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DIVISION OF GEOLOGY AND EARTH RESOURCES
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HEAT FLOW AND GEOTHERMAL STUDIES IN THE STATE OF WASHNGTON

August 1985

by

David D. Blackwell, John L. Steele,
and Shari A. Kelley

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Prepared under U.S. Department of Energy
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INTRODUCTION

Existing geothermal gradient and heat flow data for the state of Washington are summarized in this report. In addition, information on mean-annual ground surface temperatures is included. The data on which this report are based are published heat flow and geothermal gradient studies, and data collected by personnel from the Geothermal Laboratory at Southern Methodist University in conjunction with J. Eric Schuster and Mike Korosec of the Washington Department of Natural Resources (DNR). These data consist of accurate, detailed temperature-depth measurements in selected available holes throughout the State of Washington made between 1979 and 1982. Measurements of thermal conductivity on selected rock samples from these drill holes and ancilliary information required to assess the significance of the data and calculate heat flow values were obtained as well. Also included in this report is a brief discussion of temperature data based on logs made by the U.S. Geological Survey Water Resources Division (WRD) in the early 1970's. Additional detailed, temperature-depth logs collected by personnel at Washington State University (WSU) over many years (Stoffeli and Widness, 1983) are not discussed.

In the first section of the report, information is presented on the mean-annual ground-surface temperatures throughout the state of Washington. In the second part of the report the various geothermal data are presented and the heat flow and geothermal gradient results from each physiographic province within the state of Washington are discussed. In the third part of the report these data are interpreted in terms of average regional heat flow and depth of isotherms. Listings of temperature versus depth for individual drill holes are available on open file at the DNR office in Olympia. Only selected temperature-depth logs of special interest are illustrated in this report.

BACKGROUND OF MEASUREMENTS

The history of geothermal measurements in Washington began in the 1930's when U.S. Geological Survey personnel, directed by Van Ostrand, made temperature measurements at several oil wells. These data became available in open file in 1964 (Spicer, 1964) and have been made available more generally in recent years (Gaffanti, 1984). Temperature data from two of these wells (20N/28W-8 and 11N/26E-20CC) are included in the data set in this report. Estimated heat flow values have been calculated for these two holes based on thermal conductivity values measured on surface samples from lithologic units encountered in these holes.

Following these studies, there was a long hiatus until the early 1960's when R. F. Roy made heat flow measurements in the Metaline mining district in northeastern Washington. He also measured temperatures in a deep hydrocarbon exploration well drilled on the Columbia Plateau (Development Associates Basalt Explorer no. 1, 21N/31E-10CB). The heat flow values in the Metaline district were published in 1963 (Roy, 1963; Roy et al., 1968). Also in the 1960's measurements were made at several localities in the state by the U.S. Geological Survey geothermal group at Menlo Park. These results were published by Sass et al. (1971). In the mid-1960's investigations were started by the senior author of this report. The first results of these studies were published by Blackwell (1969). Preliminary results of additional studies were published by Blackwell (1974). The most up-to-date summary of heat flow and geothermal gradient from a statewide point of view is contained in the 1974 report. In that paper several preliminary heat flow values were discussed. Final heat flow values for these sites are included in this report. Temperature-depth data, individual thermal conductivity measurements, terrain correction information, etc. for each hole measured in the 1960's are listed in Sass and Monroe (1974).

In the 1970's detailed studies of the Turtle Lake Quadrangle, northeastern Washington, (the subject of a M.S. thesis by Steele, 1975) and the Indian Heaven area in the southern Washington Cascade Range (the subject of a geothermal assessment study by Schuster et al., 1978) were published. In the mid-1970's water chemistry studies indicated the possibility of anomalous heat flow values in the southern Columbia Plateau area (Swanberg and Morgan, 1979), and in 1978 a reconnaissance logging program was carried out to investigate regional geothermal gradients and heat flow. All the results up until 1979 are summarized by Blackwell (1980). That report is the starting point for the data collection and discussion included in this report.

DATA PRESENTATION

Geothermal gradient, heat flow, and ancillary information for drill holes in the state of Washington are summarized in Table 1. Included in Table 1 are location, hole name, elevation, uncorrected and corrected geothermal gradient, depth interval over which the geothermal gradient was measured, collar elevation, date of logging of the hole, surface temperature, thermal conductivity, corrected heat flow, heat flow data quality, and brief lithologic summary of the rocks encountered in the hole. Only holes where gradients or heat flow are considered to be of C quality (see below) or better are included in Table 1. Poor quality data (D and X) are included in Appendix A.

Individual holes are located by latitude and longitude to the nearest tenth of a minute, if possible. The holes are also located by township and range. Location within the section is by quarter section where A = northeast quarter, B = northwest quarter, C = southwest quarter, D = southeast quarter, and 13ABD indicates a hole in the southeast quarter of the northwest quarter of the northeast quarter of section 13. Thermal conductivity values are based on measurements of core or cutting samples, or are estimated from lithology (values in parentheses). The heat flow values are generally given to the nearest 1 mWm^{-2}, but based on the errors of the values associated in each case, the second decimal place may not be significant. The quality value of A, B, or C implies a heat flow value with an estimated error of ± 5%, ± 10%, and ± 25% respectively. A quality value of G indicates that a heat flow value is associated with a geothermal system. A quality value of D or X (Appendix A) indicates that no reliable heat flow value may be obtained. In some cases a reliable gradient may be calculated from the D quality data, however.

Table 1. Geothermal data of acceptable quality from the state of Washington. Collar elevation is in m, surface temperature is in °C, uncorrected and corrected gradients are in °C/km, thermal conductivity is in $Wm^{-1}K^{-1}$, and heat flow is in $m^{W}m^{-2}$. Date is date hole was measured. Brackets around the thermal conductivity values signify that the values were estimated from the known lithology of the well. In lithology column C.R. stands for Columbia River basalt. The quality indicator is described in the text. The references to published data (R column) are: (1) Blackwell (1969); (2) Blackwell (1974); (3) Blackwell et al (1980); (4) Roy (1963); (5) Sass et al (1971); (6) Schuster et al (1978); and (7) Steele (1975).

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY	R
40N/27E-6B3	48-59.94	119-29.59	DDH-E 7/17/71	487	11.20	155.0 225.0			23.6 .2	20.9		A	GREENSTONE SCHIST	
40N/27E-6B2	48-59.94	119-29.26	DDH-C 7/17/71	487	9.50	45.0 210.0			21.3 .1	16.8		A	GREENSTONE SCHIST	
40N/27E-6B1	48-59.84	119-29.39	DDH-A 7/17/71	487	11.40	50.0 140.0			30.2 .7	26.7		B	GREENSTONE SCHIST	
40N/27E-6B4	48-59.79	119-29.50	DDH-F 7/17/71	487	9.60	60.0 200.0			25.5 .1	22.6		A	GREENSTONE SCHIST	
40N/27E-6BDC	48-59.74	119-29.19	DDH-K-5 7/17/71	463	10.75	60.0 180.0	3.16 .08	19	25.2 .1	22.3	70	A	GREENSTONE SCHIST	
40N/33E-2ACD	48-59.71	118-35.91	DDH-702 7/15/71	1147	6.30	75.0 205.0	3.17 .13	22	25.2 .6	22.7	72	A	MESOZOIC GREENSTONE	
40N/33E-2DBB3	48-59.67	118-35.95	DDH-7011 7/22/71	1135	6.10	80.0 215.0	3.15 .13	20	25.0 .3	22.5	71	A	MESOZOIC GREENSTONE	
40N/33E-2DBB1	48-59.63	118-36.06	DDH-7012 7/15/71	1104	6.10	100.0 150.0			26.5 .3	23.9		B	MESOZOIC GREENSTONE	
40N/33E-2DBB2	48-59.57	118-36.00	DDH-7013 7/22/71	1097	5.85	130.0 155.0			25.8 .3	23.2		B	MESOZOIC GREENSTONE	
40N/43E-35D	48-55.25	117-20.00	METL-CS2 8/24/61	674		350.5 381.0	5.15	14	26.6	23.0	118	B	METALINE LS (DOLOMITE)	R
40N/43E-35D	48-55.25	117-20.00	METL-CS9 8/29/61	736		327.7 358.2	4.81	5	20.0 1.0	18.2	87	B	METELINE LS (DOLOMITE)	R
39N/41E-2BDB	48-55.00	117-35.66	DDH-3 6/16/65	707	6.67	100.0 240.0	5.98 .04	16	23.7 .1	20.8	124	B	DOLOMOTIC META. FORMA.	B6
39N/41E-2CAB	48-54.93	117-35.85	DDH-2 6/17/65	780	5.87	290.0 340.0	6.02 .04	16	22.0 .1	20.4	123	B	DOLOMITIC META. FORMA.	B6
39N/41E-2CBA	48-54.87	117-35.95	DDH-4 6/16/65	817	6.78	120.0 200.0			14.1 .4	12.4		C	DOLOMITIC META. FORMA.	
39N/41E-2CBB	48-54.86	117-36.07	DDH-5 6/16/65	853	6.78	120.0 180.0			17.2 .4	15.1		C	DOLOMITIC META. FORMA.	
39N/41E-2CBD	48-54.82	117-35.99	DDH-1 6/15/65	829	6.73	130.0 220.0			18.3 .4	16.1		C	DOLOMITIC META. FORMA.	

1 = B6
2 = B7
3 = BTR
4 = R
5 = S71
6 = SCH
7 = S75

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY	R
39N/33E- 14ABB	48-53.11	118-36.03	A TALBOT 9/10/81	548	9.40	14.0 74.0	(2.30)		24.7 .6	29.6	(68)	C	GRANITE	
39N/33E- 13BCA	48-52.84	118-35.32	LD LEWIS 9/15/81	679	9.20	39.0 89.0	(2.30)	1	31.4 .4	34.5	(80)	B	GRANITE	
37N/26E- 8DBC	48-43.01	119-35.46	DDH-1 7/24/71	987	8.20	165.0 435.0	3.50 .13	26	19.4 .2	21.5	75	A	BIOTITE GRANODIORITE	B7
37N/26E- 24DCA	48-41.15	119-29.95	R COREY 9/19/81	426	10.50	24.0 123.0	(3.18)	1	24.5 .2	23.3	(74)	B	SCHIST AND GRANITE	
37N/32E- 28D	48-40.33	118-46.49	DAVIS 10/ 9/81	883	7.60	25.0 95.0			19.6 .1	23.5		B	SEDIMENTS	
37N/32E- 33AAC	48-39.99	118-46.38	DDH-3 7/21/70	960	8.20	150.0 260.0	2.41 .04	17	30.9 .2	31.1 .2	76	A	CENOZOIC ANDESITE	
37N/32E- 34B2	48-39.80	118-45.73	DDH-B 7/31/70	1067	6.80	50.0 95.0			24.5 .8			C		
37N/32E- 34B1	48-39.80	118-45.73	DDH-A 7/21/70	1067	7.80	100.0 195.0			21.8 .2			B		
36N/20E- 19ABB	48-36.78	120-23.33	DDH-LD13 8/ 8/71	1134	7.61	75.0 170.0			23.8 .1	23.2		A	MESOZOIC METAMORPHICS	B7
36N/20E- 19ADC	48-36.48	120-23.07	DDH-LD10 8/ 8/71	1097	8.80	140.0 275.0	2.88 .08	15	28.3 .2	26.7	77	A	MESOZOIC METAMORPHICS	B7
36N/20E- 19DAB	48-36.35	120-23.15	DDH-LD7 8/ 8/71	1097	6.10	240.0 360.0	3.19 .29	4	24.0 .1	23.0	73	A	MESOZOIC METAMORPHICS	B7
36N/32E- 25ACC	48-35.63	118-44.48	KONZ 11/18/81	728	8.20	44.0 74.0			35.3 .7	31.8		C		
34N/ 1E- 1CBB	48-27.48	122-38.04	DDH-1 8/ 2/71	129	10.55	90.0 220.0	2.96 .04	25	12.7 .1	12.6 .1	37	A	QUARTZ DIORITE	
34N/26E- 23DA	48-25.77	119-30.96	DAMSKOV 9/17/81	379	11.10	104.0 184.0	(1.97)	1	24.5 .1	27.0	(53)	B	GRANITE	
33N/31E- 14BDA	48-21.75	118-52.59	DDH-1 6/20/70	1182	5.93	130.0 230.0	3.36 .13	17	16.5 1.7	20.3 1.0	68	B	ARGILLITE & QTZ MONZ	B7
33N/31E- 14ACB	48-21.75	118-52.35	DDH-3 8/ 7/70	1182	7.20	205.0 270.0	3.11 .08	9	20.4 .3	22.4	70	A	QTZ. MONZ. PORPHYRY	B7
33N/31E- 14BDC	48-21.65	118-52.78	DDH-2 6/20/70	1134	5.97	120.0 200.0	3.36 .13	18	16.8 .2	19.5	66	A	ARGILLITE & QTZ. MONZ.	B7
32N/40E- 4ADD	48-18.13	117-45.64	L HEINE 9/ 7/81	536	10.80	49.0 117.0	(4.39)	1	15.7 .3	14.1	(62)	B	QUARTZITE	
31N/44E- 34ADD	48- 8.77	117-13.27	ACI CAMP 8/19/81	740	8.10	95.0 155.0	(2.05)	1	28.3 .7	27.7	(57)	B	GRANITE	
30N/16E-	48- 6.15	120-49.81	DDH-1 8/ 5/70	1158	1.22	20.0 175.0			49.0 5.5			C		
30N/33E- 31BDD	48- 3.52	118-42.40	DDH-A 8/11/66	892	6.64	115.0 195.0	3.81	2	14.6 .1	19.7	75	A	ALTERED QTZ. MONZONITE	BT
30N/39E- 36DDB	48- 3.47	117-49.52	RDH CV-2 7/25/81	652	7.66	30.0 145.0			57.2 .5			B	TERTIARY SEDIMENTS	
						145.0 210.0			46.3 .7	45.0		B		
30N/33E- 31CAB	48- 3.35	118-42.40	DDH-B 8/23/66	1036	6.84	120.0 255.0	4.15 .21	11	11.6 .1	17.9	75	A	ALTERED QTZ. MONZONITE	BT
30N/33E- 31CAC	48- 3.21	118-42.40	DDH-C 8/16/67	963	7.68	90.0 420.0	3.76 .17	28	11.5 .2	15.8	59	A	ALTERED QTZ. MONZONITE	BT
						420.0 470:0	2.98 .21	8	17.4 1.4	23.2	69	A		
29N/37E- 36DDD	47-58.50	118- 4.00	DDH-2 10/15/72	877	6.20	60.0 380.0	3.13	25	28.4 .3	27.0	85	A	PHYLLITE - ARGILLITE	S75
28N/42E- 5D	47-56.90	117-31.55	EICKMEYR 9/ 4/81	658	9.40	19.0 144.0	(2.43)		27.5 .3	27.5	(66)	B	SED/CLAY TO GRANITE	
28N/37E- 9DBD	47-56.60	118- 9.20	S-9 8/11/70	652	10.34	100.0 133.0	3.00 .04	6	26.0 .1	25.1	76	B	PHYLLITE - ARGILLITE	S75
28N/44E- 31ADD	47-52.99	117-16.98	M POWERS 7/ 8/81	711	9.30	154.0 264.0	(2.76)	1	22.6 .1	24.9	(68)	B	SED/CLAY TO GRANITE	
27N/37E- 2BBB	47-52.40	118- 7.40	WW-EAST 8/10/72	587	11.40	90.0 150.0	3.31 .04	6	24.8	26.7	87	B	PORPHYRITIC QTZ. MONZ.	S75
27N/37E- 3AAA	47-52.40	118- 7.40	WW-WEST 8/10/72	573	11.20	60.0 100.0	3.26	6	26.5	27.8	91	B	PORPHYRITIC QTZ. MONZ.	S75

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY R
27N/37E- 22CDD	47-49.08	118- 7.77	DDH-SF15 8/15/81	542	10.60	140.0 225.0			34.9 .1			A	VOLCANICS
27N/38E- 28BBB	47-49.00	118- 1.50	S-28 8/10/72	548	8.50	100.0 145.0	2.54	2	33.8	33.0	84	B	PALEOZOIC S75 MAR.-HORNFEL
27N/37E- 26AAD	47-48.87	118- 5.92	TAYLOR 8/17/81	481	10.40	140.0 358.0			40.3			A	VOLCANICS
26N/44E- 12AAC	47-46.10	117-10.80	MANZ 7/25/81	838	8.40	120.0 159.0	(3.26)	1	24.7 .3	27.2	(89)	B	GRANITE
26N/34E- 10CAB	47-45.87	118-31.18	CTY CSTN 8/30/81	745	9.30	14.0 59.0			44.0 2.1			B	BASALT ?????
						14.0 199.0			36.8 1.4			B	
						109.0 199.0	(1.59)	1	55.4 .2	55.4	(88)	B	
26N/33E- 18ACA	47-45.20	118-42.50	DOE WILB 8/27/81	684	10.50	25.0 100.0			26.8 1.3			C	BASALT
						25.0 129.0	(1.59)		31.9 1.3	31.9	(51)	C	
						100.0 129.0	(1.59)		52.9 1.5	52.9	(84)	C	
26N/13E- 27BA	47-43.20	121- 7.21	DNR-SCN2 9/25/81	841	4.50	40.0 150.0	2.68 .17	7	36.5 .2	26.1	70	B	BIOTITE SCHIST
26N/13E- 28CD	47-42.66	121- 8.50	DNR-SCN1 9/25/81	841	3.29	20.0 100.0	2.06 .17	7	58.3 1.2	48.4	100	B	PHYLLITE
						60.0 100.0	2.06 .17	7	67.2 .5	55.6	115	B	
25N/ 9E- 4ADA	47-40.97	121-38.92	DDH-12 8/24/70	1176	4.25	120.0 145.0	3.03	2	10.5 .1	20.0	61	C	
24N*44E- 6BC	47-36.30	117-17.99	D BLACK 8/28/81	914	8.50	64.0 81.0	(2.38)	1	15.4 1.6	20.0	(48)	C	GRANITE
24N/44E- 10AD	47-35.38	117-13.22	V CARROL 7/26/81	749	8.00	25.0 147.0	(3.43)	1	27.4 .1	(30.1)	(103)	B	GRANITE

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY R
24N/36E- 16AAB	47-34.70	118-16.37	DOE TST6 8/29/81	720	9.30	66.0 139.0	(1.59)		58.7 .7	58.7	(93)	B	C. R. BASALT
						66.0 225.0	(1.59)		53.3 .9	53.3	(85)	B	
24N/31E- 16BCC	47-34.55	118-56.07	DOE TST5 8/27/81	562	10.30	19.0 149.0	(1.59)		58.7 .9	52.8	(84)	B	C. R. BASALT
						19.0 204.0	(1.59)		53.0 .9	58.3	(93)	B	
23N/11E- 1C	47-30.51	121-21.24	DDH-1 6/25/65	838	4.67	80.0 130.0	3.93 .21	9	16.2 .3	14.7	58	C	SILICIFIED B6 GRANODIORITE
23N/43E- 8AB	47-30.41	117-23.81	AUDRBERG 7/27/81	737	10.70	95.0 125.0	(1.34)	1	41.6 1.3	41.6	(56)	B	BASALT
23N/11E- 10DCA	47-29.52	121-24.15	DDH-2 7/24/65	585	12.68	86.6 251.0	3.03 .08	24	25.2 1.0	18.6	56	C	GRANODIORITE (ARTESIAN) B6
23N/ 6E- 18ADD	47-29.00	122- 5.00	BEACH 4/30/80	158	6.20	61.0 92.4			20.1 .8			C	SANDSTONE
22N/11E- 4BDA	47-25.54	121-24.80	DNR-SNQ1 10/13/81	903	4.93	110.0 145.0	2.97 .21	7	16.7 .1	14.7	44	B	PHYLLITE
22N/20E- 26CBB	47-22.11	120-18.00	NORCO-1 8/ 4/70	762	11.60	310.0 900.0	2.18 .21	18	26.8 .2	28.4	62	A	RHY., ARKOSE & SANDSTONE B7
21N/31E- 10CB	47-20.00	118-55.00	DABE-1 8/31/61	503		61.0 1250.0	1.67 .21		42.0 2.0	42.0	70	B	C. R. BASALT B7
20N/22E- 12ABC	47-14.65	120- .78	WELCH 11/13/81	390	14.00	49.0 189.0	(1.59)	1	26.1 1.3	26.0	(41)	D	C. R. BASALT
						49.0 264.0	(1.59)	1	32.1 1.0	32.0	(51)	C	
20N/12W- 8	47-14.27	124-11.47	VO-MO 1 0/ 0/30	20	9.20	304.8 1066.8	(1.30)		27.4 2.4	27.4	(36)	B	SHALE B7
20N/15E- 18DDD	47-13.22	121- .46	DDH-E 7/14/72	704	7.20	5.0 200.0			20.8 3.5			C	COAL & SHALE

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY	R
19N/17E- 23CBD	47- 7.27	120-40.88	THORP1 7/28/80	716	10.00	110.0 170.0			31.2 .6			B		
						10.0 170.0	(1.38)	1	29.4 .5	29.4 .5	(41)	B		
18N/ 9E- 29CB	47- .54	121-41.70	DNR-WTRV 9/15/81	850	6.20	115.0 140.0	2.39 .21	8	24.2 .4	19.6	47	B	PYROXENE RHYOLITE(MI)	
18N/26E- 35C	47- .26	119-31.73	F SHINN 8/26/81	345	14.90	70.0 100.0	(1.59)		49.8 1.0	49.8	(79)	C	BASALT ?	
17N/ 3E- 2DAAA	46-59.22	122-22.78	MILLER 6/27/81	145		140.0 178.0			24.5 .2			C		
16N/18E- 3BDD	46-54.40	120-33.68	KUMMER1 7/14/80	820	9.75	100.0 150.0			29.6 .2	29.6 .2		B		
16N/19E- 12DB	46-53.37	120-23.45	BADGER 11/30/81	664	10.16	59.0 333.0	(1.55)	1	> 27.3 1.1	> 27.3	> 42	C	C. R. BASALT	
						59.0 154.0	(1.55)	1	29.4 .6	29.4	(46)	C		
16N/31E- 15B	46-52.75	118-55.10	WHOLMAN 1/22/81	432	13.50	10.0 230.0	(1.59)		59.1 1.8	59.1	(94)	C	C. P. BASALT	
						10.0 50.0	(1.59)		47.0 1.3	47.0	(75)	C		
						170.0 230.0	(1.59)		57.3 1.5	57.3	(91)	B		
16N/16E- 24CCD	46-51.45	120-46.55	DGF2 7/ 1/80	832	9.29	10.0 175.0			54.3 1.4			B		
						10.0 85.0			49.6 .4	45.6		B		
16N/ 4E- 23DDD	46-51.01	122-15.36	ANDERSON 8/19/79	432	8.35	25.0 86.5	(1.97)	2	9.0 .5	10.2	(21)	C	BASALT	
16N/12W- 24DAD	46-51.00	124- 6.00	TW-1 8/ 4/71	3	11.20	60.0 155.0	1.48 .04	22	26.5 2.2	26.5	39	A	GRAVEL, SAND & CLAY	B7
16N/17E- 29ADB	46-50.96	120-43.40	DGF1 7/ 1/80	670	9.28	70.0 120.0			31.6 .4	29.0		B		
16N/21E- 33CD	46-49.63	120-12.37	YFC3 7/15/80	795	9.78	10.0 100.0	1.38		30.6 1.6	37.2	52	B		
						40.0 90.0	1.38	4	36.9 1.1	44.8	62	B		
15N/17E- 23ABC	46-46.90	120-39.95	DAY1 6/30/80	634	9.31	40.0 130.0			36.7 .6			B	SANDSTONE & CLAY	
						150.0 222.0			41.6 .5			B		
						40.0 222.0	(1.59)		38.7 .3	36.5	(58)	B		
15N/ 4E- 14DDA	46-46.78	122-15.32	B LNDSEY 8/19/79	566	6.79	100.0 122.0	1.72 .17	2	14.6 .6	19.8	34	C	BASALT	
15N/ 6E- 22ABD	46-46.49	122- 1.77	ASHFRD-1 7/17/79	965	5.84	30.0 68.0			13.7 .3			C	SHALE, COAL & SANDSTONE	
15N/18E- 28DD	46-45.37	120-34.54	MCNLLY2 7/ 4/80	500	13.20	60.0 85.0			18.6 .9			C	SANDSTONE	
						30.0 85.0			22.4 .7			C		
15N/17E- 36AAA	46-45.13	120-38.49	DNRWENAS 10/ 9/80	493	11.19	60.0 80.0			29.0			B	CLAY, SAND, GRAVEL, CONG	
						.0 80.0			27.9			B		
						75.0 595.0	(1.46)		33.3 .7	31.6	(46)	B		
14N/ 2W- 4ABD	46-43.98	122-56.24	THOMAS 6/15/79	85	8.88	90.0 150.5			20.8 .3	20.2		B		
14N/16E- 1CBD	46-43.77	120-46.74	SHRORCH 7/12/80	641	10.99	20.0 110.0	(1.46)		35.9 1.0	35.9 1.0	(53)	C	ANDESITE	
14N/44E- 1BCC	46-43.72	117-13.28	R HARLOW 9/ 2/81	781	9.30	54.0 89.0	(1.59)		22.9 .6	22.9	(36)	C	C. R. BASALT	
14N/10E- 8DCB	46-42.89	121-34.68	RDH-OHNP 9/15/81	490	6.24	75.0 115.0	2.18 .08	10	45.5 .5	33.8	74	B	EOCENE VOLCANICS	

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY	R
14N/17E- 13ADC	46-42.20	120-38.35	MURRAY3 7/ 7/80	533	13.29	20.0 60.0			55.5 1.3	56.9		B		
						80.0 130.0			48.7 3.0	49.9		B		
14N/18E- 29DBB	46-40.40	120-36.05	MCFRLNE 7/ 8/80	432	11.75	40.0 55.0			50.8 2.6			C	SAND AND CLAY	
						20.0 55.0	(1.46)		40.7 2.0	39.0	(57)	C		
14N/14E- 25BCDC	46-40.39	121- 1.76	DNR-TWIL 9/15/81	744	9.83	25.0 150.0	1.30 .13	10	93.3 .3	67.0	87	B	C. R. BASALT	
14N/15E- 29CBD	46-40.25	120-59.25	SHGLDCKR 6/29/80	696	9.19	55.0 67.0			66.1 2.4	43.7		C	ALLUVIUM	
14N/ 1W- 26CAA	46-40.21	122-46.33	REYNOLDS 6/15/79	125	8.96	75.0 92.3			19.9 1.1	19.0		C	COALBEARING SKOOKUMCHUCK	
13N/12E- 4AB	46-39.10	121-19.80	DNR-CCWR 9/15/81	1006	3.83	60.0 150.0	2.02 .21	8	65.3 .2	46.0	93	A	SANDY SLTST& MUDSTONE(JR)	
13N/12E- 2AB	46-39.00	121-17.02	DNR-SRDG 9/15/81	1006	5.79	35.0 150.0	2.56 .13	9	43.5 .2	42.3	108	A	AMPHIBOLITE (JR)	
13N/11E- 2DC	46-38.32	121-23.49	RDH-WTPS 8/27/79	1366	4.19	10.0 148.5	1.84 .15	21	52.4 .3	45.0	83	A	EOCENE (P/Q) VOLCANICS	
13N/ 4W- 7ABA	46-38.02	123-13.57	ARNOLD 9/ 1/79	85	8.41	110.0 128.5	1.99	1	20.6 .9	20.6	41	B	BLUE CLAY	
13N/19E- 11DBC	46-37.50	120-24.75	THEIGHTS 6/29/80	609	13.75	100.0 160.0			35.3 1.4			C	C. R. BASALT	
						50.0 160.0	(1.59)		34.2 .4	32.8	(52)	B		
13N/ 9E- 16BCA	46-37.22	121-41.59	RDH-PKWD 9/ 4/79	359	7.33	10.0 152.0	1.59 .10	19	45.2 .4	43.5	70	A	VOLCANIC SEDIMENTS	
13N/ 5E- 18ABD	46-36.96	122-13.63	ROM 1 6/15/79	358	7.25	10.0 55.0	(1.09)		31.5 1.0	26.9	(29)	C	EOCENE(?) SEDIMENT RX	
13N/29E- 13DB	46-36.77	119- 7.28	BAILIE 2/26/81	231	14.00	10.0 210.0	(1.59)		(48.3) 2.1	(48.3)	(77)	C	C. B. BASALT	
13N/ 1W- 18CBB	46-36.71	122-51.85	OLSON 5/26/79	85	10.07	65.0 91.0			11.5 .7	11.5		C	TERTIARY (?) SEDIMENT RX	
13N/19E- 23ABB	46-36.70	120-24.70	WATKINS1 6/16/80	402	13.62	20.0 70.0			27.8 .5	26.5		C	GRAVEL, CLAY & SAND	
13N/ 1W- 19DCD	46-35.36	122-51.12	SUNDWN 1 6/ 7/79	93	10.40	40.0 225.0			21.3 .2	21.3		A	TERTIARY (?) SEDIMENT RX	
13N/26E- 25	46-35.00	119-31.00	DH-1 1/13/70	168	15.18	53.3 182.9	1.71 .03	19	37.2 .3	37.2	64	A	BASALT	S71
13N/ 3W- 35BAB	46-34.49	123- 1.51	MOHORIC 8/31/79	170	10.00	105.0 140.0			25.5 .5			C		
						120.0 135.0	1.60	1	29.4 .5	29.4	47	C		
12N/17E- 11BBB	46-33.06	120-40.11	DECOLC-7 6/17/80	425	8.65	10.0 130.0	(1.46)		(34.2)	(34.2)	(50)	D	GRAVEL, CLAY AND SAND	
						80.0 120.0	(1.46)		64.2 1.0	64.2	(94)	C		
12N/ 2E- 5DCD	46-32.66	122-34.73	PLANT 6/16/79	284	7.36	125.0 155.0	(1.67)		22.7 .2	25.4	(38)	B	TERTIARY VOLCANICS	
12N/ 1W- 7AAB	46-32.68	122-50.81	RDH-SUB 1/ 7/72	152	9.00	50.0 565.0	(1.26)		29.0 .2	29.0	(36)	A	SHALE,SS & SILTSTONE	
						90.0 360.0	(1.09)	59	33.2 .2	33.2	(36)	A		
						375.0 565.0	(1.46)		25.2 .1	25.2	(37)	A		
12N/ 1W- 8DAA	46-32.35	122-49.46	SU-12 1/12/72	161		110.0 365.0	(1.09)	59	27.3 .3	27.3	(30)	A		
						260.0 578.0	(1.46)		21.5 .3	21.5	(31)	A		
12N/ 1W- 8CAB	46-32.28	122-50.20	SU-14 6/13/67	156	7.81	100.0 400.0	(1.09) .04	59	33.8 .1	33.8	(36)	A	SHALE,SS & SILTSTONE	S71
12N/ 1W- 8DAD	46-32.18	122-49.46	SU-11 6/12/67	157	10.60	100.0 340.0	(1.09) .04	59	34.6 .2	34.6	(37)	A	SHALE,SS & SILTSTONE	S71

