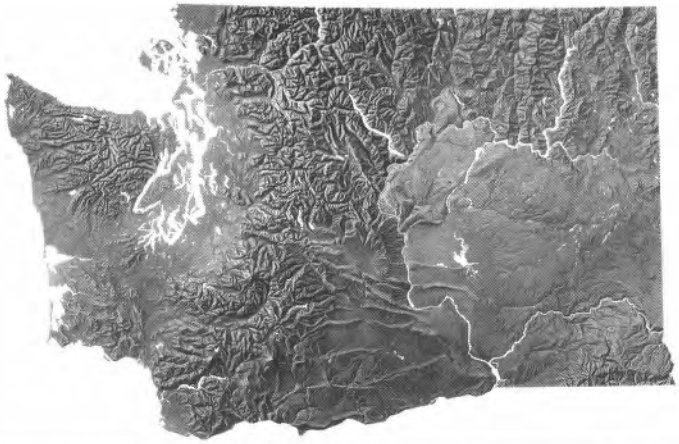

WASHINGTON GEOLOGY

Washington Department of Natural Resources, Division of Geology and Earth Resources Vol. 20, No. 1, March 1992

The 270-ton-per-day mill constructed in 1937 at Hecla Mining Co.'s Republic unit maintains a 95 percent recovery level for gold and 88 percent for silver. Hecla is now undertaking an extensive exploration program for additional ore reserves that, if successful, could lead to increased production and expansion of the mill. See related article, p. 3. Photo by Robert E. Derkey.

In This Issue: Washington's mineral industry—1991, p. 3; Coal activity in Washington—1991, p. 26; Stratigraphic interpretation of the Metaline Formation, p. 27; Central Cascades earthquake of March 7, 1891, p. 36; Policy plan for improving earthquake safety, p. 39.

WASHINGTON GEOLOGY

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Minerals and Society

by Raymond Lasmanis

"We depend on minerals throughout our lives. In fact, each year an average of 40,000 pounds of new minerals are consumed for each American. At this level of consumption, the average child will need a lifetime supply of 800 pounds of lead...750 pounds of zinc...1,500 pounds of copper...3,593 pounds of aluminum...32,700 pounds of iron...26,550 pounds of clays...28,213 pounds of salt...and 1,238,101 pounds of stone, sand, gravel and cement." American Mining Congress

Members of the public and students frequently ask what persuaded me to become a geologist. The abbreviated answer is that I knew since my high school days that I wanted to be an economic geologist. By the time I was 12, I was collecting geologic materials and reading books on the subject.

At that time, during the post-World War II period and the Korean War, society was cognizant of the value of minerals. This was reflected in public school curricula, where students were taught the direct relation between the availability of minerals and our economic well-being, as well as the nation's security. It was only natural, therefore, I decided, to take on the task of helping to provide minerals for society's benefit.

As a nation, the United States has achieved the highest standard of living anywhere in the world. In the process, we have somehow lost sight of the fact that our very existence depends on only two sources of materials—you either grow it (food or lumber products, for example) or you get it out of the ground (minerals or oil). Everything else is manufactured from these raw materials.

Our society is largely illiterate when it comes to knowing what materials go into the construction of a house, a car, or even the highways we drive. During the last year, I have heard statements such as "I didn't know concrete is made up of materials that are mined" (this from a group writing a report about growth management issues) or "I just don't like mining. Can't it be stopped?" (a common public reaction). It seems to me that our schools have failed to teach students just what the building blocks of a strong society are.

Issues surrounding sand and gravel mining are good examples of the need for education. Urban sprawl has infringed on historical sand and gravel mines. Major conflicts over land uses have resulted and will only escalate. But we can not do without sand and gravel. These are used for concrete aggregate, plaster and gunite, concrete products, asphaltic concrete, road-base cover, fill, snow and ice control, railroad ballast, and filtration/drain fields, to name a few uses. The U.S. Bureau of Mines reports that in Washington in 1990, there were 197 operators who produced 40,250,987 short tons of construction sand and gravel from 226 major pits. With a 1990 population of 4,866,692, each person's share of construction sand and gravel was 8.27 tons or 16,540 pounds. Mine operations have little adverse environmental impact, but they are commonly perceived as a major social nuisance. The result is that costs of these materials are rising as regulatory permitting is delayed and the availability of known resources is restricted by zoning or other means. A more balanced approach should be developed, based on deliberations of an informed public that recognizes that every one of us is a consumer of mineral resources. ■

Washington's Mineral Industry—1991

by Robert E. Derkey and Charles W. Gulick

INTRODUCTION

Gold production in Washington increased again in 1991, as it has nearly every year since 1985 (Fig. 1). The value of increased gold production, however, was not enough to offset a decrease in total value of nonfuel mineral production from 1990 to 1991. A preliminary value reported by the U.S. Bureau of Mines for 1991 nonfuel mineral production is $442,617,000; this is about 6.5 percent lower than the 1990 value. These preliminary figures for 1991 indicate that production of sand and gravel, crushed stone, and portland cement accounted for slightly more than 50 percent of the value of production. Forty percent of the state's nonfuel mineral value was split nearly equally between production of precious metals and production of magnesium metal from dolomite. The remaining 8 percent of the 1991 production value was from clay, diatomite, dimension stone, gemstones, gypsum, industrial sand and gravel (silica), lime, masonry cement, olivine, peat, lead, and zinc.

Of the five metal mines active in 1991, four were producing gold. The state's major precious-metal mining operations, the Cannon mine, the Republic Unit, and the Kettle River Project, produced 320,000 ounces of gold and more than 580,000 ounces of silver in 1991. Along with this increase in production, acquisition of mining properties in the state and expenditures for detailed evaluations of these properties during 1991 appear to have increased relative to 1990 levels.

Employment in the nonfuel mineral industries increased in 1990 (the latest year for which figures are available) relative to 1989. An average of 2,681 people were employed in 1990, compared to 2,152 in 1989. A significant proportion of this increase of 466 employees is attributable to the start-up of the Kettle River project near Republic by Echo Bay Minerals Co. This new mining operation provided a healthy boost to the economy of Ferry County. (See also Joseph, 1991). Despite the slight decrease in nonfuel mineral production in 1991, Washington is expected to experience continued growth in the number of persons employed in minerals-related activities and in the value of production.

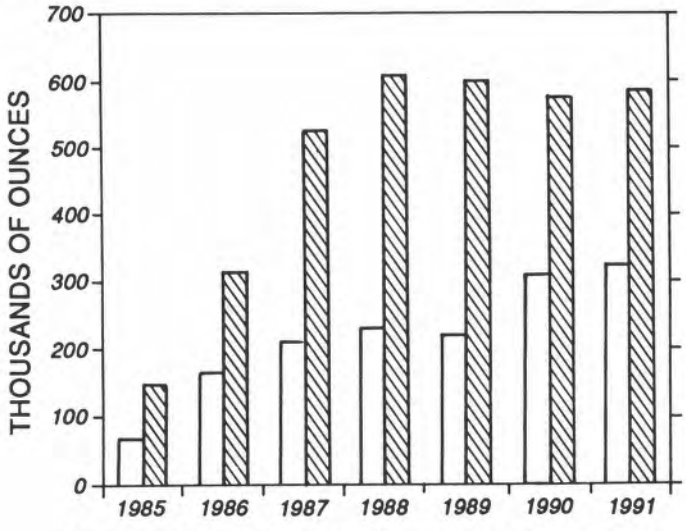

Figure 1. Gold (left bar) and silver production in Washington, 1985 through 1991.

Throughout this article, property or mine names are accompanied by a number. This number permits quick access to property location, which is shown on Figures 2a–d and other information that is given on Table 1. Table 1 summarizes mining and mineral exploration activities in Washington. The majority of this information was obtained from an annual survey of mining companies and individuals. Because not all survey questionnaires were returned, Table 1 is an incomplete measure of Washington mineral industry activity. The table includes a column in which geologic setting at or near the property/mine is briefly described. This information is taken from the recently published geologic map of Washington's northeast quadrant (Stoffel and others, 1991), the metal mines database (Derkey and others, 1990), and other published reports cited in these reports or listed at the end of this article.

The discussion of the metallic mineral industry deposits was prepared by R. E. Derkey. It is organized on the basis of deposit type and deposit geology. The industrial minerals part of this article, prepared by C. W. Gulick, is organized by commodity. Questions about this information can be addressed to the authors at the Spokane office of the Division of Geology and Earth Resources. (Address and telephone number are given on p. 2 of this publication).

METALLIC MINERAL DEPOSITS

Epithermal Gold Deposits

Hot springs like those found in Yellowstone National Park produce mineral deposits referred to as epithermal deposits (or simply hot-spring deposits). Gold and silver mineralization at the Cannon mine and deposits at Republic are the subsurface expression of formerly active hot springs. Hot-spring activity and associated epithermal deposits are commonly found in areas of active volcanism, such as the Cascade Range of Washington and Oregon. Epithermal deposits indicative of hot-spring activity are extensive in Washington; however, only a few contain minable amounts of gold and silver.

The Cannon mine (no. 74), Washington's largest gold producer, is located southwest of the city of Wenatchee (Fig. 2a). The mine is a joint venture between Asamera Minerals (U.S.) Inc. (the operator) and Breakwater Resources Ltd. Host rocks for this epithermal gold deposit (Ott and others, 1986) are Eocene clastic rocks of the Chiwaukum graben, which is a major northwest-trending strike-slip basin (Evans and Johnson, 1989). Production for 1991 was 152,010 ounces of gold and 271,352 ounces of silver from 538,769 tons of ore. This is an average head grade of 0.282 ounces per ton for gold and 0.504 ounces per ton for silver. During 1991, an exploration drift was being driven to intersect mineralization of the "A reef" zone to confirm drill-indicated reserves. Asamera Minerals also continued an extensive exploration program on properties located northwest and southeast of the mine (nos. 75–86). Several other

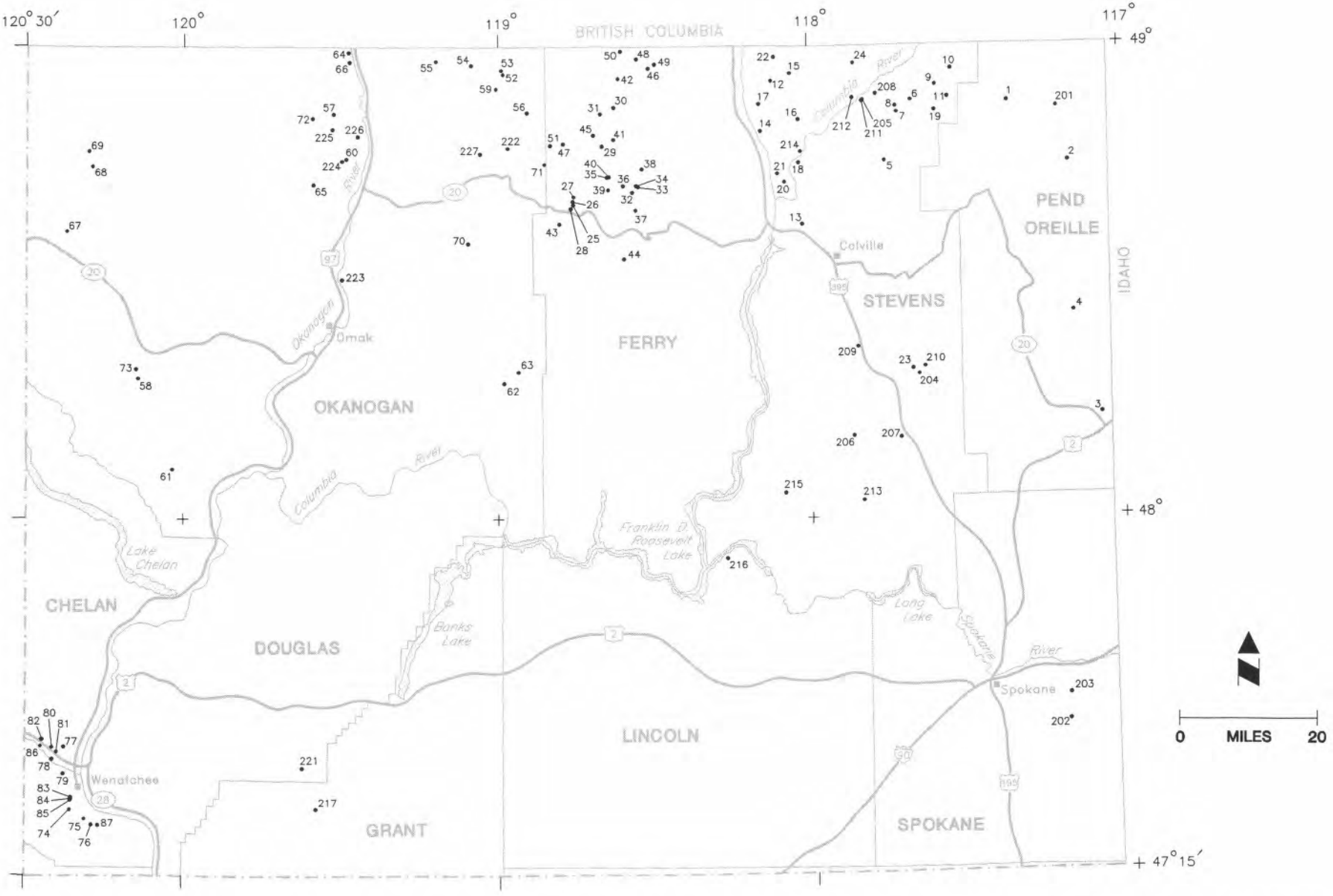

Figure 2a. Location of properties at which mineral exploration, development, or mining took place in 1991 in northeast Washington. See Table 1 for further information about each of these locations.

Figure 2b. Location of properties at which mineral exploration, development, or mining took place in 1991 in southeast Washington. See Table 1 for further information about each of these locations.

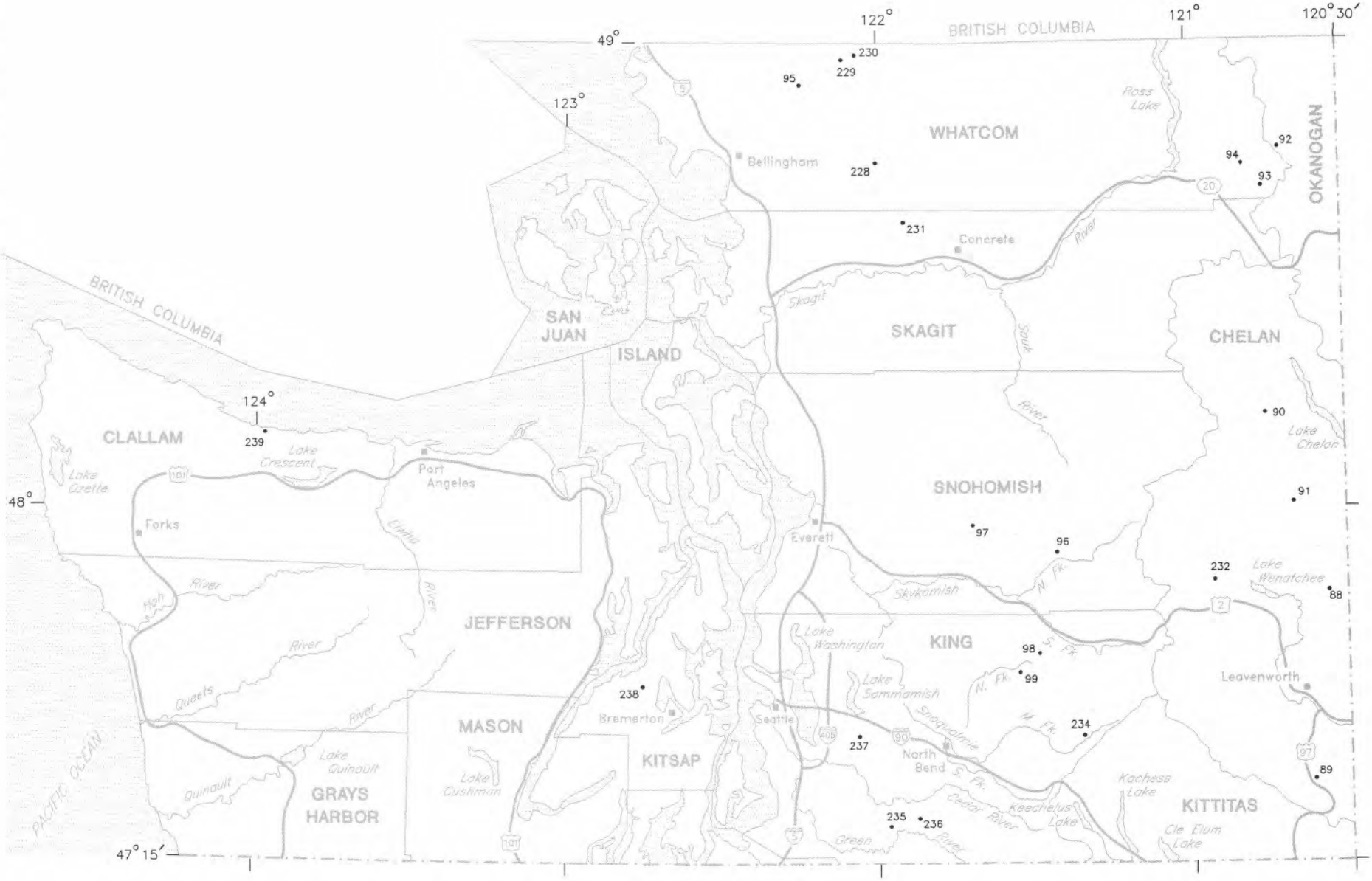

Figure 2c. Location of properties at which mineral exploration, development, or mining took place in 1991 in northwest Washington. See Table 1 for further information about each of these locations.

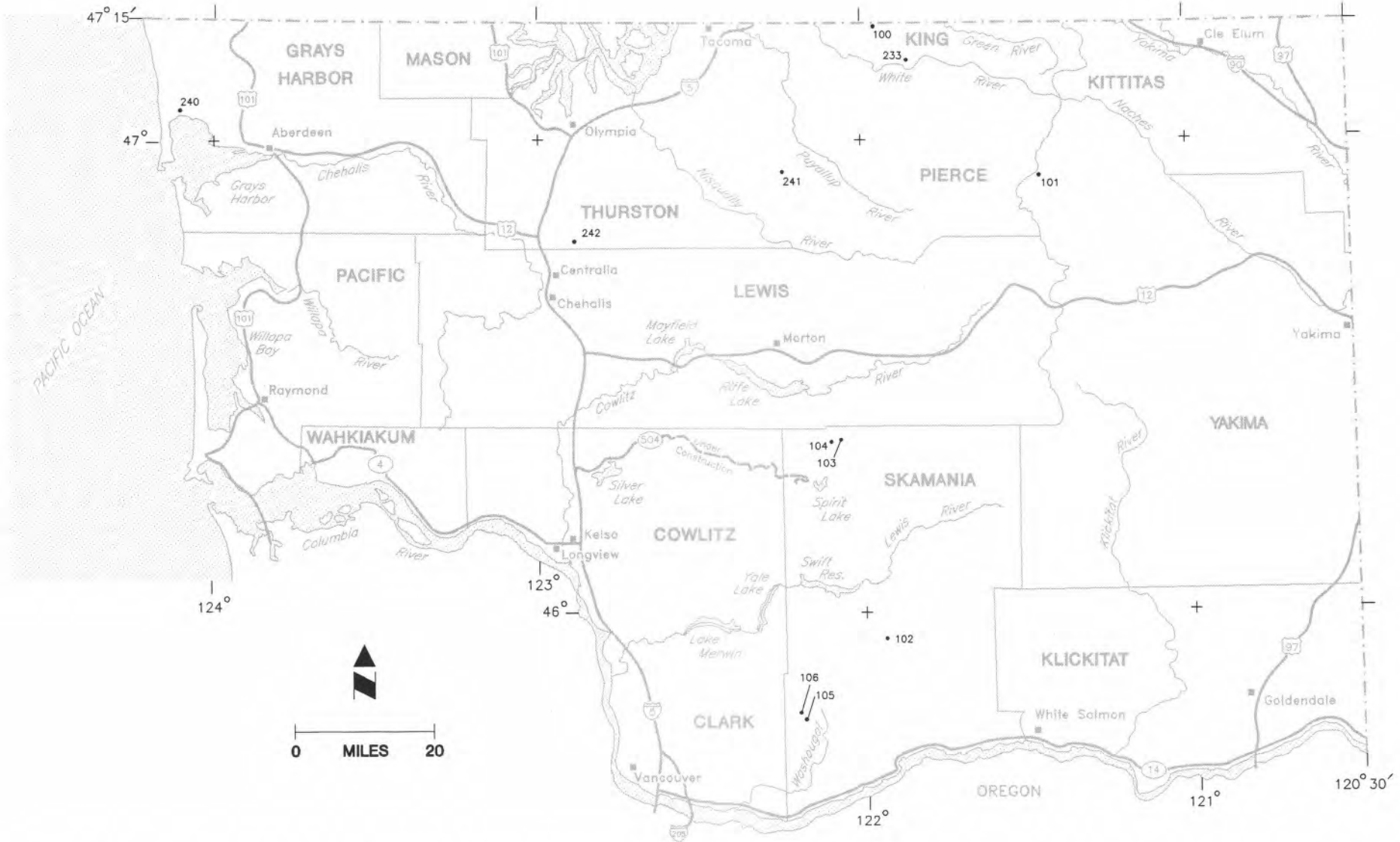

Figure 2d. Location of properties at which mineral exploration, development, or mining took place in 1991 in southwest Washington. See Table 1 for further information about each of these locations.

