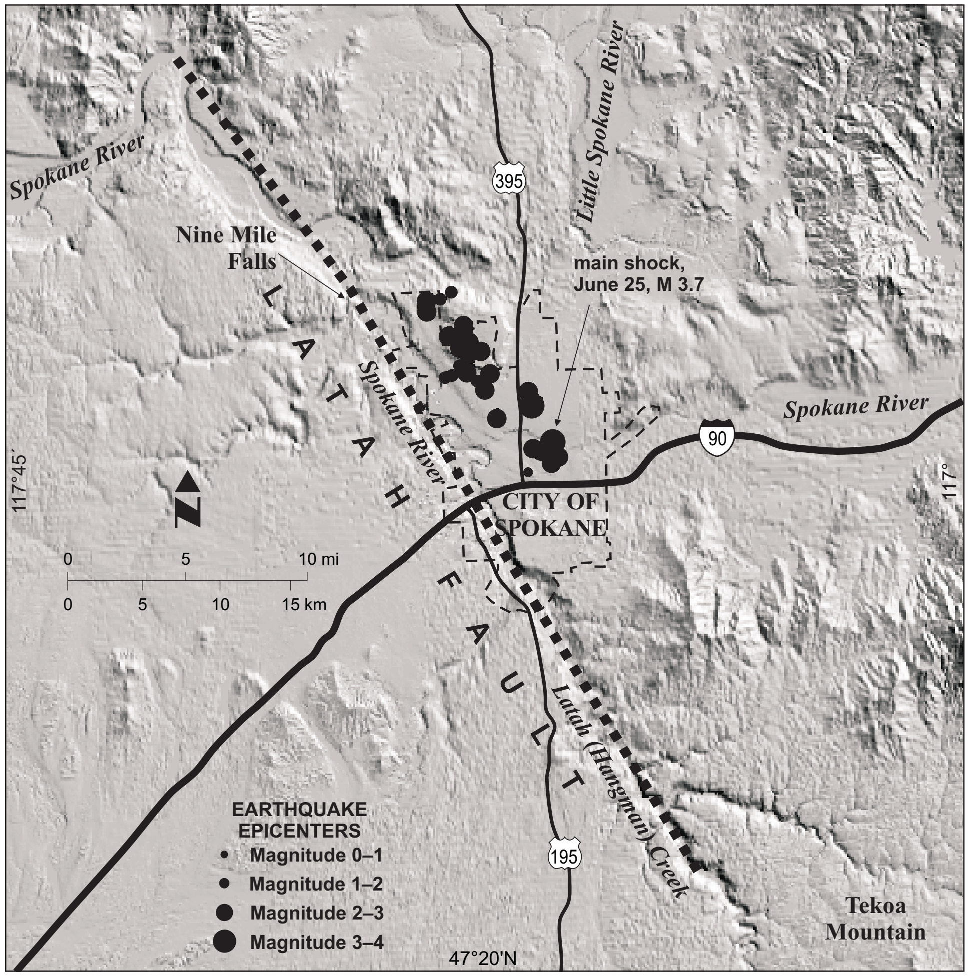


Figure 1. Relief map showing the location of the Spokane earthquake swarm of 2001 and the suspected Latah fault/Hangman Creek lineament (heavy dotted line).

The shaking took the city's residents by surprise. Many described the earthquakes as a large thump or explosion that rattled houses and buildings. Property damage was minor, but public concern was high. The recent Spokane earthquakes are characteristic of a swarm sequence, a cluster of small magnitude events occurring over a short period of time (a few months to a year, typically). An earthquake swarm near Othello in 1987 lasted about a year and included over 200 recorded events, with about 20 of them larger than magnitude 2.0. The largest earthquake in this sequence was magnitude 3.3.