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY	R
12N/ 2E- 9DAD	46-32.07	122-33.17	LCMPK 3 6/23/79	146	8.58	60.0 205.0	(1.67)		23.0 .3	23.0	(39)	B	BASALT	
12N/ 1W- 9CCC	46-31.99	122-48.66	SU-4 6/12/67	165	9.00	100.0 380.0	(1.09) .04	59	32.8 .2	32.8	(36)	A	SHALE,SS & SILTSTONE	S71
						710.0 760.0	1.77 .01	5	18.2 .1	18.2	32	A		
12N/ 1W- 8CCC	46-31.93	122-50.52	RDH-SU37 1/12/72	152	9.10	45.0 150.0	(1.09)	59	27.7 .4	27.7	(30)	A	SHALE,SS & SILTSTONE	
						150.0 395.0	(1.09)	59	33.5 .1	33.5	(36)	A		
						395.0 540.0	(1.46)		24.6 .1	24.6	(36)	A		
12N/ 1W- 17BAD	46-31.75	122-49.48	SU-10 3/19/73	167	9.50	90.0 348.0	(1.09)	59	34.8 .2	34.8	(38)	A	SHALE,SS & SILTSTONE	
12N/ 1W- 17ADA	46-31.65	122-50.07	SU-902 3/19/73	158	9.30	90.0 340.0	(1.09)	59	32.7 .2	32.7	(36)	A	SHALE,SS & SILTSTONE	
						340.0 690.0	(1.46)		24.8 .1	24.8	(36)	A		
						690.0 847.0	(1.76) .01	5	22.2 .2	22.2	(39)	A		
12N/20E- 16CA	46-31.56	120-19.54	DNR-ELPH 8/ 1/81	497	12.50	100.0 400.0	(1.59)		41.5 .1	41.5	(66)	C	C.R. BASALT	
12N/ 7E- 16CC	46-31.37	121-56.37	RDH-RAND 11/13/79	274	9.04	90.0 129.0			34.3 .5			B		
						35.0 129.0	1.75 .08	10	41.6 .6	41.6	73	A		
12N/ 3E- 17DCB	46-31.33	122-27.54	AUST 7/ 4/79	226	8.84	90.0 138.5	(1.67)		20.5 .6	20.5	(34)	B	EOCENE (?) BASALT	
12N/22E- 13CDC	46-31.25	120- .71	CHANGALA 10/14/80	521	13.50	60.0 200.0	(1.59)		34.3 .2	33.3	(53)	B		
12N/ 3E- 19CBD	46-30.44	122-29.23	MOSSRK-1 8/ 1/79	348	8.04	65.0 232.5	(1.67)		27.0 .4	27.0	(45)	C	EOCENE-OLIGO VOLCANICS	
12N/20E- 36CD	46-28.64	120-15.78	CHEYNERD 6/18/80	411	14.90	10.0 90.0			45.8 2.8			C	SEDIMENTS & BASALT	
						10.0 350.0	(1.59)		(32.3)	(32.3)	52	C		
11N/21E- 7AAC	46-27.53	120-13.50	GARETSON 12/ 5/80	390	15.00	215.0 395.0	(1.59)		31.4 .1	31.4	(50)	B	C. R. BASALT	
						85.0 450.0	(1.59)		33.7 .3	32.9	(52)	B		
11N/21E- 17ABD	46-26.70	120-13.75	CLYDE 12/ 4/80	378	14.00	145.0 225.0			40.8 .9			C	C. R. BASALT	
11N/21E- 16CDB	46-26.10	120-12.15	RAMSIER 11/19/80	388	15.47	10.0 60.0			77.9 3.6	75.0		C	SEDIMENTS & BASALT	
						60.0 130.0			48.7 .7	48.0		C		
						130.0 210.0	(1.59)		41.0 .7	41.0	(65)	C		
11N/24E- 15 1	46-26.00	119-47.00	RS-1 6/ 7/67	875	9.11	900.0 2500.0	1.59 .13	6	35.2 .2	37.5	60	B	BASALT	S71
11N/24E- 15 2	46-26.00	119-47.00	RS-2 1/14/69	875	10.40	58.0 119.0	1.72 .04	14	28.1 .2	33.3	57	B	BASALT	S71
11N/21E- 22AC	46-25.84	120-10.53	SANDLIN 6/19/80	390	15.20	20.0 365.0			33.4 .5			C	SEDIMENTS & BASALT	
						30.0 150.0			43.1 .9					
						150.0 330.0	(1.59)		28.8 .2	28.8	44	B		
11N/28E- 23BB	46-25.68	119-16.62	BATTLE 2 2/24/81	121	15.20	20.0 280.0	(1.59)		37.7 .3	37.7	60	B	C. R. BASALT	
11N/26E- 20CC	46-25.17	119-35.38	VO-SOC 1 0/ 0/30	445	15.20	30.5 670.6	(1.59)		37.4 4.4	35.6	(57)	B	C. R. BASALT	S71

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY	R
11N/22E- 30BA	46-25.00	120- 7.13	CHAPPELL 7/31/81	366	12.40	50.0 270.0	(1.59)		49.4 .5	49.4	(79)	C	C. R. BASALT	
						50.0 150.0	(1.59)		43.9 .2	43.9	(70)	B		
11N/22E- 28CB	46-24.57	120- 4.51	SPAULD R 8/ 2/81	402	12.50	27.0 104.0	(1.59)		42.5 .1	42.5	(67)	B	C. R. BASALT	
						27.0 210.0	(1.59)		39.7 .3	39.7	(63)	B		
11N/46E- 32BCA	46-23.49	117- 4.52	WWPC7-WW 2/15/78	359	11.00	15.0 405.0	(1.59)		35.6	35.6	(57)	B	BASALT WITH CLAY	
11N/45E- 32DAB	46-23.28	117-11.45	SILCOTWW 2/19/78	544	11.50	10.0 192.0	(1.59)		31.3 .5	32.0	(51)	B	C. R. BASALT	
10N/ 4E- 2DBA	46-22.65	122-15.95	DNR 83-1 7/22/83	488		25.0 140.0			50.0			B	ALLUVIUM & VOLCANICS	
10N/41E- 3DBD	46-22.37	117-39.50	NEIBLEWW 8/ 3/78	896	9.30	10.0 90.0	(1.59)		22.1 .6	27.2	(43)	C	C. R. BASALT	
10N/28E- 10ACC	46-21.97	119-17.43	BATLLES 2/11/81	115	15.10	5.0 120.0	(1.59)		34.3 1.0	34.3	(54)	C	C. R. BASALT	
10N/28E- 14ABB	46-21.73	119-16.13	BATTELLE 2/11/81	115	14.10	530.0 605.0	(1.59)		42.1 .6	42.1	(67)	B	C. R. BASALT	
						110.0 510.0	(1.59)		40.1 .2	40.1	(64)	B		
10N/ 6E- 8DDA	46-21.58	122- 4.47	DDH-9 10/25/72	1140	4.00	80.0 135.0			14.4 .5	(21.6)		C	DACITE PORPHYRY	B7
						80.0 270.0			9.9 1.1	(14.9)		C		
						120.0 270.0	3.68 .17	6	(12.5)	(18.5)	(68)	C		
10N/28E- 14	46-21.12	119-16.19	DH-3-WW 8/12/70	120		174.0 608.0	1.65 .07	16	25.1 .3	25.1	41	A	C. R. BASALT	S71
						608.0 1079.0	1.52 .03	15	34.6 .3	34.6	53	A		
						174.0 1079.0	1.59		30.0	30.0	47	A		
10N/ 6E- 18BDB	46-21.10	122- 6.40	DDH-1 10/31/71	853	8.62	205.0 210.0	3.85 .13	6	(22.0)	(18.0)	(70)	C	DACITE PORPHYRY	B7
10N/24E- 36BD	46-18.70	119-45.43	ANDSN1 4/ 8/81	420	11.70	20.0 125.0	(1.59)		62.0 1.0	62.0	(99)	C	C. R. BASALT	
						125.0 200.0	(1.59)		34.0	34.0	(54)	C		
10N/39E- 32BCA	46-18.33	117-57.87	DAYTON 11/19/81	502	9.40	49.0 229.0	(1.59)	1	32.0 .7	31.6	(50)	C	C. R. BASALT	
9N/ 2W- 1ADB	46-17.72	122-52.14	MOCK 8/ 3/79	196	8.57	20.0 135.0	(1.59)	1	13.5 .2	14.2	(23)	C	CLAY,SS & BASALT	
9N/32E- 13BA	46-16.04	118-45.21	POWER-WW 2/10/78	262	15.00	135.0 210.0	(1.59)		34.8 .6	34.8	(55)	B	BASALT WITH INTERBEDS	
9N/ 5E- 18BB	46-15.95	122-14.22	RDH-STH1 11/14/79	78	7.48	30.0 80.0			17.8 .3			B	ANDESITE LAHARS	
						30.0 122.5	1.81 .06	15	20.1 .5	20.1	36	B		
9N/27E- 23CA	46-14.82	119-24.17	DNR-KID3 3/10/81	280	14.20	160.0 350.0	(1.59)		43.1 .2	43.1	(69)	B	C. R. BASALT	
8N/44E- 2AAD	46-12.27	117-15.00	REEVESWW 7/28/78	1050	9.50	10.0 89.0			16.7 .6			C	C. R. BASALT	
8N/ 4E- 14DD	46-10.37	122-16.10	RDH-STH2 11/14/79	1066	5.50	112.0 150.0			34.4 1.0			B		
						50.0 150.0	1.85 .06	17	24.2 .8	24.2	45	B		

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY	R
8N/33E- 21D	46- 9.31	118-40.99	GLUCK-WW 2/ 3/78	288	13.40	15.0 50.0			58.6 1.6	58.6		B	C. R. BASALT	
						50.0 200.0	(1.59)		37.7 1.0	37.7	(60)	B		
8N/25E- 36AB	46- 8.38	119-37.78	DNRGOULD 3/13/81	329	13.60	5.0 240.0	(1.59)		35.0 1.7	35.0	(56)	C		
7N/46E- 2AA	46- 7.99	116-59.88	DODD-WW 2/18/78	991	5.80	160.0 275.0	(1.59)		27.6 .7	36.1	(57)	C	BASALT (?)	
7N/ 8E- 2BCD	46- 7.50	121-46.20	DGER-4 9/14/76	1207	3.10	85.0 150.0	1.25 .03	5	48.5 .5	44.5	56	A	VESICULAR BASALT	SCH
7N/ 9E- 17AA	46- 5.90	121-42.00	DGER-3 9/13/76	960	4.60	115.0 150.0	1.24 .11	4	58.5 2.5	53.4	66	A	VOLCANO- CLASTIC	SCH
7N/36E- 17CAD	46- 5.39	118-20.30	WWGC-WW 8/ 8/78	307	14.30	100.0 225.0	(1.59)		35.4 .5	35.4	(57)	B	C. R. BASALT	
7N/46E- 13BA	46- 5.25	116-59.01	HELBAR 3/ 4/78	300	14.60	15.0 85.0	(1.59)		53.0 1.0	40.8	(65)	C	C. R. BASALT	
7N/35E- 25AAC	46- 3.66	118-22.22	ARTIDBWW 1/30/78	259	11.00	85.0 260.0	(1.59)		34.0	34.0	(54)	C	C. R. BASALT	
7N/23E- 36BCA	46- 3.02	119-52.52	DNRCHES2 11/18/80	326	16.31	40.0 155.0			17.5 .2			B	C. R. BASALT	
7N/ 8E- 36C	46- 2.90	121-45.00	DGER-7 9/14/76	1213	2.80	15.0 25.0	(1.17)		70.0	58.0	(67)	C	UNCON. GLAC. SEDIMENT	SCH
6N/33E- 1DBD	46- 1.46	118-37.30	BRNAMWW 2/ 2/78	143	12.00	10.0 60.0			78.9 4.8	78.9		B	CEMENTED GRAVEL/CLAY	
						60.0 305.0	(1.05)		69.0 8.0	69.7	(73)	B		
6N/33E- 10AD	46- 1.01	118-40.65	GARDNAWW 2/ 2/78	175	7.80	20.0 85.0	(1.05)		104.1 5.0	106.8	(112)	C	CEMENTED GRAVEL	
6N/ 7E- 23BAC	45-59.90	121-53.60	DGER-5 9/14/76	914	4.80	100.0 150.0	1.23 .06	6	51.0 .4	49.8	61	A	BASALT	SCH

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY	R
6N/19E- 24BC	45-59.52	120-22.97	FOSTER 11/28/81	1116	7.00	29.0 152.0	(1.59)	1	> 37.6 1.1	> 37.6	> 60	D	C. R. BASALT	
						14.0 29.0	(1.59)	1	64.8 1.9	64.8	(105)	D		
						59.0 139.0	(1.59)	1	41.2 .7	41.2	(65)	C		
6N/ 9E- 25ACC	45-58.60	121-37.40	DGER-2 9/13/76	884	4.00	100.0 150.0	1.42 .03	8	53.8 .8	52.7	75	A	VOLCANO- CLASTIC	SCH
5N/ 1E- 5CDC	45-56.41	122-42.87	EPPERSON 8/16/79	95	9.78	100.0 177.5	(1.72)	1	19.6 .1	21.5	(37)	B	SANDSTONE & SHALE	
5N/21E- 16CAB	45-55.00	120-11.49	DOE TST7 8/23/81	706	15.11	74.0 224.0	(1.59)		49.2 6.3	49.2	(78)	D	C. R. BASALT	
						224.0 394.0	(1.59)		27.2 .7	17.2	(44)	C		
5N/14E- 22BCB	45-54.46	121- 2.86	URBAN 9/12/79	585	11.57	40.0 137.5	(1.59)	1	29.7 .3	31.2	(50)	B	C. R. BASALT	
5N/ 1E- 23CBA	45-54.12	122-39.35	GRIMM 8/ 1/79	158	8.97	120.0 246.0	(1.30)	1	32.1 .2	32.1	(42)	B	SANDSTONE & SHALE	
5N/ 2E- 25DBC	45-53.16	122-30.08	HAGEDORN 7/31/79	201	8.10	70.0 156.0	(1.59)		33.2 .3	32.0	(51)	B	BASALT ?	
5N/15E- 28DDD	45-53.04	120-55.60	H FREER 7/14/81	585	9.91	55.0 145.0	(1.59)		24.7 .4	24.7	(39)	B	QUAT. BASALT	
5N/ 3E- 28CCC	45-52.96	122-27.00	DREW 8/ 1/79	351	8.08	70.0 97.5	(2.01)		20.4 .3	20.4	(41)	C		
4N/ 2E- 14BA	45-50.22	122-31.72	EBNER 1 8/13/81	76	8.34	122.0 192.0	(1.05)		38.4 .2	38.5	(40)	B	CLAY AND BASALT	
						192.0 215.0	(1.59)		25.6 .3	25.6	(41)	B		

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY R
4N/ 3E- 18CCB	45-49.61	122-29.51	HOARSH 6/24/79	131	8.99	40.0 107.5			30.0 .6	29.4		B	
						85.0 107.5			30.7 .9	29.8		B	
						50.0 109.0			31.1 .1	30.6		B	
4N/13E- 24BC	45-49.40	121- 7.72	DNR-KLKT 9/14/81	146	14.18	70.0 110.0	1.39 .13	6	50.5 .5	37.1	52	C	C. R. BASALT
4N/ 3E- 20ADD	45-49.10	122-27.33	WINSTON 7/28/79	210	8.32	135.0 220.0	(1.59)	1	38.3 .1	38.0	(60)	B	EOCENE BASALT
4N/ 1E- 21ACD	45-49.01	122-41.24	KING 8/ 2/79	79	8.72	155.0 236.0			24.7 .2	24.7		B	SAND, CLAY, BASALT
4N/ 7E- 21CD	45-48.63	121-57.19	DNR-TRCK 9/10/81	354	5.92	50.0 150.0	1.22 .13	9	87.3 .2	75.4	92	A	VOL-CLASTIC MUDFLOWS
3N/ 5E- 4BDB	45-46.49	122-12.10	SS-20 9/15/76	553	6.13	35.0 300.0	(2.80) .08		24.4 .2	24.4	(68)	A	QTZ. DIORITE GRANODIORITE
3N/ 5E- 4BCA	45-46.48	122-12.08	SS-18 9/15/76	549	6.50	30.0 140.0	(2.80) .08		20.3 .2	20.3	(57)	B	QTZ. DIORITE GRANODIORITE
3N/ 5E- 4ACB	45-46.46	122-11.76	SS-23 9/15/76	564	6.02	15.0 150.0	(2.80) .08		16.7 .2	16.7	(47)	B	QTZ. DIORITE GRANODIORITE
						150.0 245.0	(2.80) .08		24.6 .2	24.6	(69)	B	
3N/ 5E- 4ACA	45-46.44	122-11.63	SS-21 9/15/76	570	6.35	25.0 305.0	(2.89) .08		23.5	23.5	(66)	A	QTZ. DIORITE GRANODIORITE
3N/ 5E- 4BDC2	45-46.39	122-13.02	SS-22 9/16/76	545	6.70	30.0 220.0	(2.80) .08		23.2 .3	23.2	(65)	A	QTZ. DIORITE GRANODIORITE
3N/ 5E- 4CAB	45-46.25	122-11.98	SS-3 9/16/76	521	6.85	205.0 290.0	(2.80)		24.4 .2	24.4	(68)	A	QTZ. DIORITE GRANODIORITE
3N/ 5E- 4CAC	45-46.21	122-11.96	SS-6 9/16/76	539	5.78	15.0 120.0	(2.89) .08		22.8 .2	22.8	(64)	B	QTZ. DIORITE GRANODIORITE
						120.0 215.0	(2.80)		29.2 .2	29.2	(82)	A	

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY P
3N/10E- 10CCB	45-45.36	121-32.68	TENNANT 11/24/81	362	6.22	99.0 263.0	(1.59)		17.0 .3	17.0	(27)	C	C. R. BASALT
						199.0 263.0	(1.59)		18.3 1.0	21.5	(34)	C	
3N/13E- 13DA	45-44.66	121- 6.95	D SEARLE 7/17/81	661	10.23	70.0 195.0	(1.59)		34.4 1.3			C	C. R. BASALT
						160.0 195.0	(1.59)		35.1 .5	39.0	(62)	C	
3N/13E- 21AB	45-44.23	121-10.94	J MOTT 7/ 9/81	512	10.76	65.0 150.0	(1.59)		28.5 .9	33.5	(53)	C	C. R. BASALT
3N/21E- 19BAB	45-44.12	120-13.55	RB-1 10/30/74	120	15.40	30.0 70.0	(1.59)		54.3 2.0	53.8	(85)	C	C. R. BASALT
3N/ 8E- 21BDD	45-44.07	121-48.24	DNR-CRSN 9/14/81	137	7.01	5.0 114.0	1.60 .13	13	167.6	166.0	265	G	QUARTZ DIORITE
3N/ 3E- 21DAB	45-43.77	122-26.23	ZINTZ 7/ 9/79	250	8.83	30.0 103.0	(1.59)		26.7 .2	27.0	(42)	B	EOCENE BASALT
3N/ 3E- 21DBD	45-43.60	122-26.40	BOTTMLLR 7/ 5/79	219	8.85	30.0 188.0	(1.59)	1	28.7 .3	27.0	(42)	B	EOCENE BASALT
3N/ 7E- 25DA	45-42.88	121-52.90	SMITH 11/23/81	270	7.57	59.0 213.0	(1.26)		27.9 .7	26.8	(34)	B	VOL-CLASTIC ROCKS
3N/11E- 29CCA	45-42.76	121-27.61	BNG CTY1 7/ 8/81	46	13.04	70.0 100.0	(1.59)		35.3 .5	35.3	(56)	C	C. R. BASALT
3N/ 7E- 36BDD	45-42.34	121-51.96	NIX 9/ 8/79	146	9.72	15.0 150.0			36.6 .2	38.1		B	OLIGOCENE VOLCANICS
						200.0 290.0			24.0 .1	24.4		B	
						15.0 290.0	(1.46)		31.4 .3	32.7	48	C	
3N/11E- 34DBB	45-42.12	121-24.66	HEANEY 7/ 4/81	183	11.30	25.0 100.0	(1.59)		36.6 .7	36.6	(58)	C	C. R. BASALT

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY	R
2N/ 3E- 12CAD	45-40.03	122-22.58	VALDESE 1/ 2/80	365	8.77	100.0 127.0			27.5 .4			B	EOCENE BASALT	
						25.0 127.0	(1.59)	1	23.1 .3	23.1	(37)	B		
2N/ 7E- 16CCC	45-39.16	121-57.61	RDH-NBV3 9/11/81	14	11.57	10.0 155.0			107.3 2.0			G	VOL-CLASTIC ROCKS	
						80.0 155.0	(1.46)		90.6 .9	82.4	(121)	G		
2N/ 7E- 22BBA2	45-38.91	121-56.13	DH-1203 10/28/75	41	9.30	45.0 80.0			34.8 2.1			C		
2N/ 7E- 21BAC	45-38.90	121-57.24	RDH-NBV2 9/11/81	14	9.44	50.0 195.0	(1.46)		142.6 5.3	129.6	(190)	G	VOL-CLASTIC ROCKS	
2N/ 7E- 22BBA7	45-38.88	121-56.14	USCE1440 4/12/77	51	9.45	20.0 84.5			30.4 2.8			C	CLAY, SILT & SANDSTONE	
						50.0 84.5			42.4 2.3			C		
2N/ 7E- 22BBA1	45-38.88	121-56.15	DH-1201 10/28/75	45	9.95	40.0 82.0			40.5 1.2			B	CLAY, SILT & SANDSTONE	
2N/ 7E- 22BBA8	45-38.86	121-56.15	USCE1329 4/12/77	51	9.94	25.0 75.0			29.3 1.5			B	CLAY, SILT & SANDSTONE	
2N/ 7E- 22BBC3	45-38.77	121-56.32	USCE1378 4/12/77	26	9.59	45.0 68.3			36.7 .9			C	CLAY, SILT & SANDSTONE	
2N/ 7E- 20DCA	45-38.43	121-58.52	RDH-NBV1 5/ 1/81	21	7.01	42.7 186.0			50.0 .4			B	VOL-CLASTIC ROCKS	
						100.6 179.9	1.40	5	54.2 .4	49.3	69	B		
2N/ 3E- 21CC	45-38.43	122-27.10	RDH-CAM3 9/ 4/80	610	9.65	65.0 145.0		2	35.2 .6	35.0		B	SANDSTONE & CLAY, GRAVEL	
2N/ 3E- 21DC	45-38.33	122-26.42	RDH-CAM2 2/ 6/80	79	9.02	30.0 73.0	1.34 .09	9	37.9 .9	37.0	49	B	CLAY, BASALT & GRAVEL	
2N/ 5E- 36DDA	45-36.75	122- 7.50	GROSS 7/10/79	268	8.04	10.0 30.0			43.5 .3	36.3		C	BASALT & SANDY CLAY	
						30.0 50.0	(1.05)		65.0 4.9	54.2	57	C		
						50.0 90.0	(1.59)		45.5 .7	45.5	(72)	C		
2N/ 5E- 36DDB	45-36.72	122- 7.65	PATTEN 7/25/79	274	7.05	10.0 30.0			46.2 1.8	38.5		B	CLAY AND BASALT	
						30.0 55.0	(1.05)		67.1 2.8	55.9	(59)	B		
						55.0 105.0			42.9 1.6	35.8		B		
						105.0 129.0	(1.05)		76.4 1.9	63.7	(67)	B		
1N/ 3E- 2DB	45-35.92	122-23.88	RDH-CAM1 2/ 6/80	67	9.69	60.0 150.0	1.99 .04	17	31.6 .2	31.6	50	A	BASALT & CLAYSTONE	

Usually the poor quality data are affected by intrahole water flow in holes which are intended to be water wells, and thus were uncased and ungrouted over at least part of their depth.

Terrain corrections have been made or estimated for all of the holes listed under the corrected heat flow column. The terrain corrections were generally made by the technique of Blackwell et al. (1980), or by the technique of Birch (1952). Other aspects of the heat flow/geothermal gradient measurement and calculation techniques are discussed by Roy et al. (1968) and others. A recent summary of hardware techniques for heat flow studies is contained in Blackwell and Spafford (1985).

The location of all holes for which logs were obtained by SMU/DNR are shown on Figure 1 (from Table 1 and Appendix A). Also shown are physiographic provinces for the state. Since the heat flow and geothermal gradient patterns are related to the geology and tectonics as embodied in the different provinces, these areas make natural divisions for discussing geothermal potential.

Summary maps of the heat flow and geothermal gradient data are shown as Figures 2 and 3, respectively. The data illustrated were taken from Table 1. Only one symbol is shown for each site, and where appropriate, the results have been averaged to give the values shown on the map. Both the geothermal gradient and heat flow maps have been contoured. The contouring was done by hand and at least partially based on presumed association with physiographic setting. This assumption is necessary in the northern Cascade Range and coastal provinces because of the scarcity of data within these areas. Another large data gap exists in the southeastern Washington. There seems to be

Figure 1. Location and physiographic province outline map for the state of Washington. Volcanoes in the Cascade Range are also shown for reference. Sites of holes which were logged by SMU/DNR as part of this project are illustrated in the figure. The solid symbols indicate sites where reasonable quality data (shown in Table 1) were obtained. Solid circles = A-quality values; solid squares = B-quality values; and solid triangles = C-quality values. The open symbols show sites where poor quality data (Appendix A) were obtained. Open circles = D-quality values, and open triangles = X-quality values.

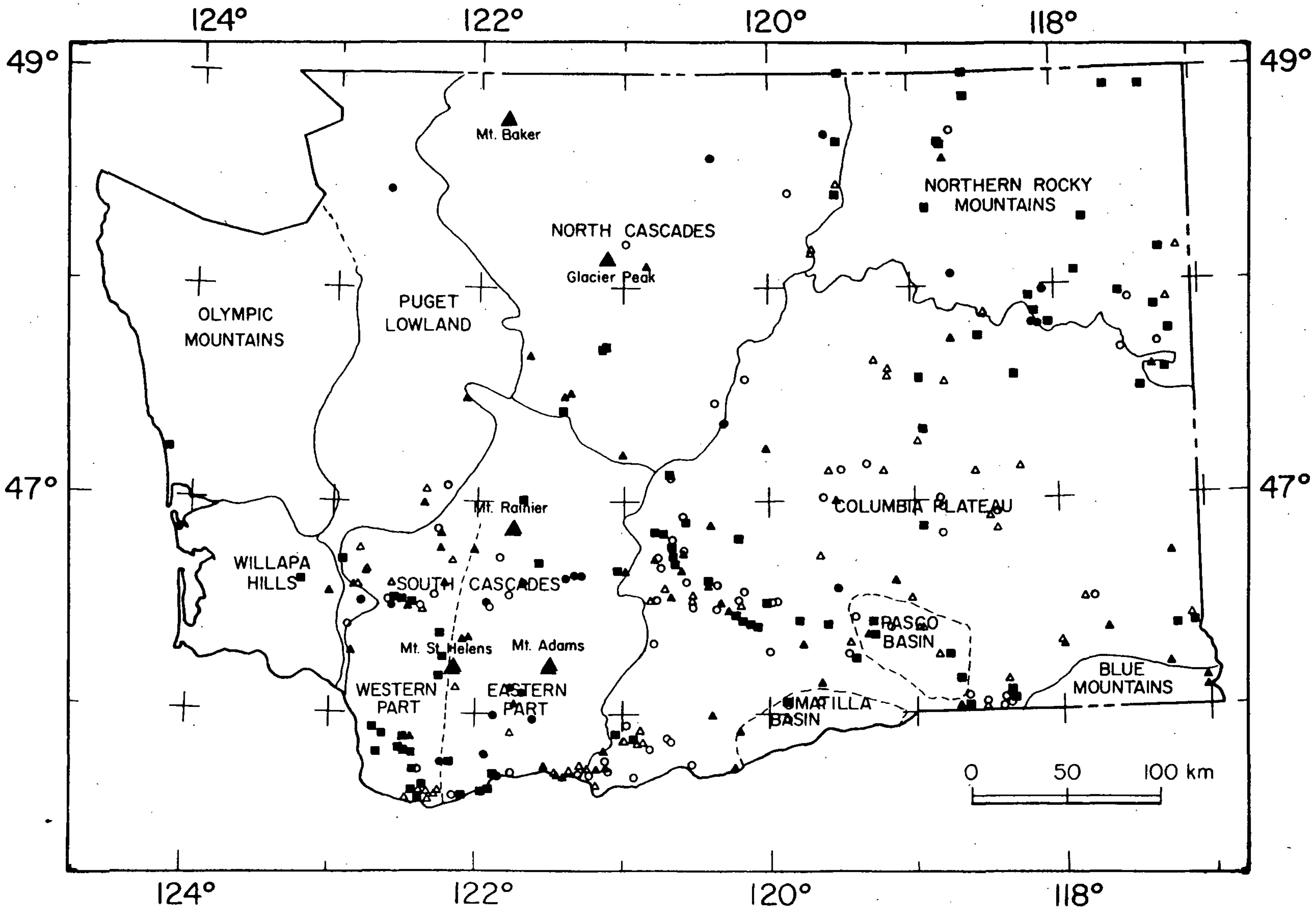

124°
122°
120°
118°
49°
47°
Mt. Baker
NORTHERN ROCKY MOUNTAINS
NORTH CASCADES
Glacier Peak
OLYMPIC MOUNTAINS
PUGET LOWLAND
Mt. Rainier
COLUMBIA PLATEAU
WILLAPA HILLS
SOUTH CASCADES
PASCO BASIN
Mt. St. Helens
Mt. Adams
WESTERN PART
EASTERN PART
BLUE MOUNTAINS
UMATILLA BASIN
0
50
100 km

Figure 2. Heat flow map of the state of Washington. Data of acceptable quality (Table 2) are plotted on this figure. The map is contoured where data density permits. Physiographic province outlines from Figure 1 are shown as an overlay on the map. The volcanoes in the Cascade Range (large solid triangles) are also shown for reference. Solid circles = A-quality values, open circles = B-quality values, and open triangles = C-quality values. The location of the cross-section illustrated in Figure 6 is indicated on the map.

