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Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

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MAIN OFFICE
Department of Natural Resources
Division of Geology
and Earth Resources
PO Box 47007
Olympia, WA 98504-7007

Phone: (360) 902-1450
Fax: (360) 902-1785
Internet:
cjmanson@u.washington.edu
rcgg490@wadnr.gov

(See map on inside back cover for office location.)

FIELD OFFICE
Department of Natural Resources
Division of Geology
and Earth Resources
904 W. Riverside, Room 209
Spokane, WA 99201-1011

Phone: (509) 456-3255
Fax: (509) 456-6115

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Cover Photo: The magnesium metal-producing operation of Northwest Alloys Inc. at Addy. Part of this facility formerly produced ferro-silicon used in the operation (buildings near the lower right corner of the photo). The main furnace complex is in the large building (right center). Dolomite is mined from the pit (upper right) adjacent to the complex. Mine areas no longer in use are being backfilled (center and left center). Water for the operation is stored in and re-used from the ponds (lower left); no water is discharged from the facility. Aerial view north along the Colville River valley. See article starting on p. 3. Photo courtesy of Northwest Alloys Inc.

DEPARTMENT'S GUIDING PRINCIPLES AND SURFACE MINE RECLAMATION

Raymond Lasmanis, State Geologist
Washington Division of Geology and Earth Resources
PO Box 47007, Olympia, WA 98504-7007

Starting in 1993, Department of Natural Resources (DNR) management developed a series of guiding principles to provide direction to employees. A final version was endorsed by Commissioner of Public Lands Jennifer M. Belcher on January 20, 1995. One guiding principle is that regulatory programs should encourage voluntary compliance and collaboration.

Additionally during 1995, the 54th Legislature passed Engrossed Substitute House Bill 1010, an Act relating to regulatory reform. Section 603 of that Act states in part: "All regulatory agencies shall develop programs to encourage voluntary compliance by providing technical assistance...."

Consistent with department guiding principles and the Regulatory Reform Act, the Division of Geology and Earth Resources has just released Open File Report 96-2, *Best Management Practices for Reclaiming Surface Mines in Washington and Oregon*, by David K. Norman, Peter J. Wampler, Allen H. Throop, E. Frank Schnitzer, and Jaretta M. Roloff. Concurrently, it is being released by Oregon Department of Geology and Mineral Industries as Open-File Report O-96-2.

This report is also a demonstration of the department's five-year goal statement to have DNR recognized as the agency of choice through partnerships with the public, other governments, and other agencies and interests. Open File Report 96-2 is the result of a project partially funded by U.S. Environmental Protection Agency through an agreement among Idaho, Oregon, and Washington.

Copies of this report can be ordered from Division of Geology and Earth Resources for $3.50 plus $1.00 for postage and handling. (See address this page and more information about the report on the back page of this issue.) ■

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University of British Columbia Professor Receives Fellowship

Susan Werner Kieffer is one of 24 individuals, and the only geologist, to be awarded a 1995 MacArthur Fellowship, given "in recognition of your accomplishments in geology which demonstrate your originality, creativity, capacity for self-direction, and ability to make a contribution to our lives." She will receive $315,000.

Dr. Kieffer is a planetary scientist. Her specialty is high-velocity, typically catastrophic, planetary events (meteorite impacts, volcanic explosions, massive floods). She has published several papers about the 1980 blast and pyroclastic flows at Mount St. Helens.

The Metallic, Nonmetallic, and Industrial Mineral Industry of Washington in 1995

Robert E. Derkey
Washington Division of Geology and Earth Resources
904 W. Riverside, Room 209, Spokane, WA 99201-1011

INTRODUCTION

The review of the nonfuel mineral industry of Washington for 1995 is organized into three commodity 'type' categories—metallic, nonmetallic, and industrial minerals. Metallic mineral deposits are those that commonly require the most processing for their intended use. The metal produced typically is compact and volumetrically small and can be economically transported considerable distances. Examples are gold and copper.

Nonmetallic mineral deposits are those that commonly require less processing and are not very different from their original rock or mineral form. Nonmetallic mineral commodities are generally bulkier in their final processed form than are metallic commodities; consequently, they are not transported as far from their source as are metallic commodities. Examples include cement, clay, and lime. Industrial minerals are those minerals that require relatively little processing and are easily recognized in their original form. They are most essential locally in that they support local road and building construction industries. Industrial minerals cannot be transported very far before transportation costs overwhelm their value. The best examples are sand and gravel and crushed stone.

Washington ranked 20th in the nation in total value of nonfuel mineral production in 1994, the last year for which production figures are available. The value, $556 million, is an estimate and represents a 10 percent increase over 1993. The increase was for magnesium metal and for the basic construction materials—crushed stone, portland cement, and sand and gravel. The value of gold production decreased by 15 percent in 1994 and will have decreased still more in 1995. These values are from the (recently closed) U.S. Bureau of Mines mineral industry surveys that are now being collected and distributed by the U.S. Geological Survey.

Table 1 (see p. 8–13) summarizes mining and mineral exploration activities in Washington for metallic and nonmetallic commodities in 1995. Numbers following deposit names in this text are keyed to the deposits and properties listed in Table 1 and to their locations on Figures 1A–D (see p. 4–7). Metal mining and exploration projects have numbers below 100 and nonmetallic mines and projects have numbers above 100.

The majority of this volunteered information was obtained from an annual survey of mining companies and individuals. Table 1 lists only those companies that returned questionnaires. It is not a complete listing of mineral activities. As in 1994, many companies and individuals reported maintaining properties, but with little expenditure beyond that required to maintain the property.

Additional details about the geology of the metallic mineral deposits and comparisons of activities in previous years in the state are available in reviews of Washington's mineral industry for 1991 through 1994 by Derkey and Gulick (1992), Derkey (1993, 1994, 1995), and Gulick (1994, 1995) and Gulick and Lingley (1993). Questions about metal mining activities and exploration can be referred to Bob Derkey in the Division's Spokane office. (See page 2 for telephone and fax numbers.)

METALLIC MINERAL INDUSTRY

Production of metallic mineral commodities accounted for approximately 34 percent of the value of Washington's nonfuel mineral production in 1994. The greatest value was for magnesium metal, followed by gold.

Major changes occurred in Washington's precious-metals mining industry late in 1994—the Cannon mine at Wenatchee closed at the end of 1994, and Hecla Mining Company's Republic Unit operations closed in early 1995. Consequently, production of precious metals has declined considerably. Only 107,000 oz of gold (Fig. 2) and 42,000 oz of silver were produced in Washington in 1995, compared to 232,000 oz of gold and 507,000 oz of silver in 1994. The estimated value of the precious metals produced in Washington in 1995 was $41.3 million, less than half the $91.6 million (estimated) for 1994.

Exploration for precious metals in Washington also continued to decrease. The focus was on precious metals in or near rocks of the Republic and Chiwaukum grabens.

Precious Metals

Gold, because of its natural beauty and durability, has differing importance to people depending on their occupation: to the artist, goldsmith, and jeweler, it is a "metal of superb and everlasting beauty", to the industrial artist it is a "metal with unique properties useful in electronics and many other artifices of man", to the numismatist, it is the "coinage metal with a long and interesting history", to the economist it is a "valu-

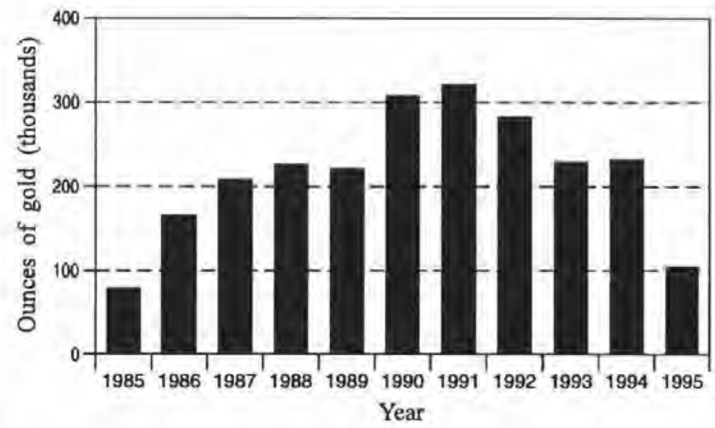

Figure 2. Gold production in Washington, 1985–1995.

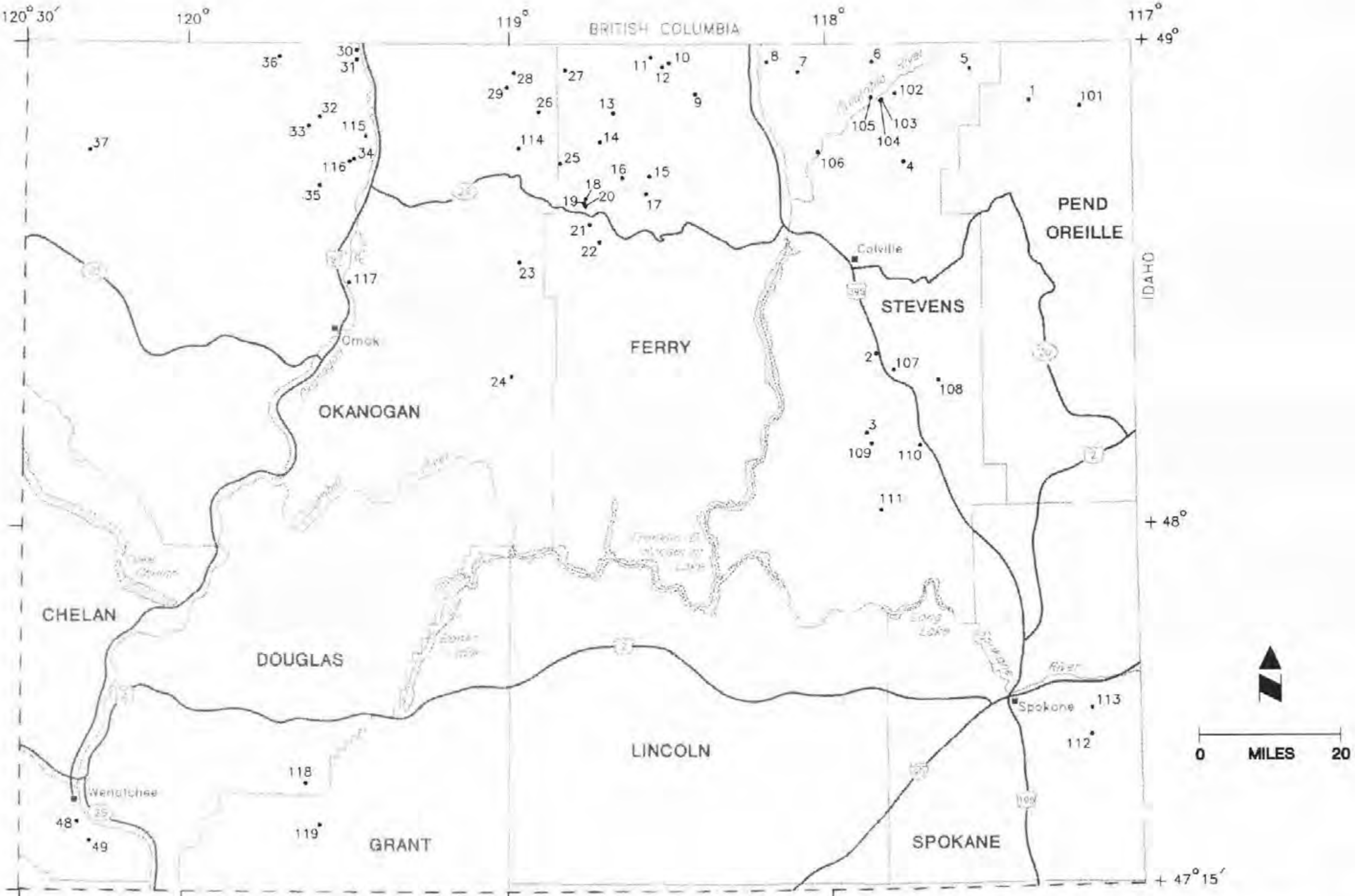

Figure 1A. Location of properties at which mineral exploration, development, or mining took place in 1995 in northeast Washington. See Table 1 for more information about each of these locations.

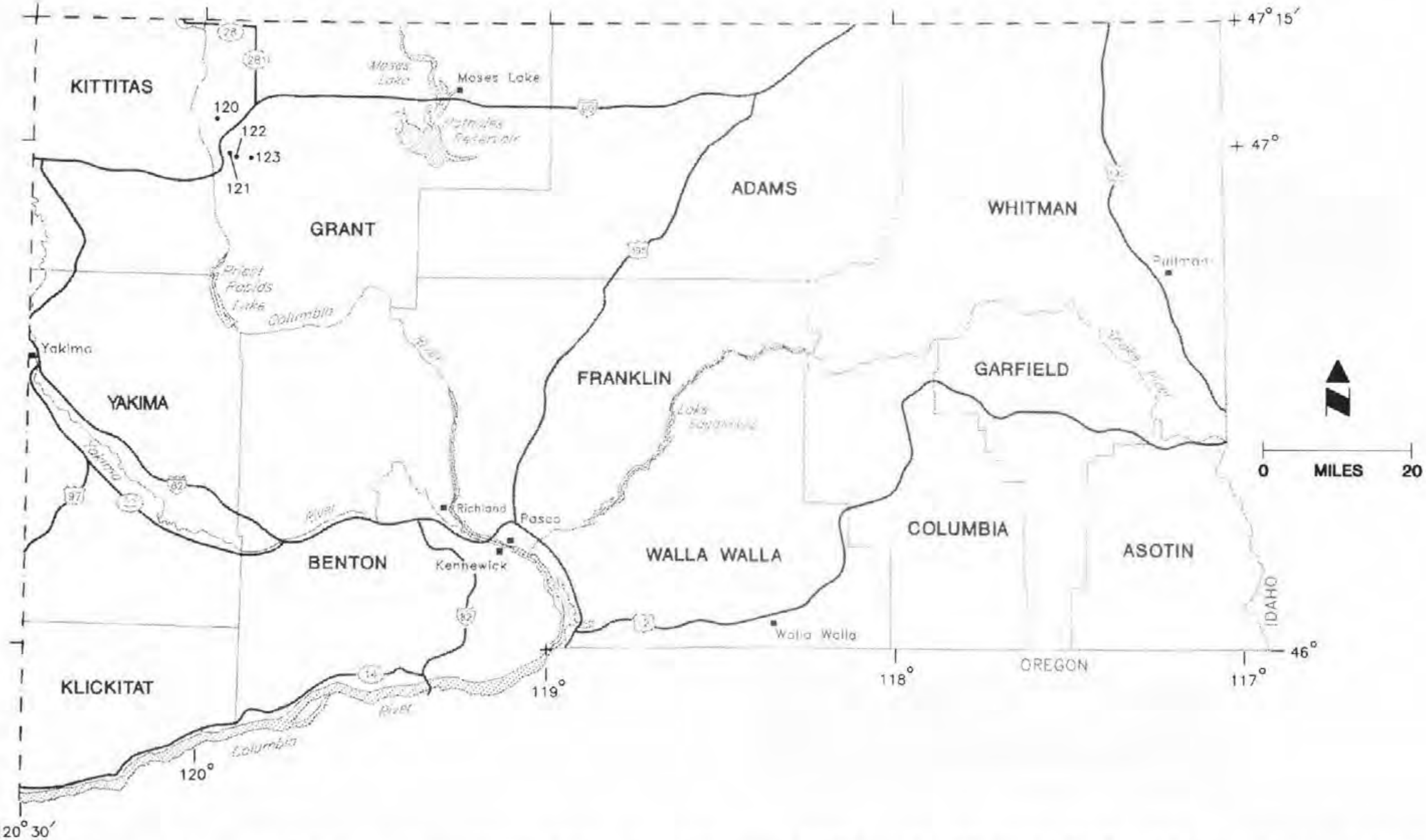

Figure 1B. Location of properties at which mineral exploration, development, or mining took place in 1995 in southeast Washington. See Table 1 for more information about each of these locations.

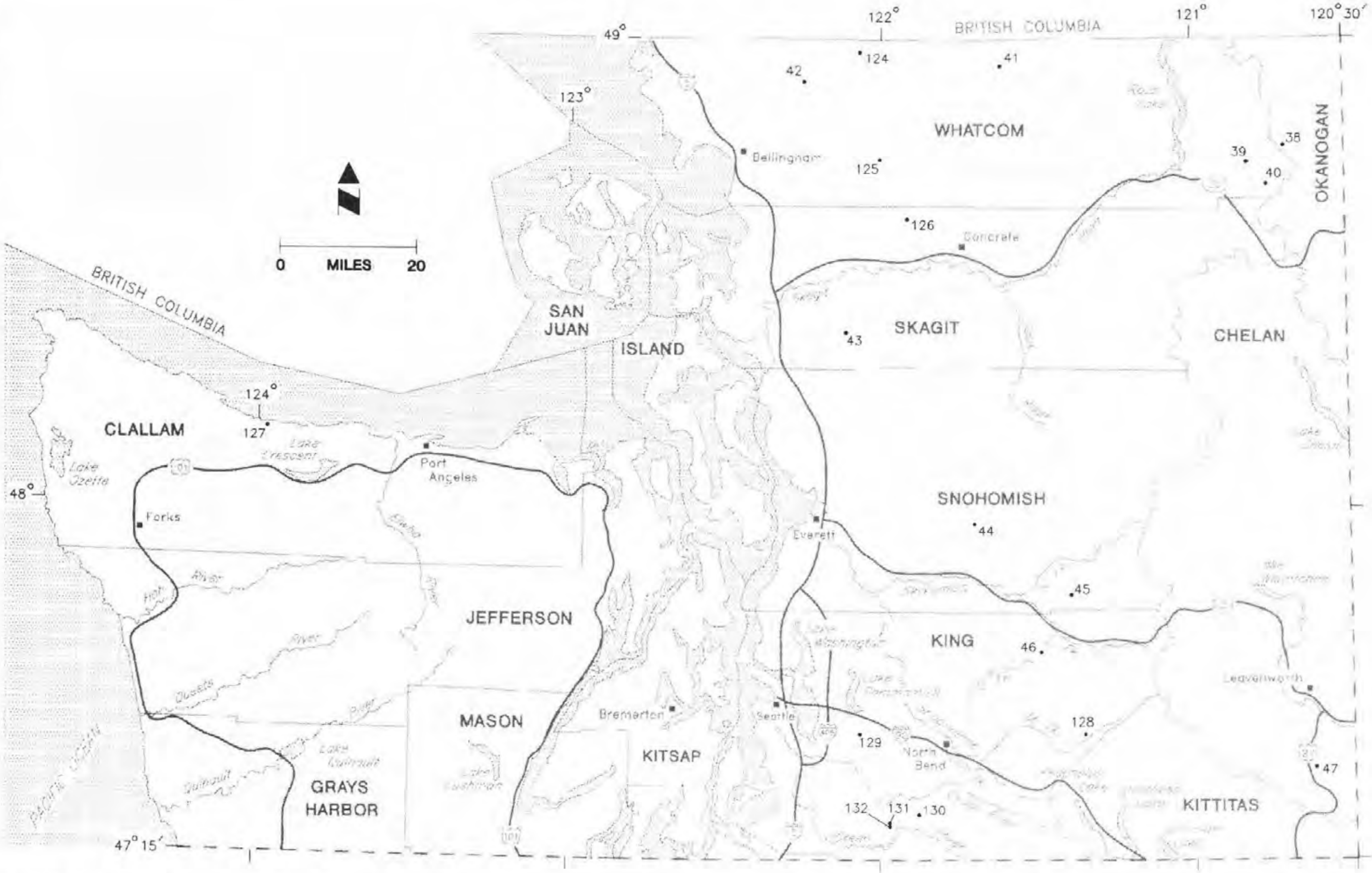

Figure 1C. Location of properties at which mineral exploration, development, or mining took place in 1995 in northwest Washington. See Table 1 for more information about each of these locations.