Table 1. Mining and mineral exploration in Washington, 1991. Property/project name is supplied by the company responding to the questionnaire. Order of entry is generally from northeast to southwest; location numbers are keyed to Figures 2a through 2d. Entries 1–106 are base and precious metal properties or projects; entries 201–242 are sites of industrial mineral activity

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
1	Pend Oreille mine	secs. 10-11, 14-15, 39N, 43E	Pend Oreille	Zn, Pb, Ag, Cd	Resource Finance Inc.	Underground drilling	Mississippi Valley-type deposit in the Cambrian–Ordovician Metaline Formation
2	Harvey Creek	sec. 17, 38N, 44E	Pend Oreille	Au, Ag, Mo	N. A. Degerstrom, Inc.	Exploration	Porphyry-style mineralization in Cretaceous–Tertiary granitic rocks
3	Glass Mountain mine	sec. 2, 31N, 45E	Pend Oreille	Au, Ag, Pb	Raven Hill Mining Co.	Mine development	Veins in shear zone in Proterozoic sedimentary rocks
4	Cooks Copper	sec. 19, 34N, 45E	Pend Oreille	Ag, Cu	Raven Hill Mining Co.	Exploration	Proterozoic rocks intruded by Cretaceous granitic rocks
5	Van Stone mine	sec. 33, 38N, 40E	Stevens	Zn, Pb, Cd	Equinox Resources Ltd.	Mining and milling	Mississippi Valley-type mineralization in the Cambrian–Ordovician Metaline Formation
6	Advance, HC	sec. 18, 39N, 41E	Stevens	Zn, Pb, Au, Ag	Bitterroot Resources Ltd.	Exploration	Shallow-dipping silicified zone in limestone contains lead, zinc, silver, and gold mineralization
7	Deep Creek	secs. 23-24, 39N, 40E	Stevens	Zn, Pb, Ag	Bitterroot Resources Ltd.	Exploration	Mississippi Valley-type mineralization in dolomitic rocks of the Cambrian–Ordovician Metaline Formation
8	Scandia	sec. 23, 39N, 40E	Stevens	Zn, Pb, Ag, Au	Bitterroot Resources Ltd.	Exploration	Mississippi Valley- and vein-type deposit in the Cambrian–Ordovician Metaline Formation
9	Calhoun	sec. 2, 39N, 41E	Stevens	Zn, Pb	Bitterroot Resources Ltd.	Exploration	Mississippi Valley-type deposit in the Cambrian–Ordovician Metaline Formation
10	Iroquois	secs. 1, 19-20, 29-30, 40N, 42E	Stevens	Zn, Pb, Ag, Au	Bitterroot Resources Ltd.	Exploration	Mineralization in a breccia zone in the Cambrian–Ordovician Metaline Formation
11	Leadpoint Consolidated properties	secs. 12-13, 39N, 41E; secs. 7-8, 7-18, 39N, 42E	Stevens	Ag, Pb, Zn	Leadpoint Consolidated Mines Co.	Surface sampling	Replacement and chimney deposits in the Metaline Formation
12	McNally	secs. 28, 33-34, 40N, 37E	Stevens	Au, Ag, Cu, Pb	Pathfinder Gold Corp.	Drilling	Replacement deposit in limestone, quartzite, and argillite cut by diabase, diorite, granite, and lamprophyre dikes
13	Gold Hill	secs. 9, 10, 16, 6N, 38E	Stevens	Au, Ag, Cu	Pathfinder Gold Corp.	Geophysics	Quartz vein and disseminated mineralization in Permian–Triassic metasedimentary rocks
14	Toulou Mountain	sec. 6, 38N, 37E; sec. 31, 39N, 37E	Stevens	Cu, Au, Fe	Pathfinder Gold Corp.	Geophysics	Mineralization along joint planes in Permian schist, quartzite, and wacke intruded by an Eocene dacite dike
15	Big Iron	sec. 24, 40N, 37E	Stevens	Au, Fe, W, Ag	Pathfinder Gold Corp.	Geologic mapping, geochemistry, geophysics	Replacement zone in graywacke with minor amounts of limestone and argillite in the Permian Mount Roberts Formation
16	Fifteen Mile Creek	secs. 17-20, 30, 39N, 38E; secs. 13, 24, 39N, 37E	Stevens	Au, Fe	Pathfinder Gold Corp.	Drilling	Greenstones of the Jurassic Rossland Volcanic Group intruded by Eocene(?) granitic rocks
17	First Thought	secs. 7, 18, 39N, 37E	Stevens	Au, Ag	Pathfinder Gold Corp./Billiton Minerals U.S.A., Inc.	Drilling	Epithermal mineralization in the Eocene Sanpoil Volcanics near Klondike Mountain Formation contact

18	Young America	secs. 28, 33, 38N, 38E	Stevens	Zn, Pb, Ag, Au, Cu	Silver Hill Mines, Inc.	Exploration	Mineralization in two parallel zones in brecciated Permian limestone with interbedded wacke
19	Bechtol	secs. 23, 26, 39N, 41E	Stevens	Pb, Ag, Fe	Cominco American Inc.	Drilling	Mississippi Valley-type mineralization in the Cambrian–Ordovician Metaline Formation
20	Kelly Hill	secs. 2, 10-11, 37N, 37E	Stevens	Au, Ag, Pb	Pegasus Gold Corp.	Exploration	Contact metamorphic/replacement zones in Permian metasedimentary rocks
21	Napoleon	sec. 3, 37N, 37E	Stevens	Au, Fe, Cu	Kennecott Corp.	Drilled; dropped property	Contact metamorphosed Permian–Triassic metasedimentary rocks
22	Hope Mountain	secs. 4, 5, 8-10, 15, 40N, 37E	Stevens	Au, Ag, Cu	Hope Mountain Mining Ltd.	Exploration	Mineralization in Permian–Jurassic argillite and metavolcanic rocks cut by Eocene monzonite porphyry dikes
23	United Copper	secs. 31-32, 33N, 41E	Stevens	Cu, Ag, Au	Lovejoy Mining, Inc.	Evaluating	Mineralized fracture zone in Proterozoic Wallace Formation argillite near the fault contact with Edna Dolomite
24	Ambrose Mining	sec. 16, 40N, 39E	Stevens	Au	A. Ambrose	Placer mining and prospecting, lode prospecting	Placer deposit
25	Republic Unit	secs. 27, 34-35, 37N, 32E	Ferry	Au, Ag	Hecla Mining Co.	Mining; exploration drifts and underground drilling	Epithermal gold veins in dacite and andesite flows, flow breccias, tuffs, and tuff breccias of Eocene Sanpoil Volcanics
26	Golden Eagle	sec. 27, 37N, 32E	Ferry	Au, Ag	Hecla Mining Co.	On hold	Epithermal mineralization in Eocene bedded tuff
27	South Penn	secs. 27-28, 37N, 32E	Ferry	Au, Ag	Crown Resources Corp./Sutton Resources Inc.	Exploration	Epithermal deposit in Eocene Sanpoil Volcanics
28	Seattle/Flagg Hill	secs. 33-34, 37N, 32E	Ferry	Au, Ag	Crown Resources Corp./Sutton Resources Inc.	Exploration	Epithermal deposit in Eocene Sanpoil Volcanics
29	Mount Elizabeth	38N, 33E	Ferry	Au, Ag	Crown Resources Corp.	Exploration	Eocene volcanic rocks of the Republic graben
30	Kettle mine	sec. 15, 39N, 33E	Ferry	Au, Ag	Echo Bay Minerals Co./Crown Resources Corp.	Mining	Epithermal veins beneath a sinter zone in Eocene Sanpoil Volcanics
31	K-2	sec. 20, 39N, 33E	Ferry	Au, Ag	Echo Bay Minerals Co./Crown Resources Corp./ Pathfinder Gold Corp.	Drilling, evaluation	Epithermal veins in Eocene Sanpoil Volcanics
32	Overlook mine	sec. 18, 37N, 34E	Ferry	Au, Ag, Cu, Fe	Echo Bay Minerals Co./Crown Resources Corp.	Mining	Gold and silver are in and close to a massive iron replacement zone in Permian–Triassic sedimentary rocks
33	Key East	sec. 18, 37N, 34E	Ferry	Au, Ag, Cu, Fe	Echo Bay Minerals Co./Crown Resources Corp.	Permitting	Iron-gold mineralization in contact metamorphosed Permian–Triassic sedimentary rocks
34	Key West	sec. 7, 37N, 34E	Ferry	Au, Ag, Cu, Fe	Echo Bay Minerals Co./Crown Resources Corp.	Permitting	Iron-gold mineralization in contact metamorphosed Permian–Triassic sedimentary rocks

Table 1. Mining and mineral exploration in Washington, 1991 *(continued)*

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
35	Lamefoot	secs. 4, 8, 37N, 33E	Ferry	Au, Fe, Ag, Cu	Echo Bay Exploration Inc.	Drilling, exploration, evaluation	Contact metamorphosed (skarned) Permian–Triassic sedimentary rocks
36	Leland	36-38N, 33-34E	Ferry	Au, Ag	Echo Bay Minerals Co./Inland Gold and Silver Corp./ N. A. Degerstrom, Inc./Pegasus Gold Corp.	Geologic mapping, rock and soil geochemistry, trenching, geophysics, drilling	Contact metamorphosed Permian–Triassic sedimentary rocks
37	Lakes	sec. 31, 37N, 34E	Ferry	Au, Ag	Echo Bay Minerals Co./Crown Resources Corp.	Drilling	Contact metamorphosed Permian–Triassic sedimentary rocks
38	Middlefork	sec. 32, 38N, 34E	Ferry	Au, Ag	Echo Bay Minerals Co./Crown Resources Corp.	Drilling	Contact metamorphosed Permian–Triassic sedimentary rocks
39	Kellogg	sec. 16, 37N, 33E	Ferry	Au, Ag	Placer Dome U.S. Inc./Equinox Resources Ltd.	Drilling	Contact metamorphosed Permian–Triassic sedimentary rocks
40	Wardlaw	sec. 4, 37N, 33E	Ferry	Au, Ag	Placer Dome U.S. Inc./Equinox Resources Ltd.	Drilling	Contact metamorphosed Permian–Triassic sedimentary rocks
41	Republic–Belcher area	37-39N, 33E	Ferry	Au, Ag	Placer Dome U.S. Inc./Equinox Resources Ltd.	Exploration	Contact metamorphosed Permian–Triassic sedimentary rocks
42	Snow Peak	secs. 13-15, 22-24, 26-27, 33-34, 40N, 33E; secs. 3-4, 39N, 33E	Ferry	Au, Ag	Phelps Dodge Corp.	Drilling, geophysics, geochemistry, geologic mapping	Replacement deposits in Permian greenstone and Eocene intrusive rocks
43	Copper Mountain	secs. 3-4, 9-10, 15-16, 22, 36N, 32E	Ferry	Au, Ag	Phelps Dodge Corp.	Drilling, geophysics, geochemistry, geologic mapping	Replacement deposits in Permian greenstone
44	Iron Mountain	secs. 1, 12, 35N, 33E; secs. 5-8, 35N, 34E	Ferry	Au, Ag	Gold Fields Mining Corp.	Drilling	Replacement(?) mineralization in Permian–Triassic metasedimentary and metavolcanic rocks
45	Empire Creek	secs. 6-7, 38N, 33E	Ferry	Au	Curlew Lake Resources Inc./ Kettle River Resources Ltd.	Geophysics, drilling	Mineralization in a 200–300-ft-thick sequence of Eocene volcanic rocks overlying granitic rocks
46	Morning Star	sec. 16, 40N, 34E	Ferry	Au, Ag, Cu, W	Morse Brothers, Morning Star Mines, Inc.	Soil sampling, drilling	Veins at the sheared contact between Permian–Triassic greenstone and serpentinite

47	Kelly Camp	sec. 9, 38N, 32E	Ferry	Au, W, Cu, Mo	Atlas Mine and Mill Supply, Inc.	Exploration	Contact metamorphosed pre-Tertiary rocks are a roof pendant in quartz monzonite and monzonite of Herron Creek igneous suite
48	Gold Mountain	secs. 7-8, 40N, 34E	Ferry	Au, Ag, Cu	Gold Express Corp./ N. A. Degerstrom, Inc.	Permitted	Gold-pyrite mineralization in an alkalic dike of the Jurassic Shasket Creek complex
49	Irish	sec. 15, 40N, 34E	Ferry	Au	Johnson Explosives	Geological and geochemical exploration	Gold mineralization in alkalic rocks of the Jurassic Shasket Creek complex
50	Lone Star	sec. 2, 40N, 33E	Ferry	Au, Cu, Ag	Wilbur Hallauer	Drilling	Disseminations and veinlets of chalcopyrite in Permian–Triassic greenstone, graywacke, argillite, and limestone
51	Manhattan Mountain	secs. 7, 18, 38N, 32E	Ferry, Okanogan	Au, Ag, Cu, Pb, Zn, talc	Westmont Gold Inc.	Sampling, geologic mapping	Epithermal gold in Eocene volcanic rocks of the Toroda Creek graben
52	Crown Jewel	sec. 24, 40N, 30E	Okanogan	Au, Cu, Ag, Fe	Battle Mountain Gold Corp./Crown Resources Corp.	Drilling for closure on orebody	Mineralization in skarn in Permian or Triassic metasedimentary rocks adjacent to the Jurassic–Cretaceous Buckhorn Mountain pluton
53	Crown Jewel exploration project	secs. 13-14, 23-26, 40N, 30E	Okanogan	Au, Cu, Ag, Fe	Battle Mountain Gold Corp./Crown Resources Corp.	Exploration of property other than the Buckhorn Mountain project	Mineralization in skarn in Permian or Triassic metasedimentary rocks adjacent to the Jurassic–Cretaceous Buckhorn Mountain pluton
54	Strawberry Lake	secs. 6-9, 17-21, 29-30, 40N, 30E; sec. 24, 40N, 29E	Okanogan	Au, Ag, Cu	Crown Resources Corp.	Limited geochemistry of drill pulps	Skarn and vein deposits in Permian–Triassic metasedimentary and metavolcanic rocks intruded by Mesozoic granitic rocks
55	Molson Gold	numerous sections, 39-40N, 28-29E	Okanogan	Au, Ag	Crown Resources Corp.	Soil sampling, magnetometer and IP surveys, drilling	Skarn and vein deposits in Permian–Triassic metasedimentary and metavolcanic rocks intruded by Mesozoic granitic rocks
56	Ida	secs. 16, 21, 39N, 31E	Okanogan	Au, Ag, Cu	Cambior USA, Inc./ Crown Resources Corp.	Drilling, trenching, sampling	Epithermal veins in Eocene Sanpoil Volcanics and Klondike Mountain Formation of the Toroda Creek graben
57	Cayuse	sec. 23, 38N, 26E	Okanogan	Au	Northwest Minerals Inc.	Geochemistry, geologic mapping	Skarn and replacement mineralization in Permian Spectacle Formation (Anarchist Group)
58	Smith Canyon	sec. 1, 32N, 21E	Okanogan	Au, Ag	Northwest Minerals Inc.	Geophysics	Vein and disseminated mineralization in Jurassic–Triassic volcaniclastic rocks
59	Crystal Group	sec. 35, 40N, 30E	Okanogan	Au, Ag, Pb, Zn, Cu	Keystone Gold Inc.	Drilling, geochemistry	Contact metamorphosed Permian Spectacle Formation intruded by Mesozoic quartz-plagioclase porphyritic rocks
60	Lucky Knock	sec. 19, 38N, 27E	Okanogan	Au, Sb	Magill and Associates	Soil sampling	Stibnite veinlets in fractured and silicified limestone of the Permian Spectacle Formation
61	Say Energy	secs. 9-16, 24, 30N, 22E	Okanogan	Au, Ag, Cu	Hunter Mines Inc.	Mapping, geochemistry, geophysics	Veins in orthogneiss of the Jurassic–Cretaceous Methow Gneiss
62	Parmenter Creek	secs. 1, 12, 32N, 30E	Okanogan	Au, Cu, Zn	Cyprus Exploration and Development Corp.	Geological and geochemical exploration	Mineralization in Cretaceous to Tertiary granitic rocks
63	Strawberry Creek	secs. 28-33, 33N, 31E; secs. 4-5, 32N, 31E	Okanogan	Au, Ag	Colville Confederated Tribes	Negotiating agreement	Mineralization in and adjacent to Eocene intrusive rocks

Table 1. Mining and mineral exploration in Washington, 1991 *(continued)*

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
64	Kelsey	secs. 5-8, 40N, 27E	Okanogan	Cu, Mo, Ag, Au	Weaco Resources Ltd.	Acquired property	Porphyry-type mineralization in Jurassic–Cretaceous Silver Nail quartz diorite
65	Starr Molybdenum	secs. 8, 16, 37N, 26E	Okanogan	Mo, Cu, W	Wilbur Hallauer	Exploration; negotiating agreement	Mineralization in the Cretaceous Aeneas Creek quartz monzonite and granodiorite
66	Hot Lake	secs. 7, 18, 40N, 27E	Okanogan	Cu, Mo, Ag, Au	Pegasus Gold Corp.	Drilling	Sulfide replacement zone adjacent to the Kelsey porphyry-type deposit
67	Mazama	secs. 17, 19-20, 36N, 20E	Okanogan	Au, Cu, Ag	Centurion Mines Corp.	Restaked claims, geochemistry, drilling, evaluating all data	Porphyry-type mineralization in fractures and in a breccia body of a Cretaceous stock
68	Craggy Peak	secs. 26-27, 34-35, 38N, 20E	Okanogan	Cu, Au, Ag, Fe	R. E. Kucera	Exploration	Tourmaline-bearing breccia pipes and alteration of Cretaceous(?) andesite of Isabella Ridge
69	Billy Goat	sec. 15, 38N, 20E	Okanogan	Au, Cu, Ag	Sunshine Valley Minerals, Inc.	Repairing underground workings	Stockwork in Cretaceous(?) andesite tuff and breccia
70	Aeneas Valley property	35N, 30E (approx.)	Okanogan	Au, Ag, Cu, silica	Sunshine Valley Minerals, Inc.	Exploration	Unknown
71	Silver Bell area	sec. 25, 38N, 31E	Okanogan	Au, Ag	Pacific Northwest Resources Inc.	Exploration	Epithermal mineralization in Eocene felsic volcanic rocks of the Toroda Creek graben
72	Copper World area	secs. 20, 29, 39N, 26E	Okanogan	Cu, Au, Ag, W, Zn, Fe	Pacific Northwest Resources Inc.	Exploration	Ore lenses in altered andesite of the Permian–Triassic Palmer Mountain Greenstone
73	Alder area	secs. 23-26, 35-36, 33N, 21E	Okanogan	Au, Ag, Cu, Zn	Pacific Northwest Resources Inc.	Exploration	Replacement and volcanogenic massive sulfide mineralization in dacitic breccias of the Jurassic–Cretaceous Newby Group
74	Cannon mine	sec. 16, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc./ Breakwater Resources Ltd.	Mining; surface and underground drilling	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
75	Compton	sec. 27, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc./ Breakwater Resources, Ltd.	Retained property; no activity	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
76	Matthews	sec. 35, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc./ Breakwater Resources, Ltd.	Retained property; no activity	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
77	Spring claims	sec. 6, 23N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
78	Jeep claims	sec. 14, 23N, 19E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry, trenching	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
79	Lake claims	sec. 30, 23N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry, drilling	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone

80	Flume claims	sec. 2, 23N, 19E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
81	Trail claims	sec. 12, 23N, 19E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
82	NW¼, sec. 34 property	sec. 34, 24N, 19E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
83	Noid	sec. 8, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Drilling	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
84	Garmany and others	sec. 8, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
85	Simon	sec. 8, 22N, 20E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Drilling	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
86	Radio claims	sec. 34, 24N, 19E	Chelan	Au, Ag	Asamera Minerals (U.S.) Inc.	Geochemistry	Mineralization in altered (commonly silicified) intervals in Eocene arkosic sandstone
87	Sec. 36 lease	sec. 36, 22N, 20E	Chelan	Au, Ag	Wilbur Hallauer	Geophysics	Mineralization in Eocene arkosic sandstone
88	Raven group	sec. 21, 27N, 18E	Chelan	Au, Ag	Raven Hill Mining Co.	Exploration	Vein in Cretaceous schist and gneiss
89	MDOI #1 property	secs. 1-3, 22N, 17E	Chelan	Au, Ag, Hg, Cu	Montana d'Oro, Inc.	Geochemistry, trenching, underground drilling	Veins in serpentinite and metasedimentary and metavolcanic rocks of the Ingalls Complex
90	Holden property	secs. 18-19, 31N, 17E; secs. 12-13, 31N, 16E	Chelan	Cu, Au, Zn, Ag	Sunshine Valley Minerals, Inc.	Preliminary evaluation of in-situ leaching	Metamorphosed volcanogenic massive sulfide
91	Gold Ring property	secs. 15, 22, 29N, 17E	Chelan	Au, Ag, Pb, Zn	Gold Ring Mine, Inc.	Bulk sample; evaluation	Rocks of the area are part of the Cretaceous Chelan complex
92	New Light	sec. 27, 38N, 17E	Whatcom	Au, Ag, Cu, Ni, Pt, Pb	Western Gold Mining, Inc.	Exploration	Quartz-carbonate-cemented slate-argillite breccia in the Lower Cretaceous Harts Pass Formation
93	Azurite	sec. 30, 37N, 17E	Whatcom	Au, Ag, Cu, Zn, Pb, Pt	Double Dragon Exploration Inc.	Repaired road to mine; sampling	Veins in sedimentary rocks of the Cretaceous Virginian Ridge Formation
94	Minnesota	sec. 2, 37N, 16E	Whatcom	Au, Ag, Cu	Seattle-St. Louis Mining Co.	Sampling, maintenance and repair	Quartz veins in argillite and feldspathic sandstone of the Lower Cretaceous Harts Pass Formation
95	South Pass Nickel	sec. 2, 39N, 4E; sec. 35, 40N, 4E	Whatcom	Ni, Co	R. E. Kucera	Exploration	Laterite developed in peridotite at the base of Eocene sedimentary rocks
96	Index Silver Creek	secs. 18-19, 28N, 11E	Snohomish	Au, Ag, Cu, Pb, Zn	Sunshine Valley Minerals, Inc.	Reopened roads; drill-site preparation	Veins trend across the contact between the Index batholith and Swauk Formation
97	Lockwood	secs. 25, 30-32, 29N, 9E	Snohomish	Au, Cu, Zn, Fe, S, Ag	Kennecott Corp./ Island Arc Resources Corp./Formosa Resources Corp.	Drilling	Kuroko-type volcanogenic massive sulfide mineralization in Jurassic volcanic rocks of the Western melange belt
98	Apex - Damon	sec. 34, 26N, 10E	King	Au, Ag, Cu, Pb	CSS Management Corp.	Milling; mine repair and development	Quartz vein in granodiorite of the Miocene Snoqualmie batholith
99	Lenox group	secs. 7, 17-18, 25N, 10E	King	Au, Ag, Cu	Joel Ray	Mine development	Mineralization in shear zones of the Miocene Snoqualmie batholith

