U.S. DEPARTMENT OF THE INTERIOR - GEOLOGICAL SURVEY
NATIONAL MAPPING DIVISION

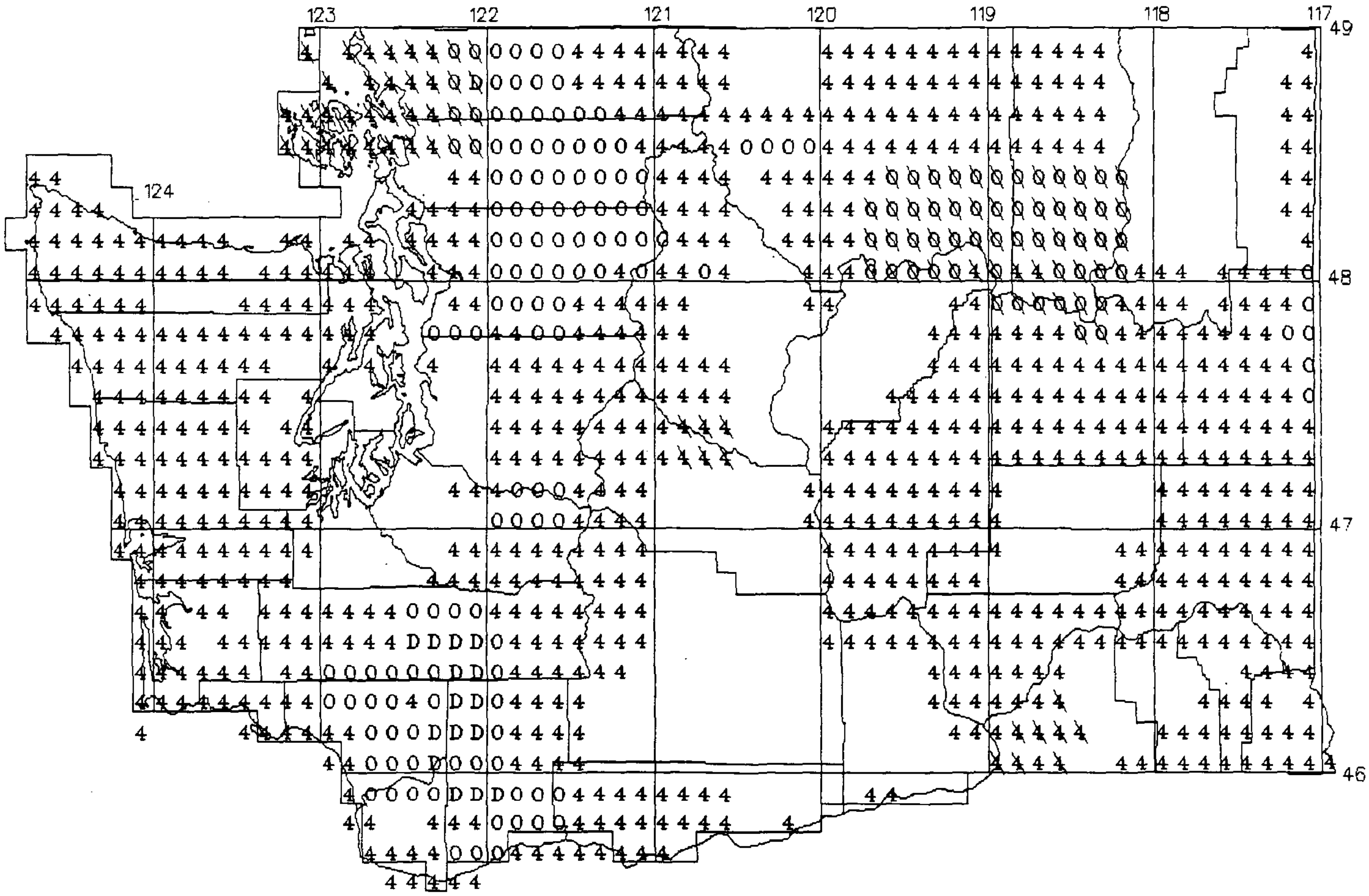
Washington

GL01546

STATUS OF ORTHO MAPPING in WASHINGTON

Rocky Mountain Mapping Center

April 1, 1991



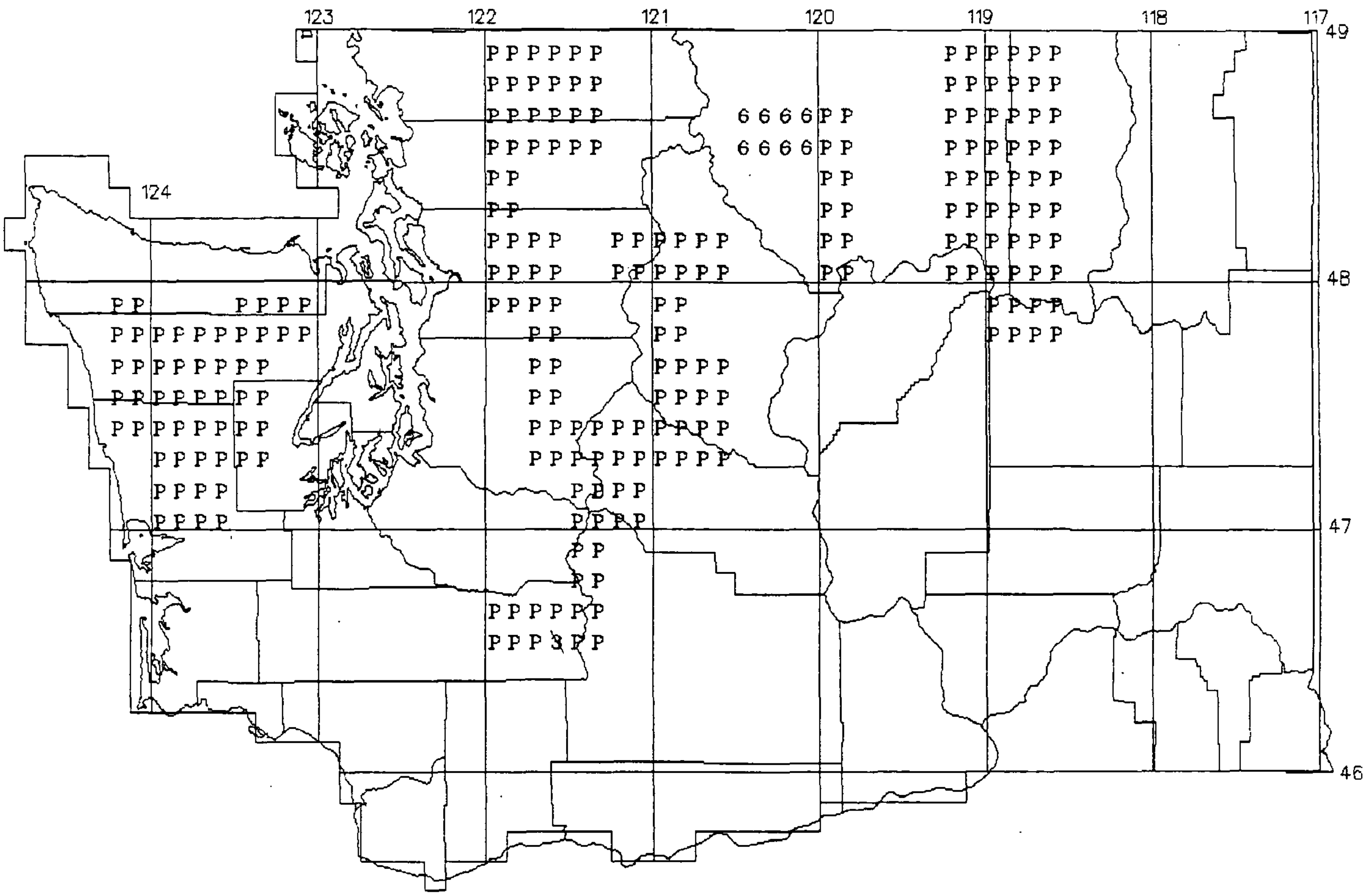
Prepared in Branch of Program Management - RMMC

WASH.

STATUS OF LINE MAPPING in WASHINGTON

Rocky Mountain Mapping Center

April 1, 1991



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U.S. GEOLOGICAL SURVEY
NATIONAL MAPPING DIVISION
EARTH SCIENCE INFORMATION CENTER - LAKEWOOD
ROCKY MOUNTAIN MAPPING CENTER
DENVER, COLORADO
(303) 236-5829
FTS 776-5829

ADVANCE MATERIAL INDEX

The accompanying pages show the status of Topographic Mapping and Orthophotoquad Mapping, and the availability of advance materials. These indexes are produced on a quarterly basis and are furnished to requestors free of charge. Following is an explanation of symbolization and ordering information.

TOPOGRAPHIC MAPPING

2 Aerial photography completed. For ordering address, see note (a).

3 Basic horizontal and vertical control surveys completed. Monumented control may or may not have been established in this quadrangle. Descriptions and unadjusted coordinates and/or elevations are published in 15-minute quadrangle lists. Advance maps are not available at this stage. Price is $1.25 per list (horizontal or vertical). For ordering address, see note (a).

4 Prints of manuscripts (without feature classification, names, boundaries or land net) compiled from aerial photographs are available for $2.50 each. See note (a) and (b).

5 Field mapping and checking completed. One-color unedited advance prints (without names) are available for $2.50 each. See notes (a) and (b).

6 Final drafting completed. Partially-edited one-color advance prints (with names) are available for $2.50 each. See notes (a) and (b).

P Maps published since the latest edition of the State Sales index to published maps. See note (c).

\ Maps published at 1:62,500-scale in 15-minute quadrangles. However, 1:24,000-scale one-color prints in 7 1/2-minute format, with appropriate accuracy and contour intervals are available at $2.50 each. See notes (a) and (b).

Screened areas represent projects in progress at Mid-Continent Mapping Center. Indicated advance materials are available through ESIC-M, USGS Building, 1400 Independence Road, Rolla, Missouri 65401. (314) 341-0851 or FTS 277-0851.

Screened areas represent projects in progress at Western Mapping Center. Indicated advance materials are available through ESIC-W, 345 Middlefield Road, Mail Stop 532, Menlo Park, California 94025. (415) 329-4309 or FTS 459-4309.

ORTHOPHOTOQUAD MAPPING

2 Aerial photography completed, generally quad-centered at 1:80,000-scale. See notes (a) and (b).

4 Advance copy available. See notes (a) and (b). Price per copy for screened image on diazo paper is $3.00; for halftone print on waterproof diazo or single weight positive paper is $15.00; for continuous tone image on photographic paper is $20.00; for screened image on mylar or continuous tone image on opaque scale stable film is $36.00.

4 Same materials available as 4, however, land net (General Land Office) is shown.

0 Second generation advance copy available. Refer to 4, above, for ordering information and prices.

0 Same materials available as 0, however, land net (General Land Office) is shown.

D Third generation advance copy available. Refer to 4, above, for ordering information and prices.

D Same materials available as D, however, land net (General Land Office) is shown.

NOTES

(a) Requests for aerial photography, control lists or advance prints should be sent to the U.S. Geological Survey, Earth Science Information Center-Lakewood, Federal Center, Box 25046, Stop 504, Denver, Colorado 80225. Payment in the exact amount must accompany order. Check or money order should be made payable to the Department of the Interior, USGS. Please do not send stamps or two party checks. Purchase orders from commercial sources must include Federal tax identification. Discount agreements are not honored. Postage and handling charges are $1.00 on all map orders of less than $10.00.

(b) In ordering material or requesting information, mark your area of interest on the accompanying index and forward it with your order. A new copy of the index will be returned to you for future use.

(c) Requests for State sales indexes (free of charge) and for published maps and charts should be sent to the Branch of Distribution, Central Region, U.S. Geological Survey, Federal Center, Box 25286, Denver, Colorado 80225. (303) 236-7477. Remittance must be made payable to Department of Interior, USGS.

(d) This explanation sheet refers to the Advance Materials Indexes for the states of Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington and Wyoming. Questions about the mapping program for the remainder of the United States should be directed to ESIC-M, USGS Building, 1400 Independence Road, Rolla, Missouri 65401. (314) 341-0851, FTS 277-0851.

Earth Science Information Center office hours are from 8 a.m. to 4 p.m. Monday through Friday.

TOKEN BI[...] - YAKIMA, WASHINGTON.

DON ZEISLOFT MAY, 19[...]

For Area Files — as you requested. Jon

PRICE, S.M., [...] of the COLUMBIA PLATEAU; in: Basalt [...] Project Annual Report — Fiscal Yea[...] Rockwell Hanford Operations rpt RHO-BWI-79-100.

