NATURAL RESOURCES

WASHINGTON GEOLOGY

VOL. 30, NO. 1/2
JULY 2002

IN THIS ISSUE

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

WASHINGTON GEOLOGY

Vol. 30, No. 1/2
July 2002

Washington Geology (ISSN 1058-2134) is published four times a year on the web by the Washington Division of Geology and Earth Resources.

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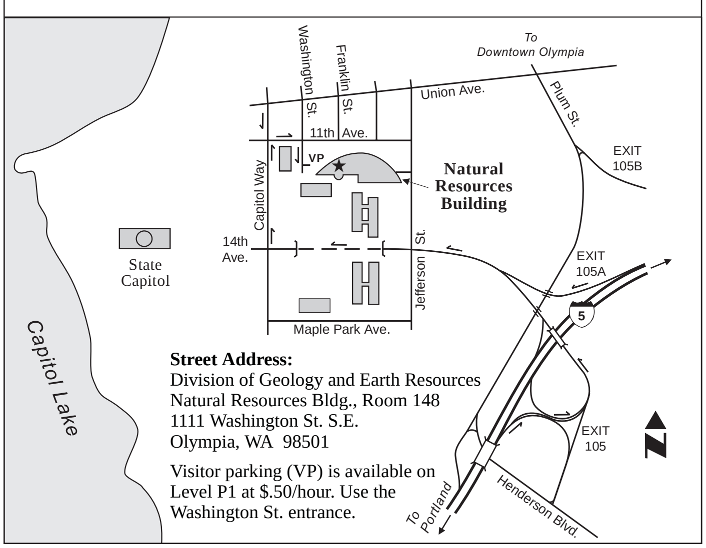

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Division Update

The Division has been going through many changes—some good, some bad, some...who knows?

One 'good thing' is that we have finally published the geologic map of the Northwest Quadrant. The four-color map comes folded in a 9½ x 12-inch envelope containing a 76-page pamphlet and three plates: the geologic map, the descriptions of map units, and ages of map units. The map is the result of a multi-year effort by geologists of the Washington Division of Geology and Earth Resources with assistance from geologists from the U.S. Geological Survey, several Washington universities, and the local geological community.

The map is dedicated to Dr. Rowland W. Tabor (USGS, retired), who is the principal author of mapping that covers approximately three quarters of the northwest quadrant. Over the last 40 years, he has published 28 peer-reviewed technical books and articles and made dozens of presentations at professional conferences. Without this work, large parts of the Cascades and Olympics would still be poorly understood.

The release of this fourth and final map completes the set of quadrant maps comprising the geologic map of Washington at 1:250,000-scale. The previous quadrant maps were published in 1987 (southwest), 1991 (northeast), and 1997 (southeast).

The approximately 4½ x 3-foot individual quadrants make a colorful wall display when mounted separately or together. Copies of the northwest quadrant may be purchased for $9.20 + .80 tax (Wash. residents only) = $10.00 per copy ($11.12 + .88 = $12.00 for a flat map in a tube) plus shipping and handling ($3.50 folded; $4.50 flat).

Another good thing is that we have reissued the color page-size geologic map of Washington and the Mount St. Helens road guide, which has been out of print for a while. The map has a new summary of the geology of Washington on the back, and the text of the road guide has been updated and several new photos have been added.

Continuing budgetary shrinkage has caused several bad things to happen. First, as of July 1, 2002, the Spokane Office is officially closed, although Bob Derkey will continue to work on mapping projects in the area through at least the next year.

Second, to cover our actual costs for printing and mailing, we have had to increase the prices of some open file reports and the cost of shipping and handling for all publication orders. (See p. 20 for more information.)

And third, with this issue, *Washington Geology* becomes a web-only publication, which means it will no longer be sent out free to subscribers, but it *will* be available on our website. Many other state surveys have been forced to take this cost-cutting measure. We regret that we do not currently have the capability to notify people by e-mail when the next issue comes out.

We will be running a certain number of xerographic copies for distribution to libraries and anyone who wishes to buy one. They won't have the quality of a printed copy, but they will be on high-quality 11x17″ paper, saddle-stitched, and quite readable. To order a paper copy of *Washington Geology*, send $1.50 per issue plus $2.50 for shipping and handling. ■

Cover photo: Outcrop of late Pleistocene Touchet beds (pronounced *too′-she*) in Burlingame ravine near Walla Walla, Washington. Each graded bed represents a flood event within the latest Pleistocene catastrophic glacial outburst flood sequence—the Missoula floods. Note the vertical clastic dike in right center of photo. See article on p. 9. *(Photo by P. K. Spencer.)*

The Metallic, Nonmetallic, and Industrial Mineral Industry of Washington—2001

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INTRODUCTION

Production of nonfuel mineral commodities in Washington in 2000 was valued at $607,000,000 (U.S. Geological Survey and Washington Division of Geology and Earth Resources, 2002). This represents nearly a 4 percent decrease from 1999. Firm numbers for 2001 are not yet available. Metallic mineral production accounted for approximately 21 percent of the value of nonfuel mineral production. Nonmetallic mineral commodities limestone, dolomite, shale, clay, diatomite, olivine, and silica accounted for approximately 22 percent, a small increase over 1999. When available, figures for nonmetallic mineral production in 2001 are expected to be lower. Industrial minerals (aggregate) accounted for approximately 57 percent of the total value of the state's mineral production in 2000.

This article is a summary of mining company activities in 2001 based on a telephone survey by the Department of Natural Resources in January and February of 2002. Location maps (Figs. 1 and 5) and summary tables (Tables 1 and 2) are provided for both metallic and nonmetallic mineral operations. All of the larger known mining operations were contacted, but because some, especially the smaller, operations were not, this report does not contain a complete listing of mineral industry activities in the state. However, the major mining operations contribute the majority of the value of the State's nonfuel mineral production.

Additional details about the geology of mineral deposits and earlier industry activities in the State are available in prior reviews of the Washington mineral industry published in the first issue of *Washington Geology* each year (Derkey, 1998, 1999; Derkey and Hamilton, 2000, 2001). Questions about metallic and nonmetallic mining activities and exploration should be referred to the Olympia office.

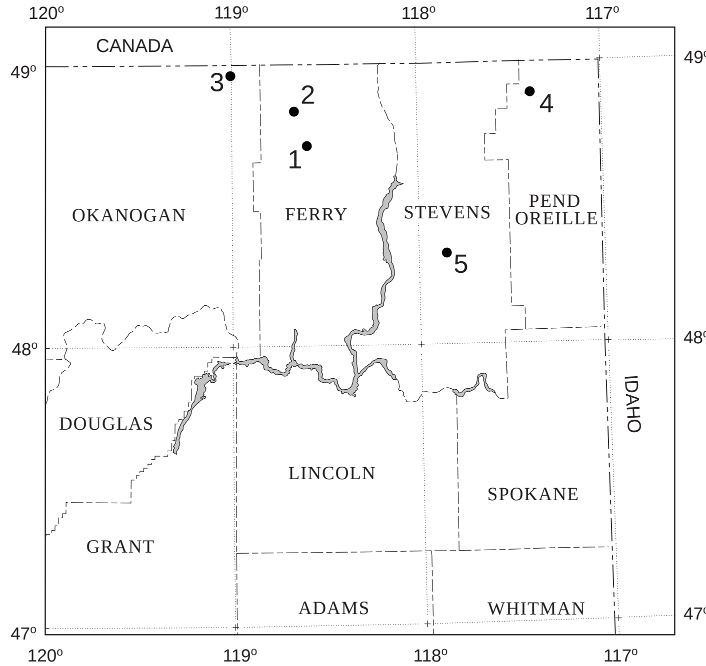

Figure 1. Location of major metal mining projects in northeastern Washington in 2001. Table 1 below identifies mines by number given on map and provides additional details about each of these projects.

Table 1. Operator and brief description of the activity and geology at major metallic mineral deposits in Washington in 2001 *(companion to Fig. 1)*

No.	Property	Location	County	Commodities	Operator	Activity	Area geology
1	Lamefoot	secs. 4, 8, T37N R33E	Ferry	Au, Ag	Echo Bay Minerals Co.	A small tonnage of ore was recovered during shutdown of the mine last summer; 74,693 tons of stockpiled Lamefoot ore containing 12,818 oz of gold was processed at the mill near the Overlook mine; gold recovery was approximately 85%	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., Kettle River Project	Mined 221,547 tons of ore from the K-2 deposit that contained 44,225 oz of gold; 265,192 tons of K-2 ore was milled containing ~47,800 oz of gold; company conducted ~15,000 ft of exploratory surface drilling adjacent to the K-2 deposit	Epithermal deposit in Eocene Sanpoil Volcanics
3	Crown Jewel	sec. 24, T40N R30E	Okanogan	Au, Cu, Ag, Fe	Crown Resources Corp.	Battle Mountain Gold, which merged with Newmont Mining, dropped its option on the deposit; Crown Resources is now exploring the possibility of developing the deposit as an underground mine	Gold skarn mineralization in Permian or 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	Teck Cominco American, Inc.	Continued permitting process; tailings disposal site prepared; planning to sink internal shaft from 900 level to Yellowhead ore horizon in 2002; mining startup delayed until 2004	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.	After ~30 years of operation, the Addy magnesium metal operation was discontinued in September 2001 because of depressed metal prices; there are no plans by parent company Alcoa to reopen the operation	Cambrian–Ordovician Metaline Formation dolomite

METALLIC MINERAL INDUSTRY

Major metal mining operations in Washington in the year 2001 included gold mining at Republic and magnesium metal production at Addy. There will be a dramatic decrease in activity in 2002, as magnesium metal operations at Addy were closed down in September of 2001. Work to reopen the Pend Oreille lead-zinc mine continued; however, Teck Cominco American has elected to delay startup of the mine until 2004 due to depressed zinc prices. Battle Mountain Gold became a wholly owned subsidiary of Newmont Mining and elected to drop their option for the Crown Jewel gold deposit. The only major known exploration project for metallic minerals in Washington in 2001 was for additional reserves in and adjacent to the K-2 gold deposit. Locations of metallic mineral properties active in 2001 are shown on Figure 1. The number in parentheses following each property name below is the number on the location map.

Mining by Echo Bay Minerals at the Kettle River Project was at the K-2 mine (2), an epithermal vein-type deposit in Eocene volcanic rocks of the Republic graben north of Republic in Ferry County. The company mined 221,547 tons of ore (44,225 ounces of contained gold) from the K-2 deposit. The company milled 265,192 tons (47,798 ounces of contained gold) of K-2 ore (including stockpiled ore) and 74,693 tons (12,818 ounces of contained gold) of stockpiled ore from the Lamefoot mine (1). Mining was completed in 2000 at the Lamefoot mine; however, a small tonnage was removed during rehabilitation operations in 2001. Total gold recovered from K-2 and Lamefoot ores was 50,349 ounces from 339,885 tons of ore; recovery was approximately 85 percent. Because haulage distances are greater and mining costs are higher, the company expects K-2 production will decrease to 35,000 ounces of gold in 2002.

Echo Bay continued to explore for mineralization to maintain their reserves in the Republic area. Their focus was northeast of the K-2 mine where they completed approximately 15,000 feet of drilling from the surface northeast of the mine. Drilling had not progressed sufficiently at the end of the year to allow the company to classify this resource as proven and probable reserves. They plan to continue drilling next year in order to prove this reserve.