Table 1. Mining and mineral exploration in Washington, 1991 *(continued)*

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
100	company properties	Cascades area	King	Au, Ag, Cu, Mo, clay, silica, sand, gravel, crushed stone	Weyerhauser Co.	Evaluating company properties	Cascades province and adjacent volcanic, volcaniclastic, and intrusive rocks
101	Morse Creek	sec. 31, 17N, 11E	Yakima	Au, Ag	Ardic Exploration and Development, Ltd.	Drilling	Tuffs of the Oligocene Ohanapecosh Formation
102	Wind River	sec. 9, 5N, 7E	Skamania	Au, Ag	Wind River Mining Co.	Property reverted to original claimants	Mineralization in Oligocene to Miocene volcanic rocks
103	Margaret	S½ sec. 8 and N½ sec. 17, 10N, 6E	Skamania	Cu, Mo, Ag, Au	Teck Exploration, Ltd.	Property acquisition dependent on obtaining prospecting permits	Porphyry deposit in quartz diorite of the Miocene Spirit Lake pluton
104	Polar Star	sec. 18, 10N, 6E	Skamania	Cu, Mo, Ag, Au	Champion International Corp.	Drilling	Breccia pipes and porphyry-type deposit in quartz diorite of the Miocene Spirit Lake pluton
105	Black Jack	secs. 3-5, 8-9, 3N, 5E	Skamania	Cu, Ag, Au, Mo	Plexus Resources Corp.	Drilling; geological and geochemical exploration	Hydrothermal tourmaline-bearing breccia pipe associated with porphyritic phases of the Miocene Silver Star pluton
106	Mountain Springs	sec. 32, 4N, 5E	Skamania	Cu	Kenneth L. Bruhn, Sr., Mining Division	Applied for permit for test mining	Mineralization associated with the Miocene Silver Star porphyry copper/breccia pipe system
201	Totem talc	secs. 23, 25-26, 39N, 44E	Pend Oreille	talc	First Miss Gold Inc./ United Catalysts	Sampling, assessment work	Talc along a high-angle fault in altered dolomites of the Proterozoic Z Monk Formation (Windermere Group)
202	Mica mine	sec. 14, 24N, 44E	Spokane	clay	Mutual Materials Co.	Using 1990 stockpile	Lacustrine clay of the Miocene Latah Formation overlying saprolitic, pre-Tertiary felsic gneiss and locally underlying silty clay of the Pleistocene Palouse Formation
203	Somers clay pit	sec. 35, 25N, 44E	Spokane	clay	Quarry Tile Co.	Mining	Lacustrine clay of the Miocene Latah Formation underlain by silty clay of the Pleistocene Palouse Formation
204	Chewelah Eagle quarry	sec. 5, 32N, 41E	Stevens	dolomite	Chewelah Eagle Mining Co.	Mining by Nanome Aggregates for their Sunlit White product	Devonian(?)–Carboniferous(?) metacarbonates
205	Janni limestone quarry	sec. 13, 39N, 39E	Stevens	limestone	Peter Janni and Sons	Leased to Pluess-Staufer Industries, Inc.	Cambrian Reeves Limestone Member of the Maitlen Phyllite
206	Lane Mountain quarry	secs. 22, 34, 31N, 39E	Stevens	silica	Lane Mountain Silica Co. (division of Hemphill Brothers, Inc.)	Mining, milling	Proterozoic Z–Cambrian Addy Quartzite
207	Nine quarries		Stevens	dolomite	Nanome Aggregates, Inc.	Mining, milling; purchased by Internat'l Marble and Stone Co. (IMASCO) in April 1991	Dolomite or dolomitic marble is mined at nine sites in Stevens County: China White, Black, Lolo Martin, Primavera/Sage Green, Cream, Rose/Red, Grey/Chartreuse, Farnsworth, and Watermary

208	Sherve quarry	sec. 8, 39N, 40E	Stevens	limestone	Northport Limestone Co. (division of Hemphill Brothers, Inc.)	Mining, milling	Limestone in the upper unit of the Cambrian–Ordovician Metaline Formation
209	Addy dolomite quarry	secs. 13-14, 33N, 39E	Stevens	dolomite	Northwest Alloys, Inc.	Mining, production of magnesium metal	Dolomite in the Cambrian–Ordovician Metaline Formation
210	Eagle barite	sec. 33, 33N, 41E	Stevens	barite	Lovejoy Mining, Inc.	Mining; evaluation	Massive to brecciated barite veins in sheared argillite of the Proterozoic Y Striped Peak Formation (Belt Supergroup)
211	Joseph & Jeanne Janni property	sec. 13, 39N, 39E	Stevens	limestone	Fortuna Mines	Leased to Pluess-Staufer Industries, Inc.	Cambrian Reeves Limestone Member of the Maitlen Phyllite
212	Flagstaff Mountain	secs. 4, 9, 39N, 39E	Stevens	barite	Mountain Minerals Co. Ltd. *dba* Mountain Minerals Northwest	Refurbish mill; mine planning	Massive bedded barite in the Devonian–Carboniferous Flagstaff Mountain sequence
213	Gehrke quarry	sec. 2, 29N, 39E	Stevens	dolomite	Allied Minerals Inc.	Mining, milling	Isolated pod of Proterozoic Y Stensgar Dolomite(?) (Deer Trail Group)
214	Northwest marble mine	sec. 19, 38N, 38E	Stevens	dolomite	Northwest Marble Products Co.	Mining, milling	Dolomite in the Cambrian–Ordovician Metaline Formation
215	Turk Magnesite	sec. 36, 30N, 37E	Stevens	magnesite	Osprey Resources	Core drilling, evaluation	Magnesitization of the Proterozoic Y Stensgar Dolomite (Deer Trail Group) at the southwestern end of the magnesite belt
216	Blue Silver quarry	sec. 21, 28N, 36E	Lincoln	dolomite	Blue Silver Mining	Mining, milling	Dolomite in the Cambrian–Ordovician Metaline Formation
217	Rock Top #Two	sec. 20, 22N, 26E	Grant	clay	Basic Resources Corp.	Sampling, testing	Montmorillonite-group clays (bentonite) as interbeds within the Columbia River Basalt Group
218	Sec. 7 pit	sec. 7, 17N, 24E	Grant	diatomite	Celite Corp. (formerly Witco)	Mining, milling	Miocene "Quincy Diatomite Bed" (Squaw Creek Member, Ellensburg Formation) occurs locally at the base of the Priest Rapids Member (Columbia River Basalt Group)
219	Sec. 8 pit	sec. 8, 17N, 24E	Grant	diatomite	Celite Corp. (formerly Witco)	Mining, milling	Same as 218
220	Sec. 3/10 pit	secs. 3, 10, 17N, 23E	Grant	diatomite	Celite Corp. (formerly Witco)	Mining, milling	Same as 218
221	Coulee Chief	sec. 24, 23N, 25E	Douglas	clay	Basic Resources Corp.	Sampling, drilling, testing	Sedimentary interbeds in the Miocene Columbia River Basalt Group near Moses Coulee
222	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
223	Brown quarry	sec. 26, 35N, 26E	Okanogan	dolomite	Pacific Calcium, Inc.	Mining, milling	Metadolomite member of the Triassic Cave Mountain Formation
224	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)
225	White Rock	sec. 35, 39N, 26E	Okanogan	limestone	Chemstar Lime Co.	Core drilling, evaluation	High-calcium limestone in the Permian Spectacle Formation (Anarchist Group)

Table 1. Mining and mineral exploration in Washington, 1991 *(continued)*

Loc. no.	Property	Location	County	Commodity	Company	Activity	Area geology
226	Poison Lake	secs. 4-5, 38N, 27E	Okanogan	gypsite	Agro Minerals, Inc.	Mining	Evaporitic lake in a small basin at the convergence of several ravines dammed by glacial deposits
227	Bonaparte Meadows peat	sec. 20, 38N, 30E	Okanogan	peat moss	The Bonaparte Co.	Mining	*Hypnum* moss in a peat bog south of Bonaparte Lake
228	Swen Larsen quarry	sec. 34, 38N, 6E	Whatcom	olivine	Olivine Corp.	Mining, milling, production of olivine (refractory) incineration systems	A portion of the 36-mi^2 outcrop area of the Twin Sisters Dunite, Whatcom and Skagit Counties
229	Kendall quarry	secs. 14-16, 22-23, 40N, 5E	Whatcom	limestone	Tilbury Cement Co.	Mining	Lower Pennsylvanian limestone
230	Silver Lake quarry	sec. 7, 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
231	Hamilton plant	sec. 17, 36N, 7E	Skagit	olivine	Applied Industrial Materials Corp. (AIMCOR)	Milling, production of olivine products	Twin Sisters Dunite
232	Nason Ridge	secs. 10, 14-15, 27N, 15E	Chelan	marble	ECC International (English China Clay)	Drilling	Podiform bodies of high-calcium, high-brightness marble in pegmatitic tonalite and tonalite gneiss of the Chelan complex
233	Superior quarry	sec. 1, 19N, 7E	King	silica	Ash Grove Cement West, Inc.	Mining, milling	Silica cap in hydrothermally altered Miocene andesites on a caldera margin
234	Spruce claim	secs. 29, 30, 24N, 11E	King	crystals	Robert Jackson	Mining	Quartz and pyrite crystals occur in large, open voids along faulted megabreccia in the northern phase granodiorite and tonalite (25 Ma) of the Snoqualmie batholith
235	Ravensdale pit	sec. 1, 21N, 6E	King	silica	Reserve Silica Corp.	Mining, washing	Sandstone of the Eocene Puget Group
236	Elk pit	sec. 34, 22N, 7E	King	shale	Mutual Materials Co.	Mining	Illite- and kaolinite-bearing shales of the Eocene Puget Group
237	Sec. 31 pit	sec. 31, 24N, 6E	King	shale	Mutual Materials Co.	Mining	Shale and sandstone of the Eocene Puget Group
238	Newberry Hill peat	sec. 26, 24N, 1W	Kitsap	peat moss	Asbury's Topsoil	Mining	Bog contains peat, humus, *Sphagnum* moss, and clay, to which sandy loam is added for a topsoil product
239	Twin River quarry	secs. 22-23, 31N, 10W	Clallam	clay	Holnam Ideal, Inc.	Mining	Mudstone(?) in three members of the upper Eocene to lower Miocene Twin Rivers Formation
240	North Bay peat	sec. 13, 18N, 12E	Grays Harbor	peat moss	Ocean Farms and Soils	Mining	*Sphagnum* moss is produced as a component for topsoil
241	Clay City pit	sec. 25, 17N, 4E	Pierce	clay	Mutual Materials Co.	Mining	Miocene or Oligocene kaolin-bearing, altered andesite
242	Bucoda pit	sec. 14, 15N, 2W	Thurston	clay	Mutual Materials Co.	Mining	Glacial clay of the lower Pleistocene Logan Hill Formation overlying silty clay of the Eocene Skookumchuck Formation

companies and individuals maintain properties in the Wenatchee area.

Hecla Mining Co.'s Republic Unit (no. 25), the major revenue-producing property for the company over the past several years, continued to produce from the Golden Promise area of the deposit. The 1991 production from the Republic Unit was 77,736 ounces of gold and 311,445 ounces of silver from 96,562 tons of ore milled. Hecla reports the ore grade at the mill averaged 0.87 ounces of gold per ton.

The highlight of the year for the Republic Unit was completion of the decline-ramp (Fig. 3), which provides more direct access to the Golden Promise orebodies. This allows the use of rubber-tired, diesel vehicles for loading ore and hauling it directly to the surface. Hecla began using the new ramp in August of 1991. The decline also provides access for exploration and development of disseminated orebodies in bedded tuffs of the Eocene Sanpoil Volcanics. Because the new access was completed to the 800 level ahead of schedule and under budget, it was extended to the 1100 level. The new 11-by-13-foot decline is 7,200 feet long and replaces the former method of transporting (tramming) ore more than a mile to the Knob Hill #2 shaft before hoisting it to the surface.

Figure 3. Completion of the new decline at Hecla Mining Co.'s Republic Unit signaled the advent of new mining methods at the mine. Pictured is a diesel, rubber-tired, 3.5-yd^3-capacity loader exiting the new decline. This vehicle is used to load 16-ton-capacity diesel trucks that haul ore directly to the surface. Previously all ore was dropped to the 1100 level, trammed 7,000 feet by rail to the Knob Hill #2 shaft, and then hoisted to the surface.

Hecla embarked on an extensive program of underground exploration and development and began remapping the geology of their numerous holdings throughout the district. Recent advances in understanding epithermal, hot-spring-type mineral deposits like that at Republic (Tschauder, 1989) spurred this program. If Hecla is successful and if considerable reserves are located, the company is likely to increase production and expand the mill (cover photo), which now has a capacity of 270 tons per day.

Hecla's Golden Eagle property (no. 26) reportedly contains more than 1 million ounces of gold at a grade of 0.13 ounces per ton (Phelps, 1991). Because of differences between ore from the Golden Eagle property and that of the Golden Promise, the Golden Eagle was put on hold during the past year, and exploration centered on the Golden Promise veins and adjacent mine areas.

Washington's other producing epithermal gold deposit, the Kettle mine (no. 30), located west of Curlew in the Republic graben, is projected to be mined out in 1992. Total production for the Kettle mine will exceed 80,000 ounces of gold. The deposit, like mineralization in the Republic district, is at or near the top of the Sanpoil Volcanics (Tschauder, 1989). The mine is part of the Kettle River Project, a joint venture between Echo Bay Minerals Co. (the operator) and Crown Resources Corp. Approximately 300 tons per day of the Kettle ore is processed at the joint venture's Key mill, located near the Overlook mine northeast of Republic.

Echo Bay/Crown Resources continued exploration on their K-2 property (no. 31), located 2 miles west-southwest of the Kettle mine. This deposit is genetically similar to the Kettle deposit.

Replacement-Type Gold Deposits

The Overlook mine is the model for replacement-type gold deposits found in contact-metamorphosed and metasomatized rocks in northeastern Washington. Host rocks for these replacement-type deposits are volcaniclastic and epiclastic rocks that were deposited in and around island arcs adjacent to the North American continent during the Permian and Triassic. These rocks were accreted to the continent in mid-Mesozoic time (Stoffel and others, 1991). Contact metamorphism and metasomatism took place when granitic to dioritic bodies ranging in age from Jurassic to Eocene intruded the Permian to Triassic rocks. Tschauder (1989) provides additional details about replacement-type deposits in the Republic graben. (Replacement-type deposits are compared with skarn-type deposits in the next section.)

The Overlook mine (no. 32), the other producing mine in the Kettle River Project, completed its first full year of production in 1991. Throughput at the Key mill, which processes ore from both the Overlook and Kettle mines, ranged from 1,500 to 2,100 tons per day. The majority of the ore for the Key mill is from the Overlook mine, with only about 300 tons per day coming from the Kettle mine. Production from both the Kettle and Overlook mines in 1991 was 90,272 ounces of gold from 644,950 tons of ore with a grade of 0.164 ounces of gold per ton.

Echo Bay Minerals and Crown Resources are in the process of obtaining permits to begin mining at the Key East (no. 33) and Key West (no. 34) deposits, located northeast of the Overlook mine. Production will begin as soon as permits are obtained. The Key East and Key West deposits, like the Overlook, are in Permian rocks.

Other Echo Bay Minerals exploration projects in similar Permian rocks include properties in the Cooke Mountain area (nos. 37-38) and at the Lamefoot property (no. 35), which became part of the Echo Bay/Crown joint venture at the end of the year. The joint venture partners are seeking permits to drive an exploration drift into the Lamefoot deposit and are expected to announce a probable reserve for

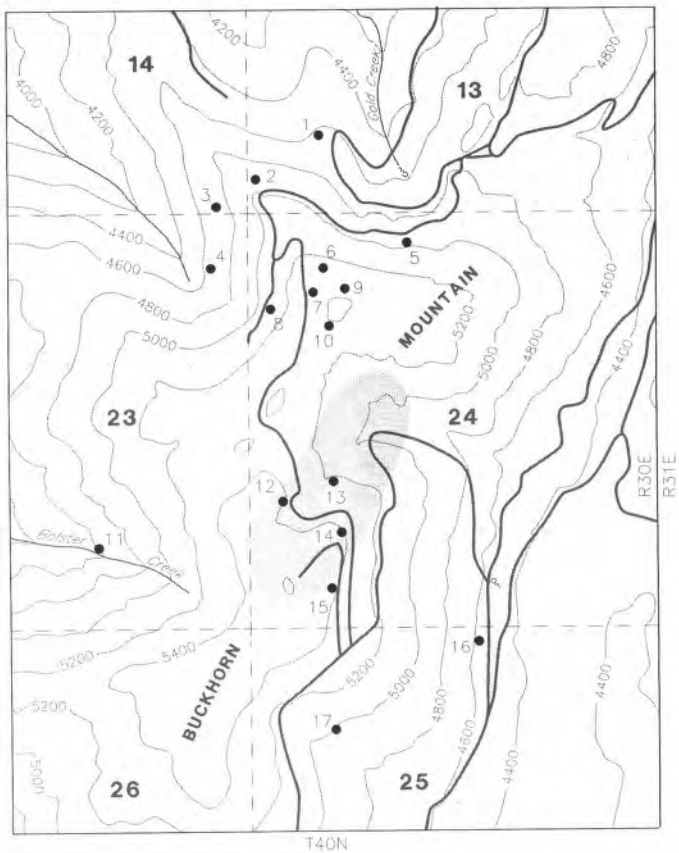

Figure 4. The approximate area of the Crown Jewel deposit is shown by the shaded pattern on this simplified topographic map, along with the location of mines and prospects in the area. Contour interval = 200 feet. 1, Caribou; 2, Rainbow; 3, Nip and Tuck; 4, Jackpot; 5, Magnetic; 6, Aztec; 7, Western Star; 8, Buckhorn adit; 9, Copper Queen; 10, Monterey; 11, Myers Creek; 12, Ironsides and Anna B.; 13, Crown Jewel; 14, Double Axe; 15, Gold Axe; 16, Roosevelt; 17, American Girl.

this prospect in mid-March. Echo Bay Minerals (the operator) also entered into a joint venture to explore the Leland property (no. 36), located between the Lamefoot deposit and the Overlook mine.

Two properties adjacent to the Lamefoot property were drilled in 1991: the Kellogg (no. 39) and the Wardlaw (no. 40), both operated by Placer Dome U.S. Inc. under a joint venture agreement with Equinox Resources Ltd. They are two of the many properties in Permian rocks of the Republic graben (Table 1). Other exploration projects investigating replacement-type deposit characteristics were active in the wedge-shaped area between the Kettle and Columbia Rivers and the Canadian border.

Readers interested in obtaining more information about iron and magnetite deposits (many of which are of the contact metasomatic type) in northeastern Washington should refer to Lucas (1977) and Broughton (1945). Details about Permian, Triassic, and early Jurassic rocks are presented by Holder and others (1989). The geology of the Republic and Toroda Creek grabens is shown on maps by Muessig (1967), Parker and Calkins (1964), and Pearson (1967). Pearson and Obradovich (1977) compiled information on the Eocene intrusive and extrusive rocks in northeastern Washington.

Skarn-Type Gold Deposits

The Crown Jewel deposit is a model for skarn-type gold deposits in Washington and southern British Columbia. Skarn (or tactite) is formed by the contact metamorphism and metasomatism of carbonate rocks. The skarn-type gold deposits are genetically similar to replacement-type gold deposits. The known skarn-type and replacement-type gold deposits in Washington are found in metasomatized Permian to Jurassic carbonate host rocks or in volcaniclastic and epiclastic host rocks, respectively. The only difference between the two types of gold deposits may be the nature and composition of the original host rocks. Gold (including that at the Crown Jewel deposit) is found in garnet skarn, in pyroxene skarn, and in skarn containing iron and copper minerals (Ettlinger and Ray, 1989). Gold at the Overlook replacement-type deposit is found in rocks containing metasomatic iron and copper minerals. Intrusive rocks associated with Washington's skarn- and replacement-type deposits range in age from Jurassic to Eocene and are commonly granitic to dioritic.

Figure 5. An old timber clearcut on Buckhorn Mountain is near the center of the newly discovered Crown Jewel orebody near Chesaw. Battle Mountain Exploration/Crown Resources announced a drill-indicated reserve of 1.6 million ounces of gold underlying and extending north-northeastward from the mountain. (See also Fig. 4.)

Extensive drilling during 1991 at the Crown Jewel deposit (no. 52), a joint venture project between Battle Mountain Gold Corp. (the operator) and Crown Resources Corp., centered on locating the margin of gold mineralization for the orebody. (See Hickey, 1992.) The deposit is within the approximate area shown on Figure 4, which covers about 60 acres on and adjacent to Buckhorn Mountain (Fig. 5). Reserves announced in December 1991 are 8.7 million tons of ore at a grade of 0.186 ounces of gold per ton, or a total of more than 1.6 million ounces of gold. Cut-off grade was 0.032 ounces per ton, waste to ore ratio was 9 to 1, and metallurgical recovery is expected to be about 87 percent. Battle Mountain also com-

pleted a small excavation to confirm results from drilling (Fig. 6). The companies initiated the permitting process in preparation for mining.

The Crown Jewel deposit is part of an 8,000-plus-acre property package known as the Crown Jewel exploration project (no. 53) that the Battle Mountain/Crown Resources joint venture is evaluating. Several other companies are studying potential skarn-type properties throughout northeastern and north-central Washington (Table 1).

Figure 6. Drill operating at Battle Mountain Exploration/Crown Resources' Crown Jewel deposit in 1991. Test excavation (in the foreground) by Battle Mountain confirmed the grade of near-surface gold mineralization indicated by drilling.

Mississippi Valley-Type Deposits

Washington contains many Mississippi Valley-type deposits in the Cambrian–Ordovician Metaline Formation (Mills, 1977; Dings and Whitebread, 1965) in the northeastern corner of the state (Fig. 7). The typical Mississippi Valley deposit contains lead and zinc minerals with, at best, trace amounts of silver as the only precious metal. Zinc generally exceeds lead in these deposits.

Mining and exploration for lead and zinc deposits in Washington have been essentially inactive over the past several years because of depressed prices for lead and zinc. The last operating mine in this type of deposit was the Pend Oreille, which closed in 1977. Increased demand and higher prices for zinc, combined with the proximity of these deposits to Cominco's smelter at Trail, B.C., resulted in Equinox Resources Ltd. reopening the Van Stone mine (no. 5) in northern Stevens County. The mine stripped overburden in 1990 in preparation for mining, which began in early 1991 (Fig. 8). Mining progressed until the end of August when, due to depressed zinc prices, it was suspended to await improvements in the economy and higher prices. The mine operated during the summer at a monthly rate of 150,000 tons of ore plus waste. Waste to ore ratio was 7 to 1; the ratio of zinc to lead was approximately 2.5 to 1. On the basis of conversion of the lead content to zinc equivalents, ore grading between 2.5 and 4 percent zinc was sent to a low-grade stockpile and ore grading more than 4 percent zinc was sent directly to the mill.