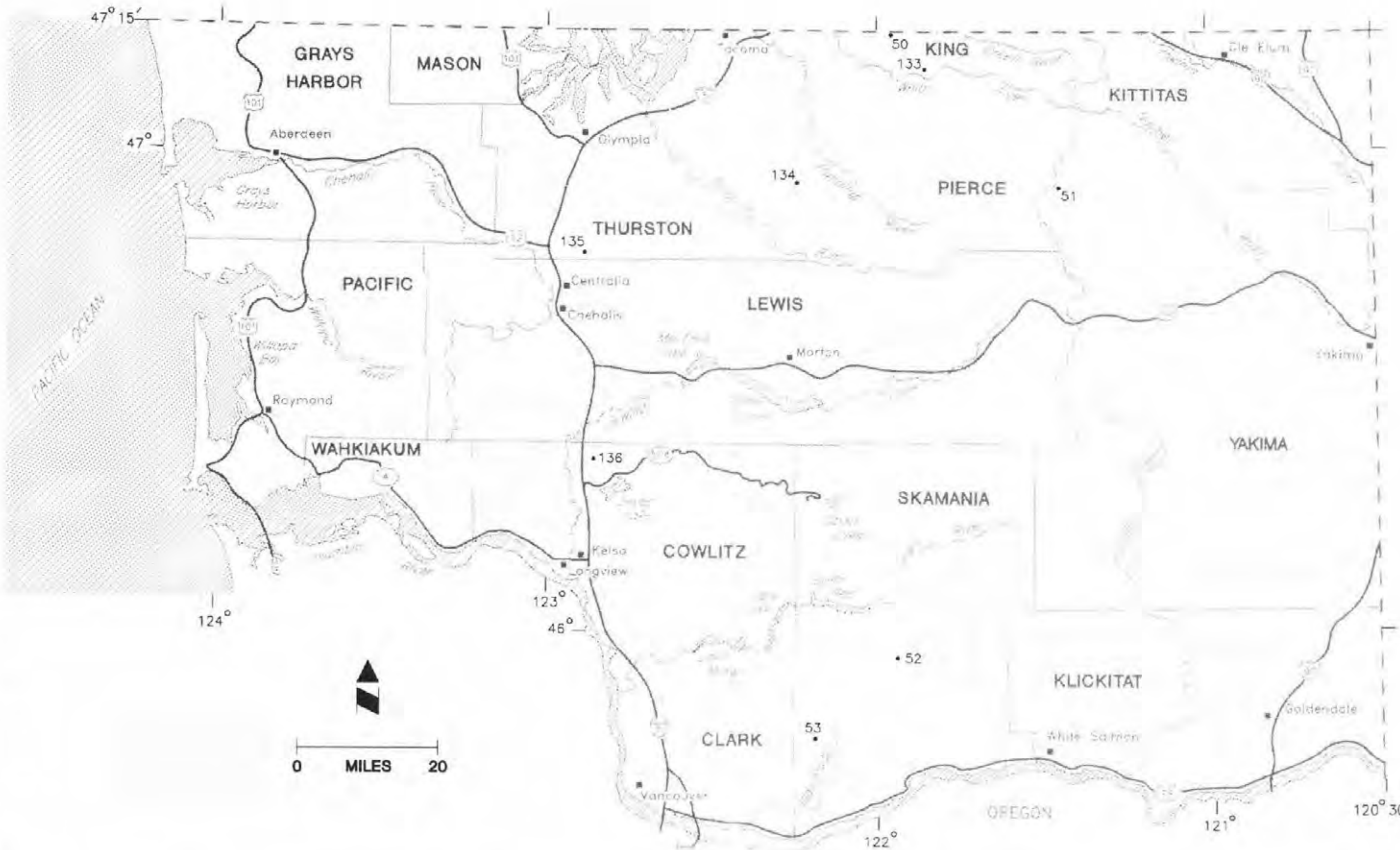

Figure 1D. Location of properties at which mineral exploration, development, or mining took place in 1995 in southwest Washington. See Table 1 for more information about each of these locations.

Table 1. Mining and mineral exploration in Washington, 1995. Property/project name is supplied by the company responding to the questionnaire. Order of entry is generally from the northeast to southwest; location numbers are keyed to Figures 1A–1D. Entries 1–53 are base and precious metal properties; entries 101–132 are sites of industrial mineral activity

Loc no.	Property	Location	County	Commodity	Company	Activity	Area geology
BASE AND PRECIOUS METALS							
1	Pend Oreille mine	secs. 10-11, 14-15, 39N, 43E	Pend Oreille	Zn, Pb, Ag, Cd	Resource Finance Corp.	Completed 1,500-ft exploration drift and 22,000 feet of underground core drilling; staked 33 new claims; geochemistry	Mississippi Valley-type mineralization in Yellowhead zone of Cambrian–Ordovician Metaline Formation
2	Addy Magnesium mine	secs. 13-14, 33N, 39E	Stevens	dolomite	Northwest Alloys, Inc.	Mining; producing magnesium metal	Cambrian–Ordovician Metaline Formation dolomite
3	Edna	SE1/4 SE1/4 sec. 9, and sec. 10, 31N, 39E	Stevens	Cu, Ag, Au	Edna Mining Group	Maintained property	Mineralized zone in Precambrian Edna Dolomite
4	Van Stone mine	sec. 33, 38N, 40E	Stevens	Zn, Pb, Cd	Zicor Mining Ltd.	Purchased property; doing some reclamation work	Mississippi Valley-type mineralization in the Cambrian–Ordovician Metaline Formation
5	Iroquois	secs. 1, 19-20, 29-30, 40N, 42E	Stevens	Zn, Pb, Ag, Au	Mines Management, Inc.	Maintained property	Mineralization in a breccia zone in Cambrian–Ordovician Metaline Formation
6	Ambrose Mining	sec. 16, 40N, 39E	Stevens	Au	A. Ambrose	Limited mining; maintained property	Placer deposit
7	Cleta Group	secs. 22, 27, 40N, 37E	Stevens	Au, Ag, Cu	David Robbins and Associates	Soil geochemistry	Vein and replacement mineralization in sheared and contact-metamorphosed Permian Mount Roberts Formation
8	Uranwash 1-4; New Indian Henry claims	sec. 13, 40N, 36E	Stevens	Au, Ag, Cu, Pb, Zn	Merle Loudon & Betty Sanstrom	Maintained property	Vein-type mineralization in Jurassic metavolcanic rocks
9	Lone Ranch	unsurveyed, T39N, R35E	Ferry	Au, Ag	Platoro Inc.	Maintained property	Gold enriched sedimentary exhalative deposit in Permian metasedimentary rocks
10	Irish	sec. 15, 40N, 34E	Ferry	Au	Johnson Explosives	Maintained property	Gold mineralization in alkalic rocks of the Jurassic Shasket Creek complex
11	Gold Mountain	secs. 7-8, 40N, 34E	Ferry	Au, Ag, Cu	Gold Express Corp./ N. A. Degerstrom, Inc.	Reclamation in progress; sold property to Globex Nevada Inc. in late December	Gold-pyrite mineralization in an alkalic dike of the Jurassic Shasket Creek complex
12	Morning Star	sec. 16, 40N, 34E	Ferry	Au, Ag, Cu, W	Echo Bay Minerals Co. lease	Geophysics, geochemistry, drilling	Volcanogenic massive sulfide mineralization in Mesozoic accreted terrane rocks
13	K-2	sec. 20, 39N, 33E	Ferry	Au, Ag	Echo Bay Minerals Co.	Underground exploration	Epithermal deposit in Eocene Sanpoil Volcanics
14	Empire Creek	sec. 12, 38N, 32E; sec. 7, 38N, 33E	Ferry	Au, Ag	Kennecott Exploration Co.	Geologic mapping, geochemistry, geophysics	Mineralization in Permian metavolcanic rocks

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
15	Hawkeye	sec. 6, 37N, 34E; sec. 31, 38N, 34E	Ferry	Au, Ag, Cu, Fe	Echo Bay Exploration Inc.	Geophysics, drilling	Gold mineralization in massive iron replacement/ skarn in Permian sedimentary rocks
16	Lamefoot	secs. 4, 8, 37N, 33E	Ferry	Au, Ag	Echo Bay Minerals Co.	Completed first full year of underground production mining	Gold mineralization in massive iron replacement/ exhalative mineralization in Permian sedimentary rocks
17	Overlook mine	sec. 18, 37N, 34E	Ferry	Au, Ag	Echo Bay Minerals Co.	Underground mining was completed in September	Gold mineralization associated with massive iron replacement/exhalative mineralization and stockwork of veinlets in Permian sedimentary rocks
18	South Penn	secs. 27-28, 37N, 32E	Ferry	Au, Ag	Crown Resources Corp./ Sutton Resources Inc.	Maintained property	Epithermal deposit in Eocene Sanpoil Volcanics
19	Golden Eagle	sec. 27, 37N, 32E	Ferry	Au, Ag	Santa Fe Pacific Gold Corp./Hecla Mining Co.	Santa Fe Pacific Gold Corp. signed joint venture agreement with Hecla Mining Co.; drilling, geologic evaluation of deposit	Epithermal mineralization in Eocene bedded tuff
20	Golden Promise	secs. 27, 34-35, 37N, 32E	Ferry	Au, Ag	Hecla Mining Co.	Mining and milling ended in early 1995 as ore reserves of the Golden Promise deposit were depleted	Epithermal gold veins in dacite and andesite flows, flow breccias, tuffs, and tuff breccias of Eocene Sanpoil Volcanics
21	Republic district properties	numerous sections, 36-37N, 32-33E	Ferry	Au, Ag	Santa Fe Pacific Gold Corp./Hecla Mining Co.	Santa Fe Pacific Gold Corp. signed an agreement with Hecla Mining Co. in August and assumed exploration responsibility for these properties	Epithermal mineralization in Eocene volcanic rocks of the Republic graben
22	Republic area state leases	Republic area	Ferry	Au, Ag	S. A. Jackson	Geophysics, geologic mapping	Epithermal mineralization in Eocene volcanic rocks of the Republic graben
23	Aeneas Valley property	sec. 8, 35N, 31E	Okanogan	Au, Ag, Cu, silica	Sunshine Valley Minerals, Inc.	Maintained property	Possible gold mineralization associated with large quartz (high-grade quartz) bodies in probable Permian rocks
24	Parmenter Creek	secs. 1, 12, 32N, 30E	Okanogan	Au, Ag	Colville Confederated Tribes	Geologic mapping, rock geochemistry	Strata-bound or shear zone mineralization in pre-Jurassic schist, gneiss, and quartzite
25	Silver Belle	sec. 25, 38N, 31E	Okanogan	Au, Ag	Jopec Resources Ltd.	Geophysics, geologic mapping	Epithermal mineralization in Eocene felsic volcanic rocks of Toroda Creek graben
26	Ida	secs. 16, 21, 39N, 31E	Okanogan	Au, Ag, Cu	Crown Resources Corp.	Retained only a portion of the property	Epithermal veins in Eocene Sanpoil Volcanics and Klondike Mountain Formation of the Toroda Creek graben
27	Graphite Creek	sec. 19-20, 40N, 32E	Ferry	Au, Ag	Echo Bay Exploration Inc.	Drilling, dropped property	Epithermal mineralization in Eocene Klondike Mountain Formation
28	Crown Jewel	sec. 24, 40N, 30E	Okanogan	Au, Cu, Ag, Fe	Battle Mountain Gold Corp./Crown Resources Corp.	Draft EIS was issued in July, comment period ended, revisions are in progress	Gold skarn mineralization in Permian or Triassic metasedimentary rocks adjacent to the Jurassic–Cretaceous(?) Buckhorn Mountain pluton
29	Crystal Butte	sec. 35, 40N, 30E	Okanogan	Au, Ag, Pb, Zn, Cu	Keystone Gold, Inc.	Geologic reconnaissance, maintained property	Skarn type mineralization in Permian Spectacle Formation intruded by Mesozoic rocks

Table 1. Mining and mineral exploration in Washington, 1995 *(continued)*

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
30	Kelsey	secs. 5-8, 40N, 27E	Okanogan	Cu, Mo, Ag, Au	Wilbur Hallauer	Maintained property	Porphyry-type mineralization in Jurassic–Cretaceous Silver Nail quartz diorite
31	Hot Lake	secs. 7, 18, 40N, 27E	Okanogan	Au, Ag	Wilbur Hallauer	Maintained property	Low-grade gold mineralization adjacent to the Kelsey porphyry-type deposit
32	Copper World/ Copper World Extension	secs. 20, 29, 39N, 26E.	Okanogan	Cu, Au, Ag, W, Zn, Fe	Wilbur Hallauer	Geophysics, geologic mapping, opened old adit	Ore lenses in altered andesite of Permian–Triassic Palmer Mountain Greenstone
33	Black Bear	NE1/4 sec. 36, 39N, 25E.	Okanogan	Au, Ag, Cu	Wilbur Hallauer	Maintained property	Veins in Permian–Triassic Palmer Mountain Greenstone intruded by felsic to intermediate rocks of probable Jurassic-Cretaceous age
34	Lucky Knock	sec. 19, 38N, 27E	Okanogan	Au, Sb	Magill & Associates	Soil and rock geochemistry, building repair	Stibnite veinlets and disseminations in fractured and silicified limestone of the Permian Spectacle Formation (Anarchist Group)
35	Starr Molybdenum	secs. 8, 16, 37N, 26E	Okanogan	Mo, Cu, W	Wilbur Hallauer	Maintained property	Porphyry-type mineralization in Cretaceous Aeneas Creek quartz monzonite and granodiorite; gold in secondary enriched zone
36	Golden Zone	sec. 7, 40N, 25E	Okanogan	Au, Ag	El Bravo Gold Mining Ltd.	Maintained property	Vein or shear zone in the Kobau Formation and Similkameen batholith
37	Billy Goat	sec. 15, 38N, 20E	Okanogan	Au, Cu, Ag	Sunshine Valley Minerals, Inc.	Maintained property	Stockwork in Cretaceous? andesite tuff and breccia
38	New Light	sec. 27, 38N, 17E	Whatcom	Au, Ag	Western Gold Mining, Inc.	Maintained property, site rehabilitation	Quartz-carbonate-cemented slate-argillite breccia in the Lower Cretaceous Harts Pass Formation
39	Minnesota	sec. 2, 37N, 16E	Whatcom	Au, Ag, Cu	Seattle-St. Louis Mining Co.	Maintained property, limited exploration	Quartz veins in argillite and feldspathic sandstone of Lower Cretaceous Harts Pass Formation
40	Azurite	sec. 30, 37N, 17E	Whatcom	Au, Ag, Cu, Pb	Double Dragon Exploration Inc.	Maintained property	Veins in sedimentary rocks of the Cretaceous Virginian Ridge Formation
41	Lone Jack	secs. 22-23, 40N, 9E	Whatcom	Au, Ag	Diversified Development Co.	Mining, shipped ore to East Helena, mine development	Quartz veins in metasedimentary rocks
42	South Pass Nickel	sec. 2, 39N, 4E; sec. 35, 40N, 4E	Whatcom	Sc, Ni, Co	Consolidated Viscount Resources, Ltd.	Obtained property, planning winter exploration program	Laterite developed in peridotite at the base of Eocene sedimentary rocks
43	Skagit Copper	secs. 1-3, 33N, 5E	Skagit	Cu, Zn, Au, Ag, Pb	Cannon Minerals	Trenching on massive sulfide lenses	Massive sulfide mineralization in accreted terrane (melange?) rocks
44	Lockwood	secs. 25, 30-32, 29N, 9E	Snohomish	Cu, Au, Zn, Ag	Island Arc Resources Corp./Formosa Resources Corp.	Maintained property	Kuroko-type volcanogenic massive sulfide mineralization in Jurassic volcanic rocks of the Western melange belt
45	Trout Creek property	sec. 20, 27N, 11E	Snohomish	Cu, Au, Ag, Zn, Pb, W, Sn, Pt	Northwest Minerals Inc.	Reconnaissance prospecting, claim staking	Shear zone/exhalative/contact metamorphic mineralization in roof pendant of the Tertiary Grotto batholith

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
46	Apex	sec. 34, 26N, 10E	King	Au, Ag, Cu, Pb	CSS Management Corp.	Maintained property, tunnel opening, portal improvements	Quartz vein in granodiorite of the Miocene Snoqualmie batholith
47	Gold Bond	secs. 2-3, 22N, 17E	Chelan	Au	Gold Bond Mining Co./ Gold Bond Resources	Maintained property	Vein mineralization in rocks of the Ingalls ophiolite complex
48	Cannon mine	sec. 16, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Mining completed in 1994, clean-up and dismantling of mine infrastructure completed in 1995, reclamation continuing	Mineralization in altered (commonly silicified) horizons in Eocene arkosic sandstone
49	Wenatchee Gold Belt project	sec. 35, 22N, 20E	Chelan	Au, Ag	Ramrod Gold USA, Inc.	Drilling	Mineralization in altered (commonly silicified) horizons in Eocene arkosic sandstone
50	Weyerhaeuser properties	Cascades area	King, Pierce, Thurston, Lewis, Cowlitz	Au, Ag, Cu, Mo, Pb, Zn, clay, silica	Weyerhaeuser Co.	Evaluation of minerals on company lands	Cascades province and adjacent volcanic, volcaniclastic, and intrusive rocks
51	Morse Creek	sec. 31, 17N, 11E	Yakima	Au, Ag	Ardic Exploration & Development, Ltd.	Maintained property	Tuffs of the Oligocene Ohanapecosh Formation
52	Wind River	sec. 9, 5N, 7E	Skamania	Au, Ag	DeLano Wind River Mining Co.	Mining, seeking permits for milling operations	Epithermal mineralization in Oligocene–Miocene volcanic rocks
53	Silver Star	secs. 3-5, 8-9, 3N, 5E	Skamania	Cu, Ag, Au, Mo	Kinross Gold USA, Inc.	Maintained property	Tourmaline-bearing breccia pipe associated with porphyritic phases of the Miocene Silver Star pluton
INDUSTRIAL MINERALS							
101	Totem talc	secs. 23, 25-26, 39N, 44E	Pend Oreille	talc	First Miss Gold Inc./ United Catalysts Inc.	Maintained property	Talc along a high-angle fault in altered dolomites of the Proterozoic Z Monk Formation (Windermere Group)
102	Sherve quarry	sec. 8, 39N, 40E	Stevens	limestone	Northport Limestone Co. (division of Hemphill Brothers, Inc.)	Mining, milling, drilling	Limestone in the upper unit of Cambrian–Ordovician Metaline Formation
103	Janni limestone quarry	sec. 13, 39N, 39E	Stevens	limestone	Peter Janni and Sons	Leased to Pluess-Staufer Industries, Inc.	Deposit is in Cambrian Maitlen Phyllite, Reeves Limestone Member
104	Joe Janni limestone deposit	sec. 13, 39N, 39N	Stevens	limestone	Joe Janni	Leased to Columbia River Carbonates	Deposit is in Cambrian Maitlen Phyllite, Reeves Limestone Member
105	Flagstaff Mountain	secs. 4, 9, 39N, 39E	Stevens	barite	Mountain Minerals Co. Ltd. *dba* Mountain Minerals Northwest	Attempting to sell property	Massive bedded barite in the Devonian–Carboniferous Flagstaff Mountain sequence
106	Northwest marble mine; other quarries	sec. 19, 38N, 38E	Stevens	dolomite	Northwest Marble Products Co.	Mining, milling, can supply color/site-specific products no longer available from Nanome Aggregates Inc.	Dolomite of the Cambrian–Ordovician Metaline Formation; additional colored dolomite products are quarried at several locations

Table 1. Mining and mineral exploration in Washington, 1995 *(continued)*

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
107	Blue Creek quarry	sec. 29, 33N, 40E	Stevens	silica	Northwest Alloys, Inc.	Maintained property	Cambrian Addy Quartzite
108	Chewelah Eagle quarry	sec. 5, 32N, 41E	Stevens	dolomite	Chewelah Eagle Mining Co.	Discontinued mining when Nanome Aggregates discontinued Washington operations	Devonian–Carboniferous(?) metacarbonate rocks
109	Lane Mountain quarry	secs. 22, 34, 31N, 39E	Stevens	silica	Lane Mountain Silica Co. (division of Hemphill Brothers, Inc.)	Mining, milling	Cambrian Addy Quartzite
110	Nine quarries	—	Stevens	dolomite	Nanome Aggregates, Inc.	Ceased all mining and milling operations in Washington in 1995	Uniquely colored dolomite or dolomitic marble was mined at nine sites in Stevens County: China White, Black, Lolo Martin, Primavera/Sage Green, Cream, Rose/Red, Grey/Chartreuse, Botte, and Watermary
111	Gehrke quarry	sec. 2, 29N, 39E	Stevens	dolomite	Allied Minerals, Inc.	Mining, milling	Isolated pod of Proterozoic Y Stensgar Dolomite(?) (Deer Trail Group)
112	Mica mine	sec. 14, 24N, 44E	Spokane	clay	Mutual Materials Co.	Mining, stockpiling, drilling, development; producing bricks	Lacustrine clay of Miocene Latah Formation overlying saprolitic, pre-Tertiary felsic gneiss.
113	Somers clay pit	sec. 35, 25N, 44E	Spokane	clay	Quarry Tile Co.	Mining, stockpiling; producing ceramic tile	Lacustrine clay of the Miocene Latah Formation overlain by silty clay of the Pleistocene Palouse Formation
114	Wauconda quarry	sec. 13, 38N, 30E	Okanogan	limestone	Columbia River Carbonates	Mining, milling	High-calcium, pre-Tertiary white marble lenses in mica schist, calc-silicate rocks, and hornfels
115	Poison Lake	secs. 4-5, 38N, 27E	Okanogan	gypsite	Agro Minerals, Inc.	Idle, attempting to sell property	Evaporitic lake in a small basin at the convergence of several ravines dammed by glacial deposits
116	Tonasket limestone quarry	sec. 25, 38N, 26E	Okanogan	limestone	Pacific Calcium, Inc.	Mining, milling	Metacarbonate rocks in the conglomerate-bearing member of the Permian Spectacle Formation (Anarchist Group)
117	Brown quarry	sec. 26, 35N, 26E	Okanogan	dolomite	Pacific Calcium, Inc.	Mining	Metadolomite member of the Triassic Cave Mountain Formation
118	Volcanic mine	sec. 13, 23N, 25E	Douglas	clay	Basic Resources Corp.	Final mine permitting, planning 1996 mining start-up	Calcium bentonite (clay) interbeds in Miocene Columbia River Basalt Group near Moses Coulee
119	Rock Top	sec. 20, 22N, 26E	Grant	clay	Basic Resources Corp.	Geologic mapping, mine planning/engineering	Plan to mine bentonite interbeds in the Columbia River Basalt Group
120	Sec. 17 pit	sec. 17, 18N, 23E	Grant	diatomite	Celite Corp.	Mining completed, reclamation in progress	Miocene "Quincy Diatomite Bed", a local sedimentary interbed at the base of the Priest Rapids Member, Columbia River Basalt Group
121	Sec. 3/10 pit	secs. 3, 10, 17N, 23E	Grant	diatomite	Celite Corp.	Mining, milling, exploration/development	Miocene "Quincy Diatomite Bed", a local sedimentary interbed at the base of the Priest Rapids Member, Columbia River Basalt Group