Canada-based Teck Corporation completed the acquisition of Cominco during 2001. The company is now known in the U.S. as Teck Cominco American, Inc. In 2001, the company prepared the tailings disposal site at the Pend Oreille mine (4) in anticipation of resuming mining. They plan to rehabilitate and modernize the old mill on the property and will ship concentrates to their smelter in Trail, B.C., which is about 40 miles from the mine. Teck Cominco American has been working with local citizens to reduce the mine's impact on northern Pend Oreille County, both during startup and during closure after reserves are depleted. On their website (http://www.teckcominco.com/operations/pendoreille/index.htm), Teck Cominco reports an ore reserve of 5.5 million tons containing 7.3 percent zinc and 1.3 percent lead. They have projected a 10-year mine life at about 800,000 tons mined per year. Most of the approximately 14 million tons of previous production, grading 2.3 percent zinc and 1.1 percent lead, came from the Josephine horizon. The new reserve at the mine is from a

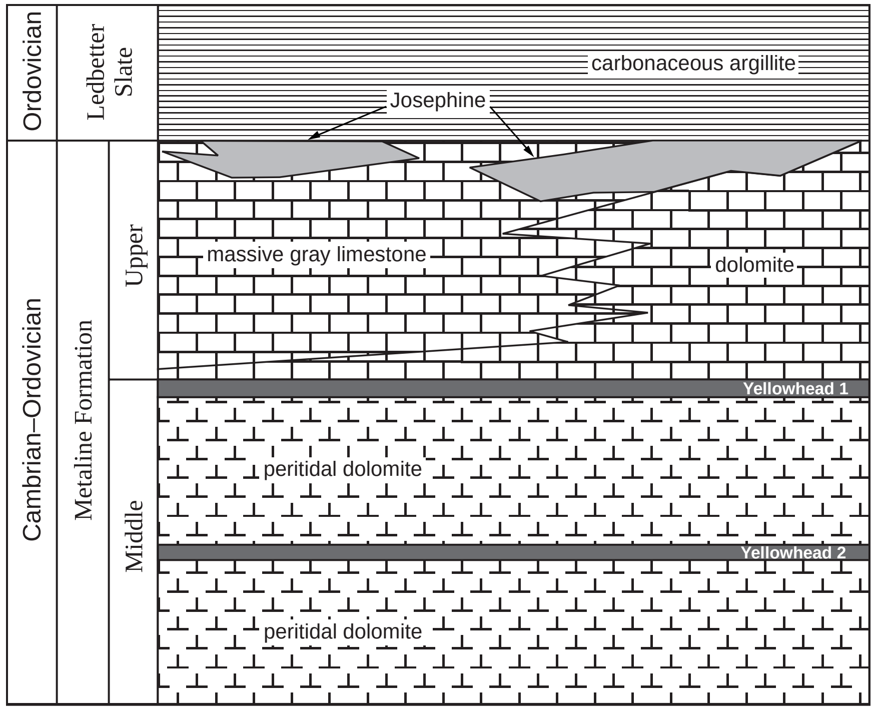

Figure 2. Schematic representation of stratigraphy at the Pend Oreille mine in the middle and upper Metaline Formation and overlying Ledbetter Slate. Horizons where mineralization occurs are shown relative to stratigraphic position. *(Modified from Teck Cominco website.)*

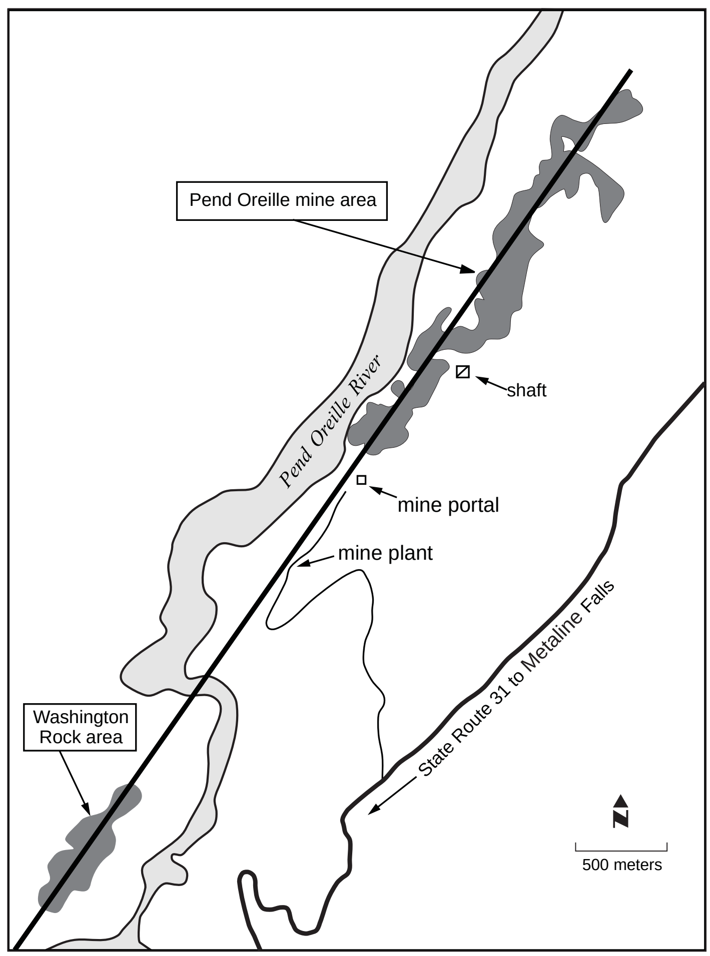

Figure 3. Projection of Yellowhead-type mineralization to the surface in the Washington Rock and Pend Oreille mine areas relative to the Pend Oreille River. Thick northeast–trending line is location of cross section on Figure 4. *(Modified from Teck Cominco website.)*

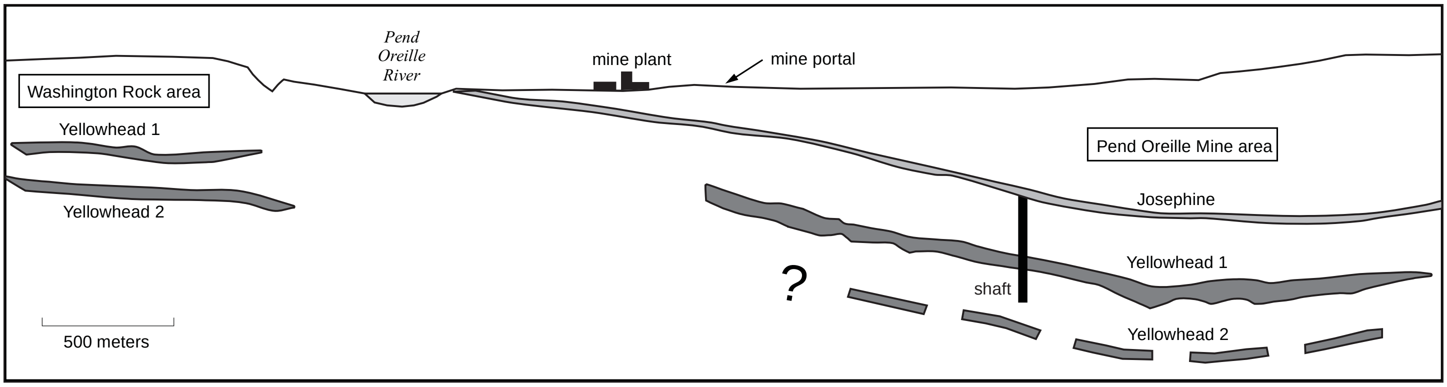

Figure 4. Washington Rock area to Pend Oreille mine area long section, looking northwest. Location of mineralized zones relative to the mine plant are depicted. Decline that descends from the mine portal to the Yellowhead 1 ore zone is not depicted on this section. Location of section is shown on Figure 3. *(Modified from Teck Cominco website.)*

deeper zone called the Yellowhead 1 zone. They have also identified a third ore horizon, which they refer to as the Yellowhead 2.

Zinc and lead deposits in Cambrian–Ordovician carbonate host rocks, such as at the Pend Oreille mine, are known in the U.S. as Mississippi Valley-type deposits. Teck Cominco calls them Irish-type deposits. The following is a portion of the information from the Teck Cominco website. “Yellowhead-type mineralization occurs in the middle part of the 1000 metre-thick Cambro–Ordovician Metaline Formation in a shallow water dolomitic facies. Josephine-type mineralization, which was exploited by earlier operators, occurs at the top of the upper Metaline Formation, which consists primarily of subtidal carbonate facies overlain by carbonaceous argillite of the Ordovician Ledbetter Formation.” See Figures 2-4 for a graphic view of the deposit distribution and characteristics. The Yellowhead ore zone is described as “NE trending en-echelon lenses that vary from 150 to 580 metres long. Overall the zone is 2100 metres long and varies in width from 100 to 200 metres Yellowhead-type mineralization is stratabound and consists of massive- and coloform-textured pyrite with later bands and crusts of pale tan to yellow sphalerite. Coarse galena occurs with sparry dolomite in interstices, between masses of sphalerite and pyrite. Mineralization is superimposed on areas of coarse zebra-banded dolomite and dolomite-altered stratabound solution collapse breccia. The ore shows local silicification. Thicknesses in the drilled resource average 6 metres but can reach over 20 metres. Several stratigraphic levels contain Yellowhead-type mineralization.”

Following their merger with Newmont Mining, Battle Mountain Gold dropped their option on the Crown Jewel gold deposit (3) near Chesaw in Okanogan County. Crown Resources Corporation is now the sole owner of the deposit. It is a skarn-type gold deposit in a sequence of Pennsylvanian to Triassic(?) clastic and carbonate sedimentary rocks adjacent to the Buckhorn Mountain pluton. Previously announced open pit minable reserves for the deposit were 8.7 million tons at a grade of 0.186 ounces of gold per ton. Crown Resources now proposes mining the deposit primarily as an underground operation and has recalculated the reserves. They report proven and probable reserves of 2.56 million tons at a grade of 0.345 ounces per ton gold (0.9 million ounces of contained gold) and an additional 0.5 million tons of possible ore at a grade of 0.383 ounces per ton gold (0.5 million ounces of contained gold).

Northwest Alloys ceased magnesium metal production in September at its plant near Addy (5) in Stevens County. The company was no longer able to compete with lower priced foreign sources. They, however, mined 670,000 tons of dolomite in 2001 compared to 634,000 tons in 2000. In addition to using reject material from the mine for road aggregate, the company processed some of their by-product for fertilizer (see below). They will continue that process until the by-product material is expended. Research continued into finding ways to use their remaining waste materials.

NONMETALLIC MINERAL INDUSTRY

Nonmetallic mineral commodities produced in Washington were used as smelter flux, soil conditioners, feed lime, landscape rock, paper filler, bricks, cement and fiber cement additives, filter material, casting sand, and glass. The number in parentheses following each property name below is the number on the location map in Figure 5.

Two companies mined limestone (calcium carbonate) and dolomite (calcium magnesium carbonate) for use as a soil conditioner and feed lime in 2001. Pacific Calcium produced from the Tonasket (110) and Brown (111) quarries in Okanogan County, and Allied Minerals produced from the Gehrke quarry (117) in Stevens County. Northwest Alloys sold approximately 11,500 tons of smelter slag from their magnesium metal operation at Addy (123) in Stevens County for fertilizer and soil conditioner. Columbia River Carbonates continued to produce calcium carbonate from the Wauconda quarry (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 (122) in Stevens County, and shipped most of it to Trail, B.C. for use as a fluxing agent in smelting. Northwest Marble Products (120) and the Whitestone Company (119), both in Stevens County, continued to produce terrazzo tile and building aggregates, as they have for a number of years.

Celite Corporation mined and processed approximately 100,000 tons from the diatomite pits (102) in Grant County. The company shipped approximately 65,000 tons of finished diatomite; most is used for filtration purposes.

Olivine Corporation mined 40,000 tons of refractory-grade olivine from its Swen Larsen quarry (125) in Whatcom County in 2001. Most of that production was shipped to Unimin, a Belgian company that produces casting sands and other refractory products at Hamilton, in Skagit County. The company also reports that initial investigation to produce ornamental olivine appears successful; the olivine polishes very well.

Mutual Materials used about 102,600 tons of clay for the manufacture of bricks and related products at their plants in Se-

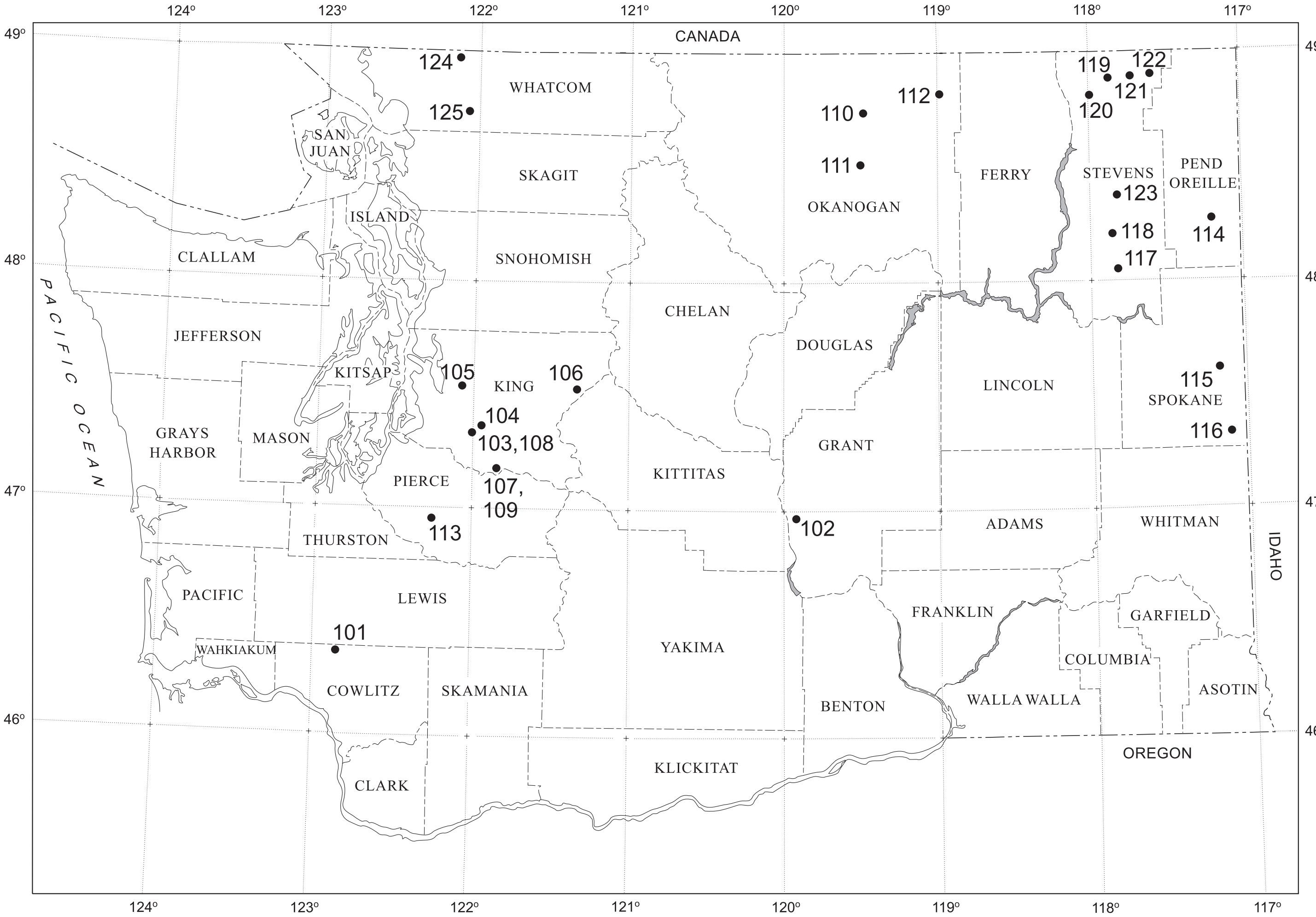

Figure 5. Location of nonmetallic mining operations in Washington in 2001. Table 2 below identifies mines by number given on map and provides additional details about each of these projects.