The mill (Fig. 9) continued to operate through October using ore from the low-grade stockpile. The mill is capable of producing 950 tons of concentrates per day. When zinc prices recover to about 55 cents per pound, the Van Stone mine will resume production, according to Equinox officials.

The Pend Oreille mine (no. 1), in another Mississippi Valley-type deposit near Metaline Falls, was the site of underground exploratory drilling by Resource Finance Inc. The target was zinc-rich ores of the Yellowhead zones. Most of the previous production from the Pend Oreille mine was from the upper part of the Josephine breccia lithofacies; however, the zinc-rich ores of the Yellowhead zones have become increasingly important with increased zinc demand. A total of 13 holes were drilled, with encouraging results, but any further exploration or development apparently awaits recovery of the price of zinc.

Volcanogenic Massive Sulfide Deposits

Volcanogenic massive sulfide deposits form when hot springs vent onto the seafloor. Present-day examples of this phenomenon have been observed on the Juan de Fuca Ridge off the coast of Oregon, Washington, and British Columbia. Interest in volcanogenic massive sulfide deposits increased with the announcement of the results of drilling on Kennecott Corp.'s Lockwood deposit (no. 97) in Snohomish County. The project is a joint venture among Kennecott (the operator), Island Arc Resources Corp., and Formosa Resources Corp. Intercepts from six drill holes averaged 2 percent copper, 3 percent zinc, 0.05 ounces of gold per ton, and 1.3 ounces of silver per ton over an average thickness of

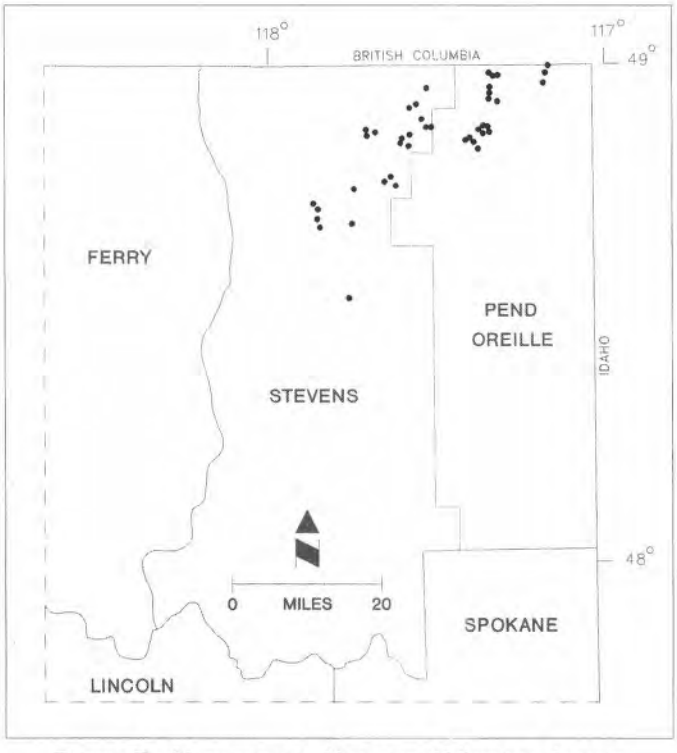

Figure 7. Many mines in Mississippi Valley-type deposits in northeastern Washington have produced lead and zinc. Mine locations are shown on this map.

40 feet. Extensive bedded pyrite was known from this deposit (Derkey and others, 1990; Carithers and Guard, 1945), and it was considered a resource for both iron and sulfur. The recent exploratory drilling, which located associated base- and precious-metal mineralization, is in an area of extensive glacial cover. The geology of the area has been described by Tabor and others (1982).

One other recognized volcanogenic massive sulfide deposit, which has had extensive production, is the Holden mine (no. 90) (Nold, 1983). Sunshine Valley Minerals, Inc., conducted a preliminary study of the property for possible mining. Other areas that have volcanogenic massive sulfide potential include the Alder area (no. 73) and the Copper World area (no. 72), both in Okanogan County.

Other Deposit Types

Several companies expressed renewed interest in Washington's numerous porphyry-type deposits (Fig. 10), many of which are described in Derkey and others (1990). In the past, these properties were examined for their copper or molybdenum resource potential. Current interest is focused on the potential for precious-metal resources as well. Porphyry-type deposits that were explored in 1991 include the Mazama property (no. 67), where Centurion Mines Corp. embarked on a program to re-evaluate all of the pre-existing data for the property. They also restaked a number of claims and completed a drilling program on the property. Pegasus Gold Corp. obtained an option on the Hot Lake property (no. 66), which is adjacent to the Kelsey porphyry deposit (no. 64). Teck Exploration, Ltd., is seeking permits to work on the Margaret deposit (no. 103), and Champion International Corp. continued to evaluate their Polar Star property (no. 104), which is near the Margaret deposit. Plexus Resources Corp. maintained their Black Jack and adjacent properties (no. 105). Kenneth L. Bruhn, Sr., applied for a permit for test mining on his Mountain Springs property (no. 106); however, the permit was not approved.

Two properties on the Colville Indian Reservation, the Parmenter Creek (no. 62) and Strawberry Creek (no. 63), saw activity in 1991. These are in or adjacent to Tertiary rocks in the southern part of the Republic graben and may be epithermal deposits or peripheral portions of porphyry-type deposits.

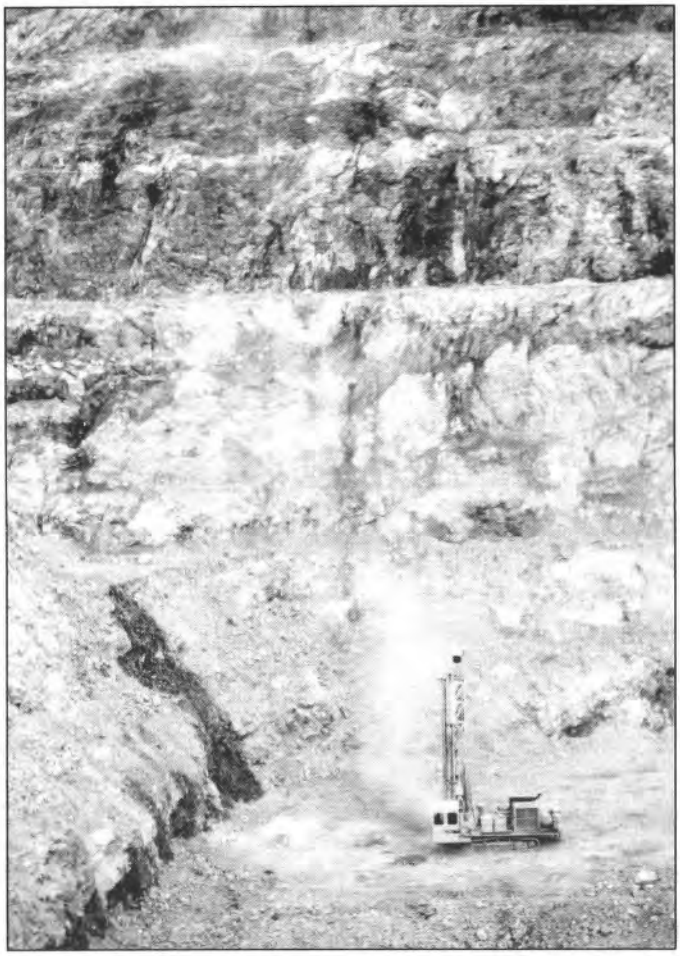

Figure 8. Production drill at work at the Van Stone mine, which was operated by Equinox Resources Ltd. through August of 1991. The mine produced zinc and lead ore for the nearby Van Stone mill.

Several deposits in rocks of the Shasket Creek alkalic complex were mined or explored over the past few years. The most notable are the Gold Mountain mine (no. 48; formerly called the Gold Dike) (Herdrick and Bunning, 1984) and the Lone Star mine (no. 50); these produced in the

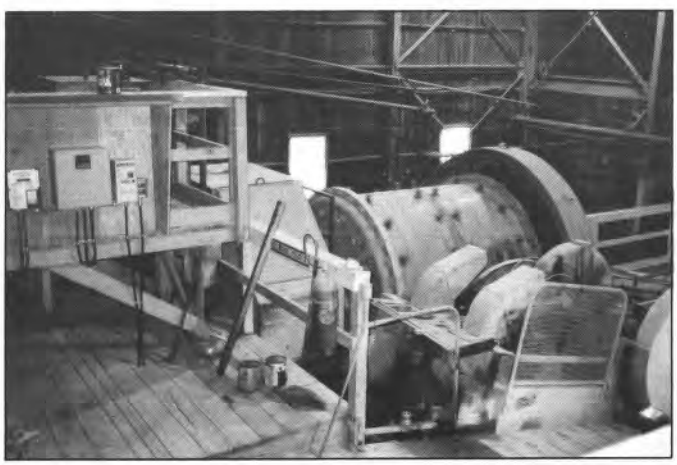

Figure 9. The ball mills and flotation cells were operating again at the Van Stone zinc-lead mine in northeastern Washington. This was the first base-metal production in Washington since the Pend Oreille mine closed in 1977. Although the mill ceased operation at the end of October, it is expected to re-open in 1992 if zinc prices recover to about 55 cents per pound.

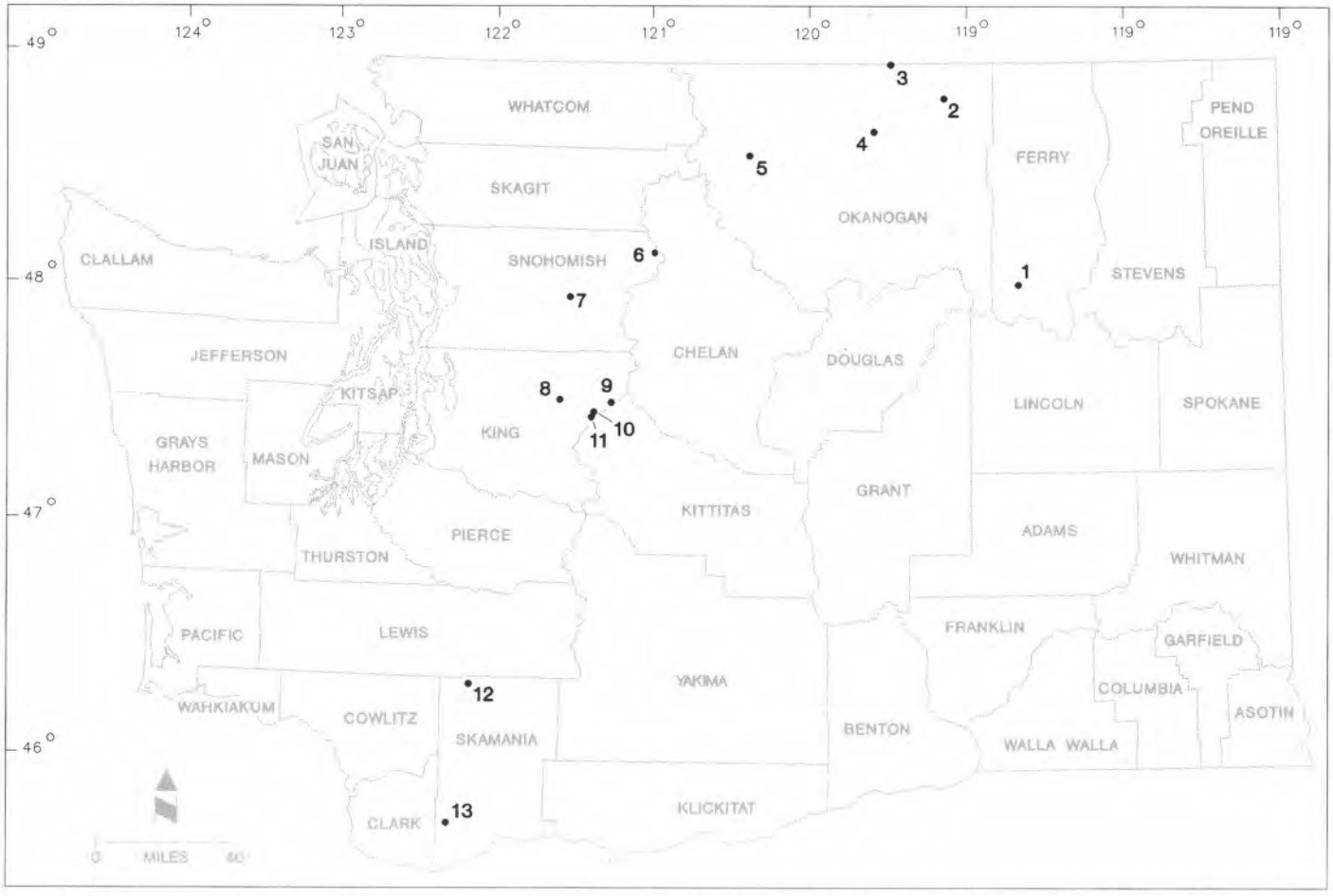

Figure 10. Locations of porphyry copper/molybdenum deposits in Washington. Descriptions of these deposits are given in Derkey and others (1990). 1, Mount Tolman; 2, Bi-Metallic; 3, Kelsey; 4, Starr; 5, Mazama; 6, Glacier Peak; 7, Sunrise; 8, Quartz Creek; 9, Dutch Miller; 10, Clipper; 11, Condor-Hemlock; 12, Margaret; 13, Black Jack.

1980s and 1970s, respectively. The Gold Mountain deposit is now a joint venture project of Gold Express Corp. and N. A. Degerstrom, Inc. Permits to mine this deposit, which consists of disseminated pyrite and gold in a dike of Shasket Creek alkalic rocks, were obtained in 1991.

CSS Management Corp. prepared the Apex mine for increased mining on their combined Apex and Damon properties (no. 98). Their principal effort, however, was directed toward research of the "Cashman" process, which uses a small, pressure-leaching mill to extract metals from ore.

Recognition of a potential for gold in shear zones prompted increased activity in the area west of Oroville and Tonasket in northern Okanogan County. Districts such as the Nighthawk (Umpleby, 1911; Rinehart and Fox, 1972), Palmer Mountain (Rinehart and Fox, 1972), and Conconully (Rinehart and Fox, 1972, 1976) are attractive for this type of deposit. This area also has potential for volcanogenic massive sulfide deposits (Copper World area, no. 72), porphyry-type deposits (Kelsey, no. 64, and Starr Molybdenum, no. 65), and possible skarn-type deposits (Lucky Knock, no. 60). With its relatively high potential, this area may be the focus of increased activity in the coming year.

INDUSTRIAL MINERALS

Preliminary production statistics for Washington from the U.S. Bureau of Mines suggest that 1991 was, in most respects, a typical year for production of industrial minerals. The overall value was slightly lower than in 1990, but two new projects, a cement plant and barite production, along with other projects under development should result in a comparable value for 1992, despite depressed prices for magnesium metal and other recession-related malaise.

Following sand and gravel and crushed aggregates, the principal nonmetallic materials quarried in Washington, in approximate descending order of value, are: dolomite and limestone, diatomite, silica, olivine, clay/shale, decorative stone, gemstones, peat, gypsum, and barite. Portland cement and lime contribute substantially to the Bureau of Mines figures for total nonfuel mineral value in Washington. However, most of the limestone for production of portland cement and lime is currently procured from sources outside of the state or country. Commodities wholly produced from imported raw materials, such as silicon and aluminum metals, are not included in the Bureau of Mines tabulation.

Construction Materials

Washington produced 40.5 million short tons of sand and gravel valued at $135.7 million (preliminary estimates). The state is the fifth largest producer of sand and gravel (round-rock aggregate) in the nation, a position it has held for a number of years. Preliminary statistics for crushed stone are 16.6 million short tons valued at $54.8 million. The

volume of both sand and gravel and crushed stone produced in 1991 was slightly higher than in 1990. However, production figures are imprecise because the Bureau of Mines estimates sand and gravel production for odd-numbered years and surveys production for even-numbered years, whereas crushed stone production is surveyed for odd-numbered years and estimated for even-numbered years. Data for the crushed stone tabulation combine locatable carbonate rock production (for lime, filler/coating, and metallurgical uses, for example) with "common variety" crushed rock aggregates for construction. These crushed carbonates are "locatable" minerals under federal mining laws owing to their inherent chemical properties. The finished products derived from them can be extremely valuable relative to crushed stone. This value-added aspect is commonly not represented in industrial-mineral products statistics.

Total production of portland cement has declined over the past two years following the mid-1990 closure of Lafarge Corp.'s cement plant at Metaline Falls. This decline is expected to be reversed in 1992 with the completion and scheduled start-up in May of Ash Grove Cement Co.'s new plant in Seattle. This will be the largest cement plant in the state, and it will have a production capacity of 750,000 short tons per year. All the limestone to be used in the manufacture of their portland cement will be barged from the Ash Grove Cement Co. quarry on Texada Island in British Columbia. Ash Grove is evaluating three Washington sources for the clay component of cement, and the silica will be derived from additional production at Ash Grove's Superior quarry (no. 233) located in King County.

Washington's only active portland cement manufacturer is the Holnam Ideal, Inc., plant in Seattle. This plant continues to produce at near its capacity of 500,000 short tons per year. Holnam Ideal's limestone is mined on Texada Island and barged to Seattle. Holnam Ideal mines their clay at the Twin River quarry (no. 239) along the Strait of Juan de Fuca, west of Port Angeles. A second portland cement plant at Bellingham is being used by Tilbury Cement Co. to grind clinker (marble-sized balls of portland cement as it emerges from a kiln). The clinker is imported from their portland cement plant at Delta, B.C.

Dolomite, Limestone, and Magnesite

Magnesium metal, produced from dolomite by the magnatherm process (Joseph, 1990), is the dominant value-added industrial mineral commodity produced in the state. Unlike silicon or aluminum metals, magnesium metal is derived from raw material quarried in Washington. The value of magnesium metal accounted for about one-fifth of the total value of the state's mineral industry during 1991. Northwest Alloys, Inc. (no. 209), the sole Washington producer, quarried more than 500,000 tons of dolomite ore for magnesium production at its Addy plant. Major dumping of magnesium on the world market by the former Soviet Union resulted in a 30 percent drop in price at the end of 1991. Consequently, Northwest Alloys could not compete and relied on its parent company, Alcoa, as sole customer. A 50 percent temporary reduction in the total workforce of 500 was announced by the company in December; this will take effect prior to March 31, 1992.

L-Bar Industries, located at Chewelah, processes magnesium- and potassium-rich sludge bar residue from the Northwest Alloys magnesium plant. The product, Ag-Mag-K, is used for soil amendment purposes. L-Bar was temporarily shut down at the end of the year.

Five other companies, Nanome Aggregates, Inc. (no. 207, plant location), Allied Minerals (no. 213), Northwest Marble Products Co. (no. 214), Chewelah Eagle Mining Co. (no. 204), and Blue Silver Mining (no. 216), produced a total of 34,000 tons of dolomite in 1991. The dolomite is crushed or ground for terrazzo chips, exposed aggregate veneers, landscaping rock, and agricultural applications.

Nanome Aggregates, Inc., best known for their wide selection of naturally colored terrazzo floor chips, became part of International Marble and Stone Co. (IMASCO) of Surrey, B.C., in April of 1991. Meridian Minerals purchased Nanome just 14 months earlier, in February of 1990. Meridian separately sold IMASCO, and subsequently Nanome, to a group of investors.

Despite abundant limestone resources throughout Washington (Mills, 1962; Danner, 1966), production in 1991 was limited. Limestone from quarries on Texada Island in British Columbia is the primary source for western Washington producers of portland cement (Holnam Ideal, Inc.), calcium carbonate fillers (J. M. Huber Corp. and Hemphill Brothers, Inc.), and lime (Continental Lime Inc.). The high-calcium limestone from Texada Island is likely to retain or gain market share owing to the low cost of transportation by barge and its high purity.

The in-state production of limestone in western Washington was primarily for rip-rap used to mitigate effects of flooding in the northwestern part of the state. Tilbury Cement Co. produced 80,000 tons at the Kendall quarry (no. 229). On the opposite side of Red Mountain from the Kendall quarry, Clauson Lime Co. produced 130,000 tons at the Silver Lake quarry (no. 230). Prior production from these high-calcium deposits was primarily used in portland cement manufacturers and the pulp and paper industry.

Eastern Washington limestone producers quarried 63,000 tons for agricultural applications, for metallurgical processing at Cominco Ltd.'s Trail, B.C., smelter, and for use in paper coatings and fillers at Columbia River Carbonates' plant at Woodland, Wash.

One of 1991's notable exploration/development efforts is Chemstar Lime Co.'s evaluation of the White Rock limestone deposit (no. 225), northwest of Tonasket, as a source of material for production of lime. This deposit received extensive attention in the late 1980s as a limestone resource for a portland cement plant at Ellisforde, Wash. The project, planned by Ciment Quebec, was later dropped.

Osprey Resources of Point Roberts, Wash., has leased the Turk magnesite deposit (no. 215) and drilled three core holes totaling 500 feet during July 1991. The drilling program delineated thick sections of white magnesite with MgO values from 34 to 51 percent and confirmed previously published results from a 1942 drilling program (Bennett, 1943).

Diatomite

Witco Chemical Corp., Washington's only diatomite producer (nos. 218–220), was acquired by Celite Corp. after an unsuccessful bid by Eagle Picher Mineral Co. and an unsuccessful buyout plan by Witco employees. Celite, originally the diatomaceous earth division of the Manville Corp. in California, was acquired by the Allegheny Corp. of New York

several months prior to the Witco acquisition. Because Manville's *Celite* line of products held 47 percent of the total market share and the Witco *Kenite* products had 13 percent, the combination of the two companies was examined closely by the antitrust division of the Washington state attorney general's office. Witco total assets were valued at approximately $7.9 million. Operations at the Quincy plant have not been affected by the change in ownership, and approximately 60,000 finished tons were produced in 1991 for filtration products and for fillers in plastics.

Diatomite in the Quincy area is found in interbeds in the Miocene Columbia River Basalt Group. The diatomite beds formed from accumulations of the siliceous skeletons of diatoms that lived in freshwater lakes on basalt-flow surfaces in the Quincy basin.