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Kinnison, H.B. & Sceva, J.E., 1963, Effects of hydraulic & geologic factors on streamflow of the Yakima River Basin, Washington: USGS Wtr. Supp. Pap. 1595.

Brown, E.H. & Ellis, R.C., (editors) 1977, Geologic excursions in the Pacific Northwest — GSA 1977 ann. mtg., Seattle; © by Western Washington Univ., Dept. of Geol., Bellingham, WA, 98225. (esp article by Bentley, R.D.)

Smith, G.O., 1901, Geology of a portion of Yakima County, WA; USGS Wtr. Supp. Pap 55, 68p. describes Clerf Spring.

Wash. Dept. of Nat. Resources, 1974, Energy Resources of Wash.; Info. Circ. #50.

Blackwell, D.D., ——, Terrestrial Heat flow & its implications on the Location of geothermal reservoirs in Wash.

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Gizienski, S.F., et al., 1975, Regional Evaluation of th[e] Geothermal Resource Potential in central Wash. A Report for WA. Public Power Supply systems by Woodward-Gizienski and Asso c's, San Diego, CA

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JON ZEISLOFT MAY, [illegible]

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___?___, 1978, ___?___ in: Basalt Waste Isolation Program, Annual Report - FY 1978: Rockwell Hanford Operations rept. RHO-BWI-78-100.

Kinnison, H.B. & Sceva, J.E., 1963, Effects of hydraulic & geologic factors on streamflow of the Yakima River Basin, Washington: USGS Water Supply Paper 1595.

Brown, E.H. & Ellis, R.C., (editors) 1977, Geologic excursions in the Pacific Northwest - GSA 1977 [illegible]; © by Western Washington Univ., Dept. of Geol., Bellingham, WA, 98225. (esp. article by [illegible], R.D.)

Smith, G.O., 1901, Geology [illegible] of Yakima County, WA; USGS Water Supply Paper 55, 68p, describes Cliff Spring.

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Alexander, G. & Lee, G., 1979, Current energy research & development in Wash. State; Wash. State Energy ~~Off.~~, WAOENG-79-4.

Swanson, D.A. et al., 1979, Aeromagnetic map and geologic interpretation of the West-central Columbia Plateau, WA and adjacent OR; USGS Map GP 917

Gizienski, S.F., et al, 1975, Regional Evaluation of the Geothermal Resource Potential in central Wash. state Report for WA Public Power Supply Systems by Woodward - Gizienski and Assoc's, San Diego, CA.

Huntting, M.T., et al., 1961, Geol. Map of Wash.; State of Wash., Dept. of Nat. Resources. (1:500,000

WASHINGTON
CLARK
WASHINGTON DIV OF GEOLOGY & EARTH RESOURCES
NW SE.

1 Camas

2-1n-3e W
WILDCAT (Temp Gradient) U

(11-30-79 BK). El: 220 GR.
Spud 12-12-79, drld to 500, cmtd pipe @ 500, TD 500.
...Temperature gradient well, comp 12-13-79.

WA1-122879

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WASHINGTON
CLARK
WASHINGTON DIV
OF GEOLOGY &
EARTH RESOURCES
SW SE.

2 Camas

21-2n-3e W
WILDCAT (Temp
Gradient) U

500. (11-30-79 BK). El: 260 GR.
Contr: Soil Sampling Service. Spud 11-28-79, drld to 233, 2 @
233, TD 233. ...Temperature gradient well, comp 12-11-79.

WA2-122879

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WASHINGTON
COWLITZ
WASHINGTON DIV OF GEOLOGY & EARTH RESOURCES
SE SE.

2 St. Helens

14-8n-4e W
WILDCAT (Temp Gradient) U

(11-30-79 BK). El: 3500 GR.
Lat 46 degrees, 10 minutes, 22 seconds N;
Long 122 degrees, 16 minutes, 06 seconds W.
Contr: Soil Sampling Service. Spud 11-1-79, drld to 505, 2 tbg cmtd @ 505, ran TMPL, BHT 46.7 degrees F (8.2 degrees C), preliminary gradient 38 degrees c/km, TD 505 (Eocene). ...Temperature gradient well, comp 11-7-79.

WA3-122879

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EARTH RESOURCES
SW SE.

Davis Mountain

3-12n-8e W
WILDCAT (Temp Gradient) U

(11-30-79 BK). El: 2000 GR.
(Well number not desingated).
Lat 46 degrees, 33 minutes, 10 seconds N;
Long 121 degrees, 47 minutes, 07 seconds W.
Contr: Soil Sampling Service. Spud 8-29-79, drld to 479, 2 tbg cmtd @ 479, ran TMPL, BHT 46.2 degrees F (7.9 degrees C), gradient isothermal, TD 479 (Eocene). ...Temperature gradient well, comp 8-31-79.

WA5-122879

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WASHINGTON
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EARTH RESOURCES
SW NW.

Longmire

6-14n-8e W
WILDCAT (Temp
Gradient) U

(11-30-79 BK). El: 2330 GR.
(Well number not designated).
Lat 46 degrees, 43 minutes, 46 seconds N;
Long 121 degrees, 51 minutes, 05 seconds W.
Contr: Soil Sampling Service. Spud 7-25-79, drld to 325, 2 tbg cmtd @ 325, ran TMPL, GG, BHT 47.3 degrees F (8.5 degrees C), gradient 57.6 degrees c/km, TD 325 (Eocene). ...Temperature gradient well, comp 7-31-79.

WA8-122879

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WASHINGTON
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Ohanapecosh

8-14n-10e W
WILDCAT (Temp Gradient) U

SW SE.

(11-30-79 BK). El: 1600 GR.
(Well number not designated).
Lat 46 degrees, 42 minutes, 54 seconds N;
Long 121 degrees, 34 minutes, 39 seconds W.
Contr: Soil Sampling Service. Spud 8-2-79, drld to 374, 2 tbg cmtd @ 374, ran TMPL, GG, BHT 52 degrees F (11.11 degrees C), gradient 45.3 degrees c/km, TD 374 (Eocene). ...Temperature gradient well, comp 8-31-79.

WA9-122879

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WASHINGTON
LEWIS
WASHINGTON DIV
OF GEOLOGY &
EARTH RESOURCES
SW SE.

Ohanapecosh

8-14n-10e W
WILDCAT (Temp
Gradient) U

(11-30-79 BK). El: 1600 GR.
(Well number not designated).
Lat 46 degrees, 42 minutes, 54 seconds N;
Long 121 degrees, 34 minutes, 39 seconds W.
Contr: Soil Sampling Service. Spud 8-2-79, drld to 374, 2 tbg cmtd @ 374, ran TMPL, GG, BHT 52 degrees F (11.11 degrees C), gradient 45.3 degrees c/km, TD 374 (Eocene). ...Temperature gradient well, comp 8-31-79.

WA11-122879

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WASHINGTON
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NW NW.

Packwood

16-13n-9w W
WILDCAT (Temp Gradient) U

(11-30-79 BK). El: 1200 GR.
(Well number not designated).
Lat 46 degrees, 37 minutes, 15 seconds N;
Long 121 degrees, 41 minutes, 35 seconds W.
Contr: Soil Sampling Service. Spud 8-23-79, drld to 498, 2 tbg cmtd @ 498, ran TMPL GG, BHT 57.5 degrees F (14.2 degrees C), gradient 48.5 degrees c/km, TD 498. ...Temperature gradient well, comp 8-27-79.

WA6-122879

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WASHINGTON
LEWIS
WASHINGTON DIV OF GEOLOGY & EARTH RESOURCES
SW SW.

Randle

16-12n-7e W
WILDCAT (Temp Gradient) U

(11-30-79 BK). El: 900 GR.
(Well number not designated).
Lat 46 degrees, 31 minutes, 22 seconds N;
Long 121 degrees, 56 minutes, 22 seconds W.
Contr: Soil Sampling Service. Spud 9-5-79, drld to 420, 2 tbg cmtd @ 420, ran TMPL, GG, BHT 57.7 degrees F (14.3 degrees C), gradient 44.5 degrees c/km, TD 420 (Eocene). ...Temperature gradient well, comp 9-10-79.

WA4-122879

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WASHINGTON
LEWIS
WASHINGTON DIV
OF GEOLOGY &
EARTH RESOURCES
SE SW.

White Pass

2-13n-11e W
WILDCAT (Temp
Gradient) U

(11-30-79 BK). El: 4480 GR.
(Well number not designated).
Lat 46 degrees, 38 minutes, 17 seconds N;
Long 121 degrees, 23 minutes, 27 seconds W.
Contr: Soil Sampling Service. Spud 8-16-79, drld to 485, 2 tbg cmtd @ 985, ran TMPL, GG, BHT 52.8 degrees F (11.56 degrees C), gradient 51.1 degrees c/km, TD 485 (Eocene). ...Temperature gradient well, comp 8-22-79.

WA7-122879

WASHINGTON
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WASHINGTON DIV
OF GEOLOGY &
EARTH RESOURCES
NE NW.

3 St. Helens

2-7n-5e W
WILDCAT (Temp
Gradient) U

(11-30-79 BK). El: 2640 GR.
Lat 46 degrees, 07 minutes, 37 seconds N;
Long 122 degrees, 09 minutes, 09 seconds W.
Contr: Soil Sampling Service. Spud 11-8-79, drld to 431, 2 tbg
cmtd @ 431, rr 11-16-79, TD 431 (Eocene). ...Temperature gradient well, comp
11-16-79.

WA10-122879

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WASHINGTON
SKAMANIA
WASHINGTON DIVISION OF GEOLOGY ET AL; EARTH RESOURCES

1 St Helens
API 46-059-90000

18-9n-5e
WILDCAT U

U

nw nw Spirit Lake 15 minute Quad.

450. El: 2560 Gr. Contr: Soil Sampling Service. Spud 9/13/79. 2 Tub @ 405. 405 TD. BHT 49.8 F (9.9C) Gradient 19.3 c/km. Ran logs, no tops reported. No cores or tests. Comp 9/20/79. Temp gradient well. (FIRST REPORT AND COMPLETION).

WA1-032880

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WASHINGTON
CLARK
CROWN-ZELLERBACH 1 Crown-Zellerbach
se se.

20-2n-3e W
WILDCAT U

750. El: 200 GR.
Contr: Turner. Spud 8-11-80, 6 @ 225, drld to 485, 1 1/2 tbg @ 485, rr 8-21-80, ran TMPL, temperature gradient: 42 degrees C/km, temperature @ 485: 15.1 degrees C, TD 485 (Troutdale). ...Temperature gradient well, comp 8-21-80 (drld on resistivity anomoly).

WA1-103180

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750.
Abandoned location.

WA1-092680

WASHINGTON
YAKIMA
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES
sw nw.

1 Tieton Willows

25-14n-14e W
WHITE PASS AREA
TG

500. El: 2440 GR.
Contr: Ponderosa. Spud 7-27-81, drld to 503, ran TMPL, preliminary BHT: 74 deg F, 2 tbg @ 503, rr 7-31-81, ran temp survey, BHT 24.14 deg C, temp gradient 89 deg C/Km, TD 503. ...Temperature gradient well, comp 9-15-81.

WA7-092581

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WASHINGTON YAKIMA WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES	1 Clear Creek	3-13n-12e W WHITE PASS AREA TG

nw nw.

500. El: 3300 GR.
(Section changed from 4; location changed from NW/4).
Contr: Ponderosa. Spud 7-17-81, drld to 503, 2 tbg @ 503, rr 7-22-81, ran temp survey, temp gradient between 196-503 64 deg C/Km, TD 503.
...Temperature gradient well, comp 9-15-81.

WA6-092581

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WASHINGTON
YAKIMA
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES

1 Sand Ridge

2-13n-12e W
WHITE PASS AREA
TG

nw ne.

500. El: 3480 GR.
Contr: Ponderosa. Spud 7-22-81, drld to 503, 2 tbg @ 503, rr 7-24-81, ran temp survey, BHT 12.36 deg C, temp gradient between 115-279, 45 deg C/Km, TD 503. ...Temperature gradient well, comp 9-15-81.

WA5-092581

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SKAMANIA
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES

1 Trout Creek

28-4n-7e W
WIND RIVER AREA
TG

ne ne.

500.

Contr: Ponderosa. Spud 8-5-81, drld to 505, ran TMPL, preliminary BHT: 70 deg F, 2 tbg @ 505, rr 8-7-81, ran temp survey, BHT 19.23 deg C, temp gradient 80-90 deg C/Km, TD 505. ...Temperature gradient well, comp 9-10-81.