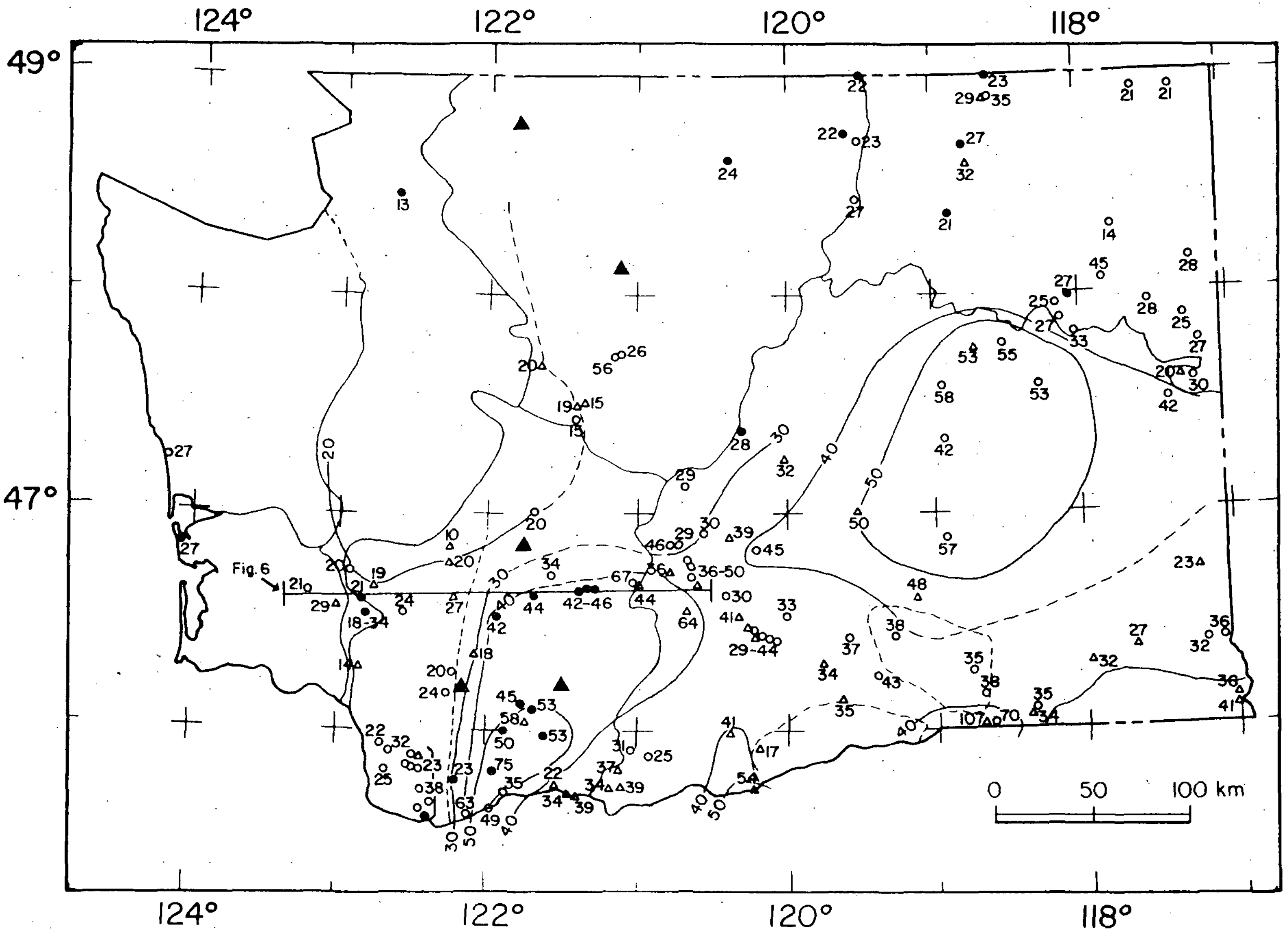
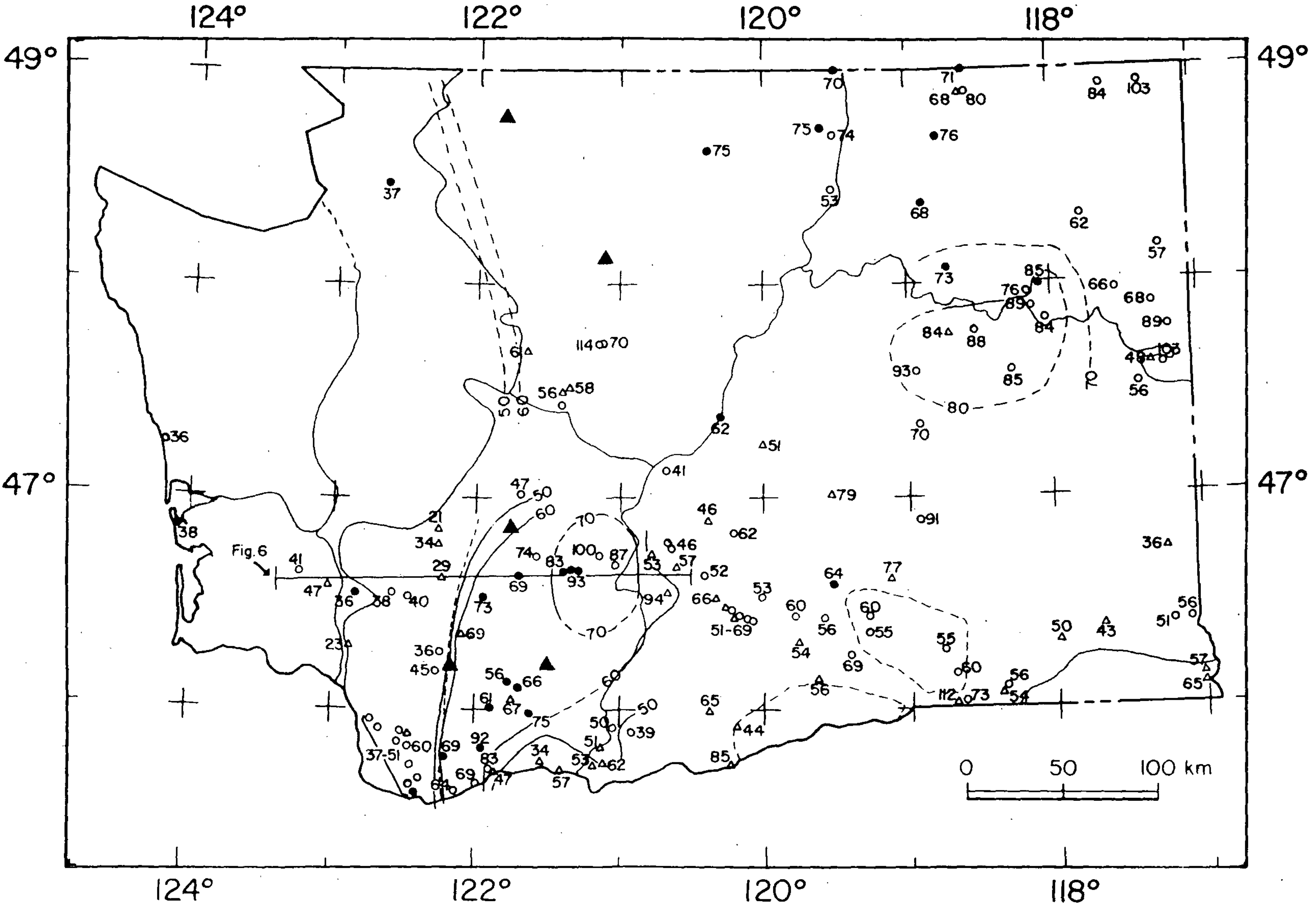

124°
122°
120°
118°
49°
47°
Fig. 6
0
50
100 km

Figure 3. Geothermal gradient map for the state of Washington. Geothermal gradients from holes or sites of acceptable quality (Table 2) are shown in this figure. Where feasible the gradients are contoured. Physiographic province outlines from Figure 1 are shown as an overlay on the map. Symbols as in Figure 2.


124°
122°
120°
118°
49°
47°
Fig. 6
0 50 100 km

little water well development along a broad northwest-southeast trending zone through the Columbia Plateau. With the exception of a few points near the center of this zone, an area 60 to 70 km wide and 200 km long has no heat flow data available. This data gap makes interpretation of the Columbia Plateau results problematical. The major patterns within the state are, however, quite well documented.

In the following sections geothermal data from each major physiographic division of the state will be discussed individually. The data are summarized in the final section.

MEAN ANNUAL GROUND SURFACE TEMPERATURE

The various research groups (WRD, WSU, SMU/DNR) have measured temperature as a function of depth in a large number of water wells in the Columbia Plateau, but, as will be discussed in a subsequent section, interpretation of individual temperature-depth curves is very difficult because of the ubiquitous presence of borehole water disturbances in the wells. These water disturbances often make it very difficult to decipher the appropriate geothermal gradient for an individual hole. Therefore, another type of systematic approach to interpretation of the data was attempted. This approach involved obtaining a bottom hole temperature from the logs for each well and independently estimating the mean-annual ground-surface temperatures at each site. The difference of these two temperatures divided by the depth of the hole gives an approximation of the geothermal gradient at each site.

Thus, as part of the analysis of the data, mean-annual ground-surface temperatures in various provinces were obtained and analyzed. The mean-annual ground-surface temperature for each individual well, where such a quantity can be determined, is listed with each site in Table 1 (and in a few cases for the holes listed in Appendix A). The temperatures were obtained by extrapolating the temperature-depth curve from the shallowest observed point to the surface. The data listed in Table 1 were analyzed by calculating a best-fitting straight line to groups of surface temperature-collar elevation data from each province or group of provinces. Results from four of these fits are shown in Table 2A. Surface temperature versus collar-elevation plots for the data from Table 1 are shown in Figure 4. Also shown on Figure 4 are the best-fitting straight lines for two of the groups of data.

On the basis of visual inspection, surface temperatures in the coastal provinces and in the western part of the Cascade Range appear to be controlled by similar influences. Data from the Columbia Plateau and northern Rocky Mountains also seem to be related. This grouping makes climatic sense, as a major factor controlling the weather is the Cascade Range axis, with much warmer and dryer weather in eastern Washington and cooler and damper weather in western Washington. Fits are also listed in Table 2A for the Northern Rocky Mountains and the Columbia Plateau provinces, individually. However, in each province there is only a limited range of elevation. Consequently, the fits are not as well determined, and the correlation coefficients are the lowest of the groups presented in Table 2A.

The variation of temperature at any individual elevation is quite large, on the order of ±2°C for the Northern Rocky Mountains and Columbia Plateau provinces, and ±1.5°C for the coastal provinces. Obviously, estimation of the surface temperature with these equations is relatively inaccurate. In an

Table 2: Mean annual ground surface temperature. In the first part of the table (A), the results of least-squares fits to surface temperature and elevation data in the form of the equation $T_s = T_0 + \alpha' z$ are presented. In the second part of the table (B), least-squares fits to surface temperature, elevation, slope orientation and slope angle data in the form of the equation $T_s = T_0 + \alpha' z + b\phi + c\theta$ are presented. T_s is mean annual ground-surface temperature, T_0 is temperature at sea level, z is elevation (in kilometers), α' is lapse rate (in °C/km), ϕ is slope angle in degrees and θ is slope orientation in degrees.

(A)

$$T_s = T_0 + \alpha' z$$

	T_0 °C	α' °C/km	N	Correlation Coefficient
Coastal Provinces + Western Cascade Range	9.78	-4.8	91	0.76
Northern Rocky Mountains	12.68	-5.7	35	0.74
Columbia Plateau + N.R.M.	15.98	-8.7	81	0.84
Columbia Plateau	15.98	-7.7	74	0.70

(B)

$$T_s = T_0 + \alpha' z + b\phi + c\theta$$

	T_0 °C	α' °C/km	b Deg.	c Deg.	Corr. Coef.
Coastal Provinces + Southern Cascade Range	10.31	-5.82	+0.024	-0.0002	0.89
Northern Cascade Range + N.R.M.	13.30	-6.87	+0.064	-0.001	0.86
Columbia Plateau	14.85	-5.1	-0.076	-0.0001	0.78

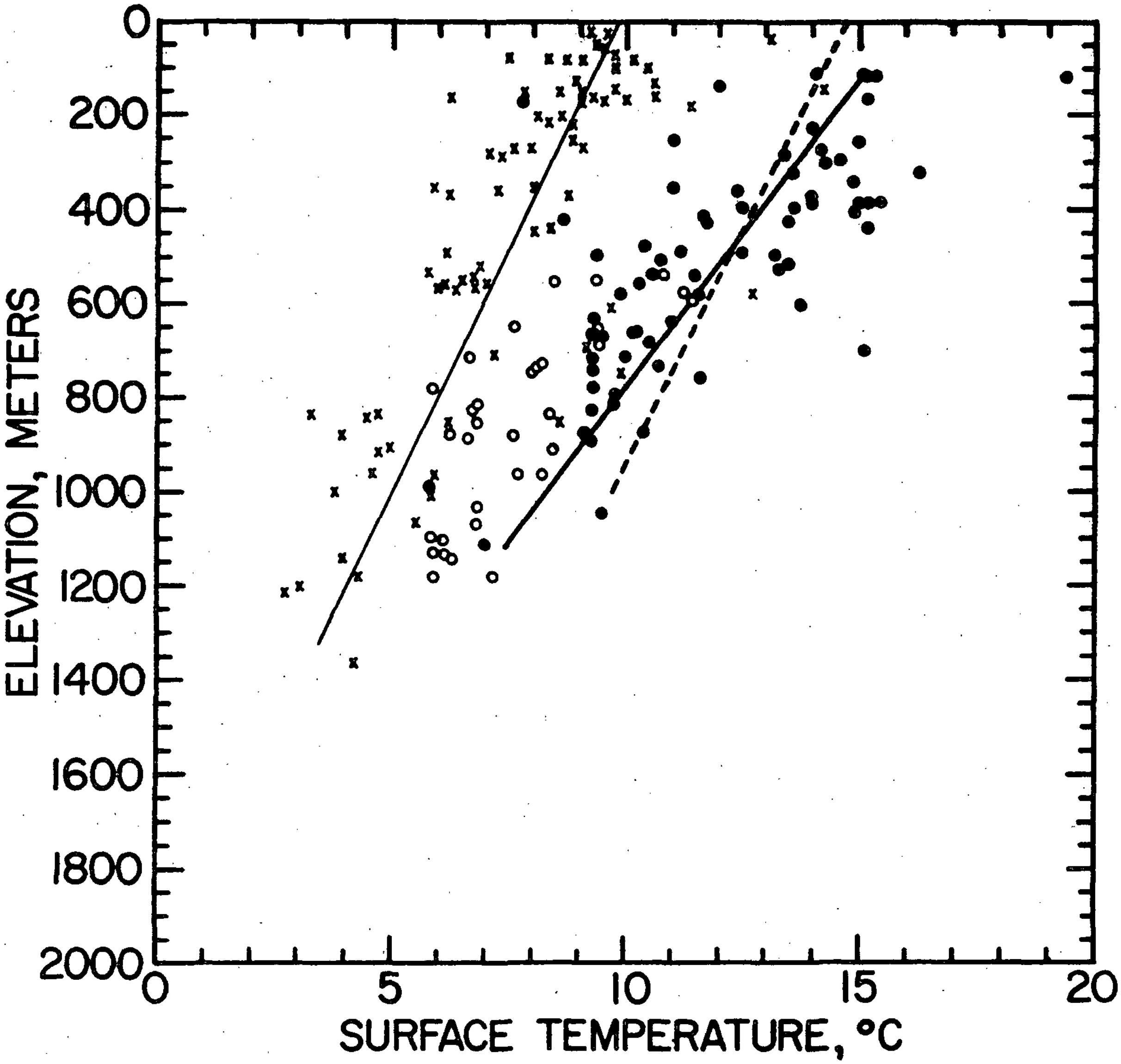


Figure 4. Surface temperature versus elevation plots for the state of Washington. Temperature data are plotted as a function of elevation for different groups of physiographic provinces. Straight lines illustrating the fit to data from the coastal provinces and western Cascade group of data (solid line to left), and the Columbia Plateau-Northern Rocky Mountain-Northeast Cascades group of data (solid line to right) are included. The two-dimensional fit from Table 2 for the Columbia Plateau-Northern Rocky Mountains is illustrated as a dashed line. Data from the Coastal Province and western Cascade Range are plotted with x's, data from the Northern Rocky Mountains are plotted with circles, and data from the Columbia Plateau are plotted with dots.

attempt to improve the accuracy of the estimation, the additional parameters of the slope orientation and inclination at each particular site were included in the calculated fits. Detailed studies discussed by Blackwell et al. (1980) indicate that within small geographic areas much of the actual variation in ground-surface temperature is related to microclimatic effects, in addition to the commonly recognized effect of elevation (controlled primarily by the lapse rate of air). All of the data that were available through 1979 were analyzed using a multiple linear regression program in order to get as accurate a model of the mean-annual ground surface temperature as possible. At that time many of the SMU/DNR holes in the Columbia Plateau were not available, and data from the Oregon part of the Columbia Plateau were included so that a larger data set could be examined. The resulting equations calculated using data from three provinces or groups of provinces are shown on Table 2B. The equations are somewhat different from those shown in Table 2A, because they include the additional terms of slope orientation and slope inclination, and because the same data sets are not compared. Correlation coefficients are improved slightly in all cases compared to similar data sets using elevation alone (Table 2A). However, it is quite clear from the size of the slope orientation and inclination terms that these effects are relatively minor. For example, localities with the same elevation and slope angle on opposite sides of a hill (i.e., a 180° difference in slope orientation) in the Northern Cascade Range and the Northern Rocky Mountains would have a maximum difference in surface temperature of 0.2°C. The maximum temperature difference in the same situation in the other two provinces would be less than 0.1°C. Similarly, for typical slope angles in the Columbia Plateau (less than 10°), the effect on the temperature would be less than .8°C.

The constant and elevation terms for the Columbia Plateau relationship can be used to plot a straight line in elevation-temperature space (see Figure 4). However, this straight line only represents part of the relationship. Plotted in this way the two relationships (from Table 2A and 2B) cross at 500 m and are never more than about 1°C different. Since the curve lifted in Table 2B for the Columbia Plateau was not constrained by the Northern Rocky Mountain data, it tends toward higher temperatures at higher elevations. For the purposes for which this information is used, the two equations can be considered statistically equivalent. The relationship in Table 2B is used in the analysis in a subsequent section of gradients from water wells logged by the WRD in the Columbia Plateau.

COASTAL PROVINCES

Included in this section is a discussion of heat flow values from the Puget Lowland, the Coast Ranges, and the western part of the southern Cascade Range (see Figure 1). The Olympic Mountains and Willapa Hill provinces are essentially untested at the present time, however. These provinces are underlain by Cenozoic rocks that have had a complex history. In northwestern Washington one heat flow measurement was obtained on Fidalgo Island from the older ophiolite complex exposed there (34N/1E-2CBB). Most of the rocks in the province are volcanic and volcanoclastic units, and thermal conductivity values tend to be below average for continental material. Hence, for a given heat flow, geothermal gradients will be slightly higher than in a basement terrain.

Throughout much of the Puget Lowland, there is a thick sequence of glacial till and gravel. Gradients are abnormally low within this glacial till and gravel due to the generally active groundwater flow in these very porous and permeable units. This circulation causes lower temperatures at depth beneath the major population centers than would be expected based on the average gradient values found in the bedrock units.

The heat flow values for this province are shown on the map in Figure 2 and in histogram form (from data listed in Table 1) in Figure 5. Geothermal gradients are shown on the map in Figure 3 and as a histogram in Figure 5. The range in geothermal gradients is from 38°C/km to 10°C/km. The higher geothermal gradients are usually associated with lower thermal conductivity rocks (such as the clay rich units). For example, the drill hole located at 12N/1W-9CCC has a range of geothermal gradient of 18-33°C/km; this variation in gradient is province associated with thermal conductivity variations within the hole. The average geothermal gradient of 24.5 ± 1.3°C/km is associated with the volcanic units that make up the bulk of the rocks exposed. Heat flow values are below normal in this province, ranging from as low as 20 to as high as 55 mWm^{-2}. The average is 39.8 ± 1.6 mWm^{-2}, which is well below the typical continental average of 60 mWm^{-2}. Hence, the geothermal potential in these provinces for anything except warm water is quite small. The only thermal manifestations are associated with hot springs in the Olympic Mountains. No data have been obtained in the vicinity of these thermal anomalies, so the geothermal significance of those features cannot be assessed from the present data. It does not appear to be very great, however.

The origin for this low heat flow is associated with the subduction of the Juan de Fuca oceanic plate beneath the western part of North America. As the oceanic block sinks beneath the continental plate, the upper part of the

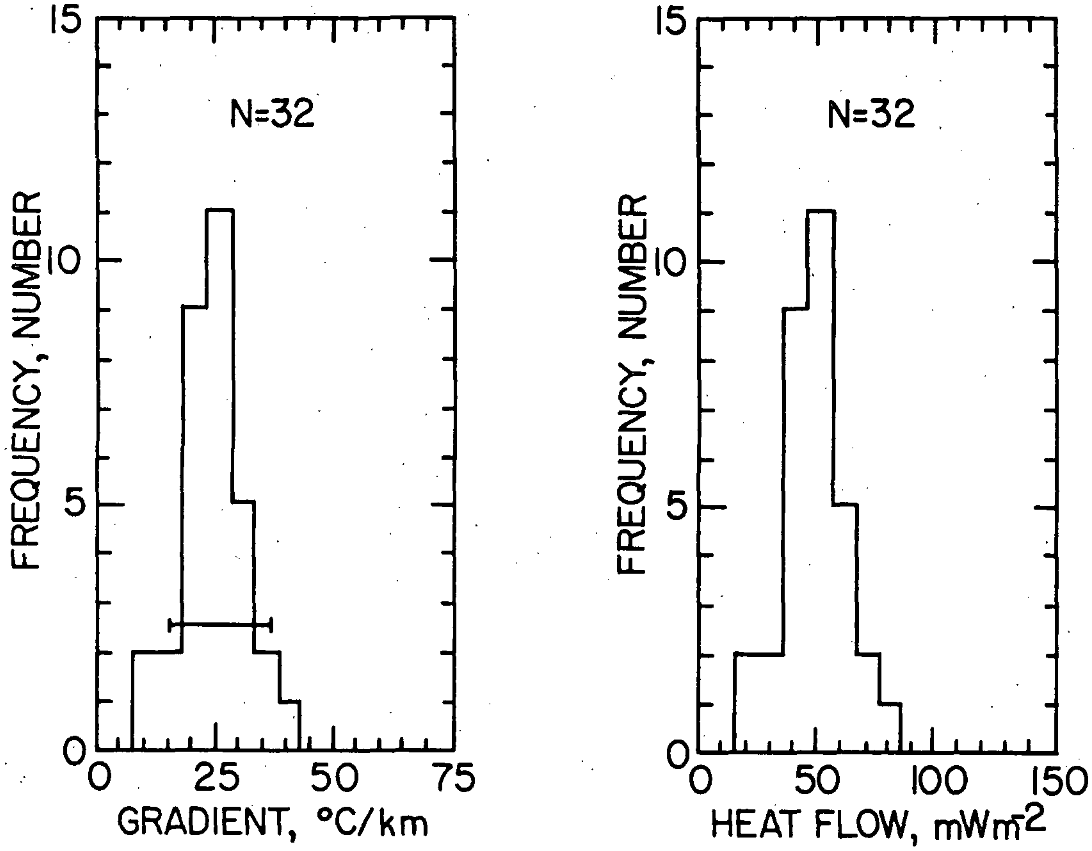


Figure 5. Histograms of geothermal gradient (A) and heat flow (B) for the coastal provinces are shown. Values are taken from Table 1. Provinces included are the Puget Lowlands, Olympic Mountains, Willapa Hills, and the Cascade Mountains west of the high heat flow zone. Band of gradients ingradient plot shows range in gradient in hole 12N/1W-9CCC associated with lithologic variations.

oceanic plate absorbs heat from the continental block, causing the low heat flow. This zone of abnormally low heat flow has been identified from British Columbia to Baja California (Roy et al., 1972; Hyndman, 1976; Blackwell, 1978). The intermediate focus earthquakes beneath the Puget Sound area are a manifestation of this subduction activity. The heat flow pattern in Oregon has been discussed in detail by Blackwell et al. (1982). In Oregon an abrupt change in heat flow from low along the coastal provinces to high in the Cascade Range is associated with a north-south zone in the western Cascade Range marked by hot springs. A similar type of boundary exists in the southern Washington Cascade Range described in the following section.

CASCADE RANGE

Regional Geothermal Setting The Cascade Range is obviously the province of greatest medium- and high-temperature geothermal potential in Washington. Clear indications of such geothermal potential within the province include five active or dormant stratovolancoes and numerous hot springs. A major part of the project involved the drilling of a number of holes in the central and southern Cascades in order to evaluate the thermal conditions there. The northern Cascades remain relatively unstudied as there are only two drill holes there. Results from those two drill holes are described by Korosec (1983).

There have been extensive studies of geothermal gradient and heat flow in the Cascade Range in Oregon. Major results include the location of a sharp eastward transition from lower than normal heat flow to much higher than normal heat flow within the Western Cascade Range, and mapping of a high heat flow zone for the length of Oregon. Average heat flow values in the high heat flow zone are 100±7 mWm^{-2} and average gradient values are 64±4°C/km (Blackwell et al., 1982; Black et al., 1983).

As part of the Oregon studies, extensive drilling was carried out near the Mt. Hood volcano (just a few kilometers south of the Columbia River). The results of the heat flow studies there are described by Steele and Blackwell (1982). The heat flow data in northern Oregon indicate that the average heat flow value in the high heat flow zone decreases in amplitude between Mt. Jefferson and Mt. Hood so that the background heat flow in the vicinity of Mt. Hood is 70 to 80 mWm^{-2} instead of the 100 mWm^{-2} observed south of Mt. Jefferson. One of the remarkable things about the heat flow and gradient pattern is the sharp western boundary to the high heat flow zone. The change from high to low heat flow occurs over a distance of approximately 20 km. The resulting half-width of 10 km indicates a depth of the source of less than 8 to 10 km. Heat flow measurements in British Columbia indicate a similar pattern of low heat flow along the coast and high heat flow inland, although the high heat flow values range from only 60 to 80 mWm^{-2}. The transition from low to high heat flow occurs along a line of gravity gradients, anomalous uplift rates, and faulting (Lewis et al., 1985; Hyndman, 1976).

<u>Washington Cascade Range Heat Flow</u> Within the state of Washington there is a transition in the geologic nature of the Cascade Range. South of approximately 47°, the geology of the Cascade Range is predominantly of Cenozoic volcanic rocks (similar to that in Oregon). There is a significant amount of late Cenozoic basaltic volcanism in the areas between the major stratovolcanoes,

Mt. Hood, Mt. St. Helens, and Mt. Rainier. Two of these centers are the Indian Heaven area in the south central part of the range and the Simco volcanic field to the southeastern part of the range. North of Mt. Rainier, the bedrock geology is predominantly early and pre-Cenozoic crystalline rocks, including both granitic intrusive rocks and metamorphic rocks. The only late Cenozoic volcanic rocks are the andesite volcanoes themselves, Glacier Peak and Mt. Baker.

The heat flow and geothermal gradients in the Indian Heaven area were studied by Schuster et al. (1978) using a number of drill holes. They found typical gradients of about 50°C/km and heat flow values of about 60 to 70 mWm^{-2}. In 1981 a line of drill holes along the Cowlitz River was established as part of this project. Drilling was contracted and coordinated by the Washington Department of National Resources with the temperature and thermal conductivity measurements being made by personnel from S.M.U.

The results of the heat flow measurements along this cross section are shown in Figure 6. A pattern similar to that observed in Oregon was obtained, although with a slightly reduced amplitude. Heat flow values west of approximately 122° West longitude are below the continental average and were discussed in the previous section. Typical values are 30 to 40 mWm^{-2}, and typical gradients are 15 to 25°C/km. Heat flow values east of that line are typically 70 to 90 mWm^{-2}, and gradients range between 34 and 67°C/km. West of approximately 120°45', heat flow values decrease to less than 60 mWm^{-2}, and geothermal gradients range from only 30 to 40°C/km. The eastern boundary of the high heat flow along the Cascade Range axis is not as well located as the western boundary and is of lower relief than the western boundary (10-20 mWm^{-2}

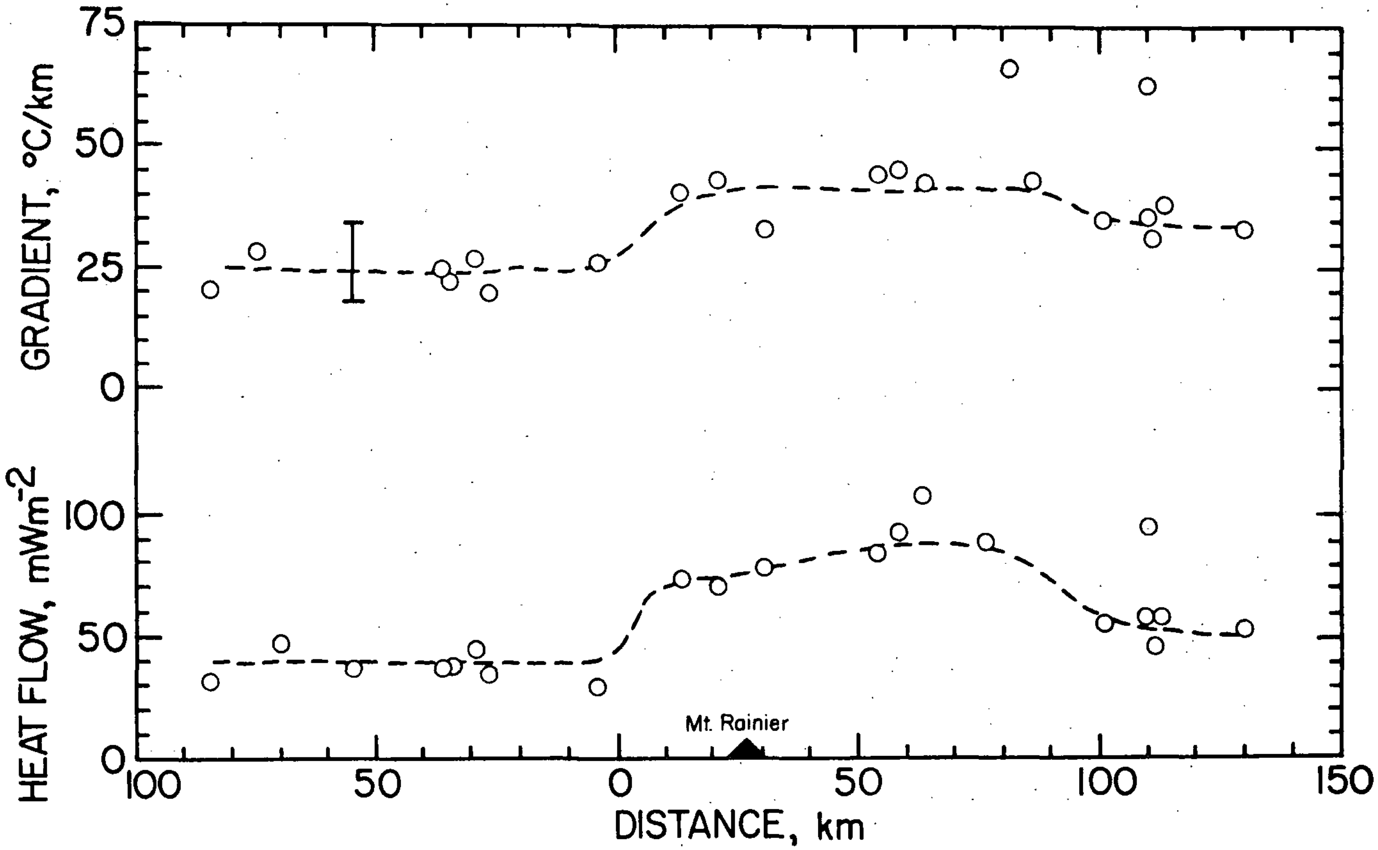


Figure 6. Heat flow cross section for the southern Cascade Range. Heat flow data are plotted as a function of distance along a line which passes approximately along the Cowlitz River in southwestern Washington. The location of Mt. Rainer is shown for reference.

instead of 30-40 mWm^{-2}). These results, together with the results from the Indian Heaven area, document a broad zone of high heat flow along the axis of the Washington Cascade Range. The sharp boundary to the west is analogous to the anomaly characteristics in Oregon.

This contrast in heat flow and geothermal gradient is clearly illustrated by temperature-depth curves from the Cascade Range and coastal provinces shown in Figure 7. Most of the holes that might be part of what could be called a "Cascade Anomaly" are shown as are about half of the wells in the low heat flow zone to the west. The difference between the two sets of data is immediately obvious, and there is no doubt that they are parts of quite separate data sets.

As shown in Figure 6, the least distance between holes that are part of the low heat flow zone and holes that are part of the high heat flow zone is approximately 20 km (distance between holes 13N/5E-18ABD and 12N/7E-16CC). This is about the same distance as the boundary between the high and low heat flow zones in Oregon and British Columbia, suggesting a similar depth to the source causing the contrast in heat flow. A similar half-width seems to be implied for the eastern side, although the boundary is constrained at only one location.