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
122	Sec. 11 pit	sec. 11, 17N, 23E	Grant	diatomite	Celite Corp.	Mine development	Miocene "Quincy Diatomite Bed", a local sedimentary interbed at the base of the Priest Rapids Member, Columbia River Basalt Group
123	Sec. 7 pit	sec. 7, 17N, 24E	Grant	diatomite	Celite Corp.	Mining, milling, exploration/development	Miocene "Quincy Diatomite Bed", a local sedimentary interbed at the base of the Priest Rapids Member, Columbia River Basalt Group
124	Maple Falls quarry	sec. 7, 18, 40N, 6E	Whatcom	limestone	Clauson Lime Co.	Mining	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, 38N, 6E	Whatcom	olivine	Olivine Corp.	Mining, milling; producing refractory olivine incineration systems	Dunite is mined from the Twin Sisters dunite (outcrop area more than 36 mi^2) in Whatcom and Skagit Counties
126	Hamilton plant	sec. 17, 36N, 7E	Skagit	olivine	Unimin Corp.	Milling; producing refractory olivine materials	Twin Sisters dunite
127	Twin River quarry	secs. 22-23, 31N, 10W	Clallam	clay	Holnam Inc.	Mining	Mudstone(?) in three members of the upper Eocene to lower Miocene Twin Rivers Formation
128	Spruce claim	secs. 29, 30, 24N, 11E	King	crystals	Robert Jackson	Extracting mineral and crystal specimens	Quartz and pyrite crystals in large, open voids along faulted mega-breccia in the northern phase granodiorite and tonalite (25 Ma) of the Snoqualmie batholith
129	Sec. 31 pit	sec. 31, 24N, 6E	King	shale	Mutual Materials Co.	Mining	Shale and sandstone of the Eocene Puget Group
130	Elk pit	sec. 34, 22N, 7E	King	shale	Mutual Materials Co.	Mining	Illite- and kaolinite-bearing shales of the Eocene Puget Group
131	Ravensdale pit	sec. 1, 21N, 6E	King	silica	Reserve Silica Corp.	Mining, washing	Sandstone of the Eocene Puget Group
132	John Henry #1	sec. 12, 21N, 6E	King	clay	Pacific Coast Coal Co.	Mining	Upper middle Eocene silty clay near the base of the Puget Group comprising a 30-ft-thick zone above the Franklin #9 coal seam (see article, p. 20)
133	Superior quarry	sec. 1, 19N, 7E	King	silica	Ash Grove Cement Co.	Mining, stockpiling	Silica cap in hydrothermally altered Miocene andesites on a caldera margin
134	Clay City pit	sec. 30, 17N, 5E	Pierce	clay	Mutual Materials Co.	Mining	Oligocene–Miocene kaolin-bearing, altered andesite
135	Bucoda pit	sec. 14, 15N, 2W	Thurston	clay	Mutual Materials Co.	Idle	Glacial clay of the Pliocene–Pleistocene Logan Hill Formation overlying silty clay of the Eocene Skookumchuck Formation
136	Castle Rock Clay pit	sec. 18, 10N, 1W	Cowlitz	clay	Ash Grove Cement Co.	Mining	Eocene–Oligocene nearshore sedimentary rocks

able standard against which wealth is measured and an imperishable medium for balancing international accounts", to the geochemist it is a "rare metal, the geochemistry of which is intricate and complex", and finally to the mining engineer and metallurgist it "presents a challenge of extraction from the earth and from its ores" (Boyle, 1987, p. 1).

Gold occurs in two types of deposits—lode and placer. A placer deposit consists of sand, gravel, and other detrital or residual material in which the valuable mineral such as gold has accumulated through weathering and mechanical concentration processes. Lode deposits consist of a vein, a series of veins, or disseminated minerals in rock. Only a small portion of Washington's gold production has been from placers.

Echo Bay Minerals Co.'s Kettle River operations at Republic was the only major gold mining operation in Washington in 1995. The Kettle River operations produced 100,419 oz of gold and approximately 22,800 oz of silver in 1995 from 547,597 tons of ore processed in its mill near Republic. The head grade was 0.212 oz of gold per ton, and recovery was 86.6 percent.

Ore for the Kettle River operations was mined from the exhalative/replacement-type Overlook and Lamefoot deposits; 19 percent came from Overlook, the remainder from Lamefoot. The Overlook mine (no. 17) was reopened in 1994, and reserves at the deposit were exhausted during 1995. The mine will be closed. Overlook has produced 1,858,181 tons of ore since it was opened in 1989; contained gold in that ore was 285,259 oz. Gold recovery at the Kettle River operations has typically been in the 80 to 85 percent range, which means the Overlook produced roughly 230,000 to 240,000 oz of gold.

Higher grade ore from the Lamefoot deposit (no. 16) resulted in Echo Bay's Kettle River operations breaking the 100,000-oz production level in 1995. In 1993 and 1994, most of the ore milled at the Kettle River operations came from the lower grade, open-pit Key deposits. Mining at Lamefoot began in December of 1994, following receipt of permits to mine above the 2,750-ft elevation only. Permits to mine below that elevation were obtained in September 1995. Exploration drilling from the surface suggests that mineralization extends to the north of the deposit now being worked. Echo Bay plans to explore this potential by drifting to it in 1996.

Lamefoot is expected to be the mainstay of Kettle River operations for several years. The company reports proven and probable ore reserves are 1,585,400 tons at 0.207 oz of gold per ton (or 328,000 oz of contained gold). An additional measured and indicated ore reserve includes 466,900 tons at 0.164 oz of gold per ton (76,500 oz of contained gold).

Echo Bay continued underground exploration at its K-2 deposit (no. 13). The deposit is near the mined-out Kettle mine, and, like the Kettle, is an epithermal vein-type deposit in Eocene volcanic rocks of the Republic graben. The announced inferred resource at this deposit is 631,000 tons that contains 0.202 oz of gold per ton. The company plans to make a production decision on the K-2 in mid- to late 1996.

Hecla Mining Co.'s Republic Unit produced 3,098 oz of gold and 15,320 oz of silver from milling ore mined in 1994 and from cleanup at the mill following shutdown. Most of the production in recent years was from the Golden Promise mine (no. 20), which was closed on January 2, 1995; the mill operated until mid-February, when processing of gold ores was completed.

During the past year Asamera Minerals (U.S.) Inc. (as operator) and Breakwater Resources Ltd. were in the process of dismantling their mill and reclaiming the Cannon mine site (no. 48) at Wenatchee. The mine closed at the end of 1994. Production from cleanup and dismantling of the mill in 1995 was 2,670 oz of gold and 3,565 oz of silver. The Cannon mine produced 1,248,911 oz of gold and 2,075,077 oz of silver from a total of 4,133,101 dry tonnes of ore from its opening in 1985 through final cleanup in 1995.

The Lone Jack mine (no. 41) operated again in 1995, producing approximately 800 tons of ore that was shipped to a smelter in East Helena, MT. The operators also drove a drift to intersect the vein on a lower level of the mine.

A draft environmental impact statement (EIS) was issued June 30, 1995, for the Crown Jewel deposit (no. 28), a Battle Mountain Gold (operator)/Crown Resources joint venture. The public comment period for the draft EIS lasted 60 days and ended on August 29, 1995. The Washington Department of Ecology and the Okanogan National Forest are now preparing the final EIS for the project. It is expected in September of 1996. The process of obtaining permits to mine will then begin; issuance of permits is expected to take about a year. Announced reserves at the Crown Jewel deposit are 8.7 million tons of ore at a grade of 0.186 oz of gold per ton, or more than 1.6 million oz of gold. For Washington, the gold estimated to be contained in the Crown Jewel deposit is second in amount only to that at the Republic Unit of Hecla Mining Co.

The most extensive exploration in Washington was for gold from epithermal deposits in Tertiary rocks of the Republic and Chiwaukum grabens. Hecla Mining Co. signed an earn-in agreement with Santa Fe Pacific Gold Corp. in August for its Republic area holdings (no. 21) in the Republic graben. The focus of the acquisition for Santa Fe Pacific is the Golden Eagle deposit (no. 19), on which they were drilling in 1995. The Golden Eagle has a possible resource of 11.3 million tons grading 0.1 oz of gold per ton. Santa Fe Pacific will earn a 70 percent interest in the project by spending $7.5 million over a 3-year period and completing a feasibility study.

Echo Bay Exploration Inc. drilled and dropped a property on Graphite Creek (no. 27) in Eocene volcanic rocks of the Toroda Creek graben northwest of the Republic graben. Ramrod Gold USA, Inc., continued their activities, including drilling on their Wenatchee gold belt project (no. 49) in the Chiwaukum graben near Wenatchee. Delano Wind River Mining Co. was mining at the Wind River deposit (no. 52) and seeking permits to establish a milling operation. Activities on all other properties with potential for epithermal-type gold mineralization (see Table 1) were to maintain the property.

The Hawkeye (no. 15) was the only project/property actively explored for replacement/exhalative-type mineralization in the Republic graben. At all other properties (see Table 1) that have potential for this type of mineralization associated with Permian to Triassic rocks of northeastern and north-central Washington, activity was limited to maintaining of property.

Gold deposits in or near rocks of the Shasket Creek alkalic complex at the north end of the Republic graben were the focus of some exploration activity or were purchased by new companies. Echo Bay Exploration was active at the Morning Star (no. 12), and N. A. Degerstrom, Inc. and Gold Express Corp.

sold the Gold Mountain deposit (no. 11) to Globex Nevada Inc. in late December.

Base Metals

Copper, lead, and zinc are here considered base metals. Many of the larger known copper deposits in Washington are in the porphyry copper category, that is, disseminated copper minerals in granitic to intermediate composition intrusive igneous rocks. Most such deposits are found in the Cascade mountains.

A major source of lead and zinc in Washington is Mississippi Valley-type (MVT) deposits in the northeastern corner of the state. Washington's MVT deposits occur in Cambrian–Ordovician carbonate rocks (Metaline Formation) where lead is commonly subordinate to zinc; they commonly are referred to as zinc/lead deposits.

Figure 3. Dolomite at Northwest Alloys dolomite mine at Addy is drilled prior to blasting. After blasting and transport to a crusher, golf-ball-size ore material is separated out and sent to the smelter (cover photo) to produce magnesium metal.

The only reported significant activity for base metals in Washington was by Resource Finance Inc. at the Pend Oreille mine (no. 1) in an MVT deposit near Metaline Falls. During the year, the company completed 1,500 ft of exploration drifting and 22,000 ft of underground core drilling and staked 33 new claims on ground adjoining existing claims. The company is awaiting higher zinc prices before initiating mining.

Zicor Mining Ltd. purchased the Van Stone mine (no. 4) in northern Stevens County, also in an MVT deposit. The mine, formerly owned by Equinox Resources Ltd. and Pan American Minerals Corp., produced zinc and lead concentrates in 1992 and early 1993. The new company is stabilizing portions of tailings created during past milling operations.

The Trout Creek property (no. 45), a new prospect in Snohomish County, is in a pendant or septum of metamorphosed volcanic or sedimentary rocks between two Tertiary granitic plutons. The base- and precious-metal prospect is near the Merchant mine (Huntting, 1956).

Exploration activities for volcanogenic massive sulfide, porphyry, skarn, and other types of base-metal deposits were largely limited to maintenance of property (see Table 1); some properties were dropped.

Other Metals

Magnesium, the eighth most abundant element in the Earth's crust, is produced from sea water and well and lake brines and from minerals such as magnesite, dolomite, brucite, and olivine. The primary use of magnesium metal is as an alloying additive with aluminum. Aluminum-magnesium alloys are used in beverage cans, automobiles, aircraft, and machinery.

Magnesium metal is the dominant value-added nonfuel mineral commodity produced in Washington. In 1991, it accounted for about 20 percent of the value of the state's mineral industry (Derkey and Gulick, 1992). Production numbers are not yet available for 1995; however, the value of production in 1995 is estimated at a similar proportion of the state's overall nonfuel mineral production.

All magnesium metal production in the state is by Northwest Alloys Inc. (a subsidiary of ALCOA) at Addy (no. 2) from dolomite rock mined from a pit (Fig. 3) adjacent to the plant (cover photo). Electrical energy used in the smelting process is readily available in northeastern Washington. Northwest Alloys uses the Aluminothermic Process, a modification of the European Magnethermic Process, to produce magnesium metal. The Aluminothermic Process requires less electrical power than the European process and is adaptable to controlling emissions.

The charge for the electric furnaces, in addition to dolomite, includes aluminum (in the form of shot), magnesite, and ferro-silicon. The process begins with heating crushed dolomite from the mine to drive off carbon dioxide (Fig. 4). The reaction is:

$$CaMg(CO_3)_2 \rightarrow MgO + CaO + 2CO_2$$

The calcined dolomite at this point in the process is referred to as dolime. The ferro-silicon, aluminum, and magnesite are added to the dolime in the furnace to promote reduction of MgO to elemental magnesium metal. The reactions in the furnace are:

$$3MgO + 3Fe_{25}Si_{75} \rightarrow 6Mg + SiO + SiO_2 + Fe_{75}Si_{25}$$
$$6MgO + 4Al \rightarrow 6Mg + Al_2O_3$$

Elemental magnesium produced in the furnace is a gas, which migrates to an adjacent, cooler vessel and condenses. The furnace operates with an argon atmosphere at 70 torr to prevent re-oxidation of the magnesium metal at the high temperatures in the furnace (1,500°C). The vessel containing elemental magnesium is taken to another part of the plant where chloride-based fluxes remove non-magnesium elements, especially calcium. When the liquid metal in the vessel reaches a purity of 99.7 percent or greater, it is cast into ingots, which is the product shipped from Addy (Fig. 5).

The major use for the magnesium from Addy is alloying with aluminum. For example, two alloys that have different proportions of aluminum and magnesium are used to make beverage cans—one is for the can and the other for the can top.

Some materials for the Addy operation are imported. Ferro-silicon comes from Norway. In past years, ferro-silicon was produced locally—the silica (quartz) was mined from the nearby Blue Creek quarry and the iron came from taconite pellets from Minnesota. The company has found that the Norwegian product is more effective than the locally produced ferro-silicon. Magnesite for the operation is purchased from China. Northwest Alloys is considering obtaining magnesite from deposits southwest of Chewelah; however, because of the relatively small amount consumed, establishing a local magnesite mining operation may make that commodity more expensive than the Chinese magnesite. Aluminum in the form of shot is obtained from Kaiser Aluminum Mead Works in Spokane. All of these materials come together at Addy and result in the production of magnesium, the most valuable metal commodity produced in Washington.

Figure 4. Dolomite ore reaches the smelter on a conveyor belt and the smelting process begins when it passes through the rotary kiln (center to left center) on its way to one of six furnaces. In this stage of the operation, carbon dioxide is driven off to produce a lime product called dolime.

The South Pass Nickel (no. 42) prospect in Whatcom County will be the object of exploration activity in early 1996. Samples from the deposit contain considerable scandium. Principal uses of scandium are in high-intensity metal halide lamps, as analytical standards, and in research. Most scandium is recovered as a by-product from processing other ores.

NONMETALLIC MINERAL INDUSTRY

Commodities produced by the nonmetallic mineral industry of Washington range from a relatively low unit-volume value to a high unit-volume value. Cement is an example of a low unit-volume value commodity. Commonly cement is not transported great distances because of its bulk and because the materials to make it are relatively widespread. Diatomite, on the other hand, has a high unit-volume value. It has many specialty uses and is found in Washington in ancient lakebed deposits.

Nonmetallic mineral commodities such as portland cement, carbonates, clays, diatomite, olivine, and silica together accounted for approximately 20 percent of the $556 million total value of nonfuel mineral production for Washington in 1994, the last year for which figures are available.

Carbonates

The principal carbonate materials used in Washington are limestone and dolomite. Large amounts are used in construction, agriculture, and the chemical and metallurgical industries. Limestone is used in the manufacture of cement; however, all of the limestone used to produce cement in Washington is from Texada Island, British Columbia. Carbonate rocks are calcined to produce lime, which is required in some chemical and metallurgical industries, as well as a soil conditioner in agriculture. Generally, lime used by chemical industries is of high purity.

Northwest Alloys produces agricultural soil conditioners by using reject materials from magnesium metal production at Addy (no. 2). The company is experimenting with using the remaining reject materials at their operation for additional agricultural land conditioners and hopes to market or use their entire production of reject materials by the year 2000. Some of their reject materials could be used to manufacture cement; however, the company has not yet thoroughly explored marketing cement. No other company is reported to have expressed interest in buying their reject material for cement manufacture.

Dolomite use for terrazzo and exposed aggregate suffered a setback when Nanome Aggregates Inc. (nos. 110 and 108) closed its Washington operations. They had mined various types and colors of dolomite from several different quarries in the Chewelah area. Northwest Marble Products Co. (no. 106), however, is able to supply the same colored dolomite products from that area.

Columbia River Carbonates continued production of carbonate for use as a paper coating and filler from its limestone (marble) quarry (no. 114) northwest of Republic.

Several other companies or quarries (nos. 102, 103, 104, 111, 116) in northeastern Washington also produced carbonates for a variety of uses in 1995.

The only known western Washington carbonate production was of limestone from the Maple Falls quarry (no. 124), owned by Clausen Lime Co.

Olivine

Olivine, a silicate containing magnesium and iron, has been used primarily as a foundry sand (Kramer, 1985). However, in recent years, the high magnesium end-member, forsterite, has been used as a slag conditioner in blast furnace production of pig iron (Teague, 1983).

Figure 5. Magnesium metal is cast into ingots or bars for shipment. Northwest Alloys produces 35-, 50- (shown above), 250-, and 500-lb ingots. Most of the magnesium produced is shipped to aluminum plants for alloying with aluminum to make beverage cans.

The Twin Sisters dunite in the North Cascades is the largest body of olivine in the United States. The dunite crops out over an area of approximately 36 mi^2; relief in the outcrop area is about 5,000 ft (Teague, 1983).

Olivine Corp. mined olivine in 1995 from its Swen Larsen quarry (no. 125) in this dunite body in Whatcom County. The company uses part of its production to construct wood and municipal waste incinerators for international consumers. Olivine Corp. also supplies crushed olivine to UNIMIN, a Belgian company that has a plant at Hamilton (no. 126). UNIMIN mills crushed olivine to produce casting sands and other refractory products.

Clays

"Clay is a natural, earthy, fine material composed largely of a group of crystalline minerals known as the clay minerals" (Patterson and Murray, 1983). Clay is among the leading industrial minerals in terms of the tonnage produced and total value (Patterson and Murray, 1983). Some uses for clays include: making bricks and tile; as an ingredient essential in cement and kitty litter and other absorbent granules; as a filler in many items, including plastics and paper; and to line and seal irrigation canals. Patterson and Murray further state that the term clay is ambiguous; it is used as the name for a group of minerals, as the name of a rock (a rock made up of clay-size particles is also referred to as shale), and for particles of the smallest size known in nature.

Clay mined in eastern Washington in 1995 came from the Mica mine (no. 112) for making bricks and from Quarry Tile Co. (no. 113) for producing ceramic tile. Mutual Materials operates the Mica mine and several quarries in western Washington (nos. 129, 130, 134). Most of the remaining clay production in western Washington (nos. 127, 132, 136) was for the cement industry. Basic Resources Corp. is progressing toward production of bentonitic clay (nos. 118, 119) to line irrigation canals and is investigating other possible markets.

Diatomite

Diatomite is an opaline silica-rich sedimentary rock made up of the skeletal remains of diatoms, unicellular aquatic plants related to the algae (Kadey, 1983). Diatoms first became abundant in the Late Cretaceous, but most commercial deposits are of Tertiary age (Bates, 1960). After the diatom dies, it sinks to the bottom of the water body in which it was living. A cubic inch of diatomite may contain as many as 40 million "shells" (Bates, 1960). The diatom structure produces a deposit of low bulk density, high absorptive capacity, high surface area, and relatively low abrasiveness.

Processed diatomite has a unique structure and chemical stability that is preferred for some purposes to any other form of silica. Its most important use is as a filter aid. Diatomite is also useful as a filler and extender in paint, paper, rubber, and plastics. It is also used as an anti-caking agent, thermal insulating material, catalyst carrier, polish, abrasive, and pesticide extender (Kadey, 1983).

All of Washington's diatomite production is by Cellite Corp. in central Washington. The company has several quarries (nos. 120-123) that are in various stages of development, ranging from planning to mining. They are also reclaiming exhausted areas.

Barite

Barite has a relatively high specific gravity, and it is relatively inert, that is, it does not break down or react with other materials. For these reasons, it is ground, mixed with drilling fluids, and used as drilling mud when drilling for oil and gas, especially where the drilling company anticipates that it might encounter gas or oil under high pressure. The high density, or weight, of the barite mud can prevent a blowout and consequent loss of petroleum resource and environmental damage.