WA4-092581

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 Form No. 611

WASHINGTON
SKAMANIA
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES
NW/4.

1 Carson

21-3n-8e W
WIND RIVER AREA
TD

500. El: 400 GR.
Contr: Ponderosa. Spud 8-7-81, drld to 500, ran TMPL, preliminary BHT: 80 deg F, hole caved in to 371, 2 tbg @ 371, rr 8-11-81, ran temp survey, temp @ 371: 27.78 deg C, temp gradient between 262-371: 360 deg C/Km, TD 500, PBTD 371. ...Temperature gradient well, comp 9-14-81.

WA3-092581

Petroleum Information. CORPORATION

WASHINGTON
PIERCE
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES

1 White River

29-18n-9e W
WEST FORK-WHITE RIVER AREA TG

nw sw.

500. El: 2800 GR.
(Location changed from ne sw).
Contr: Ponderosa. Spud 7-13-81, drld to 472, 2 tbg @ 472, ran temp survey, BHT 8.64 deg C, temp gradient 22.5 deg C/Km, TD 472.
...Temperature gradient well, comp 9-15-81.

WA2-092581

Petroleum Information. CORPORATION

WASHINGTON | 24-4n-13e W
KLICKITAT | SOUTHEASTERN
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES | 1 Klickitat | CASCADES AREA TG

sw nw.

Contr: Ponderosa. Spud 8-18-81, drld to 391, 2 tbg @ 391, rr 8-21-81, ran temp survey, BHT 20.06 deg C, temp gradient between 246-361 50 deg C/Km, TD 391. ...Temperature gradient well, comp 9-14-81.

WA1-092581

WASHINGTON
KITTITAS COUNTY
WASHINGTON DIVISION 2 Snoqualmie Pass
OF GEOLOGY & EARTH RESOURCES
nw nw (approx).

4-22n-11e W
SNOQUALMIE PASS
AREA TG

500. (7-17-81 BK). El: 2800 GR (approx).
(Location changed from ne nw).
Contr: Ponderosa. Spud 7-6-81, drld to 460, 2 tbg @ 460, ran temp survey, preliminary BHT 7.83 deg C, TD 460. ...Comp as temperature gradient well 10-13-81.

WA4-022682

Petroleum Information.
CORPORATION

 Form No. 611

WASHINGTON
KITTITAS COUNTY
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES
1 Snoqualmie Pass
se nw.

4-22n-11e W
SNOQUALMIE PASS AREA TG

500. (7-10-81 BK). El: 2980 GR.
(Location changed from sw ne).
Contr: Ponderosa. Spud 7-1-81 (est), drld to 480, encountered wtr, 2 tbg @ 480, ran TMPL, BHT 7.38 deg C/Km, TD 480. ...Comp as temperature gradient well 10-13-81.

WA3-022682

Petroleum Information. CORPORATION

 Form No. 611

WASHINGTON
KING COUNTY
WASHINGTON DIVISION 1 Scenic
GEOLOGY & EARTH RESOURCES
se sw

28-26n-13e W
SCENIC HOT
SPRINGS AREA TG

(7-10-81 BK). El: 2760 GR.
Contr: Ponderosa. Spud 6-23-81 (est), drld to 500, lost fish (T/330),500. 2 tbg @ 330, ran TMPL, BHT 97.7 deg C, gradient 68.3 deg C/Km, TD 500.
...Comp as temperature gradient well 9-25-81.

WA2-022682

Petroleum Information. CORPORATION

 Form No. 611

WASHINGTON
KING COUNTY
WASHINGTON DIVISION OF GEOLOGY & EARTH RESOURCES 2 Scenic
ne nw.

27-26n-13e W
SCENIC HOT SPRINGS AREA TG

500. (7-10-81 BK). El: 2760 GR.
(Location changed from nw ne).
Contr: Ponderosa. Spud 6-26-81 (est), drld to 500, 2 tbg @ 495, ran TMPL, BHT 99.7 deg C, gradient 38 deg C/Km, TD 500. ...Comp as temperature gradient well 9-25-81.

WA1-022682

REPRINTED FROM C.I.M. SPECIAL VOLUME No. 8, 1966.

WASHINGTON DIVISION OF MINES AND GEOLOGY
Reprint No. 10

WASHINGTON MINERAL DEPOSITS

by
Marshall T. Huntting
Washington Department of Conservation, Div. Mines and Geology

A wide variety of mineral deposits occurs in Washington. Incomplete records indicate that, from the first reported discovery of gold in 1853 through 1963, Washington's total cumulative mineral production is about $2 billion, of which about $341 million is in metallic minerals and about $1.7 billion in non-metallic minerals. All but 10 of the State's 39 counties have produced gold, silver, copper, lead, or zinc. However, by far the greatest part of the production of metals has been from the northern row of counties adjacent to the Canadian border – Pend Oreille, Stevens, Ferry, Okanogan, and Whatcom Counties – and the northern Cascade Mountains counties of Chelan and Snohomish. These are the principal areas of occurrence of Tertiary and Mesozoic intrusive rocks and pre-Tertiary metamorphic rocks.

The principal metals, in decreasing order of production value, are zinc, gold, lead, copper, silver, and uranium. Lesser amounts of tungsten, mercury, iron ore, antimony, manganese, molybdenum, and chromite have been mined.

The State of Washington can be broadly divided on the basis of rock types and structural features into the seven fairly distinct geologic areas that are described below, 1 to 7. See also Figure 12-1, to which numbers in brackets refer.

1. In the northeast is an area of slightly to moderately metamorphosed miogeosynclinal rocks of early Paleozoic age, with lesser amounts of eugeosynclinal metasedimentary rocks of late Paleozoic age and Precambrian metasedimentary rocks. In this area the structural trends are quite uniformly to the northeast. The rocks are strongly folded. Dips are steep and in places the folds are overturned to the east. Both normal and thrust faults are numerous. Intruding the older rocks in the area are large batholiths such as the Kaniksu in northern Pend Oreille County and the Colville and Loon Lake batholiths in northern and southern Stevens County. These intrusives are all thought to be Mesozoic, probably Cretaceous, in age. In western Stevens County are several small areas of Tertiary volcanic rocks. This northeastern area of Washington can be characterized as a zinc-lead province; most of the production of these metals has been from Cambrian limestones in northern Pend Oreille and Stevens Counties. Southern Stevens County also is the principal source of uranium in this State and has produced some copper and tungsten from quartz veins. The Tertiary volcanics in northwestern Stevens County have produced gold.

2. To the west in Ferry County is an area about 20 miles wide and 80 miles long north and south which is predominantly underlain by Tertiary volcanic rocks with minor sedimentary interbeds. In places these are intruded by Tertiary dacites and similar rocks. Much of this area lies within the north-northeast trending Republic graben. The Tertiary rocks in the Republic district (26, Fig. 1) are the hosts for some of the most productive gold deposits in the State.

3. Farther to the west in Okanogan County and the whole northern Cascade Mountains is a large area of pre-Tertiary low-, medium-, and high-grade metamorphic rocks which are intruded by both Mesozoic and early and late Tertiary quartz diorite and related rocks. These include schists, gneisses, migmatites, and granitic rocks. Greenstone and slightly metamorphosed sedimentary rocks, including minor fossiliferous limestones, are fairly widely distributed. Small areas are covered by sedimentary and volcanic rocks of recognized Tertiary and Mesozoic age. Structural trends in the metamorphic rocks are predominantly north-northwest. Several large thrust faults are recognized. Intrusive quartz diorites

and related rocks are of both Mesozoic and early and late Tertiary age. Several small to fairly large ultramafic rock masses are in the northern Cascades. Most of these are pre-Tertiary in age, but the Twin Sisters dunite mass, about 40 square miles in area, is believed to be Late Cretaceous or Paleocene in age. The northern Cascades is an area of high relief, and the rocks are deeply eroded. This area is primarily a copper province, and most of the copper production of the State has come from here. Many of the copper deposits have molybdenum as an accessory metal as, for example, the Star property about 6 miles west of Tonasket in central Okanogan County, where molybdenite occurs in a silicified pyritic stockwork in granitic rock. Directly overlying a large east-trending band of serpentinized peridotite in the Cle Elum River-Blewett area of the Central Cascades is a series of nickeliferous iron deposits that were formed by laterization of the ultramafic rock.

4. Erosion in the southern Cascades has penetrated the cover of Tertiary andesites and basalts in only a few places, exposing only the uppermost parts of Tertiary plutons and stocks. The volcanic rocks in the southern Cascades are moderately folded along predominantly northwest axes. To date only small "showings" of copper and minor gold, lead, and zinc have been found associated with the known intrusives. Most of these are in the Mt. St. Helens and Washougal districts (3 and 2). Most of the mercury production from Washington – about $700,000 – has come from Tertiary sedimentary rocks in the Morton district (4, Fig. 1) 12-1 in the west-central part of the southern Cascades. The mercury mineralization was localized by permeable sedimentary beds and impermeable gouge zones along faults.

5. The Olympic Mountains in the northwestern part of the State is an area of Tertiary and Mesozoic shales and sandstones. The central area is surrounded on the north, east, and south by a horseshoe-shaped band of outward dipping beds of Tertiary sedimentary rocks, at the base of which is a thick sequence of submarine basalts of middle Eocene age. In the basalts are minor interbeds of argillaceous limestone, with which are associated deposits of manganese silicates with minor manganese oxides (1). No igneous rocks other than the basalts and minor diabase are known in the Olympics. Apparently the manganese was derived from the basaltic lava and was concentrated on the sea floor at the time the lavas were extruded on the ocean bottom.

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7. The whole southeastern part of Washington, comprising at least a third of the area of the State, is covered by a thick series of basalt flows, largely of Miocene age, but including some continental sedimentary beds and basalt flows of Pliocene age. The flows and beds in this area are mostly low-dipping to flat-lying, except for a series of west and northwest-trending anticlines in the western part of the area. These rocks contain no deposits of metallic minerals but are the source from which diatomite and pumicite have been produced.

Gold

Lode gold has been mined as the principal product from approximately 116 mines, the largest of which have been the Knob Hill, Gold King, and Holden mines, in the Republic, Wenatchee, and Railroad Creek mining districts (26, 6, and 18), respectively. Other significant production has come from the Blewett, Mount Baker, Slate Creek, Monte Cristo, and Oroville-Nighthawk mining districts (7, 20, 21, 12, and 23) in the northern Cascade Mountains and from the Orient district (27) in Stevens County. Cumulative production through 1956 has been $78,302,463.

Probably somewhat less than half the gold production has come as a co-product or byproduct of base-metal mining. Early production included placer gold in fairly large amounts, but in recent years very little placer production has been recorded.

Gold deposits include free gold and auriferous sulfides in quartz veins in rocks ranging from Tertiary sedimentary and volcanic rocks to Precambrian metamorphic rocks. Some deposits occur within silicified and pyritized breccia zones in Tertiary volcanics and in older rocks. Most of the lode gold deposits are associated with granitic rocks of Tertiary age, but some appear to be related to Late Cretaceous batholiths, and a few in southern Pend Oreille County may be related to Precambrian igneous rocks.

In the Republic district (26) the gold occurs with small amounts of pyrite in low-temperature quartz-calcite veins in Tertiary volcanic and intrusive rocks. Most of the gold occurs in a series of east-dipping veins in a belt 6 miles in length in which the veins trend in a northerly direction south of Republic, then turn north-northwest near Republic, and bend to the northeast in the north end of the belt. The ore carries about 4 ounces of silver for each ounce of gold. At the Gold King mine in the Wenatchee district (6), gold occurs with very minor amounts of pyrite in quartz veins in a silicified zone near the axis of a northwest-trending anticline in nonmarine sandstone of the Swauk Formation of probable Paleocene age. Several small bodies of Tertiary intrusive igneous rocks crop out in the vicinity of the mine and along the same anticlinal axis. The Swauk district has had a small amount of lode gold production from similar deposits and some production from placer deposits. The Holden mine in the Railroad Creek district (18) had a production of 612,778 ounces of gold during its 20 years of operation. In the Blewett district (7) gold occurs in quartz veins in serpentinized peridotite that is intruded by Mount Stuart Granodiorite of Mesozoic age. At the First Thought mine in the Orient district (27) in Stevens County, gold occurs in a wide silicified and pyritized breccia zone in acid volcanic rocks of Tertiary age. Gold in the Mount Baker district (20) occurs as free gold, tellurides, and with pyrite in quartz veins that cut pre-Tertiary metamorphic rocks. To the east, in the Slate Creek district (21), gold is found in breccia zones and quartz veins in tightly folded Cretaceous sedimentary rocks just north of a large mass of granitic rock of Tertiary age. In the Monte Cristo, Silverton, Silver Creek, Miller River, Conconully, Oroville-Nighthawk (12, 14, 11, 9, 22, 23), and several other mining districts of the State, gold is associated with pyrite and arsenopyrite and with silver, copper, lead, and zinc minerals in quartz veins and in shear zones in both Tertiary and Mesozoic granitic rocks and adjacent sedimentary, volcanic, and metamorphic rocks.