Table 2. Operator and brief description of the activity and geology of nonmetallic mining operations in Washington in 2001 *(companion to Fig. 5)*

No.	Property	Location	County	Commodities	Operator	Activity	Area geology
101	Castle Rock quarry	sec. 18, T10N R1W	Cowlitz	clay	Ash Grove Cement Co.	Mined 15,000 tons	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	Miocene “Quincy diatomite bed”, local sedimentary interbed at the base of Priest Rapids Member, Columbia River Basalt Group
103	Ravensdale pit	sec. 1, T21N R6E	King	silica	Reserve Silica Corp.	Mined and washed 120,000 tons and shipped 78,000 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.	Hauled 3,000 tons from stockpile 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 and hauled 45,000 tons of shale used 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.	Mined 110,000 tons of silica for use in cement manufacture	Silica cap in hydrothermally altered Miocene andesites on a caldera margin
108	John Henry No. 1	sec. 12, T21N R6E	King	clay	Pacific Coast Coal Co.	Not active in 2001	Upper middle Eocene silty clay near base of Puget Group in a 30-ft-thick zone above the Franklin No. 9 coal seam

No.	Property	Location	County	Commodities	Operator	Activity	Area geology
109	Scatter Creek mine	secs. 5-6, T19N R8E	King	Silica	James Hardie Building Products, Inc.	Mined 120,000 tons of silicified andesite used to manufacture fiber-cement products; also shipped 20,000 tons to Lafarge Corp. for cement manufacture	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 12,335 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 6,960 tons of dolomite used for soil conditioner	Metadolomite member of the Triassic Cave Mountain Formation
112	Wauconda quarry	sec. 13, T38N R30E	Okanogan	limestone	Columbia River Carbonates	Continued mining high-brightness calcium carbonate; shipped to processing plant near Longview; used as filler in paper, paint pigments, and in plastics	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 3,150 tons; used 5,480 tons to produce bricks	Tertiary kaolin-bearing, altered andesite
114	Usk pit	sec. 7, T32N R44E	Pend Oreille	clay	Mutual Materials Co.	Mined 4,510 tons of clay-rich material, which they used to produce bricks	Holocene lacustrine deposits of clay, silt, and sand; light gray clay fires dark red
115	Mica pit	sec. 14, T24N R44E	Spokane	clay	Mutual Materials Co.	Mined 41,100 tons of clay adjacent to their brick plant south of Spokane	Lacustrine clay of Miocene Latah Formation overlying saprolitic, pre-Tertiary felsic gneiss.
116	Potratz	sec. 7 T21N R45E	Spokane	clay	Mutual Materials Co.	Hauled 3,500 tons from stockpile for brick manufacture	
117	Gehrke quarry	sec. 2, T29N R39E	Stevens	dolomite	Allied Minerals, Inc.	Processed ~6,000 tons from stockpile; stripped an area in preparation for mining; marketed product as a soil conditioner	Isolated pod of Proterozoic Y Stensgar Dolomite(?) (Deer Trail Group)
118	Lane Mountain quarry	secs. 22, 34, T31N R39E	Stevens	silica	Lane Mountain Silica Co. (*divn. of* Hemphill Brothers, Inc.)	Mined 267,443 tons of silica; shipped 105,446 tons for glass manufacture; 67,813 tons for cement plant in Richmond, B.C.; 22,516 tons for manufacturing fiberglass; 34,521 tons for sandblasting and filtering	Cambrian Addy Quartzite
119	Whitestone quarry	sec. 34, T39N R38E	Stevens	marble	Whitestone Co.	Mined approximately 17,000 tons of limestone and dolomite for terrazzo tile and other uses; also mined some quartzite	Recrystallized limestone (marble) in Cambrian Maitlen Phyllite
120	Northwest marble mine; other quarries	sec. 19, T38N R38E	Stevens	dolomite	Northwest Marble Products Co.	Mined and milled more than 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
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	Cambrian Maitlen Phyllite, Reeves Limestone Member
122	Sherve quarry	sec. 8, T39N R40E	Stevens	limestone	Northport Limestone Co. (*divn. of* Hemphill Brothers, Inc.)	Mined 32,000 tons of fluxing grade limestone; shipped to the Cominco smelter at Trail, B.C.; also used for road metal	Limestone in upper unit of Cambrian–Ordovician Metaline Formation
123	Addy magnesium mine	secs. 13-14, T33N R39E	Stevens	dolomite	Northwest Alloys, Inc.	By-product potassium chloride, magnesium chloride, magnesium oxide, and magnesium hydride processed for soil conditioner	Cambrian–Ordovician Metaline Formation dolomite
124	Clausen quarry	sec. 7, 18, T40N R6E	Whatcom	limestone	Clauson Quarry LLC	Mined approximately 70,000 tons used for rip rap, 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
125	Swen Larsen quarry	sec. 34, T38N R6E	Whatcom	olivine	Olivine Corp.	Mined and milled 40,000 tons of olivine; some polished slabs for decorative use; most production used for casting sand	Twin Sisters Dunite (outcrop area >36 mi^2) in Whatcom and Skagit Counties

attle and Spokane. The company produced from the Mica (115) and Potratz (116) pits in Spokane County and used clay rich material from the Usk pit (114) in Pend Oreille County. For their Seattle plant, the company obtained clay from the Elk (104) and Section 31 (105) pits in King County, and from stockpiled clay from the Clay City pit (113) in Pierce County.

Clays derived from weathering of pre-Miocene igneous and metamorphic rocks and deposited in Miocene lake basins around the northeastern margin of Columbia River Basalt are of interest to a Canadian company. In Spokane County, these clays are known as the Latah Formation (Hosterman, 1969). The Canadian company has been evaluating these clays in Idaho as a potential source of kaolinite. Kaolin clay is used to make glossy paper, fine china, paint, and Kaopectate. Should markets be established, these deposits in Spokane and Stevens Counties could become a viable resource.

Ash Grove Cement mined 110,000 tons of silica ore at the Superior quarry (107) in King County and 15,000 tons of clay ore at the Castle Rock quarry (101) in Cowlitz County that were used for portland cement production in Seattle. Ash Grove was exploring for additional silica reserves at Bridge Camp near Enumclaw. Pacific Coast Coal did not mine any clay from the John Henry No.1 coal mine (108) in 2001.

Lane Mountain Silica mined 267,443 tons of Addy Quartzite from the Lane Mountain quarry (118) in Stevens County. Following processing, they shipped 105,446 tons of high-purity quartz for making glass bottles and jars, 22,516 tons for making fiberglass, 34,521 tons for sand blasting and filtering, and 67,813 tons of clay/silica byproduct, recovered during processing, to make cement at a plant in Richmond, B.C.

Reserve Silica mined 120,000 tons of quartz-rich Puget Group sands from the Ravensdale pit in King County (103). Following washing, the company shipped 78,000 tons; most is used for the manufacture of bottle glass, and some is used for sand traps at golf courses.

James Hardie Building Products mined 120,000 tons of silica in 2001 from their Scatter Creek mine (109) in King County. They used most of it for the manufacture of fiber ce-

Continued on p. 20

Washington's Coal Industry—2001

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Coal production from Washington's two coal mines was up from a year ago. The Centralia Mine in north-central Lewis County and the John Henry No.1 Mine in south-central King County produced a total of 4,624,495 short clean tons of coal, 354,131 tons more than in 2000.

The state's largest coal mine, the Centralia Coal Mine, is located 5 miles northeast of Centralia (Fig. 1). The mine is totally dedicated to supplying coal to the Centralia Steam Plant. The steam plant is located a mile from the coal mine and is operated by TransAlta Centralia Generation LLC. TransAlta, a Canadian corporation, took over ownership of the Centralia Mine in May of 2000. The mine was formerly owned and operated by PacifiCorp.

The Centralia Mine completed its 31st year of production in 2001, producing 4,624,245 short tons of subbituminous coal, 354,481 tons more than it produced in 2000. The mine's average annual production over the last 5 years was 4.4 million tons per year; average annual production over the life of the mine was 4.3 million tons per year. Officials of TransAlta Centralia are planning to increase 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 in 2001 at the Centralia Mine came from 4 open pits. Coalbeds mined were the Upper and Lower Thompson, the Big Dirty and Little Dirty seams, and the Smith seam. These coalbeds are part of the Skookumchuck Formation, which is composed 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 15th full year of production in 2001. The mine was essentially idle last year, producing a mere 250 short tons of bituminous coal, down 350 tons from its production in 2000. PCCC has suffered economically due to a large landslide in the mine in January 1997, which 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.

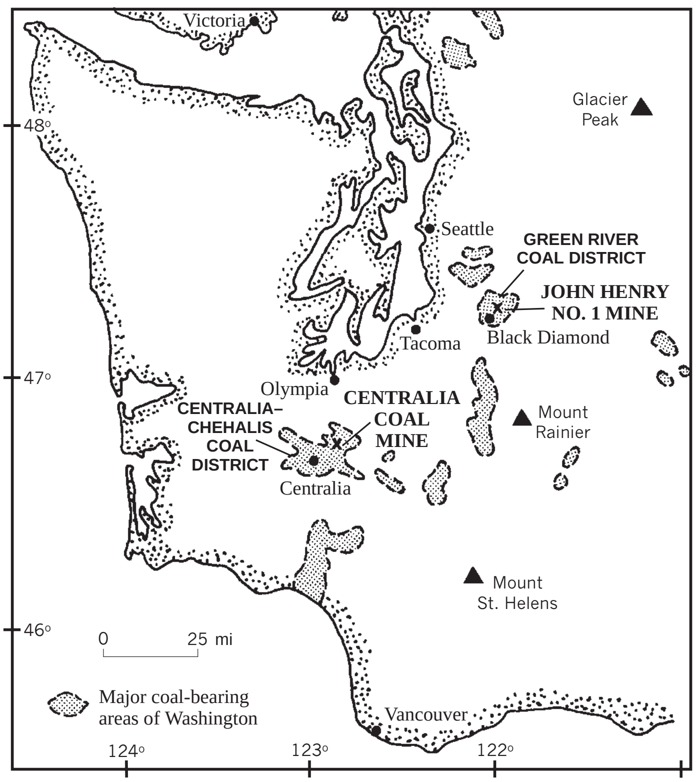

Figure 1. Coal-producing areas and districts of western Washington.

PCCC's production in 2001 went to supplying a new market, which is coal used as a filter medium for large industrial and municipal water filtration systems. Although the new market is currently small, PCCC is hopeful that it will continue to grow. Mine officials are looking for market conditions to improve over the next 3 to 4 years.

The coal mined at the John Henry No. 1 mine comes from the Franklin coal series. The Franklin coalbeds are stratigraphically near the base of the undivided Eocene Puget Group in nonmarine deltaic sedimentary rocks. ■

Pre-Late Wisconsinan Glacial Outburst Floods in Southeastern Washington—The Indirect Record

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ABSTRACT

The late Pleistocene Missoula floods left behind a variety of distinctive erosional and depositional features, including the Channeled Scabland of east-central Washington and the Touchet Beds (pronounced *too′-she*) of southeastern Washington (Fig. 1). A growing body of evidence suggests that there were earlier periods of catastrophic glacial outburst flooding that left equally distinctive imprints on southeastern Washington. Unconformity-bounded sequences of sediment exposed in the Walla Walla Valley and surrounding area, comprising graded, rhythmically deposited beds, clasts of exotic (non-basalt) lithology, and unconformity-truncated clastic dikes, indicate at least three flood episodes that pre-date the latest Pleistocene floods. Reversed magnetism in one of the units suggests that two of these events occurred either during the Matuyama Reverse Polarity Chron, prior to 780 ka, or during a reverse excursion (cryptochron) between 493 and 504 ka. The record of earlier catastrophic outburst flooding raises the likelihood that erosional features to the north (that is, the Channeled Scabland) have a long history of development and that the record of catastrophic outburst flooding in the Columbia Basin region is much more complex than even J Harlan Bretz imagined.