The seismic history of the Spokane area is poorly understood since past events did not result in any major property damage and distant seismograph stations did not pick up many of the low-magnitude earthquakes. Newspaper reports indicate that between 1915 and 1962 nine earthquakes were felt only in the Spokane area (indicating a local source), but none had the characteristics of the 2001 swarm sequence. A number of these historic earthquakes were felt most strongly in the area of the Hangman Creek lineament.

Many geologists have mapped the Spokane area, but none had confirmed the presence of any major faults with demonstrated offset that might be capable of producing earthquakes. The linear trace of Hangman Creek, however, was noted by Griggs (1973) on a tectonic map that accompanied his 1:250,000-scale geologic map of the Spokane quadrangle. He labeled it a "strong lineament—no visible offset". It can be traced for nearly 50 miles from the Tekoa Mountain area on the south to beyond Nine Mile Falls on the north. (The linear feature continues for approximately 12 miles after Hangman Creek joins the Spokane River.) The logical explanation for this was that the creek followed the trace of a fault.

Geologists in the Spokane office of the Division of Geology and Earth Resources have been mapping the geology of four quadrangles west and southwest of downtown Spokane. This past winter, they evaluated results of whole rock geochemistry tests on basalt samples that were collected to determine basalt stratigraphy in the Hangman Creek area. They found that basalt formations on the west side of the lineament did not correspond directly to those on the east side. The lack of lateral continuity in basalt flows could be attributed to erosion prior to deposition of younger flows. Alternatively, the lack of continuity could be attributed to movement on a fault roughly paralleling the lineament. This proposed fault has been informally named the Latah fault. Additional seismological analyses will be needed to determine if the coincidence of the trends of the earthquake epicenters and the Hangman Creek lineament apparent on Figure 1 is real or an artifact caused by uncorrected timing errors in determining the preliminary locations. What is clear is the importance of understanding the earthquake history and future seismic risk of the Spokane area. ■

Griggs, A. B., 1973, Geologic map of the Spokane quadrangle, Washington, Idaho, and Montana: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-768, 1 sheet, scale 1:250,000.

Insuring Future Access to Geoscience Reports

Connie J. Manson, Senior Librarian
Washington Division of Geology and Earth Resources
PO Box 47007, Olympia, WA 98504-7007

These days, many geoscience reports are available only as digital files or on the Internet. Because this allows instant access to files and money is saved by not having to make and store print copies, administrators are urging—even demanding—that more and more of our publications be digital only. But before we succumb to this demand, we need to think carefully about the long term effects of these actions.

Geoscience editors and librarians know how fragile electronic access is. It's very easy to post a new report on a server, but it's even easier to wipe it out, whether intentionally or accidentally. Web pages are readily abandoned or forgotten. Personnel move from agency to agency, company to company, without transferring their electronic files. Servers are taken out of service. Companies go out of business. The reports get lost. Some companies delete old material after a certain amount of time. This is especially a problem for the gray literature that comprises so much of the literature of the geosciences, including theses, conference papers and abstracts, agency reports, and open-file reports.

We're already seeing such materials withdrawn from servers after only a few years, and once gone, they're gone forever. But their citations live on, irretrievable, unverifiable, and the science is lost.

