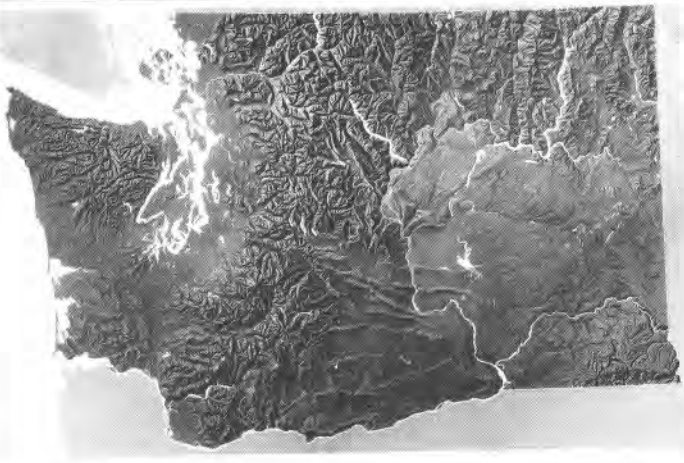

WASHINGTON GEOLOGIC NEWSLETTER

Volume 18 Number 1 March 1990

Washington State Department of Natural Resources Division of Geology and Earth Resources

Portland cement plant in Metaline Falls purchased by Lafarge Corp. in 1989, showing aerial tram that transports limestone from the quarry.

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WASHINGTON GEOLOGIC NEWSLETTER

The Washington Geologic Newsletter is published quarterly by the Division of Geology and Earth Resources, Department of Natural Resources. The newsletter is free upon request. The Division also publishes bulletins, information circulars, reports of investigations, geologic maps, and open-file reports. A list of these publications will be sent upon request.

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Washington State Mineral Data Files, Division of Geology and Earth Resources

By Raymond Lasmanis

The key to the development of a successful mineral exploration program is the availability of background information. Concepts evolve into a firm proposal for management's consideration through a process of data synthesis. In that regard, the Division's files are invaluable to the explorationist. To date, however, the value of this resource has not been fully utilized by geologists served by the Division. It may be that the obscure citation (Reference #158) in our out-of-print Bulletin 37, "Inventory of Washington Minerals; Part II, Metallic Minerals" has discouraged use of the data files. Reference 158 reads "Washington Division of Mines and Geology unpublished data".

The following paragraphs describe the various data sets, their size, general content, and location. It is hoped that knowledge of these data bases will lead to further use of the information.

Mining/prospect property files:

This is the core of the collection. It contains information about the state's metallic and industrial mineral properties dating back to the 1920s. Located in the Division's file room, there are eleven file drawers containing information about 996 individual properties. These are arranged alphabetically, from the A and C claim in Stevens County to Zinc Creek in Skamania County. The quality of the data is varied, from detailed geological/exploration reports to newspaper clippings and correspondence. These files were assembled to support the information in Bulletin 37. A card file system (17 drawers) arranged by property name as well as commodity was a key to the files until Bulletin 37 was published in 1956.

Mineral commodity files:

These files, also located in the file room, consist mostly of information on industrial minerals. They

(Continued on page 23)

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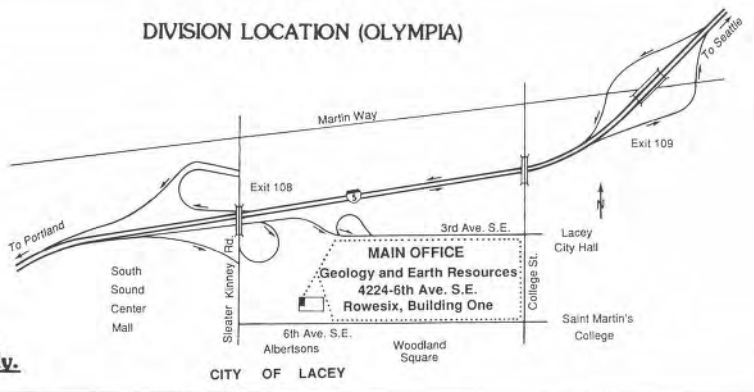

Washington's Mineral Industry in 1989

By Nancy L. Joseph

INTRODUCTION

The mineral industry in Washington is strong and growing. In 1989 four metal mines were in operation, and three new precious metal mines were in development or in the permitting stage. Twenty companies mined and produced industrial minerals, which include limestone, dolomite, silica, olivine, clay, and diatomite (Table 1). Two companies produced portland cement, and seven plants produced lime, calcium chloride, precipitated calcium carbonate, or ground limestone.

The value of magnesium metal production by Northwest Alloys, Inc. accounts for more than a quarter of the total value of the state's mineral industry, followed by sand and gravel, precious metals, and portland cement production, respectively (Fig. 1). The value of nonfuel mineral production in Washington in 1989 was $451 million, according to the U.S. Bureau of Mines. This represents an increase of less than one percent over the $448 million for 1988.

Production of magnesium metal continued at full capacity. The preliminary value of precious metals production declined because of decreased gold output and lower precious metals prices during most of 1989. Sand and gravel production, which accounts for nearly a quarter of the value of Washington's minerals, increased nearly 10 percent. Portland cement production decreased 21 percent relative to 1988, according to the U.S. Bureau of Mines; both production and value have decreased nearly 50 percent since 1987. While a slow, steady decline in prices for portland cement is a national trend, the large decline in production in Washington is in part the result of the cessation of production at the Columbia Northwest Cement Corp. plant in Bellingham in mid-1987.

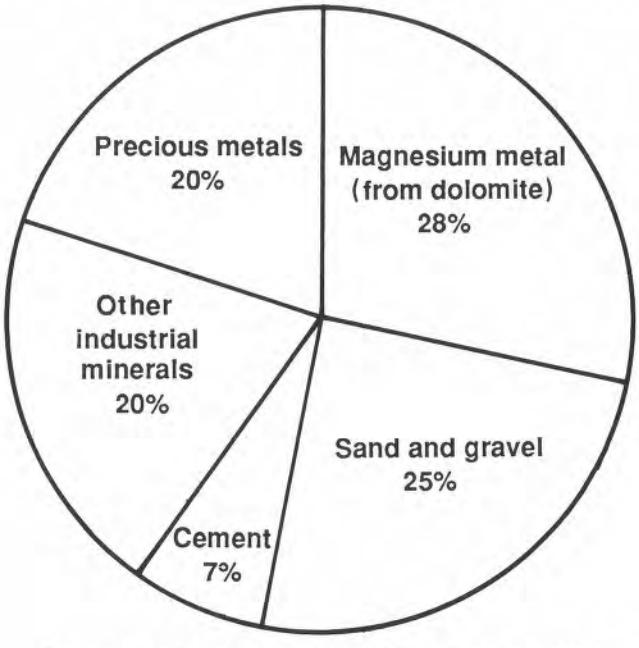

Figure 1. Industrial minerals, including the value added to dolomite by the production of magnesium metal, and sand and gravel account for more than three-fourths of the value of production of the mineral industry in Washington. Data from the U.S. Bureau of Mines, Division of Geology and Earth Resources, and published reports.

Total revenue from prospecting, mining, and quarrying on State lands was $687,080 for the fiscal year ending June 30, 1989. Increased payments related to sand and gravel quarrying resulted in a 44 percent increase in revenues to the state compared to the fiscal year ending June 30, 1988.

Calculations based on statistics for the first 6 months of 1989 supplied by the Washington State Department of Employment Security indicate that mining, mining services, and quarrying employed a projected estimate of more than 2,300 workers with an average annual payroll of more than $72 million. These figures do not account for those employed in the production of magnesium metal, portland cement, or other processors of calcium carbonate products, which together employ more than 650 additional workers. The amount paid workers in metal mining and mining services amounts to nearly half the total annual payroll; 37 percent of mine and mining-related workers are employed in metal mining.

Information in this report is summarized from voluntary replies to a questionnaire sent by the Division of Geology and Earth Resources to companies and individuals active in mineral exploration and development in the state, as well as from published information. The questionnaire is of limited scope and, therefore, details of the activities on individual properties are not always available. Not all questionnaires were returned, and some of the information requested, particularly regarding expenditures and production, is deemed confidential by many of those questioned and is not reported. Therefore, while this summary is a reliable indication of the mineral activity in Washington, it is incomplete and general in nature.

The locations of properties mentioned in this article are shown in Figures 2a and 2b, which cover western and eastern Washington respectively.

(Text continued on page 12)

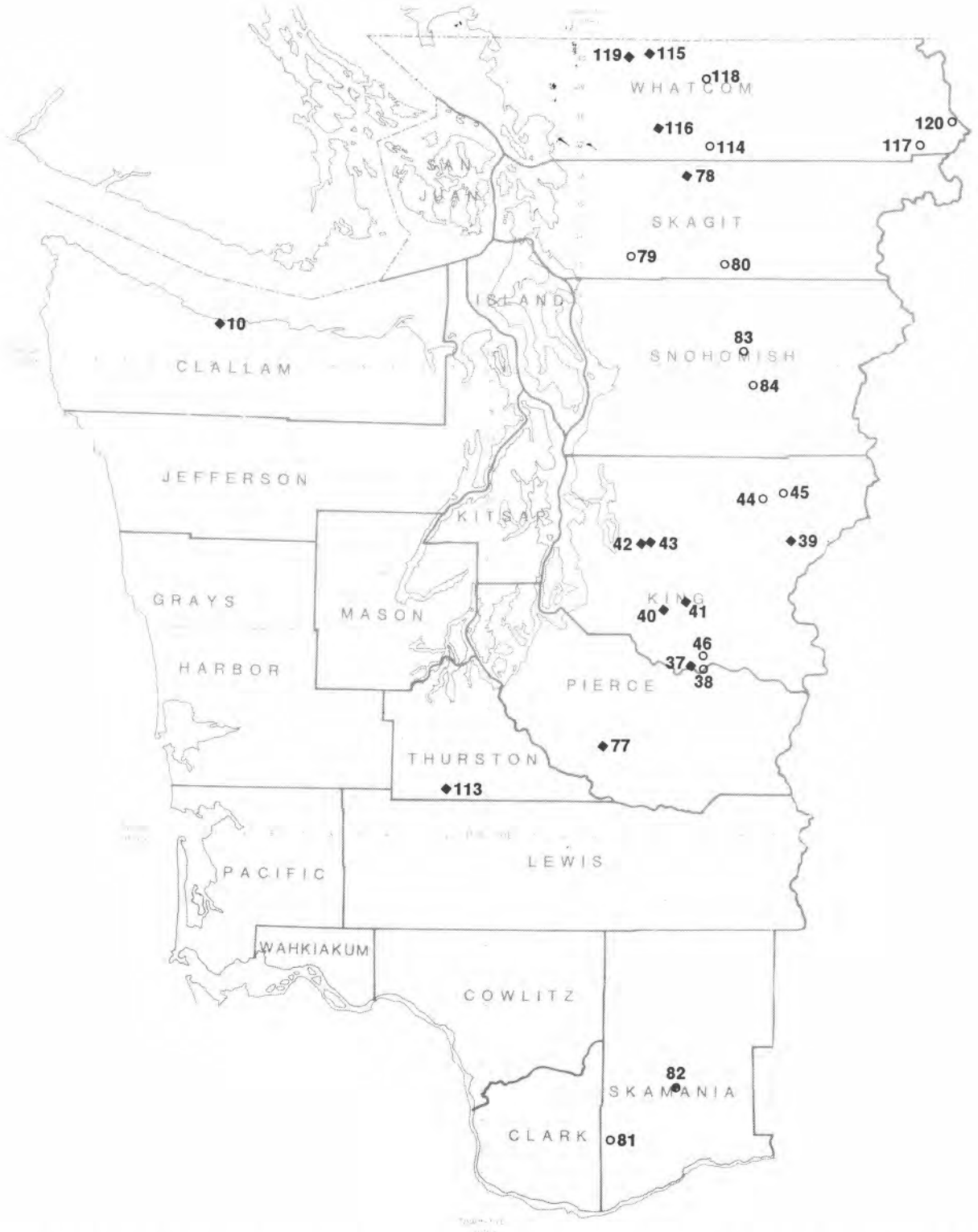

Figure 2a. Location of selected mines and prospects (metallic and industrial minerals) in western Washington. Location numbers are keyed to Table 1.

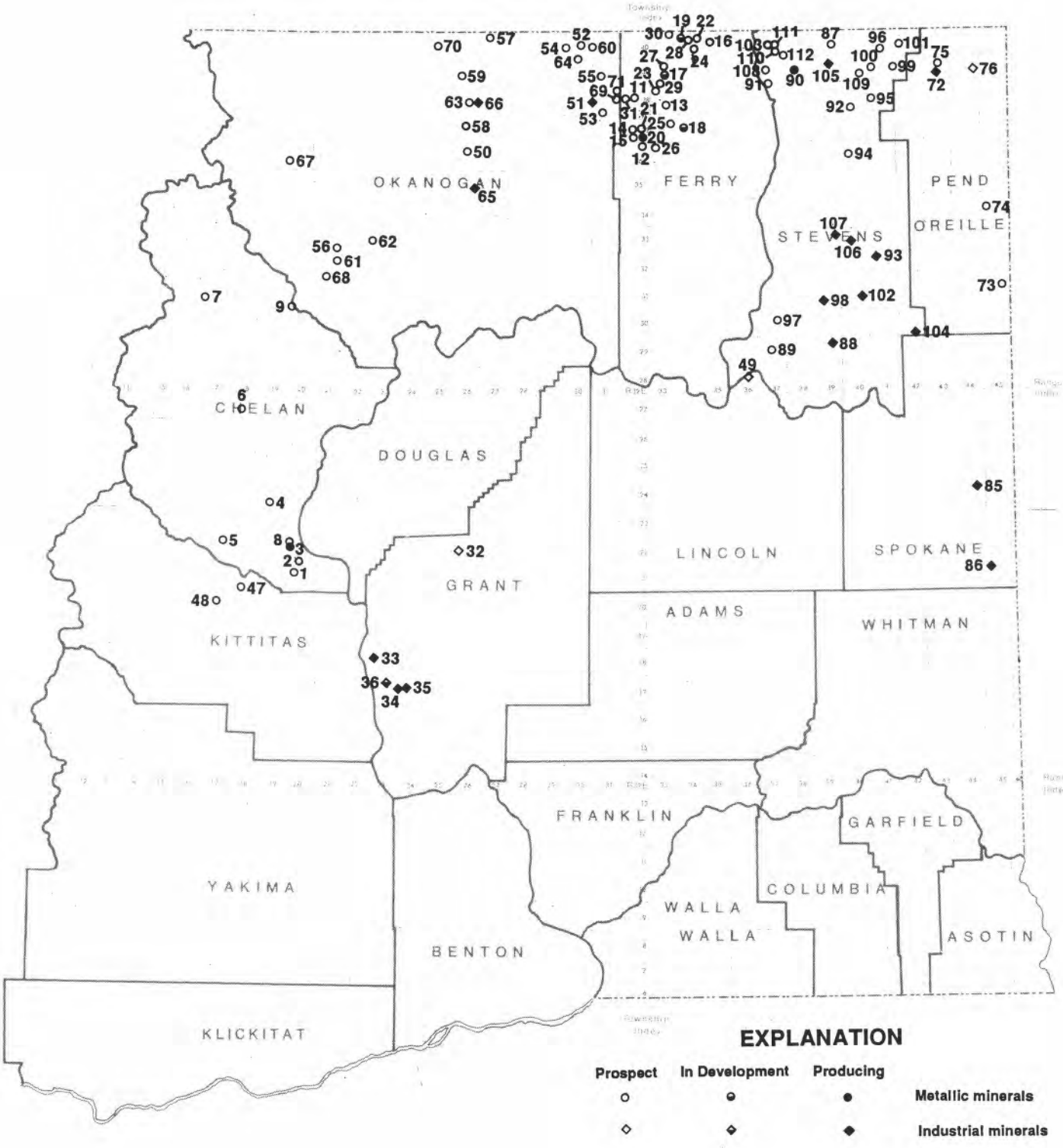

Figure 2b. Location of selected mines and prospects (metallic and industrial minerals) in eastern Washington. Location numbers are keyed to Table 1.