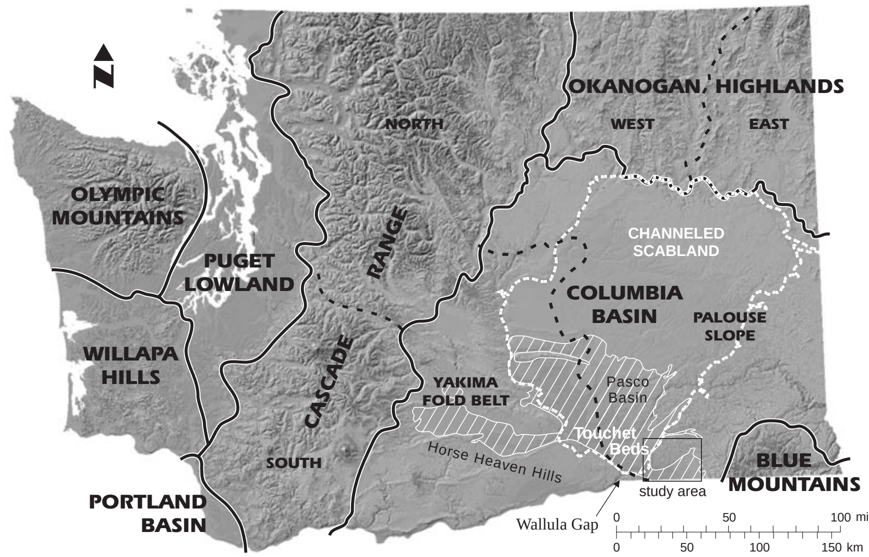

Figure 1. Relief map of Washington showing major physiographic provinces, extent of the Channeled Scabland and Touchet Beds (white lines), and location of the study area. Wallula Gap, the only outlet for water entering the Columbia Basin, is shown by an arrow.

INTRODUCTION

The late Wisconsinan (ca. 15.3–12.7 ka) Missoula floods have been extensively studied (Bretz, 1923, 1925, 1929, 1930, 1959 1969; Waitt, 1980, 1984, 1985; Spencer, 1989; Bjornstad, 1980; Atwater, 1984; Smith, 1993, to name a few). Although no consensus has been reached, the prevailing opinion is that within the latest Wisconsinan flood cycle there were as many as 40 to 70 individual catastrophic outburst floods, separated in time by decades-long periods of exposure (Waitt, 1980; Spencer, 1989; Atwater, 1984; Smith, 1993; Bunker, 1982). These floods originated at an ice dam on the Clark Fork River in western Montana. Shaw and others (1999) proposed that a subglacial lake in British Columbia may also have contributed to late Pleistocene catastrophic outburst flooding.

Several workers have addressed the possibility that similar outburst flooding occurred periodically throughout the Pleistocene. Patton and Baker (1978) discussed several exposures of pre-late Wisconsinan gravel that they interpreted to represent earlier flood events. McDonald and Busacca (1988) found unconformities in the Channeled Scabland (Fig. 1) that indicate as many as six pre-late Wisconsinan floods, one of which occurred during a period of reversed polarity. The ages of these events were constrained by tephra associated with the unconformities. Bjornstad (1980) interpreted sediments west of Touchet in the Walla Walla Valley (Cummins bridge and Reese coulee, Fig. 2) as representing one or more of these events.

More recently, Vrooman and Spencer (1990), Robertson and Spencer (1993), Gilk and Spencer (1999), and Jaffee and Spencer (2000) interpreted Bjornstad's sites, as well as others discovered in southeastern Washington and northeastern Oregon, as direct and indirect records of earlier glacial outburst flood events. In the Pasco Basin to the west of our study area (Fig. 1), Bjornstad and others (2001) documented earlier flood events in gravel bars preserved in the main path of floodwaters. Surface and subsurface data show at least three flood sequences preserved there. This paper examines the stratigraphic and sedimentologic characteristics of seven sites preserved in areas of slackwater deposition of the Missoula floods. Their record indicates three pre-late Wisconsinan events.

SEDIMENTOLOGIC FEATURES OF THE MISSOULA FLOODS

The late Wisconsinan Touchet Beds are slackwater deposits laid down during the latest Pleistocene flood sequence. They are widely exposed in the Walla Walla Valley, Pasco Basin, and nearby areas where floodwaters ponded against the Horse Heaven Hills (Fig. 1), and display unique and distinctive sedimentologic features related to flood dynamics and late-stage flood processes. The Touchet Beds are bounded at the top and base by unconformities (U-1 and U-2, Fig. 3).

Graded Beds

Most rhythmites in the Touchet Beds are normally graded, ranging in thickness from 0.3 to 1 m. In Burlingame ravine (Fig. 2 and cover) as many as 40 graded beds are exposed, each one differing from others principally in thickness. These were deposited as floodwaters backed up against the Horse Heaven

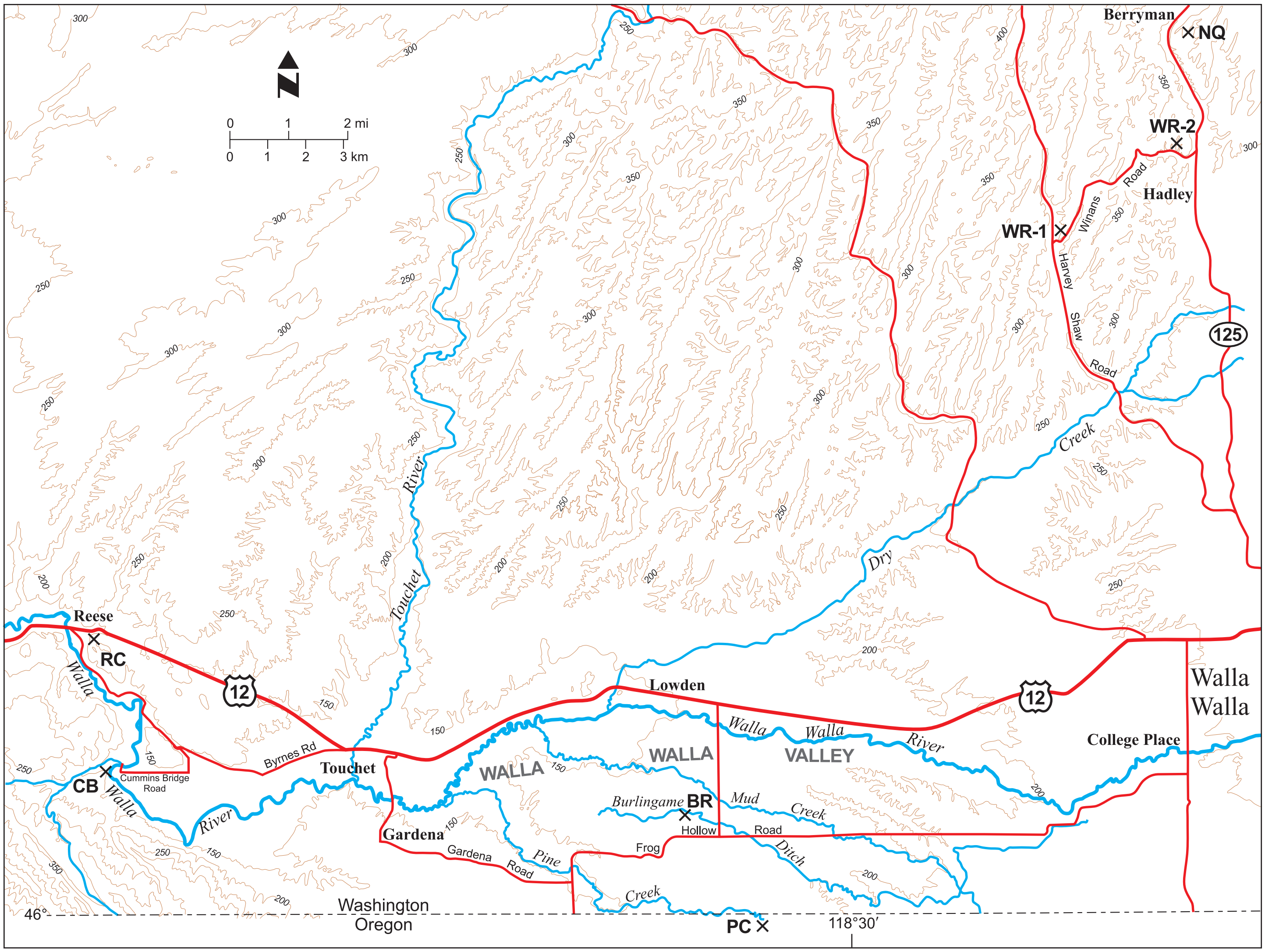

Figure 2. Map of the Walla Walla Valley and surrounding area. Pre-late Pleistocene flood localities: BR: Burlingame ravine; CB: Cummins bridge; NQ: Noble quarry; PC Pine Creek; RC: Reese coulee; WR-1,2: Winans Road. Location of study area shown on Figure 1.

Hills at Wallula Gap (Fig. 1) and flooded tributary valleys, dropping a coarse and then a fine sediment load. The coarse fraction of individual beds contains a significant quartz component, indicating an extra-basinal source.

Many of the rhythmites are capped by massive, fine- to medium-grained sediment (loess?) interpreted by Waitt (1980) as eolian. In tributary valleys (such as the Touchet River valley), which are more constricted and have a steeper gradient, the graded rhythmites are not well-developed and bedding is more irregular (Spencer, 1989).

Exotic Clasts

Exotic (non-basalt) clasts of pebble to boulder size can be found within the Touchet Beds and upon the modern topographic surface. These clasts are associated with sediment that is orders of magnitude finer (Fig. 4), suggesting an unusual mode of transport. Fecht and Tallman (1978) suggested the clasts were derived from stranded clast-rich icebergs left behind after flood events.

Clastic Dikes

The Touchet Beds contain abundant clastic dikes (cover and Fig. 5). Early workers proposed a variety of different mechanisms for dike emplacement, ranging from permafrost to filling of dessication cracks and from downward to upward injection (Jenkins, 1925; Lupher, 1944; Newcomb, 1962; Alwin and Scott, 1970). Recent work by Cooley and others (1996) and Neill and others (1997) suggests that the dikes were injected downward at or near the end of the most recent flood cycle and may have been the result of a combination of standing water in the valleys, seismic shock, and lateral spreading of poorly consolidated flood deposits.

Unconformities

The Touchet Beds are bounded by unconformities resulting from erosion by pre- and post-flood processes, as well as the flood itself. The basal unconformity truncates earlier flood sediments and non-flood deposits of varying age and lithology (for example, the Pliocene Ringold Formation and the Miocene Columbia River Basalt Group).

If there were glacial outburst floods pre-dating the late Wisconsinan Missoula floods, they would likely exhibit some combination of the depositional and erosional characteristics of the Missoula flood deposits.

Physiographic features in southeastern Washington, especially the Horse Heaven Hills, the Blue Mountains, and Wallula Gap (Fig. 1), dictate that if there were earlier episodes of flooding:

- Slackwater deposits would form in the same areas as did later flood deposits.
- Preserved outcrops of older flood sequences, if present, would be scattered as a result of burial and post-flood erosion.
- Earlier flood sequences should be bounded by unconformities.
- A variety of factors, including bioturbation, erosion, and mass wasting could obscure stratification.
- Clastic dikes might be widely scattered, but where present should be truncated at the top by erosion.
- Exotic clasts should survive unchanged, but possibly in a different context.

STRATIGRAPHY, SEDIMENTOLOGY, AND TENTATIVE CORRELATION OF STUDY SITES

Seven sites were studied for this report, each of which preserves sediment sequences displaying one or more of the features common in Missoula flood deposits. The following discussion details the stratigraphy and sedimentologic features of each site. Particular emphasis is placed on features similar to those found in the Touchet Beds, which may suggest outburst flood events. In the following discussion, unconformities are keyed by number to those shown on Figures 3 and 6. The seven sites are: Pine Creek (PC), Reese coulee (RC), Burlingame ravine (BR), Cummins bridge (CB), Winans Road I and II (WR-1,2), and Noble quarry (NQ). (See Fig. 2 for site locations, Fig. 3 for regional stratigraphic relationships, and Fig. 6 for proposed correlations.) Burlingame ravine and Cummins bridge are ‘centerpiece’ sites that show the range of variability, complexity, and completeness of the record.