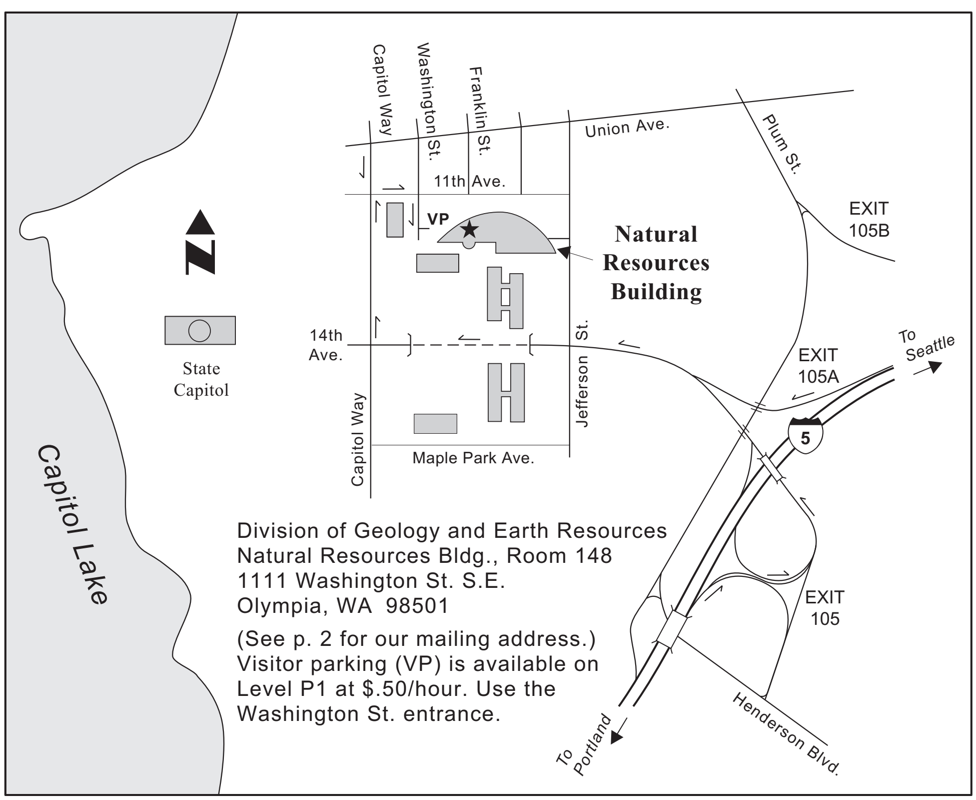
Rapid changes in computer hardware and software leave the older materials unusable and the newest materials inaccessible. Who can still read a 5.25-inch disk or a CPM file? Few people (outside of research universities) have the most current systems—the very latest browser, the state-of-the-art computer, the fastest modem, the most sophisticated oversize color plotter. By the time you upgrade your equipment, the report you needed may be gone.

Additionally, we're seeing more and more geoscience publishers (especially in state and federal agencies) abdicating their responsibilities to science and to taxpayers. Once the work has been done and the tax money spent, the information doesn't seem to be valued or deemed important enough to distribute to those who need it now or to archive it for those who will need it in the future. It "was" available online, you had your fleeting chance, but now it's gone. Sorry.

Over the last two centuries, we've seen that knowledge in the geosciences evolves through incremental steps and occasional leaps of study and research. The provenance of that knowledge requires that researchers be able to retrace all those previous steps. *All* those steps—as documented in field notes, theses, and conference papers and abstracts, as well as peer-reviewed journal papers and monographs. But if this and the next generations of geoscience data are available only on the Internet, their longevity and content are endangered by the whims and accidents of retention. In 10 or 20 or 50 years, researchers risk looking back from the mountain top to find that their path has been erased—they might know where they are, but have no idea how they got there, or how to repeat the trip a second time. Gaps in the scientific record endanger the science.

The paradigm for disseminating scientific information has clearly shifted from ink-on-paper to bits-in-cyberspace. But can or should the paradigm for archiving scientific information make the same shift? It is crucial that we find ways to maintain permanent access to these materials. It's easy to wring our hands about these problems—but, what are we doing about it? What programs do *we* have in place at our organizations to deal with this? Are we archiving paper versions of electronic reports? Are we archiving electronic versions, with the attendant metadata, software, and hardware, so we can continue to read them for many decades to come? What systems are the most reliable and most cost effective? We should be fiercely concerned about maintaining full access to our materials, in perpetuity. After all, this is happening on our watch and the future will be our judge. ■

HOW TO FIND OUR MAIN OFFICE



DIVISION PUBLICATIONS

Print Publications

Reconnaissance Investigation of Sand, Gravel, and Quarried Bedrock Resources in the Toppenish 1:100,000 Quadrangle, Washington, Information Circular 93, by Andrew B. Dunn, 23 p., 1 plate, scale 1:100,000. $4.17 + .33 tax (Wash. residents only) = $4.50.