Table 1. Mineral exploration and development in Washington in 1989. Locations given where available. See Figures 2a and 2b for property locations

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
1	Chelan	Althouse Placers,Inc.		Wenatchee Heights	Au,Ag	Property leased to Asamera Minerals
2	Chelan	Asamera Minerals (U.S.) Inc.-Exploration/ Breakwater Resources Ltd.	Wenatchee Heights-Stemilt	sec. 35, T22N, R20E; sec. 2, T21N, R20E	Au,Ag	Diamond drilling, geophysical exploration
3	Chelan	Asamera Minerals (U.S.) Inc./ Breakwater Resources Ltd.	Cannon mine	sec. 16, T22N, R20E	Au,Ag	Mining; surface and underground exploration
4	Chelan	Asamera Minerals Inc.		sec. 34, T24N, R19E	Au,Ag	Exploration
5	Chelan	Montana de Oro, Inc.	Blewett	secs. 1-3, T22N, R17E	Au	Trenching
6	Chelan	Raven Hill Mining Co.	Raven group	sec. 21, T27N, R18E	Au,Ag	Exploration
7	Chelan	Red Butte Resources Ltd.	Howe Sound tailings	secs. 7-8, T31N, R17E	Au	Leased tailings from Holden Village
8	Chelan	United States Borax & Chemical Corp.	Skyline	sec. 9, T22N, R20E		Drilling
9	Chelan	Wood, Robert	Miners Basin	sec. 31, T31N, R20E	Cu	Drilling
10	Clallam	Ideal Basic Industries, Inc.	Twin River quarry	secs. 22-23, T31N, R10W	clay	Mining
11	Ferry	Atlas Mine and Mill Supply, Inc.	Kelly Camp	sec. 9, T38N, R32E	Au	Exploration
12	Ferry	Boise Cascade Corp.		sec. 1, T36N, R32E	Au,Ag	Drilling, trenching
13	Ferry	Crown Resources Corp./Cambior USA, Inc.	Mount Elizabeth	T38N, R33E	Au,Ag	Joint venture agreement
14	Ferry	Crown Resources Corp./Sutton Resources Inc.	South Penn	secs. 27-28, T37N, R32E	Au,Ag	Exploration
15	Ferry	Crown Resources Corp./Sutton Resources Inc.	Seattle mine/Flag Hill	secs. 33-34, T37N, R32E	Au,Ag	Exploration drifting, surface drilling
16	Ferry	Cyprus Minerals Co.	Lone Ranch Creek/LDH claims	secs. 11-12, 18-19, 30, T40N, R35E	Au,Ag	Exploration
17	Ferry	Echo Bay Exploration Inc./Crown Resources Corp.	Kettle mine	sec. 15, T39N, R33E	Au	Mine development
18	Ferry	Echo Bay Exploration Inc./Crown Resources Corp.	Overlook mine	sec. 18, T37N, R34E	Au,Ag	Mine and mill development
19	Ferry	Gold Express Inc./N. A. Degerstrom Inc.	Gold Mountain	sec. 7-8, T40N, R34E	Au,Ag	Acquired property, permitting for expanded op- in 1990

Table 1. Mineral exploration and development in Washington in 1989 (continued)

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
20	Ferry	N. A. Degerstrom, Inc.	Republic Unit	sec. 35, T37N, R32E	Au, Ag	Mining underground and surface exploration
21	Ferry	Hecla Mining Co.	Golden Eagle	sec. 27, T37N, R32E	Au,Ag	Drilling
22	Ferry	Johnson Explosives	Irish	sec. 15, T40N, R34E	Au	Trenching
23	Ferry	Kettle River Resources Ltd.	Empire Creek	sec. 6, T38N, R33E	Au	Drilled by U.S. Borax
24	Ferry	Morning Star Mines, Inc.	Morning Star mine	sec.16, T40N, R34E	Au,Ag,Cu	Underground sampling, surface drilling
25	Ferry	N. A. Degerstrom,Inc./ Inland Gold and Silver Corp./Pegasus Gold Corp.	Leland/ Kellogg	T36-38N, R33-34E	Au,Ag	Geological and geophysical exploration, drilling
26	Ferry	Newmont Exploration Ltd.	Gib claims	secs. 4-5, 8, T36N, R33E	Au,Ag	Exploration
27	Ferry	Newmont Exploration Ltd.		sec.10, T39N, R33E	Au,Ag	Drilling
	Ferry	Silver Eagle Resources Ltd.			Au,Ag	Staked claims; geophysical studies
28	Ferry	Sundance Mining and Development Inc.	Gold Hill	secs. 7-8, T40N, R34E	Au,Cu	Optioned to Gold Express
29	Ferry	United States Borax & Chemical Corp.	Wheaton Ranch	T39N, R33E	Au,Ag	Held property
30	Ferry	United States Borax & Chemical Corp./Wilbur Hallauer	Lone Star	sec. 2, T40N, R33E	Au,Cu	Drilling
31	Ferry	Westmont Mining Inc.	MM Claims	secs. 7, 18, T38N, R32E	Au,Ag	Exploration; drilling
32	Grant	Basic Resources Corp.	Rock Top	sec. 20, T22N, R26E	clay	Opening of test pits
33	Grant	Witco Corp.	Sec. 17 pit	sec. 17, T18N, R23E	diatomite	Hauling from stockpile
34	Grant	Witco Corp.	Sec. 7 pit	sec. 7, T17N, R24E	diatomite	Mining
35	Grant	Witco Corp.	Sec. 8 pit	sec. 8, T17N, R24E	diatomite	Hauling from stockpile; reclamation
36	Grant	Witco Corp.	Sec. 3/10 pit	secs. 3, 10, T17N, R23E	diatomite	Mine development
37	King	Ash Grove Cement West, Inc.	Superior quarry	sec. 1, T19N, R7E	silica	Mining and crushing
38	King	Cannon Minerals	White River	sec. 6, T19E, R8E	Au	Sold lease to Weyerhaeuser
39	King	Jackson, Robert		secs. 29-30, T24N, R11E	quartz xls	Mining
40	King	L-Bar Products, Inc.	Ravensdale pit	sec. 1, T21N, R6E	silica	Mining
41	King	Mutual Materials Co.	Elk pit	sec. 34, T22N, R7E	clay	Mining

Table 1. Mineral exploration and development in Washington in 1989 (continued)

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
42	King	Mutual Materials Co.	sec. 31	sec. 31, T24N, R6E	clay	Mining
43	King	North American Refractories Co.	Blum pit	sec. 32, T24N, R6E	clay	Hauled from stockpile
44	King	Ray and Schindler	Lennox Group	secs. 7, 17-18, T25N, R10E	Au,Ag	Removed overburden
45	King	Wagner, Mark	Coney Basin	sec. 12, T25N, R10E	Au	Exploration
46	King	Weyerhaeuser Co.	White River	T20N, R8E	Au,Ag	Mining and crushing
47	Kittitas	Althouse Placers Inc.	TM claims	secs. 21, 28, 29, 32, 33, T21N, R18E	Au,Ag	Exploration
48	Kittitas	MMC Resources Corp.		secs. 10-11, T20N, R17E	Au	Exploring for placer gold
49	Lincoln	Blue Silver Mining	Crystal City mine	sec. 21, T28N, R36E	dolomite	Mine development
50	Okanogan	Baum Minerals	Turtle Lake	secs. 9-10, T36N, R26E	Au,Ag,Cu	Drilled by Newmont
51	Okanogan	Columbia River Carbonates	Wauconda quarry	sec. 13, T38N, R30E	limestone	Mining and crushing
52	Okanogan	Crown Resources Corp.	Buckhorn	T40N, R30E	Au,Ag	Extensive drill program
53	Okanogan	Crown Resources Corp.	Bodie	sec. 34, T38N, R31E	Au,Ag,Cu	
54	Okanogan	Crown Resources Corp.	Strawberry Lake	sec. 18, T40N, R30E	Au,Ag	Exploration, property acquisition
55	Okanogan	Crown Resources Corp./Sundance Mining and Dev. Inc./Cambior USA, Inc.	Ida mine	sec. 21, T39N, R31E	Au,Ag	Exploration
56	Okanogan	ECM Inc.	Alder mine	secs. 23-26, 35-36, T33N, R21E	Au,Ag,Cu	Exploration
57	Okanogan	Hallauer, Wilbur	Kelsey	secs. 5-8, T40N, R27E	Cu,Mo,Au	Drilling
58	Okanogan	Hallauer, Wilbur	Starr Molybdenum	secs. 8, 16, T37N, R26E	Mo,Cu	Drilling
59	Okanogan	Hallauer, Wilbur	Copper World Extension	secs. 20, 29, T39N, R26E	Cu	Drilling
60	Okanogan	Nordic Ltd.		secs. 23-25, T40N, R30E		Exploration
61	Okanogan	Northwest Minerals Corp.	Smith Canyon	sec. 1, T32N, R21E	Au	Geochemical exploration
62	Okanogan	Northwest Minerals Inc.	Red Shirt	sec. 18, T33N, R23E	Au	Geochemical exploration
63	Okanogan	Northwest Minerals Inc.	Okanogan Highgrade	sec. 23, T38N, R26E	Au	Exploration
64	Okanogan	Orvana Resources Corp./Keystone Gold Inc.	Crystal Butte	sec. 35, T39-40N, R30E	Au,Ag,Cu	Optioned to Crown Resources Corp.
65	Okanogan	Pacific Calcium, Inc.	Brown quarry	secs. 24-25, T35N, R26E	dolomite	Mining
66	Okanogan	Pacific Calcium, Inc.	Tonasket Limestone quarry	sec. 25, T38N, R26E	limestone	Mining and milling

Table 1. Mineral exploration and development in Washington in 1989 (continued)

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
67	Okanogan	Quintana Minerals Corp./Vanderbilt Gold Corp./ Brenda Inc.	Mazama Venture	secs. 17, 19-20, T36N, R20E	Au,Cu,Ag,	Exploration and property evaluation
68	Okanogan	Reliant Resources, Ltd./ Nord Resources Corp.	Smith Canyon	secs. 34-35, T32N, R21E; secs. 10-12, T31N, R21E	Au,Ag,Cu	Exploration
69	Okanogan	Silver Bell Inc./Crown Resources Corp.	Silver Bell	secs. 25, 35, T38N, R31E	Au,Ag,Cu	Exploration
70	Okanogan	Sunshine Valley Minerals, Inc.	Billy Goat claims	sec. 15, T40N, R25E	Au,Cu	Mine development
	Okanogan	Sunshine Valley Minerals, Inc.	Aeneas Valley Quartz	Aeneas Valley	silica	Drilling
71	Okanogan	United States Borax & Chemical Corp.	Toroda	sec. 12, T38N, R31E	Au,Ag	Drilling
72	Pend Oreille	Lafarge Corp.	Champane Placer	sec. 27, T39N, R43E	limestone	Acquired property; mining
73	Pend Oreille	Raven Hill Mining	Glass Mountain mine	sec. 2, T31N, R45E	Au,Ag	Mine rehabilitation; drilling
74	Pend Oreille	Raven Hill Mining Co.	Cooks Copper	sec. 19, T34N, R45E	Ag,Cu	Exploration
75	Pend Oreille	Resource Finance Inc./ Pintlar Corp.	Pend Oreille mine	secs. 10-11, 14-15, T39N, R43E	Zn,Pb	Drilling, dewatering, and mine evaluation done by RFI
76	Pend Oreille	Southern Talc Co./First Miss Gold Inc.	Totem Talc	sec. 23, T39N, R44E	talc	Bulk sampling, reopened and developed test pits
77	Pierce	Mutual Materials Co.	Clay City pit	sec. 25, T17N, R4E	clay	Mining
78	Skagit	Applied Industrial Materials Corp.	AIMCOR Olivine	sec. 17, T36N, R7E	olivine	Milling olivine
79	Skagit	Cannon Minerals	Skagit Copper	secs. 1-3, 11, T33N, R5E	Cu,Zn,Ag	Exploration
80	Skagit	Cannon Minerals	Telstar Claims	secs. 25-26, T33N, R8E	Ag,Au	Exploration
81	Skamania	Plexus Resources Corp.	Silver Star	secs. 3-5, 8-9, T3-4N, R5E	Cu,Ag,Mo	Drilling; geological and geophysical exploration
82	Skamania	Wind River Mining Co.	Wind River mine	sec. 9, T5N, R7E	Au,Ag	Mining
83	Snohomish	Cannon Minerals	Tri-Lux claims	secs. 27-28, 33-34, T30N, R9E	Au,Ag	Exploration
84	Snohomish	Island-Arc Resources Corp.	Lockwood	secs. 30-32, 25,T29N, R9E	Au,Cu,Zn	Geological mapping; geophysics
85	Spokane	Interpace Industries Inc.	Mica pit	sec. 14, T24N, R44E	clay	Mining and development of reserves

Table 1. Mineral exploration and development in Washington in 1989 (continued)

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
86	Spokane	Interpace Industries Inc.	Pottratz pit	sec. 7, T21N, R45E	clay	Mining
87	Stevens	A. Ambrose	Ambrose Mining	sec. 16, T40N, R39E	Au	Dredging
	Stevens	Allied Minerals Inc.	Smith/Madsen mine		dolomite	Exploration and development
88	Stevens	Allied Minerals Inc.	Gehrke mine	sec. 2, T29N, R39E	dolomite	Mining
89	Stevens	Blue Silver Mining	H and B mine	sec. 15, T29N, R37E	Au,Ag,Pb	Mine development
	Stevens	Boise Cascade Corp.	Corporate lands		Au	Exploration
90	Stevens	Boise Cascade Corp.	Gold Hill	secs. 18-19, T39N, R38E	Au,Ag	Sampling
91	Stevens	Boise Cascade Corp.	Toulou Mountain	sec. 31, T39N, R37E	Au,Ag,Cu	Sampling
92	Stevens	Callahan Mining Corp./Equinox Resources Ltd.	Van Stone	sec. 33, T38N, R40E	Zn,Pb	Feasibility study by Equinox
93	Stevens	Chewelah Eagle Mining Co.	Chewelah Eagle group	sec. 5, T32N, R41E	Ag,Cu	Drilling, sampling, road development
94	Stevens	Cordilleran Development Inc.	Shoemaker mine	sec. 8, T36N, R40E	Zn,Pb	Mined for part of year
95	Stevens	Cordilleran Development Inc.	Sierra Zinc	secs. 19-20, 29-30, T38N, R41E	Zn,Pb	Lease option
96	Stevens	Cumo Resources Ltd.	Melrose mine	sec. 27, T40N, R41E	Ag,Cu	Exploration
97	Stevens	Formation Capital Corp.	Reed Iron	sec. 14, T30N, R37E	Au	Exploration
98	Stevens	Lane Mountain Silica Co. subsidiary of Hemphill Brothers, Inc.)	Lane Mountain Silica	secs. 22, 34, T31N, R39E	silica	Mining
99	Stevens	Leadpoint Consolidated Mines Co.	Leadpoint Consolidated properties	secs. 12-13, T39N, R41E; secs. 7-8, 17-18, T39N, R42E	Ag,Pb,Zn	Surface sampling
100	Stevens	Mines Management, Inc./Equinox Resources Ltd.	Advance, HC	sec. 18, T39N, R41E	Zn,Pb	Leased to Equinox
101	Stevens	Mines Management, Inc./ Equinox Resources Ltd.	Iroquois	secs. 1, 19-20, 29-30 T40N, R42E	Zn,Pb	Leased to Equinox
102	Stevens	Nanome Aggregates, Inc.	Several quarries		dolomite	Mining and processing
103	Stevens	Newmont Exploration Inc.	White Elephant	sec. 19, T40N, R37E	Au	Drilling
104	Stevens	North American Refractories Co.	Lande pit	sec. 34, T30N, R42E	clay	Hauled from stockpile
105	Stevens	Northport Limestone Co. (subsidiary of Hemphill Brothers, Inc.)	Sherve quarry	sec. 8, T39N, R39E	limestone	Mining and crushing

Table 1. Mineral exploration and development in Washington in 1989 (continued)

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
106	Stevens	Northwest Alloys, Inc.	Blue Creek mine	sec. 29, T33N, R40E	silica	Mining
107	Stevens	Northwest Alloys, Inc.	Addy Dolomite quarry	secs. 13-14, T33N, R39E	dolomite	Mining; production of magnesium metal
108	Stevens	Orient Mining Co. (Boise Cascade Corp.)/Pathfinder Gold Corp.	First Thought mine	secs. 7, 18, T39N, R37E	Au	Geologic mapping
109	Stevens	Silver King Mines	Siver King mine	T39N, R40E	Au,Pb,Zn	Exploration
110	Stevens	Vanhorn and Watson Mining Co.	Copper Penny	sec. 29, T40N, R37E	Au,Ag,Cu	Drilling
111	Stevens	Vanhorn and Watson Mining Co.	Gold Nugget	sec. 20, T40N, R37E	Au,Ag	Drilling
112	Stevens	Western Land and Resources/Boise Cascade Corp.	McNally-Freedom claims	secs. 33-34, T40N, R37E	Au,Ag,Cu	Drilled by Boise
113	Thurston	Mutual Materials Co.	Bucoda pit	secs. 10,14, T15N, R2W	clay	Mining
114	Whatcom	Cannon Minerals	Loomis Mountain	secs. 19-20, 29, 32, T37N, R8E	Cu,Zn	Geological mapping, sampling
115	Whatcom	Clauson Lime Co.	Silver Lake No. 1	sec. 7, T40N, R6E	limestone	Mining
116	Whatcom	Olivine Corp.	Swen Larsen quarry	sec. 34, T38N, R6E	olivine	Mining
117	Whatcom	Seattle-St. Louis Mining Co.	Minnesota mine	sec. 2, T37N, R16E	Au,Ag	Exploration
118	Whatcom	Steelhead Gold Inc./FMC Gold Corp.	Excelsior mine	secs. 5-6, T39N, R8E	Au,Ag	Drilled and optioned by FMC
119	Whatcom	Tilbury Cement Co.	Kendall quarry	secs.14-16, 22-23, T40N, R5E	limestone	Mined small quantity of stone
120	Whatcom	Western Gold Mining, Inc.	New Light mine	sec. 27 T38N, R17E	Au,Ag	Surface and underground sampling
			Statewide			
		American Copper and Nickel Company, Inc.			Au	Property evaluations and reconnaissance
		Battle Mountain Exploration Co.			Au	Regional exploration
		Cominco American Resources Inc.				Exploration
		FMC Gold Co.			Au,Ag	Reconnaissance exploration
		Freeport McMoran Gold Co.			Au	Regional exploration
		Gold Fields Mining Corp.			Au,Ag	Regional exploration

Table 1. Mineral exploration and development in Washington in 1989 (continued)

Loc. no.	County	Owner/operator	Property	Location	Commodity	Remarks
		Meridian Gold Co.			Au	Exploration
		Noranda Exploration, Inc.			Au	Reconnaissance exploration
		Pegasus Gold. Corp.			Au	Regional exploration
		Phelps Dodge Corp.			Au	Exploration
		M. D. Regan and Assoc.			Au,Ag,Cu	Property evaluations
		Weyerhaeuser Co.	company lands		metals	Exploration for metals and market research for industrial minerals

(Text continued from page 3)

METALS

Development

Gold and silver, with a combined value of nearly $89 million dollars in 1989, were the primary commodities produced from metal mines in Washington (Table 2). The estimated 217,700 oz of gold produced from two mines in Chelan and Ferry Counties represent a 4 percent decrease in production and a 15 percent decrease in value from production in 1988 (Fig. 3). In contrast, silver production increased to nearly 600,000 oz. Gold production should escalate to greater than 300,000 oz in 1990 as the result of the start-up of operational production at three precious metals mines in Ferry County. Small production was also accomplished at one mine in Skamania County.

One lead and zinc mine in Stevens County was active for part of the year. Advanced exploration and feasibility studies in progress at two mines that formerly produced these metals may result in increased future base metal production.