Silver

Silver is reported to have been mined as the principal product from 38 mines, but most of the production has been a byproduct of the gold and base metal mines in the State. Total silver production of the State from 1866 through 1956 has been $12,265,109.

Of the few mines that were operated in the early days primarily for their silver content, the Old Dominion mine in the Colville district (30) of central Stevens County was probably the largest. It is reported to have produced more than $2 million from low-dipping fracture zones in Cambrian Old Dominion Limestone near its contact with Cretaceous granitic rock. The highest silver values here, as well as at most of the other silver producers in Washington, were near the surface in highly oxidized zones.

At another important producer, the Deer Trail mine (33) in southern Stevens County, the ore occurs in quartz veins in the Precambrian Edna Dolomite near its contact with a large lobe of the Cretaceous Loon Lake batholith. In the Nespelem and Sheridan districts (35 and 24), silver occurs in stephanite, argentite, pyargyrite, galena, pyrite, chalcopyrite, and tetrahedrite in veins and narrow shear zones about equally distributed between the Colville Granite of Mesozoic age and the upper Paleozoic (?) metasedimentary rocks of the Covada Group that are intruded by the granite. In the Covada district the same formations contain lead-silver-zinc veins. In the Ruby-Conconully district and the Oroville-Nighthawk district (22 and 23) to the north, the silver deposits are found at or within a short distance of the contact between older metamorphic rocks and granitic rocks of the Similkameen batholith of Mesozoic age. In these districts galena is the most abundant ore mineral; associated minerals are pyrite, sphalerite, chalcopyrite, and tetrahedrite. Oxidation has affected the veins to only shallow depths. Although Snohomish County has more silver occurrences than any other county in the State, very few, if any, of these mines were worked primarily for the silver content of their ore. Most of the ores are complex and have relatively low silver values. These deposits also are associated with Tertiary plutonic rocks.

Copper

Twenty-four mines in the State are reported to have produced copper as their principal product. Copper occurrences are distributed throughout northeastern Washington, from the Canadian border southward in the Cascade Mountains to the central part of the State, and in a few small areas in the southern Cascades. Cumulative production through 1963 has had a value of $43,412,918.

Of a total of 122,000 tons of copper produced in Washington from 1860 through 1961, about 107,911 tons came from the Holden mine during the 20-year period it operated, from 1938 through 1957. The Holden ore body consisted of a zone of sulfide disseminations 20 to 75 feet wide, 2,500 feet long, and 2,500 feet deep in a high-grade metamorphic zone of sheared schist and amphibolite in an overturned isoclinal fold that has a northwest-trending axis and a dip of about 70 degrees to the southwest. The ore shoot was parallel to the enclosing foliated metamorphic rocks and pitched about 60 degrees to the east. The ore body was cut by numerous post-ore dikes associated with the nearby Tertiary Cloudy Pass pluton and by some possibly older dikes. The Glacier Peak (Miners Ridge) property (17), only about 8 miles to the west, contains more than 20 million tons of low-grade copper ore in one or more bodies. At this property, chalcopyrite and molybdenite are disseminated in the Cloudy Pass pluton of Tertiary age near its contact with migmatitic gneiss; some of the ore is also in the gneiss. Here, as well as at several other copper properties in the Cascades, the ore occurs along a northeast lineament that crosscuts the prevailing northwest regional trends of the range (A. R. Grant, personal communication, 1965). Also here, as in other places in the Cascades, the sulfides are associated with deuterically altered intrusive rock that has been enriched in potash by the addition of secondary biotite and potash feldspar. About 8 miles to the south, on Phelps Ridge in the Chiwawa district (16) of Chelan County, the Red Mountain (Royal Development) property has chalcopyrite in a breccia zone as much as 250 feet wide at the contact of gneiss and a dioritic stock. At a number of localities in the central and northern Cascade Mountains are found breccia pipes having values in copper and, in places, molybdenite. These are more or less vertical zones that are roughly circular or elliptical in plan view. They are in Tertiary volcanics and in intrusive rocks as well as pre-Tertiary rocks. The Quartz Creek copper prospect on the Middle Fork of the Snoqualmie River in King County represents this type of deposit, and some investigators consider the Sunrise deposit in Snohomish County to be a breccia pipe also. Recent exploration has shown extensive copper mineralization associated with Snoqualmie plutonic rocks in the headwaters area of the Middle Fork of the Snoqualmie River (8). Here the copper occurs in breccia pipes, stockworks, disseminations, fracture fillings, and veins in alteration areas of potash enrichment. At the Mineral Creek property in the Snoqualmie district (8), Kittitas County, chalcopyrite, pyrite, bornite, molybdenite, and pyrrhotite occur as a stockwork in granodiorite, and the same minerals occur in a 500-foot breccia contact zone between Tertiary rhyolite and basalt. The Sunset mine in the Index district (10) of Snohomish County for several years was the leading copper producer in the State. The deposit consisted of a series of lenses of copper ore along a northwest-trending shear zone in Tertiary quartz diorite. Chalcopyrite and bornite were the principal ore minerals, occurring in places as solid, massive lenses with little or no quartz gangue.

West of the crest of the Cascade Mountains most of the copper deposits are in a narrow irregular belt that extends southward from the Darrington area in northern Snohomish County to Snoqualmie Pass in King County on the south. In this belt, which includes the Darrington, Silverton, Sultan Basin, Monte Cristo, Silver Creek, and Index districts (15, 14, 12, 11, and 10), the ore deposits occur in and near granitic rocks of late Tertiary age.

East of the crest in the Cascades also, many of the copper deposits are associated with Tertiary granitic rocks, but farther to the east, in Okanogan, Ferry, Stevens, and Pend Oreille Counties, copper deposits – mostly complex ores in quartz veins – are related to Mesozoic granitic rocks. At the United Copper and nearby properties in the Chewelah district (3) of Stevens County, copper-silver-quartz veins are parallel to the schistosity of enclosing phyllite of probable Precambrian age. The mineralizing solutions apparently were derived from a diorite pluton of probable Cretaceous age that is exposed more than a mile to the south of the mine. At the Lone Star property in Ferry County, just south of the Canadian border about 4 miles west of Danville (25) chalcopyrite is disseminated and in veinlets along the foliation of schistose serpentinized dacite in a zone 50 feet wide in the hanging wall of a diabase dike.

Zinc and Lead

Zinc has been mined as the principal product at 23 mines in the State, and lead at 36 mines. Total cumulative production of zinc through 1963 has had a value of $109 million, and lead, $52 million.

Thousands of zinc and lead occurrences, usually in quartz veins, are distributed throughout most of the areas in which copper, gold, and silver are found in northeastern Washington and in the Cascade Mountains, but most of the production has come from the replacement deposits of zinc and lead in the Metaline district (29) in northern Pend Oreille County. Other important production has come from similar deposits in the Northport (28) and other districts in northern Stevens County. Eight deposits of complex ores in the Cascade Mountains have produced a little more than 1,400 tons of lead, having a value of about $300,000; most of this came from the Kaaba mine in the Nighthawk district (23). About 21,000 tons of zinc was recovered as a byproduct of copper-gold production at the Holden mine (18) in Chelan County during the years 1943 to 1957. In the western Cascades many of the zinc-lead deposits are associated with Tertiary granitic rocks, but most of the deposits in eastern Washington that can be related to igneous sources are associated with Mesozoic granitic rocks.

In the Metaline district, zinc occurs with lesser amounts of lead as large low-grade replacement deposits of disseminated sulfides in Metaline Limestone of Middle Cambrian age, generally in a zone less than 500 feet stratigraphically below the overlying Ordovician Ledbetter Slate. The ores are in the graben bounded by the Slate Creek and Flume Creek faults. The mineral composition of the ores is simple, sphalerite and galena being the common minerals. Galena appears to be concentrated near the peripheries of the ore bodies. Generally the gangue is dark-gray jasperoid formed by silicification of limestone. Most of the ores occur in breccia zones in the carbonate rocks. Production from the Pend Oreille mine in recent years has shown a ratio of about 3 parts of zinc to 1 part lead, and the ore contained about ~~[illegible]~~ 0.05 ounce of silver for each 1 percent of lead. Although the closest outcrops of the quartz monzonite and granodiorite of the Kaniksu batholith of Cretaceous age are several miles distant from the largest known ore bodies, it has been suggested that the zinc-lead deposits are related to this batholith and that metallization took place during a late stage of its intrusive history.

Although one of the large mines in the Metaline district (29), the Grandview, was closed down in recent months, the possibility of developing significant new reserves in the district is considered to be very good.

In the Northport district (28) in northern Stevens County most of the larger zinc-lead ore bodies are also in the Metaline Limestone; some are near the overlying Ordovician slate, but others are far below the top of the limestone formation. The ore bodies are not veins but are roughly tabular replacement deposits that are parallel or nearly parallel to bedding planes. Ore is localized along bedding-plane shears in several mines. Many deposits seem to be related to major or minor faults, and at some deposits, such as those at the Van Stone and Deep Creek mines, Mesozoic granite crops out nearby. A small amount (about 25,000 tons) of lead has been produced from 1916 to the present time from nearly vertical chimneys or pipes in Metaline Limestone in the Gladstone Mountain area in the eastern part of the Northport district. In plan view the chimneys are roughly circular or ellipsoidal. They appear to be localized in breccia. The ore minerals are cerussite and galena.

Uranium

Uranium has been reported in many localities in Washington, but most of the production has come from one property, the Midnite mine (34), in southern Stevens County. Here autunite and other secondary minerals and uraninite and coffinite occur in Precambrian metasedimentary rocks and Mesozoic granitic rocks at and near their contact. Small production has come from Tertiary tuffs and lake beds in southern Stevens County and from autunite-filled joints and open fractures in alaskite and pegmatite associated with biotite-quartz monzonite of probable Cretaceous age in Spokane County (A.E. Weissenborn, oral communication, 1964).

Acknowledgements

It would be impossible to fully acknowledge all the sources of information used in preparing this paper, as a large number of the more than 200 references cited in Washington Division of Mines and Geology Bulletin 37, Inventory of Washington Minerals, Part II, Metallic Minerals,[1] were used, at least indirectly. Additional help was obtained from A. R. Grant, from Peter Misch, Professor of Geology at the University of Washington, who has worked for many years in the northern Cascade Mountains, and from the following U. S. Geological Survey geologists who are currently working in northeastern Washington: A. E. Weissenborn, Robert G. Yates, Arthur B. Campbell, Lorin D. Clark, and C. D. Rinehart.