Unlike the situation in Oregon, where the heat flow zone has been identified for a lateral distance of several hundred kilometers, the high heat flow zone along the Cascade axis in Washington seems to be discontinuous. For many years the only heat flow values in the Cascade Range were those published by Blackwell (1969) near Snoqualmie Pass in the central Washington Cascades. Heat flow values there are approximately normal for continents, and the

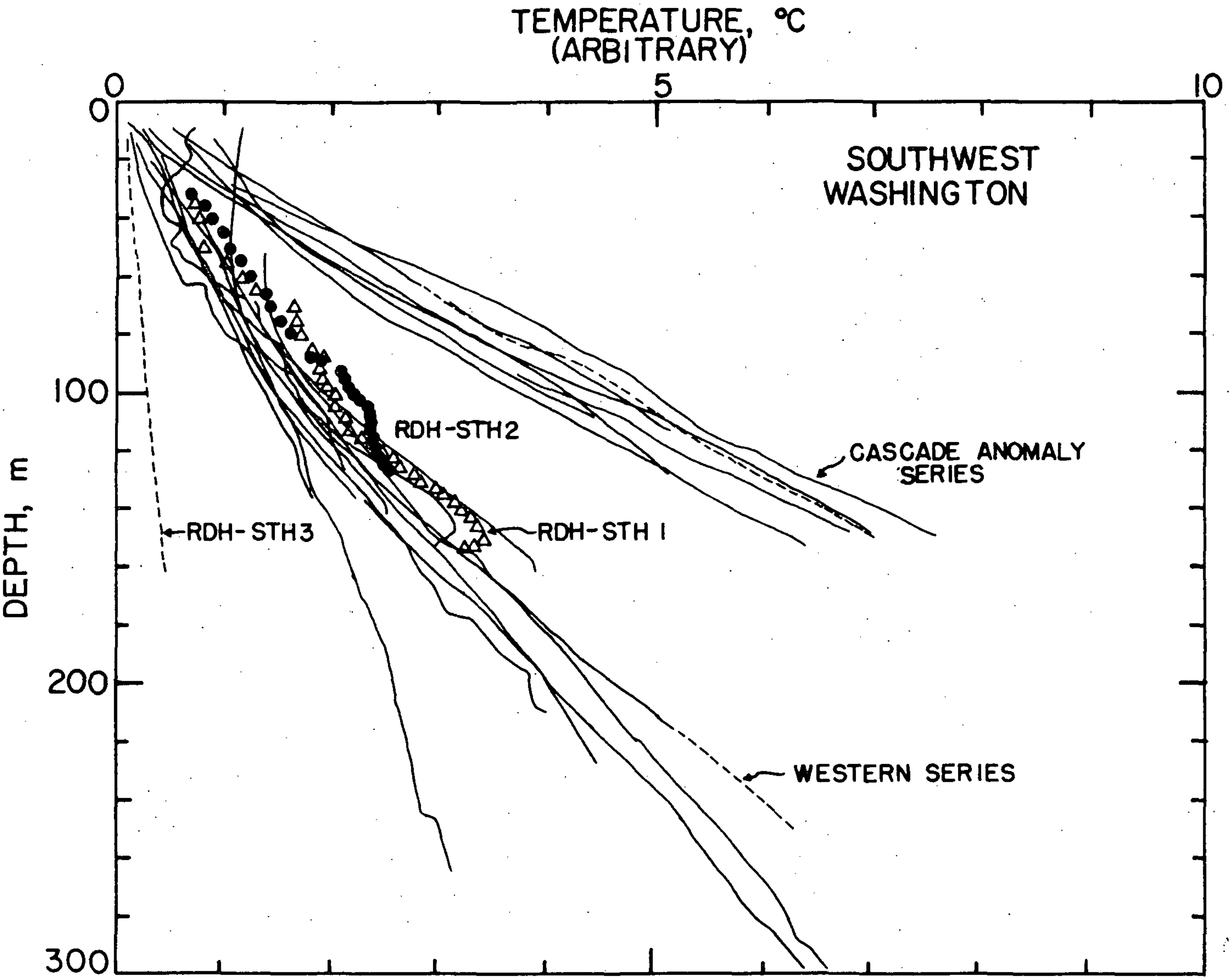


Figure 7. Temperature-depth curves for the Cascade Range and Coastal provinces. Illustrated are plots of temperature-depth data for many of the holes in the coastal provinces (low heat flow) and the Cascade Range high heat flow region (see Figure 2). Also illustrated are curves for the two holes west of Mt. St. Helens to illustrate their association with the low heat flow province.

inference was reached that there was no significant anomaly associated with the Cascades. These data stood uncontested until the heat flow measurements of the Oregon program were carried out in 1976.

In addition to the holes discussed by Blackwell (1969), a measurement was obtained just north of the Snoqualmie Pass area at a mineral exploration location, and two holes were drilled in the area as part of this project. Two other holes were drilled near the hot spring at Stevens Pass.

The heat flow values from the two holes drilled near Snoqualmie Pass (22N/11E-4BDA and 23N/11E-33CAB, Apendix B) are both low/normal and confirm the normal values obtained by Blackwell (1969). In addition, a drill hole just to the south of Mt. Rainier also has a normal heat flow value. However, at Stevens Pass one of the heat flow values is anomalously high, and is obviously affected by the hot spring circulation, whereas the other heat flow value is approximately typical for those seen in the Cascade anomaly zone between Mt. Rainier, Mt. St. Helens, and Mt. Adams. The only hole north of these holes is on the slopes of Mt. Baker near Baker Hot Springs. It is clearly affected by the hot spring circulation and does not give a typical background value for that area (Korosec, 1983). However, as discussed above, data from British Columbia suggest the presence of an axis anomaly in the Cascade Range in British Columbia. Therefore, the reason for the low values observed in the Snoqualmie Pass vicinity is not obvious. The values could be local anomalies due to some sort of water circulation, although this explanation seems unlikely since the holes are scattered over a large area and are in a variety of topographic settings. A discontinuous heat source at depth is an alternative and favored explanation for these variations in heat flow.

An interesting result of this drilling project is that Mt. St. Helens sits almost exactly on the boundary between high and low heat flow, and thus would presumably be in the most western position for a volcano associated with the Cascade Range arc. Mt. Adams appears to lie close to the eastern boundary of this anomaly. Therefore, the presence of two volcanoes at the same latitude might be explained by the fact that they are fed by local concentrations of magma which span the width of the anomalous zone, whereas at Mt. Rainier the magma is fed from the center of the anomalous heat flow zone.

Temperature-depth curves from two holes immediately west of Mt. St. Helens are superimposed on Figure 7 and clearly indicate their association with the low heat flow set of holes. These holes were drilled in 1979. The planned drilling project on the east side of Mt. St. Helens for 1980 could not be carried out, and hole 9N/5E-18BB was buried by the debris flow associated with the collapse of the north side of the volcano on May 18, 1980.

Another anomalous feature of the heat flow along the Cascade Range axis is associated with the Columbia River. Although there are several heat flow values that were typical of the anomaly zone (60 to 70 mWm^{-2}), east of Bonneville and including much of the Simco volcanic field, heat flow values average about 50 mWm^{-2}, and typical gradients are 30°C/km. Temperature-depth curves from holes in the Columbia Gorge typically suggest low gradients and often appear to be curved, possibly indicating regional down-flow of water. Temperature-depth curves from the Quaternary volcanics often are very complicated, and in some cases show evidence of transient lateral flow of warm water. Examples of the different types of temperature-depth curves are illustrated in Figure 8. Because no deep holes have been drilled in the

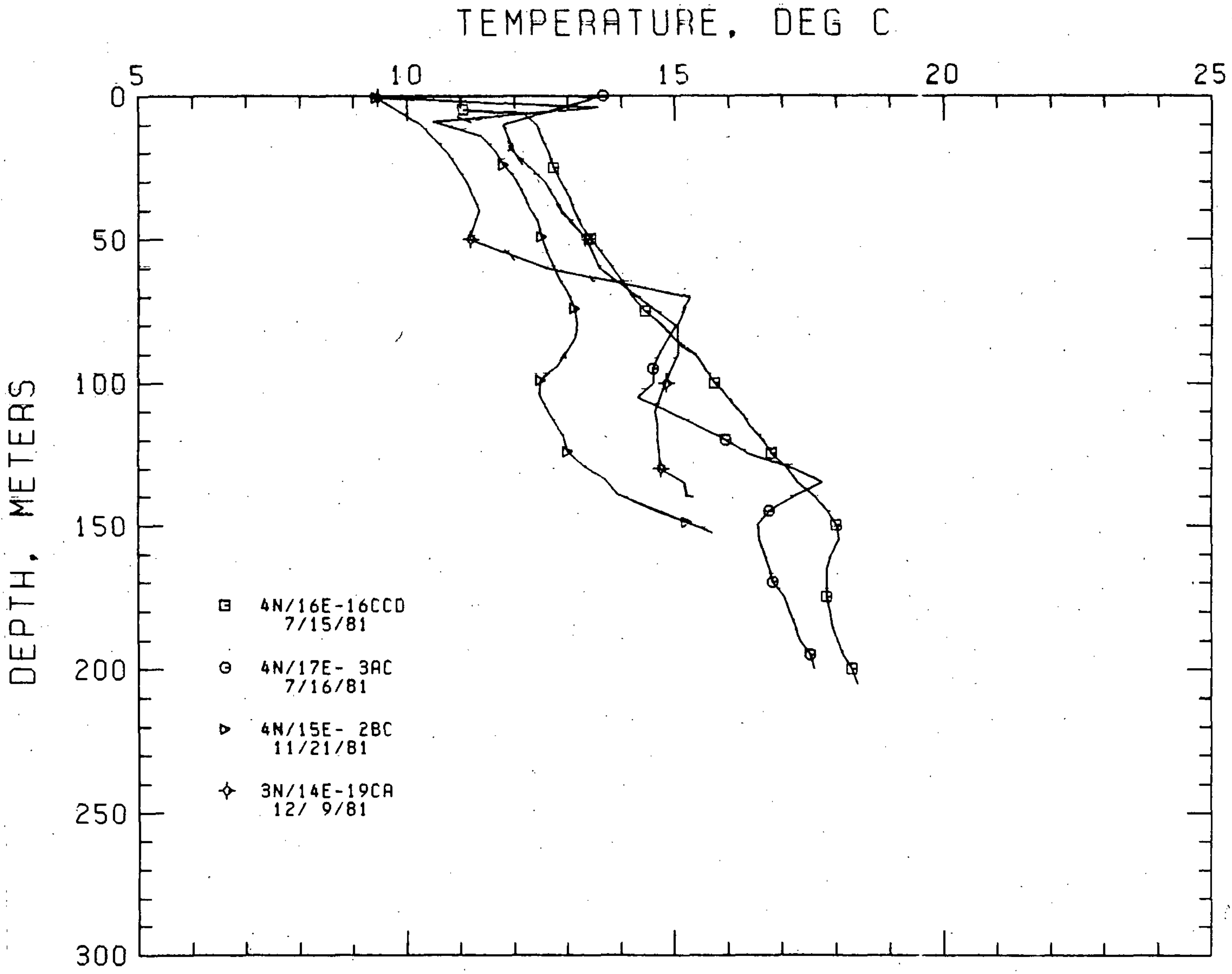


Figure 8. Temperature-depth curves for holes in the Columbia gorge. The highest gradients are in the Bonneville hot spring area, while typically low gradients are observed elsewhere. Gradients with a component of apparent lateral warm water flow are common in the area of Townships 4N/15E to 17E. Every fifth point on each log is plotted by a symbol.

gorge, or in the vicinity of the Simco volcanic field, the observed pattern may need some revision when more data are obtained. However, it seems quite clear that there must be lower heat flow values in this part of the Cascade Range axis than there are to the north and to the south. It would be extremely important from a geothermal point of view to know whether this change in heat flow is associated with fluid circulation or with a gap in the heat source at depth. If it is associated with fluid circulation, then warm fluid must be circulating upward laterally at some depth, and there might be significant undiscovered potential for geothermal resources in the Columbia Gorge. Geothermal conditions there need to be tested by drilling specifically for heat flow/geothermal gradient studies and to depths greater than 150 m to determine the controls on the heat flow in that part of the Cascade Range.

In summary, heat flow in the Washington Cascade Range is much more complex and variable than that observed in the Oregon Cascade Range. The origin of the more complex pattern is not identified; some of the variation may be due to lateral variation in the strength or depth to the heat source that causes the high heat flow. Some of the variation may be due to local fluid flow conditions, and some of the variation may be due to the much larger thermal conductivity contrasts than are observed in Oregon. In Oregon almost all the rocks are volcanic and have approximately equal thermal conductivities. In Washington, however, there is quite a wide range of conductivity, from quartzite, as in hole 23N/11E-4DD in Snolqualmie Pass, to values typical of volcanic rocks. Consequently, gradients, even without variations in heat source strength and fluid flow effect, can be expected to be much more variable than in Oregon. The fractured granitic and metamorphic rocks in the northern part of the Washington Cascade Range may be more brittle and more capable of holding open fractures, and thus be more susceptible to fluid circulation. Indeed the major geothermal field at Meager Mtn. (Fairbanks et al., 1982), where temperatures in excess of 200° have been obtained from holes drilled in fractured granitic rocks, indicates that there is certainly potential for deep fluid circulation in the geological environment existing in the Washington Cascade Range.

NORTHERN ROCKY MOUNTAINS

The northern Rocky Mountains physiographic province occupies the northeastern quarter of the state of Washington. The geology is complex, reflecting the Paleozoic and Mesozoic tectonic history of the Cordilleran Mountain chain. The area has extensive exposures of granitic basement rocks of Mesozoic and very early Cenozoic age. A few areas of Cenozoic rock exist, such as the Republic graben and other similar small extensional features. These features generally developed 30 to 45 m.y. ago during an extensional phase of tectonic activity. The province has been quite stable during the last 20 to 30 m.y. The topographic relief is high but the area is not extremely rugged. Unlike areas of similar geology in central Idaho, there are a few hot springs in the Northern Rocky Mountains in Washington. Thus there is very little overt evidence that might suggest high or moderate temperature geothermal potential. Indeed temperature measurements in over 50 holes in this province have yet to identify a gradient in excess of 35°C/km, with the one exception of a hole in very low thermal conductivity Cenozoic clay.

Histograms of corrected gradients and heat flow from data listed in Table 1 are shown in Figure 9. The average geothermal gradient is 26.0 ± 1.2°C/km and the average heat flow is 74.9 ± 2.9 mWm^{-2}. The measured gradients for the holes of acceptable quality range from 14°C/km for hole 22N/11E-4BDA to 45°C/km in hole 30N/13E-36DDB. This range in gradient reflects variations in thermal conductivity and not variations in heat flow. The highest gradient is observed in unconsolidated to semiconsolidated clays and silts within a small Cenozoic basin, and the lowest geothermal gradient is associated with the highest thermal conductivity rocks, i.e. quartzites. In general, gradients of 30°C/km or higher are associated with Cenozoic volcanic and sedimentary rocks that have generally lower thermal conductivities than the older rocks. Gradients between 20 and 30°C/km are associated with granitic rocks that make up a large fraction of the bedrock of the Northern Rocky Mountains.

The heat flow at one of the sites in the Northern Rocky Mountains, the Wilbur site in 3N/33E, has been discussed in detail by Blackwell et al. (1980), in association with terrain corrections for heat flow. Even though the uncorrected gradients vary by a factor of 3, the corrected heat flow values and gradients for all the holes are similar and are typical of others observed in the province.

There is a very small variation of heat flow values. The lowest heat flow is 48 mWm^{-2} in hole 24N/44E-6BC. This hole is relatively shallow; it has a gradient typical of other granitic gradients in this province, but a lower thermal conductivity. The heat flow in an adjacent hole (24N/44E-10AD) has a slightly higher than average gradient and thermal conductivity, which gives a higher than average heat flow. A possible explanation for these local

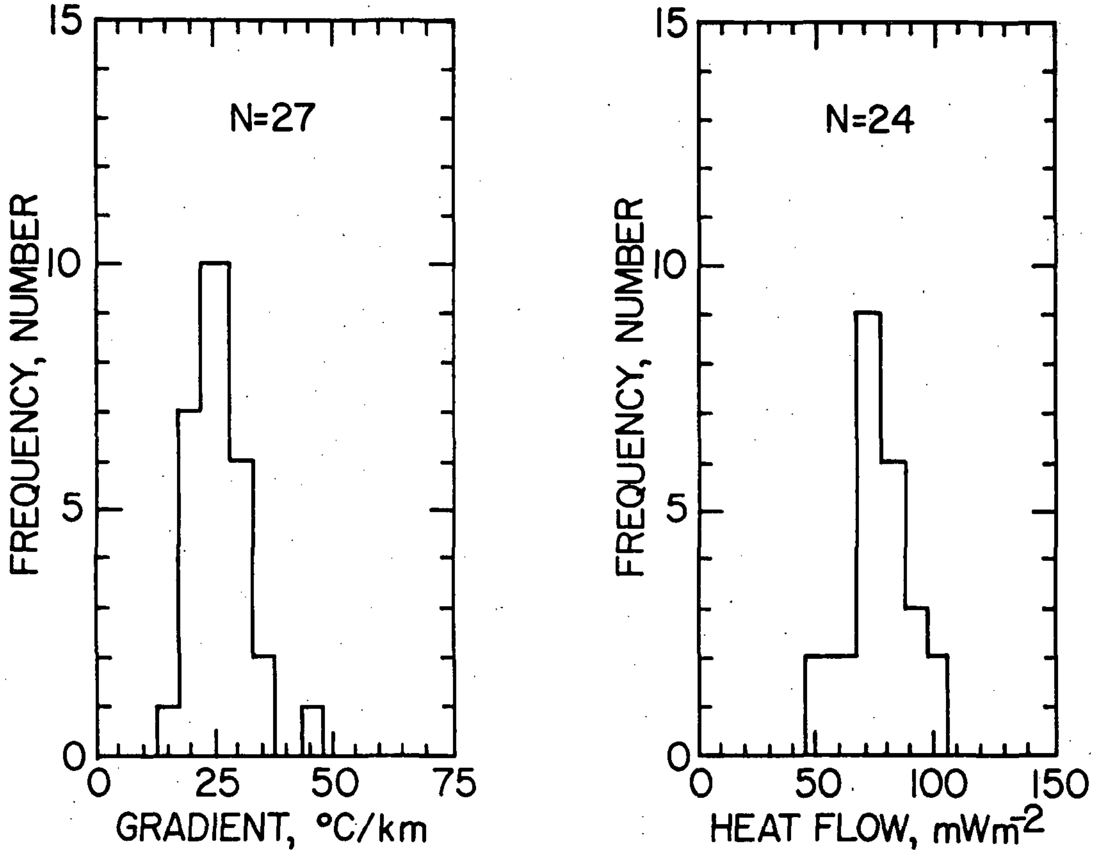


Figure 9. Histograms of geothermal gradient (A) and heat flow (B) for the Northern Rocky Mountain Province. Data are taken from Table 2.

variations in heat flow is small scale variations in conductivity, so that in this local area there is not a direct correlation between thermal conductivity and geothermal gradient. Another possible explanation is a sampling problem in these water wells; only a grab sample from a cuttings pile was obtained for thermal conductivity measurement.

Two sites of normal gradient but slightly high heat flow are found in extreme northeastern Washington (Roy et al., 1968; Blackwell, 1969). These values have been interpreted to give normal heat flow values with the high apparent heat flow associated with the refraction of heat into the very high thermal conductivity dolomites encountered at these two localities. In this case, the gradients are a more accurate measure of the background thermal conditions than are the heat flow values.

As discussed by Blackwell (1974), heat flow values in the Northern Rocky Mountains are typical of those observed throughout the Cordilleran Thermal Anomaly Zone, which includes the Basin and Range province and the Northern Rocky Mountains. No radioactivity determinations have been made as part of this study, but based on knowledge of the distribution of radioactivity in this province, the pattern remains as discussed by Blackwell (1974). Lower values of heat flow (65 - 70 mWm^{-2}) are associated with lower values of heat generation. The highest heat flow values, particularly those near the Spokane River west of the town of Spokane, are associated with radioactivity values that are above the background and range up to 4 μWm^{-3} (Steele, 1975). Based on a comparison of these data to those from other parts of the Cordillera, it would appear that the mantle heat flow in this region is on the order of 60 mWm^{-2}, and the slope associated with the heat production from the upper part of the continental crust is on the order of 10 km.

COLUMBIA PLATEAU

Introduction The Columbia Plateau occupies the southeastern third of the state of Washington. The geothermal conditions in this area are of considerable interest. Irrigation development of groundwater aquifers along flow contacts between basalt layers and in interbedded sedimentary rocks has been widespread, and a number of the water wells have been drilled to quite great depths. If an economic incentive exists, this major water resource might be a major geothermal resource as well. Geothermal energy may be used in many different ways associated with the many farming-and industrial-related projects in the Columbia Basin. Consequently, the object of this section of the report is to evaluate the geothermal conditions in this province. Because of the large number of wells and the importance of the groundwater resources, extensive hydrologic studies have been carried out in various parts of the Columbia Plateau. However, the regional setting of the detailed hydrologic studies and the way the many aquifers and areas of development interrelate is a subject for which there is very little information.

Recently, great interest has been shown in the area for gas exploration, and several wildcat wells have been drilled. In this case, knowledge of the subsurface temperatures and geothermal gradients is important in determining the amount and rate of organic maturation occuring beneath the basalt.

The thermal data for the Columbia Plateau have been collected by three different organizations - the U.S. Geological Survey Water Resources Division (WRD) operating out of Tacoma, Washington; the Department of Hydrology at Washington State University (WSU), Pullman; and Southern Methodist University/

Washington Department of Natural Resources. Some aspects of the copious WSU data base have been discussed briefly by Stoffell and Widness (1983a,b) and Widness (1983). Many of the well logs have been presented by Biggane (1980) and Stoffell and Widness (1983b).

Complexity of Temperature Logs We compiled an extensive data base of temperature logs for use in this study in an attempt to evaluate the background thermal conditions of the Columbia Plateau and in order to look for local thermal anomalies that might indicate higher than average potential for geothermal energy in particular places in the Columbia Plateau. In spite of this extensive data base, however, there are still many uncertainities about the thermal conditions in the Columbia Plateau. Most of these uncertainties arise from the fact that the holes that have been logged have been drilled almost exclusively as water wells, and the casing and cementing programs have obviously been minimal. Further, there are no holes that have been continuously cored and from which reasonably accurate *in situ* thermal conductivity estimates can be obtained. Hence we have little idea of possible vertical or lateral variations in thermal conductivity that undoubtedly must occur due to interbeds and the different proportions of vesicular versus non-vesicular basalts. The most serious problem, however, is the nature of the hydrology associated with the basaltic aquifers. The permeabilities across individual basalt flows are quite low, whereas along contacts between flows, permeabilities are quite high. Also recharge to the aquifers is quite distant from the points of development of the aquifers, and flow paths within the aquifer system may be complex and time dependent. Temperature logs for water wells in the Columbia Plateau are typically some of the most complex these authors have ever encountered, and the logs are most difficult to interpret. Thus in spite of this large data base, the thermal pattern of the Columbia Plateaus still quite ambiguous.

Some of these complexities can be illustrated by reference to specific temperature-depth curves for some of these wells. One of the most interesting wells, the Development Associates Basalt Explorer No. 1 (DABE-1), is represented by a series of logs. This well was drilled as a hydrocarbon exploration test in 1960. It was first logged by R. F. Roy on 8/31/61 (see Figure 10). Subsequently, the hole had a checkered history that culminated with its being plugged for a time by local ranchers because they could hear fluid cascading down the hole. It was opened by the U.S. Geological Survey Water Resources Division for hydrologic tests in 1972, at which time it was logged by the WSU group and by the U.S.G.S. geothermal studies program, Menlo Park, California. The hole was subsequently plugged back to a depth of 730 m and is maintained as a water level monitor well by the WRD. Well logs measured in 1981 by the SMU group, and on 6/15/72 by the WSU group are also shown in Figure 10.

Water flow conditions on the original logging in 1961 appear to be the simplest. Water entered the hole at the water table (at a depth of approximately 40 m), flowed down the hole to a depth of between 700 and 800 meters, and exited into the formation at that depth. Below 800 m, the gradient was nearly constant, and the temperature-depth curve was quite linear except for the very bottom part of the hole. The bottom isothermal section may have been due to additional intrahole water flow or due to the fact that

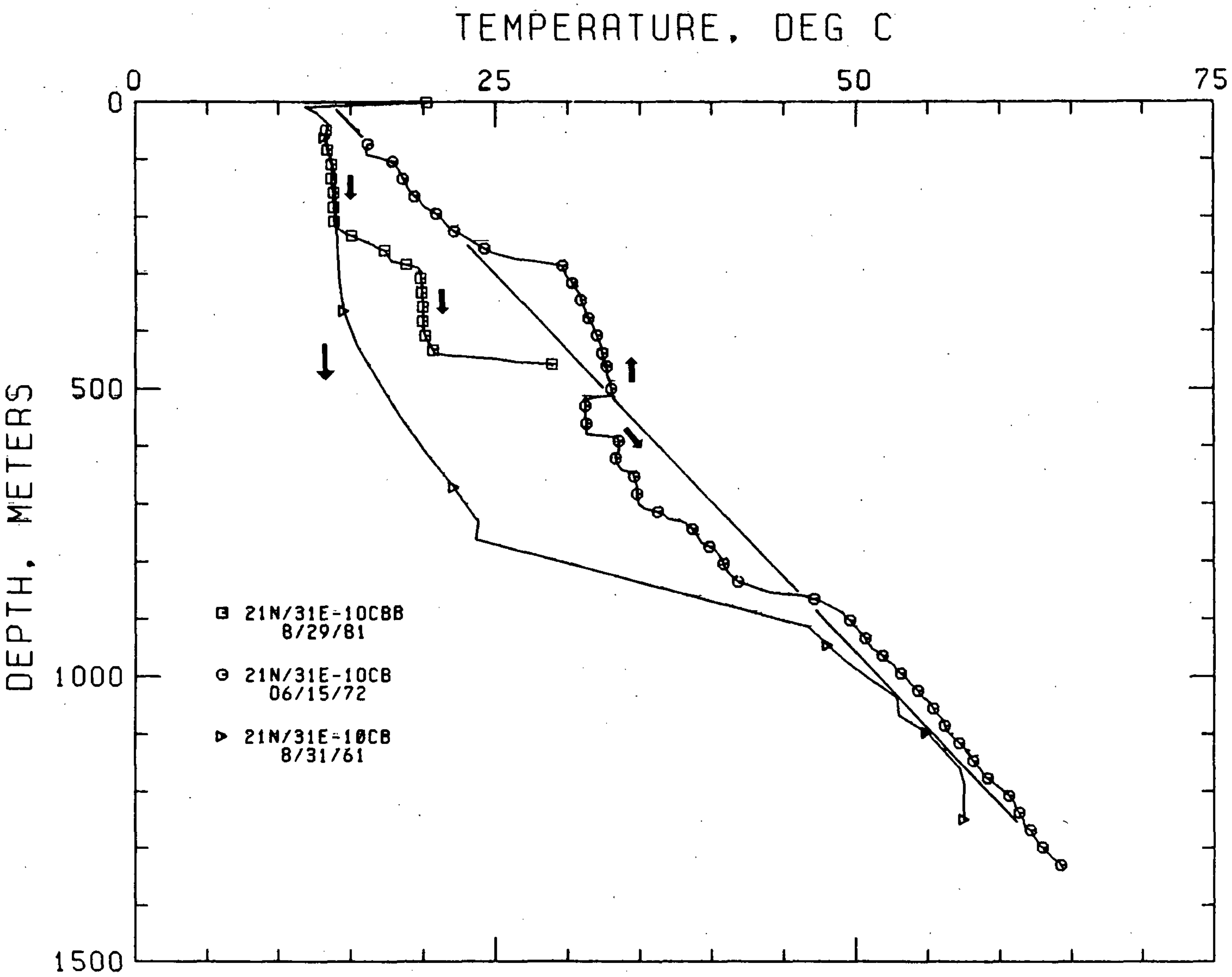


Figure 10. Temperature-depth curves for Development Associates Basalt Explorer #1. Three logs measured over a 20 year period are illustrated for this hole. Logs were obtained by R. F. Roy of Harvard University (1961), personnel from Washington State University (1972), and SMU (1981). Every fifth point on each log is plotted by a symbol.

the cable had hung up (and this fact was not recognized). The hole was logged to the end of the cable at about 1200 m.

When the hole was cleaned out in 1972, the flow pattern had changed drastically. In 1972 water flow in the hole was both up and down from an entry point of about 500 m. The rate of flow down the hole was quite low and occurred between depths of about 500 and 800 m. The artesian (up) flow occurred between 500 and 300 m. The presence of up-flow is indicated by temperatures above the interpolated temperature-depth curve from below 900 m and the surface temperature intercept (about 12°C). The curved temperature-depth relationship between 200 and 300 m and the higher than interpolated temperature suggest up-flow with that part (200-300 m) of the hole being heated from invasion of the formation at 300 m by the upward flowing warm water (from 500 m). The sharp negative-slope part of the curve between 500 and 600 m is very difficult to explain unless up- or down-flow in an aquifer outside the well bore is included. The temperature data between 100 and 200 m may represent the background gradient and thus may be unaffected by water flow in the 1972 log.

Following plugging of the hole a second time and its development as a water level monitor well, the flow pattern of the hole changed again. When the well was logging during 1981, there was down-flow through most of the hole, with water entering at the water table and exiting at two locations, between 210 and 300 m and at a depth of approximately 450 m. An aquifer at 300 meters was either donating fluid or extracting fluid. Based on local aquifer conditions within the boreholes, gradients both higher and lower than the 'true' value might be encountered. For example, if the probe had not been able to reach below 300 m in DABE-1 during the different times of logging (perhaps because of a casing change, partial hole collapse, etc.), gradients ranging from 0 to 55°C/km would have been measured.

Most of the holes in the Columbia Plateau are drilled as water wells; therefore, when a water flow of appropriate quantity is encountered or when enough water bearing zones have been encountered to allow development of the appropriate amount of fluid, drilling is terminated. As a consequence, water wells almost without exception bottom in or just below aquifers. Another limitation with the well logs is that logging starts at the water table; consequently, if the well has up-flow from the water table or a deeper aquifer, the first measured temperature may be too high. Logs of many of the wells consist of a vertical line (isothermal). Given the propensity of fluid to flow within the wells following completion, it becomes virtually impossible from a single well to decipher the nature of the thermal and fluid flow conditions existing at that location.

Because of these complexities, different approaches must be employed to determine the thermal characteristics of the Columbia Plateau. We collected as much of our own temperature data as possible, and also interpreted the existing temperature data in the WRD files. A limited amount of time was spent evaluating temperature data from the WSU files. The project remains a useful one for the future in view of the extensive WSU log data base that exists.

<u>Analysis Using WRD Temperature Logs</u> During the early 1970's, the U.S. Geological Survey Water Resources Division (WRD) collected numerous well logs

for the Columbia Plateau. These included flow logs, natural gamma logs, temperature logs, and other sorts of logs recorded in analog form on chart paper. Their primary interests were hydrological/geologic studies, and the temperature data were not extensively used. We attempted to use this large data set in order to obtain a good regional distribution of temperature gradients for the Columbia Plateaus. Because of the complexity of the temperature-depth curves, and the fact that logging did not start until the water table was reached, sometimes tens of meters below the surface, no attempt was made to measure gradients from the logs. Bottom hole temperatures were read from all of the logs and surface temperature was estimated for each of these wells based on the elevation, the direction, and the angle of the slope of the surface at the collar.

The surface temperatures were taken from SMU/DNR well logs, which had temperature measurements in air above the water table, and consequently allow a reasonably accurate estimation of the mean-annual ground-surface temperature. The temperature versus elevation/slope/orientation equation that was discussed in a previous section was used to estimate the appropriate mean annual surface temperature at the hole collar for the WRD logs. The estimated error of this approach, as discussed earlier, is at least several degrees C for any individual hole, but given the large number of holes, the systematic error should be relatively small.