Chelan County

The Cannon mine, a joint venture between Asamera Minerals (U.S.), Inc., as the operator, and Breakwater Resources Ltd., is the largest gold mine in the state and the second largest underground gold mine in the nation. An estimated 143,200 oz of gold was produced with an estimated average gold grade of 0.30 oz/ton. While gold production decreased from the 151,634 oz reported by Asamera (Asamera Minerals, Inc., 1988 Annual Report) in 1988, silver production increased substantially, resulting in record production of nearly 300,000 oz. Production costs, including royalties and shipping, were estimated by the company to be $233 per equivalent ounce of gold (Breakwater Resources Ltd., 3rd quarter 1989 report).

Asamera Minerals is a 92 percent-owned subsidiary of Asamera, Inc., which is 100 percent controlled by Gulf Canada Resources Ltd. Asamera Minerals has been for sale since it was acquired by Gulf in 1987. In November it was announced that Corona Corp. and Asamera had agreed in principle that Corona would acquire the U.S mining properties and all exploration properties of Asamera in exchange for 10 million voting shares of Corona. The agreement is subject to the approval of the board of directors of each company and the shareholders of Asamera Minerals. If approved, the transaction will take place in early 1990.

Underground exploration, aimed at increasing reserves, continued at the mine. Underground drilling was directed at defining ore limits down-dip and below the 500-ft level of the B-North area and has indicated additional reserves. Drilling was also undertaken in the northern and western extensions of the B-4 ore zone, in the B-West ore body, and in the B-neath zone. Core drill holes, as much as 2,000 ft in length, were drilled in the area immediately surrounding the mine to evaluate the effect of post-mineralization faulting and the possibilities of discovering parts of the ore body that might have been cut off by faults (Fig. 4).

The epithermal mineralization at the Cannon mine occurs in quartz-adularia-calcite veins in silicified Eocene arkose in the Chiwaukum graben. Ore minerals include pyrite, electrum, pyragyrite, tetrahedrite, chalcopyrite, and acanthite. Fluid inclusions from vein quartz and calcite suggest that mineralized fluids were boiling during gold deposition (Klisch, 1989).

Table 2. Base and precious metals production and development in 1989

Commodity	Property	Owner and/or operator	County	Type of mine	Type of mill	Production and development
Au, Ag	Cannon mine	Asamera Minerals (U.S.) Ltd./Breakwater Resources Ltd.	Chelan	Underground	Flotation	Produced approximately 143,200 oz of gold
Au, Ag	Kettle mine	Echo Bay Mines Ltd./ Crown Resources Corp.	Ferry	Underground		Mine development; production to begin in early 1990
Au, Ag	Overlook mine	Echo Bay Mines Ltd./ Crown Resources Corp.	Ferry	Underground	Flotation/ carbon-in-pulp	Mine and mill development; operational production to begin in early 1990
Au, Ag	Gold Mountain mine	Gold Express Inc./ N. A. Degerstrom, Inc.	Ferry	Open pit	Heap-leach	Acquired property; permitting for expanded operation in 1990
Au, Ag	Republic Unit	Hecla Mining Co.	Ferry	Underground	Flotation/ cyanidation	Produced ≈72,000 oz of gold; announced construction of new decline ramp for 1990
Metals	Wind River mine	Wind River Mining Co.	Skamania	Underground	Flotation	Produced 7 tons of concentrate
Zn, Pb	Shoemaker mine	Cordilleran Development Inc.	Stevens	Underground	-----	Mined for part of year

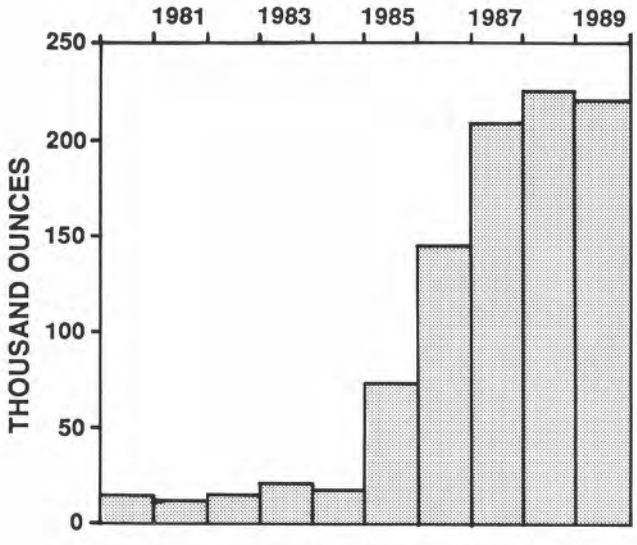

Figure 3. Estimated gold production in Washington. Gold production decreased slightly in 1989 at the two major gold mines in the state. Production increased dramatically in 1985 as a result of the opening of the Cannon mine and the increased production at the Republic Unit.

Ferry County

In June 1989, Hecla Mining Co., the operator of the Republic Unit, celebrated the production of the 2 millionth ounce of gold hoisted from a single shaft. This milestone was achieved by the Knob Hill No. 2 shaft on May 24, 1989; only six other shafts in the nation have achieved this production. The inclined shaft, which was collared in 1939 and began production in 1940, traverses a distance of 1,774 ft.

Hecla estimates that 72,000 oz of gold was produced from the underground mine in 1989 from ore averaging 0.9 oz of gold per ton. This figure represents a slight decrease from the record of 80,301 oz of gold that was produced in 1988. All production was from the Golden Promise vein system, which was first brought on line in 1986.

In December the company announced plans to begin construction of a 4,000-ft decline ramp into the Golden Promise area. The decline will access newly discovered mineralized areas in the Belligerent vein system, 600 ft northwest of the present mine area, and allow for expanded exploration in the vicinity of the Golden Promise veins. The newly discovered mineralized rock was found by underground drilling from the Golden Promise mine. The new ramp system will allow rubber-tired vehicles to drive directly from the mine to the mill. Currently, ore is trammed more than 1 mi underground from the Golden Promise area to the Knob Hill No. 2 shaft.

The Golden Promise shaft, constructed in 1986, is now used solely to transport personnel and equipment.

Updating was continued on the 52-yr-old, 240-ton-per-day flotation mill to expand its capacity to 270 tons per day. A fines treatment circuit was installed in the crushing plant to improve control in grinding and flotation. A new counter-current decantation circuit was also installed to separate liquids from solids and to replace the old five-tray thickener.

The mine employs 115 workers; 20 employees will be added to develop the new $6.6 million decline and ramp system.

In a span of 4 years Echo Bay Exploration Inc. has taken an option on the Key and Kettle properties, discovered the Overlook orebody, completed necessary permitting, and constructed a 1,500-ton-per-day mill and main haulage ways for Kettle and Overlook underground mines. The $60 million Kettle River project is a joint venture with Crown Resources Corp. and should begin production in early 1990.

The Overlook deposit, 11 mi northeast of Republic, is a magnetite replacement deposit containing phyrrhotite, pyrite, and gold in limestone of probable Permian age. A sheeted, low-angle, stockwork deposit is present in overlying clastic rocks. The contact between the two rock types is a low-angle, mylonitic fault zone that is also mineralized. The deposit is divided into four consecutively numbered zones; zone 4 contains limestone replacement ores and zone 1 contains stockwork ore. The replacement ores have the highest grade and will be mined first. The stockwork ores are the lowest grade of the four zones, but contain the greatest tonnage. A 7,800-ft decline ramp system intersects all four mineralized zones, allowing rubber-tired vehicles to be used. Room and pillar and room and rib mining systems will be employed.

The Kettle mine is approximately 1 mi west of Curlew. The deposit is an epithermal vein and breccia system in the Eocene Sanpoil Volcanics. The underground mine is accessed by a decline ramp system.

The 1,500-ton-day Key mill will serve both the Kettle and Overlook mines and is located near the Overlook mine (Fig. 5). Approximately 90 percent gold recovery is expected at the automated flotation mill, which uses a carbon-in-pulp vat-leach system.

Published reserves for the two mines are 3.9 million tons of ore grading 0.185 oz of gold per ton. It is anticipated that a total of 110,000 oz of gold will be produced annually during the first 2 years, with 85,000 oz of gold being produced each year thereafter for the 7-yr life of the mines.

Production will be resumed at the Gold Mountain mine, formerly known as the Gold Dike mine. Gold Express Corp. has purchased the deposit, which will be operated by the 50 percent joint venture partner N. A. Degerstrom Inc. The company will enlarge the open-pit mine on the ground formerly owned by

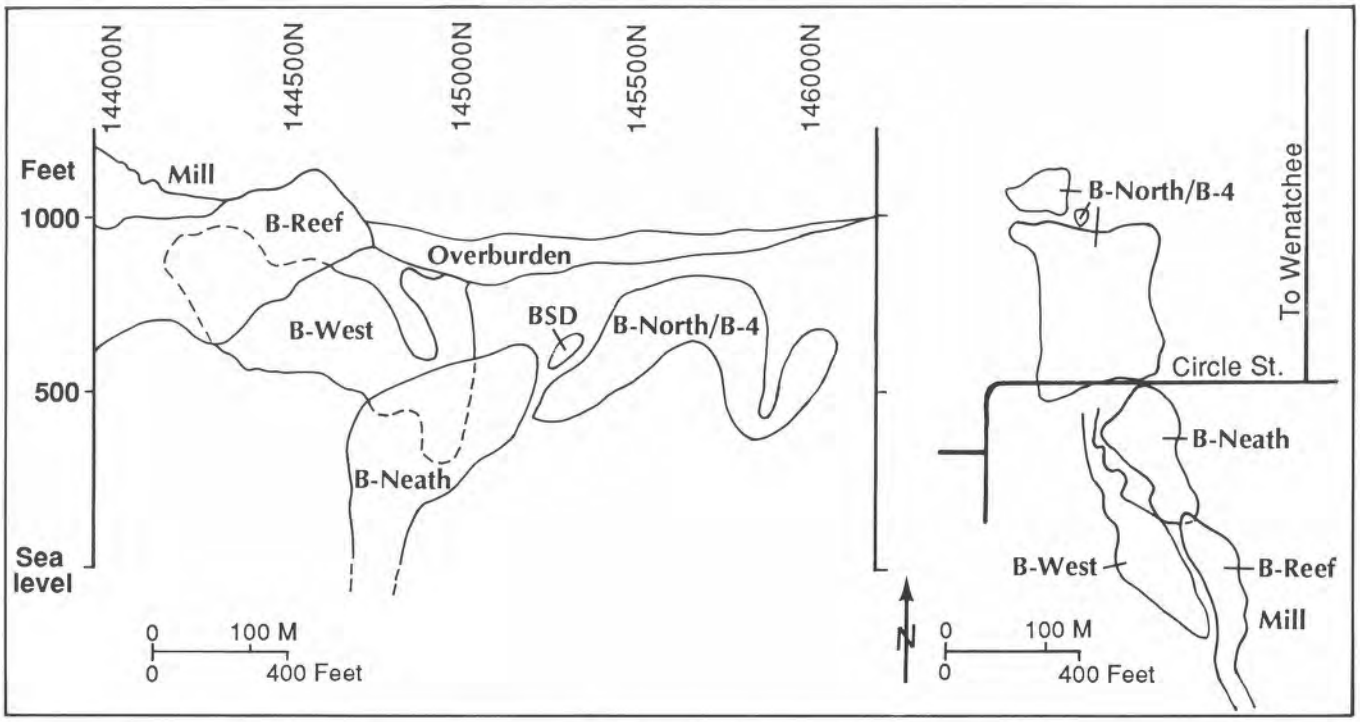

Figure 4. Long section (viewed to the southwest, left) and plan view (right) of the orebodies in the Cannon mine. Dashed lines indicate orebody projection. Modified from Asamera Minerals, Inc. annual report, 1988.

Vulcan Mountain, Inc., and on the adjacent Gold Hill property held by Sundance Mining and Development. A new heap leach pad is being permitted to accommodate the increased production.

The Gold Mountain deposit is a stockwork in alkalic intrusive rocks of probable Jurassic age (K. L. Stoffel, DGER, written commun., 1989); gold is associated with pyrite. Reserves at the property are reported to be 500,000 tons grading 0.065 oz of gold per ton. Approximately 25,000 to 30,000 oz of gold will be recovered from the deposit over the 2-yr life of the project. United States Borax & Chemical Corp. drilled several core holes at the property in 1988, but dropped its option late in that year.

Skamania County

In September, production began at the Wind River mine in Skamania County. As of late November, 7 tons of concentrate were reported to have been produced from the 500-ton-per-day mill at the site. The mine, operated by Wind River Mining Co., is in an epithermal quartz-vein deposit in volcanic rocks of probable Miocene age.

Stevens County

Lead and zinc were mined from the Shoemaker mine by Cordilleran Development, Inc., during part of the year, and ore was shipped to a mill near Greenwood, B.C., to be concentrated. Mining has ceased and will not resume until a mill can be found closer to the property or can be built at the site.

Exploration

More than 80 companies and individuals explored for metals in Washington during 1989. Gold, particularly in skarn and replacement deposits and in epithermal deposits in Eocene rocks in northeastern Washington, was the major target of this effort (Fig. 2a, b; Table 1). Rising and stable base-metal prices have resulted in increased exploration for copper, lead, and zinc throughout the state. Lead and zinc deposits in the Metaline Formation in Stevens and Pend Oreille Counties and copper porphyry deposits were afforded renewed attention.

Chelan County

Asamera Minerals has been actively exploring for precious metals in epithermally mineralized rock in silicified sandstones in the Wenatchee Heights area, 3.5 mi southeast of the Cannon mine. In excess of 100 diamond drill holes have been completed in the last 3 years in the area. Drilling was concentrated in the Matthews target area where encouraging drill intercepts had been encountered. The company reported (Asamera Minerals Inc., 1989 2nd quarter report) a high-grade drill hole (Mat-20) intersection of 65 ft grading 0.646 oz of gold per ton between 1,735 and 1,800 ft; other drill holes in the immediate area revealed gold mineralization in silicified arkosic sandstone.

Asamera has staked mining claims and selected drill targets at several sites north of the Wenatchee River. The company has also been issued a mineral lease by the U.S. Forest Service on acquired land north of Cashmere. This area, which contains outcropping Eocene arkosic sandstone, has not been a target of recent active exploration.

United States Borax & Chemical Corp. drilled three core holes at its Skyline property above Wenatchee off Skyline Drive. The prospect, 1.2 mi northwest of the Cannon mine, is along the projected trend of mineralization in the Cannon mine and the now-inactive Golden King mine.

Figure 5. Aerial view of the Key mill complex near the Overlook mine. The 1,500-ton-per-day mill shown here under construction was completed in December. (Photograph courtesy of Echo Bay Exploration Inc.)

Elsewhere in the county, Montana d'Oro, Inc. undertook minor trenching at the Blewett property in the Blewett Mining District. The property consists of quartz-calcite-talc-sulfide veins in serpentinized ultrabasic rock. Raven Hill Mining Co. did trenching and other exploration on its lode and placer claims. Robert Wood continued to explore his claims in the Miners Basin area.

Holden Village has leased the claims to the tailings at the Holden mine to Red Butte Resources Ltd. The claims were previously held by Sunshine Valley Min-

Figure 6. Reverse circulation drill at the Buckhorn Mountain project. Crown Resources Corp. drilled more than 150 rotary holes at the property in 1989. (Photograph by Raymond Lasmanis)

erals, Inc. and were given to the retreat owned by the Lutheran church in 1985. The U.S. Forest Service is presently in the process of reclaiming tailings from the mine through revegetation; rip-rap will also be placed along Railroad Creek, which drains into Lake Chelan. The Holden mine is a base and precious metal-bearing massive sulfide deposit in high-grade metamorphic rocks that produced 600,000 oz of gold, 212 million lb of copper, 40 million lb of zinc, and 2 million oz of silver from 10 million short tons of ore from 1938 to 1957 (Nold, 1983).

Ferry County

Epithermal precious metal deposits in the Eocene Sanpoil Volcanics have been an active exploration target of several companies. (See fig. 3 in Joseph, 1989.) Hecla Mining Co. continues to explore the Golden Eagle property, 3,000 ft northwest of their Republic Unit. This is a low-grade, bulk tonnage target. The company also continues to explore other properties in the Republic area. Hecla acquired the lease for county-owned mineral rights under the town of Republic in 1988.

Rotary and core drilling was done at the South Penn deposit, which is a joint venture between Crown Resources Corp. and Sutton Resources Inc. Minor core drilling was also continued by the two joint venture partners at their Seattle mine.

Drilling and trenching were undertaken by Boise Cascade Corp. south of State Route 20 immediately west of the town of Republic.

Cambior USA, Inc., entered into a joint venture agreement with Crown Resources Corp. at the 4,400-acre Mount Elizabeth property. Cambior can earn a 51 percent interest in the property through exploration expenditures. The companies are exploring for epithermal vein mineralization in the Sanpoil Volcanics. The post-mineralization Klondike Mountain Formation crops out on the property, which lies between the Republic Mining District near the town of Republic and the Kettle mine.

The Valley mine, owned by High Country Mining and Exploration, was idle in 1989. Tanqueray Resources Ltd. explored the low-angle, calcite and banded-chalcedony epithermal vein at the property in 1988.

North of the Kettle River, Newmont Exploration Ltd. holds a lease option on private property at which several holes were drilled. The company also holds the Gib mining claims, which were staked in late 1988, near Gibraltar Mountain, southeast of Republic. Epithermal precious metal mineralization in Eocene volcanic rocks is the target at both properties.

Two core drill holes were drilled by United States Borax & Chemical Corp. at the Empire Creek property held by Kettle River Resources Ltd. The property has since been dropped by Borax. Borax continued to hold the lease-option on the Wheaton Ranch property, although no exploration was done at the property in 1989. The company drilled eight core holes, totaling 4,000 ft, during the winter of 1988-89 at the Lone Star mine. Borax has a lease option agreement with Wilbur Hallauer for that massive sulfide deposit, which straddles the international border.

Skarn and replacement deposits were the target of several companies. Atlas Mine & Mill Supply, Inc., explored for gold in the tungsten-copper-magnetite-bearing skarn in the Kelly Camp area. Echo Bay Exploration Inc. explored Permian metasedimentary rocks for precious metal-bearing replacement deposits northeast of Republic. Drilling was done at several sites and property acquisitions negotiated.