Directory of Washington Mines, 2001, Information Circular 94, compiled by Donald T. McKay, Jr., David K. Norman, Mary Ann Shawver, and Ronald F. Teissere, 104 p. This is a directory of mines with current Reclamation Permits from the Department of Natural Resources. Also available on the web as a PDF file. $4.17 + .33 tax (Wash. residents only) = $4.50.

Electronic Publications

Directory of Washington Mines, 2001 (*see above*) is at http://www.wa.gov/dnr/htdocs/ger/smr.htm.

Map of Mine Sites in Washington by Donald T. McKay, Jr., is available as downloadable ArcInfo and ArcView files at http://www.wa.gov/dnr/htdocs/ger/smgis.htm. It shows the location of 1162 current and 1645 past permitted sites in Washington. As of the date of publication, only the attributed points are available; the files do not yet contain other features such as rivers, highways, county boundaries, etc.

The Digital Bibliography of the Geology and Mineral Resources of Washington State is now available on our website at http://www.wa.gov/dnr/htdocs/ger/washbib.htm. We've been maintaining this index since 1935, but we could only publish it in incremental printed volumes until 1998. We then issued the full searchable database on CD-ROM, but now—We're on the Net!

The searchable database includes the citations and indexing for all of the items we've found about the geology, geologic hazards, and mineral resources of Washington back to 1798—about 31,000 items as of September 2001. The database also includes about 5,500 other items in our library. We add about 1,000 items about Washington geology to the system annually and the database is updated monthly.

The Index to Geologic and Geophysical Mapping is available on our website as a PDF file at http://www.wa.gov/dnr/htdocs/ger/mapindex.htm.

STAFF NEWS

Cartographer Keith Ikerd provided a rock and mineral display from his personal collection to the Tumwater Timberland Library. He also supplied 1,400 mineral samples for the Hands-On Children's Museum in Olympia.

Geologist Pat Pringle and USGS geologist Kevin Scott led a field trip for the National Association of Geoscience Teachers, Northwest Section, during their meeting in Bellevue in June. Pat also led a hiking trip in August for the Mount St. Helens Institute: "Geology in the Heart of the Blast Zone: A Geologist-Guided Exploration of the 1980 Eruption as Seen from Johnston Ridge".

Geologist Tim Walsh and **librarians Connie Manson** and **Lee Walkling** presented posters at the International Tsunami Symposium in Seattle in early August. ■

PUGET SOUND LIDAR DATA ONLINE

Puget Sound LIDAR Consortium has made available public-domain high-resolution topography for western Washington at http://seattlehazards.usgs.gov/Lidar.html. LIDAR (**LI**ght **D**etection **A**nd **R**anging, also known as Airborne Laser Swath Mapping or ALSM) is a relatively new technology that employs an airborne scanning laser rangefinder to produce accurate topographic surveys of unparalleled detail. A laser mounted aboard a low-flying aircraft is used to more accurately map the topography of earth's surface.

This website is not yet fully developed but the lidar data for Puget Sound and the Snoqualmie Valley are beginning to become available.

CHANGED YOUR ADDRESS OR CHANGED YOUR MIND?

The Division pays for *Washington Geology* from an ever-tightening budget. Please let us know if you have moved or no longer wish to receive this journal by mail. (It is now available in color on the web at http://www.wa.gov/dnr/htdocs/ger/washgeol. htm.) Contact us and we will do an address change or take your name off the list immediately. If you supply your +4 digit zip extension with your new address, it saves our staff a lot of time and makes the job of maintaining an accurate mailing list easier.

If you move and do not notify us, we will have to take your name off our mailing list. To contact us, look under Main Office in the left column on p. 2.

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