An additional complexity arises in that there is a calibration problem with at least one of the WRD temperature tools. In a direct comparison in 1971 at a hole in Gig Harbor, the WRD tool measured 6°C above the SMU tool. Comparison of our equipment with another WRD tool used for a log at the hole at Westport, Washington (16N/12W-24DAD), shows that the WRD instrument and the SMU instrument are within 0.5°C of each other and give the same gradients. We attempted to sort through the U.S.G.S. data to isolate the holes which might have this calibration problem. The particular instrument that was found to be inaccurate recorded on the logs in °C. It seems to have come in use some time in 1971. In only a couple of cases were there obvious problems associated with calibration, and these will be discussed briefly below. In several of the holes, it appears that one of the instruments may in fact have been calibrated too low, and there are a couple of discrepancies between the calculated surface temperature and the surface temperature extrapolated from the temperature-depth logs. Of course, given the uncertainity of the water flow within the holes, this result is not surprising. In this case, the actual gradient shown was obtained from using an appropriate lower surface temperature to eliminate the negative gradient which would otherwise have occurred.

A number of the WRD logs were digitized in 1979. These data were then sorted to pick out the holes which were the deepest and had logs which had the best chance of showing a gradient. The average gradient for the Columbia Basin was calculated, not including holes less 75 m deep and showing the low temperature calibration problem. The average gradient for this data set was found to be approximately 40.0±2.1°C/km. Table 3 shows the location, elevation, slope angle, slope orientation, calculated surface temperature, bottom hole temperature, depth, and estimated geothermal gradient for these particular WRD drill holes in the Columbia Plateau. A histogram of this data is shown in Figure 11. If all WRD logged holes, including lower quality ones, were used, the average is 37.5 ± 2.0°C/km (N=143 using data included in Appendix B).

Table 3. Location, terrain and bottom hole temperature data from WRD well logs in the Columbia Plateau. Estimated gradient from calculated surface, and measured bottom hole temperature is shown in last column.

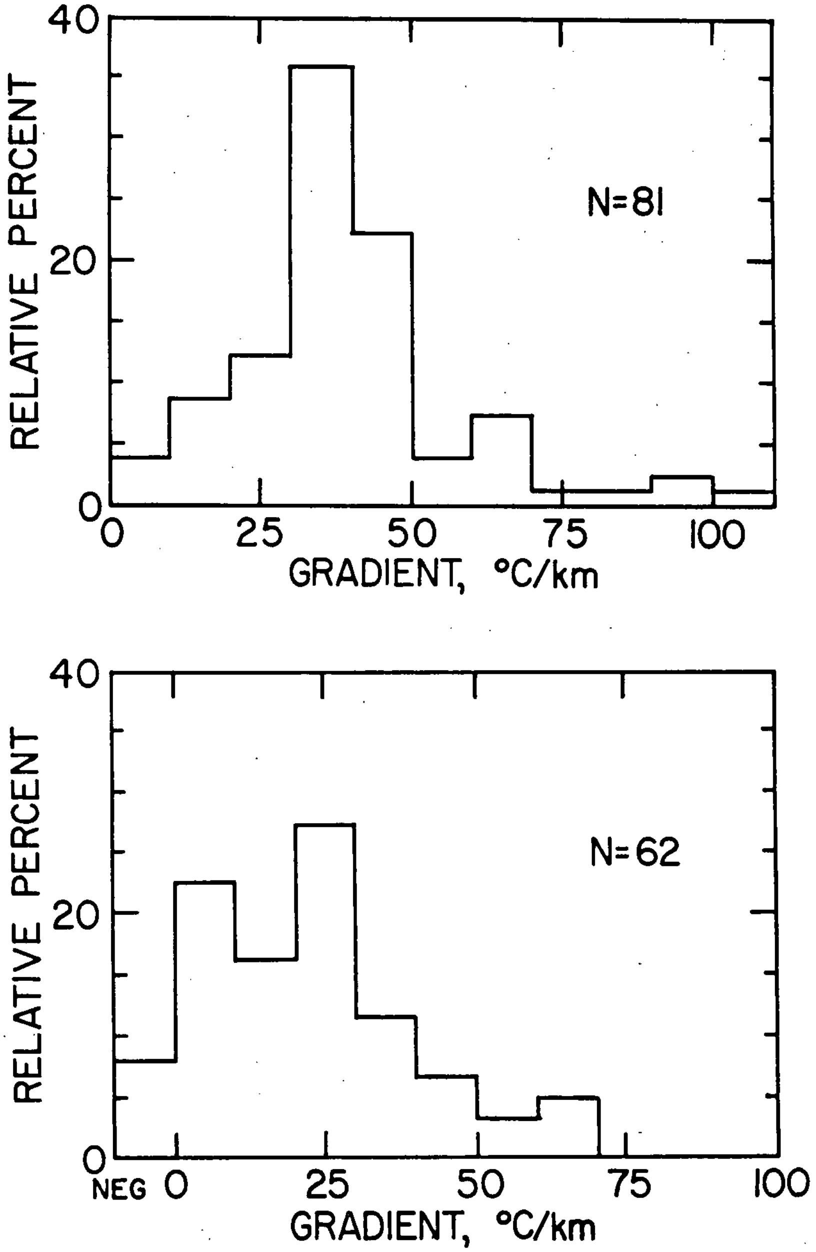
Location	Elevation m	Slope angle degrees	Slope orientation degrees	T_s °C	T_{BHt} °C	Depth m	Calculated Gradient °C/km
3N15E22AD	487.8	0.5	360	12.3	18.11	182.3	31.8
3N15E29BA	487.8	0.5	40	12.3	16.3	182.9	21.6
4N15E16BD	481.7	0	270	12.4	18.5	179.2	34.1
4N16E16CA	512.2	5.0	190	11.9	17.4	103.6	53.4
4N16E28AA	525.9	1.0	280	12.1	19.5	164.6	45.8
4N16E34AD	548.8	0.0	90	12.0	18.5	152.4	42.6
5N15E25DB	658.5	1.0	180	11.43	19.6	213.4	38.5
5N20E27AB	759.1	0.5	180	11.0	22.8	274.3	42.9
5N22E27AA	336.8	2.0	150	12.9	28.2	321.3	47.6
6N30E12DC	359.8	7.0	120	12.5	21.1	298.7	28.8
6N34E7BA	147.9	1.0	180	14.0	40.2	407.2	64.2
6N35E18AA	204.0	0.0	310	13.8	21.3	398.7	46.2*
6N35E31BD	228.0	0.0	360	13.7	19.7	292.6	20.5
7N19E10B	885.0	2.0	135	10.4	14.4	119.5	33.8
7N19E14CC	933.6	1.0	360	10.0	14.2	128.0	32.8
7N27E29DC	350.6	7.0	270	12.5	14.9	142.0	55.6*
7N35E34DB	234.8	1.0	180	13.6	17.0	220.4	35.8*
7N36E14CD	354.0	2.0	270	12.9	15.2	406.6	25.2*
7N36E17CA	300.3	2.0	230	13.2	39.1	713.2	36.4
7N36E18CC	282.0	1.0	230	13.3	18.5	170.7	30.3
7N36E19BB	267.0	1.5	220	13.4	18.2	177.7	27.5
7N36E19BD	271.3	2.0	270	13.3	31.1	470.6	37.8
7N36E33BB	295.7	0.5	250	13.3	30.2	424.0	39.9
8N24E1DA	222.5	3.0	340	13.5	23.6	381.9	26.4
9N21E26CB	214.9	0.0	230	13.7	26.5	294.4	43.3
9N22E11DA	225.6	7.0	270	13.2	20.3	165.8	43.1
10N17E36AA	311.0	1.5	120	13.1	9.2	95.4	2.1*
10N18E5DC	257.6	0.0	300	13.5	20.62	195.1	36.5
10N20E9AA	230.2	0	130	13.7	20.5	256	26.6
10N25E25BC	460.4	2.5	180	12.3	20.6	184.1	45.0
11N16E15DA	388.7	0.5	135	12.8	18.2	219.5	24.4
11N17E16BD	292.7	7.0	360	12.8	31.6	301.8	62.3
11N19E15AA	259.1	0.0	180	13.5	20.8	179.2	40.6
12N17E2AC	432.9	1.0	90	12.6	16.1	85.3	41.5
12N17E7AC	509.1	5.0	360	11.9	19.5	79.3	96.3
12N18E32CA	335.4	3.0	180	12.9	27.9	379.2	39.5
12N20E27CB	376.4	2.5	270	12.7	26.8	397.2	35.4
12N21E20CD	432.8	5.0	360	12.2	24.4	315.2	38.7
12N21E22CD	451.2	2.5	180	12.4	16.6	71.9	58.4
13N19E22CB	332.3	5.0	270	12.8	20.0	79.3	90.6
13N19E24AB	475.6	1.5	230	12.3	44.4	230.4	139.5
13N20E29BB	457.3	2.5	210	12.1	22.7	175.9	60.6
13N21E34AD	705.8	1.0	200	11.2	23.8	310.9	40.5
14N29E9AA	386.0	1.0	120	12.8	22.2	213.4	43.9
14N32E31BB	259.1	0.0	270	13.5	28.5	304.5	49.3

Table 3 (continued)

Location	Elevation m	Slope angle degrees	Slope orientation degrees	T_s °C	T_{BHt} °C	Depth m	Calculated Gradient °C/km
15N31E11BC	381.1	2.0	340	12.7	20.0	212.2	34.4
16N30E26AA	416.1	5.0	250	12.3	26.2	192.0	72.4
16N30E27DA	387.2	2.5	90	12.7	25.2	207.3	60.4
16N30E36CA	375	2.0	360	12.8	19.4	210.6	31.5
17N33E20BB	397	0.0	230	12.8	14.6	97.5	17.9
17N32E12CD	529.9	2.5	330	11.9	21.0	225.6	40.3
18N25E27CC	347.6	0.0	180	13.1	21.2	228.0	35.5
18N26E31BD	344.8	0.0	230	13.1	20.4	215.8	49.1*
18N29E26CA	341.5	0.0	130	13.1	14.7	91.4	17.1
19N28E28DB	326.2	0.5	310	13.1	22.6	292.6	32.2
19N30E13BD	437.5	1.0	135	12.5	20.2	201.2	38.1
19N32E30CC	434.4	2.0	315	12.5	19.2	165.2	40.6
19N33E7AC	536.6	2.0	360	12.0	15.5	185.4	16.8
20N30E21BD	475.6	0.5	250	12.4	25.0	322.8	39.0
20N30E22BA	486.0	0.0	180	12.4	13.5	122.0	9.2
20N30E23BC	484.8	1.5	120	12.2	34.7	337.2	66.8
20N30E28DD	466.5	2.5	335	12.3	28.5	181.4	89.3
20N33E13AA	525.9	1.0	190	12.1	17.8	173.4	32.9
20N35E17BB	604.3	0.0	180	11.8	20.9	231.7	39.4
21N30E26AC	493.9	2.5	180	12.1	21.3	170.7	53.6
21N31E22BC	517.1	3.0	270	12.0	19.8	231.7	33.7
21N31E23BD	541.2	1.0	360	12.0	16.3	225.6	19.1
21N31E27DB	537.6	2.0	40	12.0	18.4	200.0	32.0
21N31E32BB	508.8	1.0	220	12.2	21.0	211.0	41.7
22N30E35BC	525.9	0.5	150	12.1	19.1	194.5	35.8
22N31E24AC	520.7	2.5	220	12.0	17.9	210.1	28.1
24N31E16BC	579.3	1.5	230	11.8	20.1	227.1	36.5
24N32E24AA	593.9	1.0	240	11.7	13.8	120.0	17.5
24N32E30CB	581.7	1.0	20	11.8	19.4	228.6	32.9
24N36E16AA	723.2	2.0	145	11.0	12.6	229.3	7.0
24N41E3CC	724.1	1.0	210	11.1	13.9	122.8	22.8
25N22E22CC	796.3	2.0	180	10.6	12.7	170.7	12.3
25N28E25AB	553.3	0.5	270	12.0	23.0	177.4	62.1
25N30E5DC	573.2	1.0	180	11.7	14.6	197.4	36.9*
25N33E27AA	707.0	2.5	135	11.1	13.0	149.9	12.7
25N36E21BA	728.6	0.5	270	11.1	12.9	120.7	32.2*
25N37E28AA	1285.1	0.5	360	8.3	8.8	68.6	14.6*
26N32E10AD	695.1	1.0	145	11.2	19.2	181.6	43.8

*denotes holes where the extrapolated rather than calulated T_s was used in the gradient calculation.

Figure 11. Histograms of geothermal gradient obtained from analysis of the WRD data for the Columbia Plateau. The technique used to obtain the gradients is discussed in the text. (A) Higher quality data (B) Lower quality data.



Gradients in holes logged by WRD determined this way range from over 100°C/km to less than 10°C/km. An obvious approach is to look for areas with higher-than-average gradients. Four areas that contained several holes with higher-than-average gradients were identified. These were areas referred to as the Wilson Creek anomaly (20N/30E), the Othello anomaly (16N/30E), the Yakima anomaly (13N/20E), and the Lowden anomaly (6N/33E).

The anomalous holes in each of the areas and their geothermal gradients are listed in Table 3. Further examination of data from the Wilson Creek anomaly suggested that the two holes with the highest geothermal gradients, 20N/30E-23BC and 20N/30E-28DD, were affected by the high temperature calibration problem, and equivalent temperatures logged in the same hole or holes in the same section by WSU or by other WRD equipment gave temperatures approximately 8°C lower. If these holes are removed from the consideration, than typical gradients in the Wilson Creek anomaly are approximately the same as gradients in the remainder of the Columbia Plateau.

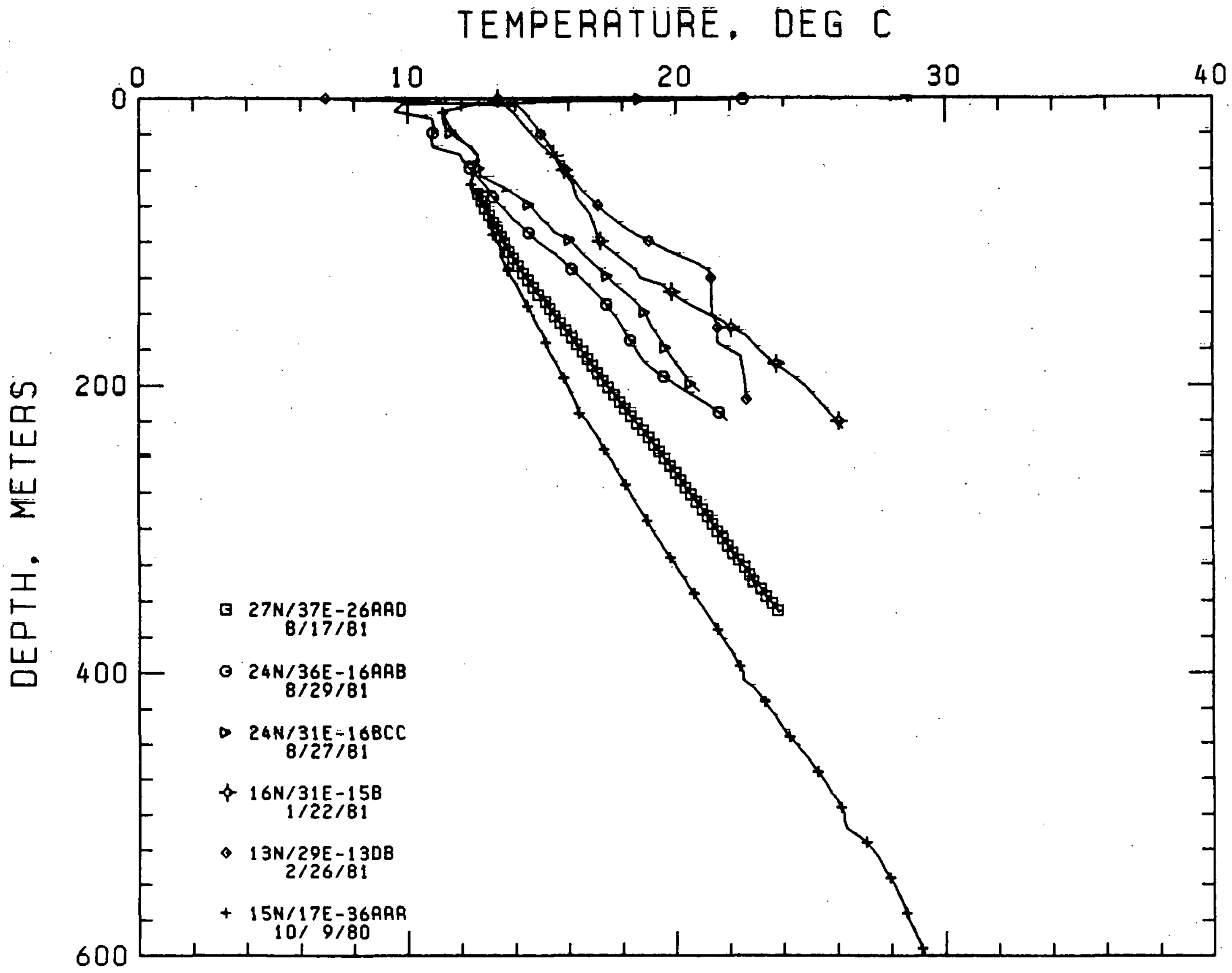
There are three holes in the vicinity of the Othello anomaly, two of which have gradients significantly higher than the typical Columbia Plateau value and one of which is significantly lower. It would be useful to have addition information in the vicinity of this anomaly.

There are four holes in the general vicinity of the Yakima anomaly. Examination of gradients for the four holes suggests that the calibration problem affected the hole with the highest gradient (13N/19E-24AB). The hole with the second highest gradient was only 79 m deep, and cannot be considered reliable. This leaves two holes, one with a gradient of 60°C/km and a depth of 176 meters, and one with a gradient of 40.5°C/km and a depth of 311 m. The cause of the high gradients is unresolved. However, none of the holes are very deep, and so deeper holes are required for evaluation. SMU/DNR data in 12S/20E indicates normal Columbia Plateau gradients there.

The Lowden anomaly is south-southwest of Walla Walla. One hole there has a bottom hole temperature of 40.3°C at 407 m. A hole logged by SMU/DNR has significantly a higher geothermal gradient as well (6N/33E-1DBD). Both the Lowden and the Yakima areas have a cover of sedimentary rocks on top of the Columbia River basalt, and there may be a large amount of interbedded sedimentary rock in the upper part of the basalt sequence. It is possible that the high gradients observed in these holes are related to low thermal conductivity in the sedimentary rocks, and are not associated with a geothermal anomaly due to circulating hot water. Further study of this area seems justified.

<u>SMU/DNR Temperature Logs</u> Several examples of temperature-depth curves from the Columbia Plateau are illustrated in this section (various parts of Figure 12). Beginning with the north part of the area (Figure 12a), hole 27N/37E-26AAD is shown as an illustration of a relatively high background gradient in the Northern Rocky Mountains. This hole was drilled in Oligocene volcanic rocks in a small graben along the Spokane River just north of the Columbia Plateau. The corrected geothermal gradient would be approximately 35°C/km because the hole was drilled along the river valley. Thus the gradient is typical for such rocks in the Northern Rocky Mountains. Also shown are temperature-depth curves for holes 24N/34E-16AAB and 24N/31E-16BCC. Although these holes are far apart, they have quite similar gradients, both in excess

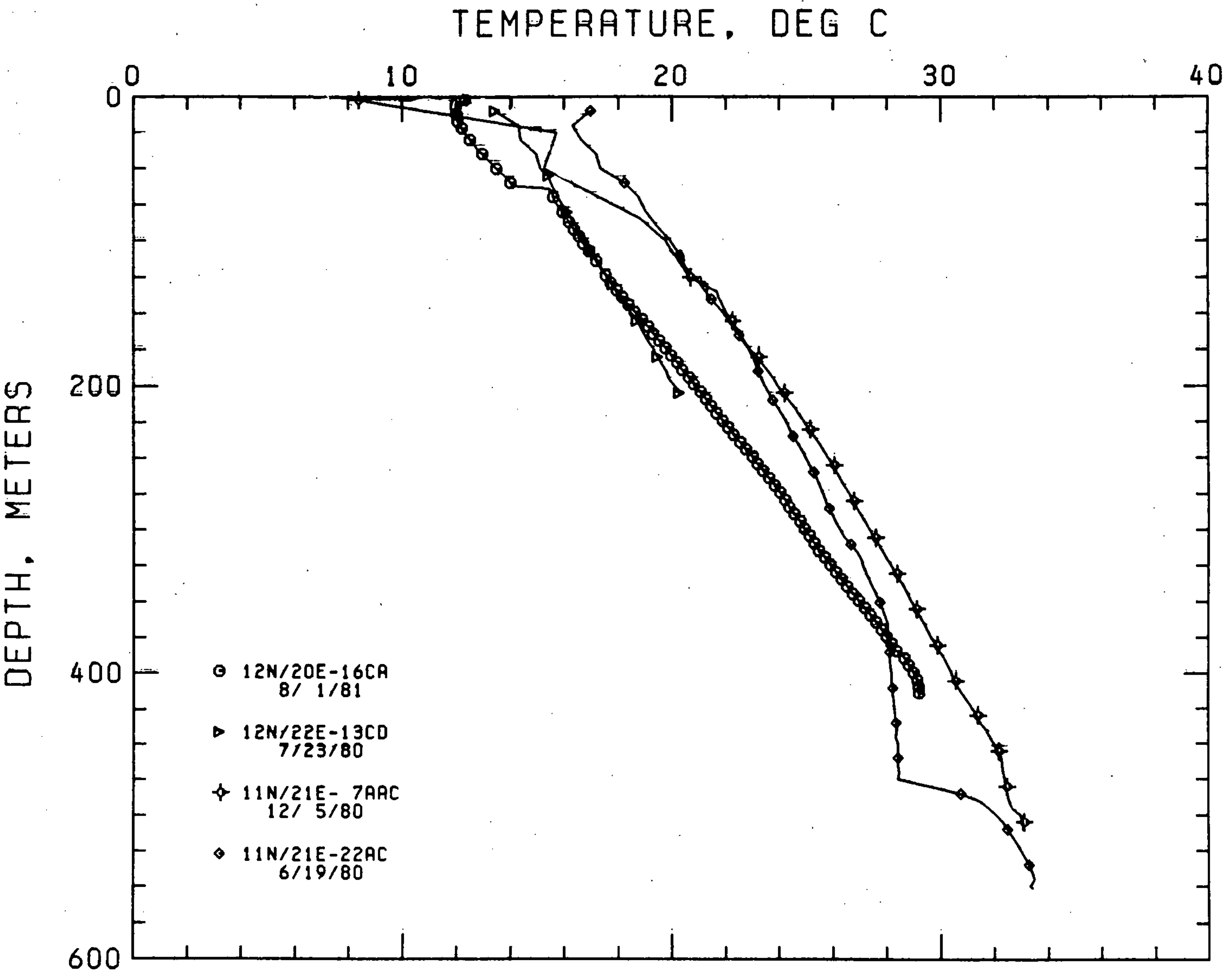
Figure 12A. Temperature-depth curves for example holes in the northern part of the Columbia Plateau. Every fifth point on each log is plotted by a symbol.



of 50°C/km. There are sections of differing gradient in each hole, but unfortunately not enough geologic information is available to know whether these variations correspond to geology or whether they are associated with some sort of water disturbance. Nonetheless, these gradients represent above average and quite linear gradients for holes from the Columbia Plateau. Hole 16N/31E-15B is also illustrated. This hole is east of Othello and west of Lynn. It also has quite a high gradient for the Columbia Plateau region. Hole 15N/17E-36AAB at the western edge of the Columbia Plateau along Wenas Creek. The gradient is quite low compared to other holes and unlike many of the other holes, it was drilled in Cenozoic sedimentary rocks. Their conductivity is somewhat lower than that of the volcanic rocks, and so the heat flow in this area is below the average value, as it is all along the east edge of the Cascade Range. Hole 13N/29E-13DB is one of the type examples for artesian conditions within the borehole. Water enters the hole near the bottom just below 200 m and flows uphole to exit at about 170 m. There is an additional effect on the flow by another aquifer at about 190 m, but whether this aquifer donates fluid or extracts fluid from the hole is not clear.

In Figure 12b a series of holes from townships 11N and 12N southeast of the Yakima are illustrated. Some of these holes are quite deep, and some give quite good gradients, while others are very disturbed by water flow. Hole 11N/21E-22AC clearly shows the effects of down-flow within the borehole from a depth of about 370 m to a depth of 430 m. Holes 12N/22E-13CD, 12N/20E-16CA and 11N/21E-7AAC have linear temperature-depth curves. All four holes are the best examples of data from these areas, and data from shallower holes or from other holes equally deep are more difficult to interpret.

Figure 12B. Example temperature-depth curves for wells in the west central part of the Columbia Plateau. Every fifth point on each log is plotted by a symbol.



Several holes from the southern part of the Columbia Plateau are illustrated in Figure 12c. Hole 11N/46E-32BCA is near the eastern margin. This temperature-depth curve is characteristic of up-flow from the bottom of the hole to an exit point in an aquifer at approximately 260 m depth. The average gradient in this hole is 36°C/km, which is typical of holes along the east edge of the Columbia Plateau. Hole 10N/24E-36BD shows up-flow from somewhere below the depth logged to a depth of about 220 m; however, the gradient above that zone in the hole is typical of the other gradients in the vicinity. Hole 10N/28E-14ABB is a deep test hole on the Hanford test site and shows a linear gradient. There is a step in the temperature-depth curve at approximately 530 m, which may correspond to some sort of water flow. Hole 9N/27E-23 shows a linear gradient.

Two holes from the Walla Walla area shown in Figure 12d (7N/21E-35AA and 7N/36E-33BB) have quite different temperature-depth curves. Hole 33BB shows clear effects of up-flow from the middle part of the borehole to 200 m and down-flow from the middle part of the borehole to the bottom. The entry point of the water would appear to be on the order of 330 to 400 m. In contrast, hole 35AA shows down-flow from the aquifer at approximately 190 m to bottom of the hole at approximately 300 m. The rather extreme variation in the types of temperature-depth curves in holes that are close together is clearly illustrated by this data set. Hole 6N/33E-1DBD is characteristic of some of the higher gradient holes observed southwest of Walla Walla. This hole has the characteristics of up-flow between a depth of about 300 m and 220 m. Even discounting this up-flow, the gradient for the hole is above average for the Columbia Plateau in general, and the temperature is over 30°C at about 250

Figure 12C. Example temperature-depth curves for holes in the south central part of the Columbia Plateau. Every fifth point on each log is plotted by a symbol.

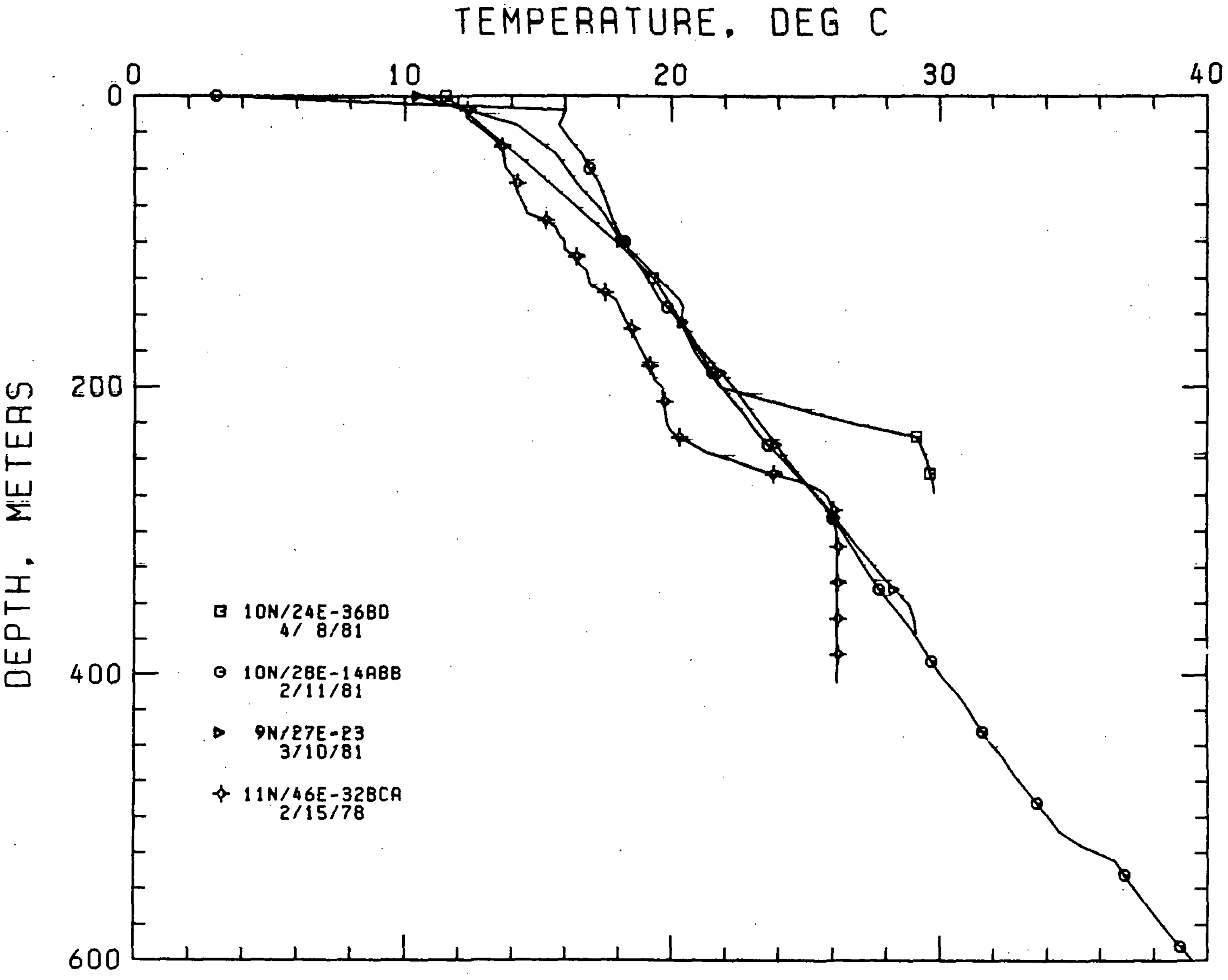
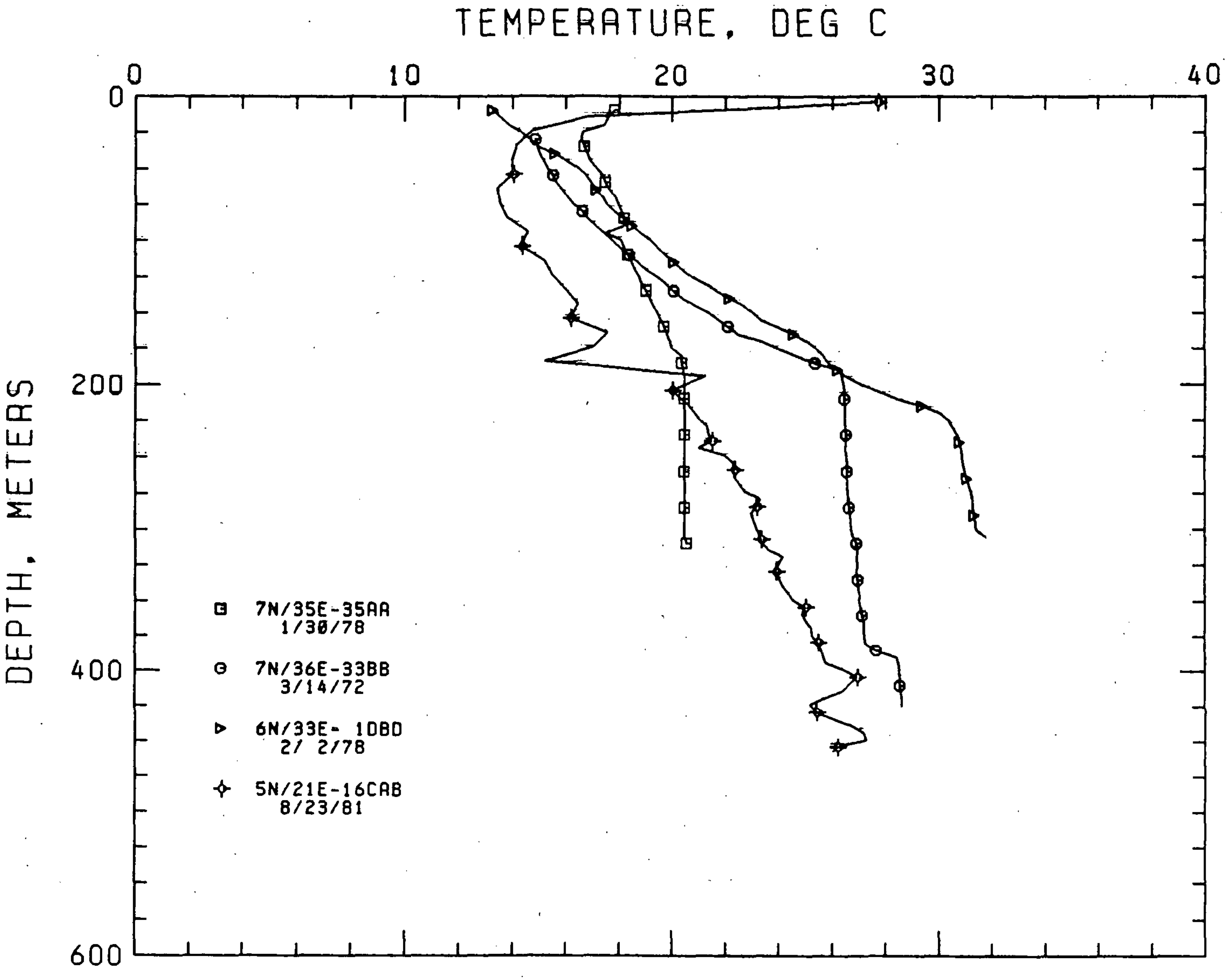


Figure 12D. Example temperature-depth curves for wells in the southern part of the Columbia Plateau. Every fifth point on each log is plotted by a symbol.



m. Hole 5N/21E-16CAB shows an irregular but linear temperature-depth curve and a relatively low gradient.