Inland Gold and Silver Corp. and Pegasus Gold Corp., in joint venture with N. A. Degerstrom, Inc., have explored the Leland/Kellogg property, which is west and north of the Overlook mine currently being developed by Echo Bay Exploration. The joint venture partners conducted airborne and ground geophysics, geochemical sampling, and geological mapping in the search for precious metals. Diamond drilling was also employed to explore for both replacement and epithermal mineralization.

Morning Star Mines, Inc., continued underground sampling at the Morning Star mine. In addition, in excess of 800 ft of surface core drilling was accomplished. The property consists of quartz and calcite veins with free gold, chalcopyrite, and pyrite in Permian and Triassic greenstones that strike parallel to adjacent serpentine (Tschauder, 1989).

Cyprus Minerals Co. continued exploration in the Lone Ranch Creek area.

Johnson Explosives undertook surface trenching and collected geochemical samples at the Irish claims. The property is in a nearly west-trending alkalic intrusive body, similar to that which hosts the Gold Mountain deposit.

Silver Eagle Resources Ltd. reported acquiring five claim blocks in the Republic graben area (*The Miners News*, Sept. 1989). The company is seeking precious metals in epithermal and replacement deposits.

At the eastern edge of the Toroda Creek graben, Westmont Mining Co. drilled several core holes seeking precious metals in Eocene volcanic rocks near Manhattan Mountain.

King County

Weyerhaeuser Company continued to explore the White River property on company-owned land east of Enumclaw. The company also acquired the State lease held by Cannon Minerals on an adjacent property of the same name. Surface quartz-alunite alteration of Miocene volcanic rocks is present at this epithermal target.

Other exploration in the county included work by Joel Ray and Royal Schidler, who explored for base and precious metals veins in shear zones in granitic rocks at the Lennox Group claims in the North Fork of the Snoqualmie River. Mark Wagner continued exploration in Coney Basin near Skykomish.

Kittitas County

MMC Resources Corp. explored the potential for renewed gold placer mining in the historic Liberty Mining District. Samples obtained by a backhoe were panned, and reverse circulation drilling was initiated in late 1989 to provide additional samples.

Okanogan County

Crown Resources Corp. has announced encouraging drill results from its Buckhorn Mountain property east of Chesaw in the northeastern part of the county. The company holds a large land position in the Myers Creek Mining District, which includes the Magnetite and the Gold Axe mines, which were last mined in 1915 (Moen, 1980). The company optioned the Crystal Butte mine, which is held by Orvana Resources Corp. and Keystone Gold, Inc. In excess of 4,000 acres of land were acquired west of Chesaw for further exploration and are part of the Strawberry Lake property.

The gold skarn at the Buckhorn Mountain property is hosted by limestone of probable Permian age and by rock of igneous affinity. Gold mineralization with magnetite and sulfides is present in a lower zone and proximal to the possible causative pluton, and with garnet, bismuthinite, and pyrrhotite in an upper zone and distal from the magnetite zone. Crown has identified several areas of interest on the basis of geochemical sampling, geophysics, and drilling. In 1989 the company drilled more than 150 rotary, reverse circulation drill holes, which averaged 350 to 400 ft in depth for a total of 50,000 ft (Fig. 6). Fifteen core drill holes totaling 5,000 feet were also drilled at the property. A drill-indicated mineral inventory of 4.3 million tons of rock grading 0.125 oz of gold per ton was reported by the company (Crown Resources Corp., 1989 3rd quarter report).

Several companies explored for precious metals in Eocene volcanic rocks in the Toroda Creek graben. Crown Resources Corp. entered into a joint venture with Cambior USA, Inc., at the Ida property. Cambior can earn a 51 percent interest in the property through exploration expenditures. The epithermal, gold and silver prospect is hosted by the Sanpoil Volcanics. Westmont Mining Co. had drilled at the Bodie mine in 1988, but has since dropped its option on the property, which is held by Crown Resources. United States Borax & Chemical Corp. drilled five shallow core holes at its Toroda project, also near Manhattan Mountain.

Several companies investigated copper porphyry deposits in the county. Vanderbilt Gold Corp. in joint venture with Brenda Inc. has entered into a lease option agreement with Quintana Minerals Corp. to explore 334 unpatented mining claims near Mazama. Eighty-two drill holes have already been drilled at the low-grade porphyry copper deposit in the Cretaceous Fawn Peak stock. Drill-indicated reserves of 149 million tons grading 0.36 percent copper and 0.01 percent molybdenum have been reported. Vanderbilt will decide by the spring of 1990 whether there are sufficient reserves to proceed with the lengthy permitting process required before beginning production at the planned open-pit mine. Elsewhere, Wilbur Hallauer drilled a 240-ft core hole at the Starr Molybdenum property on Aeneas Mountain, 10 mi west of Tonasket. Three core holes were also drilled by Hallauer at the Kelsey property. The Kelsey is a low-grade porphyry copper and molybdenum deposit with an associated mineralized skarn (Roper, 1973).

ECM Inc. continued to seek partners to explore and develop the Alder mine. This massive sulfide deposit in the Lower Cretaceous Buck Mountain Formation was last mined in the 1950s.

Northwest Minerals Inc. explored several precious metals targets in the county. Disseminated sulfides and precious metals in a shear zone associated with the Smith Canyon fault were the target of exploration west of Twisp. The company explored gold-bearing fault-controlled veins at the Okanogan Highgrade property near Tonasket. Soil and rock geochemical analyses were used to test the Red Shirt prospect in gabbros along the Pasayten fault.

The Turtle Lake property held by Baum Minerals was explored and drilled by Newmont Exploration Ltd.; the lease was subsequently dropped. The property is a strata-bound, volcanic-rock-hosted deposit.

Pend Oreille County

Resource Finance Inc. (RFI) has been actively exploring the Pend Oreille mine with the goal of reopening the zinc producer in light of rising zinc prices. The company has acquired a lease option from Pintlar Corp., a wholly owned subsidiary of Gulf Resources Corp. The mine was last active in 1977, when it was closed because of a strike at the now-defunct Bunker Hill smelter in Kellogg, Idaho, which was owned by Gulf Resources.

RFI has undertaken a major effort to dewater the cavernous underground mine; the pumps were shut off in mid-1986. Evaluating the reserves in the mine's Yellowhead zone has been the object of deep surface and underground drilling. The strata-bound ores in the Yellowhead zone are in the dolomite unit of the Metaline Formation, approximately 1,000 ft below the breccias of the Josephine zone that is at the contact of the Metaline Formation with the Ledbetter Slate (Dings and Whitebread, 1965). The Josephine zone was the main target of previous mining at the site. Published drill-indicated reserves are 3 million tons of ore grading 9.8 percent zinc and 1.9 percent lead over a thickness of 10.8 feet. A decision on the future of the project will be made early in 1990. The company estimates that $30 million will be required to open the facility *(The Northern Miner*, Jan. 8, 1990).

Raven Hill Mining Co. has explored two properties in the county. Surface exploration continued at the Cooks Copper property, where silver and copper mineralization is the target. Conduit and fans for ventilation were installed, and dewatering began at the company's Glass Mountain mine. Surface trenching and core drilling were also undertaken at the property in exploring for base and precious metals in the Precambrian Prichard Formation.

Skagit County

Cannon Minerals holds several mineral properties in the county. Mining claims were located and exploration conducted at the Telstar property northwest of Darrington. The property contains altered serpentine and disseminated sulfides in intrusive rock. Geological mapping and surface-rock geochemical sampling were used to test the Skagit Copper property south of Cultus Mountain. The property is on a massive sulfide body in Jurassic ultrabasic rocks.

Skamania County

Drilling was undertaken by Plexus Resources Corp. at the Silver Star property 36 mi northeast of Vancouver. The company reports published reserves at the porphyry deposit as 2.9 million tons grading 1.62 percent copper, 0.035 percent molybdenum, and 0.35 oz of silver per ton. The company undertook geological mapping and geophysical exploration at the property; a feasibility study was done by a third party.

Snohomish County

Island-Arc Resources Corp. conducted detailed geological mapping and geophysical exploration at the Lockwood property in the Sultan River drainage. The property contains a gold-bearing massive sulfide deposit in Late Jurassic to Cretaceous sedimentary and volcanic rocks.

Cannon Minerals explored the Tri-lux claims southwest of Silverton by geological mapping and geochemical sampling. The base and precious metals deposit is associated with ribbon cherts of Jurassic age.

Stevens County

Orient Mining Company, a joint venture between Boise Cascade Corp. and Pathfinder Gold Corp., explored for precious metals in Eocene volcanic rocks at the First Thought mine. Reverse circulation drilling, geologic mapping, and investigation of the old underground workings at the mine were accomplished at this epithermal target.

Newmont Exploration Ltd. drilled several holes near the old Kettle River mine seeking precious metals. The company has staked claims in the area and holds a lease-option from Mike Powers on his mining claims in the area.

Boise Cascade Corp. has explored for gold and base metals at several properties. Reverse circulation drilling was done at the McNally-Freedom property, which is in the Jurassic Rossland Group and is held by Western Land Resources. Geological mapping and geochemical sampling were also undertaken at the Gold Hill property near Kettle Falls, where sulfide veins and stockwork cut a Tertiary dike that intrudes Permian metasedimentary rocks.

Vanhorn and Watson Mining Co. conducted core drilling and sampling at the Copper Penny and Gold Nugget properties. These prospects are in the Rossland Group.

Formation Capital Corp. investigated the gold potential of the magnetite-ludwigite-bearing skarn at the Reed Iron deposit east of Fruitland. Also near Fruitland, overburden was removed and new mineralization discovered by Blue Silver Mining at the H and B (Aichen Bee) mine.

Rising lead and zinc prices have resulted in the re-evaluation of the potential of several base-metal mineral deposits in Stevens County. Equinox Resources Ltd. has negotiated an option to purchase the Van Stone mine held by Callahan Mining Corp., United States Borax & Chemical Corp., and Brinco Ltd. The company has completed a pre-feasibility study examining the potential of developing an underground mine. Equinox has acquired funding from Cominco Ltd. for a feasibility study under a convertible debenture agreement; Cominco will also have a priority right to future concentrate purchases from the mine, which is 25 mi south of the Trail (B.C.) smelter owned by Cominco. The work planned includes 5,000-10,000 ft of underground drilling, detailed mine design, environmental studies, and permitting. Underground minable reserves are reported to be 1.6 million tons grading 6.5 percent zinc and 1.5 percent lead. The property includes a 1,100 ton/day mill and other infrastructure that were last employed when Asarco Inc. ran an open pit operation at the property from 1950 to 1971.

Yellowhead type mineralization is present in dolomite in the middle unit of the Metaline Formation; the deposit is in the contact metamorphic halo of the Cretaceous Spirit pluton. Equinox also has options on the Advance, HC, and Iroquois mines from Mines Management, Inc.

Other companies exploring for base and precious metals in the county include Leadpoint Consolidated Mines Co., who did surface trenching on their properties in the Northport Mining District. Silver King Mines continued exploration at the Silver King mine.

Whatcom County

FMC Gold Corp. obtained an option to evaluate the potential of the Excelsior mine held by Steelhead Gold Inc. FMC dropped the option after extending the original agreement 60 days (*The Northern Miner,* Jan. 8, 1990). The company conducted a feasibility study of the property, and drilled six core holes outside the area of known mineralization, and has collected surface samples. The gold deposit, last mined in 1916, is contained in a series of sedimentary and volcanic rocks of the Jurassic Wells Formation.

Cannon Minerals staked claims and conducted geological mapping and geochemical sampling at the Loomis Mountain property northwest of Concrete. Disseminated and massive sulfides are present in intermediate volcanic rocks in the Cultus Formation.

In the eastern part of the county, Seattle-St. Louis Mining Co. continued exploration of the vein system at the Minnesota mine. Surface and underground sampling was continued by Western Gold Mining, Inc. at the New Light mine in the Slate Creek Mining District.

Statewide Exploration

Meridian Gold Co. explored for precious metals in a variety of mineralized environments throughout the state, including on company-owned lands. Noranda Exploration, Inc., explored for metals in porphyry, skarn, epithermal, and massive sulfide deposits. Other companies exploring for precious metals include FMC Gold Co., Freeport McMoran Gold Co., Gold Fields Mining Corp., Battle Mountain Exploration Co., Pegasus Gold Corp., Phelps Dodge Corp., and American Copper and Nickel Co., Inc. Other companies also exploring for metals in the state include Cominco American Resources Inc., and M. D. Regan and Associates.

INDUSTRIAL MINERALS

Development and Exploration

Twenty companies produced industrial minerals from 29 sites in Washington during 1989 (Table 3). Industrial minerals, including sand and gravel, and value-added products produced from industrial minerals accounted for more than three quarters of the value of the mineral industry in Washington (Fig. 1). Dolomite had the highest value because of the value added to that mineral through the production of magnesium metal by Northwest Alloys, Inc. A majority of the limestone mined was used in the manufacture of portland cement. In excess of 500,000 tons of silica were mined by four operations for uses that included plate glass, colored glass bottles, and cement. Clay was produced by four companies for use in cement and structural bricks. Diatomite was produced by one company, and two companies generated products from olivine mined in the state.

Thirteen companies produce processed calcium carbonate products (Table 4). The majority of these companies are in the Puget Sound area and use limestone from Texada Island in southwestern British Columbia, which is barged to the plant sites. Precipitated calcium carbonate (PCC) is produced from a free-standing plant in Tacoma operated by Tacoma Lime Company, a division of Continental Lime, Inc. At the Weyerhaueser Paper Co. paper plant in Longview effluent from the lime kilns at that plant is utilized. Additional PCC plants at paper plants will likely come on line in the future. Lime is produced by Tacoma Lime and as a byproduct of the production of magnesium from dolomite by Northwest Alloys in Stevens County. Ground and crushed limestone and dolomite are also mined and produced by several companies in the state.

Portland cement is produced by two companies, Lafarge Corp. in Metaline Falls and Ideal Basic Industries, Inc. in Seattle., while Ash Grove Cement West, Inc. is planning to construct a state-of-the-art portland cement plant on tidewater in Seattle (Table 4). The U.S. Bureau of Mines estimates that 600,000 tons of portland cement worth $29.6 million were produced in the state in 1989. This represents a 21 percent decrease in production and value from 1988, and a nearly 50 percent decrease in value and production from 1987 when the Columbia Northwest Cement Corp. plant and quarry in Whatcom County were still in operation.

Washington is the ninth largest producer of sand and gravel in the nation. An estimated 33 million short tons, worth $112 million, were mined in 1989. A majority of the production comes from the aggregate-rich, ice-margin deposits in the Puget Sound region and from late Wisconsin Lake Missoula flood deposits in Spokane County. Approximately 900 pits and quarries are permitted by the state. The Lone Star Northwest facility in Steilacoom is the eighth largest sand and gravel operation in the U.S. and the only plant on the list of the top ten producers in 1988 not located in California.

Clallam County

Ideal Basic Industries, Inc., extracted 100,000 tons of clay from the Twin River quarry. The clay is barged to its Seattle plant, where it is used in the manufacture of portland cement. The clay is mined from weathered mudstones of the Twin River Group of Oligocene age.

Grant County

Witco Corp. continues to be the sole producer of diatomite in the state. The bulk of the production was derived from the pit in section 7, 7 mi south of Quincy. A new pit was permitted in the Frenchman Hills, but it had not gone into production as of late

Table 3. Properties producing industrial minerals in 1989

Commodity	Property	Owner and/or Operator	County	Production and development
Clay	Twin River quarry	Ideal Basic Industries, Inc.	Clallam	Mined 100,000 tons
Clay	Mica pit	Interpace Industries Inc.	Spokane	Mined 10,000 tons
Clay	Pottratz pit	Interpace Industries Inc.	Spokane	Mined 24,000 tons
Clay	Sec. 31 pit	Mutual Materials Co.	King	Mined 90,000yd^3
Clay	Elk pit	Mutual Materials Co.	King	Mined 5,000 yd^3
Clay	Clay City pit	Mutual Materials Co.	Pierce	Mined 8,000 yd^3
Clay	Bucoda pit	Mutual Materials Co.	Thurston	Mined 8,000 yd^3
Clay	Lande pit	North American Refractories Co.	Stevens	Hauled 2,000 tons from stockpile
Clay	Blum pit	North American Refractories Co.	King	Hauled 3,500 tons from stockpile
Diatomite	Sec. 17 pit	Witco Corp.	Grant	Hauled 15,000 tons
Diatomite	Sec. 7 pit	Witco Corp.	Grant	Mined 150,000 tons
Diatomite	Sec. 8 pit	Witco Corp.	Grant	Hauled 15,000 tons
Dolomite	Gehrke mine	Allied Minerals, Inc.	Stevens	Mining
Dolomite	Several quarries	Nanome Aggregates, Inc.	Stevens	Mining and processing
Dolomite	Addy Dolomite quarry	Northwest Alloys,Inc.	Stevens	Mined 700,000 tons
Dolomite	Brown quarry	Pacific Calcium, Inc.	Okanogan	Mining
Limestone	Silver Lake No. 1	Clauson Lime Co.	Whatcom	Mining
Limestone	Wauconda quarry	Columbia River Carbonates	Okanogan	Mined 60,000 tons
Limestone	Champane Placer	Lafarge Corp.	Pend Oreille	Acquired property; mined 250,000 tons
Limestone	Sherve quarry	Northport Limestone Co.(subsidary of Hemphill Brothers, Inc.)	Stevens	Mined 40,000 tons
Limestone	Tonasket Limestone quarry	Pacific Calcium, Inc.	Okanogan	Mining and milling
Limestone	Kendall quarry	Tilbury Cement Co.	Whatcom	Mined 9,000 tons
Olivine	AIMCOR Olivine	Applied Industrial Materials Corp.	Skagit	Milling olivine
Olivine	Swen Larsen quarry	Olivine Corp.	Whatcom	Mined 80,000 tons
Quartz crystals	Jackson, Robert		King	Mining
Silica	Ravensdale pit	L-Bar Products, Inc.	King	Mined 100,000 tons
Silica	Lane Mountain quarry	Lane Mountain Silica Co. (subsidiary of Hemphill Brothers, Inc.)	Stevens	Mined 300,000 tons
Silica	Blue Creek mine	Northwest Alloys, Inc.	Stevens	Mined 12,000 tons
Silica	Superior quarry	Ash Grove Cement West, Inc.	King	Mined 115,000 tons

1989. The diatomite is mined from lakebed deposits interstratified with flows of the Columbia River Basalt Group.

Testing of the non-swelling bentonite clay from the Rock Top property for specific market applications was done by Basic Resources Corp. The deposit consists of clay in sedimentary layers interbedded with flows of the Columbia River Basalt Group.