Silica

Three companies produced silica in Washington during 1991. Lane Mountain Silica Co. (no. 206) produced 300,000 tons for glass, golf course sand traps, and other uses. Ash Grove Cement West, Inc., produced 130,000 tons of silica at the Superior quarry (no. 233) for portland cement. Ash Grove exported 40,000 tons to Tilbury Cement in Delta, B.C.; however, in 1992 Ash Grove will begin to use much of their silica production in-house at their new Seattle cement plant. Reserve Silica Corp. (no. 235) of Ravensdale mined 60,000 tons of silica sands primarily for cement and glass.

Olivine

Olivine Corp. mined 60,000 tons of refractory olivine ore from the Swen Larsen quarry (no. 228) in the Twin Sisters Dunite deposit (Ragan, 1963). Most of the olivine is sold to AIMCOR and processed into a variety of refractory products at their Hamilton plant (no. 231) in Skagit County. Olivine Corp. continues to utilize a small portion of their refractory mineral production for the manufacture of wood- and municipal-waste incinerators, which they market.

Clay/Shale

Clay production for bricks and ceramic tiles continued on the east and west sides of the state by Mutual Materials Co. (nos. 202, 236, 237, 241, 242) and the Quarry Tile Co. (no. 203). The largest production of clay was from Holnam Ideal's Twin River quarry (no. 239) on the Olympic Peninsula near Port Angeles, from which 109,000 tons of high-aluminum clay from the Eocene Twin River Group sediments was barged to their portland cement plant in Seattle. Additional clay will be needed in Washington when Ash Grove Cement opens its new plant in Seattle.

Building Stone

Ashlar, flagstone, rubble, and veneers were produced during 1991 by at least four companies. Rough construction stones were quarried from andesite, basalt, marble, and quartzite, respectively, by Heatherstone Inc., Gilbert Western Corp., Whitestone Co., and Raymond Fosback Masonry. Crushed landscaping rock and larger landscaping boulders, crushed and natural river rock, moss rock, and other stone materials were marketed, particularly in the populous, high-growth corridor of western Washington. More detailed information on building and decorative stone will be published in a future issue of *Washington Geology*.

The Bureau of Mines value of production for the category "stone (dimension)" is extrapolated from information obtained from producers of rough construction stone. However, true dimension stone has not been produced in Washington for several years.

Gemstones

The Bureau of Mines mineral commodity specialist defines gemstones as those rocks and minerals from which gemstones can be prepared. Gemstone products include carvings or *objets d'art*. The Bureau of Mines reported Washington's gemstone production value for 1991 at $285,000. This includes a significant portion of the state's production of petrified wood and picture rock by Northwest Gem Co., Rockhanger Minerals, Lee and Son, and others. Quartz crystal, another important Washington gemstone, is mined from breccia pipes (no. 234) in the Snoqualmie batholith near North Bend. Gemstone producers are not tabulated in Table 1 or located on the accompanying figures. The gemstone statistics do not take into account the large numbers of hobbyists who produce items from quartz, agate, jasper, picture rock, and the like, nor the preeminence of many mineral crystal specimens that are collected in the state such as those from the Spruce claim (no. 234). Several world-class mineral collecting localities were highlighted in the July/August 1991 (Washington State Issue) and November/December 1991 issues of *Rocks and Minerals* magazine.

Barite

Washington contains 28 known former barite mines or prospects in Stevens and Pend Oreille Counties (Moen, 1964), but it will experience its first barite production in more than a decade in early 1992. Mountain Minerals Co. Ltd. of Lethbridge, Alberta, has refurbished a mill on Sheep Creek near Northport and is in the start-up stage of producing from bedded barite on Flagstaff Mountain (no. 212). The barite will be used in drilling mud. The company is doing business as Mountain Minerals Northwest.

Gypsum and Peat

Agro Minerals, Inc., of Oroville (no. 226) produced small amounts of gypsite (an earthy form of gypsum) for fertilizer. Two major manufacturers of gypsum wall board in Seattle, Domtar Gypsum and James Hardie Gypsum, continue to satisfy their requirements for raw materials by importing relatively inexpensive ore from Mexico.

At least three peat producers (nos. 227, 238, 240) were active in widely separated parts of Washington. The primary use of peat is in topsoil mixes.

COMMODITIES PRODUCED FROM IMPORTED RAW MATERIALS

Other valuable nonfuel mineral commodities produced in Washington are lime, silicon metal, and aluminum metal. Lime production statistics are included in the U.S. Bureau of Mines value for nonfuel mineral production in Washington, but aluminum and silicon metals are not. A portion of the lime produced in Washington is from imported limestone, whereas nearly all of the raw materials for silicon and aluminum metal originate at sites outside the state.

Silicon

Approximately 18,000 tons of high-quality silicon metal (>96% Si, <0.03% Fe) was produced by Silicon Metaltech at their Rock Island plant (near Wenatchee). They transport, by rail, 50,000–60,000 tons per year of massive, high-purity (≈99.8% SiO_2) quartzite ore from Golden, B.C., to this plant. All three furnaces are operating, and the outlook is improving at Silicon Metaltech despite the continuance of Chapter 11 bankruptcy proceedings. Silicon metal dumping by Argentina, Brazil, and China was exposed during 1991, with resultant import tariffs as high as 140 percent for the Chinese material. Both Silicon Metaltech and Northwest Alloys are capable of producing ferrosilicon; however, neither have resumed doing so.

Aluminum

Aluminum metal production from Washington-based plants was estimated at 1.24 million metric tons with an approximate value of $1.6 billion in 1991 (Patricia Plunkert, U.S. Bureau of Mines, oral commun., 1992). The average price declined from 74 cents per pound in 1990 to 59.5 cents per pound in 1991. This was a result of reduced demand combined with increased supply, particularly aluminum from the former Soviet Union.

The value of aluminum metal produced in Washington is appreciable, and if it were included in the Bureau of Mines valuation of total nonfuel mineral production, Washington would jump from its 1991 rank of twenty-fourth in the nation to fourth.

Lime

Continental Lime Inc., a wholly owned subsidiary of Graymont Ltd., continued production of hydrated lime and quicklime at their Tacoma plant. The high-calcium limestone used by Continental is barged from limestone quarries on Texada Island. A slight downturn in sales during 1991 resulted in minor excess capacity and reflects Continental Lime's reliance on paper industry customers. This is expected to be a short-term downturn, as the national trend is toward increased lime consumption. Two major and expanding markets for lime are in the manufacture of caustic soda from sodium carbonate (trona) and for flue-gas desulfurization. As an example, Spokane's new waste-to-energy plant (garbage incinerator) currently consumes 80 tons of lime per week for flue-gas treatment. At the minimum (85 percent) on-line availability of this plant alone, more than 3,500 tons of lime per year will be required to treat the stack gas.

Other lime manufactured in Washington is mainly derived from paper plant effluents and not directly mined. Continental Lime continues to operate a precipitated calcium carbonate (PCC) plant at its Tacoma complex. PCC plants produce crystalline calcium carbonate fillers and coatings for "acid-free" paper, which has a neutral or alkaline pH. All but one of Washington's fine-quality paper plants have converted from acid to alkaline paper manufacture, thus incorporating PCC or ground calcium carbonate as paper coatings and fillers. Pfizer Inc., Specialty Minerals Group, owns the three other PCC plants in Washington, at Camas, Longview, and Wallula. These recently constructed satellite PCC plants are adjacent to the James River, Weyerhaeuser, and Boise Cascade paper manufacturing plants, respectively. Pfizer now operates 21 PCC plants throughout the United States.

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Northeast Washington Geological Society

The first 1992 meeting of an informal organization known as the Northeast Washington Geological Society is scheduled for March 29, when Byron Berger of the U.S. Geological Survey will speak on gold deposits in Uzbekistan, including the giant Muruntau deposit. NEWGS speakers present topics of interest to the mineral exploration and mining community of this part of Washington. Meetings are held at the Somewhere Else Banquet Hall in Republic, and the March presentation begins at 7:30; a social hour precedes the talk. For additional information about NEWGS and scheduled events, write to NEWGS, P.O. Box 658, Republic, WA 99166, or phone 509/775-3022.

Northwest Geological Society

A regional association for professionals, students, and other interested persons, the Northwest Geological Society provides a forum for the presentation and discussion of a wide range of geologic topics, emphasizing those of the Pacific Northwest or of fundamental scientific interest. Meetings are the second Tuesday of the months between October and May at the University Plaza Hotel, NE 45th St., Seattle. A no-host bar and dinner are followed by a speaker and discussion. Anyone may attend the meetings. Field trips (members only) are in June and September. 1992 membership dues are $20/yr (professional) and $5/yr (student). Address inquiries to Donn Charnley at 19344 11th Ave. NW, Seattle, WA 98177.

Annual Pacific Northwest Mining and Metals Conference

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Preconvention Short Courses (April 6–7)

Exploration Geochemistry – Stan J. Hoffman, Prime Geochemical Methods Ltd.

MagmaChem—Metal Series – Stanley B. Keith, MagmaChem Exploration, Inc.

Alkalic Systems – Felix Mutschler, Dept. of Geology, Eastern Washington Univ.

Wetlands Design for Bioremediation – John T. Gomley, Knight Piesold and Co.

Technical Sessions (April 8–10)

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Cannon gold mine, Washington

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Coal Activity in Washington—1991

by Henry W. Schasse

Washington's coal activity continued to focus on the state's two producing coal mines, which are in western Washington. Total production from the two mines was more than 5 million tons for the fourth consecutive year. There were no exploration efforts directed toward finding new coal deposits in Washington in 1991.

The state's largest coal mine, the Centralia Coal Mine (Fig. 1), is in its second year of production under new ownership and is operated by Centralia Mining Co. The mine, which straddles the border between Thurston and Lewis Counties, produced 4,891,950 short tons in 1991, an increase of about 18,000 short tons over last year's total. Subbituminous coal is surface mined at Centralia, currently from four pits and 12 coalbeds representing eight coal seams and splits of three of those seams. The coal is mined from the middle of the Skookumchuck Formation, a nearshore and nonmarine member of the Eocene Puget Group. Since its fourth year of operation, when production leveled off, the mine has produced an average of 4.5 million tons per year. Production over the 21-year life of the mine has averaged 4.2 million tons. The mine's sole customer is the Centralia Steam Plant, located about a mile from the mine in Lewis County.

The state's other coal mine, the John Henry No. 1 open-pit mine, operated by the Pacific Coast Coal Company (PCCC) (Figs. 1 and 2), achieved its design capacity of 250,000 tons per year for the first time since it opened in 1986. The mine is located 2 miles northeast of Black Diamond in south-central King County. With its 150-tons per day beneficiation plant in full operation, the mine produced an all-time high of 251,459 short tons of bituminous coal during 1991, nearly doubling its 1990 production.

Ninety-nine percent of the John Henry mine's 1991 production was exported to Japan and Korea for use as steam coal and in cement manufacturing. Use of the remaining one percent of production was divided among public institutional heating, industrial use, and residential heating. PCCC continues to mine from four coal seams of the Franklin coal series (Franklin Nos. 7, 8, 9, and 10), which are stratigraphically near the base of the Eocene Puget Group (undivided) in nonmarine deltaic sedimentary rocks.

PCCC had considered co-use of the John Henry mine for disposal of construction demolition material and had also considered applying for permits with county and federal authorities. The company abandoned those plans because King County decided to ship demolition material by rail to sites outside the county. ■

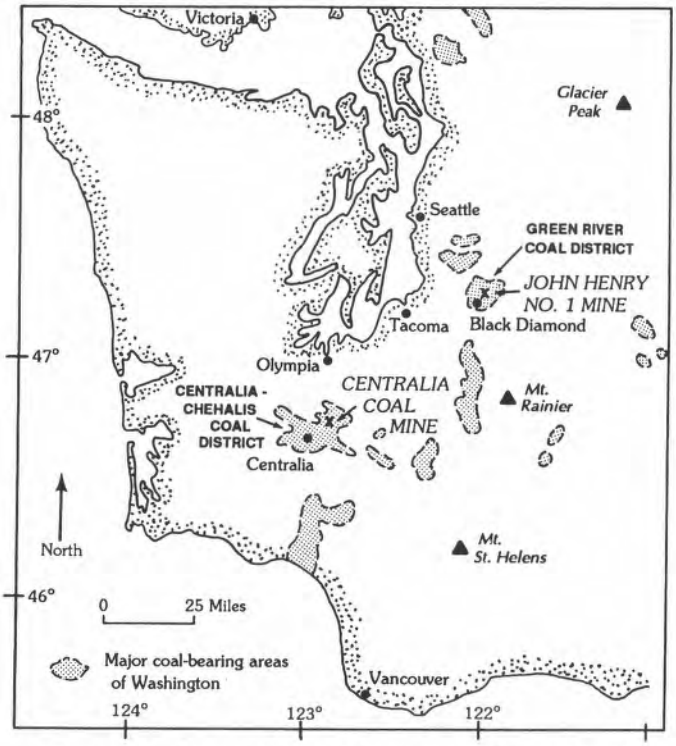

Figure 1. Active coal-producing areas and districts of western Washington.

Figure 2. John Henry No. 1 mine, Pit No. 1, January 1992. Coal from the Franklin Nos. 7, 8, and 9 coal seams is being removed from the dipping highwall. This highwall is a limb of a northeast-plunging anticline that is now exposed in three dimensions on the mine floor. The limb shown dips 40–45 degrees to the northwest. The scraper attached to the bulldozer blade allows selective removal of each coal seam as dictated by customer needs. (See the photograph on p. 27 in vol. 19, no. 1 of *Washington Geology* for another view of this structure.)

Depositional and Stratigraphic Interpretations of the Cambrian and Ordovician Metaline Formation, Northeastern Washington

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INTRODUCTION

The Metaline Formation crops out in much of Pend Oreille and Stevens Counties in northeastern Washington (Fig. 1). The formation, named by Park and Cannon (1943) for rocks exposed near Metaline Falls, was assigned a Cambrian age on the basis of trilobites collected from the nearby Lehigh quarry. This thick (>1,600 m), predominantly carbonate sequence conformably overlies the Maitlen Formation and is at most places conformable with the overlying Ledbetter Formation.

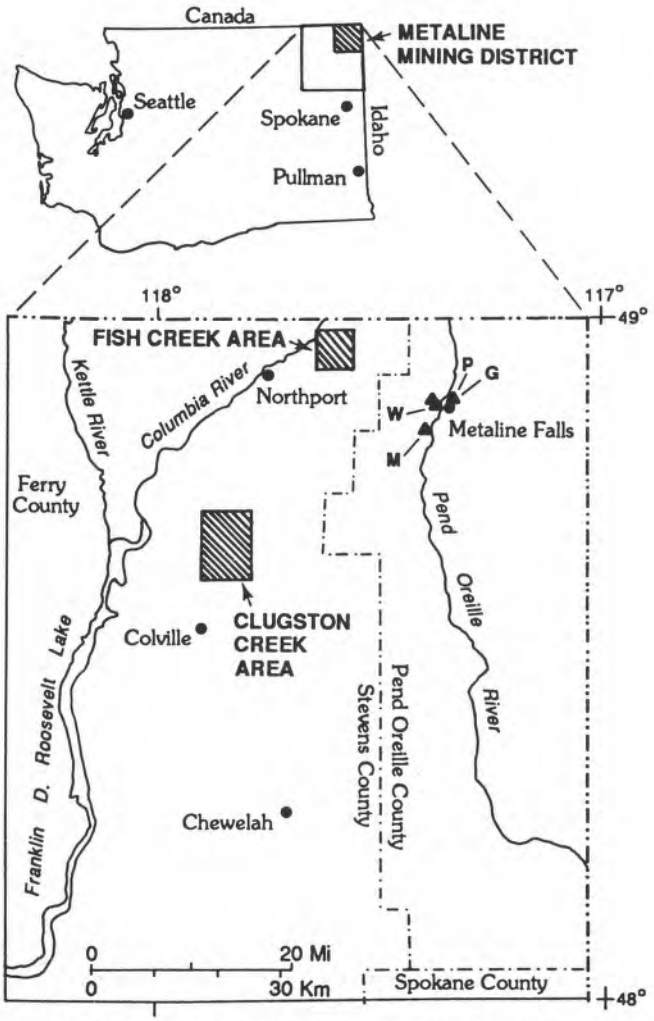

Figure 1. Location map showing major geographic areas and other sites mentioned in text. G, Grandview mine; M, Metaline mine; P, Pend Oreille mine; W, West Side Pend Oreille mine.

Stratigraphic relations within the Metaline are difficult to ascertain because of extensive glacial deposits and soil cover, dense forest, complex folding and faulting, incomplete stratigraphic sections, abrupt facies changes, general absence of marker horizons, and sparse paleontologic control. These factors have contributed to a variety of interpretations of Metaline stratigraphy and deposition (Park and Cannon, 1943; Dings and Whitebread, 1965; Addie, 1970; Mills, 1977; Fischer, 1981).

In recent years there has been considerable research on the Metaline Formation. This work includes biostratigraphic studies (Repetski, 1978; Carter, 1989a, 1989b; Repetski and others, 1989; Schuster and others, 1989), a dolomitization study (Fischer, 1988), and regional depositional studies (Bush, 1989, 1991).

In the last twenty years mine development and exploration by Resource Finance Inc. (present owner of the Pend Oreille mine), Pintlar Inc., The Bunker Hill Company, Gulf Resources and Chemical Exploration Company, and Pend Oreille Mines and Metals have provided opportunities to collect data about the Metaline Formation. Much new and unpublished stratigraphic and structural information has been gained from study of core samples and underground mine exposures in and around the Metaline mining district of Pend Oreille County (Fig. 1).

Several theses about the Metaline Formation have also been completed in the past 13 years, including those by Harbour (1978), Hurley (1980), Fischer (1981), Dansart (1982), Janik (1982), Cleveland (1982), Bending (1983), and Colligan (1984). These studies, as well as the data mentioned above, have led to new interpretations that may help unravel the complicated stratigraphic relations of the Metaline Formation.

Dings and Whitebread (1965) initially subdivided the Metaline into three major stratigraphic units, but they cautioned that these units did not have definite time value or stratigraphic position. They defined a lower thin-bedded limestone-shale, a middle light-gray bedded dolomite, and an upper gray massive limestone unit. Subsequent work has shown that, indeed, these three units are not in a consistent stratigraphic succession, nor do they have time-stratigraphic boundaries. This article uses parts of Dings and Whitebread's lithologic unit designations, but it avoids the adjectives lower, middle, and upper because they imply lateral continuity and stratigraphic succession. We recommend that the terms lower, middle, and upper not be used to describe Metaline lithologic units.

In addition to the three units originally recognized by Dings and Whitebread (1965), two other Metaline units have been described: intraformational breccia (Yates, 1964,

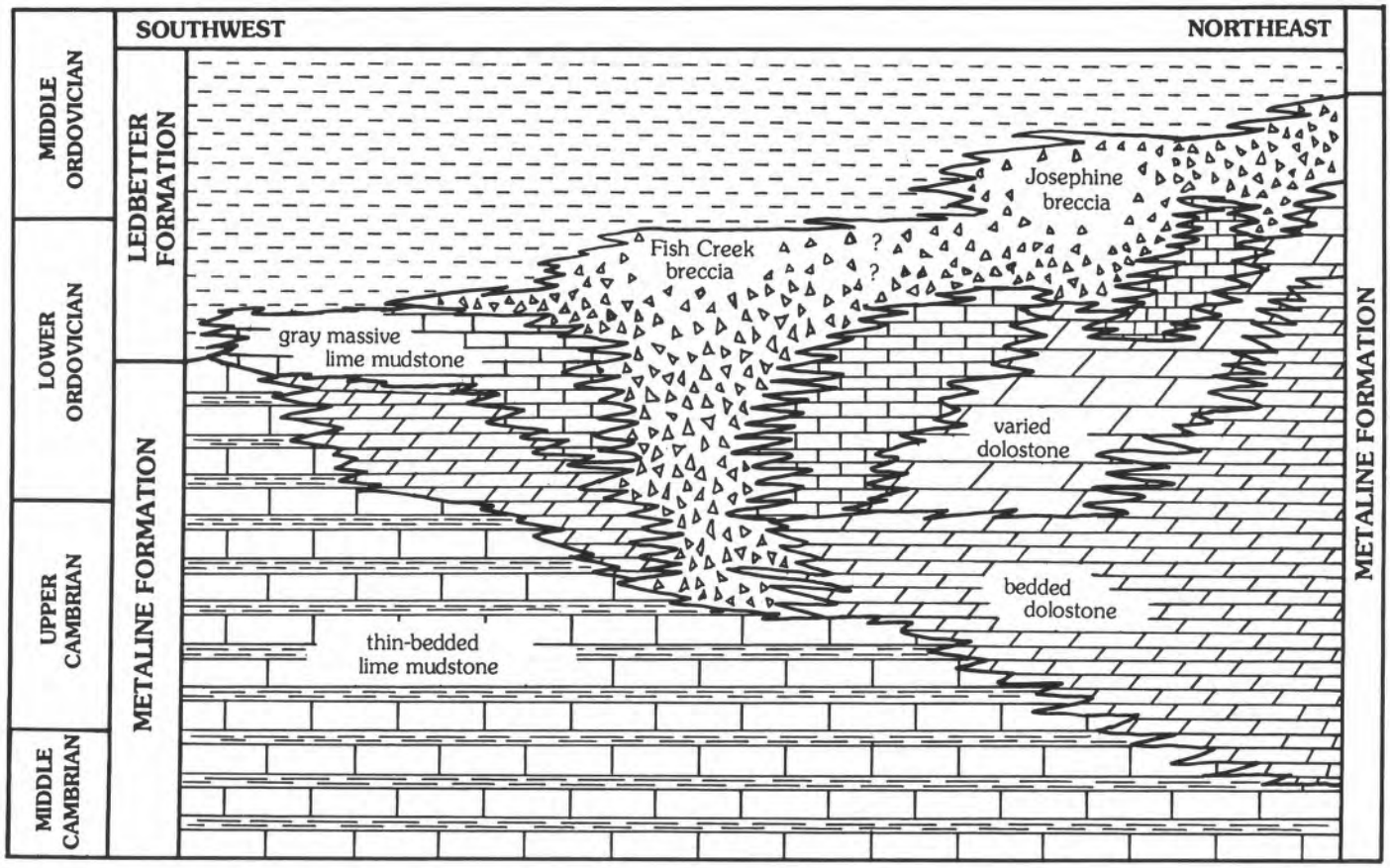

Figure 2. Diagrammatic cross section illustrating relations among lithofacies in the Metaline Formation of northeastern Washington.