Pine Creek

This site was first documented by Jaffee and Spencer (2000). An exotic-bearing diamict is exposed at the base of the section. Clasts are as much as 12 cm in diameter and include granitic and metamorphic lithologies. A clastic dike cuts the diamict and is truncated at the top (unconformity 3). Atop the diamict is a lens of exotic gravel, suggesting reworking of the upper portion of the diamict after its emplacement. A thin (2 m) interval of weakly stratified, sand-silt-clay rhythmites containing an upper zone of oxidized root casts unconformably overlies the diamict. This unit is truncated by unconformity 2 and is overlain by sand-silt rhythmites (Touchet Beds), which are in turn overlain by about 0.5 to 1 m of loess.

The deposits at the Pine Creek site probably represent three flood sequences. The youngest is the Missoula flood sequence (Touchet Beds). Unconformably underlying it are the weakly stratified, sand-silt-clay rhythmites, bounded by unconformities (U-2 and U-3, Figs. 3, 6), which represent an older flood episode. The oldest flood sequence is the exotic-bearing diamict. The lower boundary of the oldest flood sequence is not exposed at this locality.

The diamict was likely emplaced by liquefaction and mass-wasting of primary flood deposits (see Reese coulee below). The clastic dike was probably emplaced during the liquefaction event and truncated by the unconformity that marks the upper boundary of the diamict (U-3).

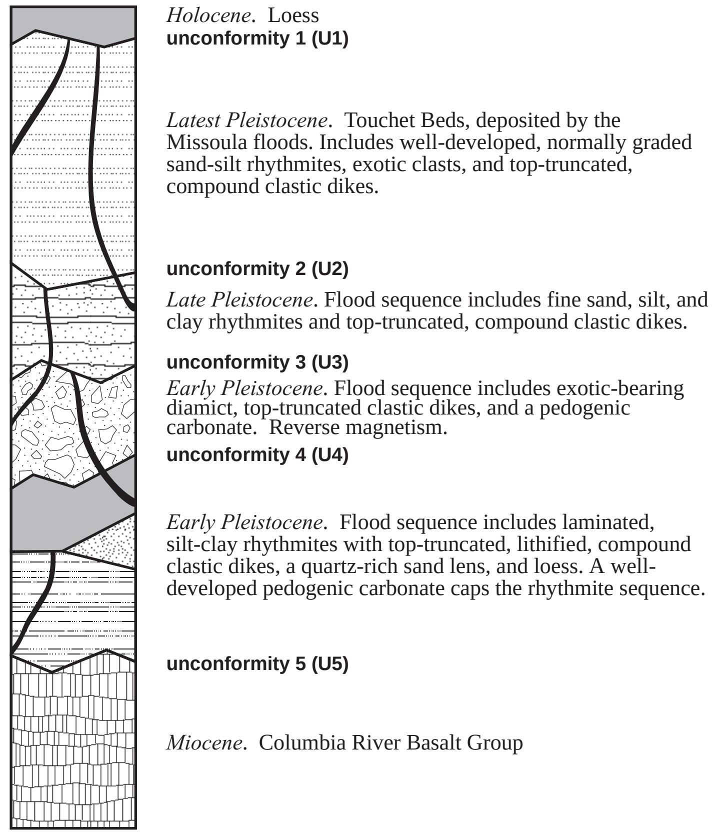

Figure 3. Regional stratigraphic relations of catastrophic outburst flood deposits. Five major unconformities are recognized, delineating four outburst-flood episodes. See Figure 6 for explanation of rock units.

Reese Coulee

Stratigraphic and sedimentologic relationships were documented for this site by Vrooman and Spencer (1990). Bjornstad (1980) and Bjornstad and others (2001) mention this site briefly. The basal unit of Columbia River basalt is unconformably (U-4,5) overlain by an exotic-bearing diamict containing a caliche horizon. Clasts within the diamict have granitic and metamorphic lithologies (Fig. 4). The diamict is cut by clastic dikes that are truncated along an erosional surface at the top (U-3). We correlate this unit with the diamicts at Pine Creek and Cummins bridge. Above the diamict is a sequence of 6 to 8 cyclically deposited silt-over-colluvium packets, each of which is capped by a caliche. Typical Touchet Beds unconformably (U-2) overlie these cyclic sediment packets.

Kevin Pogue (Whitman College, oral commun., 2001) obtained a reversed magnetic signature for the diamict at this site. This raises two possibilities for its age. First, it may have been deposited during the Matuyama Chron, prior to 780 ka. However, this requires that unconformity 3 (U-3, Figs. 3, 6) represent a significant interval of time, and we do not have any absolute age control on the time represented.

The second possibility is that the diamict was deposited during a Brunhes Chron reverse excursion. Such an excursion occurred between 493 and 504 ka and is referred to by Cande and Kent (1992) as the C1n-1 cryptochron. This age is more consistent with relative age estimates for the diamict based on the number and stage of development of caliche horizons in the colluvium as suggested by Vrooman and Spencer (1990).

Vrooman and Spencer (1990) believed that this site represents two outburst flood events—the youngest recorded by the Touchet Beds, and the older event by the diamict near the base of the section. They interpreted the diamict as flood-deposited sediments that were reworked as debris flows, which developed concurrently with dike emplacement. They interpreted the overlying caliche-capped sediment packets as cyclical, climatically driven periods of colluviation, loess deposition, and stability.

Figure 4. Granitic clast in diamict of the Reese coulee section. Note the size disparity of the clast and the enclosing sediment.

Burlingame Ravine

Waitt (1980) documented the stratigraphic and sedimentologic characteristics of this site. Recent work by Jaffee and Spencer (2000) revealed a previously unrecognized, poorly exposed unit at the base of the sequence. This 1 m thick unit consists of thin, sand-silt-clay rhythmites, only a few of which are exposed. The unit is cut by two generations of clastic dikes. The older dikes are sandy and truncated along an erosional surface (U-2). Overlying the basal unit is a thick sequence of about 40 sand-silt rhythmites (Touchet Beds) with clastic dikes that extend downward into the basal unit.

The lowermost unit in Burlingame ravine displays rhythmic bedding similar to that preserved in the overlying Touchet Beds. In addition, clastic dikes truncated along an erosional surface beneath the Touchet Beds were probably emplaced by processes similar to those in the Touchet Beds. The dikes are made up of a mixture of basalt sand and an abundance of quartz grains, indicating an extra-basinal source. Based on overall similarity in sedimentologic characteristics and stratigraphic position, we believe that this lower unit correlates with the stratified sediments below the Touchet Beds at the Pine Creek and Cummins bridge sites. The Burlingame ravine section preserves two outburst flood sequences. The younger is represented by the Touchet Beds and the older by the stratified sediments underlying the Touchet Beds.

Figure 5. Close-up of a compound clastic dike in the Touchet Beds. Dikes in earlier flood sequences strongly resemble these dikes.

Cummins Bridge

The stratigraphy at this site was documented by Bjornstad (1980) and Robertson and Spencer (1993), who found Touchet Beds overlying a sequence of massive and stratified sediment bearing exotic clasts; however, we interpret the sedimentology slightly differently. The lowermost exposures at Cummins bridge consist of an exotic-bearing diamict with granitic and metamorphic clasts as much as 10 cm in diameter. Well-developed caliche horizons occur within and on top of the diamict. The upper caliche is overlain by a thick (~10 m) sequence of weakly stratified, sand-silt-clay rhythmites ranging in thickness from 0.4 to 1 m and diminishing in thickness upwards. Clastic dikes cut this sequence, which is unconformably overlain by sand-silt rhythmites (Touchet Beds).

The Cummins bridge site records three flood sequences. The youngest is the Missoula floods, represented by the Touchet Beds. The next oldest event is represented by the weakly stratified, sand-silt-clay rhythmites beneath the Touchet Beds and bounded by unconformities 2 and 3 (Fig. 6). The oldest flood sequence is represented by the exotic-bearing diamict. Based on similarity in sedimentologic characteristics and stratigraphic position, we correlate the diamict and overlying weakly stratified sediments with similar intervals at Pine Creek.

Winans Road I

Details of the stratigraphy and sedimentology at this site were documented by Gilk and Spencer (1999). The lowermost unit is

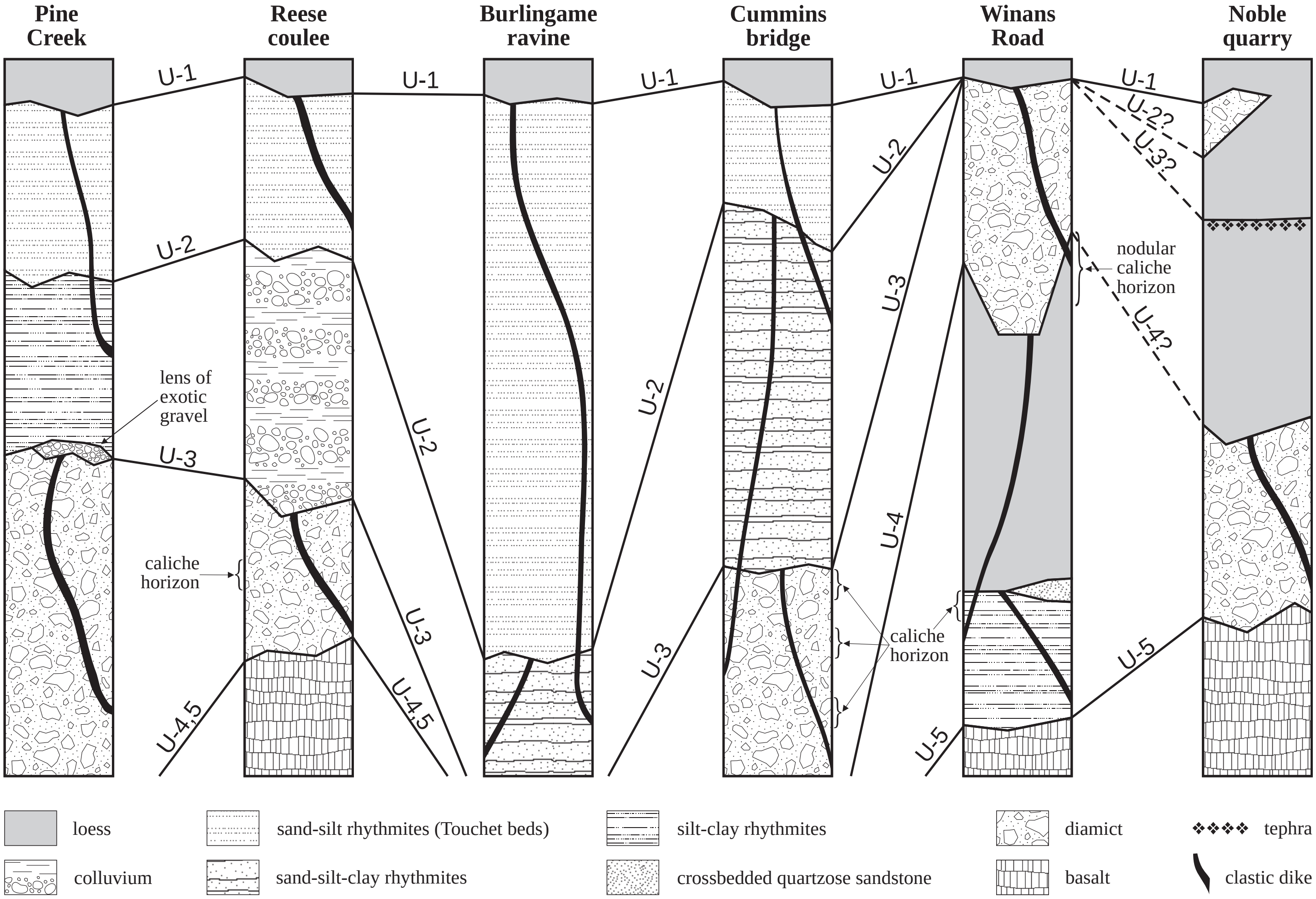

Figure 6. Correlation chart of stratigraphic sections studied for this report. Correlations are based on similarities in stratigraphic sequence, exotic-clast lithologies, and truncated clastic dikes. Pleistocene outburst flood sequences are separated by major unconformities (U-1, U-2, etc.).

Columbia River basalt, which is overlain by a complex association of sediments including caliche soils, quartz-rich sands, apparent wind-blown silts, and a diamict. Three generations of clastic dikes are also present.

At the base of the section, weathered, rounded basalt clasts rest upon fractured basalt. About 1.5 m of fine-grained, thinly stratified silt-clay rhythmites overlie the basalt. This unit is cut by lithified, compound clastic dikes that terminate at the base of a caliche. Overlying the lower beds is a discontinuous, 0.5 m thick bed of quartz-mica sand. Above the sandy interval is a sequence of about 2 m of silt (loess) capped by a well-developed caliche.

The second caliche is cut by an unconformity (U-4), above which is a diamict containing basaltic, granitic, and metamorphic clasts as much as 15 cm in diameter. At this site, U-4, a concave-upward surface resembling a channel is cut into the loess. From within the diamict, we recovered an argillaceous clast with faceted, striated surfaces that suggest the clast was at some time transported at the base of a glacier. The association of large exotic clasts and fine-grained sediment may indicate ice-rafting as a mechanism for bringing clasts into the region. Post-depositional mass-wasting of primary flood deposits likely generated the channelized diamict.