King County

L-Bar Products, Inc., mined 100,000 tons of silica sand at its Ravensdale pit. The sand is mined, washed, screened, and dried to produce silica for colored bottles and cement. The sand is mined from the Eocene Puget Group.

Ash Grove Cement West, Inc. mined, crushed, and screened 115,000 tons of silica at its Superior quarry. The mine, which began operation in 1987, supplies silica primarily for the production of portland cement. However, uses also include aggregate,

Table 4. Selected producers of processed calcium carbonate products, 1989

Commodity	Owner and/or operator	County
portland cement	Ideal Basic Industries, Inc.	King
portland cement	Lafarge Corp.	Pend Oreille
lime	Tacoma Lime, a division of Continental Lime, Inc.	Pierce
lime	Northwest Alloys, Inc.	Stevens
precipitated calcium carbonate	Tacoma Lime, a division of Continental Lime, Inc./ G. K. Carbonates	Pierce
precipitated calcium carbonate	Pfizer Corp.	Cowlitz
calcium chloride	Tacoma Chemical Co.	Pierce
calcium chloride	Occidental Chemical Corp.	Pierce
ground limestone	J. A. Jack and Sons, Inc. (Hemphill Brothers, Inc.)	King
ground limestone	Columbia River Carbonates	Cowlitz
ground and crushed dolomite	Allied Minerals Inc.	Stevens
ground and crushed limestone	Nanome Aggregates, Inc.	Stevens
crushed dolomite and limestone	Pacific Calcium, Inc.	Okanogan
crushed dolomite	Northwest Marble Products Co.	Stevens

decorative stone, sand blast sand, and roofing granules. The low-alkaline, microcrystalline quartz deposit consists of altered and silicified Miocene volcanic rock.

Mutual Materials Co. was the largest clay producer in the state. The company mined shale from the Eocene Puget Group from the section 31 pit west of Issaquah and, during the first part of the year, from the Elk pit. The clay is used to manufacture structural brick. North American Refractories Co. hauled clay from the stockpile at the Blum pit near Preston.

Lincoln County

Blue Silver Mining reported setting up a portable crusher and screen at the Crystal City mine located near Miles in the northern part of the county. The white rock is reported to contain 31.5 percent CaO and 21 percent MgO.

Okanogan County

Columbia River Carbonates, a limited partnership of Bleek Management, Inc. and Genstar Carbonates Inc., mined and crushed 60,000 tons of high-calcium carbonate at its Wauconda quarry. The white marble is sent by rail to the Columbia River Carbonates plant at Woodland, near Vancouver, where it is ground to produce several grades of fine and ultrafine powder and slurry.

Pacific Calcium, Inc. continues to mine limestone from the Tonasket Limestone quarry and dolomite from the Brown quarry near Riverside. The carbonates are crushed in Tonasket and sold for poultry feed and soil amendment and as a lawn-care product.

Pend Oreille County

The Lehigh Portland Cement Co. plant in Metaline Falls and three cement terminals in Washington and Montana were purchased by Lafarge Corp. in mid-1989 (cover photograph). The dry-process facility produces type 1-2 and type 3 portland cement. This is the only operation in the state to produce portland cement from rock that is mined in Washington. Approximately 250,000 tons of limestone are quarried from the Cambrian-Ordovician Metaline Formation annually.

Southern Talc Co., as the operator in joint venture with First Miss Gold Inc., continued exploration at their Totem Talc property. Bulk sampling was done at the property to obtain samples for mill production tests. The company has submitted plans to the U.S. Forest Service for a possible commercial operation at the site. The deposit is in a shear zone in the Precambrian Z Monk Formation. Exploration for talc has been extended to other similar properties in the Monk Formation in the County.

Pierce County

Mutual Materials Co. mined 8,000 yd^3 of clay from Miocene rocks at the Clay City pit.

Skagit County

Applied Industrial Materials Corp. (AIMCOR) crushed and screened olivine purchased from a local source. The company produces olivine flour for use as foundry and blast sands.

Spokane County

Interpace Industries, Inc., continued mining clay from the Pottratz pit and white plastic clay from the Mica pit. A drilling program was used to target future

reserves. Structural bricks produced at the plant, including light-colored bricks, are sold nationwide.

Stevens County

Northwest Alloys, Inc., a wholly owned subsidiary of Aluminum Co. of America, mined approximately 700,000 tons of material from the Addy Dolomite quarry. The value of production from Northwest Alloys' mine and plant complex at Addy is the highest of any operation in the state because of the value added to the dolomite by the production of magnesium metal at the plant. The company is one of only three producers of magnesium metal in the U.S. and produces 15-20 percent of the world capacity for the metal. The plant, which operated at full capacity in 1989, is the largest employer in Stevens County.

Northwest Alloys shut down its silicon furnaces in November because of depressed prices for 75 percent ferrosilicon. The furnaces, which had been idle since 1985, had resumed operation in April of 1988, when prices of the silicon rose because of increased demand from the steel industry. Ferrosilicon is used in the plant's silicothermic process (whereby magnesia in calcined dolomite is reduced by silicon). Approximately 12,000 tons of quartzite from the Addy Quartzite were mined from the Blue Creek mine near Addy before the production of ferrosilicon ceased.

L-Bar Products, Inc. continues to produce fertilizer from magnesium sludge from the Northwest Alloys plant. The fertilizer is marketed as "Ag Mag K".

Allied Minerals Inc. was acquired in 1988 by an employee-owner group. The company extracts dolomite from the Late Proterozoic Stensgar Dolomite at the Gehrke mine. Exploration and mine development were undertaken at the Smith/Madsen mine. Allied operates a grinding and bagging plant near Springdale. The dolomite is used as a filler in fertilizer and as decorative garden rock.

White and colored dolomite was mined and processed by several companies, including Nanome Aggregates, Inc. Chewelah Eagle Mining Co. improved the access road to its quarry near Eagle Mountain, from which approximately 1,600 tons of dolomite were extracted.

Hemphill Brothers, Inc. continues to operate two industrial mineral properties in the county. Lane Mountain Silica Co., the largest silica producer in the state, produced 230,000 tons of high-grade silica from a friable area of Addy Quartzite. Northport Limestone Co. mined, crushed, and screened 40,000 tons of metallurgical-grade limestone from the Sherve quarry east of the Columbia River. The limestone is sold for flux to the Cominco Ltd. smelter in Trail, B.C.

North American Refractories Co. hauled clay from the stockpile at the Lande pit northeast of Deer Park.

Thurston County

Mutual Materials Co. mined 8,000 yd^3 of clay from the Bucoda pit, in Eocene marine and nonmarine sediments. The clay is used for structural brick.

Whatcom County

Olivine Corp. continues to mine olivine from the Swen Larsen quarry. The company mined 80,000 tons of fresh, unaltered olivine from the Jurassic Twin Sisters dunite. The company uses the stone in the fabrication of modular olivine refractory slabs used in the waste incinerator pioneered by Olivine Corp. Olivine from the quarry is also sold to AIMCOR.

Clauson Lime Co. continues to extract fossiliferous, Early Pennsylvanian limestone (Danner, 1966) from the Silver Lake Deposit No 1 near Maple Falls. The stone is used for pulp rock and aggregate.

Tilbury Cement Co. of Delta, B.C., mined a minor amount of limestone and shale from the Kendall quarry. The company purchased the quarry and the cement plant in Bellingham from Columbia Northwest Cement Corp. in 1987, and ceased operation at the quarry. Clinker imported from Canada is being ground at the former cement plant to produce portland cement.

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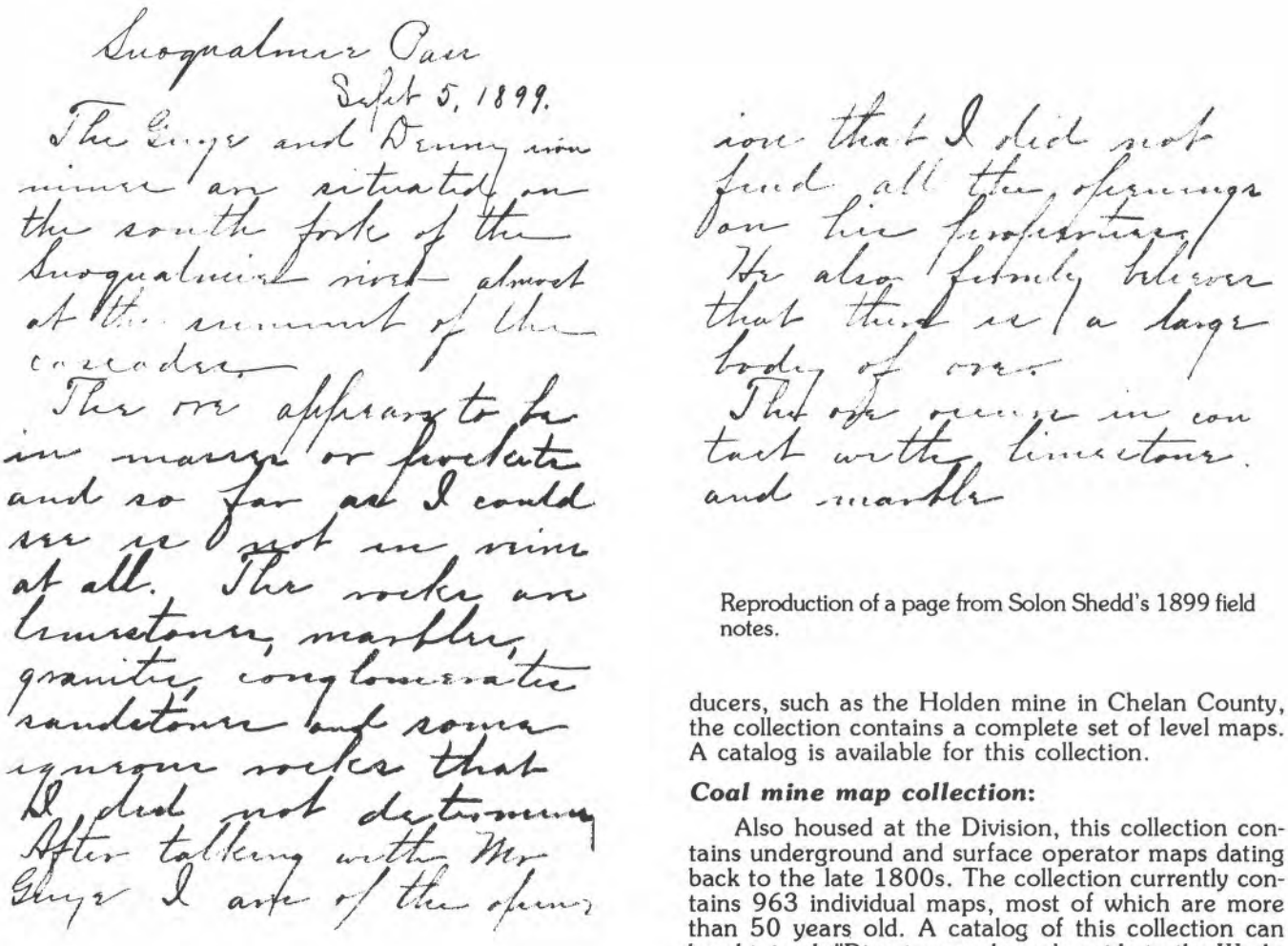

Snoqualmie Pass
Sept 5, 1899.

The Kings and Denny min
mines are situated on
the south fork of the
Snoqualmie river almost
at the summit of the
cascades

The ore appears to be
in masses or pockets
and so far as I could
see as yet no vein
at all. The rocks are
limestones, marbles,
granites, conglomerates
sandstones and some
igneous rocks that
I did not determine
After talking with Mr
Kings I am of the opinion
that I did not
find all the openings
on his properties.
He also firmly believes
that there is a large
body of ore.
That ore occurs in con
tact with limestone.
and marble

Reproduction of a page from Solon Shedd's 1899 field notes.

MINERAL DATA FILES

(Continued from page 2)

are arranged alphabetically, from abrasives to zirconium. The eight file drawers house data on mineral analysis, testing results, marketing, and property information. In researching silica, as an example, these files would provide the first level of data.

Defunct mining companies:

In the file room there are one and a half drawers containing correspondence and corporate listing information for mining companies that were incorporated in the state but have let their charters lapse. The files date back to the 1920s and can be very helpful in answering questions about long-gone mining companies.

Metallic mine map collection:

Located in the Division's library are six flat map file drawers containing 493 individual mine maps. These are arranged in folios by county and then alphabetically by mine name. Most of the plates are actual operator's mine maps. From the largest producers, such as the Holden mine in Chelan County, the collection contains a complete set of level maps. A catalog is available for this collection.

Coal mine map collection:

Also housed at the Division, this collection contains underground and surface operator maps dating back to the late 1800s. The collection currently contains 963 individual maps, most of which are more than 50 years old. A catalog of this collection can be obtained: "Directory and user's guide to the Washington State coal mine map collection", Division of Geology and Earth Resources Open File Report 83-8. (The catalog is free, but please send $1 to cover postage and handling.)

Works Project Administration (WPA) files:

Established in 1934 during the Depression, this project employed 150 geologists and mining engineers to examine mineral deposits and promote their development. Every major mine or prospect was examined and reported on. Metallurgical and marketing studies were conducted. One file drawer in our file room contains detailed and concise reports from 1934 to 1941. These are arranged by investigator as well as by commodity, such as manganese deposits (Olympic Peninsula) or chromite/dunite in the Twin Sisters, Whatcom County. These investigations provided the data for the Division to publish commodity reports such as Bulletins 34 and 39, Reports of Investigations 1, Information Circular 6, and others.

Mines-to-Market Road file:

A program that paralleled the state-wide mineral investigations project of the WPA was established to

encourage mineral production by providing funding for construction of roads to remote sites. The program was established by the legislature in 1939 with an initial $100,000 appropriation. A file drawer in the file room contains mine property reports in support of grant requests. The files are arranged chronologically from 1934 through 1951 and cover such well-known areas as Monte Cristo and Sultan Basin. Appropriations ceased in 1951, and the Mine-to-Market Road Commission was disbanded by the legislature in 1975.

Division field notebooks:

Also as part of the library collection, there are 143 notebooks taking up18 linear feet of shelfspace. The many field books date from 1899 (Solon Shedd) and contain notes on geology, mineral prospects, mines, fossil localities, and other field observations made by Division staff through 1962 and selected materials through the mid-1980s. The books are labelled by county or commodity if a major project was under way to produce a Division publication. Obscure prospect evaluations and maps can be gleaned from this source by a diligent reader.

Our library is open to the public, and space is available to conduct research. To obtain data from the file room, assistance must be requested from Division staff. The files do not contain any proprietary data. A public copy machine is available in the Division's Olympia office. If readers have questions about these files, please contact the State Geologist.

Coal Activity in Washington in 1989

By Henry W. Schasse

There was no exploration activity for coal in Washington for the first time in more than 15 years. The state's two producing coal mines continue to mine at a healthy rate—producing slightly over 5 million tons of coal during 1989.

Pacific Coast Coal Co., Inc., operator of the John Henry No. 1 open-pit coal mine in the Green River Coal District east of Black Diamond (Fig. 1), recently formed a partnership with the Japanese firm, DIA, Inc. (a wholly owned subsidiary of Mitsubishi Corporation). The newly formed company, Pacific Coast Coal Co. (PCCC), will build a 15- tons-per-hour wash plant to beneficiate coal mined from the John Henry No. 1 mine. The plant will be constructed at the mine site and is expected to be completed by October 1990. Since the mine began production in October 1986, PCCC has trucked the raw coal product 2 miles to the Palmer Coking Coal Company's coal wash plant at Black Diamond for beneficiation.

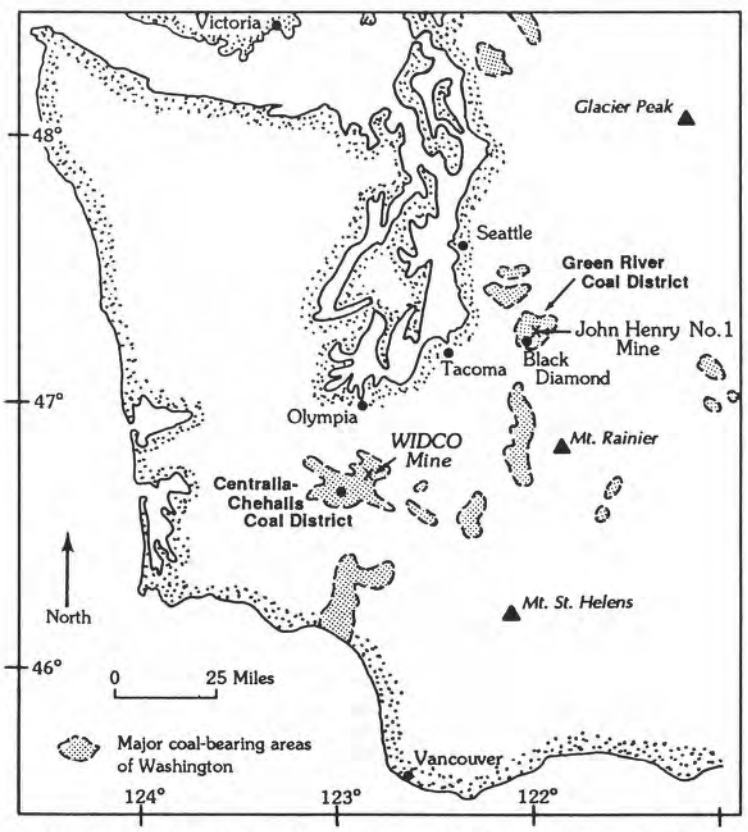

Figure 1. Active coal-producing areas and districts, western Washington.