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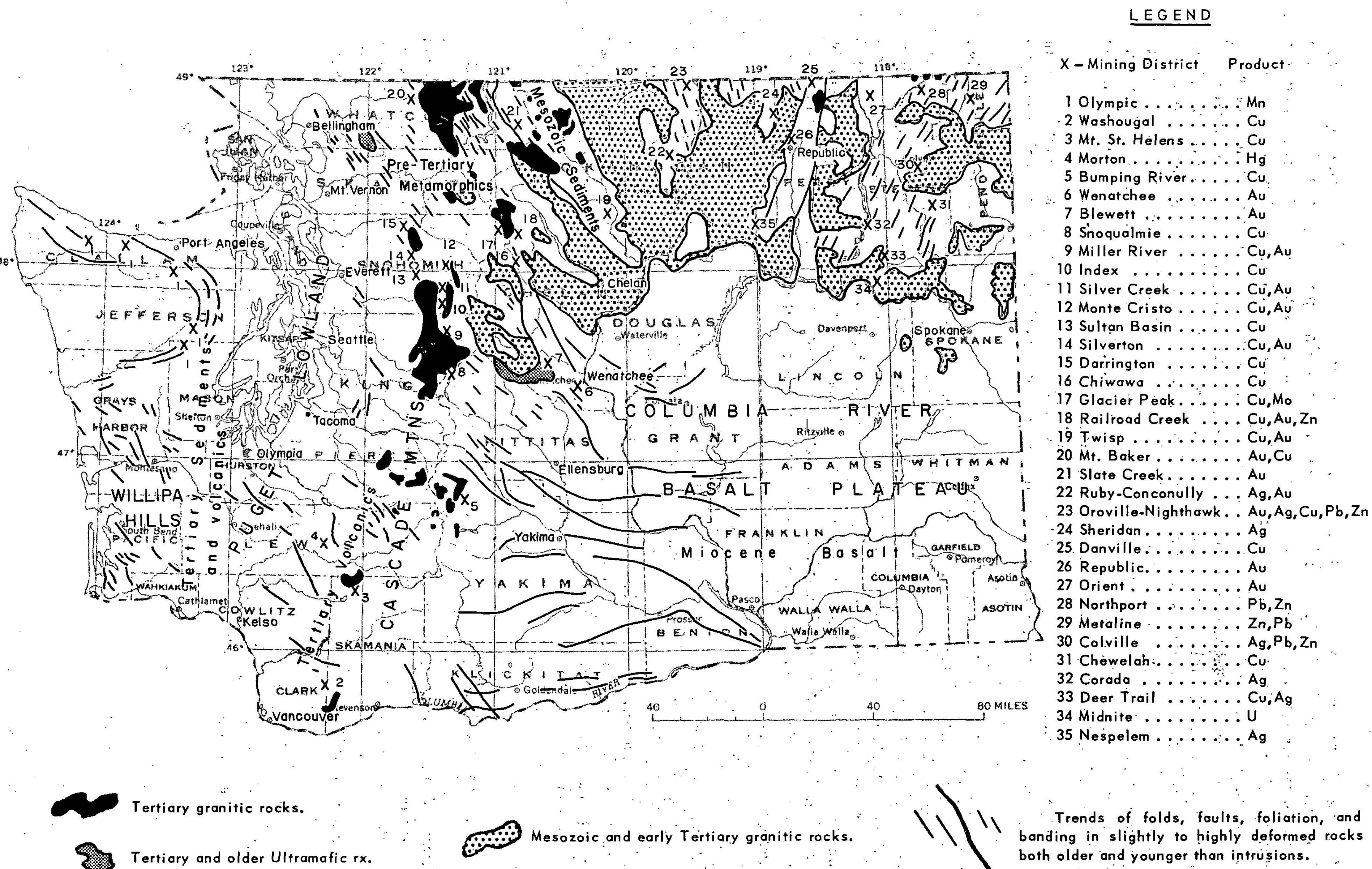

Figure 12-1.

Map showing granitic and ultramafic rocks, structural trend lines and locations and products of mining districts in Washington.

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WASHINGTON MINERAL DEPOSITS

by

Marshall T. Huntting

Washington Department of Conservation, Div. Mines and Geology

A wide variety of mineral deposits occurs in Washington. Incomplete records indicate that, from the first reported discovery of gold in 1853 through 1963, Washington's total cumulative mineral production is about $2 billion, of which about $341 million is in metallic minerals and about $1.7 billion in non-metallic minerals. All but 10 of the State's 39 counties have produced gold, silver, copper, lead, or zinc. However, by far the greatest part of the production of metals has been from the northern row of counties adjacent to the Canadian border – Pend Oreille, Stevens, Ferry, Okanogan, and Whatcom Counties – and the northern Cascade Mountains counties of Chelan and Snohomish. These are the principal areas of occurrence of Tertiary and Mesozoic intrusive rocks and pre-Tertiary metamorphic rocks.

The principal metals, in decreasing order of production value, are zinc, gold, lead, copper, silver, and uranium. Lesser amounts of tungsten, mercury, iron ore, antimony, manganese, molybdenum, and chromite have been mined.

The State of Washington can be broadly divided on the basis of rock types and structural features into the seven fairly distinct geologic areas that are described below, 1 to 7. See also Figure 12-1, to which numbers in brackets refer.

1. In the northeast is an area of slightly to moderately metamorphosed miogeosynclinal rocks of early Paleozoic age, with lesser amounts of eugeosynclinal metasedimentary rocks of late Paleozoic age and Precambrian metasedimentary rocks. In this area the structural trends are quite uniformly to the northeast. The rocks are strongly folded. Dips are steep and in places the folds are overturned to the east. Both normal and thrust faults are numerous. Intruding the older rocks in the area are large batholiths such as the Kaniksu in northern Pend Oreille County and the Colville and Loon Lake batholiths in northern and southern Stevens County. These intrusives are all thought to be Mesozoic, probably Cretaceous, in age. In western Stevens County are several small areas of Tertiary volcanic rocks. This northeastern area of Washington can be characterized as a zinc-lead province; most of the production of these metals has been from Cambrian limestones in northern Pend Oreille and Stevens Counties. Southern Stevens County also is the principal source of uranium in this State and has produced some copper and tungsten from quartz veins. The Tertiary volcanics in northwestern Stevens County have produced gold.

2. To the west in Ferry County is an area about 20 miles wide and 80 miles long north and south which is predominantly underlain by Tertiary volcanic rocks with minor sedimentary interbeds. In places these are intruded by Tertiary dacites and similar rocks. Much of this area lies within the north-northeast trending Republic graben. The Tertiary rocks in the Republic district (26, Fig. 1) are the hosts for some of the most productive gold deposits in the State.

3. Farther to the west in Okanogan County and the whole northern Cascade Mountains is a large area of pre-Tertiary low-, medium-, and high-grade metamorphic rocks which are intruded by both Mesozoic and early and late Tertiary quartz diorite and related rocks. These include schists, gneisses, migmatites, and granitic rocks. Greenstone and slightly metamorphosed sedimentary rocks, including minor fossiliferous limestones, are fairly widely distributed. Small areas are covered by sedimentary and volcanic rocks of recognized Tertiary and Mesozoic age. Structural trends in the metamorphic rocks are predominantly north-northwest. Several large thrust faults are recognized. Intrusive quartz diorites

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Copper

Twenty-four mines in the State are reported to have produced copper as their principal product. Copper occurrences are distributed throughout northeastern Washington, from the Canadian border southward in the Cascade Mountains to the central part of the State, and in a few small areas in the southern Cascades. Cumulative production through 1963 has had a value of $43,412,918.

Of a total of 122,000 tons of copper produced in Washington from 1860 through 1961, about 107,911 tons came from the Holden mine during the 20–year period it operated, from 1938 through 1957. The Holden ore body consisted of a zone of sulfide disseminations 20 to 75 feet wide, 2,500 feet long, and 2,500 feet deep in a high-grade metamorphic zone of sheared schist and amphibolite in an overturned isoclinal fold that has a northwest-trending axis and a dip of about 70 degrees to the southwest. The ore shoot was parallel to the enclosing foliated metamorphic rocks and pitched about 60 degrees to the east. The ore body was cut by numerous post-ore dikes associated with the nearby Tertiary Cloudy Pass pluton and by some possibly older dikes. The Glacier Peak (Miners Ridge) property (17), only about 8 miles to the west, contains more than 20 million tons of low-grade copper ore in one or more bodies. At this property, chalcopyrite and molybdenite are disseminated in the Cloudy Pass pluton of Tertiary age near its contact with migmatitic gneiss; some of the ore is also in the gneiss. Here, as well as at several other copper properties in the Cascades, the ore occurs along a northeast lineament that crosscuts the prevailing northwest regional trends of the range (A. R. Grant, personal communication, 1965). Also here, as in other places in the Cascades, the sulfides are associated with deuterically altered intrusive rock that has been enriched in potash by the addition of secondary biotite and potash feldspar. About 8 miles to the south, on Phelps Ridge in the Chiwawa district (16) of Chelan County, the Red Mountain (Royal Development) property has chalcopyrite in a breccia zone as much as 250 feet wide at the contact of gneiss and a dioritic stock. At a number of localities in the central and northern Cascade Mountains are found breccia pipes having values in copper and, in places, molybdenite. These are more or less vertical zones that are roughly circular or elliptical in plan view. They are in Tertiary volcanics and in intrusive rocks as well as pre-Tertiary rocks. The Quartz Creek copper prospect on the Middle Fork of the Snoqualmie River in King County represents this type of deposit, and some investigators consider the Sunrise deposit in Snohomish County to be a breccia pipe also. Recent exploration has shown extensive copper mineralization associated with Snoqualmie plutonic rocks in the headwaters area of the Middle Fork of the Snoqualmie River (8). Here the copper occurs in breccia pipes, stockworks, disseminations, fracture fillings, and veins in alteration areas of potash enrichment. At the Mineral Creek property in the Snoqualmie district (8), Kittitas County, chalcopyrite, pyrite, bornite, molybdenite, and pyrrhotite occur as a stockwork in granodiorite, and the same minerals occur in a 500-foot breccia contact zone between Tertiary rhyolite and basalt. The Sunset mine in the Index district (10) of Snohomish County for several years was the leading copper producer in the State. The deposit consisted of a series of lenses of copper ore along a northwest-trending shear zone in Tertiary quartz diorite. Chalcopyrite and bornite were the principal ore minerals, occurring in places as solid, massive lenses with little or no quartz gangue.

West of the crest of the Cascade Mountains most of the copper deposits are in a narrow irregular belt that extends southward from the Darrington area in northern Snohomish County to Snoqualmie Pass in King County on the south. In this belt, which includes the Darrington, Silverton, Sultan Basin, Monte Cristo, Silver Creek, and Index districts (15, 14, 12, 11, and 10), the ore deposits occur in and near granitic rocks of late Tertiary age.

East of the crest in the Cascades also, many of the copper deposits are associated with Tertiary granitic rocks, but farther to the east, in Okanogan, Ferry, Stevens, and Pend Oreille Counties, copper deposits – mostly complex ores in quartz veins – are related to Mesozoic granitic rocks. At the United Copper and nearby properties in the Chewelah district (31) of Stevens County, copper-silver-quartz veins are parallel to the schistosity of enclosing phyllite of probable Precambrian age. The mineralizing solutions apparently were derived from a diorite pluton of probable Cretaceous age that is exposed more than a mile to the south of the mine. At the Lone Star property in Ferry County, just south of the Canadian border about 4 miles west of Danville (25) chalcopyrite is disseminated and in veinlets along the foliation of schistose serpentinized dacite in a zone 50 feet wide in the hanging wall of a diabase dike.

Zinc and Lead

Zinc has been mined as the principal product at 23 mines in the State, and lead at 36 mines. Total cumulative production of zinc through 1963 has had a value of $109 million, and lead, $52 million.

Thousands of zinc and lead occurrences, usually in quartz veins, are distributed throughout most of the areas in which copper, gold, and silver are found in northeastern Washington and in the Cascade Mountains, but most of the production has come from the replacement deposits of zinc and lead in the Metaline district (29) in northern Pend Oreille County. Other important production has come from similar deposits in the Northport (28) and other districts in northern Stevens County. Eight deposits of complex ores in the Cascade Mountains have produced a little more than 1,400 tons of lead, having a value of about $300,000; most of this came from the Kaaba mine in the Nighthawk district (23). About 21,000 tons of zinc was recovered as a byproduct of copper-gold production at the Holden mine (18) in Chelan County during the years 1943 to 1957. In the western Cascades many of the zinc-lead deposits are associated with Tertiary granitic rocks, but most of the deposits in eastern Washington that can be related to igneous sources are associated with Mesozoic granitic rocks.

In the Metaline district, zinc occurs with lesser amounts of lead as large low-grade replacement deposits of disseminated sulfides in Metaline Limestone of Middle Cambrian age, generally in a zone less than 500 feet stratigraphically below the overlying Ordovician Ledbetter Slate. The ores are in the graben bounded by the Slate Creek and Flume Creek faults. The mineral composition of the ores is simple, sphalerite and galena being the common minerals. Galena appears to be concentrated near the peripheries of the ore bodies. Generally the gangue is dark-gray jasperoid formed by silicification of limestone. Most of the ores occur in breccia zones in the carbonate rocks. Production from the Pend Oreille mine in recent years has shown a ratio of about 3 parts of zinc to 1 part lead, and the ore contained about 0.05 [illegible] ounce of silver for each 1 percent of lead. Although the closest outcrops of the quartz monzonite and granodiorite of the Kaniksu batholith of Cretaceous age are several miles distant from the largest known ore bodies, it has been suggested that the zinc-lead deposits are related to this batholith and that metallization took place during a late stage of its intrusive history.

Although one of the large mines in the Metaline district (29), the Grandview, was closed down in recent months, the possibility of developing significant new reserves in the district is considered to be very good.