Barite is found in two major deposit types: fissure and replacement vein deposits and bedded or sedimentary deposits. Most of the deposits in Washington occur in the northeast part of the state (for example, no. 105), a few are found in the north central part of the state, and only one in western Washington (Moen, 1964). At the present time, there is little demand for Washington barite. The weight of the mineral in relations to its value precludes transporting it great distances for consumption; other deposits closer to major oilfields and lower priced barite from China are more commonly used resources. At Washington deposits that have been active in recent years, the property owner either is trying to sell the property or has dropped it.

Table 2. Some rockery and decorative and dimension stone producers in Washington in 1994 and 1995. Not all quarries listed here reported production in 1995

Property	Location	County	Commodity	Company
Whitestone quarry	sec. 34, 39N, 38E	Stevens	decorative stone	Whitestone Co.
Moonlight quarry	sec. 24, 38N, 37E	Stevens	decorative stone	Whitestone Co.
Kifer quarry	sec. 2, 36N, 37E	Ferry	decorative stone	Raymond Fosback Masonry
Cactus quarry	sec. 16, 13N, 31E	Franklin	rockery	Meridian Aggregates Inc.
Chikamin quarry	sec. 22, 29N, 17E	Chelan	decorative stone	Joe Mahaffee
Two Rivers quarry	sec. 15, 27N, 16E	Chelan	decorative stone, rockery	Two Rivers Sand and Gravel
Kendall quarry	secs. 14-16, 22-23, 40N, 5E	Whatcom	limestone	Tilbury Cement Co.
Whatcom and Skagit quarry	sec. 6, 36N, 4E	Skagit	decorative stone	Whatcom Skagit Quarry
unnamed quarry	sec. 13, 34N, 1E	Skagit	decorative stone	Island Frontier Landscape Construction Co.
Pacific quarry	sec. 33, 34N, 4E	Skagit	rockery	Meridian Aggregates Inc.
Mats Mats quarry	sec. 4, 28N, 1E	Jefferson	rockery	Lone Star Northwest
Iron Mountain quarry	sec. 17, 30N, 7E	Snohomish	rockery	Iron Mountain Quarry Inc.
Granite Falls quarry	sec. 8, 30N, 7E	Snohomish	rockery	Meridian Aggregates Inc.
Cadman Rock quarry	sec. 19, 27N, 7E	Snohomish	rockery	Cadman Rock Co. Inc.
Alpine Miller Rock quarry	secs. 15-16, 27N, 9E	Snohomish	rockery	Alpine Rockeries Inc.
Marenakos Rock Center	various	various	decorative stone	Marenakos Inc.
Mine 11	sec. 11, 21N, 6E	King	decorative stone	Palmer Coking Coal Co.
Franklin Rock quarry	sec. 18, 21N, 7E	King	decorative stone	Palmer Coking Coal Co.
Enumclaw quarry	sec. 1, 20N, 6E	King	rockery	Enumclaw Quarry Inc.
410 quarry	sec. 20, 20N, 7E	King	rockery	410 Quarry Inc.
Miller River Quarry	sec. 28, 26N, 11E	King	rockery	Meridian Aggregates Inc.
Buckley quarry	sec. 7, 19N, 7E	Pierce	rockery	Washington Rock Quarries Inc.
Wilkeson quarry	sec. 27, 19N, 6E	Pierce	rockery, dimension stone	Rockeries Inc.; Marenakos Inc.
Kapowsin quarry	sec. 8, 17N, 5E	Pierce	rockery	Washington Rock Quarries Inc.
Lynch Creek quarry	sec. 13, 16N, 4E	Pierce	rockery	Randles Sand and Gravel Inc.
Hercules quarry	sec. 37, 16N, 1W	Thurston	decorative stone	Northwest Stone Inc.
Johnson Creek	sec. 24, 16N, 1W	Thurston	rockery	Sea Tac Rock Co.
Jones quarry	sec. 29, 18N, 2W	Thurston	rockery, decorative stone	Jones Quarry Inc.
Snow Queen quarry	sec. 36, 14N, 11E	Yakima	decorative stone	Heatherstone Inc.
Blockhouse quarry	secs. 5, 8-9, 4N, 15E	Klickitat	decorative stone	D. M. Layman Inc.
Red Rock quarry	sec. 27, 4N, 16E	Klickitat	decorative stone	Bishop Red Rock Inc.
Fisher quarry	sec. 8, 1N, 3E	Clark	decorative stone	Gilbert Western Corp.

Silica

Silica consists of the elements silicon and oxygen; these are most commonly the mineral quartz. Although quartz deposits of high purity may have formed in several ways, the most common is as beach sands. Most beach sands, however, contain enough grains of other minerals that they are not pure enough to be used for manufacturing glass. The Addy quartzite in northeastern Washington, derived from a Cambrian beach sand, and a sandstone of the Eocene Puget Group in western Washington are used for glass manufacture.

Lane Mountain Silica Co. (no. 109) mines Addy quartzite near Chewelah, and Reserve Silica Corp. (no. 131) mines Puget Group sands to produce silica, primarily for the manufacture of bottle glass. Ash Grove Cement Co. (no. 133) mined silica for use in the manufacture of cement.

INDUSTRIAL MINERAL INDUSTRY

Industrial mineral commodities, construction sand and gravel, and construction stone accounted for approximately 46 percent of the $556 million total value of nonfuel mineral production for Washington in 1994, the last year for which figures are available. The overall production value of construction sand and gravel, the single most valuable nonfuel mineral commodity in Washington, was $174 million.

Construction Sand and Gravel

The value of construction sand and gravel is so high because of the volume needed to support the construction industry of the state. The Department of Transportation and county road departments use numerous pits for maintaining roads throughout the state. Large private companies use sand and gravel to make concrete for home and business construction. The size of these companies tends to depend on the size of the market in the community. The greater Seattle area, Spokane, the Tri-Cities, and Vancouver have large sand and gravel operations and typically more than one company competing for the concrete business. (See Lingley and Manson, 1992.)

Large road-construction projects require large amounts of sand and gravel. Sand and gravel sources for these projects should be fairly close to the construction site because transporting sand and gravel a long distance greatly increases the cost of the project.

Major operators in the greater Seattle area in King County are Cadman, Inc., Stoneway Concrete Co., M. A. Segale, Inc., Miles Sand and Gravel Co., and Lakeside Industries. In Snohomish County, they are Associated Sand and Gravel, Inc., and Cadman, Inc., at the Everett pit, and in Pierce County, Woodworth and Co., Inc., Lone Star Northwest, Corliss Co., and Tim Corliss and Son, Inc. In the Olympia area, a major operator is Nielson Pacific Ltd. at the Nisqually pit. Gilbert Pacific operates in Clark County at the English pit. Central Pre-Mix Concrete Co. operates a plant in Yakima, and Central Pre-Mix and Acme Materials and Construction Co. have large operations at sand and gravel pits in the Spokane and Tri-Cities areas. Several companies may operate from a large, single pit area, and companies may have different pits for specific types of sand or gravel.

The list of major sand and gravel operators in the larger communities in Washington is far from complete. A more extensive list of sand and gravel operators is available in Lingley and Manson (1992). Smaller operators in these communities, as well as in other communities of the state, commonly can meet local or smaller needs. The 'yellow pages' can give an indication of the activity of the local sand and gravel industry.

Construction Stone

Construction stone quarried in Washington can be classified into two major categories by use—dimension stone and crushed stone. Crushed stone is rock that has been broken, crushed, or ground to smaller fragments, and dimension stone is rock that has been trimmed or cut to a desired shape or size (Laurence, 1973). Building stone in Washington is described in detail by Moen (1967). More recent articles about the building and decorative stone industry in Washington include Gulick (1992) and Knoblach's (1993) brief histories of Washington's stone industry.

In Washington, numerous producers (Table 2) quarry various types of rock to produce crushed landscape rock, rockery (rock used to create a non-mortared wall or barrier), veneer, landscape boulders, rubble or fill, rectangular pieces of stone trimmed to essentially rectangular shapes (termed ashlar), exposed aggregate, terrazzo, flagstone, and cinders (Gulick, 1992). Sand and gravel operators commonly crush oversize rocks, which can then be used instead of round rock aggregate (a term often used for the non-crushed version).

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Erratum

The correct Internet address for the National Center for Earthquake Engineering Research is:

http://nceer.eng.buffalo.edu

This was reported incorrectly in the last issue of *Washington Geology*. Please make a note of the correction. Our apologies to the Center.

Dam Safety Conference

The Canadian Dam Safety Association and the Canadian National Committee of the International Commission on Large Dams will hold a joint conference in Niagara Falls, Ontario, from October 6 to 10, 1996. Session themes include the economics of dam safety and tailings dams. A poster session is part of the program for this meeting.

For more information, contact Grant Smith in Toronto: *Phone:* 416-592-5359; *Fax:* 416-592-4446, or *E-mail:* grant.fsmith@hydro.on.ca.

Washington's Coal Industry—1995

Henry W. Schasse
Washington Division of Geology and Earth Resources
PO Box 47007, Olympia, WA 98504-7007

In 1995, Washington's two coal mines, the Centralia mine in north-central Lewis County and the John Henry No. 1 mine in south-central King County, together produced 4,856,769 short tons, down a mere 11,000 tons from 1994.

The state's largest mine, the Centralia Coal Mine, is operated by the Centralia Mining Company, a division of PacifiCorp. The mine is located 5 miles northeast of the city of Centralia (Fig. 1). Its sole customer is the Centralia thermoelectric plant, situated about a mile from the mine.

The mine completed its 25th year in 1995, producing 4,626,756 short tons of subbituminous coal. This amount is only 8,000 tons less than for the previous year. The mine's average annual production for the past 5 years has been 4.7 million tons; average annual production over the mine's lifetime is 4.3 million tons.

Coal production in 1995 came from four open pits. Coalbeds mined were the Big Dirty, Little Dirty and two splits of this coalbed, Smith, Lower Thompson, Upper Thompson, Tono No. 1, Tono No. 2, and Penitentiary. These coals are part of the Skookumchuck Formation, which is composed of nearshore marine and nonmarine sedimentary rocks. The formation is a 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). It produced 230,013 short tons of bituminous coal in 1995, down only 3,000 short tons from 1994. The John Henry No. 1 completed its ninth full year of production in 1995. The mine is operated by the Pacific Coast Coal Company (PCCC), a joint American and Japanese venture.

PCCC made 54 percent of its sales to the local industrial market, where coal is used largely in the manufacturing process to produce cement and lime in the Puget Sound area. A small amount of those sales were to local public institutions for space heating. The industrial sales value was up from 38 percent of total sales a year ago.

Of the remaining tonnage, 46 percent was exported to South Korea for steam coal. A tiny amount was sold to local residential customers for space heating.

In 1995, PCCC mined coal at its Pit No. 1 (Fig. 2) from four coalbeds, the Franklin Nos. 7, 8, 9, and 10. (See also Fig. 3.) The Franklin coalbeds are stratigraphically near the base of the undivided Eocene Puget Group in nonmarine deltaic sedimentary rocks.

During the past year PCCC extended its workings to the southwest,

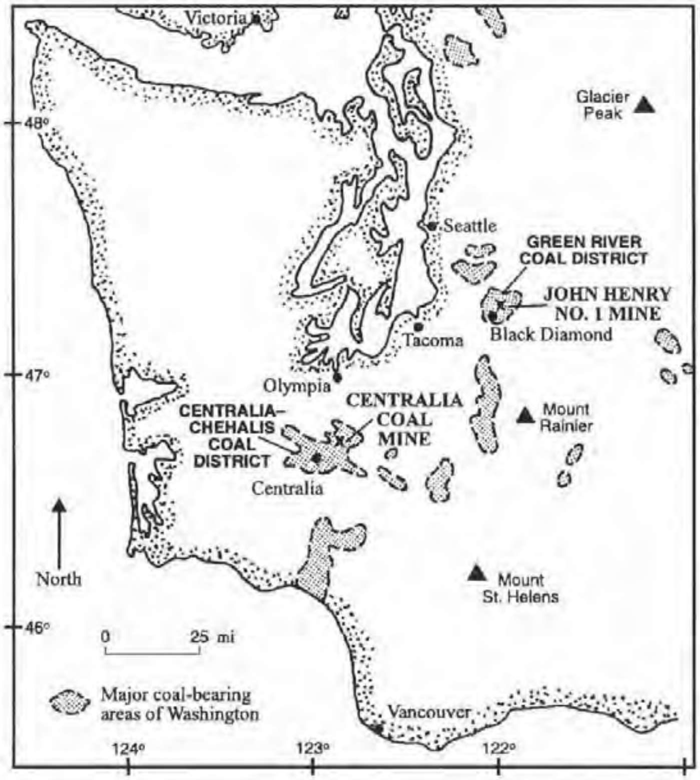

Figure 1. Coal-producing areas and districts, western Washington.

Figure 2. John Henry No. 1 coal mine, Pit No. 1, in January 1996. This view to the northeast shows mining on the southeast limb of the anticlinal structure. Light-colored ('bare rock') material to the left of the large truck forms the floor of the Franklin No. 7 coalbed. The Franklin Nos. 7, 8, and 9 coalbeds merge in this part of the mine; very little sedimentary rock separates the coals. The Franklin No. 10 coalbed is exposed in the highwall to the right out of view.

Figure 3. John Henry Pit No. 1 in January 1996. In this view to the west, the Franklin No. 9 coalbed is exposed just above the fill on the northwest limb of the anticline near its crest in the left half of the photo. Franklin Nos. 7 and 8 coalbeds are buried beneath the fill. Franklin Nos. 10 (exposed above the right edge of ponded water) and 11 (exposed just beneath the upper haul road and also in the right foreground) are the next two seams higher in the stratigraphic section.

mining coals near the crest of the anticline within the mine and along the southeast limb of the structure. In early January 1996, PCCC was mining the Franklin Nos. 7, 8, and 9 coalbeds along the southeast limb where these coalbeds occur stratigraphically close to each other (Fig. 2).

PCCC also mines a clay bed between the Franklin Nos. 9 and 10 coalbeds. The clay is blended with high alumina clay for manufacturing portland cement. ■

Extensive Flood Damage at Mount St. Helens

The floods of February 1996 severely damaged roads in the Mount St. Helens National Volcanic Monument. All access to east side of Mount St. Helens has been cut; therefore the popular tourist locations, such as Windy Ridge and the Harmony Falls Trail, will not be accessible until late summer, if at all, in 1996.

The Cispus Bridge is out, closing Forest Roads (FR) 25 and 26. FR 26 is so heavily damaged by landslides north of Ryan Lake that it may never be reopened as a through road. U.S. Forest Service engineers are currently debating whether to install a temporary bailey bridge over the Cispus River because of the expense. An alternate route to Iron Creek and FR 99 via FRs 23 (Fig. 1) and 76 is also out. FR 90 is extensively damaged along Swift Reservoir; a collapse at Marble Creek is so large that it may require bridging. On southern FR 25, Pine Creek bridge is out and Muddy River bridge is questionable. There is extensive but less serious damage at many other places along FRs 25 and 99. But even after snowpack is gone, repairs cannot begin there until roadbuilding equipment can move past the major outages along both ends of FR 25. These areas will also remain inaccessible until July or later.

There is additional damage on the southwest flank of the mountain. Parts of Merrill Lake Road (FR 81) and Kalama Road are out. Pine–Muddy fan, Lahar Lookout, and Lava Canyon via FR 83 are still accessible, as are Ape Cave and the Trail of Two Forests. Forest Road 8123 is open to Goat Marsh and to the Butte Camp trailhead, but it is closed between Blue Lake and the Sheep Canyon Trailhead because of landslides on the steep slopes above Goat Marsh and farther west.

SR 504, the Spirit Lake Highway, is still open as far as Coldwater Ridge Visitor Center. Anyone planning field trips or touring in the Mount St. Helens area should stay aware of road conditions by checking at visitor facilities. ■

Figure 1. A major washout on the Cispus River Road (FR 23).

The Minerals of Walker Valley, Skagit County, Washington

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

Dan G. and LaVonda M. Vandenburg
623 Fruitdale Road
Sedro-Woolley, WA 98284

INTRODUCTION

In the late 1960s, spectacular mineral specimens were discovered in an outcrop of hydrothermally altered volcanic rock in the Cascade foothills in western Skagit County. A portion of the site has subsequently been quarried as a source of road fill, uncovering a large area of bedrock that was previously obscured by soil and vegetation.

Prized collectors' items include large geodes containing crystals of clear quartz, amethyst, calcite, and siderite (Fig. 1), accompanied by seams and nodules of gem-quality agate. Located about 15 km east of Mount Vernon (Fig. 2), the Walker Valley collecting site has been described in magazines and guide books (Jackson, 1978; Jackson and Jackson, 1974, 1975; Hadley, 1975, 1976, 1990; Pluard, 1977; Pattie, 1985; Ream, 1985; Gannaway, 1993; Claude, 1995), but the geology of the deposit has received little attention. In this article, we review the physical and chemical processes that were responsible for the origin of the various minerals.

GEOLOGIC SETTING

The geology of the Walker Valley area is shown in Figure 2. Geodes occur in a body of volcanic rock that strikes N75°E and dips 65°W. Contacts with other units are not exposed, but the relatively gentle inclination of sedimentary strata at several nearby locations suggests that the igneous material originated as a dike rather than as a surface flow.

To casual observers, the outcrop appears to be a 100-m-wide mass of brecciated rhyolite bordered on either side by unaltered black basalt (Fig. 3). However, thin sections and chemical analyses indicate that the rock consists of andesite of fairly uniform composition and that the bleached central zone was caused by later hydrothermal alteration. Atomic absorption spectrophotometric analysis of a typical sample of dark rock indicated the composition to be:

SiO_2	61.42%	Na_2O	3.55%
Al_2O_3	12.32%	CaO	4.96%
TiO_2	1.12%	K_2O	2.03%
MgO	0.83%	MnO	0.15%
Total iron calculated as		H_2O^+	0.20%
Fe_2O_3	14.30%		

Two samples of light-colored rock gave approximately the same results for all elements except iron. Total Fe_2O_3 in these samples was 10.83 percent and 11.89 percent. These decreased iron values were caused by the partial dissolution of ferruginous minerals during hydrothermal alteration. Light and dark rocks both plot as andesite on the total alkali-silica diagram of LeBas and others (1986) and the International Union of Geological Sciences classification pyramid (Le Maitre, 1989).

Thin sections of the dark rock reveal phenocrysts of plagioclase and clinopyroxene in a glass-rich matrix. In some samples, much of the glass has been altered *in situ* to produce microscopic blebs of amorphous hisingerite, a rare hydrous iron silicate.

In thin sections of light-colored samples, plagioclase laths occur along with siderite, sericite, chlorite, and clays, the latter minerals all having formed as alteration products. Hisingerite is no longer present, individual masses having been dissolved or oxidized to limonite.

Basement rocks in this area consist of a complex tectonic mélange of Paleozoic and Mesozoic rocks that were brought together when pieces of oceanic crust collided with the western edge of North America. These folded and faulted metamorphic rocks are locally overlain by the Early Tertiary nonmarine Chuckanut Formation and nearshore marine conglomerates and sandstones of the Bulson Creek sedimentary unit. Other Cenozoic rocks include eight outcrops of rhyolite and andesite that originated as volcanic flows, welded tuff beds, or intrusive dikes.

10 cm

Figure 1. Quartz-lined geode from the Walker Valley site in Skagit County.

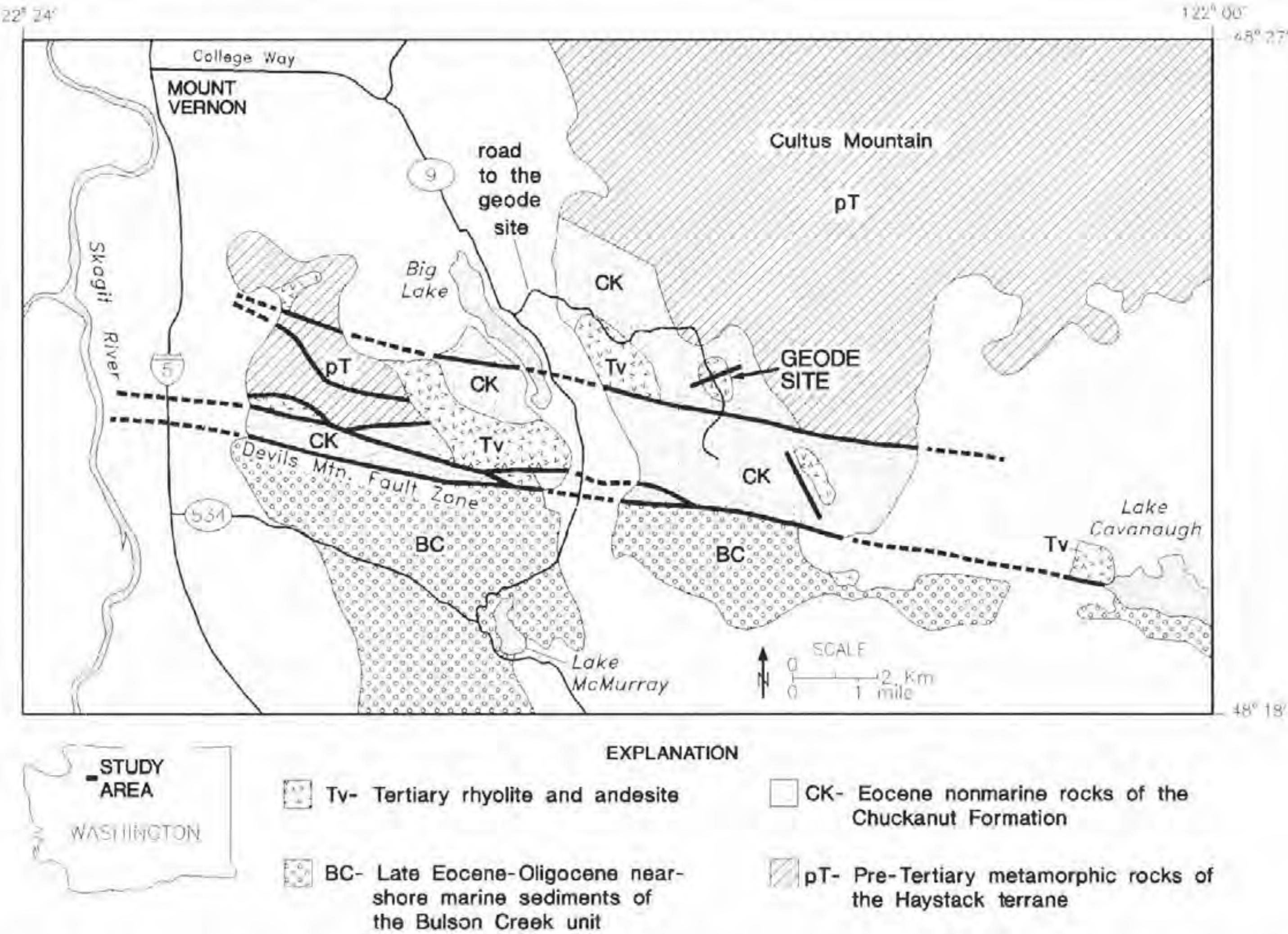

Figure 2. Geologic map of Cascade foothills in western Skagit County. No pattern, unconsolidated Quaternary deposits. Heavy lines are faults. (Modified from Whetten and others, 1988.)