1976), and Josephine unit (McConnell and Anderson, 1968). A new lithologic unit, the varied dolostone, is introduced in this report. The intraformational breccia was subsequently renamed the Fish Creek member by Fischer (1981) and in this paper it is called the Fish Creek breccia.

This article describes these six major lithofacies of the Metaline Formation (Fig. 2) and relates each to terminology and paleontological data presented by other workers. This text also incorporates recent data and interpretations, the most important of which are:

(1) The upper part of the Metaline Formation ranges in age from Early to Middle Ordovician (Fig. 3) (Repetski and others, 1989; Schuster and others, 1989; Carter, 1989a, 1989b).

(2) Breccias in the Josephine and Fish Creek lithofacies formed primarily by debris flow mechanisms (McConnell and Anderson, 1968; Fischer, 1981; Bush, 1991).

(3) Parts of the Metaline and Ledbetter Formations are coeval (Repetski and others, 1989; Schuster and others, 1989).

(4) Metaline lithofacies and the Ledbetter Formation represent a complex mosaic of shallow-water platform carbonates, basinal clastics and carbonates, subtidal outer ramp carbonates, and slope deposits (Bush, 1991).

(5) Significant parts of the Metaline were deposited in fault-controlled environments near the shelf edge (Bush, 1991).

LITHOFACIES

Thin-bedded Lime Mudstone

This lithofacies consists primarily of thin-bedded to laminated, gray to black lime mudstone, interbedded with shale, argillite, phyllite, calcareous phyllite, and dolostone. Dings and Whitebread (1965) initially referred to this unit as their lower thin-bedded limestone-shale, and Fischer (1981) used the term lower member. Dings and Whitebread (1965) reported a thickness of 290 m in the Metaline district, but Fischer (1981) reported a thickness of only 120 m from measured sections near Metaline Falls. Schuster (1976) estimated the lithofacies to be 914 m thick in the Clugston Creek area (Fig. 1).

Fischer (1981) further subdivided this lithofacies into five limestone units, which he named the gray mudstone, the gray packstone-wackestone, the black packstone-wackestone, the black mudstone, and the ooid-arenite microfacies. Although oolitic, intraclastic, and skeletal mudstones, wackestones, and packstones are present, dark-colored, thinly bedded and laminated lime mudstone and shale dominate. Pyrite is a minor constituent throughout the lithofacies and, in places, constitutes as much as 4 percent of individual samples (Fischer, 1981).

In addition to the above lithologic types, breccias within the thin-bedded mudstone facies have been noted by Hurley (1980). These breccias typically consist of light-colored angular fragments in a dark fine-grained matrix and commonly occur below black argillites.

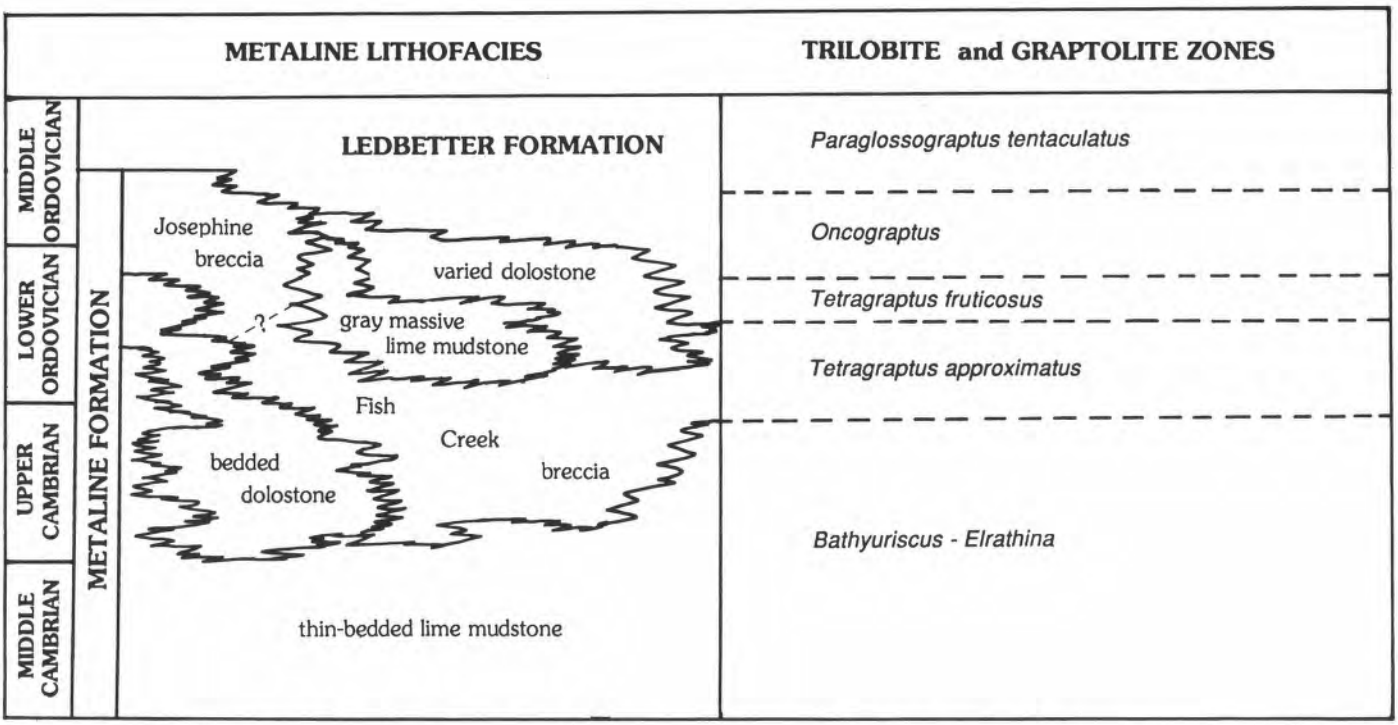

Figure 3. Comparison of biostratigraphic zones and Metaline Formation facies.

The fossil component of the thin-bedded lime mudstone facies consists of trilobite and echinoderm fragments, oncoids, *Epiphyton*, traces of boring algae, and phosphatic inarticulate brachiopods. The darker laminated units are typically nonfossiliferous, but other intervals contain local concentrations of fossil fragments. In places, trilobite preservation is excellent, and assemblages have been assigned by A. R. Palmer (U.S. Geological Survey) to the *Bathyuriscus-Elrathina* Zone of the Middle and Upper Cambrian (Dutro and Gilmour, 1989).

The thin-bedded lime mudstone lithofacies generally makes up the lower part of the Metaline (Fig. 2), where it is in gradational contact with the underlying Maitlen Formation and at most places is in sharp contact with the overlying bedded dolostone unit. Intervals of this lithofacies have also been identified in core samples from the Metaline district within the bedded and varied dolostone lithofacies. The stratigraphic configuration and horizontal extent of these interbedded intervals is not certain. However, the contacts appear to be conformable, and the units extend laterally for a few miles and pinch out north of Metaline Falls.

Lochman-Balk (1971) correlated the thin-bedded lime mudstone lithofacies with the lower Lakeview Formation in northern Idaho (Fig. 4, 5). The lower Lakeview is lithologically similar and consists, from the base upward, of pyritic, dark-colored parallel laminated lime mudstone, black shale, and mottled lime mudstone (Bush, 1989). Trilobite assemblages place the boundary between the *Bathyuriscus-Elrathina* and *Bolaspidella* Zones in the upper one-third of the lower Lakeview (Motzer, 1980). The easternmost outcrop of similar lithologic units that are considered to be of the same age as the thin-bedded lime mudstone is 6 mi east of the Montana–Idaho border near Heron, Montana (Bush, 1989). Figure 4 illustrates regional correlation of the Metaline Formation with sequences of similar ages at Lakeview, Idaho, and in the Libby Trough, Montana, and Figure 5 shows the distribution of outcrops of lower Paleozoic rocks in northeastern Washington and areas to the east.

The lime mudstone and shale were deposited under dominantly low-energy subtidal conditions on the outer edge of a ramp, seaward of the transgressing clastic shoreline (Fischer, 1981). Conditions were generally anoxic, but at times were sufficiently oxygenated to allow benthic organisms to survive. Fischer (1981) considered distribution of his five microfacies in the thin-bedded lime mudstone lithofacies to be related to changing conditions of oxygenation according to the model of oxygen stratification developed by Byers (1977). Oxygen starvation caused reducing conditions that, in turn, limited carbonate production on the ramp.

Subtidal channels, storm deposition, and shoaling occurred on the ramp as climatic, tectonic, and sea-level conditions changed. Locally, debris-flow breccias developed, probably in association with slumping. These breccias, in conjunction with the intertonguing of the thin-bedded lime mudstone with the bedded dolostone unit and the presence of the ooid-arenite microfacies, indicate that local shoaling resulted in an outer distally steepened ramp on which developed a patchwork of migrating environments.

Bedded Dolostone

The bedded dolostone lithofacies ranges to as much as 1,402 m thick in the Clugston Creek area (Cleveland, 1982) and consists of a monotonous succession of nonfossiliferous gray and black, fine- to medium-grained, parallel bedded dolostone interlayered with massive, gray, featureless, fine- to medium-grained dolostone. Dings and Whitebread (1965) originally used the term bedded dolomite for this unit, and Fischer (1981) informally called this unit the middle member.

Harbour (1978) studied numerous cores of this lithofacies from the central part of the Metaline mining district in Pend Oreille County, and on the basis of that study he divided the sequence into six laterally discontinuous lithotypes. Cleveland

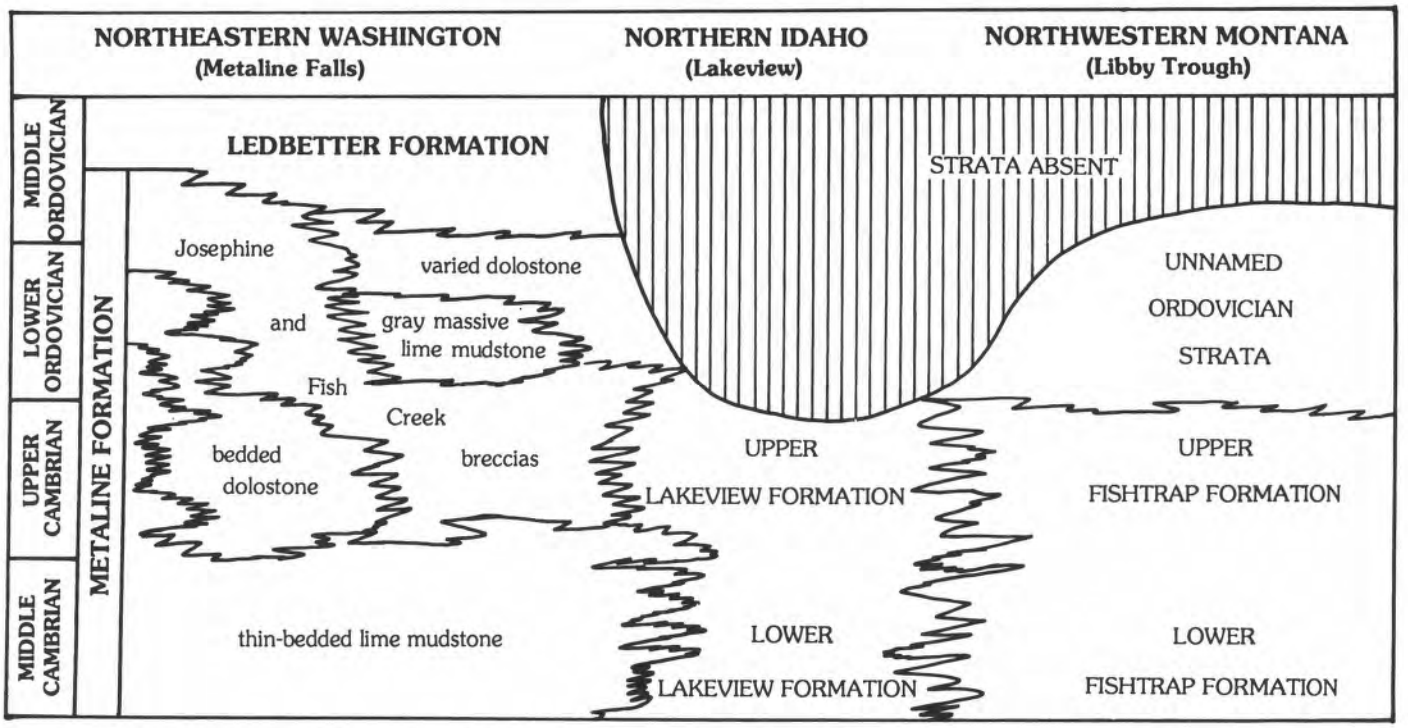

Figure 4. Correlation chart comparing Metaline lithofacies with other Cambrian–Ordovician units in northern Idaho and northwestern Montana.

(1982) added a seventh lithotype, which is exposed in the Clugston Creek area. The lithotypes are (1) black birdseye dolomite, (2) cryptalgal laminated dolomite, (3) dolomitized, laminated, intraclastic floatstone, (4) gray massive dolomite, (5) dolomitized oncolitic floatstone, (6) lenticular-bedded dolomite, and (7) breccia.

Fischer (1981, 1988) studied the diagenetic fabric of the bedded dolostone and noted that each lithotype contains depositionally derived features that have been diagenetically altered by several stages of dolomitization. The least altered samples retain a fine-grained micritic fabric and contain well-preserved recognizable grains. The more altered samples are composed of a mosaic of dolomite in which constituent crystals range from subhedral to anhedral and in which only ghosts of depositional grains are recognizable. Fischer (1988) noted that the gray massive dolostone lithotype is the most altered. It consists of featureless gray dolostone or gray dolostone that contains vugs and pods of white sparry dolomite, zebra dolomite, and, rarely, relict grains. Fischer (1988) concluded that the gray massive dolostone represents a diagenetic fabric and is not, as suggested by Harbour (1978) and Cleveland (1982), a depositional lithotype.

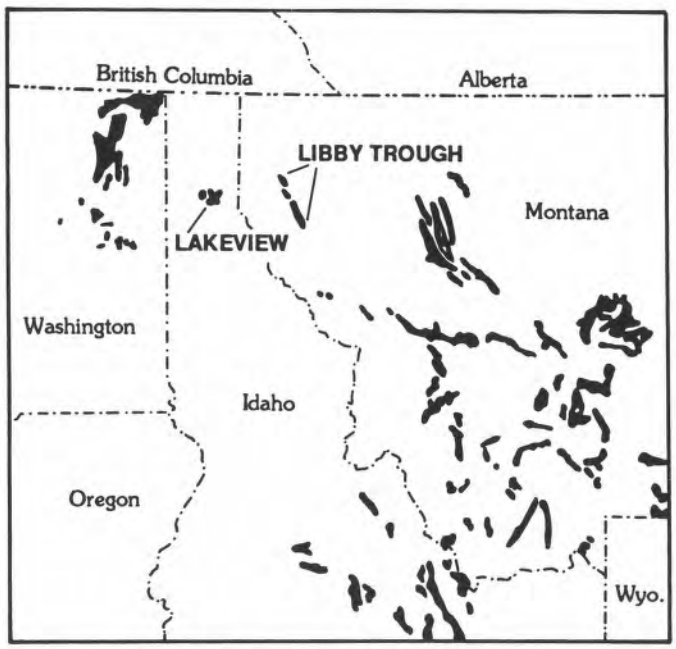

Figure 5. Distribution of lower Paleozoic outcrops in northeastern Washington, northern Idaho, and northwestern Montana.

The bedded dolostone occurs stratigraphically between the thin-bedded and the gray massive lime mudstone lithofacies in most areas. However, in other areas it is overlain by the Ledbetter Formation, the varied dolostone, or the Josephine breccia lithofacies. In addition, it is laterally equivalent to parts of the Ledbetter Formation and to the Josephine, Fish Creek, massive lime mudstone, and varied dolostone lithofacies of the Metaline (Fig. 2).

Aadland (1979), Bush and Fischer (1981), and Bush (1989) correlated the bedded dolostone lithofacies with the upper Lakeview Formation in northern Idaho and the upper Fishtrap Formation in western Montana (Fig. 4). The upper Lakeview Formation has been subdivided, from its lowermost unit upward, into a peloidal-ooid dolopackstone, a cryptalgal dolobindstone, and an upper crystalline cryptalgal dolomudstone lithofacies (Bush, 1989). The upper Lakeview is highly altered and has a diagenetic history similar to that reported by Fischer (1988) for the bedded dolostone lithofacies.

Harbour (1978) and Cleveland (1982) considered the bedded dolostone lithofacies to have been deposited in a low-energy, shallow subtidal and peritidal mosaic that, according to Bush and others (1980) and Bush and Fischer

(1981), covered much of northeastern Washington and all of northern Idaho and western Montana during the Middle and Late Cambrian. Bush (1989) suggested further that most bedded dolostone deposition occurred in intertidal and supratidal algal shoal environments. A re-evaluation of the sedimentological data has led to a more recent interpretation that shoal development was not as extensive as earlier thought and that subtidal deposition may have been more common (Bush, 1991). The bedded dolostones are considered to have been deposited in shallow subtidal environments with local shoaling to intertidal and supratidal environments at the seaward end of a ramp (Bush, 1991).

Gray Massive Lime Mudstone

Park and Cannon (1943), Dings and Whitebread (1965), McConnell and Anderson (1968), and Fischer (1981) provide detailed descriptions of the massive lime mudstone lithofacies. Dings and Whitebread (1965) referred to this lithofacies as the upper gray massive limestone unit, and Fischer (1981, 1988) referred informally to the same unit as the upper member of the Metaline Formation.

This lithofacies consists almost entirely of nonfossiliferous, light- to medium-gray, massive, featureless lime mudstone. A few intervals are thin bedded and contain crinkled black carbonaceous laminations or are mottled by reticulate, black, carbonaceous shale or dolostone. Nodular chert is locally common in the upper part of the unit. Shale occurs locally as conformable to disconformable seams and lenses. Irregular pods and lenses of fine- to coarse-grained dolomite are also common.

Although the lithofacies for the most part is nonfossiliferous, Bending (1983) reported stromatolites and oncolites in its eastern exposures. Schuster and others (1989) found Lower and Middle Ordovician conodonts near the top of this lithofacies in the Clugston Creek area.

Bending (1983) considered the Fish Creek lithofacies to be laterally equivalent to the bedded dolostone lithofacies. Dings and Whitebread (1965) and Fischer (1981) indicated that parts of the Fish Creek breccia laterally interfinger with the massive lime mudstone. At exposures near Metaline Falls, the massive lime mudstone is in gradational contact with the underlying bedded dolostones and in a few places grades upward into the black dolostones and the Josephine lithofacies.

Results of drilling during the past 20 years indicate that the distribution of the gray massive lime mudstone lithofacies is more stratigraphically and areally localized than previously thought. In some areas, the sequence may reach a thickness of 630 m, but in adjacent areas it is absent. Cambrian or Ordovician lithologic equivalents of the gray massive lime mudstone unit are not recognized in northern Idaho or western Montana.

Fischer (1984) noted that intraclasts and peloids are common in this lithofacies and that the lack of complex depositional grains in conjunction with the lack of body fossils suggest a shallow subtidal environment sufficiently lacking in oxygen to exclude virtually all benthic organisms. He suggested further that storm deposition alternating with periods of quiescence accounts for the presence of both intraclasts and lime mudstone.

Varied Dolostone

In much of northeastern Washington, the Cambrian rocks described as hydrothermally altered, crystalline, and intermixed crystalline and bedded dolomite by Dings and Whitebread (1965) and those referred to in unpublished company reports as lower dolomite belong to a distinct stratigraphic unit herein informally named the varied dolostone unit. This lithofacies locally exceeds 300 m in thickness. Although much of its original nature is masked by coarse-grained dolomite replacement, many of the primary depositional features recognizable in its fine-grained parts are substantially different from those of other Metaline units. These depositional features include: dominance of hummocky, irregularly lenticular and disconformable bedding, marked lithologic heterogeneity and abundance of shale, and abrupt lateral changes in lithology. Some lithologies occur as large blocks in which bedding attitudes differ from those of adjacent lithologies.

This lithofacies consists of several types of dolostone. However, gray, massive, clastic, and wavy-laminated dolostone dominate. The massive dolostones are featureless, fine to medium grained, and, in places, texturally similar to parts of the bedded dolostone lithofacies. The wavy-laminated dolostones contain undulating or lenticular, discontinuous dark- and light-gray laminations. The clastic dolostones are light to dark gray and fine to medium grained and have a speckled appearance resulting from a variety of grain colors as well as from dark grains in a light matrix. Angular, shard-like fragments of gray to black shale and irregular, angular clasts of clear to black chert are locally abundant. Undulating bedding, cross-stratification, poor to good sorting, and graded bedding are common. These clastic dolostones occur in bodies that range from irregular beds and lenses to disconformable trough fillings.

Less common rock types in the varied dolostone lithofacies include black massive dolostone, black fenestral dolostone, thin-bedded parallel laminated dolostone, gray massive dolostone, lime mudstone, and oncolitic dolofloatstone. Black massive dolostone is fine to medium grained and locally argillaceous and laminated and occurs in both conformable and disconformable beds and masses. In places, discordant bodies of black dolostone separate large blocks of other varied dolostone lithologies in much the same way that dark matrix separates different lithologies in the Josephine breccia. Black fenestral dolostone consists of fine- to medium-grained black dolomite with coarse white dolomite spots, many of which are elongate and subparallel to bedding. Several kinds of breccias in discordant as well as concordant bodies are also present in the varied dolostone. Some of these bodies resemble breccias in the Josephine. Quartzite and dolomitic quartz sandstone occur rarely in lenses as much as a meter thick at various stratigraphic positions within the varied dolostone.

The varied dolostone lithofacies is not recognized outside the Metaline mining district, and a petrographic study of the unit has not been undertaken. It is transitional between gray bedded dolostone, gray massive lime mudstone, and the Josephine breccia lithofacies, and it exhibits characteristics of each of these units. The presence of oncoids, lack of body fossils, and the interbedded nature of the varied dolostone lithofacies suggest this unit was deposited in a poorly oxygenated, shallow subtidal environment close to a deeper

basin. Storms, tidal channels, and slumping may account for cross-beds, intraformational folds, troughs, and hummocky and lenticular beds.