In the Northport district (28) in northern Stevens County most of the larger zinc-lead ore bodies are also in the Metaline Limestone; some are near the overlying Ordovician slate, but others are far below the top of the limestone formation. The ore bodies are not veins but are roughly tabular replacement deposits that are parallel or nearly parallel to bedding planes. Ore is localized along bedding-plane shears in several mines. Many deposits seem to be related to major or minor faults, and at some deposits, such as those at the Van Stone and Deep Creek mines, Mesozoic granite crops out nearby. A small amount (about 25,000 tons) of lead has been produced from 1916 to the present time from nearly vertical chimneys or pipes in Metaline Limestone in the Gladstone Mountain area in the eastern part of the Northport district. In plan view the chimneys are roughly circular or ellipsoidal. They appear to be localized in breccia. The ore minerals are cerussite and galena.

Uranium

Uranium has been reported in many localities in Washington, but most of the production has come from one property, the Midnite mine (34), in southern Stevens County. Here autunite and other secondary minerals and uraninite and coffinite occur in Precambrian metasedimentary rocks and Mesozoic granitic rocks at and near their contact. Small production has come from Tertiary tuffs and lake beds in southern Stevens County and from autunite-filled joints and open fractures in alaskite and pegmatite associated with biotite-quartz monzonite of probable Cretaceous age in Spokane County (A.E. Weissenborn, oral communication, 1964).

Acknowledgements

It would be impossible to fully acknowledge all the sources of information used in preparing this paper, as a large number of the more than 200 references cited in Washington Division of Mines and Geology Bulletin 37, Inventory of Washington Minerals, Part II, Metallic Minerals,[1] were used, at least indirectly. Additional help was obtained from A. R. Grant, from Peter Misch, Professor of Geology at the University of Washington, who has worked for many years in the northern Cascade Mountains, and from the following U. S. Geological Survey geologists who are currently working in northeastern Washington: A. E. Weissenborn, Robert G. Yates, Arthur B. Campbell, Lorin D. Clark, and C. D. Rinehart.

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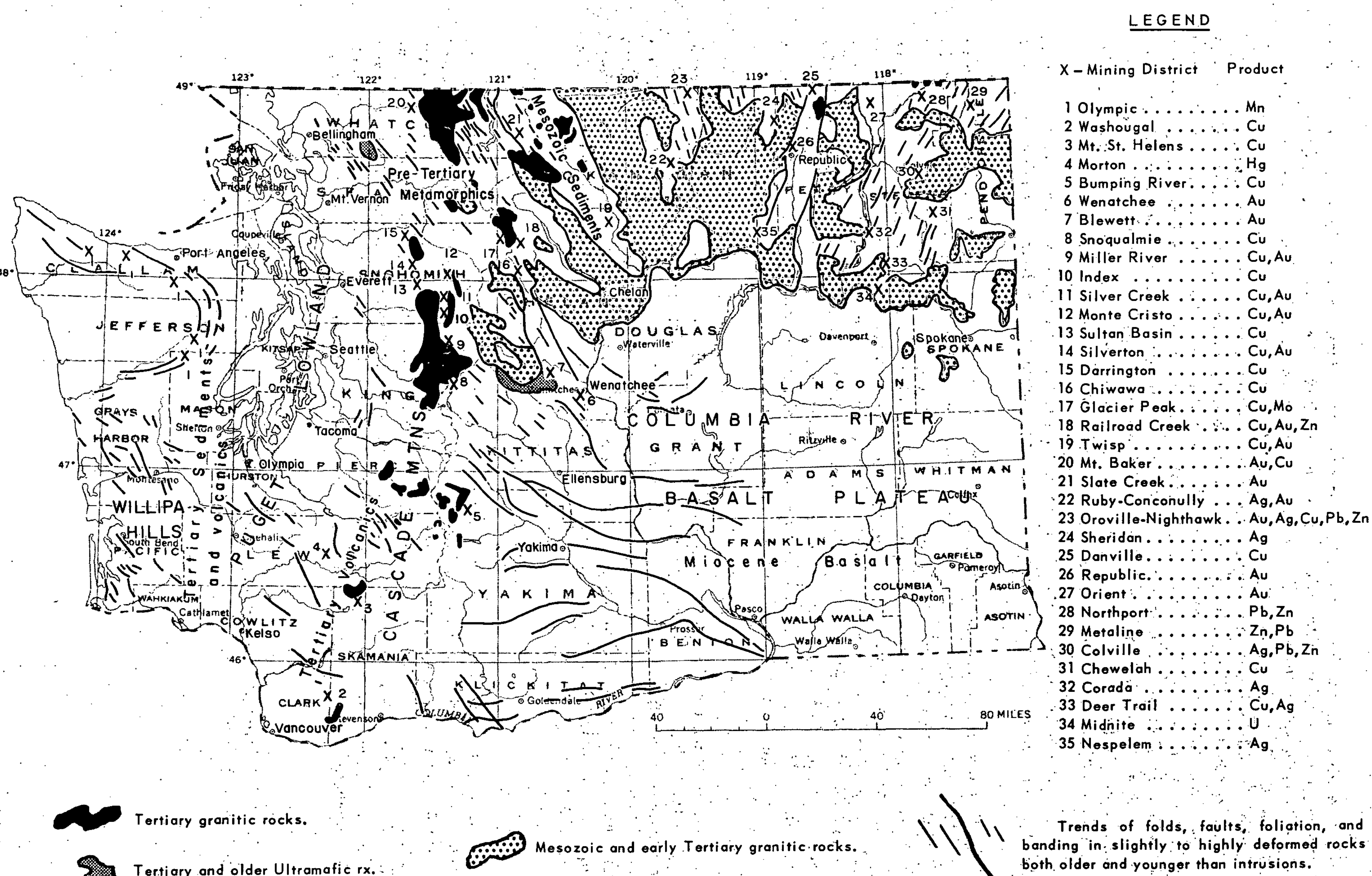

Figure 12-1

Map showing granitic and ultramafic rocks, structural trend lines and locations and products of mining districts in Washington.

Wash Dept Nat Res

AREA WA Gems

GEM AND ORNAMENTAL STONE LOCALITIES OF WASHINGTON

(From Bulletin 37, Part 1, Inventory of Washington Minerals--Nonmetallic Minerals)

CLALLAM COUNTY

1. * Name: Olympic Peninsula. Loc: Olympic Peninsula, particulary along west coast near mouth of Quillayute River. Descr: Spherulitic jasper, originating in association with manganese deposits of the Olympic Peninsula, occurs in gravels at mouth of Quillayute River and up and down coast in that general vicinity. Value: Of value to collectors only. Ref: 3, p. 19.

1A. Name: Agate Bay. Loc: At Agate Bay on Strait of Juan de Fuca, just W. of Crescent Bay, in T. 31 N., R. 8 W. Descr: Agates in gravel beaches have weathered out of glacial drift and possibly out of basalt nearby. Value: Of value to collectors. Ref: 3, p. 18-19.

1B. Name: Ed. B. Loc: SE¼ sec. 24, (30-11W), 6½ mi. W. of Lake Crescent. Descr: Spherulitic jasper in masses as much as 6 in. across filling spaces between basalt pillows. Value: Of value to collectors only. Ref: 3, p. 19.

1C. Name: Lake Crescent. Loc: In gully at 2,000-ft. elevation, 1 mi. NW of W. end of Lake Crescent. Descr: Boulder of spherulitic jasper weighing several tons. Value: Of value to collectors. Ref: 3, p. 19.

SKAGIT COUNTY

2. Name: James Stephens. Loc: NW¼NW¼ sec. 16, (34-5E). Descr: Ferrous anthophyllite somewhat serpentinized. Has also been called nephrite jade and jadeite. Mining operations of Northwest Talc & Magnesium Co may have removed or covered the anthophyllite. Value: Of value to c lectors only, although a few pounds were sold as jade by the origina owner. Ref: 3, p. 29.

2A. Name: Scott. Loc: SW¼SE¼ sec. 27, (36-5E), 6 mi. NE of Sedro W Descr: Material similar to that at James Stephens property is sai occur here. Value: Of value to collectors only. Ref: 3, p. 29.

SNOHOMISH COUNTY

3. Name: Darrington. Loc: Vicinity of Darrington. Descr: A bla (gabbro?) that contains chatoyant feldspar and presents a ver appearance when polished. Value: Appears to have possibilit ornamental stone.

PIERCE COUNTY

4. Name: Siegmund Ranch. Loc: 1 mi. E. of Clay City, near cen (17-5E). Descr: a 1-ft. exposure on the extension of a 25- contains crystals that project inward from both walls. Wh the center, their tips are amethystine. Value: Of value Ref: 3, p. 28.

THURSTON-LEWIS COUNTY

5. Name: Tono. Loc: Tono coal mining district. Descr: Agate and chalcedony. Value: Of value to collectors only. Ref: 3, p. 30.

5A. Name: Skookumchuck. Loc: In canyon of Skookumchuck River, S. of Vail. Descr: Chalcedony containing minutely banded green chert. Value: Of value to collectors only. Ref: 3, p. 30.

6. Name: Newaukum River. Loc: Upper Newaukum River. Descr: Agate and chalcedony are common in stream gravels. Value: Of value to collectors only. Ref: 2, p. 46, 3, p. 25.

6A. Name: Chehalis Valley. Loc: Secs. 24 and 25, (13-4W) and in roadside ditches between Adna and PeEll. Descr: Agates in sandy clay. Value: Of value to collectors only. Ref: 3, p. 26.

6B. Name: Centralia. Loc: S½NE¼ Sec. 12, (14-2W), 4½ mi. E. of Centralia. Descr: Agate fragments at surface of the ground. Value: Of value to collectors only.

6C. Name: Fall Creek. Loc: NW¼NW¼ Sec. 35, (15-1E). Descr: Plasma and bloodstone as cavity fillings in basalt and as float near an abandoned quarry. Value: Of value to collectors only. Ref: 3, p. 27.

6D. Name: Doty. Loc: Near E. ¼ cor. Sec. 15, (14-5W). Descr: Bed composed largely of pyroxene crystals, some of gem quality, occurs interbedded with Eocene tuff. Value: Of value to collectors only. Ref: 3, p. 27.

COWLITZ COUNTY

. Name: Silver Lake. Loc: W½ Sec. 5, (9-1E). Descr: Agate, jasper, and highly colored petrified wood occur abundantly in the soil above underlying hardpan at depths of 6 in. to 2 ft. Value: Of value to collectors only. Ref: 3, p. 20.

PACIFIC COUNTY

me: Bear River. Loc: NW¼ Sec. 5, (10-10E), 2 mi. N. of mouth of Bear ver. Descr: Agates in gravel on bedrock at base of Pleistocene sands clays. Value: Of value to collectors only. Ref: 3, p. 27.

CLARK COUNTY

Red Rock quarry. Loc: Secs. 8 and 9, (1-3E) near Camas. Descr:

SKAMANIA COUNTY

8. Name: Wind River. Loc: On Wind River, about 17 mi. N. of Carson. Descr: Opals said to occur as amygdules in lava buttes. Not known whether the opal is of precious or common variety. Value: Unknown, but warrants investigation. Ref: 3, p. 29.

9. Name: Rainbow prospect. Loc: NW¼ sec. 5, (2-5E). Descr: Small quantity of amethystine quartz on dump of a shaft. Value: Of value to collectors only. Ref: 3, p. 29.

9A. Name: Stevenson. Loc: Near E. Fk. Spring Creek, about 4 mi. NW of Stevenson. Descr: Buff-gray chalcedony as cavity fillings as much as 10 in. long in surface soil. Value: Of value to collectors only. Ref: 3, p. 29.

KITTITAS COUNTY

10. Name: Horse Canyon (Virden). Loc: W½ Sec. 34, (20-17E). Descr: Attractive blue chalcedony. Value: Of value to collectors only. Ref: 3, 23.

10A. Name: Cumby. Loc: SE¼ sec. 21, (21-15E) on Middle Fk. Teanaway River. Descr: Attractive jasp-agate in veinlets in basalt. Value: Several hundred pounds were mined and sold in 1955.

10B. Name: Lion Gulch. Loc: NE¼ sec. 24, (21-17E) in Lion Gulch. Descr: Green sandstone suitable for building stone. Value: Quarried in 1954 by Washington Green Sandstone, Inc., Moses Lake, Washington.

10C. Name: Redtop-Cle Elum Lake. Loc: A belt of Teanaway basalt 1 to 4 mi. wide extending about 50 mi. westward to Cle Elum Lake and beyond. Descr: Agates and chalcedonic nodules and geodes in Teanaway basalt. In sec. 16, (21-17E) are abundant agates, including blue varieties, and geodes in soil and basalt bedrock. Value: Of value to collectors only. Ref: 3, p. 23-24.