The Walker Valley site is the only place in these volcanic units where geodes have been found (Fig. 4). Their presence at this particular location is the result of episodes of hydrothermal activity that did not affect neighboring igneous bodies.

Regional mapping led geologists to infer that the host rocks at this site are part of the Chuckanut Formation (Marcus, 1991; Whetten and others, 1988). This interpretation was confirmed in 1994 when quarrying exposed a 1-m-thick lens of carbonaceous siltstone within the brecciated andesite.

The geology and mineralogy of the Walker Valley locality suggest that the following sequence of events was responsible for the development of the geode zone:

1. Deposition of Early Tertiary arkosic sediment

Sandstone, conglomerate, and siltstone of the Chuckanut Formation were deposited on a flood plain bordering a meandering river that existed from about 55 million to 40 million years ago, prior to the rise of the North Cascades. These sedimentary strata are separated from the older metamorphic basement rock by faults or unconformities.

2. Formation of andesitic dikes

Slickensided surfaces in the outcrop indicate that magma intruded along a fault that developed when sedimentary rocks of the Chuckanut Formation were uplifted during the rise of the North Cascades range (Fig. 5). This zone of crustal weakness can be traced for at least 2 km in an east-west direction, suggesting that its origin is related to activity along the Devils Mountain strike-slip fault zone, a major structural feature of the region (Lovseth, 1975; Tabor, 1994).

Although geodes occur only where the fault zone is associated with igneous activity, brecciation and silicification of host rock at other locations along the fault has produced deposits of gem-quality agate, the best known of these being the Fly-by-Night claim located along the power line access road about 2 km west of the geode site (Jackson, 1987; Claude, 1995).

The age of the Walker Valley dike has not been determined, but nearby igneous rocks of similar composition have zircon fission-track ages of 39.9 ± 2.4 to 52.7 ± 2.5 ma (Whetten and others, 1988).

As the molten rock began to cool, the release of water vapor and other gases caused vesicles to develop. These cavities range in diameter from about 0.5 to 50 cm (Fig. 6). Their smooth walls and spherical or ovoid shapes are evidence that the host material was relatively fluid. In contrast, gas bubbles in viscous rhyolitic lavas and welded tuffs typically have star-shaped cross-sections, formed when expanding gas vapor

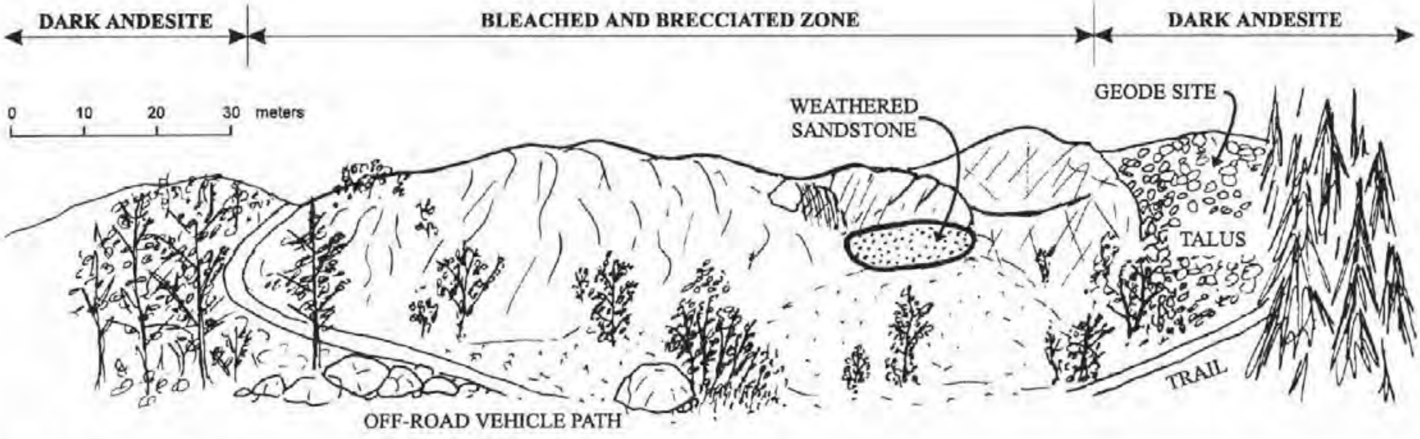

Figure 3. Sketch of the outcrop.

caused the sticky lava to yield in a series of rips and tears. Agate-filled "thunder eggs" from central Oregon provide classic examples of this phenomenon (Ross, 1941).

3. Initial hydrothermal activity

Eventually the molten rock chilled enough that it became solid, producing hard, brittle andesite. During the final stages of cooling, shrinkage caused the development of narrow fractures that intersected the vesicles. These cracks allowed warm mineral-laden water to percolate through the dike, precipitating various minerals as veinlets and cavity fillings. This episode of epithermal activity probably involved solutions at fairly low temperatures and circulating at a crustal depth of less than 1 km (Guilbert and Park, 1986).

Analysis of fluids trapped in microscopic inclusions provides a potential method for determining temperature and pressure at the time of crystallization, but the half-dozen polished slices of quartz and calcite that we examined contained no fluid inclusions. More persistent efforts might be more successful. However, the high degree of transparency typical of Walker Valley crystals is related to the scarcity of microscopic inclusions.

The hydrothermal solutions likely originated when surface water penetrated into the rocks along fractures and porous zones. Water expelled during compaction of adjacent sedimentary rocks may have made an additional contribution. Heat generated by a local body of magma warmed this ground water, causing a decrease in density that promoted upward flow. This ascending plume of hot water leached

Figure 4. Elaine Mustoe collecting geodes in dark-colored andesite. The contact with bleached, brecciated andesite is at the base of the cliff on the left side of the photo.

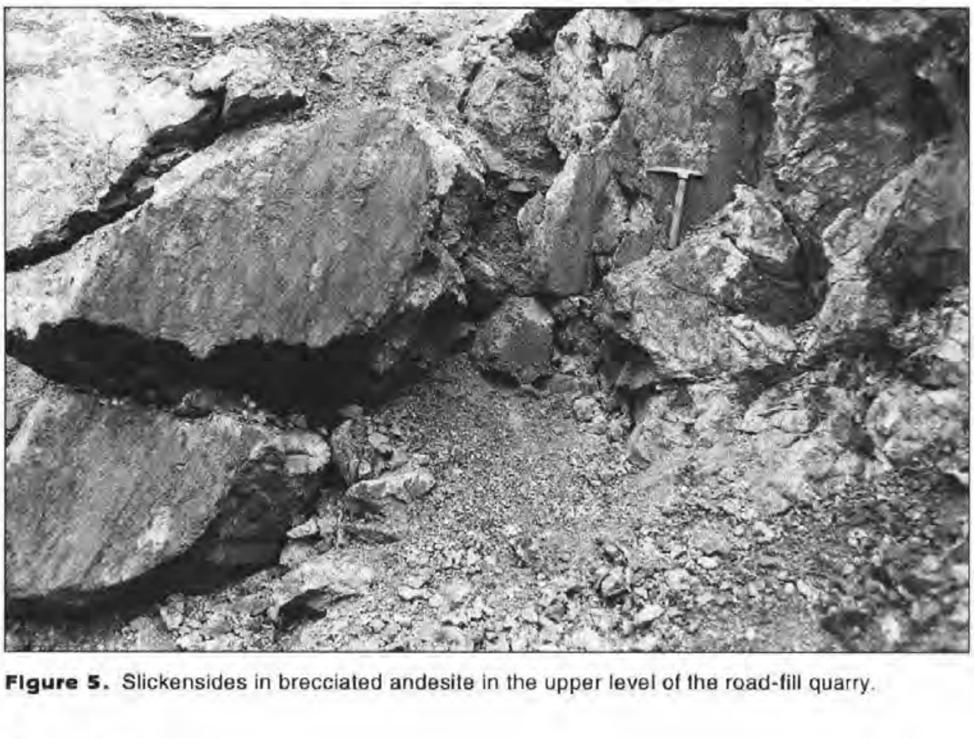

Figure 5. Slickensides in brecciated andesite in the upper level of the road-fill quarry.

elements from the enclosing host rock in proportions that reflect the chemical composition of this crustal material. The Walker Valley hydrothermal deposits primarily contain minerals composed of silica, calcium, and iron, three of the most common rock-forming elements.

4. An explosive hydrothermal event related to faulting

Early stages of mineralization were caused by hot water that gently trickled through fractures and vesicles. However, a later hydrothermal episode behaved quite differently, causing extensive brecciation and alteration within the dike (Fig. 7). The triggering mechanism for this hydrothermal event may have been an episode of seismic activity that created new fissures within the outcrop area, providing a conduit for superheated hydrothermal solutions that arrived with explosive force. At temperatures above the 374°C critical point, water exists as a very dense gas, and a sudden decrease in confining pressure would have caused an abrupt phase change, generating violently boiling liquid and a huge volume of steam capable of shattering the surrounding rock.

This hydrothermal event created an extensive breccia zone. The transition between the fractured material and the adjacent unaltered dike rock is fairly abrupt, a pattern of alteration that suggests that the previous mineralization event filled the original fractures and vesicles so thoroughly that later generations of hydrothermal fluids were unable to penetrate andesite adjacent to the breccia. The contact between bleached breccia and unaltered andesite can be traced uphill from the main collecting site for at least a kilometer, suggesting the possibility that geodes may occur well beyond the present zone of discovery. Although this Washington Department of Natural Resources land is open to exploration by rockhounds, the rugged topography and extensive soil cover create difficult collecting conditions.

Figure 6. Andesite exposure showing quartz-filled cavities. The white circular shapes near the hammer are quartz-filled geodes.

5. Continued regional uplift exposed the dike to the surface

Erosion of the surrounding sedimentary rock left the more resistant andesite as a ridge. Weathering, soil development, and luxuriant plant growth eventually obscured all surface evidence of the contact zone between the dike and its host rock.

MINERALOGY

Minerals precipitate from aqueous solutions because of a variety of physical and chemical factors, including temperature, pressure, acidity (pH), oxidation-reduction potential (Eh), and the concentration of dissolved elements. Successive mineral layers in Walker Valley geodes provide clues that allow us to reconstruct the hydrothermal history of the deposit. Precipitation can be triggered due to a temperature drop caused by contact of the hydrothermal solution with cool wall rock, a proc-

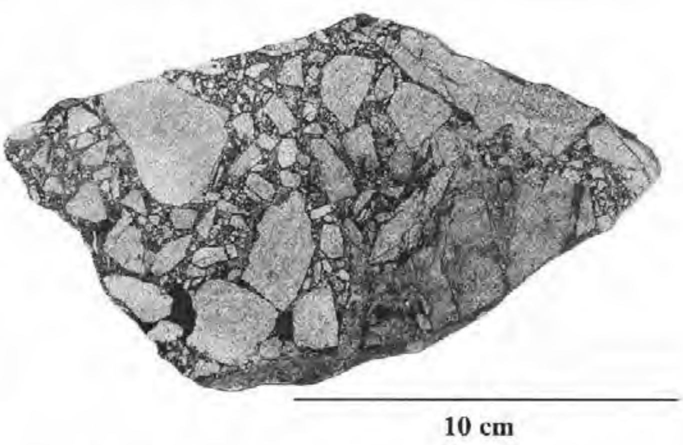

Figure 7. Breccia composed of clasts of bleached andesite in a ferruginous matrix.

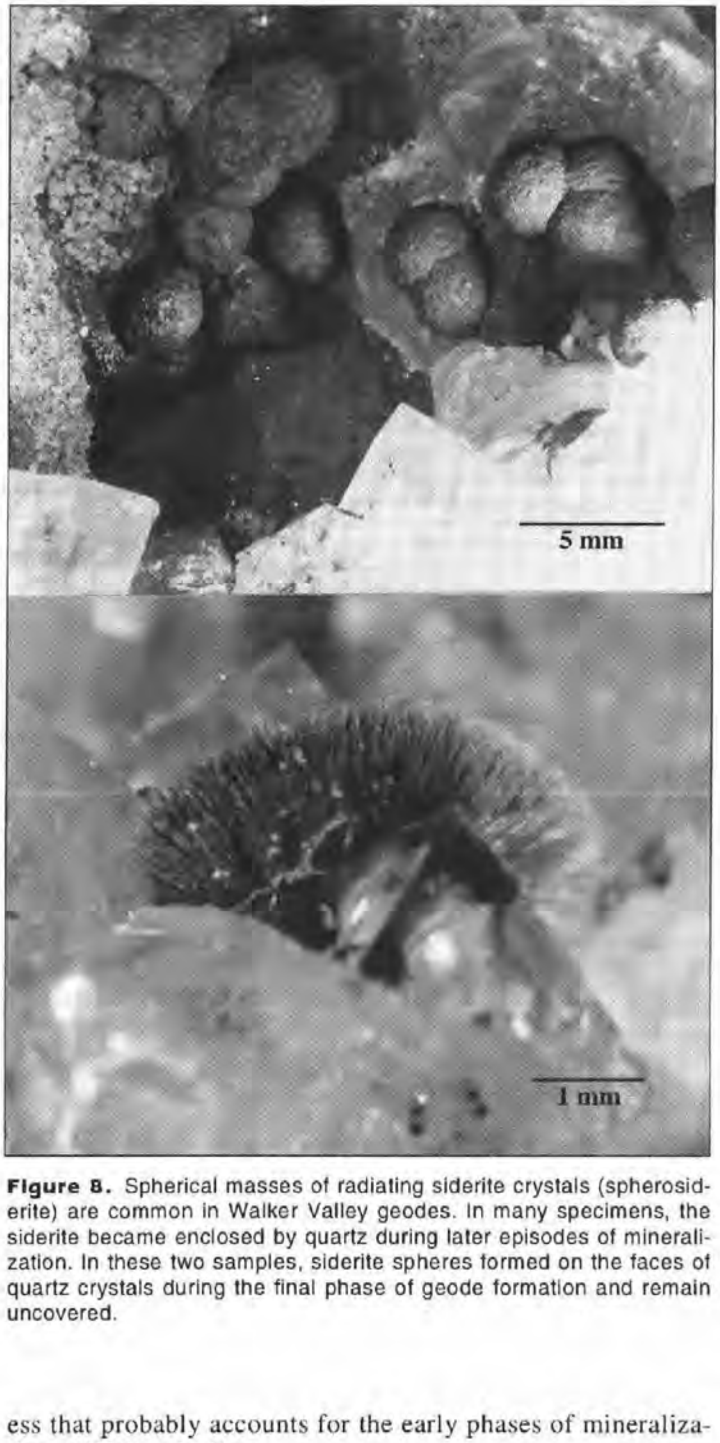

Figure 8. Spherical masses of radiating siderite crystals (spherosiderite) are common in Walker Valley geodes. In many specimens, the siderite became enclosed by quartz during later episodes of mineralization. In these two samples, siderite spheres formed on the faces of quartz crystals during the final phase of geode formation and remain uncovered.

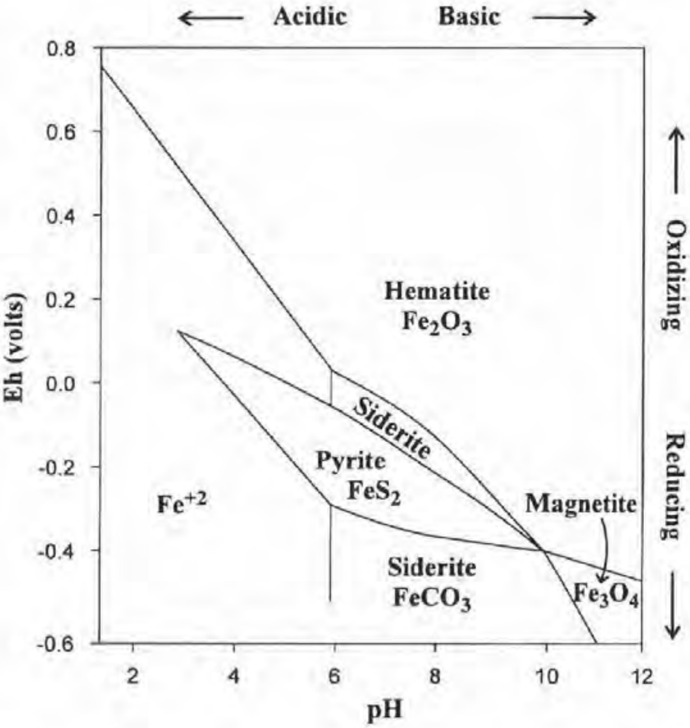

Figure 9. Stability range of common iron minerals at 1 atmosphere of pressure, 25°C temperature, and Fe^{+2} concentration of 10^{-6} M. (Modified from Krauskopf, 1967, p. 252).

ess that probably accounts for the early phases of mineralization at Walker Valley.

Mineral formation may also occur when ascending hydrothermal waters encounter open fractures, resulting in a drop in pressure that causes sudden boiling. This type of event probably played an important role during the last stage of the mineralization sequence.

The stages of mineralization described below are generalizations based on examination of numerous geodes, but not every specimen shows all of these features.

Stage 1: Hisingerite, quartz, and spherosiderite

Walker Valley geodes typically contain an outermost layer of hisingerite in contact with the adjacent andesite, providing a brittle parting layer that often allows specimens to be removed from the matrix with relative ease. These layers typically consist of several thin laminations of hisingerite alternating with crystalline quartz. Hemispherical masses of fibrous microcrystalline siderite may occur within the quartz (Fig. 8). Less commonly, the outer wall of the geode consists of a single hisingerite layer as much as 1 cm thick and resembling obsidian in color and luster.

The high ferric iron content of hisingerite suggests that the mineral forms in oxidizing environments, but conditions required for its precipitation have never been experimentally determined. The stability ranges of common iron minerals are shown in Figure 9.

Siderite forms under reducing conditions within a wide pH range, whereas an increase in oxidation potential causes dissolved iron to crystallize as hematite or goethite. The presence of carbonaceous sedimentary rock adjacent to the dike may have contributed to reducing electrochemical conditions in circulating hydrothermal waters by providing a source of reducing agents created during anaerobic decomposition of organic matter.

The initial precipitation of quartz as crystalline crusts provides several clues about the hydrothermal environment. Experimental studies suggest that silica is likely to precipitate as opal at temperatures of 100°C or less. At temperatures of 100°–300°C, crystalline quartz forms if levels of dissolved silica are low, but higher silica levels result in precipitation of chalcedony (Krauskopf, 1956; White and Corwin, 1961). At higher temperatures, silica may be deposited as cristobalite. The mineralization therefore tells us that early hydrothermal activity involved dilute silica solutions containing iron and carbonate ions flowing through fissures and vesicles at a temperature between 100° and 300°C.