PCCC mines bituminous coal from four coal seams of the Franklin coal series, which are stratigraphically near the base of the Eocene Puget Group in nonmarine deltaic sediments. The coal seams currently being mined are the Franklin Nos. 7, 8, 9, and 10. During 1989, PCCC produced 115,416 clean tons of coal from the John Henry No. 1, an increase of more that 5,000 tons above the previous year's production. Forty-seven percent of its 1989 production was exported to Japan and Korea to be used at cement plants and for electrical power generation. Thirty-three percent of the 1989 production went to Ideal Cement Co., and 10 percent was used at the Centralia steam plant to bring coal mined at the Washington Irrigation and Development Company (WIDCO) mine within environmental standards. The remainder of the mine's production was used by several public institutions to fuel their heating plants. With its new beneficiation plant coming on line, PCCC hopes to be able to increase its production to 150,000 tons during 1990 and to 200,000 tons during 1991 as it acquires new customers.

WIDCO continues to be the state's largest coal producer. It produced 4,897,890 clean

tons of coal in 1989, approximately 130,000 tons less than it produced during 1988. Production comes from its mine at Centralia (Fig. 1) in the Centralia-Chehalis Coal District where it produces subbituminous coal from five coal seams in the middle part of the Skookumchuck Formation, an upper member of the Eocene Puget Group. WIDCO's sole customer is the Centralia thermo-electric power plant. The mine's annual production since its opening in 1971 has averaged 4.1 million tons per year.

WIDCO's sister company, WIDCO Waste Services (WWS), announced in early October its plans for developing a 50-million-ton regional municipal solid-waste landfill. The future site of the proposed regional landfill would be on 600 acres at the Centralia Coal Mine and would consist of two pits currently in various stages of mining and reclamation and from which WIDCO has mined coal over the past 19 years. The project site is 1 mile south of the town of Bucoda in southern Thurston County (Fig. 2). The proposed landfill would serve areas throughout western Washington. WWS has already completed an initial feasibility study, a preliminary engineering design, and cost estimate. The company is currently in the third phase of its project development schedule, which includes engineering and design, permit acquisition, and responding to bid requests. WWS expects to complete this phase by March 31, 1992. If the project comes to fruition, the landfill would be scheduled to begin operation during the last quarter of 1992.

For additional details of the project, contact Sandra Crews, public/customer relations representative for WWS, P.O. Box 1002, 1611 N. National, Chehalis, WA 98532; (206) 748-9898.

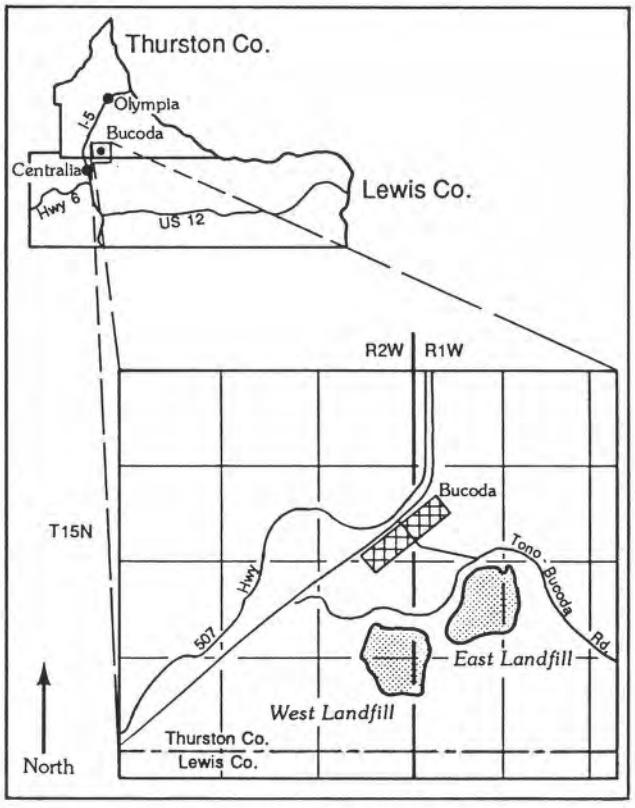

Figure 2. Site of proposed landfills, WIDCO Waste Services.

Pringle Joins Division Staff

Patrick T. Pringle came to work at the Division of Geology and Earth Resources on February 1 as a Geologist 2. Pat earned Bachelors and Masters degrees at the University of Akron and also studied at the University of California, Santa Barbara and the University of Colorado. He worked for the Ohio Environmental Protection Agency and the Akron Public Health Department before moving west. Since 1982, he has been with the U.S. Geological Survey at the Cascades Volcano Observatory in Vancouver, Washington.

Pat specializes in debris flows and geochronology. He has worked on debris flows in the Grand Canyon and lahars from the Cascade volcanoes, most recently deciphering the chronology of the latest eruptive episode at Mount Hood. Pat's duties with the Division will include continued studies of debris flows in the Cascades, as well as support for the State's geologic map and Timber/Fish/Wildlife programs.

Vertical Land Movement in Coastal Washington

By Hugh Shipman

Washington Department of Ecology

Recent interest in the "greenhouse effect" has prompted concern that the rate of sea-level rise might increase significantly in the next several decades as a result of an increase in global atmospheric temperature. This warming is expected because the amount of carbon dioxide (CO_2) in the atmosphere is increasing rapidly. However, the issue is controversial, and little is understood about the complex relationship between global temperature and sea level, nor is much known about existing rates of sea-level change.

Even a small rise in sea level would affect the shorelines of Washington State by increasing the frequency of coastal flooding, accelerating erosion rates, inundating wetland habitats, and contaminating freshwater aquifers. The Department of Ecology, which administers the state's Shoreline Management Act, is interested in these potential impacts, and one of the Agency's tasks during the past year has been to survey the literature on vertical land movements in the state. Vertical land movements are an important component of relative sea-level change, and identification of affected areas and rates is crucial to understanding differences in different parts of the Northwest. The following article is a summary of this literature review.

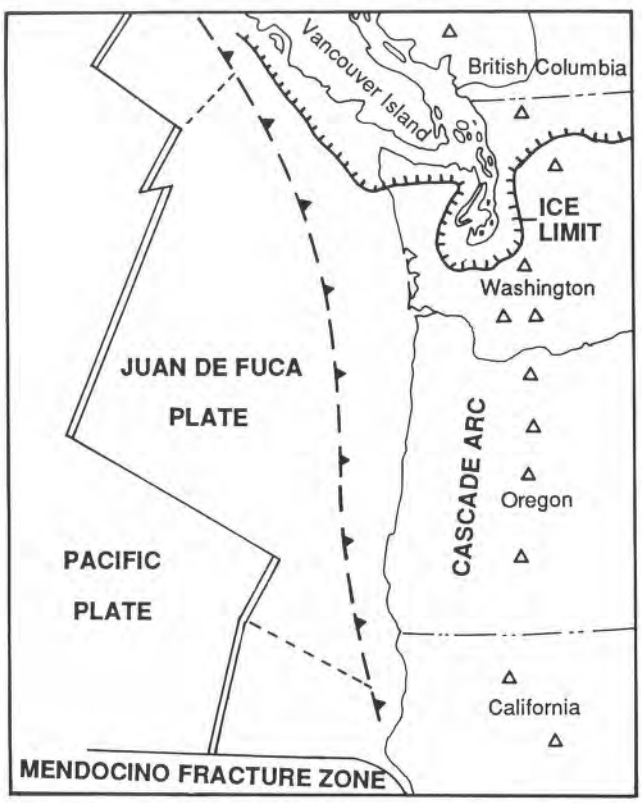

Figure 1. Plate tectonic setting of the Pacific Northwest. Also shown is the maximum extent of Fraser glaciers in western Washington.

Relative sea-level change occurs when the global ocean level rises or falls, or when the local land surface moves up or down. Global, or eustatic, sea level is a function of such diverse factors as oceanic (sea-floor) spreading rates, the volume of the polar ice caps, and barometric pressure. Vertical land movements are a function of plate motion, isostasy, sediment compaction, and local structural deformation. Washington's position on the edge of the Cascadia subduction zone is largely responsible for the present pattern of relative sea-level change, although as recently as about 10,000 yr ago the pattern was dominated by isostatic movements related to loading, and then unloading, by the Cordilleran ice sheet.

The Outer Coast

The coast range and continental shelf of Washington are composed of a Tertiary accretionary wedge and fore-arc basin, and the resulting deformation patterns are complicated (Oldow and others, 1989). Some areas, such as the Olympic Mountains, were uplifted significantly during the late Tertiary, whereas some parts of the central coast and the shelf have subsided (Palmer and Lingley, 1989). The complexity of vertical movements results in part from the oblique nature of Cascadia subduction and in part from the accretionary origins of the continental margin (Fig. 1).

The oldest detailed record of relative sea-level change along the Washington coast comes from upper Pleistocene coastal estuarine deposits and marine terraces. Fluctuations in eustatic sea level between 200,000 and 100,000 yr ago, resulting from the advance and retreat of continental ice sheets, left a sequence of subtidal and intertidal sediments that are now exposed in bluffs around Willapa Bay (Clifton, 1983). The stratigraphy is consistent with fluctuations in global sea level (Bloom and others, 1974) and constrains uplift rates to a maximum of 1 mm/yr in that area.

There are several raised marine terraces along Washington's Pacific coast (Rau, 1973, 1980; Adams, 1984). The best developed of these terraces has been correlated with the 82,000-yr-old Whiskey Run terrace in Oregon (Washington Public Power Supply System, 1986). This terrace surface is about 13 m above sea level near Bay Center on Willapa Bay and ranges from near sea level to an elevation of 50 m along the northern section of the coast (West and McCrumb, 1988). Sea level was at least 20 m below its present level 82,000 yr ago (Bloom and others, 1974), implying uplift rates of 0.3-0.8

mm/yr (West and McCrumb, 1988) along the coast. The differences are, in part, a result of local deformation related to shale diapirism (Rau, 1973).

Sea level dropped about 130 m during the last glacial maximum, and then rose rapidly as the ice melted. Sediments in Grays Harbor record more than 50 m of submergence during the last 10,000 yr, the majority of it occurring prior to 6,000 yr ago (Phipps and Peterson, 1989). The rapid rise of sea level during the early Holocene created and maintained an embayed, tide-dominated coastline. When the rate slowed, the present progradational barrier beaches and dunes began to form (Cooper, 1958; Davis and Clifton, 1987). The progradation of the barrier spits during the last few thousand years may be a function more of sediment flux from the Columbia River than of changes in relative sea level.

The most useful record of late Holocene submergence along the coast has come from marsh stratigraphy. Submergence has resulted in progressive burial of coastal marsh surfaces by as much as 5 m during the last 5,000 yr (Atwater, 1988), but evidence from these coastal sequences suggests that submergence occurred episodically (Atwater, 1987). The stratigraphy indicates that during each episode the marsh surface dropped 0.5 to 2.0 m and subsequently was inundated and then buried by intertidal muds. Atwater attributes these deposits to coseismic subsidence associated with large subduction-zone earthquakes (Atwater, 1987). The recurrence interval averages about 600 years (but the variance is large), with the most recent event believed to have been about 300 yr ago.

There is little other geological evidence of late Holocene sea-level change on the outer coast. Archaeological sites near Neah Bay indicate net uplift over the last several thousand years, but the extremely high erosion rates farther south along the coast (Rau, 1973) are more consistent with a stable or submerging shoreline.

Puget Lowland

The Puget Lowland occupies a broad Tertiary downwarp between the Cascade Range and the Olympic Mountains, but details of its subsidence have been largely obscured by Pleistocene glacial advances. The present surficial geology and geomorphology of the lowland are primarily consequences of the advance and retreat of the Puget lobe of the Cordilleran ice sheet during the Fraser Glaciation around 15,000 yr ago (Fig. 1).

Major vertical movements occurred in the Puget Lowland during the early Holocene as the ice retreated and isostatic equilibrium was restored. The glacier began to retreat from the southern part of the lowland by 13,500 yr ago, and the northern part was free of ice 1,000 yr later (Thorson, 1989). The ice was 1,000 m thick at Seattle and about twice that in the Bellingham area, resulting in depression of the land surface by 50 to 100 m in the Puget Sound region and by more than 200 m in the Fraser Lowland to the north. Isostatic rebound occurred rapidly as the ice retreated; the most rapid rebound was in the north where the ice had been thicker.

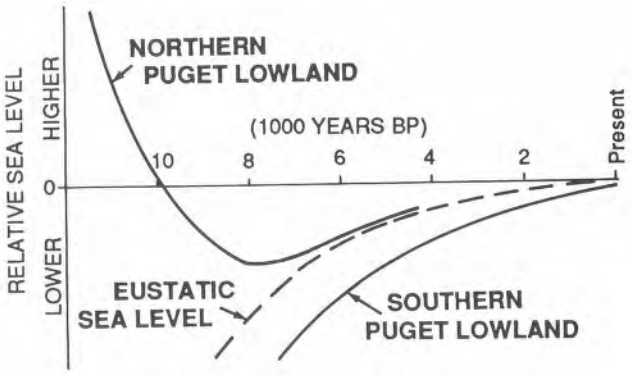

Figure 2. Relative sea level in the Puget Lowland during the Holocene. Curves are highly schematic due to both the uncertainty of the data and the original variability. Sea level in the northern Puget Lowland reflects early Holocene glacial rebound and late Holocene stability. Sea level in the southern Puget Lowland reflects continuing subsidence combined with eustatic sea-level rise.

Also during the Holocene, eustatic sea level rose as the large continental ice sheets melted, so the relative sea-level history at a given location in the Puget Lowland is a complicated function of glacial rebound, eustatic rise, and vertical tectonic land movement (Fig. 2). Terraces and stranded marine deposits in the northern part of the lowland are evidence of higher relative sea level immediately following deglaciation (Easterbrook, 1963; Clague, 1983). Sea level reached its lowest position in the Fraser Lowland, about 10 m below the present level, about 8,000 yr ago (Mathews and others, 1970; Clague, 1983), by which time rebound had essentially ceased (Thorson, 1989).

Stratigraphic sections in peat bogs in the southern Fraser Lowland and on southern Vancouver Island are thin and suggest relatively small amounts (less than 2 m) of submergence during the last 5,000 yr (Mathews and others, 1970; Clague, 1989). Similarly, archaeological sites north of Bellingham and in the San Juan Islands indicate relative stability with respect to sea level during the late Holocene (Grabert and Larsen, 1975; Stein, 1984). However, studies to the south, on Whidbey Island (Heusser, 1960) and on the Hood Canal (Eronen and others, 1987), indicate submergence of 4 to 5 m in the last 5,000 yr.

The subsidence picture in the central Puget Sound area is complicated by a raised marine terrace at Restoration Point on Bainbridge Island. Described by Gower and others (1985) and Bucknam and Barnhard (1989), this wavecut surface has been uplifted at least 7 m in the last 1,700 yr. This feature may be related to a major east-trending fault zone known in the subsurface (Gower and others, 1985). Although a similar raised surface is present at Alki Point in West Seattle, the terrace has not been traced laterally north or south.

Table 1. Sea-level changes at selected Pacific Northwest tide stations. Rates in mm/year; positive values indicate uplift, negative values indicate subsidence. From Lyles and others (1987)

Location	Whole Record		1959-86	
	Rate	Error	Rate	Error
Seattle	-2.0	0.1	-1.9	0.4
Astoria	0.3	0.4	0.9	0.7
Neah Bay	1.1	0.3	1.6	0.6
Friday Harbor	-1.4	0.3	-1.0	0.6

NOTE—Years of record: Seattle 1899-1986; 1983 missing. Astoria 1926-1986; 1925, 1945, 1946, 1984 missing. Neah Bay 1935-1986; 1934, 1951, 1959, 1976, 1978 missing. Friday Harbor 1934-1986; 1962, 1963, 1964 missing.

Modern Measurements

Vertical land movement during the last century can be estimated from tide gauges and releveling surveys. Tide gauges, though a direct measure of relative sea-level change, record a highly variable signal. It takes precise, long-term measurements to detect a change of millimeters in a signal that varies daily by 2 or 3 m due to regular tides and that varies by tens of centimeters over several years simply because of changes in Pacific Ocean circulation patterns.

Changes in relative sea level at each of the four continuously maintained tide stations in the Northwest are shown in Table 1. These data indicate a gradual emergence of the outer coast (Neah Bay and Astoria) and a submergence of the Puget Lowland (Seattle and Friday Harbor) over the last several decades.

Resurveying established benchmarks provides another direct measure of relative vertical land movement, and, if a tide gauge can be included for control, relative sea-level change. Leveling surveys in the Northwest have generally substantiated the overall picture of eastward tilting of western Washington and Oregon (Ando and Balazs, 1979; Reilinger and Adams, 1982). However, the most recent and most comprehensive analysis of leveling and tide data (Holdahl and others, 1989) indicates a more complex picture of vertical movements in Washington (Table 2, Fig. 3).

The eastward tilting of the Oregon and Washington coast ranges has been attributed to strain associated with continuing subduction of the Juan de Fuca Plate. (See, for example, Ando and Balazs, 1979.) The complexities that appear in the more detailed analysis of Holdahl and others (1989) reflect several additional characteristics of Cascadian subduction. Significant along-strike differences in the angle of descent of the subducting plate and the amount of sediment being subducted give rise to differences in vertical deformation along the margin (Davis and Hyndman, 1989). This explains in part the rapid uplift rates of the northwestern Olympic Peninsula.