Fish Creek Breccia

This lithofacies was previously referred to as the intraformational breccia by Yates (1976). Fischer (1981) suggested the name "Fish Creek member of the Metaline Formation" for exposures in the Fish Creek area, 13 km northwest of Metaline Falls (Fig. 1). "Fish Creek breccia" is used in this paper to convey that, in general, angular fragments are more abundant than rounded fragments in this lithofacies. Yates and Robertson (1958), Yates (1976), and Hurley (1980) described the lithofacies as a light- to dark-gray, fine- to medium-grained, thin-bedded dolostone that is interbedded with lensoidal sedimentation units of breccia.

Breccias consist of angular to subrounded, tabular fragments of thin-bedded dolostone supported by dark-gray to black, fine-grained dolostone matrix. In places, fragments exhibit contorted bedding. Orientation of fragments ranges from chaotic through subparallel to imbricate. Locally, breccias can be traced laterally into non-brecciated bedded dolostone. The lithofacies is almost entirely dolostone, although nodular chert is abundant locally. Fine-grained pyrite is common in minor amounts, and phosphatic materials occur sparingly as pellets, disseminated grains, and rare fossils.

Fischer (1984) noted rare echinoderm plates, but, in general, the Fish Creek breccia is neither fossiliferous nor bioturbated. Yates (1976) noted phosphatic fossils ranging in age from Middle Cambrian through Early Ordovician(?). Much of the lithofacies has a clastic texture in which both normal and reverse graded bedding are common. Sedimentation units are commonly truncated by disconformable surfaces and scours, and soft-sediment folds are common.

Yates and Robertson (1958) and Yates (1964) indicated that in some areas of Stevens County the intraformational breccia unit is directly overlain by the Ledbetter Formation, whereas in others it is separated by a transitional sequence of as much as 154 m of interbedded gray limestone and shale, gray to black argillite and shale, black shale and dolostone, and dolostone breccia. Where the transitional sequence is absent, the intraformational breccia is conformable with and gradational into the Ledbetter (Hurley, 1980; Yates, 1964, 1976; Yates and Robertson, 1958). Hurley (1980) and Fischer (1984) noted that parts of the Fish Creek breccia are equivalent in age to some parts of the bedded dolostone and the massive lime mudstone lithofacies. Yates and Robertson (1958) noted a conformable and gradational contact with the bedded dolostone unit in some areas, while Fischer (1984) suggested that in northernmost Pend Oreille County, the breccia lies directly on the thin-bedded lime mudstone lithofacies.

The stratigraphic and temporal relations of the Fish Creek breccia are not as clearly known as those of the other lithofacies. As illustrated in Figure 4, it is interpreted to be interbedded with parts of all the other lithofacies, including the Josephine breccia. The two breccia units are considered to be distinct since the dominately finely laminate tabular fragments in the Fish Creek breccia distinguish it from the Josephine.

These stratigraphic relations, in particular the interbedding with all the other lithofacies, were probably caused by the debris flow origin of the breccias. Hurley (1980) and Fischer (1984) had earlier concluded that the Fish Creek breccia likely formed as a result of intermittent submarine slumping and debris flows.

Josephine Breccia

The Josephine breccia comprises a wide variety of lithologies, some of which are present in other stratigraphic units. As a result, the Josephine can not be recognized by the occurrence of a single lithology, but rather by the combination of several distinct lithologies and sedimentary characteristics. The lithofacies was originally described by McConnell and Anderson (1968, p. 1467), who noted that "It hardly can be called uniform in its characteristic irregular brecciation and marked diversity of rock types within it...in contrast to the near uniformity and usual lack of brecciation in the other units of the Metaline Limestone."

The Josephine lithofacies is distinguished by the following features:

(1) Discontinuous occurrence at the top of the Metaline Formation as a heterogeneous assemblage of pyritic, black or dark-gray dolostone with minor chert, lime mudstone, and argillite.

(2) Abundance of matrix-supported breccias with varied fragment and matrix lithologies.

(3) Irregular interbedding of breccias and non-breccias, and dominance of undulating, discontinuous, and disconformable bedding surfaces.

(4) Abrupt lateral variation of lithology and character of bedding.

(5) Scarcity of fossils.

(6) Presence of minor pelletal phosphates.

The Josephine breccia generally occupies a stratigraphic position at the top of the Metaline Formation directly below the Ledbetter Formation. McConnell and Anderson (1968) and Addie (1970) considered the unit to be present everywhere in the Metaline mining district where the top of the Metaline is exposed and unfaulted, but a review of outcrops and drill cores indicates that it is most persistent laterally and stratigraphically near the Pend Oreille, Grandview, and Metaline mines (Fig. 1). Dings and Whitebread (1965) did not recognize the Josephine as either a discrete lithologic facies or stratigraphic unit, but examination of much of what appears on their geologic map as "silicified dolomite" indicates that it should be included in the Josephine breccia lithofacies. As defined by McConnell and Anderson (1968), the Josephine is not recognized outside the Metaline district.

The thickness of the Josephine breccia generally varies from 0 to 65 m, although in a few areas it may be as much as 165 m thick. In a few locations, the thickness variations are interpreted to have resulted from faults that offset the top of the gray massive lime mudstone but that do not offset the Josephine or the Ledbetter/Josephine contact.

In most locations, the Josephine breccia grades laterally and vertically into and is interbedded with the varied dolostone and massive lime mudstone lithofacies. In a few localities, Josephine contacts with the gray massive lime mudstone and varied dolostone units are restricted to a single sharply defined stratigraphic position and are laterally continuous for hundreds of meters. However, in other places, the contact with the gray massive lime mudstone and varied dolostone

is gradational. These gradational contacts range from locally interbedded to irregularly gradational, steeply interdigitate, or ragged and discordant. Locally, particularly near the West Side Pend Oreille mine workings, the Josephine lithofacies appears to have been deposited on the step-faulted upper surface of the gray massive lime mudstone lithofacies.

Contacts between the Josephine breccia and the varied dolostone lithofacies are similar to contacts between lithologies within the Josephine. Local discordance is more pronounced at contacts with the gray massive lime mudstone, perhaps because of the uniform character of the lime mudstone and because the lime mudstone is easy to recognize. However, gradations are common, particularly from lime mudstone fragments to typical Josephine breccia with dolostone fragments.

In the Pend Oreille mine, the contact between the Josephine lithofacies and Ledbetter Formation is gradational over an interval several meters thick in some locations, but it is a paper-thin, easily defined, and locally disconformable surface in others. Although the contact marks a transition from dominantly coarse fragmental carbonates to fine siliciclastics and from chaotic, uneven, and irregular bedding to even and planar bedding, lithologic and bedding relations at the contact are similar to those within the breccia and among the Josephine breccia, massive lime mudstone, and varied dolostone lithofacies. In addition, Carter (1989b) has shown that rocks of both uppermost Josephine and lowermost Ledbetter in the Pend Oreille mine are within the *Paraglossograptus tentaculatus* graptolite zone of the early Middle Ordovician. These observations suggest that the contact marks a locally abrupt change in the proportion and character of carbonate and argillite sedimentation but does not represent a significant depositional hiatus.

Many of the peculiar characteristics of the Josephine breccia are common to sediment-gravity flow deposits known from deep-water environments along modern and ancient continental margins. Two lower Paleozoic examples well documented in the literature are the Cow Head Breccia of Newfoundland (Hubert and others, 1977) and parts of the Hales Formation of Nevada (Cook and Taylor, 1977). McConnell and Anderson (1968) and Addie (1970) proposed a similar origin for Metaline breccias when they suggested that the lithofacies formed in anoxic waters basinward of an organic reef complex. They envisioned fragmentation and downslope transportation of shallow-water deposits by slumps, debris flows, and turbidity currents. Although there is little evidence for organic reefs in the Metaline, detailed lithologic observations from core and mine exposures offer support for the interpretation of sediment gravity flow as the primary transportation mechanism for many of the Josephine lithologies.

In contrast, Mills (1977) considered the breccias immediately adjacent to the Ledbetter/Metaline contact as part of a regionally extensive paleokarst and solution-collapse system below the angular unconformity between the Ledbetter and Metaline Formations. He referred to the system as the "Josephine Breccia" and included in it the breccias of the "Josephine unit" named by McConnell and Anderson (1968) along with a variety of other predominantly discordant breccias in the Metaline Formation throughout the region.

Stratigraphic, lithologic, and paleontologic studies in the district over the past two decades support the original interpretation of the Josephine breccia as marine sedimentary rocks transitional between the Metaline and Ledbetter Formations. Josephine and other Metaline lithofacies and, to a much lesser degree, the Ledbetter Formation are cut by, and included as fragments within, most of the breccia lithologies that were used in the composite earlier definitions of "Josephine breccia".

Carter's (1989a) identification of graptolite specimens collected by C. F. Park, Jr., in the central part of the Metaline district in 1937 indicates that the base of the Ledbetter immediately west of the Pend Oreille River is as old or older than the *Oncograptus* Zone of the upper Lower Ordovician. Carter (1989b) concluded that the contact exposed in the Pend Oreille mine just east of the river lies in the *Paraglossograptus tentaculatus* Zone of early Middle Ordovician age. On the other hand, Carter (1989a) stated that the base of the Ledbetter in the Clugston Creek area of Stevens County may be as old as the *Tetragraptus fruticosus* or *T. approximatus* Zones of Early Ordovician age. These differences in age indicate that regional transgression of basinal Ledbetter facies over adjacent and coeval Metaline platform facies was a rapid occurrence in the Early Ordovician. However, in the area now east of the Pend Oreille River, carbonate sedimentation persisted into the Middle Ordovician.

SYNDEPOSITIONAL FAULTING

We consider syndepositional faulting to have strongly influenced stratigraphic relations in the Metaline Formation. In the central part of the Metaline district and in outlying areas, core drilling and mining have exposed linear features in the upper parts of the Metaline that persist for several hundred meters along strike. The abundance and consistent orientation of linear structures strongly suggest that local block faulting and tilting along a north-northeast trend occurred during deposition of much of the upper part of the Metaline Formation. In places, the faults are identified by local offset of the top of the gray massive lime mudstone lithofacies accompanied by thickening and lithologic changes of the Josephine breccia (without offset of either the Josephine or the Ledbetter) across the faults. The faults are also identified by a north-northeast-trending stratigraphic fabric in the central part of the district that is paralleled by a pattern of younger normal faulting.

Syndepositional faults may have magnified the effect of regional subsidence by creating oversteepened and unstable slopes between subtidal platform environments and deeper basinal environments. Faulting and oversteepening would have resulted in a horizontal interfingering or a mosaic of environments along a north-northeast trend, indicating abrupt changes in water depth and depositional conditions. Slope deposits formed by slumping from oversteepened areas promoted the interbedding of lithologic units observed in the Josephine. Actual planes of movement are rarely recognizable, perhaps due to diagenetic reconstitution, so that the only vestiges of the faults may be the abrupt facies changes themselves.

SUMMARY

Stratigraphic relations of Metaline lithofacies have been difficult to define because of a lack of continuous exposures, stratigraphic markers, and macrofossils, as well as the effects of mineralization and diagenetic and hydrothermal alteration.

Post- and syndepositional faulting and abrupt facies changes also contribute to the difficulties. In addition, the Metaline Formation was deposited near the seaward edge of a distally steepened ramp adjacent to basinal environments. The result is a mosaic of interlayered and lensoidal sequences that represent a wide range of depositional environments.

The use of lower, middle, and upper to modify Metaline lithofacies has created confusion and should not be used in the future. The intertonguing of the Metaline lithologic units discourages the use of any term suggesting consistent stratigraphic succession, position, or age.

At this time, six lithofacies adequately encompass the range of major sedimentary rock types in the Metaline Formation. Two of these, the Josephine and Fish Creek breccia lithofacies, should be used formally. The next step will be to formalize names for the remaining lithofacies as members. However, considerable additional field, petrologic, and paleontological data must be gathered before member names can be assigned.

ACKNOWLEDGMENTS

We thank Mark D. McFaddan and Peter E. Isaacson from the University of Idaho for continued encouragement. Special thanks to J. Thomas Dutro, Jr., of the U.S. Geological Survey, who critically read the manuscript before its submittal. Partial financial support was provided by the Idaho Mining and Mineral Resource Research Institute. Resource Finance Inc. provided much of the subsurface data for our study. Critical comments and suggestions by Katherine M. Reed, Division of Geology and Earth Resources, and Cameron R. Allen of Cominco American greatly improved the manuscript.

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Editor's note: A companion article describing mineralization and mining in the Metaline Formation will appear in a future issue.

Staff News

The Division has hired **Wendy Gerstel** as a Geologist 2 in the Environmental Geology section. Wendy received her bachelor's degree from the University of New Hampshire and a master's from Humboldt State University, where she studied glacial and volcanic deposits on Lassen Peak. Along the way, she also studied at the University of Salzburg and the University of Colorado.

Wendy has worked for the U.S. Geological Survey in a variety of mapping projects, and most recently she worked as an engineering geologist with the U.S. Forest Service in the Willamette National Forest. An avid skier, she is a member of the National Ski Patrol.

Wendy's duties with the Division will focus on slope stability and Quaternary geology, as well as compilation of the mapping for the western Olympic Mountains for the state geologic map project.

Kelli Ristine started with the Division in January, replacing **Cheryl Hayes** as a Clerk Typist 2. Kelli was previously employed by the Transportation Improvement Board, which was her first job with the State.

Kelli will be serving as receptionist, answering the phones and keeping an eye on the counter. She also monitors publication inventories, among other duties. She and her husband, Chris, are expecting their first baby in September.

Geological Society of America, Cordilleran Section Meeting

Hilton Hotel and Conference Center
6th Ave., Eugene, OR, May 11–13

The Cordilleran Section is meeting jointly with the Pacific Coast Section of the Paleontological Society of America. The meeting is sponsored by the Department of Geological Sciences, University of Oregon. The preregistration deadline is April 17.

The meeting features ten symposia, which will cover topics of broad Pacific Northwest significance. Included is the Second Symposium on the Regional Geology of the State of Washington. Conveners are State Geologist Raymond Lasmanis and Prof. Eric Cheney, University of Washington. This session will be held Tuesday, May 12, and will be followed by a social hour.

Six pre-meeting and four post-meeting field trips are scheduled for areas in Oregon and northern California. *Oregon Geology* will be publishing some trip guidebooks.

The Washington Division of Geology and Earth Resources is preparing to publish a volume of papers presented at the Washington symposium.

Further information about this meeting can be obtained from A. Dana Johnston, Dept. of Geological Sciences, University of Oregon, Eugene, OR 97403; 503/46-5588, fax 503/346-4692.

The Central Cascades Earthquake of March 7, 1891

by T. E. Johnson, R. S. Ludwin, and A. I. Qamar
Geophysics Program, University of Washington

While reviewing newspaper accounts of earthquakes in Washington and Oregon prior to 1928, we have discovered evidence that an earthquake on March 7, 1891 (7:40 P.M. local time), was much larger than previously thought. Before our investigation, this earthquake was known to have been felt only at the lighthouses on Smith Island and at Admiralty Head (Bradford, 1935; Townley and Allen, 1939). It is not included in the Earthquake History of the United States (Coffman and von Hake, 1973), which lists earthquakes with Modified Mercalli intensities (MMI) V or greater. (The MMI scale was developed by Wood and Neumann (1931) to measure felt earthquake effects.)

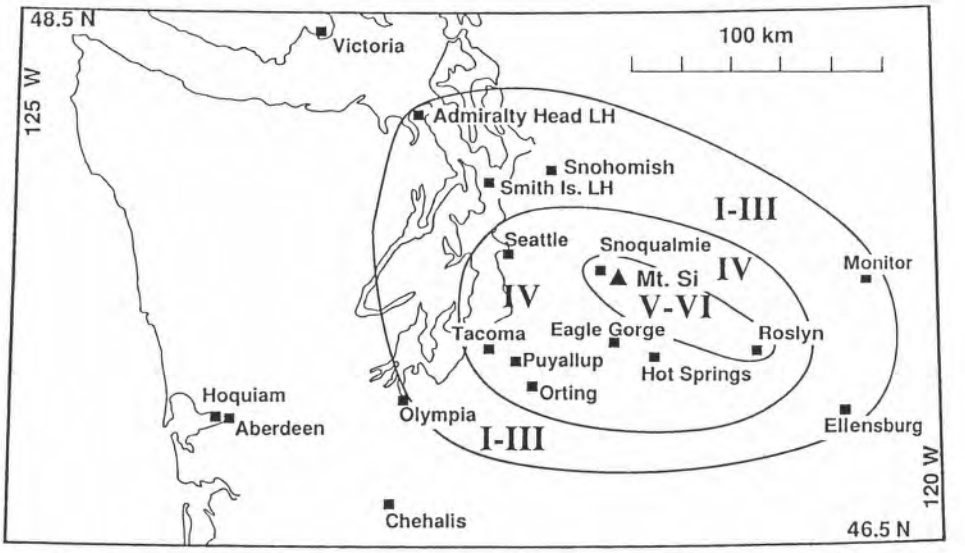

Figure 1. Estimated isoseismal contours for areas which experienced modified Mercalli intensities V–VI, IV, and I–III in the March 7, 1891 earthquake. Lighthouse locations are indicated by LH; Mount Si is shown as a triangle.

Through old newspaper reports and a diary entry, we now have evidence that the earthquake had intensities as high as VI, was felt on both sides of the Cascades, and did some minor damage. Figure 1 shows our estimate of the felt area of the 1891 earthquake and the distribution of areas where MMI IV and V–VI were experienced.

The apparent focus of the 1891 earthquake was east of Seattle in the central Cascades, close to Mt. Si, where a number of earthquakes have been located in a tight spatial cluster since instrumental coverage began in 1970, and where felt earthquakes of magnitudes 5.6 (Zollweg and Johnson, 1989) and 4.5 (Tom Yelin, U.S. Geological Survey, written commun., Dec. 11, 1991; coda duration on the Longmire seismic station) occurred in 1945 and 1963, respectively. For the 1891 earthquake, which had a total felt area of approximately 36,000 km², we estimate a magnitude of 5.0 (Toppozada, 1975).

INFORMATION FOR RE-EVALUATION OF THE 1891 EARTHQUAKE

Modified Mercalli Intensity V–VI

Roslyn

"The shock was severe enough to rock houses, stop clocks, and shatter crockery. Disturbance caused vertigo and nausea in several persons. Everybody rushed to the street."
(*Seattle Post-Intelligencer*, March 8, 1891)

Snoqualmie

"Heavy shock....The rocks from Mount Si came rolling down and made a loud rumbling noise, which was plainly heard."
(*Seattle Telegraph*, March 8, 1891)

Modified Mercalli Intensity IV

Eagle Gorge

"Eagle Gorge felt three severe shocks."
(*Seattle Telegraph*, March 8, 1891)

Snohomish

"In a number of Snohomish stores the shelves with their contents were given a good shaking up."
(*Snohomish Daily Sun*, March 9, 1891)

Hot Springs

"A lively shock....Things were shaken up, chandeliers swayed and crockery rattled." (*Seattle Post-Intelligencer*, March 8, 1891)

"The hotel and depot shook lively. No damage done."
(*Seattle Telegraph*, March 8, 1891)

Orting

"People rushed out to find the cause of the disturbance."
(*Tacoma Daily Ledger*, March 8, 1891)

Puyallup

"Light shocks were also felt in...Puyallup and surrounding villages." (*Seattle Telegraph*, March 8, 1891)

Seattle

"The effect was felt most severely by those in the upper floors of the six and seven story buildings downtown. There the chandeliers swayed sharply and men standing up found it difficult to keep their feet." (*Tacoma Daily Ledger*, March 8, 1891)

"A vase in her room nearly fell from the mantel over the fireplace....the pencil of a *Post-Intelligencer* reporter who was writing made a crooked mark, as if someone had pushed his arm....the stores and dwellings rocked to and fro, and hanging lamps swung backward and forward like the pendulum of a clock...."
(*Seattle Post-Intelligencer*, March 8, 1891)

Table 1. Extract from the Modified Mercalli Intensity scale developed by Wood and Neumann (1931).

IV. Felt indoors by many, outdoors by few.
Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience.
Vibration like that due to passing of heavy, or heavily loaded trucks.
Sensation like heavy body striking building or falling of heavy objects inside.
Rattling of dishes, windows, doors; glassware and crockery clink and clash.
Creaking of walls, frame, especially in the upper range of this grade.
Hanging objects swung, in numerous instances.
Disturbed liquids in open vessels slightly.
Rocked standing motor cars noticeably.

V. Felt indoors by practically all, outdoors by many or most; outdoors direction estimated.
Awakened many, or most.
Frightened few—slight excitement, a few ran outdoors.
Buildings trembled throughout.
Broke dishes, glassware, to some extent.
Cracked windows—in some cases, but not generally.
Overturned vases, small or unstable objects, in many instances, with occasional fall.
Hanging objects, doors swing generally or considerably.
Knocked pictures against walls, or swung them out of place. Open or closed doors, shutters, abruptly.
Pendulum clocks stopped, started, or ran fast or slow.
Moved small objects, furnishings, the latter to slight extent.
Spilled liquids in small amounts from well-filled open containers.
Trees, bushes shaken slightly.

VI. Felt by all, indoors and outdoors.
Frightened many, excitement general, some alarm, many ran outdoors.
Awakened all.
Persons made to move unsteadily.
Trees, bushes shaken slightly to moderately.
Liquid set in strong motion.
Small bells rang—church, chapel, school, etc.
Damage slight in poorly built buildings.
Fall of plaster in small amount.
Cracked plaster somewhat, especially fine cracks chimneys [sic] in some instances.
Broke dishes, glassware, in considerable quantity, also some windows.
Fall of knick-knacks, books, pictures.
Overturned furniture in many instances.
Moved furnishings of moderately heavy kind.

VII. Everybody runs outdoors.
Damage negligible in buildings of good construction; slight to moderate in well-built ordinary structures.
Considerable damage in poorly built or badly designed structures. Some chimneys broken.
Noticed by persons driving cars.

VIII. Damage slight in specially designed structures, considerable in ordinary substantial buildings with partial collapse, great in poorly built structures.
Panel walls thrown out of frame structures.
Fall of chimneys, factory stacks, columns, monuments, walls.
Heavy furniture overturned.
Sand and mud ejected in small amounts.
Changes in well water.
Persons driving cars disturbed.

Tacoma

"The bookkeeper noticed the lamp moving, then found that his hand was traveling in a wavering line over the paper. Accompanying this was a feeling that he was moving. The rows of hanging lamps which hang on both sides of the room swung quite violently from one side to another. The lighter of the wares jarred against one another." (*Tacoma Daily Ledger*, March 8, 1891)

"Several hundred felt the shock but thought it was due to blasting...." (*Seattle Post-Intelligencer*, March 8, 1891)

"No damage was done, although articles in china and glassware stores rattled a trifle, and occupants of sixth floors rushed from rooms fearing the structures were about to topple." (*Oregonian*, March 8, 1891)

Modified Mercalli Intensity I–III

Ellensburg

"The shock was [a] light one and a great many failed to notice it." (*The Ellensburg Capital*, March 12, 1891)

Not reported felt in the *Ellensburg Daily Localizer*.