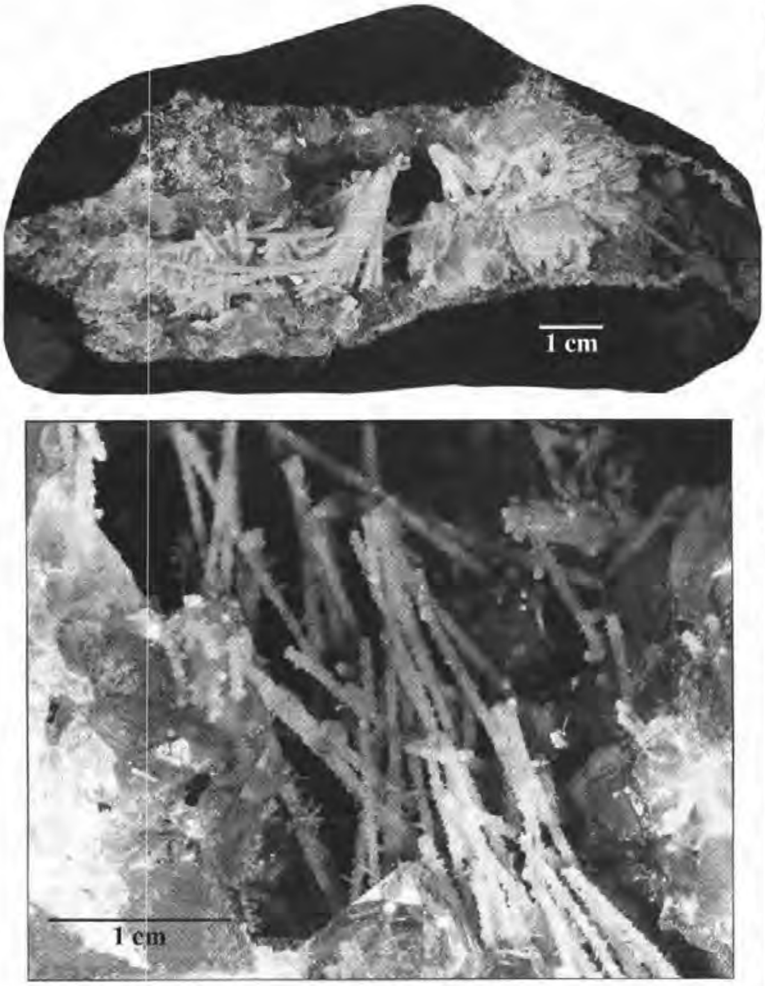

Figure 10. Geode containing clear quartz crystals and rod-like white calcite crystal masses.

Stage 2: Euhedral quartz and amethyst

Subsequent mineral layers show a gradual shift in the conditions of crystallization. Many geodes contain coarsely crystalline quartz linings, and a few contain clear quartz crystals in the form of stalactitic columns as wide as several centimeters in diameter. A particularly spectacular example is on display at the Thomas Burke Memorial Washington State Museum at the University of Washington in Seattle. Amethyst crystals in light to medium shades line the central cavities of many geodes, occurring as purple terminations on quartz crystals that are otherwise colorless. Amethyst's color is caused by Fe^{+3} ions present as an interstitial impurity. This Fe^{+3} is evidence of shallow crustal depth, because quartz formed at deeper levels contains interstitial iron in the Fe^{+2} valence state (Cohen, 1985). The presence of amethyst provides an indication of dissolved iron within the hydrothermal fluids, even after hisingerite and siderite were no longer being precipitated.

Stage 3: Siderite and calcite

While spherosiderite is found in the outermost geode layers, ordinary siderite occurs in the central zone of some geodes as brown or amber-colored crystals, generally as columnar masses of stacked plates, radiating rods, or jackstraw arrangements. In some geodes, these crystals have later been encased by clear quartz, producing a pattern that rockhounds call 'sagenite'.

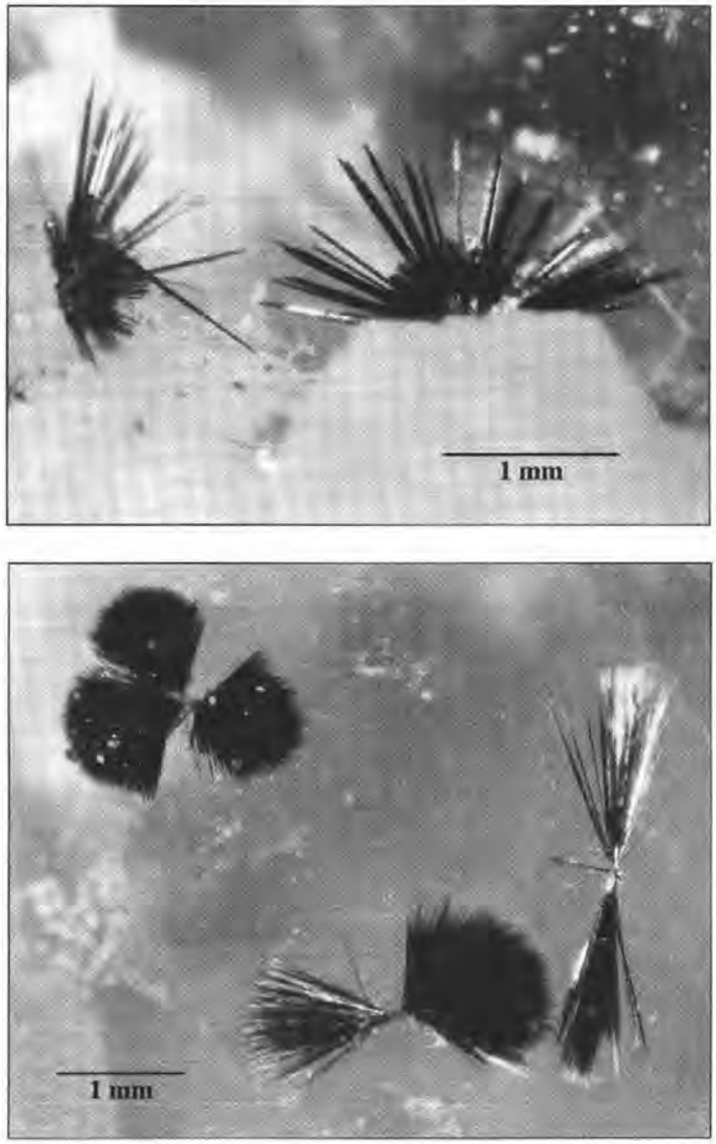

Figure 11. Microcrystals of goethite on quartz from the interior of a geode.

Calcite occurs in geode centers in a variety of habits, including white jackstraw clusters (Fig. 10), dendritic shapes, large translucent yellowish crystals, and clear crystalline masses showing prominent rhombic cleavage.

Many specimens have an empty central area, created when the circulation of hydrothermal fluids was obstructed after narrow fractures leading to the cavities became completely mineralized. These fractures contain the same minerals found in the adjacent geodes. The effectiveness of this sealing-off process is evident when collectors use hammers and chisels to quarry the andesite—the first hint that a geode is close at hand is often leakage of water that has been trapped inside it for millions of years.

Stage 4: Goethite, pyrite, and hematite as microcrystals

In addition to the large crystals that line the geodes, examination with a binocular microscope reveals a wealth of microcrystals present as encrustations on the surfaces of the central cavity. Goethite is the most abundant micromineral, generally occurring as radiating sprays of acicular crystals (Fig. 11). Tiny hexagonal plates of hematite are present in a few specimens. Both minerals indicate that oxidizing conditions existed during the final stage of geode filling, in contrast to the strongly reducing environment that prevailed during the main mineralization episode.

The sporadic occurrence of pyrite at Walker Valley is rather puzzling. Pyrite and siderite both form under similar conditions of Eh and pH (Fig. 9), and the scarcity of pyrite suggests that percolating waters had a low sulfur content, so that iron was unable to crystallize as a sulfide. However, in 1992, the Vandenburgs found a geode containing three intergrown pyrite cubes, each about 1 cm in width. Pyrite also occurs as microscopic cubes and pyritohedrons encrusting surfaces of quartz and goethite in the central cavities of some geodes. These occurrences may represent a chemical environment where sulfur was present as a local anomaly, perhaps derived from the adjacent volcanic matrix.

Goethite and pyrite have been observed as inclusions in quartz crystals bordering the central geode cavity. However, these iron minerals more commonly occur as encrustations on the surface of the quartz, indicating that most microcrystal formation took place after silica deposition had ceased.

Stage 5: Minerals of the brecciated zone

The previous four stages describe the minerals found in geodes and fissures in the zone where fresh, dark-colored andesite occurs. The mineralogy of the brecciated zone shows several important differences. The enclosing host rock has been bleached and oxidized, and mafic minerals have been dissolved. Iron released from this decomposition has led to the precipitation of hydrous iron oxides along fracture zones and as breccia matrix. Hisingerite that had previously formed in geodes or fissures has been either been dissolved to create voids or oxidized to limonite or goethite. Extensive silicification along fractures resulted in the deposition of chalcedony, creating the white, gray, and blue 'seam agate' prized by collectors. The presence of whitish crusts of cristobalite (Fig. 12) provides evidence of high-temperature hydrothermal fluid, and mordenite (a zeolite) has been identified from x-ray diffraction patterns. However, well-crystallized specimens of any kind are scarce, and the mineralogy of the brecciated zone has not been studied in detail.

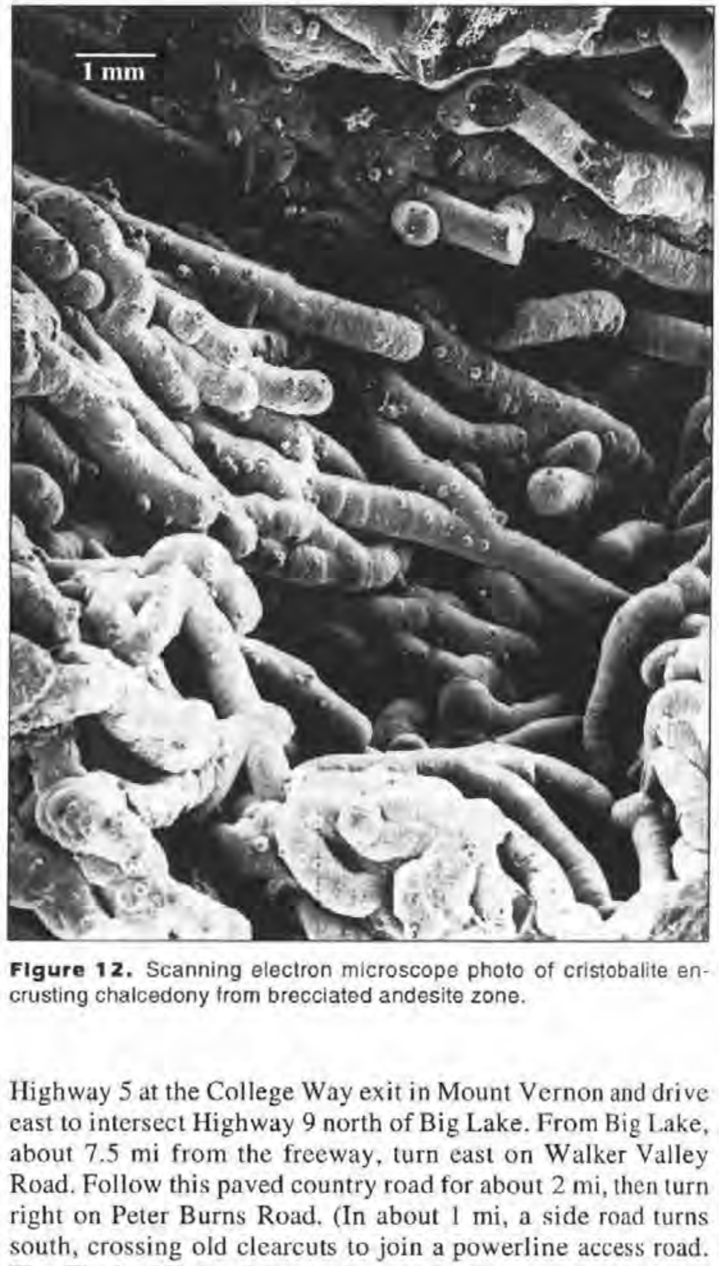

Figure 12. Scanning electron microscope photo of cristobalite encrusting chalcedony from brecciated andesite zone.

COLLECTING INFORMATION

The Walker Valley site is managed by the Department of Natural Resources and is leased to the Washington Mineral Council, a nonprofit organization that strives to maintain public access to collecting sites. Commercial collecting at the site is not allowed, and power tools and explosives are both prohibited, but there are no fees or quantity limits. Permission to collect is not required, but visitors are asked to refrain from littering, building fires, or otherwise causing damage.

Geodes are relatively abundant in certain areas of the deposit, but their extraction requires strenuous labor and skilled use of hammers, chisels, and pry bars. Hammering the brittle host rock yields razor-sharp shards, making protective goggles a necessity.

For those with less zeal for hard-rock mining, a large talus slope produces attractive specimens, but rockfall hazards make this site suitable only for small groups.

The site (Fig. 2) can be reached year-round by ordinary passenger vehicles. An easy approach is to leave Interstate Highway 5 at the College Way exit in Mount Vernon and drive east to intersect Highway 9 north of Big Lake. From Big Lake, about 7.5 mi from the freeway, turn east on Walker Valley Road. Follow this paved country road for about 2 mi, then turn right on Peter Burns Road. (In about 1 mi, a side road turns south, crossing old clearcuts to join a powerline access road. The Fly-by-Night claim and several other agate collecting sites are located along this very rough road.) To reach the geode-bearing outcrops, stay on Peter Burns Road, passing the entrance to an off-road vehicle recreation area parking lot in another half-mile. The Mineral Council site is located a half-mile farther, where the road passes a prominent zone of rust-colored cliffs.

The geode-bearing zone can be reached by walking a few hundred feet up a path through the forest on the south side of the outcrop or by driving a quarter-mile farther and turning left on a logging road that ascends one switchback to the top of the quarry.

Acknowledgments

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Report on the First Symposium on the Hydrogeology of Washington State

Nadine Romero
Washington Department of Ecology
PO Box 47600, Olympia, WA 98504-7600

The State of Washington held its first major ground-water science conference in late August 1995 at The Evergreen State College in Olympia. More than 360 professionals attended, coming from the Pacific Northwest and beyond. More than 70 presentations and 30 posters were delivered in concurrent sessions during the two-and-a-half-day symposium. Theme sessions featured physical hydrology, ground-water modeling, geophysics, geochemistry, applied technology, and ground-water science policy. A ground-water sampling workshop was offered, and a trade and poster exhibition was also presented.

Sponsored by the Washington Department of Ecology, the broad goal of the symposium was to bring together for the first time the ground-water and hydrologic science community to present and discuss current research and the status of Washington's ground water. The success of the symposium was signaled by the large turnout and response from more than 150 environmental consulting firms, government agencies, tribes, and universities. After the compilation of evaluations and commentary on this first gathering, a second symposium is being considered for The Evergreen State College in August 1997.

Opening Remarks

Mary Riveland, Director of the Department of Ecology; Carl. R. Goodwin, Chief of the Washington District, U.S. Geological Survey's Water Resources Division, Tacoma; and Michael Barcelona, Director of Field Operations and Research and Adjunct Professor of Civil Engineering, University of Michigan, Ann Arbor, presented the opening remarks.

Goodwin described the tremendous challenges that scientific agencies face with legislators, citing the recent proposal

Continued on page 39

Geohydrology of Peone Prairie, Spokane County, Washington

David E. Boleneus
9910 N. Ridgecrest Drive
Spokane, WA 99208

Robert E. Derkey
Washington Division of Geology and Earth Resources
904 W. Riverside, Spokane, WA 99201-1011

INTRODUCTION

Peone Prairie lies approximately 3 mi northeast of the Spokane city boundary (Fig. 1). Mead, an unincorporated area undergoing rapid suburban growth, is located at the west edge of Peone Prairie. Local residents and state and county governments are concerned about water availability and water quality for this rapidly increasing population.

This report describes the various aquifer and confining (or aquitard) units penetrated during drilling and the results of ground-water, geophysical, and oil-field tests made in 1977 and 1978 as part of a mineral exploration venture. The drilling took place on Peone Prairie in an area 4 mi east-to-west by 3 mi north-to-south. The subsurface geology and hydrology presented in this report are based on results of this drilling, and although the information is adaptable to the hydrologic analysis presented here, it may be limited because some of the tests were specific to mineral exploration.

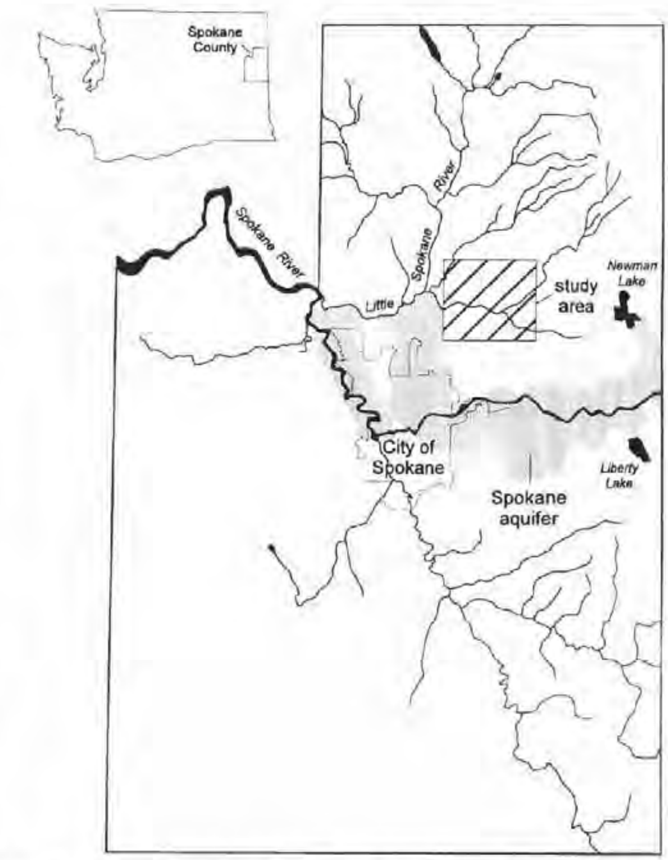

Figure 1. Location of the study area in Spokane County. Peone Prairie is the south two-thirds of the Mead quadrangle. The Spokane Valley/Rathdrum Prairie Aquifer area is represented by the dotted pattern.

PREVIOUS STUDIES

The most relevant geologic mapping in the greater Spokane area consists of two 1:62,500-scale geologic maps of the Greenacres (Weis, 1968) and Mount Spokane (Weissenborn and Weis, 1976) 15-minute quadrangles. Other maps include the 1:100,000-scale Spokane quadrangle (Joseph, 1990) and a 1:125,000-scale reconnaissance geologic map of the west half of the Spokane 1 x 2 degree sheet (Griggs, 1966). In 1992–94, W. J. Gerstel, C. W. Gulick, and Derkey of the Washington Division of Geology and Earth Resources (DGER) mapped (at 1:24,000 scale) Pleistocene and younger deposits of the Spokane Valley/Rathdrum Prairie aquifer and adjacent areas for the Spokane County Water Quality Management Program. Figure 2 is a 1:60,000-scale portion of that map.

The subsurface information and interpretations presented in this paper are based on results of an exploratory drilling (ground geophysics and rotary) program (Boleneus, unpublished data). Resistivity and gravity surveys completed in 1977 showed that as much as 1,000 ft of sediment overlies crystalline basement. In 1978, fourteen rotary drill holes were completed and logged electrically using natural radioactivity, spontaneous potential, resistance, and caliper devices. Additionally, samples taken at 10-ft intervals in these holes were described by a geologist on the site. Collectively, these data are referred to as 'borehole logs' for this report. Coincident with drilling and logging, geologists made eight drill-stem tests on selected sand intervals in six boreholes from which water levels were recorded; they also took water samples for helium analyses.

GEOLOGY

Rock and sedimentary units underlying Peone Prairie include, from oldest to youngest, metamorphic rocks of the Priest River metamorphic core complex, Mount Spokane granite and alaskite, pegmatite, and aplite, Latah Formation and Columbia River Basalt Group, glacial lake deposits, and Lake Missoula catastrophic flood deposits.

Older Rocks

Mount Spokane granite (unit Kgm) (Cretaceous) is predominant in outcrops in the hills immediately surrounding the prairie. It is a foliated to massive, medium- to fine-grained biotite-muscovite granite containing quartz, K-feldspar, plagioclase, muscovite, and biotite (Joseph, 1990). Scattered bodies of Eocene to Cretaceous alaskite, pegmatite, and aplite (unit Tka) are also present in the hills around the prairie. Both granitic rock units intrude high-grade metamorphic rocks of the Priest River metamorphic core complex (Rehrig and others, 1987; Armstrong and others, 1987).