A second generation of clastic dikes originates at the base of the diamict-filled channel, where they are abruptly truncated. The dikes extend downward into the lowest interval of the sedimentary sequence—the fine-grained, thinly stratified sediment. The relationship between the dikes and the basalt surface at the base of the section cannot be observed at this locality. The section is capped by a thin bed of Holocene loess.

We agree with Gilk and Spencer's (1999) interpretation that the deposits record two pre-late Wisconsinan outburst flood events. The younger event is recorded by the diamict, which, based on similarity in clast composition and stratigraphic position, we correlate with the diamicts at Pine Creek, Cummins bridge, and Reese coulee. The older flood event is represented by the weakly stratified basal unit containing lithified clastic dikes. We have found no other unit in the region showing the stratigraphic and sedimentologic characteristics of this interval. The youngest outburst flood event, represented by the Touchet Beds, is not preserved at this locality.

Winans Road II

This site was first studied by Jaffee and Spencer (2000). The basal unit at this site is Columbia River basalt. Overlying the bedrock is an interval of weakly stratified, silt-clay rhythmites capped by a well-developed caliche horizon. Clastic dikes are present in this interval and appear to terminate at the base of the caliche. Above the caliche is an interval of sand and silt (loess) capped by a nodular caliche. This caliche is overlain by a diamict containing clasts of basalt, quartz, and mafic intrusive rock as much as 2 cm in diameter. The diamict also contains a clastic dike that penetrates the underlying nodular caliche.

The Winans Road II site is only a few kilometers east of the Winans Road I site. Based on the overall similarity of the two sites, we think that the Winans II diamict represents a distal portion of the diamict exposed at Winans I. For simplicity, both Winans Road sites are treated as one on Figure 6.

Noble Quarry

Recently investigated in conjunction with reconnaissance studies of the region (Mullin and Spencer, unpub. data), this site preserves a thick sequence of sediments of diverse character. At the base of the section, and overlying the Columbia River basalt along an erosional surface (U-5), is about 2 m of poorly sorted, exotic-bearing sediment riddled with caliche and containing truncated clastic dikes. This unit is overlain unconformably (U-4?) by fine-grained sediment that displays few sedimentary structures (probably loess), but which contains a tephra. Tephra geochemistry (Nick Foit, Washington State Univ., written commun., 2000) indicates a match with the Paoha Island tephras from Mono Lake, California (ca. 161,000 yr B.P.). The tephra is truncated by an erosional surface (U-3?), which is overlain by another fine-grained, structureless sediment sequence. At the top of the section is a second exotic-bearing diamict with an erosional base. Within the Noble quarry section there are five unconformities (Fig. 6).

Correlation of the Noble quarry diamicts with others in our study area is difficult. Lithologically, the diamicts are similar to those at the Pine Creek, Reese coulee, Cummins bridge, and Winans Road sites. However, the upper diamict at Noble quarry sits above the tephra tentatively identified as that from Paoha Island (161 ka), thus the diamict was deposited within the Brunhes Normal Polarity Chron and well after the reverse excursion (cryptochron C1n-1 of Cande and Kent, 1992) and is younger than the diamicts at other sites.

The lower diamict at the Noble quarry site occurs in a stratigraphic sequence that is similar to that observed at Reese coulee. Field magnetometer data suggests that the lower diamict is reversely magnetized. If so, it might correlate with the Reese coulee diamict.

The two Noble quarry diamicts are clearly of different ages as seen by their stratigraphic separation. Placement of the Noble quarry site into the framework established herein awaits further clarification of field relationships and discovery of other, similar sites. However, the presence of truncated clastic dikes and exotic clasts in the lower part of the section suggests similarity to other units in the region in terms of process.

CORRELATION

The seven stratigraphic sections studied for this report are tentatively correlated on the basis of three primary criteria—unconformities, stratigraphic sequence, and sedimentologic features.

Unconformities

We recognize five major unconformities in the sections under study. The unconformities bound units containing sedimentologic features that suggest catastrophic flood origin. These features include large clasts of exotic lithology, rhythmically graded fine and coarse sediment packets, and clastic dikes with truncated tops.

As shown on Figures 3 and 6, the unconformities help to delineate several generations of clastic dikes. Each generation is associated with sediments representing a flood sequence and is truncated by the next younger flood sequence.

Stratigraphic Sequence

Not all outcrops under study display all of the unconformity-bounded units shown on Figure 3. However, in outcrops displaying more than one unit, the stratigraphic sequence is the same. Within unconformity-bounded units, sedimentologic characteristics are consistent from outcrop to outcrop.

Sedimentologic Features

In our correlations, we also compared lithologies contained in the diamicts exposed between unconformities 3 and 4 in the Pine Creek, Reese coulee, Cummins bridge, and both Winans Road sites. These contain clasts of variable composition, including felsic and mafic intrusive, metamorphic, and metasedimentary lithologies. While the sites vary in what proportions of these lithologies occur, they are unified in that all non-basalt clasts have an extra-basinal source. In addition, quartzite resembling that exposed in the Belt Supergroup of northern Idaho and western Montana is present in all diamicts. In the late Pleistocene Touchet Beds, exotic clasts are generally interpreted to have been rafted into the area within ice bergs (Fecht and Tallman, 1978). Given the size disparity between the host sediment and the exotic clasts, such an origin seems reasonable for these clasts as well.

One final sedimentologic feature is worth mentioning. In the Winans Road I section, just above the silt-clay rhythmites and occupying the same stratigraphic position as the caliche in which the lithified dikes terminate is a lenticular accumulation of medium to coarse sand. The sand is cross-stratified, oxidized, and contains clasts of quartz, feldspar, and mica. The unit is unique to this section; indeed, such a unit at this stratigraphic position is unknown in southeastern Washington. The significance of the unit is speculative at this point. However, the sandy material certainly has an extra-basinal source, possibly derived from the Columbia River (Richard Waitt, U.S. Geological Survey, oral commun., 2001), and may be a result of re-working of older flood sediments.

DISCUSSION

The well-known history of the late Pleistocene Missoula floods begs the question: “Why couldn’t similar processes have operated throughout the Pleistocene, as long as there was glacial ice disrupting drainage patterns at the ice-margin?” Previous workers (Patton and Baker, 1978; McDonald and Busacca, 1988) addressed this question and found both erosional and depositional evidence in the Channeled Scabland.

If such processes occurred, they should have generated flood sequences similar to, but distinguishable from, the late Pleistocene deposits. The flood sequences should be widespread in areas where floodwaters backed up against an obstruction, as the Missoula floods did against the Horse Heaven Hills at Wallula Gap (Fig. 1), but should be spottily preserved, as a result of erosion and reworking before and during the Missoula floods, or hidden beneath younger deposits.

The magnitude of erosion of the coulees in the Channeled Scabland north of the Walla Walla Valley argues for a much longer erosional history than merely the late Pleistocene Missoula floods, as was pointed out by Patton and Baker (1978). This may include prior development as fluvial valleys and subsequent modification by catastrophic outburst floods over the course of the middle to late Pleistocene. Earlier catastrophic outburst flood events may have played an important role in the physiographic development of the Channeled Scabland.

The scenario of deposition of flood sediments bearing exotic clasts, subsequent reworking of those deposits as debris flows, and emplacement of clastic dikes generated by seismic shocks, is consistent with current thinking regarding the origin of late Pleistocene Missoula flood sediments (Cooley and others, 1996; Neill and others, 1997). The general stratigraphic relationships of the diamicts, the weakly stratified sediments, and clastic dikes below the Missoula flood deposits argue for multiple episodes of flooding, seismicity, dike emplacement, and post-flood erosion, all prior to the late Pleistocene Missoula floods.

We propose three pre-late Pleistocene flood sequences (Table 1). The oldest of these is represented by the stratified, lithified-dike-bearing sediment in the Winans Road section between unconformities 4 and 5. A second, younger event is recorded in the diamicts occurring between unconformities 3 and 4 in the Pine Creek, Reese coulee, Cummins bridge, and Winans Road sections (and pending further clarification of field relationships, the Noble quarry section). A third event is recorded between unconformities 2 and 3 in the Pine Creek, Burlingame ravine, and Cummins bridge sections. This flood history culminates in the well-known late-Pleistocene Missoula floods, represented by the Touchet Beds lying between unconformities 1 and 2.

Table 1. Chronologic summary of catastrophic outburst flood events in the Walla Walla Valley area

1. **Early flood event** deposits stratified sediment at Winans Road sites. Possible seismic event results in clastic dike injection, followed by deposition of quartz-rich sand and loess. Age of event uncertain, probably deposited during the Matuyama Reversed Polarity Chron.
2. **Second flood event** deposits exotic-bearing sediment at Pine Creek, Reese coulee, Cummins bridge, and Winans Road sites. Possible seismic event causes liquefaction of flood sediment and deposition as mudflows, accompanied by clastic dike injection. Age uncertain; reverse magnetism at Reese coulee suggests deposition during the Matuyama Reversed Polarity Chron or a reverse excursion within the Brunhes Normal Chron.
3. **Long period of colluviation** punctuated by formation of caliche soils at Reese coulee site.
4. **Third flood event** deposits thinly stratified rhythmites at Pine Creek, Burlingame ravine, and Cummins bridge sites. Age uncertain; deposit unconformable beneath late Wisconsinan Touchet Beds. Possible seismic event results in clastic dike injection.
5. **Fourth flood event** culminates outburst flood history of eastern Washington with widespread deposition of late Wisconsinan Touchet bed slackwater sediments. Age of final event provided by Mount St. Helens set S tephra (~13,000 ka) near top of section. Possible seismic event results in clastic dike injection.

ACKNOWLEDGMENTS

We would like to thank Bob Carson, Kevin Pogue, and John Winter of the Whitman College Geology Department for numerous and informative discussions and field trips, all of which helped clarify the regional geologic picture. Bob Carson and Judy Zachariason thoughtfully reviewed an early draft of this report. Thanks to Dr. Richard Waitt of the U.S. Geological Survey for his insights and observations in the field and to Nick Foit of the Washington State University Geology Department for the tephra analysis. From the Washington Division of Geology and Earth Resources, we thank Pat Pringle, Tim Walsh, and Karen Meyers for their critical review and comments and Jari Roloff for editing and help with the figures. Finally, we wish to acknowledge the Rall Summer Science Support Program and the Sally Ann Abshire Research Scholar program of Whitman College for generous financial support. Amanda Werner, Jamie Robertson, Sara Gilk, and Tim Mullin contributed by their participation in field excursions to, and analysis of, the various sites detailed in this report.

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New Aerial Photos of Northwestern Washington Available

Two new aerial photo projects are now available for purchase: (1) Low-altitude color photos of parts of the Puget Lowland taken in 2001 (Project NW-C-01), and (2) medium-altitude black and white photos of the Olympic Peninsula taken in 2000 (Project OL-QT-00).

Project NW-C-01 covers all or a portion of Pierce, King, Snohomish, Skagit, Whatcom, Island, San Juan Counties, excluding some federal lands, at a scale of 1:12,000 (1 in. = 1,000 ft). There is complete stereo coverage over the entire project, making it possible to get a three-dimensional view of the land. Each photo shows an area of approximately one section, or one square mile. The color contact prints measure 9 in. by 9 in.

Project OL-QT-00 covers all of the Olympic Peninsula, including Grays Harbor, Jefferson, Clallam, and Mason Counties and Olympic National Forest and Park. The photos are quarter township-centered at a nominal scale of 1:32,000 (1 in. = ~½ mi). There is complete stereo coverage over the entire project. Each aerial photo covers approximately one-quarter township (9 mi^2). The black-and-white contact prints are 9 in. by 9 in.

These aerial photos were used primarily for the production of orthophoto maps, which are corrected to eliminate displacement caused by terrain relief. Orthophotos are true to scale and often include section lines and some geographic names. Accurate measurements can be taken directly from the orthophoto images. The orthophotos are available in quarter-township format as paper copies at a scale of 1:12,000 (1 in. = 1,000 ft) or digitally in TIFF file format on compact disk.

Full township orthophotos, which cover 36 square miles, are also available digitally as TIFF images on compact disk. They include imagery derived from the photos, but not the geographic reference information available on the paper copies. Digital orthophotos are useful in geographic information systems to underlay digital vector data, such as ownership boundaries, survey data, contours, and transportation routes.

DNR has over 800,000 aerial photos of the state in its archives, some of which date back to the 1960s. The photos are made available to the public for a fee under a mapping and aerial photography cost-recovery program.

DNR invites federal and state agencies, counties, and private companies to participate in new projects that include their areas of interest or ownership. (Call Photo Map Sales at 360-902-1234 for more information.) This Aerial Photo Participation Program allows other groups to share in the flight costs, minimizing duplication of flying efforts and reducing costs to both the DNR and participants. Project NW-C-01 was supported in part by twelve county, private, university, and federal agencies. Project OL-QT-00 was supported in part by cooperation with eight other agencies including the U.S. Forest Service, U.S. Bureau of Reclamation, Jefferson and Grays Harbor counties, the Quinault Indian Nation, and the Makah Tribe.