Table 2. Vertical land movement at selected Washington and British Columbia locations. Sea-level change is based on a eustatic sea-level rise of 1 mm/yr. Positive values indicate uplift and emergence; negative values indicate subsidence and submergence. Based on analysis of Holdahl and others (1987)

Location	Land movement		Relative sea-level change	
	mm/yr	(in./100 yr)	mm/yr	(in./100 yr)
Astoria	1.7	(6.7)	0.7	(2.8)
Toke Point	-1.0	(-3.9)	-2.0	(-7.9)
Aberdeen	-0.3	(-1.2)	-1.3	(-5.1)
Neah Bay	2.5	(9.8)	1.5	(5.9)
Port Angeles	0.4	(1.6)	-0.6	(-2.4)
Seattle	-1.4	(-5.5)	-2.4	(-9.4)
Auburn	-2.6	(-10.2)	-3.6	(-14.2)
Tacoma	-2.4	(-9.4)	-3.4	(-13.4)
Olympia	-1.0	(-3.9)	-2.0	(-7.9)
Bremerton	-0.8	(-3.1)	-1.8	(-7.1)
Anacortes	0.2	(0.8)	-0.8	(-3.1)
Friday Harbor	0.4	(1.6)	-0.6	(-2.4)
Rockport	-1.5	(-5.9)	-2.5	(-9.8)
Blaine	-0.4	(-1.6)	-1.4	(-5.5)
Vancouver, BC	0.7	(2.8)	-0.3	(-1.2)
Victoria, BC	0.2	(0.8)	-0.8	(-3.1)

Regional patterns of vertical movement tend to obscure local details, such as subsidence of deltas due to natural compaction or due to ground-water removal. Mathews and others (1970) described settling in the Fraser delta, including the area around Blaine, Washington. An analysis by Holdahl and Hardy (1979) indicated possible subsidence in the Puyallup delta, and there is anecdotal evidence of subsidence in the Skokomish delta. Rates of subsidence may be too low for consideration in engineering studies and at too small a scale to show up in regional leveling studies, but they may still be sufficiently high to affect local relative sea-level change.

The pattern of vertical land movements in western Washington determined from leveling and tide gauges (Fig. 3) is generally consistent with evidence of vertical movements from the geologic record and with the overall tectonic regime of the Cascadia margin. In some areas, such as the central coast around Willapa Bay and Grays Harbor, long-term trends (uplift) are inconsistent with the modern measurements. This may be in part due to errors in the recent data, but more likely reflect non-uniform rates of uplift and subsidence, possibly related to episodic movements associated with large earthquakes.

Rates of vertical movements in Washington, coseismic events aside, are generally quite small. Maximum uplift, recorded at Neah Bay, is 2.5 mm/yr. Maximum subsidence, at Tacoma, is 2.4 mm/yr. However, these rates account only for the land movement component of relative sea-level change, not the

component due to eustatic sea-level changes.

Modern Trends in Global Sea Level

The results of world-wide monitoring of tide gauges during the 20th century show that sea level has increased at 1.0–1.2 mm/yr (for example, Gornitz and others, 1982; Barnett, 1984). These rates reflect many assumptions about measuring techniques, sampling biases, and regional patterns of vertical land movement.

Eustatic sea-level rise is small compared to rates of vertical land movements in tectonically active regions such as Alaska, and in rapidly subsiding areas such as Venice and Bangkok or in the Mississippi and Nile Deltas, where present submergence rates may exceed 1 cm/yr.

In Washington, the rate of eustatic rise is similar to the rate of vertical land movement. Current rates of eustatic sea-level rise lessen the amount of emergence in Neah Bay and Astoria that would be expected from uplift rates alone, and increase rates of submergence in Puget Sound above the rates due to subsidence. (See last column of Table 2.)

"Greenhouse"-induced Sea-level Changes

Although current rates of eustatic sea-level rise are fairly low, there is growing concern that the rate may accelerate significantly during the coming decades as a result of a rapid rise in the temperature of the Earth's atmosphere. It is now well established that the level of CO_2 in the atmosphere has risen from 280 to 350 ppm in a little more than 100 yr, and that this increase is primarily a result of burning fossil fuels. Along with several other rapidly increasing gases, CO_2 contributes to the heating of the planet by allowing short-wavelength radiation from the sun to pass through the atmosphere, but preventing long-wavelength thermal radiation from escaping. This is popularly known as the "greenhouse effect". The hypothetical effect of doubling the amount of CO_2 in the atmosphere (which is predicted to happen toward the middle of the next century) would be an increase in the average temperature of the Earth's atmosphere of between 1.5° and 4.5° C (2.7° and 8.1° F), assuming no unforeseen feedbacks (positive or negative).

Global warming threatens to raise sea level for two basic reasons: ocean water expands with increasing temperature, and glaciers melt. The amount of sea-level change will depend on regional variations in the amount of warming, the degree and rate of mixing in the oceans, changes in precipitation patterns over polar regions, and many other factors.

Several models of the response of sea level to global warming have been developed, and estimates of the magnitude tend to fall in the range of a few tens of centimeters to a few meters of rise by the year 2100 (Barth and Titus, 1984; Hoffman and others, 1983; National Research Council, 1987).

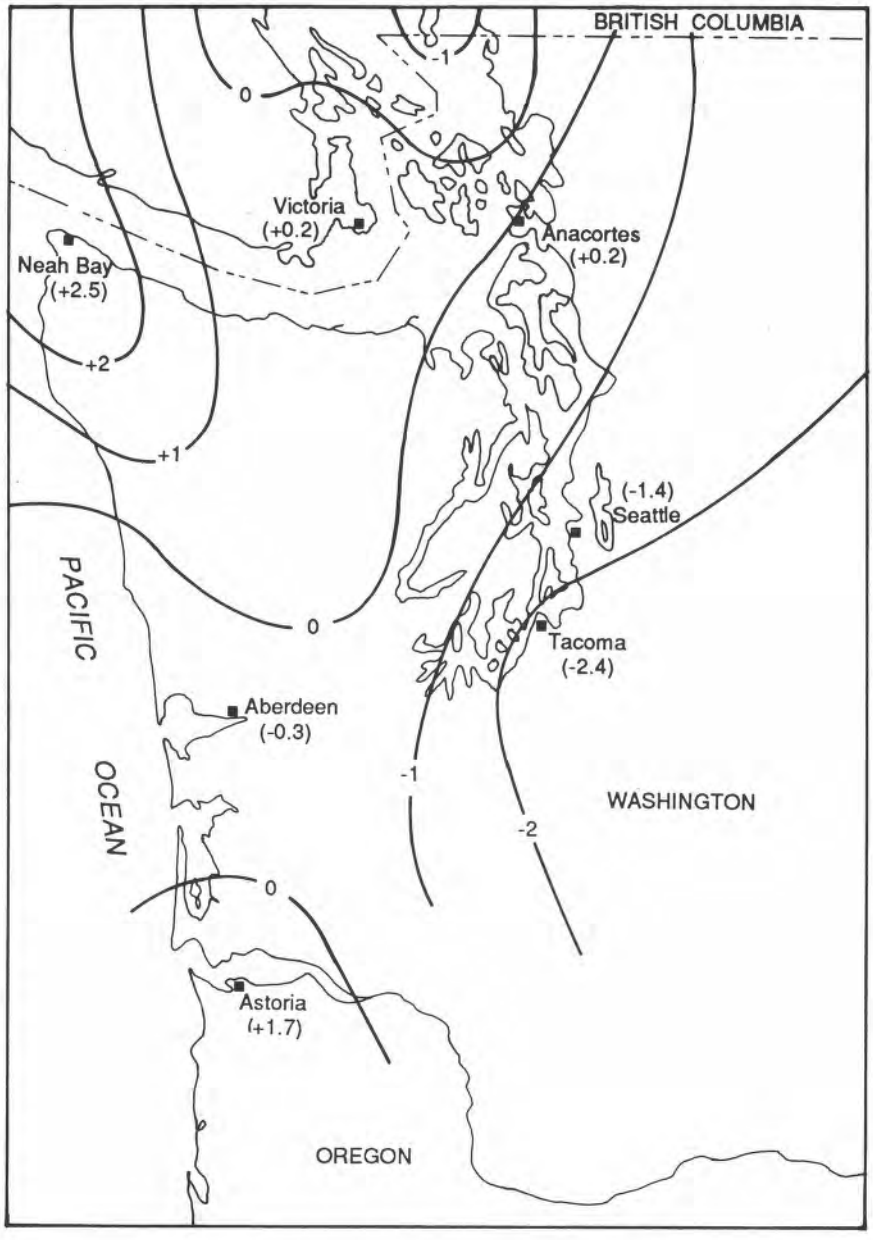

Figure 3. Contours of vertical land movement in coastal Washington. Based on analysis of Hohldal and others (1989), using tide gauges and leveling data. Values are rates of absolute vertical motion in mm/yr. Positive values denote uplift; negative values denote subsidence. Changes in relative sea level require subtraction of eustatic rate from numbers on the map. (Modified from Hohldahl and others, 1989)

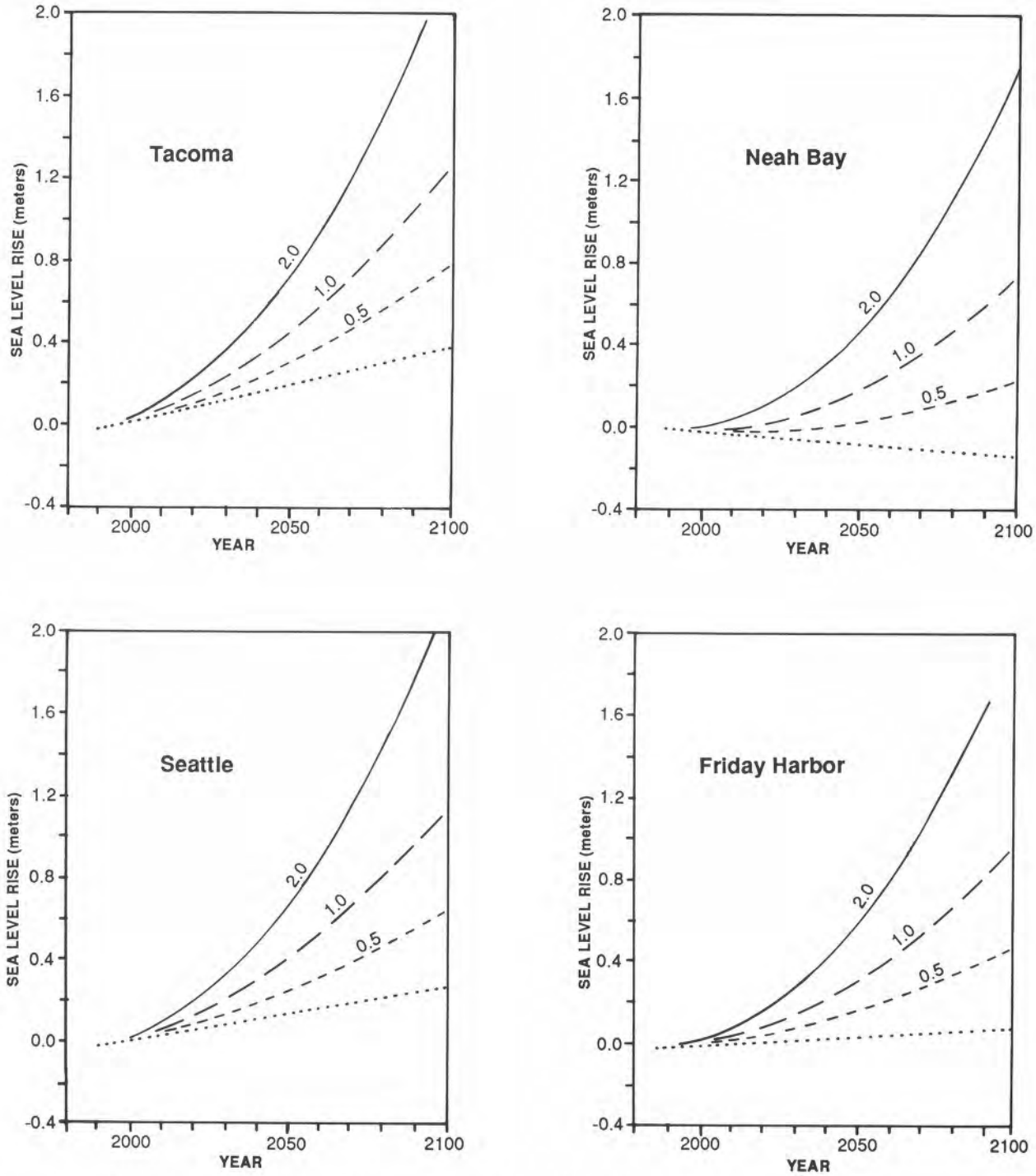

Figure 4. Sea-level rise at four cities in Washington State. For each city, four scenarios are shown. The lowermost curve is the projection based on current trends. The upper curves are based on global sea level rising by 0.5, 1.0, or 2.0 m by the year 2100.

The rise is expected to increase with time, so the most dramatic effects would occur later in the next century. Because of the uncertainty in the pace and magnitude of rise expected, the standard approach has been to consider low, middle, and high scenarios of 0.5, 1.0, and 2.0 m by the year 2100 (Titus, 1988).

Figures 4 and 5 demonstrate the impact of existing vertical land movements on proposed scenarios of sea-level change. Note that vertical land movement remains a significant component for the next several decades, but that the eustatic component dominates in the long run. Currently, sea level is rising at Tacoma and falling at Neah Bay. However,

by later in the 21st century, sea level could be rising rapidly at both.

Implications

Increased sea levels would have numerous impacts on both human and natural systems. Current rates of beach erosion (for example, in southwest Washington) and bluff erosion (along Puget Sound and the Olympic Peninsula) would accelerate. Wetlands in the Willapa Bay and Puget Sound areas might be lost through inundation or erosion, unless they are capable of migrating landward or can accrete vertically. Sea-water intrusion into freshwater aquifers would increase, exacerbating an already existing problem in places such as Island County. Coastal flooding, whether around Grays Harbor or in Puget Sound, would become more frequent and more serious. Many of these impacts are existing problems that require attention regardless of whether sea level changes. Rising sea level would simply accelerate the processes or make events more frequent.

Conclusions

Washington has a complex history of vertical land movement, influenced by the unique characteristics of Cascadian subduction and by isostatic response to the advance and retreat of the Cordilleran ice sheet. The tide gauge and leveling data show that areas around Neah Bay and Astoria are presently rising, but that the central coast is subsiding very slowly. Puget Sound is subsiding, but the northern Puget Lowland and southern Fraser Lowlands are relatively stable.

Rates of these vertical land movements, combined with estimates of current eustatic sea-level rise, determine relative sea-level change along Washington's coast. At present, relative sea level is rising in some places and falling in others, despite an increase in eustatic sea level. If the rate of sea-level rise increases as a result of "greenhouse" warming, positive vertical land movements will delay the impacts for a few decades in emergent regions. However, vertical land movements in Washington remain slow compared to even the more modest rates of sea-level rise projected for later in the next century.

Although the uncertainty about future sea level change is high, the potential risks are also great. Given the uncertainty, much of the emphasis will be on developing strategies for shoreline planning that have value regardless of the magnitude of sea-level change. Perhaps the most important task for geologists will be to increase public awareness of long-term coastal processes.

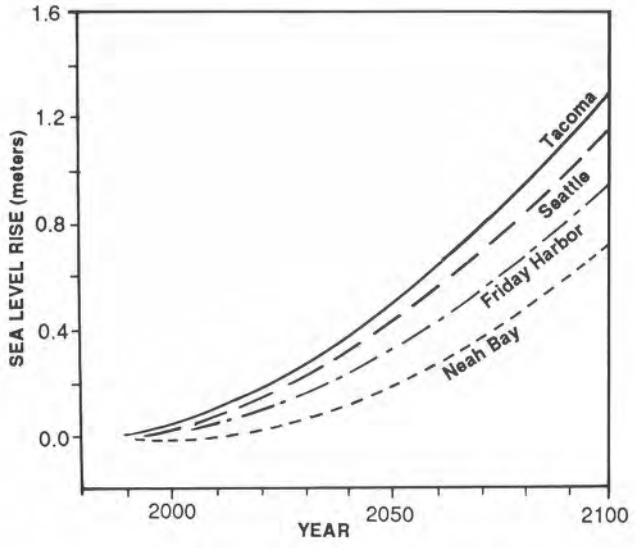

Figure 5. Sea-level rise scenarios for selected Washington localities. Curves are based on a global sea-level rise scenario of 1 m by 2100. The differences between the curves result from the different rates of vertical land movement at each location.

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Addendum

This article reflects work done in the Sea Level Rise Project in the Shorelands and Coastal Zone Management Program at the Washington Department of Ecology. The project is funded through the National Oceanic and Atmospheric Administration's Office of Coastal Resource Management.

Two additional documents may be of interest to readers: "Vertical Land Movements in Coastal Washington: Implications for Relative Sea Level Changes" and "Sea Level Rise in Washington State: Technical Issues and Preliminary Policy Responses". For further information or to obtain these reports, contact Douglas Canning, Shorelands and Coastal Zone Management Program, Department of Ecology, PV-11, Olympia, WA 98504, or telephone (206) 459-6785.

New Mineral Inventory for Washington

By Robert Derkey

Currently, the best available summary of information on Washington's metallic mineral deposits is Marshall T. Huntting's "Inventory of Washington minerals, Part II, Metallic minerals" (Bulletin 37), which was published in 1956. The current gold exploration fever in Washington, especially in the northeastern part of the state, has resulted in numerous requests for this now out-of-print publication. New ideas for mineral deposit genesis have developed over the years, and extensive data are ready to be added to the 1956 inventory.

Bob Derkey and Ray Lasmanis of the Olympia staff and Nancy Joseph in Spokane are now working to prepare a new mineral inventory to be entered on a standard IBM PC (or PC compatible) computer using GS MODS. GS MODS, written by Bruce Johnson of the U.S. Geological Survey (USGS Open-File Report 87-636), is a Mineral Occurrence Database System (MODS) designed to organize, analyze, and display mineral occurrence information that is commonly used for assessment of mineral resource potential.

The new inventory will include location, commodity, ore minerals, gangue, production, and reference information for each mine; it will be similar to Bulletin 37. However, additional "location" information in the new inventory will include latitude and longitude and reference to 1:250,000-scale, 1:100,000-scale, and the largest scale (1:24,000 or1:62,500 scale) map coverage for each deposit. The new inventory will also include more extensive information about the deposit geology. Replacing the single "deposit" field for each mine or occurrence in Bulletin 37 will be new fields: deposit type; host rock name, lithology, and age; mineralization age; description of associated igneous rocks and age; tectonic setting; ore controls; and geologic setting.