10D. Name: Liberty. Loc: At heads of Williams and Boulder Creeks. Descr: Abundant agate-filled geodes reported. Probably in Teanaway basalt. Value: Should be investigated. Ref: 3, p. 23.

10E. Name: Squaw Creek. Loc: In Squaw Creek area 10 mi. E. of Yakima R. Descr: Onyx agate reported as massive interbasalt-flow filling. Va Some material is said to have been sold. Ref: 3, p. 24.

11. Name: Ginkgo Petrified Forest State Park. Loc: In E. central pa T. 17 N., R. 22 E. Descr: Opalized logs and log fragments abunda in the basalt and interbasalt sediments. Value: Currently a sta park; hence removal of samples prohibited. Ref: 3, p. 24-25.

DOUGLAS COUNTY

12. Name: Moses Coulee. Loc: Along the Coulee. Descr: Fire opal reportedly found here as cavity fillings. Value: Unknown, but warrants investigation. Ref: 2, p. 46, 3, p. 20.

GRANT COUNTY

13. Name: Saddle Mountains. Loc: Along summit of Saddle Mountains. Descr: Opalized wood is abundant. Value: Suitable for ring stones, brooches, etc. Ref: 1, p. 395-401, 426-430; 3, p. 21.

YAKIMA COUNTY

14. Name: Mount Adams. Loc: SW cor. sec. 27, (8-11E). Descr: Light pinkish-gray andesite that breaks into sheets from ½ to 3 or 4 in. thick and 6 to 8 ft. across. Value: Has been used for flagstones, stone benches, and other decorative purposes. Recently operated by Joe Marsten, Portland, Oregon.

15. Name: Dog Lake. Loc: On both sides of Clear Creek from Dog Lake to Tieton River. Descr: Light-gray andesite which breaks into long flat tablets of various sizes. Value: Suitable for flagstones and patio blocks. Currently operated in a small way.

16. Name: Yakima. Loc: NE¼ sec. 12, (13-18E). Descr: Red and maroon jasper with irregular yellow opal phases occurs in a 1-ft. bed associated with basalt. Value: Suitable for small ornaments. Ref: 3, p. 32.

17. Name: Barrel Springs. Loc: sec. 18, (12-24E). Descr: Opalized wood. Value: Used by Indians for arrowheads. Suitable for cutting and polishing. Ref: 3, p. 32.

18. Name: Sunnyside-White Bluffs road. Loc: In small gullies crossed by the Sunnyside-White Bluffs road, sec. 26 or 35, (12-23E). Descr: Exposures of a bed composed of a tangle of petrified wood fragments. Value: Suitable for cutting and polishing. Ref: 3, p. 32.

19. Name: Sunnyside. Loc: Reported on N. side of Yakima River W. of Sunnyside. Descr: Agates in smooth washed gravel. Value: Unknown. Ref: 3, p. 31.

FRANKLIN COUNTY

9. Name: White Bluffs. Loc: Along E. bank of Columbia River NW of Pasco, in T. 11 N., R. 28 E. Descr: Agates in iron-stained forming bluffs. Value: Of value to collectors only. Ref: 3, p. 20-21.

KLICKITAT COUNTY

21. Name: Roosevelt. Loc: secs. 16 and 17, (3-21E). Descr: Abundant opalized wood between basalt flows and exposed in soil. Value: Of value to collectors only. Ref: 3, p. 25.

21A. Name: Laurel. Loc: NE¼ sec. 10, (5-11E). Descr: Red scoria. Value: Currently produced by William Tubbs, Glenwood, Washington.

OKANOGAN COUNTY

22. Name: Tunk Creek. Loc: N½ sec. 5, (35-27E). Descr: Thulite occurs as lenses as much as 3 ft. across in hornblende schist. Value: Has been used locally in brooches and fireplace facing. Note: Small crystals of sapphire and ruby have been found associated with the thulite. Ref: 3, p. 27; 9, p. 856; 10, p. 519-527.

23. Name: Roosevelt mine. Loc: Center sec. 24, (40-30E). Descr: Zoisite occurs with epidote, green garnet, and other contact metamorphic minerals. Value: Of value to collectors only. Ref: 12, p. 45.

24. Name: Nespelem. Loc: Reported in N. center sec. 4, (31-30E). Descr: Turquoise. Value: Unknown; warrants confirmation. Ref: 3, p. 27.

FERRY COUNTY

25. Name: Republic. Loc: Reported 15 mi. N.E. of Republic. Descr: Amethyst, details unknown. Value: Unknown. Ref: 3, p. 20.

STEVENS COUNTY

26. Name: Smoky Bullion. Loc: NE¼ sec. 3, (37-39E). Descr: Thulite occurs as ½-in. veinlet. Value: Of interest to collectors only. Ref: 3, p. 30.

PEND OREILLE COUNTY

27. Name: Timber Mountain. Loc: W. center sec. 29, and S. center sec. 32, (36-4E). Descr: Thulite crystals ½ in. or less in size occur in pegmatite. Value: Of value to collectors only. Ref: 3, p. 28; 8, p. 57.

28. Name: Reis. Loc: On W. bank of Pend Oreille River in sec. 12, (31-45E). Descr: Amethyst crystals in a quartz vein. Value: Of value to collectors only. Ref: 3, p. 28; 5, p. 46.

LINCOLN COUNTY

29. Name: Mondovi. Loc: Reported 1 mi. N.W. of Mondovi; also a mile or so N. of Mondovi. Descr: Fire opals said to be large and of excellent quality. Value: Unknown; warrants investigation. Ref: 3, p. 27.

WHITMAN COUNTY

30. Name: Hole in the Ground (Bach). Loc: On farm of H. C. Bach, probably in NW¼NE¼ sec. 22, (2041E). Descr: Sheeted metamorphic rock, in various shades of red, purple, and brown, breaks into slabs 1 to 2 in. thick and several feet across. Value: Quarried occasionally and used for flagstones, patio paving, table tops, and benches.

31. Name: Ringo. Loc: On hill W. of Ringo station in sec. 18, (16-46E). Descr: 75-ft. bands of quartz, some of which is amethystine. Value: Probably of value to collectors. Ref: 3, p. 31; 4, p. 75.

32. Name: Whelan. Loc: SW¼ sec. 20, (15-46E). Descr: Precious opal occurs as cavity fillings in basalt at depth of 22 ft. Value: Deposit operated commercially in 1891-1892. Sales amounted to $5,762 in 1891. Now nonoperative but may still contain good opal. Ref: 2, p. 46; 3, p. 30-31; 6, p. 776; 11, p. 874.

33. Name: Moses. Loc: sec. 17, (11-45E). Descr: Precious opal said to occur in a prospect pit and as float along railway below prospect. Value: Warrants confirmation. Ref: 3, p. 31; 7.

QUARTZ CRYSTALS

WHATCOM COUNTY

34. Name: Yellow Aster Butte. Loc: Near S. ¼ cor. sec. 18, (40-9E). Descr: Quartz crystals 1/8 to 4 in. long in vugs in quartz veins. Value: Probably of value to collectors only.

JEFFERSON COUNTY

35. Name: Mount Anderson. Loc: NW¼SW¼ sec. 28, (26-5W). Descr: Clear quartz crystals as much as 2 in. long are said to be quite numerous. Value: Probably of value to collectors only. Ref: 3, p. 22.

36. Name: Rustler Creek. Loc: SW¼SW¼ sec. 31, (25-7W). Descr: Quartz crystals 2 in. long and 1 to 1½ in. in diameter occur in open portions of a quartz vein. Value: Of value to collectors only. Ref: 3, p. 22.

SNOHOMISH COUNTY

37. Name: Silvertip Peak. Loc: Reported near Weden Creek-Silver Creek divide SE. of Mackinaw prospect. Descr: A few clear quartz crystals said to have been found, one of which was 4 in. long and 2 in. in diameter. Value: Unknown; warrants investigation. Ref: 3, p. 30.

KING COUNTY

38. Name: Devil's Canyon. Loc: S½ sec. 27, (25-10E), 300 ft. above Devil's Canyon prospect. Descr: Vuggy zone about 400 ft. wide in which are many clusters of clear quartz crystals, most of the crystals being less than 2 in. long and ½ in. in diameter. Value: Probably of value to collectors only. Ref: 3, p. 23.

39. Name: Clipper. Loc: N. center sec. 1, (23-11E). Descr: Vuggy zone contains clear quartz crystals. Value: Might be useful in electronics; warrants investigation. Ref: 3, p. 23.

40. Name: Denny Iron. Loc: NE¼ sec. 6, (22-11E). Descr: Vugs and joint planes lined with quartz crystals. Excellent crystals have been found in float. Value: Deserves prospecting. Ref: 3, p. 22-23.

KITTITAS COUNTY

41. Name: Lake Cle Elum. Loc: On W. shore of Lake Cle Elum near prominent beach where island exists at high water. Probably in sec. 29, (21-14E). Descr: Quartz crystals in geodes. Value: Of value to collectors only. Ref: 3, p. 24.

CHELAN COUNTY

42. Name: Crown Point mine. Loc: SE¼ sec. 8, (31-16E), at head of cirque basin W. of Lyman Lake in long adit 200 ft. below molybdenite vein. Descr: Vuggy zone in diorite contains clusters of quartz crystals as much as 2 in. long. Value: Probably of value to collectors only. Ref: 3, p. 18.

OKANOGAN COUNTY

43. Name: Early Winters Creek. Loc: On mountain just NW. of lower part of Early Winters Creek. Descr: Said to be deposit of large, slightly smoky quartz crystals. Value: Unknown; should be investigated. Ref: 3, p. 27.

44. Name: Sheridan district. Loc: Area at head of E. Fk. Toroda Creek. Descr: Workings in this vicinity said to expose quartz crystals of fairly large size. Value: Unknown; should be investigated. Ref: 3, p.27.

WHITMAN COUNTY

45. Name: Colton. Loc: Near center sec. 7, (13-46E), on Bald Butte near Colton. Descr: Smoky quartz crystals said to be numerous in a sand pit. Value: Warrants investigation. Ref: 3, p. 31.

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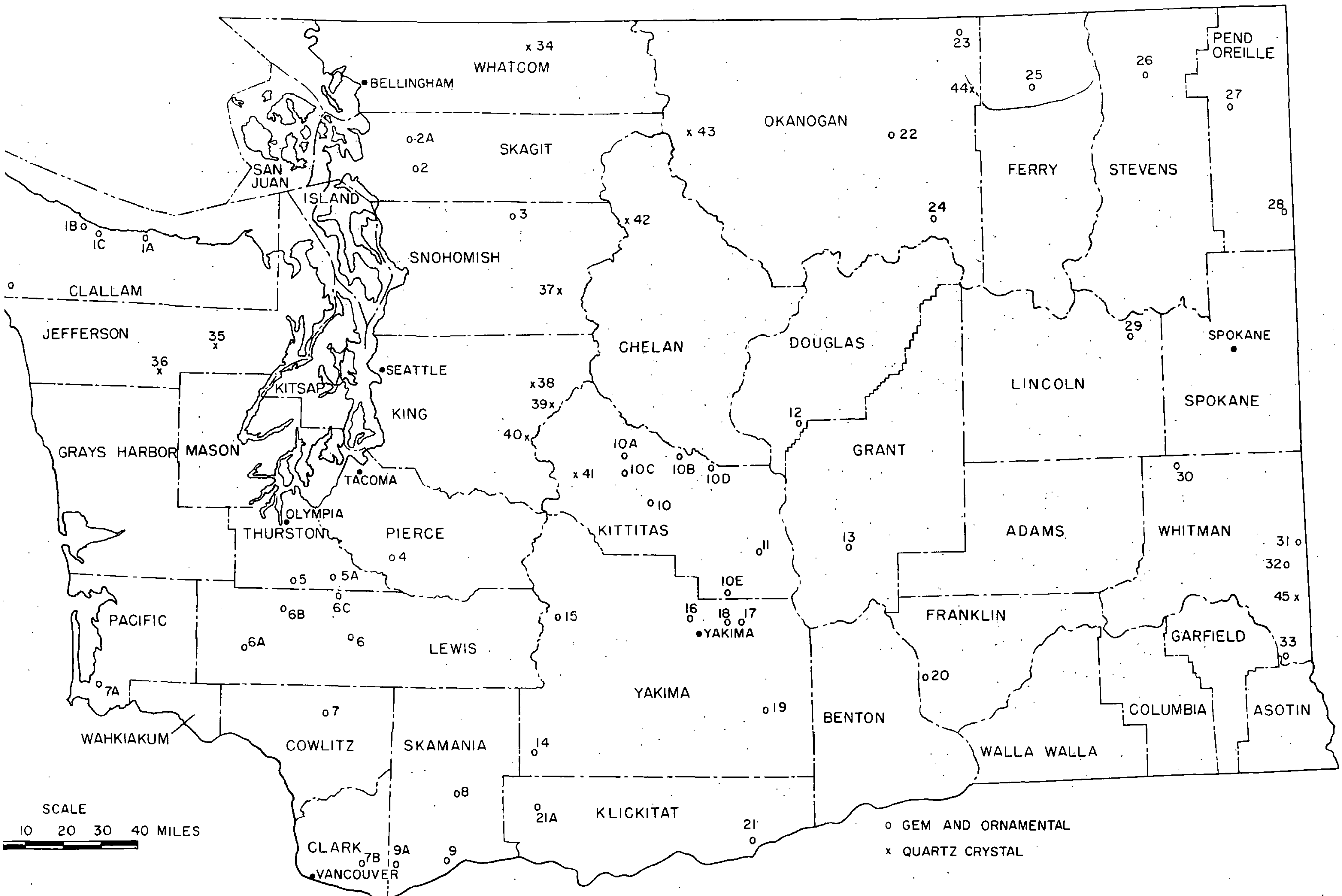
WHATCOM
BELLINGHAM
SKAGIT
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ISLAND
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MASON
TACOMA
OLYMPIA
THURSTON
PIERCE
PACIFIC
LEWIS
WAHKIAKUM
COWLITZ
SKAMANIA
CLARK
VANCOUVER
OKANOGAN
CHELAN
DOUGLAS
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YAKIMA
KLICKITAT
GRANT
BENTON
FERRY
STEVENS
PEND OREILLE
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A quartz–aragonite–talc schist from the lower Skagit Valley, Washington