Based upon analysis of the detailed temperature logs discussed in the last subsection and the temperature data collected by the WRD, it would appear that the gradient range throughout the Columbia Plateau is between 30 and 55°C/km, with the mean value being 41.1 ± 2.5°C/km. The mean heat flow, excluding data from the western edge of the province is 61.1 ± 3.5 mWm^{-2}. There is a lack of detailed geological information, and it is not clear whether the variation in gradients is associated with the thermal conductivity variations within the basalts or between basalt and sedimentary rocks, or whether it reflects genuine changes in heat flow in various locations throughput the plateau. There is weak evidence, as presented in Figures 2 and 3, for higher than average gradients on the western and eastern margins of the plateau. Clearly logs from this province are complex and difficult to interpret, and the exact average gradient cannot be determined with the present data set. Temperature logs clearly show differences in aquifer heads and also suggest these aquifer head differences may change with time under the influence of irrigation development. Nevertheless, warm water at a temperature of 45 to 65°C should be encountered everywhere within this province at a depth of one kilometer. No evidence has been discovered for major geothermal anomalies associated with fluid circulation. Because of the head differences, it is clear that various aquifers, even those very close spatially, are not well connected. Local vertical leaks along dikes, in fractures zones or erosional gaps in flows could cause local fluid circulation anomalies, however. Some of these might be discovered as geothermal development proceeds.

DISCUSSION

A summary of the average heat flow and geothermal gradient values for the various provinces for specific areas discussed in this report are shown in Table 4. These results document the variations discussed in previous sections. These results include low heat flow in the coastal provinces west of the Cascade Range heat flow anomaly, variable heat flow in the Cascade Range and typical heat flow values of 70-80 mWm^{-2} in the Northern Rocky Mountains. It is unfortunate that there are no data for the transition between the Northern Rocky Mountains and the Cascade Range, or for the Cascade Range at the latitude of the Northern Rocky Mountain province. Based on the results from Canada (Lewis et al., 1985), it appears that heat flow values in the two provinces might be similar. If this is the case, the nature of heat loss must be quite different. The heat flow in the Cascades may be related to a heat source at 10 km, whereas the heat source in the Northern Rocky Mountains is associated with current or past thermo/tectonic events associated with the whole Cordilleran Mountain chain and affecting a much larger area than just the volcanic arc.

Heat flow in the Columbia Plateau seems to be significantly lower than that observed in the Northern Rocky Mountains, at least if the area immediately south of the Northern Rocky Mountains is excluded. This difference in heat flow may be associated with differences in heat loss from the mantle or differences in the heat production from radioactivity within the crust. If the crust beneath the Columbia Plateau is thin and mafic as is indicated by seismic refraction data discussed by Hill (1972), then the heat

Table 4. Summary of gradient and heat flow for various areas of Washington

	Gradient			Heat Flow		
	Average °C/km	SE	N	Average mWm^{-2}	SE	N
Coastal Provinces	24.5	1.3	32	39.8	1.6	29
Northern Rocky Mountains	26.0	1.2	27	74.9	2.9	24
Cascade Range (All except Gorge)	39.9	3.8	22	69.7	3.2	24
Cascade Range (Columbia Gorge)	32.4	2.5	8	50.5	3.9	8
Columbia Plateau (All)	39.8	1.8	54	61.4	2.0	51
Columbia Plateau (Western Margin)	32.8	2.3	7	51.0	1.7	5

flow from the mantle within this province might be essentially the same as the heat flow at the surface.

These patterns in the Pacific Northwest are similar to the patterns discussed by Blackwell (1978), except that there is now much more data on the heat flow in and west of the Cascade Range. Geothermal gradient patterns for Washington are similar to the heat flow patterns; however, there is a major difference in the gradient between the Cascade Range anomaly region in the southern part of the Cascades and the Northern Rocky Mountains even though the heat flow values are quite similar. This difference is associated with the fact that the volcanic rocks in the southern Cascade Range have generally lower thermal conductivities and thus the geothermal gradient is higher by almost a factor of 2. Temperatures are therefore expected to be much higher at depth, and in fact at 10 km, temperatures beneath the Cascade Range are probably twice as high as those beneath the Northern Rocky Mountains. High gradients are also observed in the Columbia Plateau. These high gradients are partially related to the fact that the basalts have a low thermal conductivity. The gradients are slightly lower than those observed in the Cascade Range anomaly area, with the exception of a few holes in the north central part of the plateau. The geothermal gradient beneath the Columbia Plateau will decrease with depth when the pre-basalt rocks are encountered because it is quite likely that the sedimentary/ metamorphic/igneous rocks that make up the basement have higher thermal conductivities than the volcanic rocks. Hence at a depth of 10 km the temperatures beneath the Columbia Plateau are probably closer to those in the Northern Rocky Mountains than to those in the Cascade Range anomaly region.

Because of the relatively high gradients and because of the many existing wells, the low- to medium- temperature geothermal potential for the Columbia Plateau province is quite large. Temperatures of over 40°C will be encountered in drill holes 500-1000 m deep throughout most of the Columbia Plateau. Higher temperatures might be encountered if actual circulating fluid systems could be identified. So far none of these have been encountered. The potential for high temperature geothermal systems is greatest in the Cascade Range. Moderate temperature geothermal potential also exists there, although lack of extensive commercial and industrial development in the area would lower the value of energy compared to similar temperature fluids in the Columbia Basin.

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Appendix A. Geothermal data of poor quality for the state of Washington. Collar elevation is in m, surface temperature is in °C, uncorrected and corrected gradients are in °C/km, thermal conductivity is in $Wm^{-1}K^{-1}$, and heat flow is in $m^{W}m^{-2}$. Date is date hole was measured. Brackets around the thermal conductivity values signify that the values were estimated from the known lithology of the well. In lithology column C.R. stands for Columbia River basalt. The quality indicator is described in the text.

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY
37N/33E-7AAA	48-43.52	118-40.94	PRATHER 9/15/81	791	7.60	19.0 62.0			35.5 1.8	34.8		D	
37N/26E-25A	48-40.84	119-29.92	GILDROY 9/19/81	451	10.00	4.0 134.0						X	
37N/32E-34B3	48-39.80	118-45.73	DDH-C 7/31/70	1067	7.48	40.0 55.0			36.0 .3			D	
35N/26E-36DD	48-29.02	119-29.74	DOE TST1 9/21/81	332	12.10	19.0 66.5	(2.85)	1				X	
34N/24E-20ADB	48-26.04	119-50.71	USFS OK 9/20/81	1646	3.20	59.0 65.0			51.1 1.4			D	
31N/15E-	48-11.85	120-58.57	DDH-2 9/ 2/70	1823	2.50	70.0 75.0			21.6 .3			D	
31N/15E-	48-11.85	120-58.57	DDH-141 9/ 2/70	1752	3.61	50.0 95.0						X	
31N/25E-27DC	48-10.54	119-40.38	DOE TST3 9/17/81	249	12.40	14.0 44.0						X	
31N/25E-27DB	48- 9.27	119-40.61	DOE TST2 9/20/81	268	13.10	24.0 88.0	(2.89)	1				X	
31N/45E-27CD	48- 9.22	117- 6.18	N HEFNER 9/ 9/81	666	9.50	64.0 115.0	(2.43)	1				X	
28N/42E-14CDC	47-55.10	117-27.51	NYBAKKEN 7/25/81	634	9.70	35.0 70.0	(2.43)	1	35.6 1.0	35.6	(86)	D	SAND AND BASALT
28N/44E-24ABB	47-54.97	117-10.98	J OSTBY 9/ 7/81	983	8.00	9.0 98.0	(2.64)	1				X	ALLUVIUM
28N/44E-30DD	47-53.42	117-17.13	DOE TST4 9/ 6/81	646	8.20	1.0 34.0						X	ALLUVIUM
27N/34E-1BCD	47-52.09	118-28.76	WASH WPC 9/14/81	444	11.00	1.0 151.0						X	SAND TO GRAN TO COBBLES
27N/37E-10CB	47-51.00	118- 8.00	RDH-SF13 7/24/81	469	10.69	40.0 125.0						X	ALLUVIUM
26N/44E-32ADD	47-42.49	117-15.67	HAGAN 4/ 4/81	719	9.90	29.0 64.0			34.2 1.0			D	SAND & CLAY

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY
25N/ 9E- 4AAD	47-41.07	121-38.92	DDH-11 11/ 1/72	1231	3.68	5.0 130.0						X	
25N/42E- 9BBD	47-40.97	117-30.84	M MOE 8/20/81	627	8.10	80.0 142.0	(1.59)		41.0 5.6	41.0	(65)	D	SAND, GRAVEL & BASALT
25N/28E- 24BAB	47-39.28	119-15.00	ISAAK 2 1/29/81	554		20.0 130.0						X	
25N/29E- 34DDD	47-36.78	119- 8.93	ISAAK 1 1/29/81	527	11.00	20.0 270.0						X	
24N/29E- 15AB	47-34.78	119- 9.33	ISAAK 3 1/30/81	539	11.45	25.0 310.0						X	
24N/21E- 14DAB	47-34.28	120- 9.37	REYNOLDS 11/12/81	1194	8.40	24.0 85.0	(1.67)	1	14.8 .8	14.8	(24)	D	C. R. BASALT
24N/32E- 26BAA	47-33.08	118-45.29	TMCPHRSN 9/23/81	566	12.06	44.0 144.0	(1.59)	1				X	BASALT
23N/20E- 29C	47-27.24	120-21.85	GAHRING 9/29/81	356	13.20	99.0 154.0	(2.18)		19.3 .2	21.2	(46)	D	ARKOSE AND S.S. EOCENE?
23N/11E- 33CAB	47-26.13	121-24.53	DNR-SNQ2 10/13/81	899		50.0 140.0	3.69 .33	5				X	QUARTZITE (ARTESIAN)
21N/31E- 32BBC	47-16.36	118-57.42	KISSLER 8/21/81	508	13.86	1.0 215.0						X	
20N/22E- 12ABC	47-14.65	120- .78	WELCH 11/13/81	390	14.00	49.0 189.0	(1.59)	1	26.1 1.3	26.0	(41)	D	C. R. BASALT
						49.0 264.0	(1.59)	1	32.1 1.0	32.0	(51)	C	
19N/28E- 4CA	47- 9.88	119-18.96	MOSES LK 8/25/81	349	13.20	19.0 144.0	(1.59)		37.4 3.1	37.4	(59)	D	GRAVEL AND BASALTS
						14.0 54.0	(1.59)		50.9 2.1	50.9	(81)	D	
19N/36E- 14B	47- 8.55	118-14.80	GERING 12/11/80	558		2.0 210.0						X	C. R. BASALT
19N/27E- 18BC	47- 8.52	119-29.25	ELLSTAD 1/23/81	373	12.90	10.0 51.0			75.6 2.1			D	
TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY
19N/26E- 17D	47- 8.20	119-34.83	DODSON 1/11/81	371		10.0 70.0						X	
19N/29E- 17DC	47- 8.00	119-11.70	DUNKIN 1/12/81	371		10.0 160.0						X	
19N/34E- 20A	47- 7.87	118-33.72	KAGELE 12/11/80	561	10.87	2.0 190.0						X	
19N/17E- 26CDA	47- 6.32	120-40.59	LETSEN 7/28/80	676	9.52	160.0 195.0			42.5 5.0			D	
						10.0 200.0	(1.46)	1	2.4	2.4	(35)	D	
18N/ 5E- 6CDA	47- 4.18	122-13.21	BENJAMIN 8/22/79	167	8.17	60.0 68.0	(1.67)	1	13.8 .2	10.7	(18)	D	GLACIAL DRIFT
18N/ 3E- 12DBD	47- 3.47	122-21.81	BETHL HS 8/21/79	140		.0 85.0	2.47	1				X	GLACIAL DRIFT
18N/25E- 36A	47- .58	119-37.55	BARKER 5 1/11/81	344	15.50	20.0 45.0			27.3 .7	27.3		D	
18N/32E- 33CB	47- .24	118-48.42	FRANZ 11/15/81	428	14.00	164.0 214.0	(1.59)	1	19.1 .3	19.1	(31)	D	BASALT
17N/32E- 14	46-57.60	118-47.17	DNR-CRB 3/12/81	472	14.00	20.0 189.0	(1.59)		42.5 4.0	42.5	(68)	D	
17N/35E- 28DB	46-55.95	118-24.88	BAUMANN1 5/ 7/81	548	10.80	25.0 200.0	(1.59)		17.4 4.5	17.4	(28)	D	C. R. BASALT
17N/18E- 34BCC	46-55.23	120-34.75	KUMMER3 7/14/80	746	9.71	50.0 70.0			22.6 .8			D	
17N/35E- 31CCD	46-54.92	118-27.88	BAUMANN2 5/ 7/81	527	10.27	30.0 230.0						X	C. R. BASALT
16N/18E- 4DAA	46-54.24	120-34.29	KUMMER2 7/14/80	768	9.35	.0 40.0						X	
16N/ 4E- 14CD	46-51.91	122-16.34	WW-14P1 12/ 8/71	243	9.31	40.0 75.0			12.4 .6			D	CLAY AND ROCK
16N/ 4E- 22BAB	46-51.75	122-17.43	DN SMITH 8/19/79	262	9.04	65.0 74.0			> 9.5 .5			D	

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY
16N/35E- 22CDA	46-51.41	118-24.52	BAUMN1WW 2/ 9/78	519	8.80	.0 315.0						X	C. R. BASALT
15N/32E- 16BD	46-49.97	118-47.35	STELGER 6/ 0/80	372	13.00	40.0 100.0			(98.0)			D	
16N/32E- 34BC	46-49.97	118-47.35	PHILLPSA 4/ 9/81	431	13.20	20.0 370.0						X	
15N/17E- 2DBD	46-49.00	120-39.30	PICATTI 6/30/80	600	13.53	40.0 90.0	(1.46)		25.2 1.2	23.2	(34)	D	SAND, GRAVEL & CLAY
15N/17E- 24ADD	46-46.70	120-37.50	DAY2 7/ 1/80	487	10.02	5.0 155.0						X	
15N/ 1W- 21BBB	46-46.63	122-49.17	RDH-1 8/ 9/79	75	11.42	5.0 78.5						X	EOCENE SHALE & SANDSTONE
15N/18E- 28AA	46-45.89	120-34.62	MCNLLY1 7/ 4/80	542	13.31	60.0 140.0			9.5 .7			D	SANDSTONE
15N/18E- 28CAD	46-45.52	120-35.04	YOUNG 7/ 2/80	490	11.73	10.0 75.0			27.1 2.1			D	SANDSTONE
						40.0 75.0			17.5 2.5			D	
15N/18E- 29DDD	46-45.20	120-35.67	BOYD 7/ 2/80	469	12.50	.0 60.0						X	SANDSTONE
14N/16E- 1ABC	46-44.14	120-46.29	ENGLAND 7/ 9/80	625	12.35	40.0 105.0			7.3 .5			D	C. R. BASALT
14N/16E- 1ADA	46-44.07	120-45.73	HUCK 7/10/80	633	12.60	130.0 170.0			2.3 .4			D	C. R. BASALT
						10.0 110.0			14.3 .9			D	
14N/25E- 1B	46-44.05	119-38.38	BATLLE93 2/25/81	207		5.0 68.0						X	
14N/16E- 1DAA	46-43.88	120-45.77	MARMION 7/12/80	623	12.50	70.0 115.0	(1.42)	1	24.8 2.2	24.8 2.6	35	D	BASALT
14N/17E- 6BD	46-43.77	120-45.30	PERHAM 7/25/80	610	11.25	45.0 160.0			24.6 3.1			D	BASALT, SS & GRAVEL
14N/ 8E- 6BCC	46-43.76	121-51.13	RDH-LONG 8/14/79	720	6.00	10.0 99.5	1.72 .06	10	> 28.0	> 25.0	> 43	D	VOLCANIC BRECCIA
14N/ 5E- 4CAD1	46-43.43	122-10.98	MOUNCE 6/ 6/79	451	8.65	3.0 49.7						X	TERTIARY (?) SEDIMENT RX
14N/ 5E- 4CAD2	46-43.40	122-10.80	PENNGTON 6/12/79	449	9.08	3.0 49.0						X	TERTIARY (?) SEDIMENT RX
14N/18E- 7DBD	46-42.80	120-37.40	MURRAY1 7/ 2/80	655	10.88	10.0 50.0						X	
14N/17E- 19DAB	46-41.15	120-44.70	KNUTSON 7/ 3/80	571	11.72	40.0 65.0						X	SANDSTONE
14N/17E- 19DCB	46-41.01	120-45.02	MNSPRGR 7/ 8/80	599	12.54	10.0 150.0	(1.72)	1	63.2	63.2	(108)	D	C. R. BASALT SEDIMENTS
14N/17E- 20CDD	46-40.80	120-43.80	DARDEN 6/30/80	561	10.15	50.0 60.0			44.0 5.8			D	BASALT ,SS & CLAY
						10.0 60.0			35.3 5.4			D	
14N/ 1W- 23DDA	46-40.77	122-45.65	AGNEW 6/14/79	135	10.66	1.0 74.5						X	TERTIARY SEDIMENT RX
13N/19E- 12CCD	46-37.30	120-23.90	CARLHILL 7/10/80	579	14.72	20.0 97.5			29.8 2.2	28.9		D	C. R. BASALT
13N/19E- 14AA	46-37.10	120-24.30	WATKINS3 7/11/80	561	13.38	10.0 210.5	(1.46)		27.3	26.5	(39)	D	CLAY, SAND, BASALT & SS
13N/ 2E- 17BBA	46-36.94	122-35.47	STANSELL 5/26/79	232	11.27	.0 101.0						X	TERTIARY (?) SHALE
13N/ 1W- 17ADA	46-36.93	122-49.43	ANDERSON 5/25/79	92	10.17	.0 54.0						X	CLAY
13N/19E- 23BA	46-36.70	120-24.75	WATKINS2 6/16/80	402	14.21	10.0 80.0						X	CLAY & SAND
13N/18E- 15CAD	46-36.70	120-33.70	FCNAZ 7/ 3/80	381	12.52	30.0 55.0			39.2 4.7			D	SANDY CLAY & GRAVEL MATX.
13N/19E- 24AA	46-36.26	120-23.07	GJR-WW 3/13/72	457	16.60	120.0 225.0	(1.59)		26.4 .6	26.4	(42)	D	

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY
13N/20E- 20BAD	46-36.20	120-20.90	COPPNALL 6/28/80	527	14.40	35.0 65.0			17.6 .5			D	BASALT & CLAY
13N/20E- 20BDA	46-36.15	120-21.20	CHAMPOUX 6/28/80	493	11.44	.0 215.0	(1.55)	1	(51.5)	(49.4)	(77)	D	
13N/17E- 28ABB	46-35.60	120-42.49	DECOLC-6 6/17/80	477	12.12	10.0 140.0						X	GRAVEL,CLAY BASALT,CLAYS
13N/ 2W- 25AAA	46-35.32	122-52.05	DRUCKMAN 7/ 5/79	91	10.00	16.0 30.0			18.2 .5	18.2		D	
13N/ 1W- 29DCC	46-34.61	122-49.95	WULZ 6/ 8/79	102	10.46	.0 67.5						X	
13N/21E- 34AD	46-34.35	120-10.29	MARTINEZ 7/22/80	709	11.40	20.0 290.0	(1.59)		> 33.1 .7	> 32.5	> 52	D	BASALT WITH SAND/SHALE
12N/18E- 1BD	46-33.48	120-30.75	DECOLC-9 6/16/80	307	13.71	5.0 62.0						X	CLAY AND GRAVEL
12N/ 4E- 3BCD	46-33.34	122-17.99	WARK 6/ 8/79	316	8.34	27.0 84.0			6.5 .3			D	
12N/ 4E- 4DAB	46-33.21	122-18.36	BISHOP 6/ 8/79	287	9.03	19.0 42.5	(1.67)		17.4 .8	15.7	(26)	D	BASALT ?
12N/ 8E- 3DCD	46-33.18	121-47.10	RDH-DVSM 9/ 6/79	610	12.05	50.0 146.0	1.68 .08	19	(5.4)	(5.4)	(9)	D	EOCENE/OLIGO VOLCANICS
12N/17E- 11BBB	46-33.06	120-40.11	DECOLC-7 6/17/80	425	8.65	10.0 130.0	(1.46)		(34.2)	(34.2)	(50)	D	GRAVEL, CLAY AND SAND
						80.0 120.0	(1.46)		64.2 1.0	64.2	(94)	C	
12N/ 2E- 11AAD	46-32.67	122-30.77	HADDALER 5/24/79	184	10.23	.0 88.0						X	BASALT
12N/16E- 12CC	46-32.38	120-46.36	SHELTON 7/21/80	582	12.36	.0 105.0			(25.1)			D	C. R. BASALT
12N/30E- 11DAC	46-32.20	119- .58	MESATOWN 1/13/81	207	11.96	25.0 55.0						X	C. R. BASALT
12N/ 3E- 7CDB	46-32.12	122-29.03	GOODWIN 5/24/79	210	9.33	40.0 86.0	(1.67)		19.1 1.2	19.1	(32)	D	BASALT ?
12N/ 1E- 12DCB	46-32.11	122-37.39	TALBOTT 6/ 4/79	171	9.60	30.0 125.0	(1.00)		20.5 1.4	20.5	(21)	D	CLAY, SHALE & SANDSTONE
12N/19E- 17BAD	46-32.00	120-31.25	DOE 11/24/80	280		.0 50.0						X	
12N/16E- 13BBC	46-31.93	120-46.44	HERKE 7/24/80	536	9.82	10.0 70.0			63.9 4.8			D	BASALT WITH SANDY LAYERS
12N/ 2E- 16AAA	46-31.89	122-33.33	LKSDCM 1 6/23/79	136	9.18	70.0 106.0	(1.67)		18.2 1.4	18.2	(31)	D	
12N/16E- 15DBA	46-31.75	120-48.88	HMWHITE 7/21/80	574	9.82	10.0 75.0						X	
12N/40E- 17ADA	46-31.58	117-49.26	DODGEJCT 2/27/78	381	13.40	.0 90.0						X	C. R. BASALT
12N/21E- 16CA	46-31.52	120-11.94	DNR 7/22/80	481	15.77	10.0 235.0	(1.55)	1	45.5 2.3	42.2	(65)	D	BASALT WITH SAND-CLAY
12N/ 2E- 16ADC	46-31.50	122-33.38	LCMPK 2 6/ 1/79	149	8.65	39.0 59.8	(1.67)		21.1 1.2			D	MID-TERTIARY ANDESITE
12N/23E- 16DBD	46-31.43	119-56.65	BLK RCK 10/25/80	434	9.99	2.0 225.0			50.7 5.9			D	C. R. BASALT
12N/40E- 14DAD	46-31.19	117-45.56	SCOTT-WW 7/29/78	591	11.40	15.0 62.5	(1.59)		33.9 .4	40.0	(64)	D	BASALT
12N/23E- 20BAC	46-31.03	119-58.33	BLKRK2 7/23/80	462	13.03	10.0 100.0	(1.59)	1	22.3 2.7	21.5		D	C. R. BASALT
12N/21E- 22CAC	46-30.75	120-11.30	MARTINEZ 10/22/80	482	16.36	.0 198.0						X	
12N/ 3E- 23DCC	46-30.34	122-23.76	MARCHANT 6/ 9/79	253	9.34	25.0 81.0			7.6 .1			D	
12N/ 2E- 20CCC	46-30.24	122-35.57	MFPKFS 1 5/22/79	85	9.90	20.0 57.0			25.6 .8			D	ANDESITE FLOWS
12N/ 7E- 27CAB	46-30.00	121-55.10	POL-RAN1 9/ 7/79	281	8.74	15.0 34.3			38.5 .7	36.7		D	
12N/ 3E- 25CAB	46-29.90	122-22.92	CHURCH-2 8/29/79	420	5.13	135.0 152.0						X	

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU <SE>	NO. TC	UN. GRAD <SE>	CO. GRAD <SE>	CO. H.F. <SE>	Q H.F.	LITHOLOGY SUMMARY
12N/18E- 26DDB	46-29.67	120-31.25	DOUGLAS 10/31/80	308	13.61	30.0 70.0			53.7 2.1			D	
12N/20E- 31AD	46-29.30	120-21.45	BROOKS 6/17/80	341	13.75	10.0 130.0			29.9 2.3			D	SEDIMENTS & BASALTS
11N/27E- 14BAD	46-26.60	119-23.85	BATTLLE1 2/11/81	164	14.20	40.0 95.0	(1.59)		41.3 1.5	41.3	66	D	C. R. BASALT
11N/46E- 19BB	46-25.40	117- 5.87	PTWLMAWW 1/17/78	234	12.57	15.0 160.0						X	C. R. BASALT
11N/ 2W- 26BDC	46-24.66	122-54.01	WALLACE 8/14/79	24	12.15	190.0 261.5			8.6 .4			D	SILTSTONE & CLAYSTONE
						15.0 190.0			13.6 .1			D	
11N/31E- 33ABD	46-23.92	118-56.07	HUNNEL 2 2/ 5/81	192	14.92	20.0 128.0						X	C. R. BASALT
11N/31E- 32DB	46-23.55	118-57.45	HUNNEL 1 2/ 5/81	175	14.02	20.0 128.0						X	C. R. BASALT
11N/29E- 34D	46-23.45	119- 9.68	LINDSEY 3/ 9/81	213	12.70	10.0 30.0			108.0 3.1	108.0		D	
10N/27E- 28AHC	46-19.70	119-26.00	BATLLE56 2/24/81	121		10.0 140.0						X	C. R. BASALT
10N/16E- 26ACA	46-19.60	120-46.90	LAWENCE 6/15/80	378	9.76	20.0 135.0	(1.59)		46.3 7.0	46.3	(74)	D	SAND, GRAVEL & BASALT
10N/39E- 30AA	46-19.43	117-58.63	WARNERWW 2/10/78	512	11.73	5.0 32.5						X	C. R. BASALT
9N/23E- 7BCC	46-16.87	119-59.79	MANDRELL 11/17/81	211	13.00	24.0 74.0	(1.59)		58.1 1.5	58.1	(93)	D	BASALT
9N/27E- 16BBA	46-16.17	119-26.78	DNRBEN40 3/11/81	219	13.50	70.0 94.0	(1.59)		184.6 7.5	184.6	(293)	D	C. R. BASALT
9N/32E- 17AB	46-16.01	118-49.51	DNR-BP2 4/22/81	158	14.61	7.5 46.0						X	
8N/36E- 30BA	46- 8.95	118-21.44	VANAUSWW 1/13/78	262	10.42	10.0 65.0						X	BASALT WITH SOME CINDERS
7N/ 5E- 2BA	46- 7.62	122- 9.15	RDH-STH3 11/14/79	805	3.80	25.0 130.0	2.05 .08	13				X	
7N/36E- 19BD	46- 4.39	118-21.51	DKFF-WW 3/15/72	271		110.0 250.0						X	C. R. BASALT
7N/33E- 24DC	46- 3.97	118-37.40	MT-WW 3/16/72	183	14.80	200.0 235.0	(1.59)		17.0 .5	17.0		D	BASALT
7N/35E- 25ABA	46- 3.79	118-22.34	GUG-WW 1/30/78	259	11.40	45.0 70.0			33.7 9.8			D	SEDIMENTS & BLUE CLAY
7N/35E- 35AA	46- 2.93	118-22.30	WWCOLLWW 1/30/78	240	15.90	100.0 165.0			27.4 .4			D	BASALT AND CLAY
7N/36E- 33BB	46- 2.89	118-19.29	WW-7 3/14/72	297	15.59	10.0 425.0	(1.59)		> 33.3	> 33.3	> 53	D	BASALT
7N/25E- 36CC	46- 2.62	119-38.50	DOE PAT 8/24/81	222	13.90	29.0 79.0	(1.59)		32.0 1.0	32.0	(51)	D	C. R. BASALT
						29.0 250.0	(1.59)		23.9 2.6	23.9	(38)	D	
7N/34E- 36CAD	46- 2.33	118-30.27	STILERWW 2/ 8/78	173	12.00	10.0 32.5	(1.00)		55.4 3.2	55.4	(56)	D	SEDIMENTS
6N/36E- 4CA	46- 1.47	118-20.68	HILLRDWW 1/31/78	290	11.85	35.0 57.5	(1.13)		81.8 3.6	81.8	(93)	D	SEDIMENTS - SILTY CLAY
6N/35E- 10DA	46- .63	118-23.33	WWFLCAMP 3/ 5/80	230	12.08	35.0 125.0			23.7 1.5			D	GRAV, BOULD, CLAY+BASALT
						10.0 176.5			19.1 .7			D	
6N/34E- 12CCC	46- .34	118-30.65	FROG-WW 2/ 8/78	205	13.10	10.0 70.0						X	SAND, GRAVEL & CLAY
6N/19E- 24BC	45-59.52	120-22.97	FOSTER 11/28/81	1116	7.00	29.0 152.0	(1.59)	1	> 37.6 1.1	> 37.6	> 60	D	C. R. BASALT
						14.0 29.0	(1.59)	1	64.8 1.9	64.8	(105)	D	
						59.0 139.0	(1.59)	1	41.2 .7	41.2	(65)	C	