Our immediate goal is completion of a preliminary database. This will be developed from data in Bulletin 37 and other sources and is planned for release as an open-file report, "Major metal mines of Washington" for the Northwest Mining Association convention in December of this year. Major metal mines are those mines with significant recorded production.

In the coming months, Division geologists will glean prospect and occurrence information for the State from all available sources. When completed in about 4 years, the new mineral inventory will provide both summary and detailed mineral resource information for the public and private sectors and will be of use in mineral resource-related aspects of land development and land management. A current version of the database will be maintained in the Olympia office and will be available to provide information for use by the general public during the course of, as well as following completion of the project.

The Division's publications list was updated and released in November 1989. The list includes our formal and open-file reports, and there are author and subject indexes. The list is free, but if ordering by mail, please include $1 for postage and handling. See our mailing address, page 2.

Offshore Seismic Survey Data Now Available

By Linden Rhoads

The Washington Division of Geology and Earth Resources (DGER) has recently acquired copies of several offshore seismic surveys from the University of Washington and the U.S. Geological Survey.

Figure 1. Storage facility for seismic data.

These data are available (initially on a limited basis) to the public for the cost of reproduction.

These data acquisitions are part of an ongoing effort, supported by a grant from the Minerals Management Service, to construct a library of reflection and refraction seismic profiles and potential-field surveys for the state of Washington and adjacent offshore area. The project's objectives are to archive otherwise unavailable data and to provide a single source of public-domain seismic data for use in education, research, and industry.

To date, the acquisitions are:

- Single-channel data from University of Washington cruises in 1967 in the Strait of Juan de Fuca: *Thomas G. Thompson* Cruises 2 and 13, *Oceaneer* Cruise 10.
- The 1976 and 1980 single-channel data from the U.S. Geological Survey cruises of the *Don J. Miller;* the multi-channel data from 1976, 1977, and 1980 cruises in the Pacific Ocean on the *S.P. Lee*; and the 1987 multi-channel seismic reflection data from Puget Sound acquired by the late Sam Harding.
- Several lines from a 1980 Western Geophysical survey west of Cape Flattery.

A facility has been established in the DGER Olympia office to house the data sets (see photo). The data sets are catalogued in dBaseIII+; the catalogue also is available to the public.

Mark Holmes of the U.S. Geological Survey and Walt Lynn of Western Geophysical assisted DGER in obtaining these data. Profiles from surveys conducted by Oregon State University are in the process of being obtained.

DGER would like to expand its collection. Organizations willing to contribute data should contact Bill Lingley at DGER.

U.S. Mineral Consumption

According to a recent U.S. Bureau of Mines information release, every American requires large quantities of new nonfuel minerals each year. Over his or her lifetime, the average newborn child will need:

- 95 pounds of lead, primarily for car batteries, solder, and electronic components
- 57 pound of zinc, as an alloy with copper to make brass, as protective coatings on steel, and as chemical compounds in rubber and paint
- 1,500 pounds of copper, used mostly in electric motors, generators, communications equipment, and wiring
- 3,593 pounds of aluminum in many products, from beverage cans and lawn chairs to military aircraft and ships
- 32,700 pounds of pig iron, for kitchen utensils, cars, ships, and large buildings
- 26,500 pounds of clays, for producing bricks, paper, paint, glass, and pottery
- 28,213 pounds of salt for cooking, plastics, highway de-icing compounds, and detergents
- 1,238,101 pounds of stone, sand, gravel, and cement for roads, homes, schools, offices and other facilities.

Geologic History of the Tiger Mountain State Forest

By Timothy Walsh

EDITOR'S NOTE—This text is designed to accompany a recent Washington Department of Natural Resources map release, Tiger Mountain State Forest, available (free) from the Division of Engineering's Photo and Map Sales office at 1065 S. Capitol Way, Olympia, WA 98504 (MS EV-11; (206) 753-5338).

The Tiger Mountain State Forest lies in an anomalously west-trending spur of the Cascade Range. The oldest rocks exposed in the forest are the mudstones, sandstones, and conglomerates of the Raging River Formation (Fig. 1). These rocks were deposited in middle Eocene time, about 48 million years ago, in a marine embayment with a margin steep enough to cause abundant slumping of the newly deposited sediments. Nearby volcanoes, to the east and possibly the south, provided sediment to the bay, as did the older rocks that these volcanoes were built on. Over time, the eastern part of this bay filled with sediments, and the shoreline migrated west to approximately the present location of Interstate Highway 5. Deltas were built out by deposition from large streams rising in northeastern Washington or perhaps Idaho; delta fronts migrated to this area and formed coal swamps in which the sandstones, siltstones, and coals of the Tiger Mountain Formation were deposited.

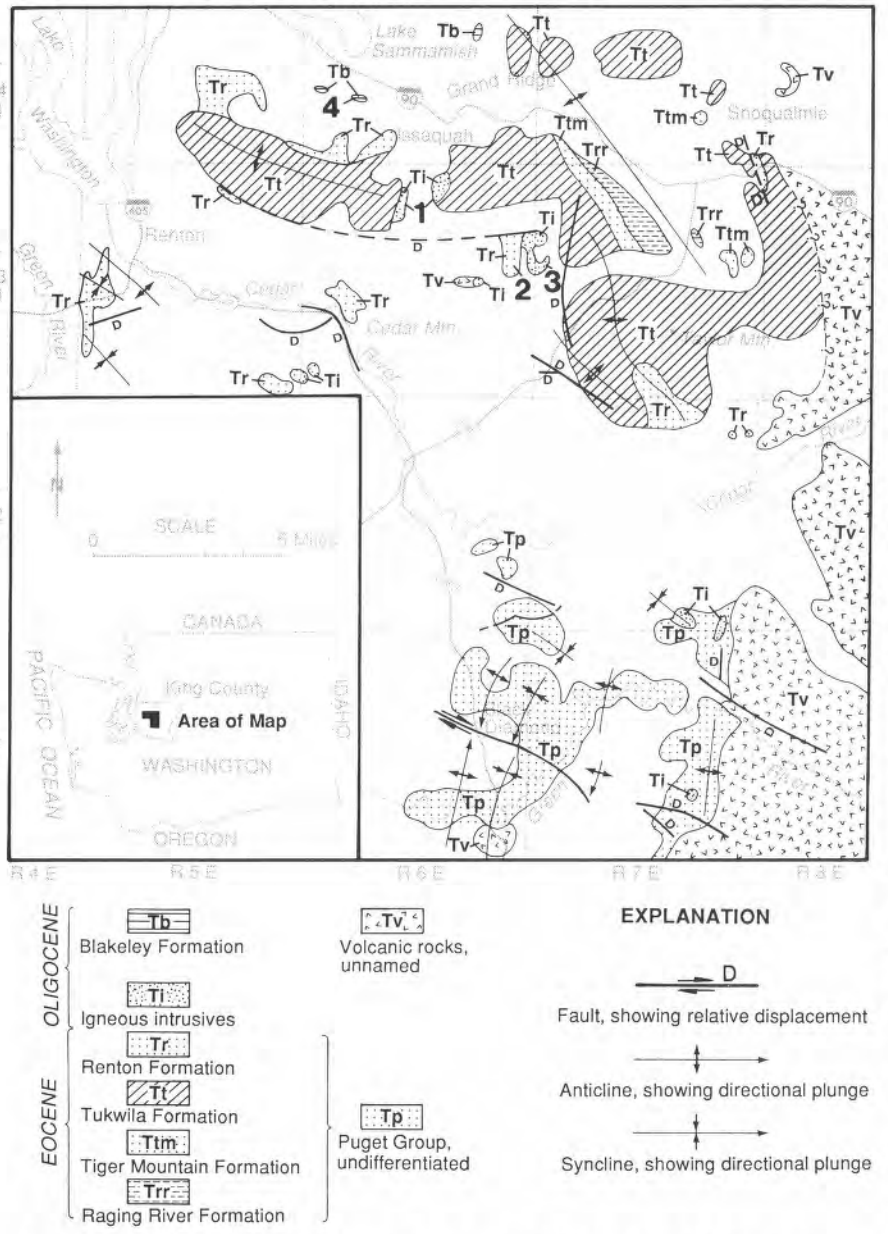

Figure 1. Generalized geologic map of a part of King County, Washington. The numbered localities are referred to in text and lie within the Tiger Mountain State Forest. Unpatterned and unlabelled areas are unconsolidated Quaternary sediments. (Modified from Warren and others, 1945; Vine, 1969.)

Approximately 45 million years ago, a volcano located where West Tiger Mountain and Squak Mountain now lie began to erupt. This volcano, which produced rocks known as the Tukwila Formation, was probably similar to Mount St. Helens. It produced airfall and ash-flow tuffs (rocks made up of particles exploded out of a volcano) rather than lava flows, as well as debris flows (lahars) that were similar to the Toutle River mudflow that nearly reached Kelso and Longview in 1980. The lava that was within the Tukwila volcano slowly cooled in the core of the volcano and produced a coarse-grained crystalline rock known as andesite porphyry. The andesite can be seen in the steep walls of Squak and West Tiger Mountains where Issaquah Creek (and precursor streams) have deeply dissected the mountain sides (loc. 1, Fig. 1).

Once the Tukwila volcano ceased erupting, about 41 million years ago, subsidence of the embayment area resumed, and deltas were re-established here, depositing the sandstones, siltstones and coals of the Renton Formation. Coals from the Renton Formation were mined at the nearby towns of Renton,

Maple Valley, Cougar Mountain, and Issaquah. Remnants of small mining operations can still be seen along the trails of the Fifteenmile Creek gorge (loc. 2, Fig. 1).

About 38 million years ago, the volcanoes that produced much of the Cascade Range began to erupt. The products of these volcanoes are found mostly to the east of Tiger Mountain State Forest. However, several sills (intrusive igneous rocks) produced by these volcanoes can be seen in the State Forest. These sills are like lava flows, but because they are dense and the sediments they intrude are relatively lighter, they flow out under the sediments, commonly at depths less than 300 feet. These sills are well exposed along Fifteenmile Creek and in a quarry along the West Side Road at about the common corner of sections 13 and 24 (T23N, R5E) and sections 18 and 19 (T23N, R6E) (loc. 3, Fig. 1).

During this time (the Oligocene epoch) large volumes of tuffs were produced in the Cascade Range. There may have been as much as a 5,000-foot thickness of these rocks deposited in the Tiger Mountain State Forest area, but they were eroded when these hills were uplifted. To the west, around Seattle, Bellevue, and Newport Hills, are marine sedimentary rocks that were derived (in part) from the rocks eroded from the Tiger Mountain area and from airfall ash from Cascade volcanoes. These Oligocene marine rocks are known as the Blakeley Formation. They are well exposed along the frontage road on the south side of Interstate Highway 90 in section 13 (T24N, R5E) where marine fossils can readily be found (loc. 4, Fig. 1).

Uplift and erosion probably continued intermittently until about 2 million years ago, when glaciers began occupying Puget Sound lowland. The Tiger Mountain area has exposed sediments recording at least two glaciations. The age of the older one(s) is not known. The younger glaciation is known as the Fraser Glaciation, and its deposits in this area are called Vashon Drift. The drift was deposited between 17,000 and 12,000 years ago in the area of this state forest. The deposits are mostly sands and gravels deposited by meltwater streams, but they include tills (poorly sorted mixtures of many grain sizes commonly known as hardpan), clays, and silts deposited in lakes, and sands and gravels deposited by deltas pouring into ice-dammed lakes, such as the delta that is well exposed in the large gravel pits at the north end of Issaquah. The Vashon ice sheet in this area was thick enough to completely cover East Tiger Mountain, the tallest peak in the forest, although Rattlesnake Mountain, immediately to the east of the Tiger Mountain State Forest on the eastern edge of the area in Figure 1, was glaciated only as high as about 3,500 feet.

As glaciers retreated out of the area, blocks of stagnant ice were stranded, forming kettle lakes, and former drainages were rerouted, leaving the present physiography.

Suggested Reading

(All references are available for review at the library of the Department of Natural Resources, Division of Geology and Earth Resources [DGER] in Olympia. Only DGER publications can be purchased there).

Vine, J. D., 1969, Geology and coal resources of the Cumberland, Hobart, and Maple Valley quadrangles, King County, Washington: U.S. Geological Survey Professional Paper 624, 67 p.

Walsh, T. J., 1984, Geology and coal resources of central King County, Washington: Washington Division of Geology and Earth Resources Open File Report 84-3, 24 p.

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Pringle Joins Division Staff

Patrick T. Pringle came to work at the Division of Geology and Earth Resources on February 1 as a Geologist 2. Pat earned Bachelors and Masters degrees at the University of Akron and also studied at the University of California, Santa Barbara and the University of Colorado. He worked for the Ohio Environmental Protection Agency and the Akron Public Health Department before moving west. Since 1982, he has been with the U.S. Geological Survey at the Cascades Volcano Observatory in Vancouver, Washington.

Pat specializes in debris flows and geochronology. He has worked on debris flows in the Grand Canyon and lahars from the Cascade volcanoes, most recently deciphering the chronology of the latest eruptive episode at Mount Hood. Pat's duties with the Division will include continued studies of debris flows in the Cascades, as well as support for the State's geologic map and Timber/Fish/Wildlife programs.

Selected Additions to the Division of Geology and Earth Resources Library

November 1989 through January 1990

THESES

Appelgate, T. Bruce, Jr., 1989, Tectonic and volcanic structures of the southern flank of Axial volcano, Juan de Fuca Ridge—Results from a SeaMARC I sidescan sonar survey: Oregon State University Master of Science thesis, 161 p., 1 plate.

DeChant, Jennifer H., 1989, Sedimentary petrology, depositional environment and paleogeographic significance of the upper Hoko River Formation, northern Olympic Peninsula, Washington: Western Washington University Master of Science thesis, 195 p., 6 plates.

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Livesay, David M., 1986, The hydrogeology of the upper Wanapum Basalt, upper Cold Creek valley, Washington: Washington State University Master of Science thesis, 159 p.

Pinto Alvarez, Luis A., 1989, Use of sediment fractionation techniques to establish a geochemical link between natural-occurring PAH and 3-oxytriteropenoids in Columbia River sediments: Oregon State University Master of Science thesis, 100 p.

Poujol, Michel, 1988, High resolution seismic refraction study of the uppermost oceanic crust near the Juan de Fuca Ridge: Oregon State University Master of Science thesis, 93 p.

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Miller, C. D., 1989, Potential hazards from future volcanic eruptions in California: U.S. Geological Survey Bulletin 1847, 17 p., 1 plate.

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Ward, P. L.; Page, R. A., 1989, The Loma Prieta earthquake of October 17, 1989—What happened...What is expected...What can be done: U.S. Geological Survey, 16 p.

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Finch, W. I.; Otton, J. K.; McCammon, R. B.; Pierson, C. T., 1990, The 1986 estimate of undiscovered uranium endowment for surficial uranium deposits in the Sandpoint and Spokane 1 degree x 2 degree quadrangles, Washington and Idaho: U.S. Geological Survey Open-File Report 90-2, 16 p.

Hays, W. W., editor; Huey, Linda, compiler, 1989, Proceedings of Conference XLVIII, 3rd annual workshop on earthquake hazards in the Puget Sound, Portland area: U.S. Geological Survey Open-File Report 89-465, 321 p.

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Steeples, D. W., editor, 1989, Geophysics in Kansas: Kansas Geological Survey Bulletin 226, 312 p.

Wetmiller, R. J., Drysdale, J. A.; Horner, R. B.; Lamontagne, M., 1989, Canadian Earthquakes—1985-1986: Geological Survey of Canada Paper 88-14, [50 p.].

New Division Releases

Report of Investigations 30: Geology of the Upper Proterozoic to Lower Cambrian Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite, Stevens and Pend Oreille Counties, northeastern Washington, by Kevin A. Lindsey, David R. Gaylord, and Louis H. Groffman. This 37-page report describes the stratigraphy, paleontology, depositional history, and economic geology of the three formations. Because the Gypsy and Addy Quartzites have not been formally defined previously, type sections have been designated. The price of this report is $1.38 + .12 tax (Washington residents only) = $1.50.

Open File Report 90-1: Geologic map of the Ritzville 1:100,000 quadrangle, Washington, compiled by C. W. Gulick. This seven-page report includes one plate. The price is $.93 + .07 tax = $1.00

Open File Report 90-2: Geologic map of the Moses Lake 1:100,000 quadrangle, Washington, compiled by C. W. Gulick. The nine-page report includes one plate. The price is $.93 + .07 tax = $1.00.

Open File Report 90-5: Geologic map of the Robinson Mountain 1:100,000 quadrangle, Washington, compiled by K. L. Stoffel and M. F. McGroder. This 39-page report includes one plate. The price is $1.85 + .15 tax = $2.00.

These are the first releases in a series of maps that will be used to prepare a 1:250,000-scale geologic map of the northeast quadrant of Washington.

Open File Report 90-3: Geologic and geophysical mapping of Washington, 1984 through 1989, and theses on the geology of Washington, 1986 through 1989, compiled by Connie J. Manson. This 28-page report, including seven plates, supersedes the previous update, Open File Report 89-1. The price is $.93 + .07 tax = $1.00.

Open File Report 90-4: Proposed revision of nomenclature for the Pleistocene stratigraphy of coastal Pierce County, Washington, by John B. Noble. The price is $1.62 + .13 tax = $1.75. This 54-page report contains a wealth of information gathered during years of geohydrologic investigations in the southern Puget Sound area.

Reprints available

The Division has reprinted two reports that have been out of print for some years. The two bulletins listed below are again available, but in limited quantities. They will be sold on a first-come, first-served basis.

Barksdale, J. D., 1975, **Geology of the Methow Valley, Okanogan County, Washington**: Washington Division of Geology and Earth Resources Bulletin 68, 72 p., 1 pl. The price is $4.87 + .38 tax = $5.25.

Huntting, M. T., 1956, **Inventory of Washington minerals; Part II, Metallic minerals**: Washington Division of Mines and Geology Bulletin 37, v. 1, 428 p. The price is $6.50 + .50 tax = $7.00. [*See related article, p. 33.*]

Add $1 to each order for postage and handling. Orders should be sent to the address on page 2.

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