Monitor

"The house trembled and shook." (From the diary of Helen Margaret Parrish, March 8, 1891; copy contributed by her granddaughter, Betsy Detroit.)

Admiralty Head Lighthouse

A light shock (Bradford, 1935).

Smith Island Lighthouse

A slight shock (Bradford, 1935).

No Felt Reports Found

The earthquake was not reported felt in the *Aberdeen Herald*, the *Hoquiam Washingtonian*, the *Chehalis Bee*, or the *Washington Standard*, a weekly published in Olympia; nor was it reported felt in the Victoria, B.C., *Daily Colonist*.

ACKNOWLEDGMENTS

This research was funded under USGS grant 14-08-0001-G1510 on Earthquake Intensities. We thank Betsy Detroit for contributing a copy of her grandmother's diary entry, and Chris Trisler for calling our attention to this earthquake.

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Do You Know Of Original Accounts Of Earthquakes That Occurred Before 1928?

Diary entries and newspaper accounts of felt earthquakes (felt in Washington, Idaho, Oregon, and Montana) that took place before 1928 are being collected by Ruth Ludwin of the University of Washington Geophysics Program. She needs to know where the diary was written or, for newspaper reports, the name of the newspaper, date and place of publication, as well as the page and column numbers for the earthquake story. If you have such material, she would appreciate having photocopies of it.

Ruth is also searching for newspaper indexes, which have proven to be especially helpful in documenting uncataloged earthquakes. She needs to know if there is a pre-1930 index to your local paper.

Please address information to Ruth Ludwin, Geophysics Program AK-50, University of Washington, Seattle, WA 98195.

Out-of-Print Publications Available

The following publications, long unavailable, can now be purchased from the Northwest Geological Society. For information about cost and mailing of these reprints, contact Dale Kramer at 783-0151 (home) or write to the Northwest Geological Society, 834 NW 50th, Seattle, WA 98107.

Liesch, B. A.; Price, C. E.; Walters, K. L., 1963, Geology and ground-water resources of northwestern King County, Washington: Washington Division of Water Resources Water-Supply Bulletin 20, 241 p., 3 plates (1 color).

Luzier, J. E., 1969, Geology and ground-water resources of southwestern King County, Washington: Washington Department of Water Resources Water-Supply Bulletin 28, 260 p., 3 plates (1 color).

Walters, K. L.; Kimmel, G. E., 1968, Ground-water occurrence and stratigraphy of unconsolidated deposits, central Pierce County, Washington: Washington Department of Water Resources Water-Supply Bulletin 22, 428 p., 3 plates (2 color).

Corrections

In *Washington Geology*, vol. 19, no. 4, the view in the photograph on page 38 is from the northeast; on page 41, left column, second paragraph, the text should read "During the 1991 legislative session..."; and the photo credit on page 53 should be Kent Reynolds.

Division Publication Activity—1991

by Renee Christensen

During 1991, the Division of Geology and Earth Resources published one report in the Geologic Map series (GM-39), consisting of text, three large plates in color, and the accompanying topographic map (TM-2). We also published seven open-file reports, four issues of *Washington Geology*, and bibliographies for 26 counties. These reports total 1,316 pages of information.

Of the publications in all our formal series, we distributed 5,320 copies. Of those formal publications for which we charge, we sold 2,571 and gave away 984 complimentary copies. Of the formal publications that are free, we mailed or gave out over the counter 1,765 copies.

We received orders for 3,312 copies of reports in our open-file series. Only 44 copies of free open-file reports were mailed out or distributed over the counter, but nearly 820 copies of reports in this series were given out on a complimentary basis.

The Division also distributed 4,381 copies of miscellaneous free information packets, brochures, and flyers, such as "Placer gold mining in Washington" and "Gems and minerals of Washington". We also gave away many copies of our list of publications.

The four issues of *Washington Geology* (formerly the *Washington Geologic Newsletter)* totaled 180 pages. This publication is mailed to an average of 3,824 addresses; by the end of 1991, there were approximately 4,010 people or institutions on the mailing list. We gave 1,378 copies to visitors or persons requesting particular issues.

During the year, the clerical staff handled orders and requests for 31,471 copies of our printed materials. This averages about 125 items per day being mailed or sold or given to visitors.

A Policy Plan for Improving Earthquake Safety in Washington: Fulfilling Our Responsibility*

December 1, 1991

EXECUTIVE SUMMARY

The Seismic Safety Advisory Committee

We all remember the 1989 earthquake near San Francisco...the immediate chaos, the collapsed freeway, the tragedies of death, destruction and homelessness. Washington has experienced earthquakes of similar magnitude and will experience them again. Mindful of our risk, the Legislature mandated the Department of Community Development to establish a Seismic Safety Advisory Committee (SSAC). The SSAC was charged with developing a comprehensive plan and making specific recommendations for improving seismic safety in Washington.

Policy Oriented Mission And Goals

Lengthy reports already exist explaining why Washington needs a seismic safety policy and providing generic information on improving earthquake preparedness. Rather than duplicate other work, the SSAC's goals have emphasized developing and prioritizing practical and realistic strategies and initiatives which the state can begin to implement immediately.

Broad Participation

The SSAC's work program involved the broad participation of state agencies, emergency response personnel, building officials and professional organizations from the beginning. The SSAC's work program used formal committees and individual contacts to maximize statewide involvement. Focus groups and public meetings were held in eastern and western Washington, and a survey was mailed to 2,500 government and private organizations to increase involvement in the policy development process.

Project Approach

The SSAC's work program focused on:

- Reviewing the current status of earthquake readiness.
- Developing strategies to improve readiness.
- Identifying initiatives to implement strategies.

The Earthquake Threat In Washington

Washington has experienced earthquakes as large as the recent event that shook San Francisco. In 1949 Olympia was rocked by a magnitude 7.1 earthquake. Again, in 1965, the Seattle–Tacoma area was rattled by a magnitude 6.5 earthquake.

Serious Earthquake In Your Time? A Definite Possibility

Major earthquakes with magnitudes between 6 and 7.5 can be expected every 30 to 50 years. We do not know when, but we do know that they will occur. Anyone spending half their life in western Washington should expect to live through a major earthquake.

Geologists See The Potential For A Catastrophic Earthquake

This summer Washington's earthquake threat was front page news. The news media reported recent research findings which show that coastal regions of Washington experienced a massive earthquake about 300 years ago, and that geologists see the potential for another great earthquake in the Pacific Northwest. Such an earthquake could be many times more damaging than San Francisco's recent earthquake.

We Should Prepare For A Major Earthquake

The conclusion that the SSAC draws from the earthquake risk is that we must prepare for an earthquake of at least magnitude 7.5, and probably larger, in which

- People will be injured and die.
- People will be left homeless.
- Lives and communities will be disrupted.
- Business will suffer direct loss from property damage.
- Recovery will take months or years to complete.

Being prepared can reduce all of these adverse impacts.

Our Readiness For An Earthquake

The SSAC reviewed the status of our readiness for an earthquake in Washington. What they found is cause for concern. While some organizations and individuals are prepared, most are not.

Our Emergency Response Capacity Will Be Overwhelmed

The SSAC is concerned that our response capacity will be hampered by inadequate communication systems, a lack of public preparedness, and the low priority placed on local emergency planning.

Schools Are Cause For Concern

There are a great many older, unreinforced masonry school buildings that are at risk. Tentative estimates indicate there are 350 to 400 unreinforced masonry school buildings, containing up to 155,000 children.

Fire And Medical Facilities Are Vulnerable

Many of our older firehouses and hospitals are vulnerable. When an earthquake strikes we need these facilities to be fully operational.

Our Transportation Lifelines Are Not Secure

The Washington State Department of Transportation is seismically strengthening key bridges. This is only a start. We need to know the risks to local bridges, marine facilities, port facilities, highways, transit systems, airports and rail facilities so that we can selectively strengthen crucial routes, staging areas, and airport facilities.

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* Raymond Lasmanis was the author of the interim report (delivered Dec. 1, 1991, and from which this has been taken verbatim), as well as co-chairman of the SSAC. Additional copies of the full report are available from the Department of Community Development, MS/GH-51, Olympia, WA 98504-4151.

Utilities Have Not Addressed Seismic Risk

Only a few of the many water and wastewater utilities in the state have assessed seismic vulnerability. Electric utilities have done some vulnerability assessments. The natural gas companies in Washington have done limited work to address seismic safety.

Now Is The Time To Act

There is no doubt that some time in the future Washington will experience a large and damaging earthquake. It could happen as you read this report, or it could happen next week or next year. When it does occur, there will be deaths, injuries and disruption that could and should have been prevented.

At an early stage, the SSAC concluded that the State should devote its energies to identifying measures which will increase earthquake safety. With every earthquake, we learn more about the behavior of buildings, lifelines and people during these events. There is a huge body of knowledge which we can apply right now to reduce seismic risks in Washington. The primary emphasis of the SSAC has been on identifying how the State can improve seismic safety.

Practical Recommendations For Increasing Seismic Safety

The SSAC emphasized developing policy and action recommendations which are realistic and build on other work that is currently underway. These recommendations are practical, achievable, and a wise investment.

Program Oversight Is Essential

A body providing leadership and oversight is required to ensure that the SSAC's recommendations are acted upon. The SSAC's top priority for immediate legislative action is the authorization in statute of an oversight committee with staff support to oversee implementation of the SSAC's recommendations. This committee will lead a multi-agency program and budget development process.

A Multi-Year Effort Is Required

Improving seismic safety is a long-term proposition. Seismic safety cannot be improved overnight, nor can it be improved by legislation alone. The SSAC has carefully crafted a multi-year work program which, when implemented, will significantly enhance seismic safety in Washington.

This work program prioritizes initiatives which:

- Reduce the risks to life, public safety and property.
- Are realistic and feasible.
- Create momentum for the overall program.

The work program involves a multi-agency and multi-jurisdictional effort and builds on current public and private sector work currently underway.

Priorities For Action

The following are top priority recommendations for action.

I. Establishing seismic safety oversight

a. Create by legislation an interagency seismic safety policy committee.

II. Improving emergency planning

a. Conduct a state-level review of emergency communication systems and implement the review recommendations.
b. Clarify the liability law for volunteer emergency workers and implement a central registry of trained emergency worker and volunteer personnel.
c. Prepare and implement a multi-media awareness and education program.
d. Provide standardized materials to help local jurisdictions more effectively train personnel.
e. Standardize planning guidelines for local jurisdictions as part of ongoing emergency planning.
f. Increase awareness of structural and nonstructural earthquake hazards as part of ongoing education.

III. Strengthening buildings

a. Assess the seismic vulnerability of school facilities and improve seismic safety as part of long-range capital planning.
b. Develop and submit amendments to the State Building Code Council that require seismic strengthening during planned remodel projects.
c. Support the review of current Uniform Building Code Seismic Zone 3 boundaries.
d. Develop financial incentive programs to assist with seismic strengthening projects.
e. Support and coordinate the geological mapping of sensitive areas.
f. Support the implementation of a strong motion instrumentation program in Washington.

IV. Strengthening our lifelines

a. Establish statewide policy goals for mitigation of seismic risk to lifelines.
b. Continue the funding for the current Washington State Department of Transportation bridge retrofit program.
c. Identify critical lifeline routes that include state and local roads, bridges, transit routes, and port facilities.
d. Develop a work program for seismic vulnerability assessments of local bridges.
e. Require seismic vulnerability assessments and adoption of seismic mitigation standards for water and wastewater utilities.
f. Require post-earthquake response and recovery plans for water and wastewater utilities.
g. Provide a rigorous program of training in seismic safety for lifeline organizations.
h. Develop standardized seismic safety guidelines for lifeline emergency plans.

Appendix E: Authorizing Legislation

The Department [of Community Development] shall create a seismic safety advisory board to develop a comprehensive plan and make recommendations for improving the state's earthquake preparedness. The plan shall include an assessment of and recommendations on the adequacy of communications systems, structural integrity of public buildings, including hospitals and public schools, local government emergency response systems, and prioritization of measures to improve the state's earthquake readiness. The Department shall report to the Senate and House of Representatives Committees on energy and utilities by December 1, 1991. An interim report shall be made to the Committees by December 1, 1990. ■

History of Cooperative Topographic Mapping In Washington

by J. Eric Schuster

The mandate of the Washington State Geological Survey, as passed by the 1901 legislature, included no provision for cooperative investigations with the U.S. Geological Survey (USGS). This was corrected in 1903, when the legislature amended the 1901 act by adding the following:

> The said board of geological survey is hereby authorized to make provisions for topographic, geologic, and hydrographic surveys of the State of Washington in cooperation with the United States geological survey in such manner as in the opinion of the said board will be of the greatest benefit to the agricultural, industrial, and geological requirements of the State of Washington: Provided, that the Director of the United States Geological Survey shall agree to expend on the part of the United States upon such surveys a sum equal to that expended by the said board.

This legislation remains in effect as RCW 43.92.060. Unfortunately, when the legislature gave the state geological survey this new duty and opportunity, it did not renew its appropriation, and the survey was dormant for several years.

In 1909, the legislature passed a second act authorizing the Washington State Geological Survey to engage in cooperative topographic and hydrographic work with the USGS. They also renewed the survey's appropriation: $30,000 for the cooperative topographic and hydrographic work, and $20,000 for the survey's geologic projects.

With new funding available, the Board of Geological Survey, the governing body of the Washington State Geological Survey, held planning meetings on April 16 and May 4, 1909. At the April meeting, they discussed cooperative hydrographic and topographic mapping with J. C. Stevens, District Engineer of the USGS. Stevens had been given authority to arrange for such cooperative work by USGS Director G. O. Smith. The Board authorized Governor M. E. Hay to complete all necessary cooperative arrangements with the U.S. government. On May 4, the Board decided that $10,000 would be used for cooperative hydrographic work and $20,000 for topographic mapping. Governor Hay and State Geologist Henry Landes were to decide which quadrangles were to be topographically mapped.

Quincy Is First Quadrangle Printed

They lost no time. Landes reported to the Board at their November 30, 1909, meeting that USGS field parties had completed work on the Mount Vernon 30′ quadrangle and were three-fourths finished with the Quincy, Morrison (Winchester), Red Rock, and Beverly 15′ quadrangles. The Quincy quadrangle was printed by the USGS in November 1910, the Winchester quadrangle in December 1910, the Mount Vernon and Red Rock quadrangles in January 1911, and the Beverly quadrangle in June 1912.

Cooperative topographic mapping was to go on for 82 years. The same general scheme was followed from start to finish. The state geological survey and its successors supplied one-half of the funds, and the USGS supplied the field parties and did the map preparation and printing.

Many of the early cooperative topographic maps are for areas in the arid central part of Washington. This probably reflects Landes' interest in irrigation projects. He knew that development of such projects depended heavily on the existence of good topographic maps from which canal routes, the extent of irrigable lands, and possible surface-water sources could be realistically determined.

Production Costs Vary With Relief of Terrain

Topographic mapping continued as a cooperative effort of the USGS and the Washington State Geological Survey and its successors. By 1946, Sheldon Glover, the State Geologist and Supervisor of the Division of Mines and Geology, could state in the biennial report of the Division that 169 quadrangles had been topographically mapped in Washington. These covered 77.83 percent of the state's land area, and 51 of these quadrangles had been produced cooperatively. He further reported that a topographic map of a mountainous quadrangle, like the Mount Constance quadrangle in the Olympic Mountains, cost about $18,000 to produce; a rolling lowland quadrangle like the Chehalis quadrangle cost about $14,500; and a treeless quadrangle of low relief, like the Connell quadrangle, cost $12,800. These are all 30′ quadrangles; 15′ quadrangles cost approximately twice as much to produce. A purchaser had to pay 20 cents per copy for these maps.

Twenty years later, 80 cooperative topographic quadrangles had been completed or were in preparation. The State's contribution to the program totaled $499,443. These figures were reported by Marshall T. Huntting, State Geologist and Supervisor of the Division of Mines and Geology, in his biennial report for the period July 1, 1964, to June 30, 1966.

Documents in Division files show that an additional $235,000 in topographic cooperative agreements were entered into between July 1, 1966, and June 30, 1981. This brought the total State contribution to $734,443 and the total number of cooperative quadrangle maps completed to about 110.

Budget Cuts End Division Involvement

Budget cuts in 1981 ended the Division's involvement in cooperative topographic mapping, and by the time finances permitted resumption of the cooperative program, completion of first-time topographic mapping in Washington was in sight, and the relatively small contribution the Division was able to make was not deemed to be needed. Cooperative efforts, however, were being continued by the Division's parent organization, the Department of Natural Resources.

The Division's cooperative contributions over the years helped to create a significant fraction of the state's 30′ and 15′ topographic quadrangle maps and sped the recently celebrated completion of 7½′ topographic mapping. ■

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

November 1991 through January 1992

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Northeast Quadrant Map A Winner

The Division's **Geologic map of Washington—Northeast quadrant** (GM-39) recently won an Award of Achievement in the Technical Reports category of the 1991 Art, Online, and Publications Competition sponsored by the Puget Sound Chapter of the Society for Technical Communication. The map of the southwest quadrant was similarly honored in 1988.

LOCATION OF MAIN OFFICE

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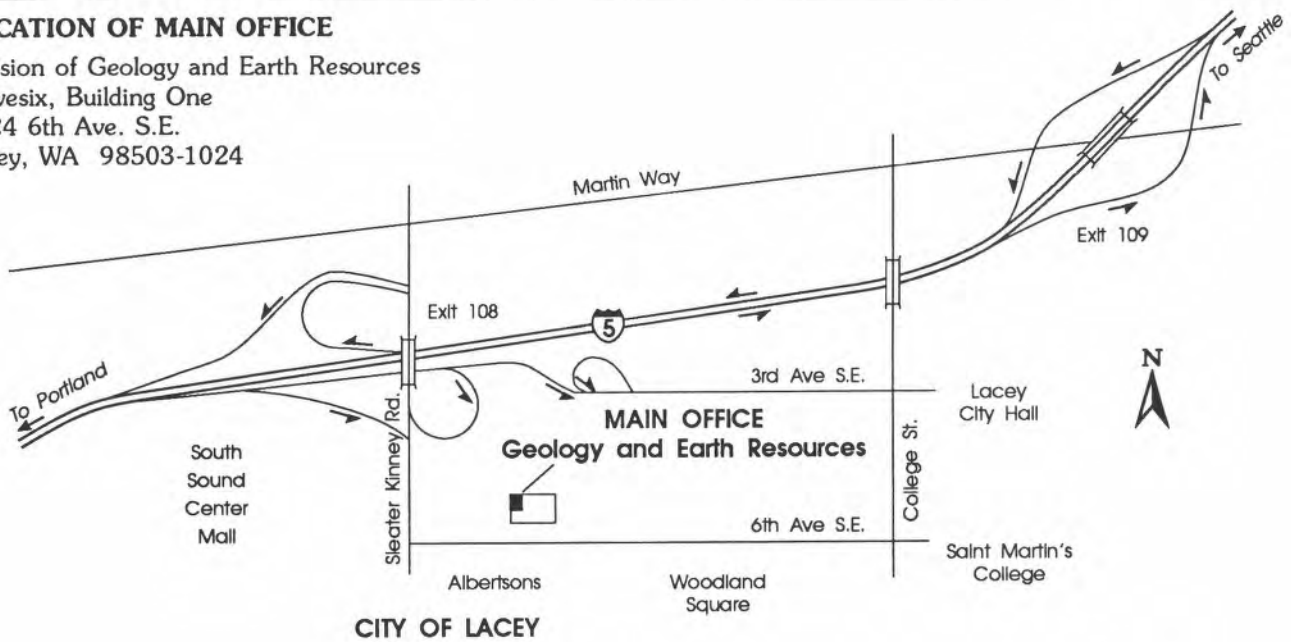

New Division Releases

Prediction of sediment yield from tributary basins along Huelsdonk Ridge, Hoh River, Washington, Open File Report 91-7, by R. L. Logan, K. L. Kaler, and P. K. Bigelow. This report describes the results of field investigations and study of aerial photographs to determine the volume of sediment yielded by slope failures in this area on the west side of the Olympic Peninsula. The study was conducted to assist in developing resource management alternatives for Hoh River basins. The 14-page report costs $0.93 + .07 tax (for Washington residents only) = $1.00.

Geologic and geophysical mapping of Washington, 1984 through 1991, and, Theses on the geology of Washington, 1986 through 1991, Open File Report 92-1, compiled by Connie J. Manson. The report consists of 36 pages (including 8 plates). *This report supersedes the previous version, Open File Report 91-1.* The price is $3.23 + .27 tax = $3.50.

Seismic hazards of western Washington and selected adjacent areas—Bibliography and index, 1988–1991, Open File Report 92-2, compiled by C. J. Manson. This report continues the previous bibliography (Open File Report 88-4) and includes citations for the entire Cascadia subduction zone. Publication has been supported by the National Earthquake Hazards Reduction Program through the U.S. Geological Survey. This 250-page report is free.

A colored geologic map of Washington at 1:2,250,000 (or 1 in. = approx. 37 mi) is now available free from the Division. This map (8½ x 14 in.) was compiled by J. Eric Schuster. Included are an explanation of the 22 map units and a list of sources used in compilation.

County Bibliographies

A bibliography of geologic information for **Okanogan County** has been added to this series, bringing the total to 26 counties covered by these compilations in support of the Growth Management Act. Copies are available on paper or disk (IBM-compatible). Paper copies are free, but please include $1 with each order to cover postage and handling. To obtain a disk copy, send us a 5.25-in. or 3.5-in. formatted disk. We will copy the file and return your disk. Please specify whether you want the file in Word Perfect 5.0 or 5.1 or ASCII. The Okanogan file is 190 kilobytes (K), and it is the same file listed below in the full series.

We have recently completed 1991 updates to the series of **county bibliographies**. The updated material has been appended to paper and disk copies, which are available separately. Write or call us to order paper copies. If you want the file(s) on disk, check the list below to be sure you send us enough disks to contain the file(s).

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Our mailing address, on p. 2 of this publication, has recently been revised—we now have a post office box number. In order to serve you as promptly as possible, we would appreciate having your Zip Code and the four-digit extension for your address with your correspondence.

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