Latah Formation

The Miocene Latah Formation (unit Tl) (Hosterman, 1969; Pardee and Bryan, 1926; Robinson, 1991) consists of poorly indurated lacustrine and fluvial deposits of gray to tan to yel-

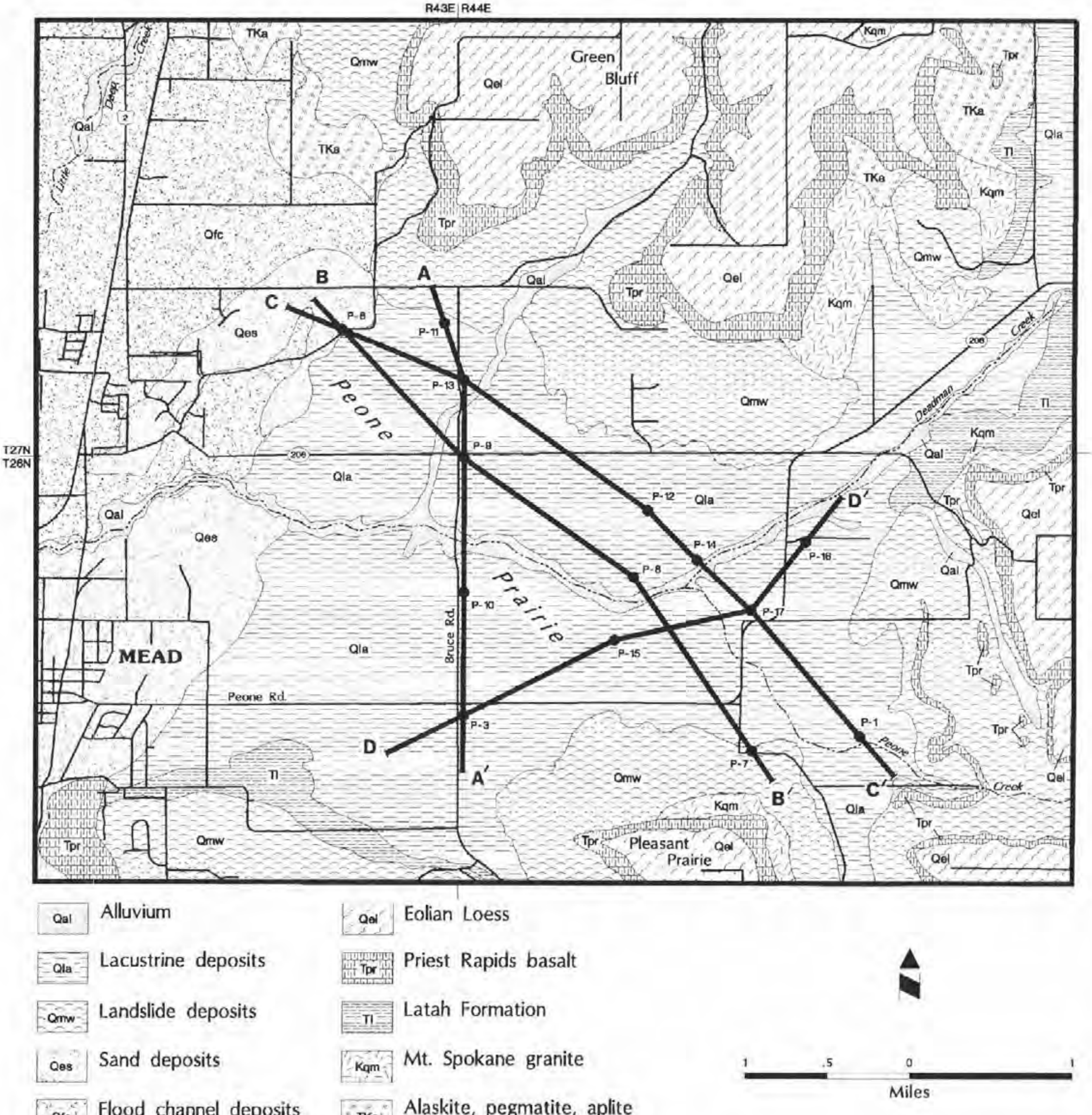

Figure 2. Geologic map, with drill hole locations, of the Peone Prairie area northeast of Spokane. Geologic cross sections A–A′—D–D′ are shown in Figure 5.

low-orange siltstone, claystone, sandstone, and minor conglomerate. These deposits are thought to span the later stages of a period of Miocene "deep weathering" (Robinson, 1991) and are interbedded with and underlie the local units of the Columbia River Basalt Group. Borehole cuttings indicate the sandstones are arkosic to quartzose, fine to coarse grained and locally pebbly, and olive brown to medium light gray; grains are rounded to angular. Claystone varies from brownish gray to greenish gray to olive gray and is commonly silty. Pyrite and organic matter contents in the formation range from 0 to 0.5 percent and 0.5 to 1.5 percent, respectively. Latah deposits are extensive and thick in areas interpreted as paleo-depressions (low areas) and pinch out in paleo-higher areas. The topography in Latah time was not unlike that of Spokane today.

Columbia River Basalt

Basalts of the Columbia River Basalt Group (Miocene, Reidel and Fecht, 1987; Griggs, 1976; Swanson and others, 1979) are described as "flows of dense, dark, tholeiitic basalt, usually from 50 to 150 ft thick, and essentially flat lying" (Griggs, 1973). Two formations of the Columbia River Basalt Group are exposed in the Spokane area: the Wanapum Basalt (Priest Rapids Member) and the Grande Ronde Basalt (Joseph, 1990). Only the Priest Rapids (unit Tpr) is exposed in the map area of Figure 2. It forms the "rim rock" flows (Pardee and Bryan, 1926) of Green Bluff and Pleasant Prairie and the prominent bluff at the east edge of the map area.

Figure 3. Quaternary lakebeds in a roadcut on Bruce Road. Slope wash obscures bedding, which includes two clay beds (light bands; 3–6 in. thick) and silt and fine sand beds (as much as 3 ft thick).

Quaternary Deposits

Quaternary sediments of Peone Prairie consist of Pleistocene glacial lakebeds (unit Qla) (Hosterman, 1969) of predominantly sand, silt, and clay with scattered boulders. The lakebeds commonly occur as remnants in tributary valleys (including Peone Prairie) north of the Spokane Valley and are probably deposits of glacial Lake Columbia (D. F. Stradling, Eastern Washington Univ., oral commun., 1995; Waitt and Thorson, 1983). Drop stones as large as 2 ft in diameter, presumably carried by icebergs into the glacial lake, occur in some of the lakebeds; several were uncovered during construction of the Mt. Spokane–Mead High School.

Bedding in the lakebeds is obscure; in places it is contorted, which suggests a debris-flow origin. Silt and fine sand beds range up to 3 ft in thickness; clay interbeds between 3 and 6 in. in thickness are exposed in roadcuts along Bruce Road (Fig. 3).

Figure 4. The mass-wasting unit shown on the geologic map (Fig. 2) contains basalt slump blocks that poke to the surface on grass-covered hillslopes like the one shown here.

Borehole cuttings show that Quaternary lacustrine deposits (unit Qla) are fine to pebbly and consist of metamorphic rock fragments, some basalt fragments, and little quartz. Limonite staining is common. Clays in this unit range from yellowish brown to olive-brown to medium gray and are commonly silty. Quaternary sediments contain traces of pyrite and organic matter ranging from 0.5 to 1.5 percent; some samples contain as much as 10 percent.

West of Peone Prairie near Mead (Fig. 2), glacial Lake Missoula flood deposits (unit Qfc) are sparsely interbedded with the lakebeds (Kiver and Stradling, 1989; Waitt and Thorson, 1983; Waitt, 1985). The flood deposits are poorly sorted and commonly range from sand to pebble gravels. Many of these interbeds in the Peone Prairie area may be tributary channel deposits; they are not shown on Figure 2. The flood deposits were probably carried into the area by eddy currents tributary to the main flood channels. Where the Missoula flood currents were stronger, glacial lakebeds are not preserved and flood deposits predominate.

Mass-wasting deposits (unit Qmw) occur in areas adjacent to basalt rimrocks. They consist of pebble- to block-size gravel and breccia deposits that apparently slumped, slid, or were carried by debris flows into the lake (Fig. 4). They are all underlain by the Latah Formation in Peone Prairie and likely formed where poorly consolidated deposits of the Latah Formation were eroded, which resulted in undercutting of overlying basalt rimrocks.

Surficial (Unconsolidated) Deposits

Unconsolidated deposits of the Peone Prairie area include surficial wind-blown sand (unit Qes) and loess deposits (unit Qel) and alluvium (unit Qal). These deposits are included on the geologic map (Fig. 2) but are not shown on the cross sections (Fig. 5).

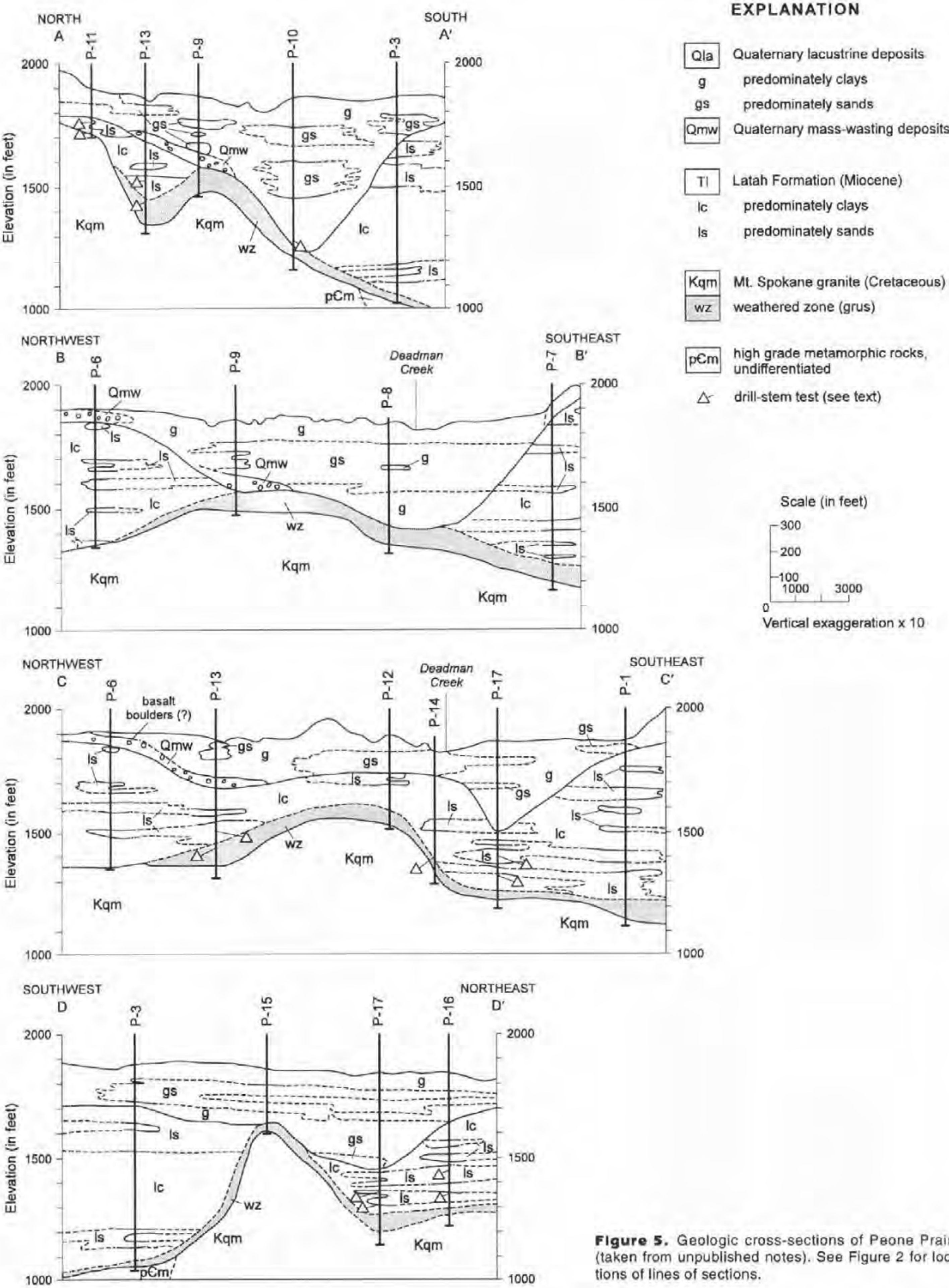

Figure 5. Geologic cross-sections of Peone Prairie (taken from unpublished notes). See Figure 2 for locations of lines of sections.

Wind-blown sand deposits overlie glaciolacustrine and flood deposits on the western side of the prairie and in the Mead area. Some display cross bedding typical of sand dunes. Sub- to well-rounded sand grains are predominantly lithic fragments. Locally, the sand deposits contain beds or lenses of reworked Mazama volcanic ash (dated at 6.8 ka), commonly at or near the surface in the Peone Prairie area.

Loess grains are far smaller than sand grains, and thus they are carried great distances by wind. Where hilltops and fairly flat surfaces of the prairie that are still covered by loess are tilled for farming, the loess is commonly dark brown; loess has not been preserved on the slopes (Fig. 6).

Figure 6. View across a tilled field of a portion of Peone Prairie. Surfaces that have low relief (foreground) and hilltops generally retain a veneer (typically less than 3 ft) of loess and are dark brown on slopes. Where loess has been eroded, the lighter colored lake beds are exposed.

Alluvium, the youngest material on Peone Prairie, occurs along Deadman Creek and other local drainages.

SUBSURFACE AND AQUIFER GEOLOGY

We used borehole logs to construct two northwest–southeast, one north–south and one east–west cross section (Fig. 5). These indicate the extent of the various local aquifers. Cross sections show the magnitude of Pleistocene erosion and subsequent sedimentation events. A representative borehole log (Fig. 7) provides an example of the comprehensive and complementary value of information that constitutes the borehole logs used in constructing the cross sections.

Used in combination, borehole samples and borehole geophysical logs (radioactivity, spontaneous potential [SP], resistance, and caliper) are of enormous value in identifying and describing sedimentary units and in allowing detailed stratigraphic correlation of units and hydrogeologic analysis across the study area. Natural radioactivity and resistance logs are particularly sensitive to changes in grain size and composition of units penetrated. The SP log, in addition to providing lithology distinctions, signals changes in conductivity of waters between the borehole and formation (Driscoll, 1987, p. 180-201; Keys, 1989).

Borehole data permit interpreting the depositional setting of rock and sediment intervals (Fig. 7). Fining-upward and coarsening-upward sequences are indicated from borehole logs. In conjunction with helium data, interpretation of depositional setting can provide important inferences about aquifer geology beyond the borehole site.

Weathered Granite Aquifer

At three sites (P-9, -12, -15), buried hills of granite were identified. Interpreted as the pre-Latah weathering surface, these hills were again exposed prior to deposition of the Quaternary lacustrine deposits.

The weathered zone, or grus, overlying granitic basement was identified from borehole logs to be soft and possibly friable and sufficiently fractured to act as an aquifer. Drills penetrated this zone rapidly, and borehole logs show it has characteristics that differ from those of the sediments above and the basement rock below. Data show the weathered zone varies from 14 to 151 ft thick and averages 70 ft thick. This zone occurs in all the prairie boreholes and may represent an important aquifer where thick sections occur at shallow depths, as at boreholes P-9 and P-13.

Latah Formation

The poorly indurated Latah sands are as widespread as Quaternary sands. Latah sands that produce water are considered porous and permeable based on qualitative characteristics of drill-stem tests and lower resistance values exhibited on borehole logs and drill penetration rates; however, permeability and porosity tests were not made. Sand composition approximates that expected from erosion of the underlying granitic rocks. Aquifers in the Latah consist of medium to coarse sands. The geophysical log responses are consistent with deltaic (coarsening upward), fluvial point bar (fining upward), or channel deposits.

The Latah consists of at least five coarsening-upward, possibly lake-filling cycles (Robinson, 1991). Thickness of the entire Latah Formation varies from 4 ft in P-15 to 695 ft in P-1, the thickest uninterrupted sedimentary thickness identified in the region. The average thickness of the Latah is 350 ft; it is more than 350 ft thick in seven of the boreholes (P-1, -3, -6, -7, -13, -14, -16).

Sand beds determined to be porous and permeable (see above) constitute 25 percent by volume of the Latah section, indicating that significant aquifers may be present. The specific yield for such material normally ranges from 25 to 35 percent (Fetter, 1994, p. 93). Taken together, this indicates that total water volume in this aquifer varies from 6 to 10 percent.

Thickness and depth of significant shallow Latah sands are:

Borehole no.	Depth (ft)	Total thickness (ft)
P-1	200–250, 280–300	70
P-3	180–250, 275–315, 330–370	150
P-12	150-190	40
P-13	265–283, 311–370	77
P-16	285–305, 359–371*	32

* Drill-stem test interval; see p. 36

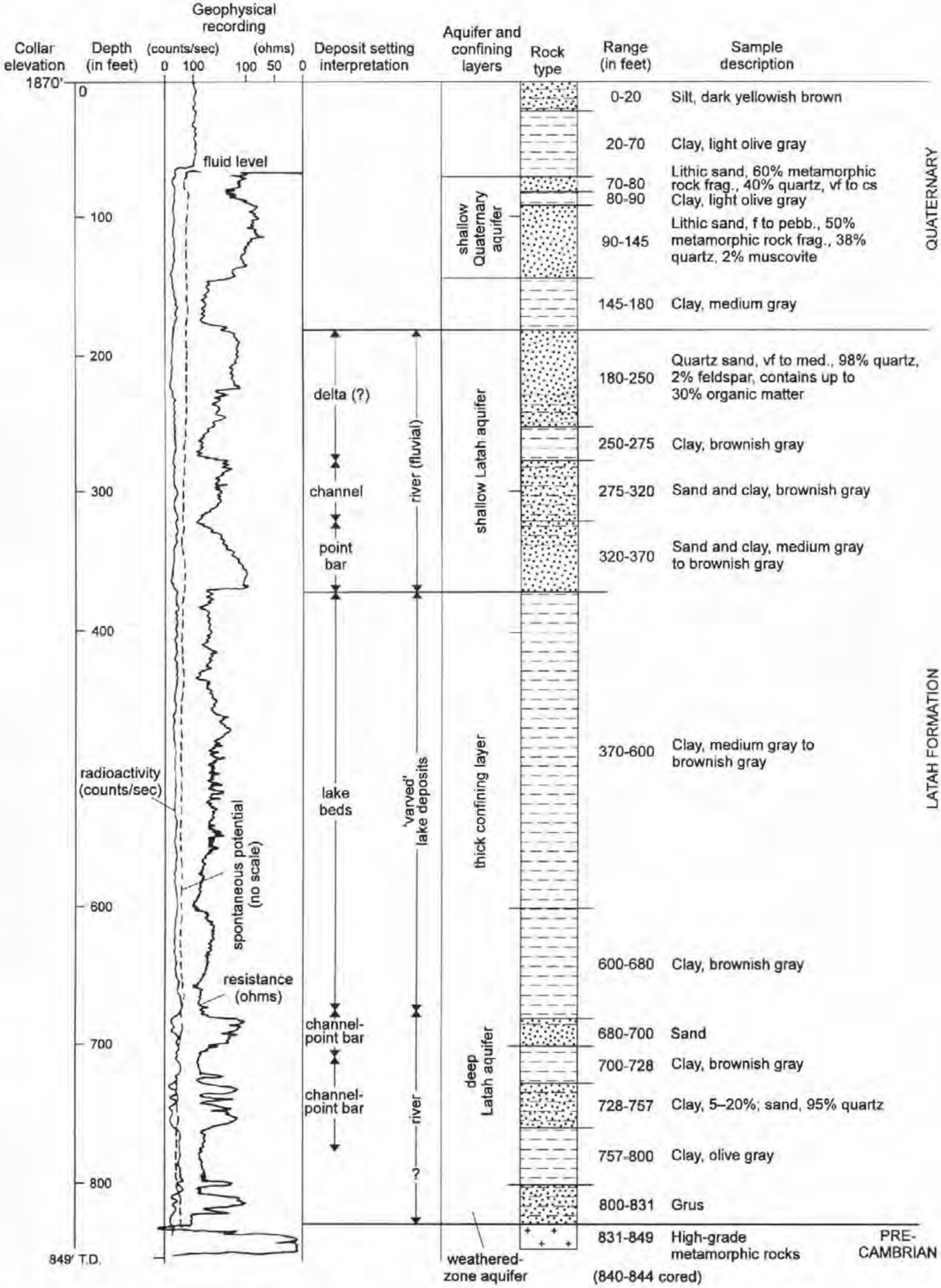

Figure 7. Representative borehole log and interpretation for rotary drill hole P-3, NW1/4SW1/4 sec. 7, 26N, 44E.

A thick, alternating silt and clay sequence in borehole P-3 at 370 to 605 ft depth can also be positively identified in borehole logs for P-1, P-7, and P-14. This alternating sequence may underlie about one-half the study area and may be similar to clay deposits correlatable across the Latah basin (Robinson, 1991). The sequence probably acts as an excellent confining layer between shallow and deep Latah sands and likely represents one of the extensive lakebed deposits.

Less significant Latah sands that lie below the lakebeds are:

Borehole no.	Depth (ft)	Total thickness (ft)	Interpretation
P-1	535–555	20	Basal channel sand
P-3	680–700	20	Beach(?) sand
P-3	728–757	29	Basal fluvial sand
P-7	480–520	40	
P-7	660–700	40	
P-14*	455–485	30	Basal fluvial sand
P-16*	507–545	38	Basal channel sand
P-17*	540–560, 585–590	25	Basal fluvial sand

* Drill-stem test interval

Quaternary Units

The Latah was completely removed along the center of the Deadman Creek paleo-valley; this is indicated by borehole logs at P-8, P-9, P-10, and P-15. The thickest section, 600 ft, of Quaternary glaciofluvial and glaciolacustrine sediment occurs at P-10. At drill sites P-8, P-10, and P-17 near Deadman Creek (and perhaps nearest the center of the paleo-Deadman Creek valley), Pleistocene erosion cut a valley nearly 600 ft deep and 2 mi wide. The present-day Peone Prairie is 3 mi wide with 100 ft of relief, following refilling of the valley by younger sediments.

Based on qualitative estimates from borehole logs, the Quaternary sedimentary section contains 35 percent (by volume) sand; the specific yield for such material normally ranges from 25 to 40 percent (Fetter, 1994, p. 93). We estimate that the total water volume in this aquifer varies from 9 to 14 percent (by volume). Because Quaternary aquifers are the shallowest, their potential for use is greatest. Likewise, shallow aquifers have the highest likelihood for recharge from surface water sources, including contaminated sources.