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY
6N/23E- 36BD	45-57.73	119-52.50	DNRMCR1 5/ 6/81	262	12.80	20.0 90.0			23.1 1.2			D	C. R. BASALT
						90.0 160.0	(1.59)		48.9 .4	48.9	(78)	D	
5N/15E- 7AB	45-56.34	120-58.47	PRESCOTT 12/14/81	713	9.00	54.0 84.0	(1.59)		31.4 1.4	31.4	(50)	D	QUAT. BASALT
5N/15E- 13BDC	45-55.26	120-52.68	WELLSMAN 12/ 1/81	818	7.46	.0 166.5						X	QUAT. BASALT
5N/21E- 16CAB	45-55.00	120-11.49	DOE TST7 8/23/81	706	15.11	74.0 224.0	(1.59)		49.2 6.3	49.2	(78)	D	C. R. BASALT
						224.0 394.0	(1.59)		27.2 .7	17.2	(44)	C	
5N/ 8E- 22ABC	45-54.80	121-46.80	DGER-6 9/14/76	1067	2.58	15.0 55.0	1.26 .21					X	QUAT. BASALT
5N/ 2E- 24DDA	45-53.91	122-29.51	WALLAM 8/ 1/79	243	8.74	35.0 104.0	(1.46)	1				X	VOLCANICS & BASALT
5N/17E- 33BB	45-52.89	120-41.54	MCKAY 11/28/81	701	17.95	39.0 177.0	(1.42)	1	53.4 4.7	53.5	(76)	D	QUAT. BASALT
						134.0 169.0	(1.42)	1	52.9 1.4	52.9	(75)	D	
5N/15E- 31CBB	45-52.32	120-59.20	VANPAT. 10/ 8/81	509	12.17	59.0 139.0						X	QUAT. BASALT
5N/16E- 31CC	45-52.22	120-51.67	CASE 11/21/81	640	10.93	19.0 124.0	(1.59)	1				X	QUAT. BASALT
5N/14E- 36CDC	45-52.21	121- .09	RICHARD 12/15/81	488	11.00	49.0 116.5						X	QUAT. BASALT
4N/17E- 3AC	45-51.77	120-39.95	B COLE 7/16/81	689	11.94	20.0 200.0	(1.59)		30.5 2.1	30.5	(49)	D	QUAT. BASALT
4N/15E- 2BC	45-51.71	120-54.15	CASE 2 11/21/81	533	11.40	19.0 152.5						X	QUAT. BASALT
4N/16E- 16CCD	45-49.51	120-49.07	GLDL 1 7/15/81	506	12.10	80.0 150.0	(1.59)		45.3 .6	45.3	(72)	D	C. R. BASALT
						10.0 205.0	(1.59)		34.7 1.2	34.7	(55)	D	
4N/16E- 21BA	45-49.40	120-49.09	O LEARY 7/16/81	506	13.40	70.0 150.0	(1.59)		18.8 .5	18.9	(30)	D	C. R. BASALT
3N/ 5E- 4BDA	45-46.50	122-11.94	SS-8 10/ 9/75	565	6.71	20.0 70.0	(2.80) .08	22	15.1 .7	15.1	(42)	D	QTZ. DIORITE GRANODIORITE
3N/ 5E- 4BDC1	45-46.45	122-11.98	SS-4 7/14/75	558	6.90	30.5 152.4	(2.80) .08		15.5 .2	15.5	(44)	D	QTZ. DIORITE GRANODIORITE
3N/13E- 1DC	45-46.16	121- 7.24	WAGNER 12/ 9/81	634	9.61	20.0 87.0	(1.59)		27.3 .8	27.0	(44)	D	C. R. BASALT
3N/18E- 11CBA	45-45.45	120-31.65	GOODNOE 12/24/81	403	13.44	50.0 110.0	(1.59)		29.9 1.4	32.9	(52)	D	C. R. BASALT
3N/12E- 9DD	45-45.41	121-18.07	WEAVER 12/ 4/81	521	11.37	19.0 139.0	(1.51)	1				X	C. R. BASALT
3N/12E- 13DCC	45-44.46	121-14.82	JELLUM 12/12/81	402	12.06	1.2 95.5						X	C. R. BASALT
3N/ 3E- 23BDB	45-43.98	122-24.38	PLEW 7/31/79	442	8.02	30.0 183.5	(1.59)		22.5 1.0	27.3	(44)	D	EOCENE BASALT
3N/11E- 24ACD	45-43.98	121-22.17	NBR SMT 7/ 8/81	317	11.37	50.0 235.0						X	BASALT
3N/14E- 19CA	45-43.75	121- 6.32	PARISH 12/ 9/81	630	10.55	20.0 140.2	(1.59)	1	(36.7)	(36.7)	(58)	D	C. R. BASALT
3N/12E- 21DD	45-43.53	121-18.18	BAILEY 12/ 3/81	295	13.97	19.0 143.0	(1.38)	1				X	C. R. BASALT
3N/ 8E- 27ACD	45-43.17	121-46.79	CALLAHAN 9/14/79	115	7.73	60.0 84.0			29.2 2.2	30.9		D	EO-OLIGO VOLCANICS
3N/11E- 30ADA	45-43.15	121-28.32	BNG CTY2 7/ 8/81	46	9.75	20.0 87.5						X	C. R. BASALT
3N/ 7E- 25DB	45-42.87	121-53.11	THOMPSON 11/22/81	250	8.20	39.0 56.0	(1.26)		32.4 1.1	31.0	(49)	D	VOL-CLASTIC ROCKS

TWN/RNG SECTION	N LAT DEG MIN	W LONG DEG MIN	HOLE NO. (DATE)	COLLAR ELEV.	SURFACE TEMP.	DEPTH INTERVAL	AVG. TCU (SE)	NO. TC	UN. GRAD (SE)	CO. GRAD (SE)	CO. H.F. (SE)	Q H.F.	LITHOLOGY SUMMARY
3N/12E- 28DCD	45-42.63	121-18.36	BRADLEY 9/13/79	161	10.96	35.0 185.0	(1.59)		33.0 2.4	33.9	(54)	D	C. R. BASALT
3N/11E- 34BD	45-42.16	121-24.90	MCBRIDE 12/ 2/81	231	10.70	59.0 106.4	(1.59)		32.6 1.3	32.6	(52)	D	C. R. BASALT
3N/13E- 31CB	45-42.10	121-14.11	L DANIEL 7/10/81	274	10.56	120.0 170.0	(1.59)		26.2 .7	26.2	(42)	D	C. R. BASALT
3N/15E- 34CCB	45-41.80	120-55.46	JAEKEL 9/13/79	594	10.80	40.0 149.0	(1.59)	1	> 26.8 1.5	> 28.0	> 44	D	C. R. BASALT
2N/13E- 16CA	45-39.44	121-11.47	ZEIGLER 12/10/81	89	14.34	44.0 97.0						X	BASALT
2N/ 7E- 22BBA3	45-38.90	121-56.11	DH-1204 10/28/75	42	10.10	40.0 60.0			24.6 1.3			D	
2N/ 7E- 22BBA4	45-38.87	121-56.09	DH-1209 10/28/75	52	10.61	15.0 63.0			22.3 2.9			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BBA6	45-38.86	121-56.09	DH-1029 10/28/75	52	11.41	15.0 80.0			18.6 1.1			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BDA5	45-38.86	121-56.05	DH-1210 10/28/75	52	12.25	30.0 68.7			5.1 2.5			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22ABC	45-38.85	121-55.70	DH-1083 10/28/75	51	9.38	5.0 65.0			19.4 2.9			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BBC1	45-38.77	121-56.34	USCE1462 4/12/77	25	8.90	20.0 52.5			45.6 6.5			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BBD1	45-38.77	121-56.18	USCE1385 4/12/77	27	10.45	10.0 73.0			33.9 1.0			D	CLAY, SILT & SANDSTONE
2N/ 7E- 22BBC2	45-38.76	121-56.34	USCE1465 4/12/77	25	9.17	20.0 61.5			47.2 2.5			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BBC5	45-38.76	121-56.22	USCE1371 4/12/77	27	10.32	15.0 58.5			31.2 2.4			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BBC4	45-38.75	121-56.29	USCE1455 4/12/77	26	10.43	25.0 65.1			29.9 3.7			D	CLAY,SILT & SANDSTONE
2N/ 7E- 22BBD2	45-38.75	121-56.14	USCE1475 4/12/77	29	10.18	20.0 57.0			39.2 3.7			D	CLAY, SILT & SANDSTONE
2N/ 4E- 24CCA	45-38.34	122-15.87	L CODY 7/ 2/81	290	9.52	30.0 90.0						X	BASALT
2N/ 3E- 26AAC	45-38.34	122-24.04	FRENCH 6/10/79	134	11.39	.0 54.0						X	CLAY, SAND & GRAVEL
2N/ 4E- 29ABB	45-38.11	122-20.46	WITTERS 6/30/79	207	10.14	5.0 52.0						X	SANDSTONE & CLAYSTONE
2N/ 4E- 29ACB	45-37.90	122-20.43	WILLIAMS 6/27/79	201	11.49	5.0 61.5						X	CLAY
2N/ 4E- 27DAA	45-37.61	122-17.52	PG SMITH 7/ 2/81	88	10.82	20.0 37.5						X	
2N/ 5E- 35BBC	45-37.14	122- 9.76	RICHARDS 9/ 7/79	414	8.15	10.0 103.0	(1.59)	1				X	VOLCANICS
2N/ 5E- 34CC	45-36.60	122-11.00	KADOW 12/ 8/81	271	8.85	45.0 105.0	(1.46)		23.0 .5	36.5	(38)	D	GRAVEL AND CLAY
						105.0 124.0	(1.05)		35.7 1.4	36.0	(37)	D	
1N/ 4E- 6BCC	45-36.06	122-22.28	ZIMMER 7/ 9/79	164	10.49	10.0 46.5						X	CLAY & ROCK
1N/ 3E- 6CCD2	45-36.00	122-29.33	NIELSN 2 6/26/79	62	11.08	10.0 76.0						X	CLAY, SAND & GRAVEL
1N/ 3E- 6CCD1	45-36.00	122-29.33	NIELSN 1 6/26/79	62	11.37	10.0 57.5						X	CLAY, SAND & GRAVEL
1N/ 4E- 5DAD	45-35.91	122-19.94	HATTON 6/19/79	135	10.69	40.0 65.0						X	
1N/ 5E- 1CDD	45-35.65	122- 8.12	SKM CS 1 9/ 6/79	37	11.28	10.0 46.5						X	
1N/ 3E- 11CDC	45-34.92	122-24.36	CRWN ZLL 9/ 6/79	8	14.67	10.0 73.0						X	SANDY CLAY & BASALT

APPENDIX B

Location	Elevation m	T_s °C	T_{BHT} °C	Depth m	Calculated Gradient °C/km
4N16E21AB	506.1	12.3	18.0	150.6	37.8
6N24E22AD	167.7	14.0	22.5	195.1	43.5
6N34E3CB	196.0	13.8	17.2	50.9	57.5
7N26E5AB	344.5	13.1	19.2	326.5	18.7
10N24E24BA	551.8	12.1	14.3	109.8	20.0
11N18E30AD	260.7	13.5	18.0	103.7	43.4
11N22E21CC	420.7	12.7	22.3	207.3	46.2
12N22E14BA	603.6	11.4	15.2	149.1	25.4
12N22E15AC	579.3	11.9	12.8	37.8	22.8
12N22E29AA	548.8	12.1	12.2	102.1	0.7
13N18E12AA	437.5	12.6	24.8	200.6	60.7
14N20E20CC	658.5	11.5	17.0	183.5	30.1
15N18E29BA	515.2	12.2	13.2	106.7	8.9
17N26E8CD	347.6	13.1	18.0	97.6	50.3
17N26E35DA	341.5	13.1	15.2	49.4	41.5
17N34E7CC	426.8	12.7	17.4	201.2	23.3
18N18E36AB	498.2	12.3	28.4	262.2	61.3
18N29E28CD	341.5	13.1	15.0	61.0	30.8
18N29E34CC	341.5	13.2	16.9	133.8	28.5
18N31E2AD	372.9	13.0	13.0	122.0	0.0
18N31E18BA	396.3	12.8	21.8	240.2	37.3
18N34E32DC	498.5	12.3	16.2	182.9	21.2
19N28E29CB	320.1	13.2	19.7	232.0	27.7
19N29E9DD	375.0	13.0	16.7	170.7	21.9
19N30E20BB	419.5	12.7	13.5	307.0	2.5
19N30E28BC	417.7	12.7	11.4	211.0	- 6.3
19N31E24BC	451.2	12.6	17.9	190.6	28.1
19N32E15CC	495.4	12.3	15.4	205.8	14.9
19N33E8CA	547.3	12.1	13.5	134.2	10.6
19N35E14CD	548.8	12.1	16.4	186.3	22.9
19N36E2AA	579.3	11.9	12.3	115.8	3.5
20N29E15AD	410.7	12.8	10.6	158.5	-13.4
20N30E23A	501.5	12.2	19.2	219.5	31.7*
20N31E6CA	485.1	12.4	13.9	182.9	8.2
20N31E14AA	457.3	12.5	13.6	132.0	7.7
20N32E15CA	510.7	12.3	14.7	237.8	10.1
20N34E10BD	583.8	11.9	17.8	237.8	24.8
20N36E6DD	585.4	11.9	14.2	135.9	17.0
21N30E12BA	485.1	12.4	13.3	231.7	3.9
21N31E24CA	538.1	12.1	14.9	182.9	15.4
21N32E32DD	529.3	12.2	15.1	182.9	15.8
21N33E5DC	475.6	12.4	10.9	75.6	-20.6
21N33E17DA	543.9	21.1	18.3	207.3	30.0
21N35E7AC	612.2	11.8	20.1	128.0	64.8
22N34E26BA	602.1	11.8	12.7	152.4	6.0

Appendix B (continued)

Location	Elevation m	T_s °C	T_{BHT} °C	Depth m	Calculated Gradient °C/km
22N35E23CB	602.1	11.8	10.3	105.5	-14.0
23N32E3CD	598.5	11.8	15.3	140.2	25.0
23N34E19CD	612.8	11.8	12.8	204.9	5.0
23N41E13BB	731.7	11.2	11.3	164.6	1.1
23N41E13BC	731.7	11.2	14.0	187.2	15.3
23N42E2BD	707.3	11.3	16.4	189.0	27.3
23N42E25BA	722.6	11.2	12.5	134.2	9.7
24N32E11DD	581.4	11.9	10.3	140.2	- 1.6
24N32E35DB	625.0	11.7	12.6	187.8	4.6
24N36E2DC	724.1	11.2	11.3	91.5	1.2
24N36E2DD	731.7	11.2	14.0	187.2	15.2
24N36E16AA	723.2	11.2	13.8	73.2	34.9
24N41E31DC	728.7	11.2	13.5	111.9	20.8
25N22E28AB	792.7	10.8	16.2	184.5	28.9
25N36E25BA	722.6	11.2	12.6	49.6	28.4
26N32E10CD	682.9	11.4	14.6	119.2	26.9
26N33E18CD	686.0	11.4	12.9	152.5	9.9
26N33E29CD	673.5	11.4	13.1	86.7	19.5

The surface temperatures for these holes were calculated using the elevation term only (i.e. the slope and orientation correction was ignored except on the holes indicated by the *).

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF-1652-A
PAMPHLET

MINERAL RESOURCE POTENTIAL OF THE GLACIER PEAK WILDERNESS AND ADJACENT AREAS, CHELAN, SKAGIT, AND SNOHOMISH COUNTIES, WASHINGTON

By

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STUDIES RELATED TO WILDERNESS

Under the provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and related acts, the U.S. Geological Survey and the U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Areas officially designated as "wilderness," "wild," or "canoe" when the act was passed were incorporated into the National Wilderness Preservation System, and some of them are presently being studied. The act provided that areas under consideration for wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. The act directs that the results of such surveys are to be made available to the public and be submitted to the President and the Congress. This report discusses the results of a mineral survey of the Glacier Peak Wilderness (NF031), Mount Baker-Snoqualmie and Wenatchee National Forests, Chelan, Skagit, and Snohomish Counties, Wash. The area was established as a wilderness by Public Law 88-577, September 3, 1964. The study area also includes eight areas classified as proposed wilderness (06031A, D, G) during the Second Roadless Area Review and Evaluation (RARE II) by the U.S. Forest Service, January 1979, and one area (06031C) proposed as an administrative addition.

MINERAL RESOURCE POTENTIAL SUMMARY

Geologic, geochemical, geophysical, and mine and prospect surveys were conducted in 1976-82 to evaluate the potential for mineral resources in the Glacier Peak Wilderness and proposed additions. Eleven areas, covering about 20 percent of the study area, have a moderate to high potential for the occurrence of base- and precious-metal resources. Six properties, two of which are in areas recommended for wilderness addition (06031D and G), contain demonstrated resources for copper, lead, zinc, gold, and silver. The most important demonstrated resource is the porphyry copper-molybdenum deposit at the Glacier Peak prospect, near the center of the wilderness, where drilling has delimited a deposit totaling 1.9 billion tons of mineralized rock. Although porphyry copper-molybdenum deposits are the primary type of deposit that occurs in the study area, areas of potential for the occurrence of precious-metal resources in hot-springs deposits, for the occurrence of base- and precious-metal resources in hydrothermal veins and limestone-replacement deposits, and for the occurrence of copper, zinc, gold, and silver resources in volcanogenic massive-sulfide deposits have also been identified.

At 1983 metal prices, none of the mineral deposits in the study area would be mineable; however, at historically high metal prices, portions of the Glacier Peak prospect would be mineable by underground, bulk-mining methods. In addition, the Pioneer property would be mineable, if the inferred reserves are proven, even with dilution due to the narrow vein width. Metal prices substantially higher would be required to cause the Holden and Royal Development mines to be reopened, although additional exploration, particularly at the latter mine, could change the economics of the properties.

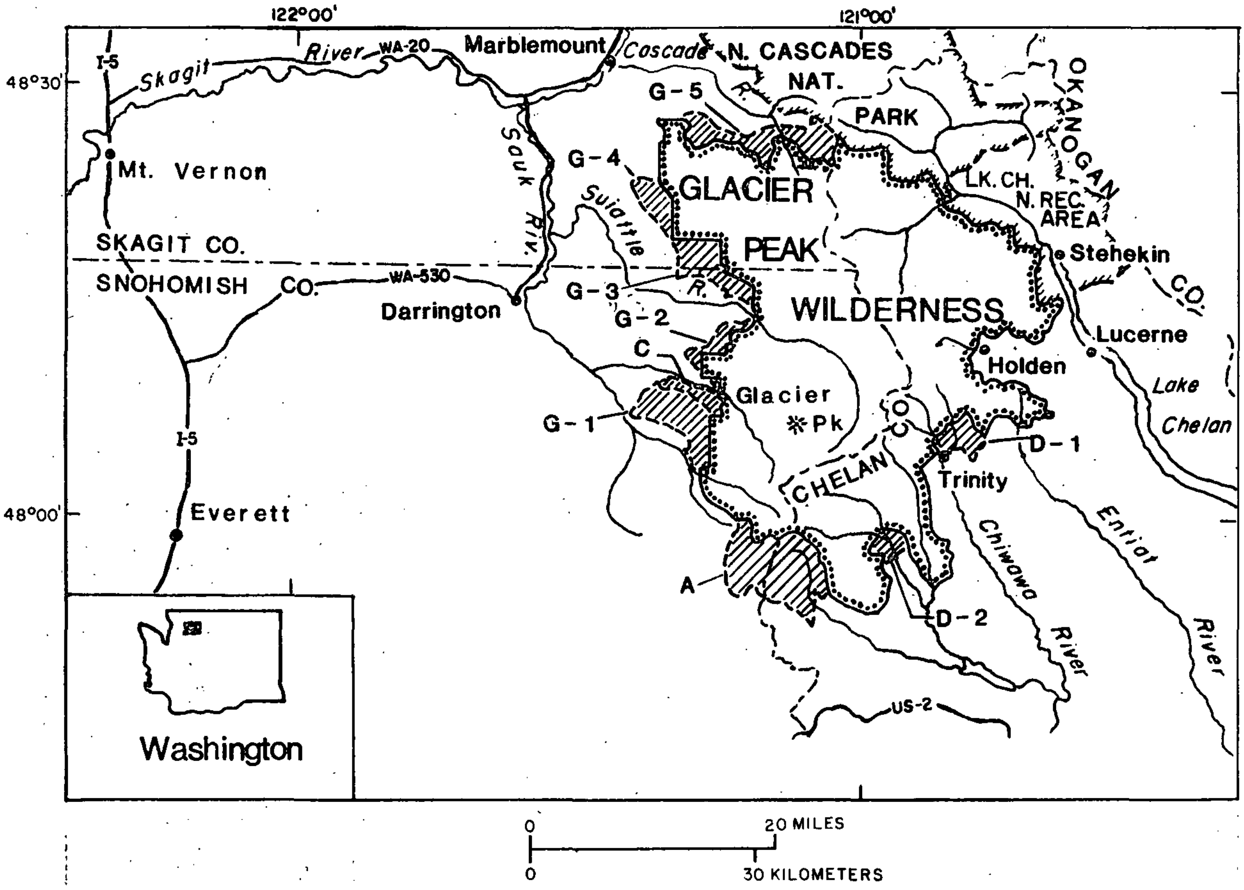
A low potential for geothermal resources exists on the northeast side of the Glacier Peak volcano, and a cinder resource of 24 million cubic yards is identified at the White Chuck cinder cone, in the wilderness. Because both areas are remote, no reserves were identified. No fossil-fuel resources were identified in the study area.

INTRODUCTION

Location, access, and geographic setting

The Glacier Peak Wilderness encompasses 464,741 acres, including 483 acres of patented mining and millsite claims. Also included in the present study are nine areas adjoining the wilderness (fig. 1) that total 90,034 acres of recommended wilderness additions. All these lands are here collectively called the "study area." Access to the study area is provided by generally well-maintained trails from gravel or dirt roads along major valleys above Darrington, Marblemount, Stehekin, Holden, Trinity, and Lake Wenatchee. Other than the main access trails across a few passes (Cloudy Pass, Buck Creek Pass, White Pass, and Indian Pass), trails are rough, infrequently maintained, or nonexistent.

The Glacier Peak Wilderness extends southward about 40 mi along the crest of the northern Cascade



EXPLANATION

•••••••• Boundary of wilderness

▨ Areas recommended for addition to wilderness

Figure 1.—Map showing location of the Glacier Peak Wilderness and adjacent areas, Chelan, Skagit, and Snohomish Counties, Wash. Areas recommended for addition to the Glacier Peak Wilderness are designated by letters: A, area 06031A; C, area 06031C; D, two areas making up addition 06031D; and G, five areas making up addition 06031G.

Range, Wash., from the southern border of North Cascades National Park. It consists of rugged, highly varied, mostly alpine terrain cut by numerous deep river valleys and dominated by the volcanic cone of Glacier Peak (10,541 ft), rising 3,000-4,000 ft above most nearby summits. Though now dormant, Glacier Peak has been one of the most active Cascade volcanoes in the past few thousand years, with minor activity as recent as the 18th century. The Cascade crest is the drainage divide for waters flowing westward into Puget Sound and eastward into the Columbia River, and it also forms a climatic barrier. Dense fern, low deciduous brush, and forests of Douglas fir, western hemlock, and red cedar dominate the rain forests of the western valleys in sharp contrast with more open forests of larch and pine on eastern slopes. Small glaciers and permanent snowfields cover extensive areas along and west of the crest but are rare to the east. The area west of the Cascade crest is in the Mount Baker-Snoqualmie National Forest, and the area to the east is in the Wenatchee National Forest.

Present and previous studies

Evaluation of the potential for mineral resources in the Glacier Peak Wilderness and adjoining areas of wilderness recommendation (fig. 1) was carried out by the U.S. Bureau of Mines in 1976-79 and by the U.S. Geological Survey in 1979-82. Work by the U.S. Bureau of Mines consisted of sampling, mapping, and evaluating known mineral deposits and occurrences (Stotelmeyer and others, 1982) and reviewing county and U.S. Bureau of Land Management mining-claim records. More than 1,300 lode claims and a few placer claims in the Glacier Peak Wilderness and more than 300 lode claims in adjacent areas recommended for wilderness addition have been located since prospecting of the region began in the late 1800's. Work by the U.S. Geological Survey involved three separate, but coordinated, lines of investigation: (1) geologic mapping and collection of bedrock samples (Ford and others, in press); (2) stream-sediment geochemical surveys (Church and others, 1982); and (3) geophysical surveys using aeromagnetic methods (Flanigan and others, 1983) and gravity methods (Sherrard and Flanigan, 1983). Results of extensive mineral exploration programs in and near the study area by Bear Creek Mining Co. (Spokane, Wash.) were made available for the present study (Grant, 1982). Work by many others, obtained from the extensive literature on the geology and mineral resources of the area (Ford, 1983), was also incorporated in the study.

Geologic setting

The study area, in the south-central part of the north Cascades, consists of a terrane of crystalline rocks of great variety and structural complexity (Misch, 1966) that extends from near Stevens Pass (U.S. Highway 2) northward into British Columbia and from the western foothills of the Cascades eastward to near the Methow Valley and the Okanogan Range. Within this terrane, sedimentary and igneous rocks of early Paleozoic, or older, to Mesozoic age were transformed into schists and gneisses during one or more phases of regional metamorphism, the latest occurring near the end of the Mesozoic Era. Many intrusions of granitic, dioritic, and gabbroic rock were affected by the metamorphism; some had been emplaced prior to metamorphism but others probably were intruded during metamorphism. Most of the country rocks were intensely deformed during metamorphism. Following metamorphism, fault troughs (grabens) and basins developed and were filled with sediments eroded from nearby highlands; the Chiwaukum graben of early Tertiary age lies just south of the eastern part of the Glacier Peak Wilderness, and the eastern bounding fault (Entiat fault) of the graben extends northwestward to form a major structural feature within the wilderness. Another of the Cascades major faults, the Straight Creek fault, also of early Tertiary(?) age but of transcurrent type, lies along the west margin of the wilderness and separates schist and gneiss of high metamorphic rank from metavolcanic and metasedimentary rocks of low metamorphic rank to the west. Widespread granitic intrusive activity continued through the early Tertiary to Miocene time. Miocene granitic magmas intruded to very shallow crustal levels, and some may have reached the surface as lavas. The Cascades were uplifted and deeply dissected by erosion prior to building of andesitic to dacitic volcanic cones, such as Glacier Peak and Mount Baker, in Quaternary time.

Mining activity

All or parts of five mining districts are within the study area (fig. 2). The Stehekin, Railroad Creek (Holden), and Chiwawa districts are on the east side of the wilderness; part of the Cascade mining district is in the northern part of the study area; and the Sampson district is near the center of the wilderness. Since 1891, about 1,600 lode claims have been located in the study area. Additional large claim blocks were staked periodically to cover the deposit at the Glacier Peak prospect.

The earliest known mining claims recorded in the study area apparently were located in 1891 at the head of the South Fork of Agnes Creek and on the divide between the Little Wenatchee River and the North Fork of the Sauk River. Surveyers searching for a railroad route over the Cascade Range noted mineralized areas on Railroad Creek in 1887, and J. H. Holden prospected the area in 1892. In 1896, he staked what later became the Holden mine, Washington's largest copper mine, which operated from 1938 to 1957. Farther up the canyon, the Crown Point molybdenum deposit was probably discovered in 1897 or 1898, and a mill and mine camp were constructed.

Other early claim locations in the study area were made during 1892 on Flat Creek in the northwest corner of the wilderness and on a mineralized area, later to be patented, which was located on the Middle Fork of the Cascade River, in area 06031G. Discoveries were also made south of Trinity in the Chiwawa River drainage basin, and the Royal Development (Red Mountain) mine in area 06031D was probably discovered after the turn of the century.

The Glacier Peak prospect, the most significant mineral deposit in the study area, was first located as a vein occurrence about 1900 by Sampson Mining Co. Early exploration of the property was by short adits following copper-rich shear zones. Later exploration utilized diamond drilling and revealed a huge disseminated porphyry copper-molybdenum deposit.

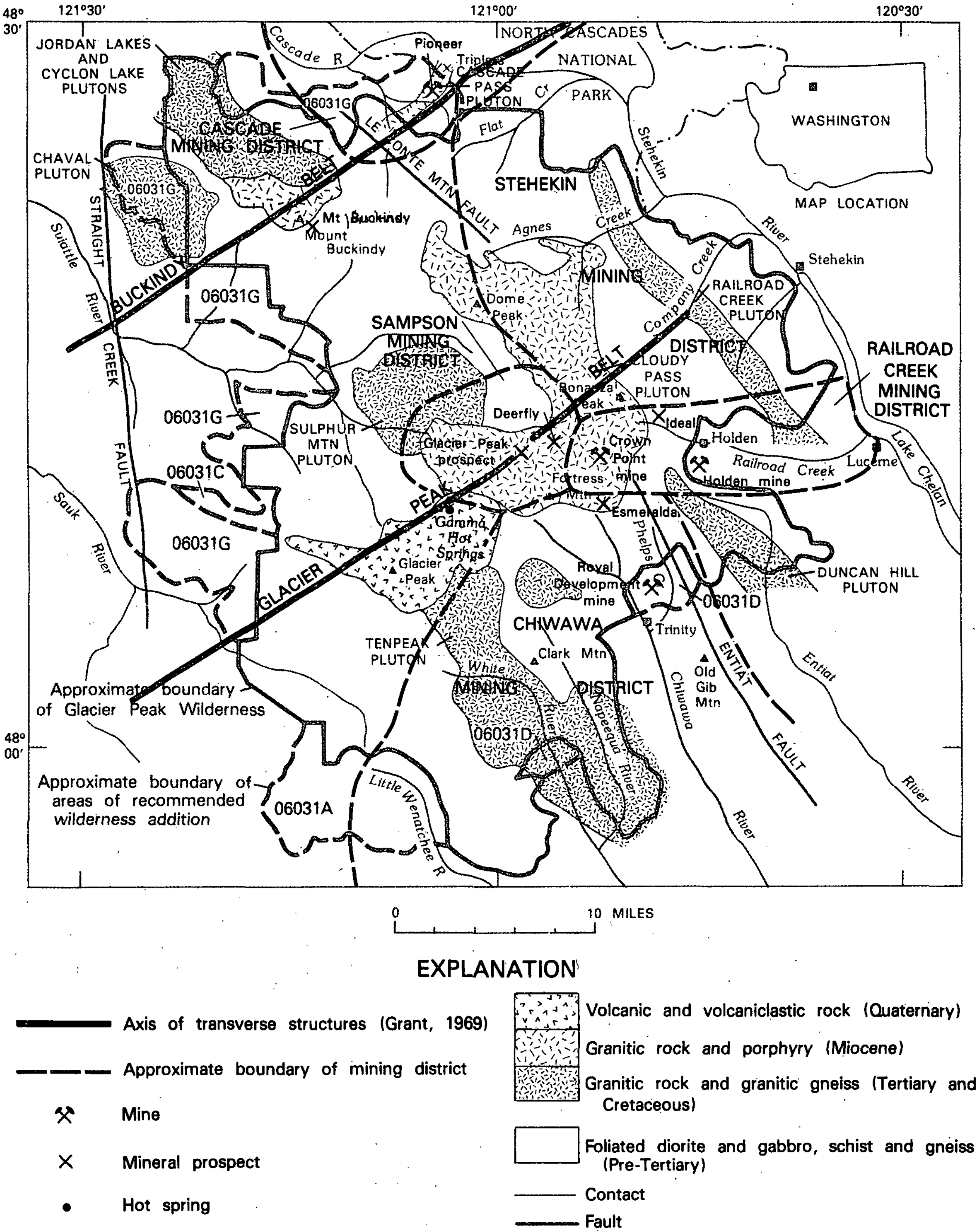


Figure 2.--Map showing location of mining districts and major mineral deposits and their relation to the regional structural belts defined by Grant (1969).