Aerial photos are $10 each, plus 8% sales tax. Paper orthophotos are $8 each, plus tax. Digital orthophotos are $100 per township, plus tax. Shipping and handling charges are on a per order basis and depend on the size of the order; however, the standard charge is $4.50.

Photos are available from the Department of Natural Resources; Photo and Map Sales; PO Box 47031; Olympia, WA 98504-7031. Mail orders must be prepaid; checks are payable to the Department of Natural Resources. Orders should include the legal description in township, range (east or west) and section. For more information, call (360) 902-1234. Staff can help you locate the proper area and figure the cost for your order.

Photos may also be purchased from DNR's Photo and Map Sales office on the first floor of the Natural Resources Building at 1111 Washington St. SE, in Olympia. Office hours are 8:30 a.m. to 4:30 p.m., Monday through Friday. ■

Diversion of Meltwater from Kautz Glacier Initiates Small Debris Flows near Van Trump Park, Mount Rainier, Washington

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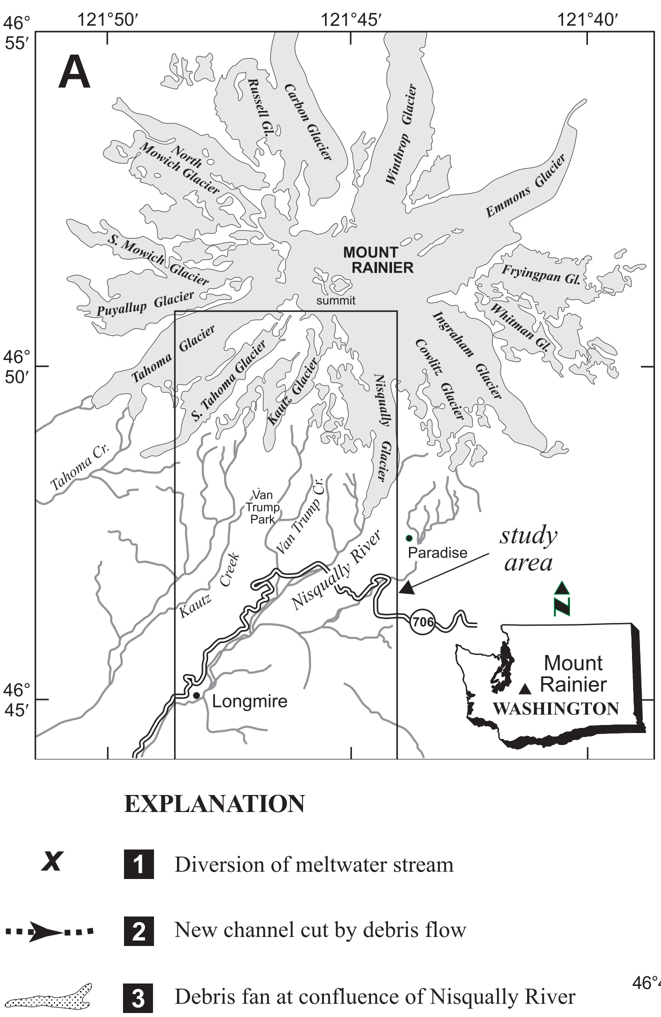
On the evening of August 14, 2001, slumping of loose glacial debris triggered a debris flow on the south slope of Mount Rainier above Van Trump Park. This debris flow swept down Van Trump Creek to its confluence with the Nisqually River (Fig. 1). Rapid melting of upper Kautz Glacier during hot summer weather was instrumental in initiating this debris flow. On August 13, a meltwater stream on the east margin of Kautz Glacier began to spill muddy water into the Van Trump basin through a 2- to 3-m (7–10 ft)-deep notch in the left-lateral moraine at the lower end of Wapowety Cleaver at an



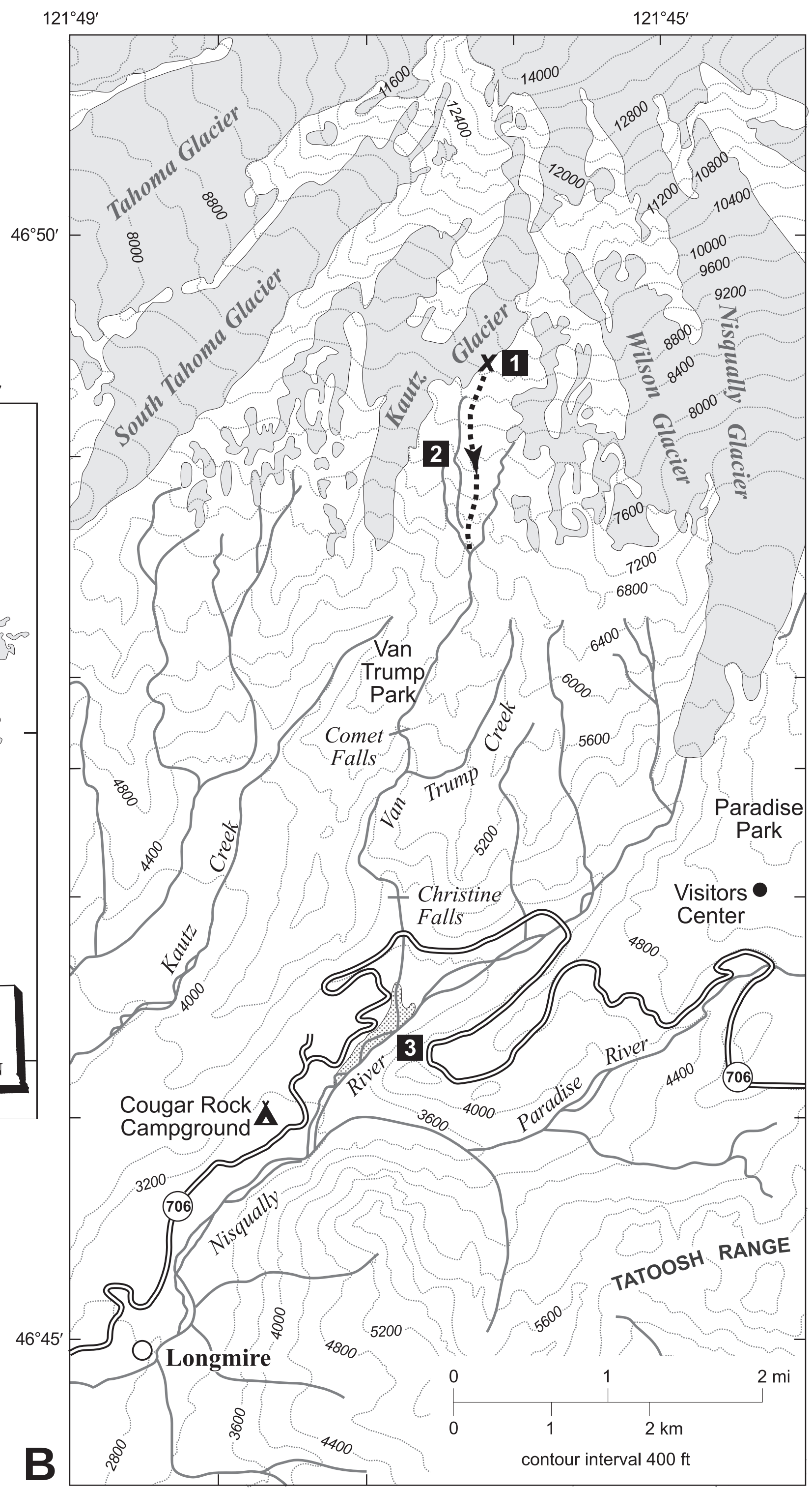


Figure 1. **A.** Map showing location of Mount Rainier and study area. **B.** Map of study area showing diversion of meltwater and path of channel incised during debris-flow events of August 14 and 15, 2001.

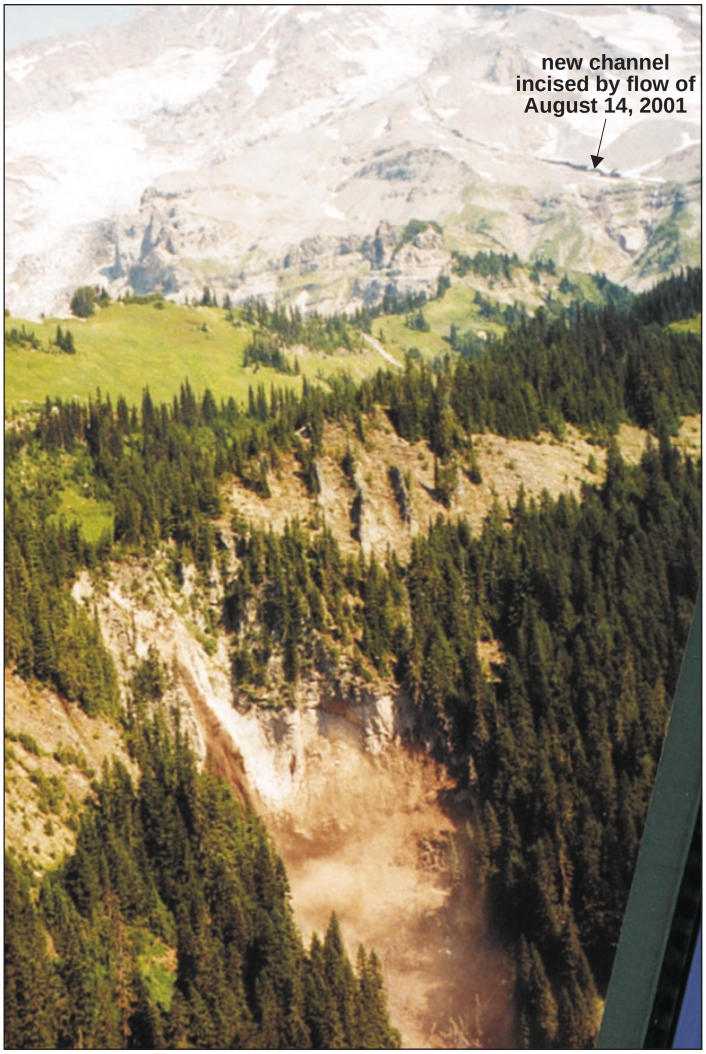


Figure 2. The south side of Mount Rainier, Kautz Glacier (center top and left), upper Van Trump drainage basin (upper center), and Comet Falls (lower left). Note debris flow descending Comet Falls. *Taken August 15, 2001, by C. Driedger.*

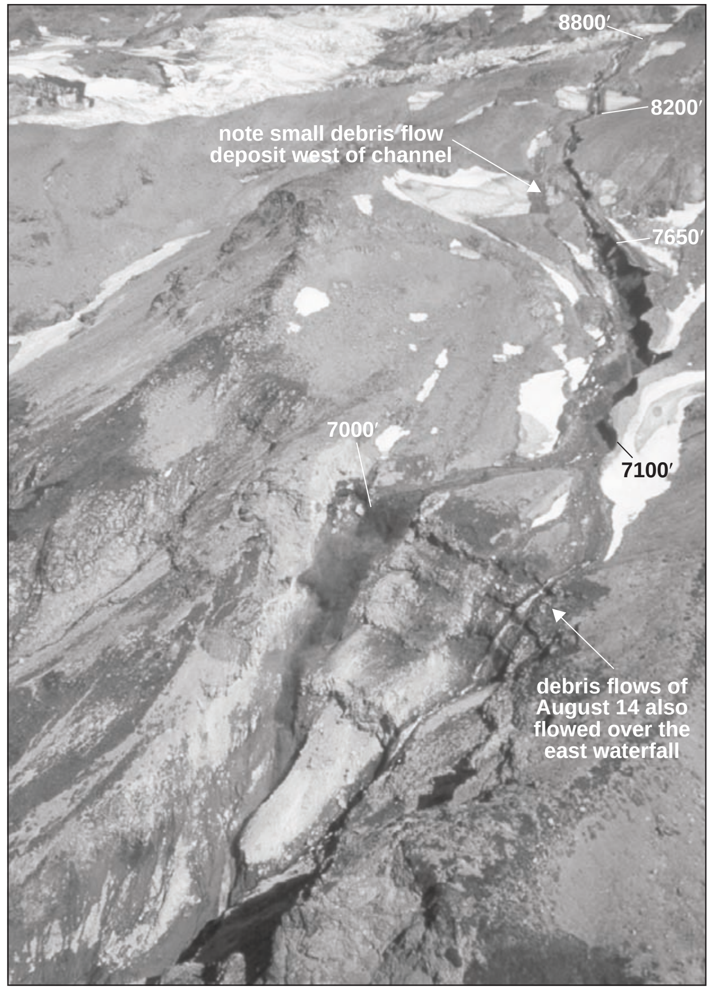


Figure 3. Meltwater diversion, newly incised channel, and debris flow descending waterfall, the top of which is at altitude 2134 m (7000 feet). The larger debris flow of August 14 descended both branches of the waterfall. *Taken August 15, 2001, by J. W. Vallance.*

altitude of about 2682 m (8800 ft)(Figs. 2 and 3). Beginning about 9:00 p.m. on August 14, the flow incised a channel through the 5 to 30 m (16–98 ft) thick ground moraine in Van Trump Park and formed the largest of a series of debris flows. Progressive slumping of the glacial deposits during the next few hours formed additional debris flows and created a steep-walled channel that was visible at first light on August 15 (Figs. 2 and 3).