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Abstract

A thin metaperidotite layer containing the assemblage quartz + aragonite + talc crystallized under blueschist facies conditions in the Darrington Phyllite, northwestern Washington. It is inferred from this occurrence that the stability field of talc + $CaCO_3$ + quartz extends across the calcite–aragonite phase boundary.

Introduction

On the basis of field evidence, talc was added by ...ley (1948, 1951) to Bowen's (1940) list of minerals to be expected during the progressive metamorphism of siliceous dolomite. Experimental work in the mixed volatile system CaO–MgO–SiO_2–H_2O–CO_2 has subsequently confirmed a stability field for the mineral pair talc + calcite (Metz *et al.*, 1968; Gordon and Greenwood, 1970; Skippen, 1971, 1974; Slaughter *et al.*, 1975). At lower temperatures, or higher CO_2-fugacities, talc + calcite + CO_2 react to form dolomite + quartz + H_2O; at higher temperatures, talc + calcite + quartz react to tremolite + CO_2 + H_2O, and talc + calcite react to tremolite + dolomite + CO_2 + H_2O.

However, talc is not common in metamorphosed siliceous dolomite (*e.g.* Melson, 1966; Hutcheon and Moore, 1973), and its absence has been ascribed to a number of factors, *viz.* the narrow field of stability of talc + calcite on the T–X_{CO_2} diagram (Skippen, 1971, 1974; Slaughter *et al.*, 1975), production of a low-temperature, very CO_2-rich fluid by buffering along the reaction curve dolomite + potash feldspar + H_2O = phlogopite + $CaCO_3$ + CO_2 (Gordon and Greenwood, 1970; Trommsdorff, 1972), low pressures of metamorphism (Skippen, 1974), and high temperatures of metamorphism (Slaughter *et al.*, 1975).

This paper describes a rock containing the mineral assemblage talc + quartz + aragonite, from which it is inferred that the field of talc + $CaCO_3$ + quartz extends across the calcite–aragonite phase boundary.

Regional setting

The quartz–aragonite–talc schist occurs as a 1 to 3 m wide layer within graphitic phyllite in a small roadside quarry overlooking the Skagit River, on the South Skagit Highway, 2 1/2 miles east of its junction with Washington State Highway 9 (Clear Lake Quadrangle). The rocks in the vicinity of the quarry belong to the Darrington Phyllite, a unit of pelites, semipelites, and plagioclase-rich psammites, which is conformably overlain by the metabasaltic Shuksan Greenschist, an actinolitic greenschist with blueschist intercalations (Vance, 1957; Misch, 1959, 1966; Bryant, 1955; Jones, 1959). The metamorphism of this sequence was interpreted by Misch (1959) as representing an intermediate P/T range within a comprehensively-defined blueschist facies. Within this subfacies range, crossite and crossite–glaucophane schists formed under higher, and actinolitic greenschists, under lower oxygen fugacities (confirmed by Brown, 1974). Epidote is abundant, whereas lawsonite occurs sporadically in some phyllites and metapsammites, and jadeite has not been found, although pyroxenes in the chloromelanite range (optically) occur in some metabasalts south of the Skagit (Bryant, 1955; Vance, 1957; Jones, 1959). Aragonite has recently been identified in blueschist ten miles east of the locality here described.

At the quarry, the country-rock graphitic phyllites contain phengite, chlorite, quartz, and albite. Some 100 yards farther west graphitic phyllite contains accessory lawsonite and epidote, as well as what appears to be aragonite being replaced by calcite. The various phyllites contain the record of an S_1, S_2, S_3 sequence. S_1 survives in some panels between S_2 planes. The dominant foliation S_2 parallels the axial plane of tight folds of S_1, with major transposition of phyllosilicate and graphite layers. Asymmetric open folding of S_2 has led to an oblique incipient S_3, with further transposition of graphite and some phyllosilicate.

Quartz–aragonite–talc schist

The thin quartz–aragonite–talc schist forms a flattened isoclinal fold of S_1. Except in the narrow hinge, all foliation seen in the talc layer represents S_2, which is marked by strongly aligned talc flakes, mostly much less than 0.5 mm long, accompanied by minor chlorite. S_2 is openly microfolded. This chlorite-talc fabric is partially replaced by 1 to 4 mm quartz and aragonite xenoblasts, commonly elongate parallel to S_2, and by S_2-elongate glomeroblastic aggregates of both minerals. Some quartz and aragonite crystals include trains of S_2 chlorite–talc fabric. There is no visible sign of reaction between the talc and the later-formed quartz and aragonite (Fig. 1).

The talc layer is sharply bordered by originally nearly monomineralic chlorite schist several millimeters thick. The chlorite fabric is identical to that of talc and is similarly and extensively replaced by S_2-elongate quartz xenoblasts which include trains of S_2 fabric of chlorite, openly folded in places. The chlorite selvage clearly represents a tectonically drawn-out blackwall reaction zone between metaperidotite and enclosing metasediment; the talc schist layer, which contains accessory chromite and a variety of sulfides containing Ni, Fe, and Cu, is all that remains of the metaperidotite at the outcrop. The chlorite selvage lacks carbonate but contains minor tremolite in discrete layers (in one sample, at the talc–chlorite boundary).

Although the replacement quartz and aragonite postdate the talc and chlorite S_2 fabric and its open microfolding, they were nevertheless affected by considerable late-stage deformation. Both show strained extinction, and aragonite has secondary polysynthetic twinning. Moreover, widely spaced S_3 planes oblique to S_2 cut the replacement quartz xenoblasts, which at such shears are locally granulated and annealed as fine-grained mosaic. This feature is best displayed in the chlorite selvage which also shows local transposition and recrystallization of chlorite in S_3. The same pattern is shown less distinctly in the talc layer, involving transposition of talc into S_3. An irregular growth of minor amounts of calcite has formed at the expense of some of the aragonite.

Thus, the main growth of quartz and aragonite took place after formation of S_2 but predates S_3. Talc crystallized during movement on S_1, recrystallized during formation of S_2 and recrystallized again, in minor amounts, on S_3. We therefore infer that the intimate association of talc, aragonite, and quartz constitutes a stable assemblage. Tremolite did not form as a reaction phase between talc and introduced

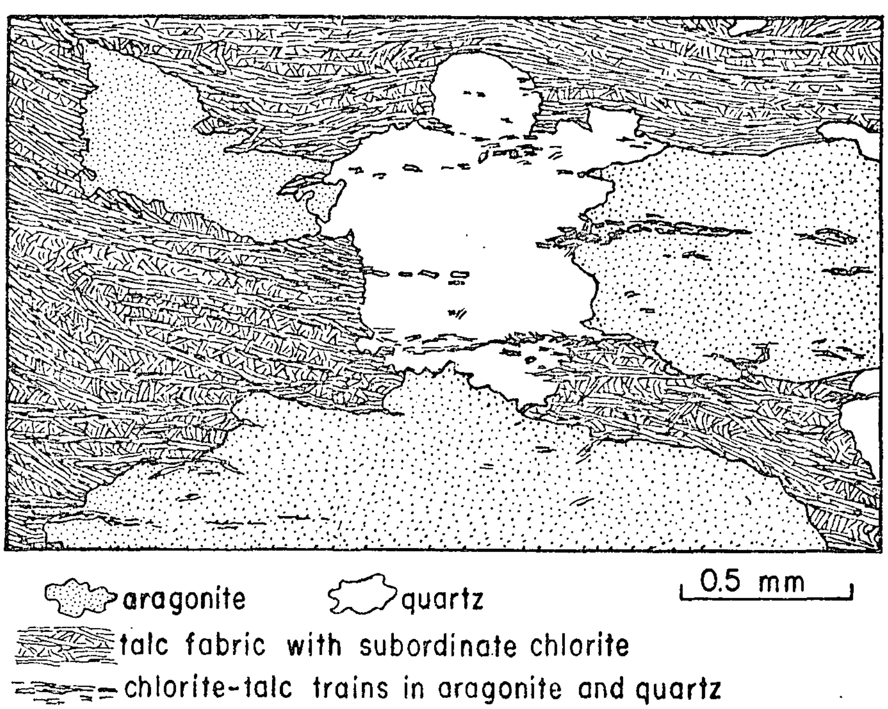

FIG. 1. Chlorite-bearing talc schist partially replaced by aragonite and quartz.

TABLE 1. Microprobe analyses of phases in talc schist

	Chlorite	Talc	Chromite		Aragonite
SiO_2	29.3	61.6	–		–
TiO_2	.01	.00	.11		–
Al_2O_3	16.4	.03	12.1		–
Cr_2O_3	3.9†	.05	52.3		.00
FeO*	12.2	4.45	23.6	$FeCO_3$	.04
MgO	25.1	28.7	9.47	$MgCO_3$	.15
CaO	.06	.01	.09	$CaCO_3$	98.69**
MnO	.19	.03	.54	$MnCO_3$	.00
NiO	.33	.16	.09	$NiCO_3$	.03
[illegible]	.09	.10	–		–
[illegible]	.02	.02	–		–
				$SrCO_3$	1.09
	87.60	95.15	98.30		100.00

* total Fe as FeO † very variable ** by difference

carbonate and silica, although it did grow in minor amounts on S_2 in the chloritic blackwall, where f_{H_2O} was presumably higher than in the talc layer.

Conclusions

Aside from Fe in the talc and Sr in the aragonite, the compositions of the talc, aragonite, and quartz can be rather well expressed by the system $CaO-MgO-SiO_2-H_2O-CO_2$ (Table 1). The stabilizing effect of Fe in the talc will be more than counterbalanced by Fe in tremolite, the alternate silicate phase, the over-all effect being minimal (Rice, 1975; Thompson, 1975). Similarly, the effect of Sr in aragonite is likely to be counterbalanced by Mg in calcite, the alternate carbonate phase; again, the overall effect on the stability of the assemblage talc–aragonite–quartz will be minimal (see also Skippen and Hutcheon, 1974).

South of the Skagit River, the temperature of the metamorphism of the Darrington Phyllite and Shuksan Greenschist cannot have exceeded ≈400°C, the upper limit of stability of lawsonite (Crawford and Fyfe, 1965; Newton, 1966; Liou, 1971). Pressures of 7 and 9 kilobars are required to stabilize aragonite at 300°C and 400°C respectively (Johannes and Puhan, 1971). The aragonite formed in the course of the regional metamorphism, and therefore at temperatures most likely high enough to ensure its back-reaction to calcite, had it formed from strained calcite in the calcite stability field (Brown *et al.*, 1962). We therefore conclude that natural talc, aragonite, and quartz are a stable paragenesis at pressures in excess of the calcite–aragonite inversion curve. Even if the talc + calcite stability field contracts with increasing pressure, as claimed by Slaughter *et al.* (1975), it is still in existence at pressures high enough to convert calcite to aragonite.

Acknowledgments

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