Aquifers at depths below the water table (or unconfined) aquifer are called confined aquifers. Significant sands of the Quaternary confined aquifers occur at the following intervals:

Borehole no.	Depth (ft)	Total thickness (ft)
P-8	103–122, 200–298	117
P-9	95–130, 200–234	69
P-10	120–190, 260–410	220
P-15	67–92, 111–155	69
P-16	85–100, 150–190	55

Aquifer sand sizes are dominantly medium to coarse, locally pebbly, and include basalt boulders(?) in boreholes P-6, P-9, and P-13. Boreholes listed above are located near Deadman Creek, so potential for water recharge from surrounding uplands appears good.

The origin and significance of basalt boulders(?) encountered in boreholes remains problematical. They may be either undisturbed flows of basalt or mass-wasting (landslide) deposits. Because they occur on a sloping Latah erosion surface and occur sporadically in only three holes, it is hard to imagine the basalt as undisturbed flows. Furthermore, there is no evidence of palagonite or a baked zone. Therefore, we think the basalt intercepted in the three boreholes marks a depositional hiatus between Miocene and Quaternary time and favors the mass-wasting interpretation. A bouldery zone would be an excellent aquifer because it is extremely coarse grained and would have good hydraulic communication with recharge areas.

The Quaternary sediments in the subsurface also include numerous thin, interbedded, repeated lacustrine clay and silt beds. Hosterman (1969) observed varved lakebeds in outcrops and in shallow borings; these can also be seen in roadcuts along Bruce Road (Fig. 3). The thickness of this sequence varies, but this varved clay-silt sequence is prominent in boreholes near Deadman Creek (P-8, -9, -10, -13, -14, -15, and -16); depths range from 0 to 300 ft. Locally, these beds are interbedded with or overlie the Quaternary aquifer sands. The clay interbeds might significantly restrict vertical water movement (percolation), including water flow from storm-water runoff and seepage from septic systems. Percolation problems and near-surface saturated silts could pose problems for development in the area.

HYDROGEOLOGY

Water Test Procedures

Drill-stem test (DST) equipment, commonly used in oil-well testing, was used to obtain hydraulic head data (Fig. 8). This equipment is designed to sample fluids and determine pressures in specific aquifers. At Peone Prairie, the DST equipment was connected to the drill pipe and used to obtain eight water samples from selected deep aquifers in six boreholes (Table 1). In the paragraphs below, the procedures are ex-

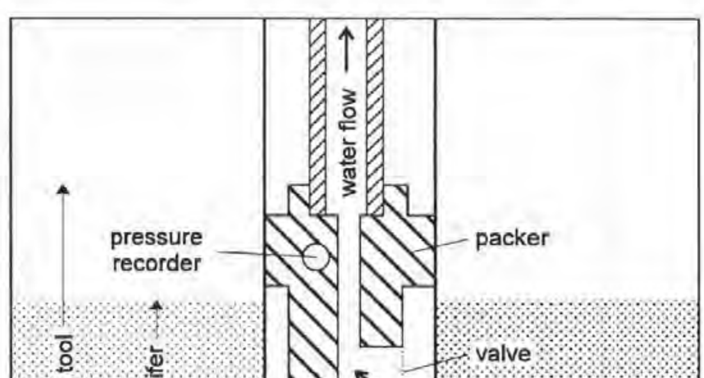

Figure 8. Diagrammatic view of drill-stem test. The drill pipe is attached and the test is operated from the drilling rig at the surface.

Table 1. Summary of hydraulic head and water analysis data. **, purposely omitted

Boring	Surface elevation (ft)	Test Interval (ft)	Formation	Hydraulic head[1]	Pressure head (ft)	Helium content (ppm)	Remarks
P-10	1,870	594–626	granitic rocks	**	68	5.25	Weathered zone
P-11	1,900	128–167	Latah	**	125	2.05, 3.04	Questionable results
P-13	1,855	310–346	Latah	**	192	5.27, 5.79	
P-13		405-436	granitic rocks	**	271	5.34, 5.35	Weathered zone
P-14	1,830	449–496	Latah	1,502	121	7.90, 14.46	Basal fluvial sand
P-16	1,875	350–386	Latah	**	252	9.58, 13.15	
P-16		500–546	Latah	1,770	395	27.72, 42.79	Basal fluvial sand
P-17	1,860	520–566	Latah	1,662	322	24.06, 27.91	Basal fluvial sand
P-17		583–606	Latah	—	—	—	Test failed

[1] Sum of test interval elevation and pressure head

plained, and we then discuss interpretations of hydraulic head and helium results from the 1978 work.

We first used an electric borehole-diameter measuring device (caliper log) to select the positions to place the DST tool across a test interval (Fig. 8). The DST equipment simultaneously isolates the test interval's upper and lower boundaries and opens a valve exposing the formation hydraulic environment to the atmosphere, much like a piezometer (a water-level measuring device) tube. Formation water enters the pipe and rises to a point of equilibrium. After 45 to 90 minutes, the pull-down force exerted by the drill rig is released to close the valve and free the packers, the pipe is withdrawn, and the water level reached is recorded as the pressure head. Total hydraulic head is determined by adding test interval elevation to pressure head, that is, the level to which the water has risen in the pipe (Table 1). Areal mapping of hydraulic heads defines the potentiometric surface and is important because it will indicate an aquifer's water flow direction and the relative locations of recharge and discharge areas for that aquifer.

Specific conductance of the water was measured to ensure quality control by comparing measurements taken along the various vertical sections of drill pipe. A stabilized low specific conductance indicated that water originated from the formation and not the borehole fluid.

The quality of water from private wells and springs used for domestic purposes on Green Bluff, upper Deadman Creek and Peone Prairie varied considerably. (Sample points are not shown on map.) Eight springs and 45 wells were sampled and the owners interviewed by Paul Nordstrom in 1978. Wells sampled were as deep as 500 ft. Alkalinity as bicarbonate ranged from 36 to 204 ppm (average 50 ppm), pH ranged from 5.9 to 7.2, and alkalinity as carbonate ranged from 3 to 48 mg/l except in a 95-ft well where water had an undesirable taste; that water tested 7,670 mg/l carbonate alkalinity. Sulfurous odor and iron and calcium deposits (as a carbonate or sulfate) on water faucets and in sinks were common. Three of those interviewed noted bacteria problems with their water, a number used water softeners, and two were treating their water with chlorine. Seven wells had turbid water, and eleven had water with a slightly to very unpleasant taste or odor. Quality of water in the Peone Prairie area needs further study.

Helium Analyses

Helium (He) is a radioactive decay product of natural earth materials, principally uranium and thorium. Because He is inert, it can be traced through the hydrogeologic environment and provide valuable insights into water movement. The usefulness of He values is in indicating an aquifer's relative communication, or lack of it, with recharge and discharge areas, termed dynamic equilibrium (Fetter, 1994). Detecting anomalous He is dependent on knowing the background He content of local recharge waters. To establish a local background value, 62 surface-water samples were collected in the Peone Prairie, upper Deadman Creek, and Green Bluff areas. Average He was 5.35 ppm (standard deviation 0.21 ppm). Any value exceeding 5.77 ppm (mean plus 2 standard deviations) was considered anomalous.

Deeper Latah Beds

Water samples analyzed for He came from the DST tool chamber and lowest drill pipe sections. He values from the deeper Latah sand aquifer in P-14, P-16, and P-17 are anomalously high (7.90 to 42.79 ppm). Reasons for high He contents in aquifer water remain somewhat enigmatic. High He values are best attributed to the efficient sealing of layers enclosing this deep Latah aquifer or to lack of He diffusivity in the aquifer. High He may also indicate that recharge is low and cannot sufficiently dilute the natural helium flux from the bedrock, suggesting that the aquifer is isolated.

A third possible explanation, that a nearby uranium deposit is supplying abnormal quantities of He to the aquifers, can be rejected upon comparing the He values in samples taken from the weathered zone aquifer (P-10, P-13; see Table 1) to those from the basal Latah aquifers. Furthermore, a highly fractured basement rock at this location can enhance He movement upward to the aquifers (Martin Marietta Corp., 1978, pt. I, p. 2-5). Low He values indicate potential for water supplies from the weathered zone and shallow aquifers. High He in the basal Latah suggests this aquifer receives little recharge, which may reduce its potential as a water source.

He in the Weathered Zone

He values in the weathered zone aquifer ranged from 5.25 to 5.35 ppm, about the background level. Because the weathered zone is areally extensive, follows the pre-Latah erosional topography, and is enclosed by leaky confining layers, recharging of the weathered zone is more likely than for the basal Latah aquifer. This suggests the weathered zone may contain a useful water supply.

Hydraulic Head Tests

Some preliminary potentiometric results were provided by this reconnaissance exploration. Three boreholes (P-14, -16, -17) at which water levels were measured (fortuitously) penetrated the same Latah sand as the one indicated at 680–700 ft depth in the representative log borehole P-3 (Fig. 7). From these data, total hydraulic heads were calculated and a potentiometric surface determined. The potentiometric surface generally indicates the aquifer's flow direction from recharge to discharge. (See Table 1.) Because three wells were tested, a 3-point analysis of the potentiometric surface was possible. This analysis indicates a west-northwest slope, approximately paralleling Deadman Creek. Therefore a water recharge area probably lies to the east-southeast and a discharge lies to the west-northwest.

PRELIMINARY CONCLUSIONS AND TOPICS FOR STUDY

Further investigation is needed to confirm many of the preliminary observations below. However, several conclusions can be drawn from this 1978 reconnaissance study.

Aquifers

Potential aquifers include (shallowest to deepest) Quaternary sands, including the bouldery zone (15–300 ft in thickness), Latah Formation sands (0–230 ft in thickness), and the weathered zone of bedrock or grus (14–151 ft in thickness). The greatest combined aquifer sand thicknesses appear to lie south of Deadman Creek. Depth to bedrock ranges from 100 to 831 ft. Helium analysis suggests that all but the deep (basal) Latah aquifer are in hydraulic communication with areas of ground-water recharge.

Latah Sequences

The Peone area is remarkable for two reasons: first, it exhibits a thick, uninterrupted sedimentary sequence of the Latah, and second, the sand content (percent sand) of the Latah here is greater than expected. Lakebed, fluvial, and deltaic sequences shown on borehole logs in the Latah Formation indicate that extensive interconnectivity of sand deposits probably occurs in the area. Similar sequences are also indicated in the Quaternary sediments. Thick Latah sequences likely extend beneath nearby basalt-covered plateaus.

Permeability and porosity of the sands and other materials that compose the aquifers are expected to range far below that of the Spokane Valley aquifer.

Data from this test are insufficient to describe the water supply. Streamflow, runoff, and precipitation data not used here should be studied in conjunction with other well test results. Engineering tests must be made to determine aquifer storativity and transmissivity values. Deep borings should be made in the surrounding area to obtain new borehole data and determine the extent of aquifers.

Recharge and Discharge

Hydraulic head testing indicates that recharge areas may lie to the east-southeast and discharge areas may lie to the west-northwest for the deep Latah aquifer. Obtaining hydraulic head data from new and existing borings will clarify this preliminary observation.

Shallow Clay Aquicludes

Thick, varved clay-silt layers are located at the surface and at shallow depths across Peone Prairie. If suburban development is considered, the ability of this aquiclude to reject or impede vertical seepage may be a concern and requires further investigation. Storm-water runoff in areas with the clay-silt layers at shallow depths present special problems and require further study.

Water quality

Preliminary water quality data from wells and springs at Green Bluff and Deadman Creek are insufficient to characterize the prairie area's drinking water supply. High iron content of water supplies is a common complaint.

ACKNOWLEDGMENTS

The authors thank Rexcon Inc. for permission to use borehole data for this report. Many people contributed to the success of this project. Drill-stem test equipment was supplied and operated by Johnston Testers, a division of Schlumberger of Casper, WY. Paul Nordstrom of ScienTerra collected and analyzed water samples for helium on a mass spectrometer at Whitworth College Physics Department under the direction of the late Prof. Glen Erickson. Jack Roylance originated and directed the project. Don Hansen suggested the use of the drill-stem testing. Hansen, Gunther Jarre, and John Brehm supervised various aspects of the project. Bill Smallwood, Dave McClure, Dan Walline, Mike Schuler, Marilyn Poss-Plahuta, Ken Bullis, and Gene Halstead provided geologic and geophysical assistance to the senior author during drilling operations. We also thank D. F. Stradling and E. P. Kiver of Eastern Washington University for explanations of glacial and Lake Missoula flood deposit geology of the Spokane area. W. J. Gerstel, DGER, mapped and field checked photogeologic mapping of Quaternary deposits in the Spokane area including part of the map area included here. Bea Lackaff digitized the geologic information for Spokane County and provided the line work on which the geologic map is based. Mitch Linne of U.S. Bureau of Mines reviewed an earlier version of this article. Robin Peterson, U.S. Bureau of Mines, drafted Figures 5, 7, and 8. Josh Logan and Stephen Palmer of DGER made significant editorial contributions.

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Symposium on Hydrogeology *Continued from page 29*

and actions to abolish the U.S. Geological Survey. He identified four tasks that ground-water scientists must accomplish:

- Assure that everyone who needs hydrologic data can quickly and easily get all available information.
- Ensure comparable and high-quality data.
- Disentangle the technical and societal elements of major water issues.
- Educate Washington's citizens about basic hydrology and ground-water processes so that they can make informed choices as they vote.

Goodwin asked ground-water scientists to step out of their comfort zones in the technical arena, to think about water as if they were social scientists, and to be aware of the deep-seated social struggles that are intertwined with major water issues.

Barcelona called for skilled and well-trained hydrologists to make critical decisions in practice and policy. He emphasized that stronger interdisciplinary and field training should be provided to college and graduate students by ground-water professionals in higher education.

Keynote Speaker

The keynote speaker was R. Allen Freeze, co-author with John Cherry of the textbook "Groundwater" (published by Prentice-Hall). His talk, "Ground water remediation and its ethical conundrums—The question of mass removal and risk reduction in an adversarial regulatory environment", called for societal and regulatory realization that mass removal approaches are often not a pragmatic means of containing contaminants. Freeze explained that ground water remediation requires flexible approaches, not narrow regulation.

Ground-Water Sampling Workshop

More than 70 scientists took part in the ground-water sampling workshop presented by Barcelona, Mark Varljen (hydrogeologist and president of Applied Hydrogeologic Research, Inc., Seattle, WA) and David Kaminski (vice president, QED Ground Water Specialists, Walnut, Creek, CA). The emphasis of the workshop was on micro-purging techniques for sampling ground water. The challenge is moving away from the traditional evacuation of three well volumes to a new standard practice.

Internet Access

Several of the plenary session presentations and all symposium research abstracts are now available on the Internet by choosing an option from Ecology's home page on the World Wide Web (http://olympus.dis.wa.gov/www/access/ecology/ecyhome.html). For updates on development of the second symposium, please also refer to this home page. ■

Editor's note: This article was delayed due to page constraints in the previous issue.

WASHINGTON STATE DEPARTMENT OF
Natural Resources

RECLAMATION AWARDS NOMINATION FORM

(Please print or type the information. Nominations must be received by November 1, 1996.)

Please check the category for which you wish to nominate the site:

☐ Commissioner of Public Lands' Recognition for Reclamation

☐ Good Neighbor Award

☐ Commissioner of Public Lands' Recognition for Reclamation for a Small Operation (less than 16 acres)

☐ All of the above

Person making the nomination: ______________________ Phone: (____)__________

Organization or business nominated: ______________________

Name of site: ______________________

Location: ______________________

DNR Reclamation Permit Number (if known): ______________________

Description of reclamation: *(You may attach a separate sheet.)* ______________________

Presentation material included with nomination: *(We suggest at least 12 slides and 6 color photos.)*

☐ 35-mm slides (how many?) ______ ☐ Photos (how many?) ______ ☐ Video

All presentation material becomes the property of the Department of Natural Resources.

Your address: ______________________

City/State/Zip + extension: ______________________

Send this nomination form to:

Regulatory Section
Division of Geology and Earth Resources
PO Box 47007
Olympia, WA 98504-7007

Surface Mine Reclamation Awards

The Department of Natural Resources (DNR) is establishing three annual awards to recognize outstanding reclamation of surface mines. These awards will honor permit holders who reclaim mines in an exemplary manner. Awards will also recognize reclamation efforts on sites exempt from the Surface Mine Reclamation Act [RCW 78.44] because of size or because a site was abandoned by earlier mine operators prior to 1971. Criteria for evaluating entrants are described below by award category. If no mine reclamation has occurred that meets the stringent criteria of each category, no award may be granted for that year. Nominations for awards can be made by the public, permit holders, DNR, or other agencies. Nominations received by November 1 will be eligible for that year's award.

Commissioner of Public Lands' Recognition for Reclamation

To receive this award, an operation must meet or exceed the DNR-approved reclamation plan. Exemplary reclamation may include, but it is not limited to:

- Innovation or creativity in reclamation, such as creating unique wetlands or enhancing wildlife and fish habitat or topographic elements.
- Voluntary reclamation of mined land that is exempt from reclamation under the Act.
- Use of native plant species in revegetation.
- Innovative research and approaches to reclamation that can be applied at other mines.
- Attention to water quality and erosion prevention
- Orderly segmental mine development resulting in high-quality reclamation.
- A consistent long-term commitment to reclamation.
- Methods that enhance the environment and reduce reclamation liability, such as mining to a final slope.
- No significant enforcement actions in the past 10 years

Commissioner of Public Lands' Recognition for Reclamation for a Small Operation

The criteria are as for the Recognition for Reclamation award, except that the operation is less than 16 acres in size.

Good Neighbor Award

The winner of this award works unselfishly with neighbors and the community in a spirit of cooperation to reflect a positive image of the mining industry. For example, the operator may have developed cooperative projects that benefit the environment and the community.

The Award Process

Winners will be selected by a panel of five judges: the Commissioner of Public Lands or a designee, a representative of the mining industry, two representatives of environmental interest groups, and a representative of state environmental agencies.

DNR surface mine reclamationists will present the candidates to the panel. Because the judges may not have opportunities to visit the nominated operations, 35-mm slides, photos, or videos showing conditions before, during, and after reclamation will help the judges review the nominees. At least twelve slides and six color photos should be submitted. Written descriptions of site reclamation will help the panel reach their decision. These descriptions may include the history of reclamation, planned development, partnerships made with neighbors, and direct benefits to the immediate environment, as well as specific information about topsoil handling, sloping, revegetation, water control, and other interesting aspects of the reclamation.

Winners will receive an award and public recognition from a press release issued by the Jennifer Belcher, Commissioner of Public Lands. They will also be nominated for national honors.

Nominations should be made on the form on the facing page. Please feel free to copy it. ■

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

November 1995 through January 1996

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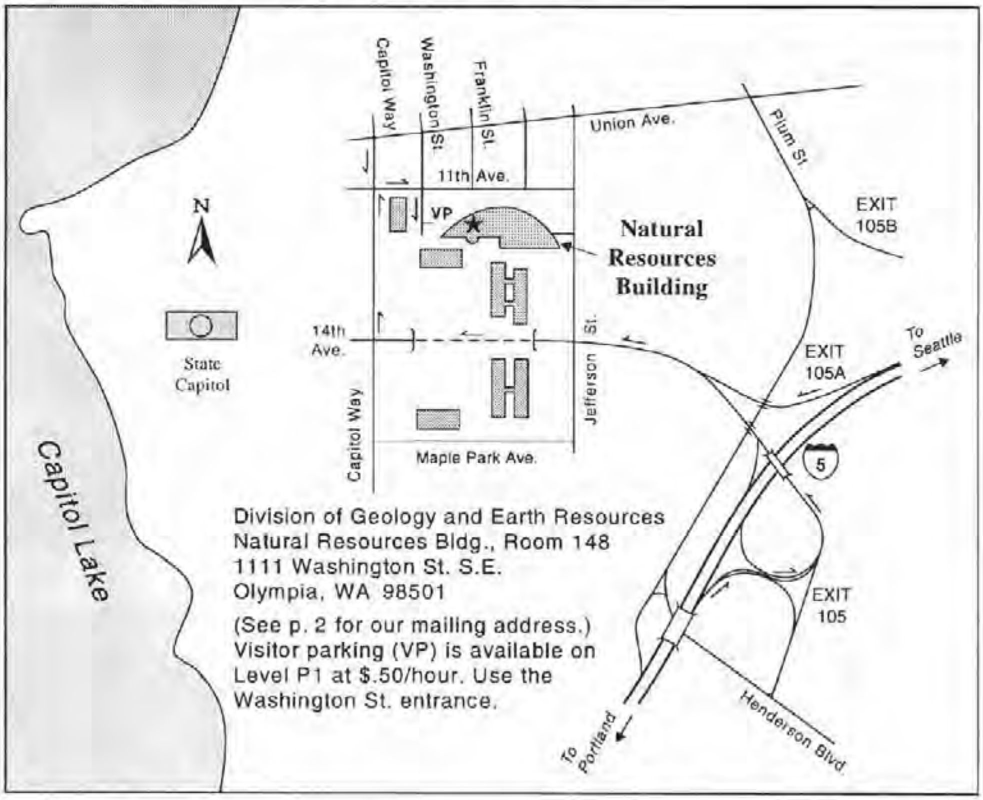

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WASHINGTON STATE DEPARTMENT OF
Natural Resources
Jennifer M. Belcher - Commissioner of Public Lands
Kaleen Cottingham - Supervisor

Department of Natural Resources
Division of Geology and Earth Resources
PO Box 47007
Olympia, WA 98504-7007