Field reconnaissance showed that the initial debris source of the August 14 debris flows is a zone between altitudes 2377 m and 2500 m (7800 and 8200 ft)(Fig. 3). The flows eroded and incorporated the bulk of their sediment between altitudes 2164 m and 2662 m (7100 and 7650 ft)(Fig. 3). Along this reach, the new channel is 10 to 30 m (33–98 ft) deep and 25 to 50 m (82–164 ft) wide. The total volume of debris removed from the reach between altitudes 2164 m and 2500 m (7100 and 8200 ft) is about 250,000 m^3 (327,000 yd^3).

Below the unnamed waterfall at 2134 m (7000 ft)(Fig. 3), the debris flow cascaded over smaller falls and through bedrock channels, but it neither removed nor deposited a significant amount of sediment until it neared its confluence with the Nisqually River about 5.5 km (3.4 mi) downstream. There it formed a 1 to 4 m (3.3–13 ft) thick debris fan that extends from a few tenths of a kilometer up Van Trump Creek to over 0.7 km (0.44 mi) downstream in the Nisqually River valley (Fig. 4). The fan varies from 30 to 120 m (98–394 ft) wide and has an approximate volume of 160,000 m^3 (209,280 yd^3). The largest flow, occurring on August 14, maintained coherence as debris flow and continued beyond the Wonderland Trail footbridge near Cougar Rock Campground, 7 km (4.4 mi) downstream of its source. Between 7 and 10 km (4.4–6.2 mi) downstream, at Longmire, the flow gradually lost its coherence as a debris flow and became a muddy sediment-laden flood. The remaining approximately 100,000 m^3 (130,800 yd^3) of debris was emplaced in these reaches above Longmire. The muddy flood at Longmire caused a stage rise of 0.6 to 0.75 m (2–2.5 ft) and continued flowing within the river banks to Alder Reservoir about 47 km (29 mi) downstream.

In the future, heightened meltwater stream flow originating along the east margin of Kautz Glacier may again cause slumping of channel walls in glacial deposits that initiates small debris flows between elevations 2165 m and 2332 m (7100 and 7650 ft). This process is more likely during periods of hot summer weather, but could occur during periods of intense rainfall in fall and early winter, if the freezing level is well above the elevation of the diversion. We expect small debris flows to dis-

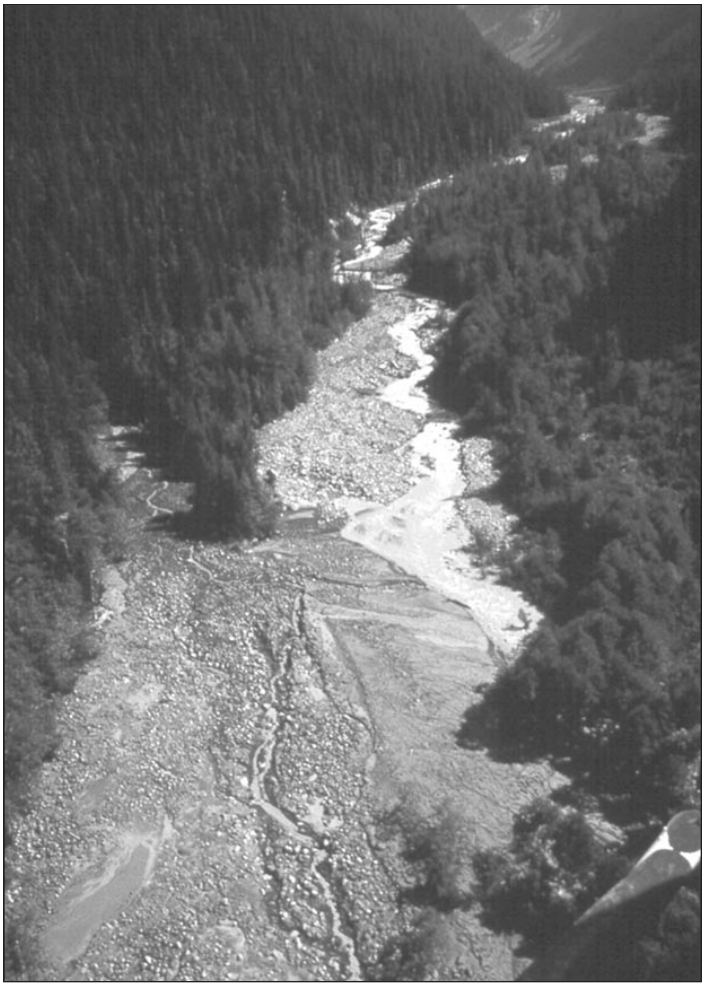


Figure 4. Debris fan formed by debris flow of August 14, 2001, at the confluence of Van Trump Creek *(left)* and the Nisqually River *(upper right to center)*. Fan is 100 to 120 m (328–394 ft) wide and 1 to 4 m (3.3–13 ft) thick in this area. *Taken August 15, 2001, by J. W. Vallance.*

sipate in the region below Comet Falls (Fig. 2). Larger flows could reach the Nisqually River.

The Van Trump debris flows of August 2001 generated considerable public attention, although they were modest in size and areal extent. They were comparable in size and character to many debris flows that occurred in the valleys of South Tahoma, Kautz, Nisqually, and Winthrop glaciers on multiple occasions during the 20th century. All originated with movement of excess meltwater through or across loose glacial rock debris. The meltwater was meteorologically produced; none was derived from volcanism (Walder and Driedger, 1994).

Hydrologic and meteorological events can trigger small debris flows like those at Van Trump Creek at or near glacier margins or termini anywhere in Mount Rainier National Park. Because they are not related to volcanism, such events occur with little, if any, warning and can be a hazard to Park visitors. Nonetheless, because of their size, these small to medium debris flows pose little threat to communities beyond the boundaries of Mount Rainier National Park.

Larger debris flows associated with landslides and eruptions, here termed *lahars* for distinction, can be orders of magnitude larger than the Van Trump debris flows of August 2001. Such lahars often begin with magma intrusion that triggers failure of locally weakened rock masses, or eruptive processes that catastrophically melt snow and ice. Volcanic earthquakes and small explosions precede eruptions that generate lahars (Scott and others, 1995). Only on the west side of Mount Rainier, where there are steep cliffs containing abundant weak altered rock susceptible to avalanching, is there a credible threat of unheralded large lahars.

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Murdock Trust Grant Awarded to Vancouver Teacher and DNR Geologist

The Department of Natural Resources (DNR) has received a $14,000 grant from the M. J. Murdock Charitable Trust to allow high school science teacher Rusty Weaver to carry out research with DNR geologist Pat Pringle over the next two summers.

Weaver, of Heritage High School in Vancouver, Wash., and Pringle, of DNR's Division of Geology and Earth Resources, will conduct research on the Bonneville landslide along Washington's Columbia Gorge. The research project is titled: "Use of dendrochronology for dating and an improved understanding of the Bonneville landslide, Columbia Gorge, Washington."

Known in Native American oral history as "the Bridge of the Gods", the Bonneville landslide dammed the entire Columbia River, formed a temporary lake that later drained, and drowned trees whose remnants were observed and described by explorers Lewis and Clark. The slide, possibly triggered by an earthquake, is estimated to have occurred several centuries ago.

DNR will receive the $14,000 grant from the Partners in Science Program of the Murdock Trust, established by the late Melvin J. (Jack) Murdock of Vancouver, Wash. The program provides high school science teachers with opportunities in cutting-edge science to revitalize their teaching skills and encourage the use of inquiry-based methods in teaching science.

Grants are based on the qualifications of the teacher's scientist mentor, the quality of the scientific research proposed, and the potential school benefits.

Applications are accepted from high school teachers and mentors from five Pacific Northwest states to conduct summer research. The Murdock Trust seeks to strengthen this region's educational and cultural base in creative and sustainable ways by making grants to organizations. ■

DIVISION PUBLICATIONS

Print Publications

Geologic Map of Washington—Northwest Quadrant, Geologic Map GM-50, by Joe D. Dragovich, Robert L. Logan, Henry W. Schasse, Timothy J. Walsh, William S. Lingley, Jr., David K. Norman, Wendy J. Gerstel, Thomas J. Lapen, J. Eric Schuster, and Karen D. Meyers, 3 plates (Plate 1, scale 1:250,000), 76 p. text, 14 figures, 2 tables. $9.20 + .80 tax (Wash. residents only) = $10.00 per copy ($11.12 + .88 = $12.00 for a flat map in a tube).

Roadside Geology of Mount St. Helens National Volcanic Monument and Vicinity, Information Circular 88 [revised edition 2002], by Patrick T. Pringle, 132 p., 70 black and white figures, coated cover. Price not yet available, contact our office for more information.

Geologic Map of Washington, 2002, compiled by J. Eric Schuster. This color 8½ x 14″ plate (scale 1:2,250,000) includes an explanation of 22 time-lithologic units. **The Geology of Washington State**, a summary adapted by Lynn Moses from an article by Raymond Lasmanis, is on the back side, along with a relief map of the physiographic provinces of Washington. *Free*.

Reconnaissance Investigation of Sand, Gravel, and Quarried Bedrock Resources in the Snoqualmie Pass 1:100,000 Quadrangle, Washington, Information Circular 96, by William S. Lingley, Jr., David A. Knoblach, and Celia K. B. Nightingale , 70 p., 5 appendices, 4 figures, 4 tables, and 1 plate, scale 1:100,000. $8.80 + .70 tax (Wash. residents only) = $9.50.

Inactive and Abandoned Mine Lands Inventory—Apex Mine, Money Creek Mining District, King County, Washington, Open File Report 2001-2, by Fritz E. Wolff, Donald T. McKay, Jr., and David K. Norman, 8 p. $.93 + .07 tax (Wash. residents only) = $1.00. [also on the web at http://www.wa.gov/dnr/htdocs/ger/pubs_ol.htm]

New Pricing Effective July 01, 2002

To cover our actual costs for printing and mailing, we have increased the prices of some open file reports (OFRs) and the cost of shipping and handling for all publication orders.

Due to an increase in the cost of reproducing large-format plates (now run on the plotter instead of the ozalid), we must increase the price of many OFRs. These prices supersede those listed in the April 2001 version of our publications list. However, while supplies last, we will continue to charge the old prices for in-stock OFRs that contain plates already produced by the older, less-expensive method. Contact our office for details (see p. 2).

To cover our shipping costs, we have switched from the former flat fee of $1.00 to the cost schedule shown at right. For each additional $20.00 in publication costs over $110.00, add $1.00 in postage and handling. For more information, go to http://www.wa.gov/dnr/htdocs/ger/pubcost.htm.

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Some Division Out-of-Print Items Available

As geological surveys consolidate their holdings, items marked out-of-print in our publications list are often returned to the Division. These will be made available on a first come, first served basis to folks who request them. Availability changes daily, so we cannot post titles on the web. If you are looking for a particular item, call (360) 902-1450 or e-mail geology@wadnr.gov to see if we have it. The item itself will be free, but we will ask you to pay shipping.

Mineral Industry *(Continued from p. 8)*

ment for Hardiboard. They also shipped 20,000 tons to the Lafarge cement plant in Seattle for cement manufacture.

INDUSTRIAL MINERALS

The construction and paving industries are the principal consumers of industrial minerals. Most large operations for sand and gravel in the state are near heavily populated areas where the need for aggregate is greatest. As urban and suburban development spreads in Washington, potential sources of aggregate are being covered by roads and buildings. New operations are prohibited because of the proximity to housing. The result is that aggregate is being trucked in from remote sites to the construction areas where it is needed. Increasing transportation costs can rapidly increase the cost of gravel.

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WE CAN NOW PRINT ON DEMAND

We have just finished converting our open-file reports to an electronic format so that we will be able to print on demand. One of the big problems in our way, in addition to finding time to scan the texts, has been that the maps were on mylar (heavy clear plastic) and had to be reproduced on the ozalid machine, a technology that uses ammonia to develop a blueprint-like product. In addition to being environmentally hazardous (an ammonia leak cleared the building a couple of years ago), the ozalid machine is just about defunct.

Earlier this year, we sent 439 mylars of maps out to be scanned into TIFF files and saved on compact disks. This summer, we hired Colin Wright, computer guru extraordinaire, to take the scanned files from the original CDs, convert them from TIFFs to PDFs (Adobe Acrobat portable document files), scan the text, and save all the parts of each open-file report on a fresh CD. Now we have the capability to plot out the OFR maps and print the texts, and we don't have to rely on aging (and dying) technology. We hope to make the entire OFR map series available on CD soon for those who have access to a plotter.

Colin Wright is a 2002 graduate of Capital High School in Olympia and has successfully completed the Microsoft Office User Specialist (MOUS) Certification course, earning 21 college credits.