Bear Creek Mining Co., the exploration subsidiary of Kennecott, completed confirmation drilling in 1959, although additional exploration and patent application holes were drilled as late as 1970.

ACKNOWLEDGMENTS

The results of a large project such as this are never wholly the authors' alone. We wish to thank many co-workers and assistants for their diligent efforts in the sample collection and mapping completed during this study. We thank Peter Misch, University of Washington, and A. R. Grant for office and field consultations, and R. C. Babcock, Jr., vice-president, Bear Creek Mining Co., for permission to use company data. In particular, the field studies of many previous workers (Ford, 1983) were invaluable in compiling the geologic data. Claude McLean and Fred Schaub, Darrington Ranger District, and Glenn Hoffman, Lake Wenatchee Ranger District, provided U.S. Forest Service facilities and data for the study. We also thank Keith Miller, Superintendent, for permission for helicopter landing in the North Cascade National Park areas adjoining the Glacier Peak Wilderness and the U.S. National Park Service personnel at Stehekin for their cooperation and use of their facilities. We thank R. B. Dickinson for access to the Royal Development mine and Charles Isreal, caretaker at Trinity, for the use of camp facilities. Fieldwork could not have been completed in this difficult alpine terrain without the skillful work of our helicopter pilots, Anthony Reece, Gary Lot, LeRoy Brown, Ben Van Etten, Michael Wood, and the late Jack Johnson. We are indebted to our co-workers, W. H. Nelson, R. A. Sonnevil, R. A. Loney, R. A. Haugerud, S. L. Garwin, and the late Carl Huie; E. L. Mosier, J. M. Motooka, J. G. Frisken, R. S. Werschky, R. C. Bigelow, George VanTrump, Jr., A. D. McCollaum, B. F. Arbogast, C. M. McDougal, W. R. Willson, and J. G. Evans; the late Mark Sherrard; and F. L. Johnson, E. L. McHugh, F. E. Federspiel, D. K. Denton, Jr., and S. A. Stebbins for their diligent efforts to complete parts of the Glacier Peak folio (MF-1652), so necessary as the raw-data base for this assessment of potential mineral resources. Finally, we thank our colleagues (Erickson, 1982; Cox, 1983) for their open discussions of the geologic, geochemical, and geophysical characteristics and peculiarities of mineral deposits.

GEOLOGY, GEOCHEMISTRY, AND GEOPHYSICS PERTAINING TO MINERAL RESOURCE ASSESSMENT

Geology

The Glacier Peak study area transects the crystalline core of the north Cascades, a structurally complex and highly varied metamorphic and plutonic terrane of Mesozoic and older units (Misch, 1966, 1977). These units were extensively intruded by Tertiary granitic plutons, some as young as Miocene. The study area occupies a southward projection of the area of copper-molybdenum porphyry deposits of predominantly Tertiary age in the Canadian cordillera (Christopher and Carter, 1976). Among the numerous prospects, mineral occurrences, and deposits of varied type known in the study area (Grant, 1982; Stotelmeyer and others, 1982), the most important deposits are the porphyry-copper type accompanied by peripheral hydrothermal veins associated with granitic rocks and porphyritic phases of shallow-level Miocene plutons.

Two principal episodes of major, medium- to high-rank regional metamorphism affected the sedimentary and igneous rocks of this part of the north Cascades (Misch, 1966, 1977). One metamorphic event occurred about 415 m.y. ago in the early Paleozoic, and the other about 60-90 m.y. ago near the end of the Cretaceous (Mattinson, 1972). Original ages of pre-Upper Cretaceous rocks are, in general, poorly known because of extensive resetting of mineral ages by the younger metamorphism. Mattinson's (1972) uranium-lead ages from zircons of about 220 m.y. for the Marblemount Meta-Quartz Diorite of Misch (1966) and the Dumbell Mountain plutons of Cater and Crowder (1967) show that granitic intrusive activity began at least as early as the Triassic. These bodies form a northwest-trending central belt in the study area (unit pTqd), extending from the Cascade River in the north to east of Trinity. Extensive intrusive activity also occurred about 90 m.y. ago in the Late Cretaceous, according to Mattinson's (1972) uranium-lead ages for the Eldorado Orthogneiss of Misch (1966) and potassium-argon and uranium-lead ages reported by Tabor and others (1980, 1982) for the Tenpeak pluton and Sloan Creek plutons. Two large plutons of dioritic, quartz dioritic, and tonalitic to gabbroic composition (Chaval and Riddle Peaks plutons) are undated, but their involvement in regional metamorphism also suggests a pre-Tertiary age. Numerous radiometric ages show that major granitic intrusive activity continued through the early Tertiary (Railroad Creek and Duncan Hill plutons and other smaller ones) and into the Miocene (Cloudy Pass and Buckindy plutons and related smaller bodies). Sulfide mineralization is chiefly associated with the Miocene plutons and, to a lesser extent, with the Riddle Peaks and possibly a few other plutons. Many large plutons, including the Tenpeak, Sloan Creek, Sulphur Mountain, High Pass, Jordan Lakes, Chaval, Cyclone Lake, Downey Creek, and Railroad Creek plutons, show little or no evidence of associated hydrothermal mineralization.

Numerous, mostly high-angle, faults occur in the study area, but two of regional magnitude are dominant: the Entiat fault in the interior and the Straight Creek fault near the west margin of the study area. The Entiat fault extends from the study area at least 30 mi southeastward to near Wenatchee, where it forms the east-bounding fault of the Chiwaukum graben. To the north, in the study area, the Entiat fault was intruded by the Cloudy Pass pluton. In pre-Miocene time, the Entiat fault probably continued north of the Cloudy Pass pluton as the LeConte Mountain fault. The Straight Creek fault, which is a probable strike-slip fault, is cut by a Miocene pluton (Grotto batholith) and extends northward and southward beyond the limits of the study area (Misch, 1966, 1977; Tabor and others, 1982). Many mineral properties and occurrences are near the Entiat fault, but none occur near the Straight Creek fault within the study area.

The distribution of prospects, deposits, and known mineral occurrences described by Grant (1982) and Stotelmeyer and others (1982) shows a marked concentration in the east-central part of the wilderness, northeastward from a line approximately along the Chiwawa River, through Glacier Peak prospect to the Mount Buckindy area. In that sector, many mineral properties are in or near two of Grant's (1969) mineralized "transverse structural" belts, or lineaments (see fig. 2). The belts trend northeastward across the dominant northwest-trending structural grain and are characterized by closely spaced subvertical joints, en-echelon fractures, and shears that Grant (1969) considered to be high-level expressions of deep crustal movement.

Many mineral properties and prospects in the study area are in the Buckindy belt. These include the Mount Buckindy, Milt Creek, Michigan, Skagit, Pioneer (Epoch), and Grand Republic properties (Stotelmeyer and others, 1982), of which the most significant are the Mount Buckindy and Pioneer. Mineral properties that are in the Glacier Peak belt include the Glacier Peak porphyry copper-molybdenum deposit along Miners Ridge, the Deerfly, Fortress Mountain, Esmeralda, and Copper Point prospects, and the Crown Point mine. These properties and prospects occur in or near the youngest dated (Miocene) plutons of calc-alkaline tonalite, granodiorite, and some granite; properties in the Buckindy belt are associated with the Buckindy pluton and the Cascade Pass dike of Tabor (1963), and properties in the Glacier Peak belt are associated with the Cloudy Pass pluton. Porphyry copper-molybdenum deposits occur in hosts of similar type in the Canadian cordillera, where metallogenic epochs of the porphyry-ore formation are dated at 200-195 m.y., 185-175 m.y., 155-140 m.y., 80-65 m.y., 50 m.y., 40-35 m.y., and 26-18 m.y. in age (Christopher and Carter, 1976). Potassium-argon ages of the Buckindy pluton (R. J. Fleck, written commun., 1982), Cascade Pass pluton (Engels and others, 1976; and R. J. Fleck, written commun., 1982), Cloudy Pass pluton (Tabor and Crowder, 1969), and of granodiorite from the Royal Development mine(?) (Engels and others, 1976) are within or near the youngest episode of the Canadian mineralization. Other, generally undated, small bodies of porphyry occur widely through mainly the eastern part of the study area. The plug at Old Gibb Mountain yielded an older age of 43.9 m.y. (Cater and Crowder, 1967), indicating a considerable age span for intrusive activity. However, though undated, many small bodies of porphyry are believed to be related to the larger plutons dated as Miocene, including many around the periphery of the Cloudy Pass pluton that are too small to delineate at 1:100,000 scale. Some of these satellite plutons are, or appear to be, related to known mineral occurrences in the wilderness between Phelps Creek and the Chiwawa River.

Large areas of both the Buckindy and Cloudy Pass plutons appear barren of significant sulfide mineralization. Both are shallow-level intrusions containing breccias that suggest explosive venting of late-stage, volatile-rich fluids. Intrusive breccias are particularly common in and near the southern and eastern parts of the Cloudy Pass pluton (Cater, 1969); they also occur in the northern parts of the pluton (Grant, 1966). Numerous masses of sulfide-bearing and altered breccia on Phelps Ridge, located in the wilderness between Phelps Creek and the Chiwawa River, are closely associated with porphyry plugs that are probably related to the Cloudy Pass pluton (Cater, 1969). Distribution of these breccias and the 24.5 m.y. age of granodiorite at Trinity (Engels and others, 1976) strongly suggest that the Cloudy Pass pluton underlies the Swakane Biotite Gneiss along Phelps Ridge. Pipelike bodies of intrusive breccia associated with porphyry plugs cut biotite gneiss in the roof of the Buckindy pluton at Mount Buckindy. Breccias of probable explosive origin also occur near the roof of the Cascade Pass dike, an apparent northeastward extension of the Buckindy pluton. The slightly different ages of the Cascade Pass pluton (18 m.y., Engels and others, 1976) and the Buckindy pluton (15 m.y., R. J. Fleck, written commun., 1982) indicate that they may be separate intrusions. Most areas of significant mineralization, including the Glacier Peak deposit on Miners Ridge, properties on Phelps Ridge, and the Pioneer and Mount Buckindy properties, occur in granitic rock, porphyry, or country rock near the roof of intrusive bodies. Deeply eroded parts of the plutons generally appear barren of mineralization.

Venting of the Miocene magma chambers may have included the eruption of magma forming the volcanic deposits of Gamma Ridge (Tabor and Crowder, 1969). Although they have not been dated, small bodies of volcanic rocks near Ross Pass, on northern Lyall Ridge, near Round Lake, and elsewhere may be of similar origin.

Although the dominant mineralization of porphyry copper-molybdenum type known in the study area was clearly related to the Miocene plutonism, other types of mineral deposits may be related to earlier igneous or, possibly, metamorphic events. The deposit at the Holden mine, for example, occurs in a belt of schist and gneiss that extends through the east-central part of the study area. The deposit shows no conclusive relation to plutons in the vicinity and is considered by DuBois (1954) to be related to high-rank regional metamorphism. A gangue mineral from the mine, phlogopite, gave an age of 44.1 m.y. (Engels and others, 1976), which is younger than the latest regional metamorphism in Cretaceous time, but older than the Miocene plutonic events that formed the Glacier Peak deposit. The deposit is near the north end of the Duncan Hill pluton (Cater, 1982), which has yielded potassium-argon ages in the range of 46-43 m.y. (Engels and others, 1976), spanning the age of the Holden gangue. This age equivalence may reflect thermal resetting of the phlogopite by contact metamorphism rather than showing a direct relation of the Holden deposit to the Duncan Hill pluton.

The Riddle Peaks pluton is mostly hornblende-bearing, layered gabbro (Cater, 1982) and contains five small claims in oxidized and mineralized rock. Disseminated sulfide and iron-titanium oxide minerals are common in the gabbro, but concentrations of more than a few modal percent have not been found. Bodies of this type may contain inconspicuous but significant amounts of platinum-group metals, commonly in small segregations that are difficult or impossible to identify without more detailed geochemical and microscopic studies. Chromite lenses, a common igneous association in other layered gabbroic plutons, have not been identified in this pluton. Finally, numerous, mostly small, bodies of metaperidotite or other ultramafic rocks, some of which contain prospects, are widely scattered in a central schist belt in the study area.

Geochemistry

A geochemical survey was made during the summers of 1979 and 1980. Collection of stream sediments, supplemented by heavy-mineral-concentrate samples panned from stream sediments, constituted the reconnaissance phase of the investigation. Samples were collected primarily from first-order-stream drainage basins representing areas of 1-2 mi^2, although some represent larger drainage basins. The minus-80-mesh fraction (<177 micrometer) of the stream-sediment samples was separated for analysis.

Emission spectrography was used for most of the analytical work (Church and others, 1982, 1983a), although a new method, a partial digestion in aqua regia followed by analysis using an Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP), was also applied to the stream sediments (Church and others, 1983c). Mineralogical studies (Church and others, 1982, 1983a) were made of the nonmagnetic heavy-mineral concentrates collected in 1980. Representative suites of rock samples were collected from each major formation and were analyzed to determine thresholds for each of the geologic terranes (S. E. Church, unpub. data, 1983). Studies of altered zones not previously defined (Grant, 1982), as well as detailed sampling of mineralized areas, were used to define elemental suites indicative of mineralization. Anomalous elemental concentrations in stream sediments were defined from these data. The suite comprising copper, molybdenum, tungsten, gold, cobalt, lead, zinc, and silver is associated with the porphyry-copper mineralization at the Glacier Peak deposit and is a common association for porphyry-copper systems in the Canadian cordillera (Pilcher and McDougall, 1976). The suites comprising lead, silver, and zinc; lead, arsenic, and antimony; and lead, silver, and molybdenum are found in the northeastern part of the study area and represent base-metal and precious-metal hydrothermal systems.

Geophysics

Data obtained from an aeromagnetic survey flown specifically for this study were added to existing data (Flanigan and others, 1983); the magnetic data were collected along northeast-southwest flight lines spaced 0.5 mi and 1.0 mi apart at 1,000 ft terrain clearance.

Several of the magnetic features seen in the composite aeromagnetic data may be associated with geologic features, some of which may be important indicators of mineralization. A regional belt of magnetic anomalies, both highs and lows, that trends north-northwest across the northeast part of the study area is associated with a belt of plutonic and metamorphic rocks along the Entiat fault. Major transverse structural zones trending N. 30°-90° E. are reflected by the northeast alinement of magnetic anomalies associated with the Mount Buckindy and Cascade Pass plutons (Grant, 1969). These anomalies define the Buckindy belt. An east-west magnetic low, within the magnetic high defined by the Cloudy Pass pluton, crosses the southern part of the pluton near the Glacier Peak deposit and extends eastward beyond Holden. This magnetic signature characterizes mineralization within the Cloudy Pass pluton and is coincident with the Glacier Peak transverse structural belt. Many local magnetic anomalies ranging from a few tens to several hundred gammas can be spatially related to plutonic rocks mapped at the surface.

Known mineral deposits in the study area show three types of spatial relationships with the magnetic anomalies. One group of prospects seems to be spatially related to northwest-trending magnetic lineaments or linear zones of steep magnetic gradient; the Holden mine is a good example. A second group of prospects seems to be spatially related to the outer perimeter, or flanks, of magnetic anomalies associated with some of the Cretaceous and younger plutons such as Riddle Peaks and Mount Buckindy plutons. The Mount Buckindy and Milt Creek prospects are typical of this second class. The third group of prospects is along the east-west magnetic low that parallels the axis of the Cloudy Pass pluton; the Glacier Peak, Deerfly, and Fortress Mountain prospects are the most significant of this group.

MINING DISTRICTS AND MINERALIZATION

U.S. Bureau of Mines personnel examined mines, prospects, and claims in and near the study area (Stotelmeyer and others, 1982). More than 100 sites were examined during the study, and 890 lode samples were taken from mine and prospect workings, outcrops, stockpiles, and dumps (data on file at the U.S. Bureau of Mines, Western Field Operations Center, Spokane, Wash.). Our investigations indicate that the study area is relatively unexplored for minerals. Until recently, a combination of geographical and geological factors adversely affected prospecting and exploration: the harsh environment no doubt was one of the factors, but the lack of bonanza-type oxide and secondary mineralization, resulting from recent glaciation and rapid erosion, discouraged early prospectors. In more recent years, large companies capable of financing exploration for huge, low-grade primary deposits in the igneous rock, or of delineating the erratic occurrences of the rich, pod-shaped sulfide deposits in the metamorphic rock requiring detailed geophysical studies, have been excluded from the area because of environmental constraints.

Results of our mine and prospect evaluation are briefly summarized below for each mining district (fig. 2). Properties having identified metallic resources are listed in table 1, and mines and prospects having possible undiscovered metallic resources are described in table 2. Numbered property locations are from the mines and prospects report by Stotelmeyer and others (in press), who also described other properties examined during the study. There is no current mining activity in the study area.

Sampson district

The Sampson district, in Snohomish County immediately west of the Cascade Range crest, is the most important mining district in the study area. This small district in the center of the wilderness contains only two properties; it is accessible only by trail or helicopter. In the early 1940's, the Glacier Peak deposit was recognized as a low-grade, large-volume porphyry-copper deposit. It is characterized by disseminated and stockwork copper and molybdenum mineralization. A smaller, but similar, deposit of this type may underlie Fortress Mountain about 2 mi southeast of the Glacier Peak prospect where granitic rocks have also intruded gneiss host rock. The Deerfly prospect, a peripheral precious-metal vein deposit, contains indicated and inferred resources of silver, gold, and copper (table 1). The district has had no mineral production and is currently inactive. Eighteen patented claims, consisting of 360 acres in the Suiattle River drainage basin, cover the Glacier Peak deposit.

Chiwawa district

The Chiwawa district includes the Chiwawa, White, Napeequa, and Little Wenatchee River drainage basins. Formerly, the districts were part of the much larger Leavenworth mining district. Access is by all-weather roads, and the main mining and mineralized areas in the study area are relatively accessible by trail.

The Royal Development, or Red Mountain, mine is in area 06031D. The ore occurs in a mineralized breccia pipe at or near the contact of granitic and metamorphic rocks. Copper, silver, and gold were produced between 1929 and 1940, and the total output was about 18,000 tons of ore, from which about 215,000 lbs of copper, 17,000 oz of silver, and 29 oz of gold were recovered. Active exploration was underway in 1981 at this property. Seventy-four claims of the 142-claim group at the Royal Development mine extend into the wilderness. Thirty-eight claims in the group are in area 06031D, nine of which are patented (180 acres); the rest of the claims in this group are adjacent to area 06031D.

Elsewhere in the district, there is evidence for a porphyry copper-molybdenum deposit or a breccia-pipe deposit (Esmeralda property) to the north, along Phelps Ridge within the wilderness. There are six patented claims and one mill site in the wilderness along Phelps Creek.

Production records also suggest that about 7,000 tons of pumice may have been produced between 1943 and 1947 from a small open pit southeast of the Royal Development mine.

Railroad Creek district

Railroad Creek drains part of the eastern portion of the Glacier Peak Wilderness and empties into Lake Chelan. Between 1938 and 1957, the Holden mine produced about 10 million tons of ore that yielded more than 212 million lbs of copper, 40 million lbs of zinc, 2 million oz of silver, and 600,000 oz of gold. The wilderness boundary is at the western edge of the Holden townsite. All material, supplies, and personnel for the Holden mine were brought 45 mi by barge from Chelan or flown in by float plane to Lucerne and then trucked 12 mi to the mine site. A shuttle bus is presently operated between Lucerne and Holden, which is now a church camp.

Recorded mineral production from within the wilderness is molybdenum ore from the Crown Point mine on upper Railroad Creek. Output was reported to be 10-12 tons in 1901-02, and small amounts of ore were also produced between 1903 and 1917.

Currently, there is one claim on a silver-bearing quartz vein (Ideal prospect, fig. 2) in the wilderness, on the east side of Bonanza Peak.

Stehekin district

The Stehekin mining district lies principally northeast of the Glacier Peak Wilderness. Only the part southwest of the Stehekin River is in the study area, and there has been no mining in this part of the district. This area has been little explored for minerals despite the intensity of mineralization, probably because of the difficult access.

Cascade district

About half the Cascade mining district is in the study area; the rest is in North Cascades National Park. Only the section containing the Middle Fork of the Cascade River and the lower part of the South Fork of the Cascade River was studied. The district contains the Pioneer patented claim group (9 claims, 179 acres). Indicated and inferred silver, lead, and zinc resources occur in a hydrothermal vein deposit in area 06031G. Also at the north end of the wilderness, the patented claim group of the Johannasburg mine extends into area 06031G. A small amount of high-grade lead-silver ore was produced in 1953 and 1955, most likely from that part of the claim group inside North Cascades National Park.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

Three types of commodities have been examined in the mineral resource evaluation of the study area: metallic resources, nonmetallic resources, and energy resources.

The classification of mineral resources for known deposits found in the study area was made using the terminology of U.S. Geological Survey "Circular 831" (U.S. Bureau of Mines and U.S. Geological Survey, 1980). The classification of the mineral potential of an area, however, represents an integration of measurable data and the subjective evaluation of the degree to which those data, and the interpretation of the geologic conditions inferred, represent a known mineral deposit type. We use three terms, "high," "moderate," and "low," to describe the potential for mineral resources of certain areas within the study area. An area having a high potential for mineral resources is one in which most of the geologic criteria outlined in applicable mineral-deposit models are met. Furthermore, a deposit of that general type and age must exist in the western cordillera. An area having a moderate potential is one in which the geologic criteria permit a particular deposit type, but in which the geochemical or geophysical evidence for mineralization is less well defined; however, a reasonable chance for the occurrence of concealed mineral deposits exists. An area having a low potential is one for which the data do not indicate geologic conditions favorable for ore accumulations. Some areas of low potential are tentatively classified as such on the basis of limited data. An area of low potential may include areas of concealed mineralized rock as well as areas of dispersed mineral occurrences.

Potential for metallic mineral resources

In the evaluation of metallic resources of the study area, we draw heavily on previous studies of mineralization and on our collective experience and

Table 1.--Mines and prospects with estimated metallic resources in the Glacier Peak Wilderness and adjacent areas, Chelan, Skagit, and Snohomish Counties, Washington

[Underlined names refer to properties having a high probability for undiscovered resources]

No. on map[1]	Property	Type	Tonnage (except where noted)	Resource classification[2]	Commodity	Grade
Sampson mining district						
48	Glacier Peak prospect.	Disseminated copper-molybdenum.	1.9 billion	Total identified resource.	Copper---------------- Molybdenum disulfide	0.334 percent 0.15-0.02 percent
			41.3 million	Measured restricted reserve.	Copper-------------- Molybdenum disulfide Gold---------------- Silver-------------- Tungsten trioxide---	0.71 percent 0.046 percent 0.015 oz/ton 0.25 oz/ton 0.03 percent
46	Deerfly (probable extension of Glacier Peak prospect).	Disseminated silver--	174,000	Indicated and inferred; subeconomic.	Silver-------------- Gold---------------- Copper--------------	0.75 oz/ton 0.005 oz/ton 0.05 percent
Railroad Creek mining district						
38	Ideal-----------	Fissure vein----------	34,000	Indicated and inferred; marginal reserve.	Silver--------------	1.42 oz/ton
43	Crown Point mine	Shear zones----------	1,300	Measured and indicated; subeconomic.	Gold---------------- Silver-------------- Copper-------------- Lead---------------- Zinc---------------- Molybdenum disulfide	trace 2.92 oz/ton 2.6 percent 0.39 percent 0.72 percent 0.06 percent
23	Holden mine (adjoins Wilderness).	A. Shear zones (underground).	3 million	Measured; indicated and inferred; marginal reserve.	Copper-------------- Gold---------------- Silver-------------- Zinc----------------	1.1 percent 0.06 oz/ton 0.2 oz/ton 0.3 percent
		B. Tailings pile-----	9 million	Measured; marginal reserve.	Gold---------------- Silver-------------- Copper-------------- Zinc---------------- Pyrite (recoverable) Silica (free SiO_2)	0.048 oz/ton 0.1 oz/ton 0.07 percent 0.3 percent 5.0 percent unavailable
Cascade mining district						
7	Pioneer (area 06031G).	Fissure vein (1.5 ft wide).	734,000	Indicated and inferred; restricted reserve.	Silver-------------- Lead---------------- Zinc---------------- Copper-------------- Gold----------------	6.46 oz/ton 6.4 percent 6.5 percent 0.52 percent 0.015 oz/ton
5	Silver Queen (adjoins Wilderness).	Sulfide (limestone-replacement forming two pod-shaped ore bodies).	60 (first pod)	Occurrence----------	Silver-------------- Lead---------------- Zinc---------------- Copper-------------- Gold---------------- Cadmium-------------	5.35 oz/ton 5.0 percent 2.0 percent 0.40 percent 0.01 oz/ton 0.01 percent
			9 (second pod)	----do--------------	Zinc---------------- Cadmium------------- Silver-------------- Copper-------------- Lead----------------	12.0 percent 0.18 percent 0.95 oz/ton 0.17 percent 0.65 percent
Chiwawa mining district						
64	Royal Development mine (area 06031D).	Breccia pipe---------	8.5 million	Inferred; marginal reserve.	Copper-------------- Silver-------------- Tungsten------------	0.4 percent 0.9 oz/ton unavailable

[1] Numbers correspond to locations shown on accompanying map, MF-1652-A.

[2] U.S. Bureau of Mines and U.S. Geological Survey (1980).

Table 2.--Mines and prospects with possible undiscovered metallic resources in the Glacier Peak Wilderness and adjacent areas, Chelan, Skagit, and Snohomish Counties, Washington

[Properties are not sufficiently exposed or studied to enable estimate of tonnage and grade]

No. on map[1]	Property	Type	Commodities	Description and remarks	Sampling (sample lengths are in parentheses)
				Stehekin mining district	
35	Carmen------	Sulfide (limestone-replacement).	Lead Zinc Silver Copper Cadmium byproduct	On mineral belt extending to Holden mine. May intersect Copper King structure. Several shallow prospect pits.	Nineteen samples: ten ranged from 0.74 to 6.9 percent lead (5.0 and 4.0 ft, respectively) and averaged 2.0 percent; twelve ranged from 0.81 to 7.0 percent zinc (4.0 and 2.0 ft, respectively) and averaged 3.0 percent; nine ranged from 0.9 to 3.7 oz silver per ton (2.0 and 15.0 ft, respectively) and averaged 2.1 oz; six ranged from 0.10 to 0.53 percent copper (2.0 ft) and averaged 0.29 percent.
36	Copper King	Shear zone-----	Copper Cobalt Silver byproduct	Two adits, 5 ft and 14 ft long. Possible ore shoot may occur at intersection of this zone with trend of Carmen deposit. Cobalt may be only localized.	Seven samples: one assayed 0.34 percent cobalt, 0.11 percent copper, and 0.5 oz silver per ton (1.2 ft); one assayed 0.36 percent copper and 0.3 oz silver per ton (0.8 ft); one grab sample assayed 0.26 percent cobalt.
32	Goericke----	Porphyry copper	Copper Silver	Rugged terrain inhibits prospecting; on Holden trend.	Fifteen samples: one sample of float assayed 4.4 percent copper and 1.0 oz silver per ton; another sample of float assayed 0.9 percent copper; one chip sample assayed 1.2 oz silver per ton (2.0 ft); twelve samples of accessible parts of numerous pyritized areas on ridge crests were essentially barren.
				Railroad Creek mining district	
29	Mary Green--	Shear zones----	Copper Silver byproduct	Copper-rich pockets. Potential for limestone replacement; on Holden trend. Three adits as much as 370 ft long and several prospect pits.	Twenty-five samples: two of nine samples at workings near the ridge crest contained 1.5 percent copper (3.0 and 3.2 ft), another contained 0.14 percent copper (4.0 ft), and all ranged from 0.1 to 0.5 oz silver per ton. Sixteen samples from across isolated patches of pyritized rock along the canyon slope indicated no other anomalous mineral concentrations.
44	Victor------	Fissure vein---	Silver Lead Zinc	Sulfide veinlets. Possible extension of Crown Point mine. A 92-ft adit.	Five samples: one assayed 1.5 oz silver per ton, 1.4 percent lead, 4.0 percent zinc, 0.04 percent cadmium and 0.25 percent copper (0.2 ft); another assayed 1.4 oz silver per ton, 1.9 percent lead, and 0.60 percent zinc (0.2 ft).
24	Sevenmile-Antimony (adjoins wilderness).	Vein-----------	Antimony Gold byproduct Silver byproduct	Exploration target only. Also examined by U.S. Bureau of Mines in 1953. Caved adit 50 ft long.	Seven samples: one of three samples from the 1953 examination contained 2.72 percent antimony, and one sample assayed 1.0 percent nickel (no widths given); two of four samples from the 1977 examination assayed 0.48 and 0.31 percent antimony (select and grab samples, respectively); gold assayed from a trace to 0.01 oz per ton, and silver assayed from 0.2 to 0.4 oz per ton in those four samples.

				Chiwawa mining district	
53	Copper Point	Shear zones and possible breccia pipe.	Gold Silver Copper Lead Zinc	Patented claims. About 14 short adits and numerous prospect pits. Shear zones are very narrow. Contact of Entiat fault and Cloudy Pass pluton.	Eighty samples: fifteen assayed significant silver, ranging from 0.4 oz per ton (0.5 ft) to 5.1 oz per ton (0.6 ft) in chip samples, and 8.8 oz per ton in a select sample; ten chip samples assayed from 0.10 to 0.47 percent copper (0.6 to 1.0 ft, respectively), and eight select or grab samples assayed from 0.15 to 5.3 percent copper; six samples contained greater than 0.75 percent lead, ranging from 0.76 to 3.9 percent (0.5 and 0.6 ft, respectively); five contained greater than 0.75 percent zinc, ranging from 0.83 to 2.0 percent (0.6 and 0.3 ft, respectively); eighteen samples contained measurable gold, assaying from 0.01 to 0.05 oz per ton (1.0 ft).
56	Esmeralda---	Porphyry copper or breccia pipe.	Copper Gold Silver	Widespread hydrothermal-alteration area containing disseminated sulfides, and locally containing high grade gold and silver deposits at possible ancient fumaroles or boiling centers. Workings consist of five adits, two shafts, and at least six prospect pits.	Forty-two samples: nine assayed 0.1 percent or more of copper, ranging from 0.16 to 2.2 percent (2.0 and 1.2 ft, respectively); fifteen samples contained measurable gold--seven chip samples assayed from 0.01 to 0.15 oz per ton (1.1 and 1.2 ft, respectively), three select samples assayed 0.04 oz, 0.14 oz, and 0.37 oz per ton, and five grab samples assayed from 0.01 to 0.04 oz per ton; nine samples had assays ranging from 0.5 to 4.8 oz silver per ton (1.0 and 1.2 ft, respectively); six samples had an arsenic content greater than 1.0 percent, assaying as high as 29.0 percent in a select sample and 24.0 percent in a chip sample (1.2 ft).
57	Peacock-----	Epithermal deposit.	Silver Gold Copper Arsenic	Small deposits. Possible extensions of Esmeralda deposit. Several prospect pits.	Four samples: one select sample assayed 5.3 oz silver per ton, 0.07 oz gold per ton, 0.51 percent copper, and 27.0 percent arsenic; another sample assayed 1.4 oz silver per ton.
				Sampson mining district	
51	Fortress Mountain.	Porphyry copper	Copper	May be extension of Glacier Peak prospect.	Five grab samples of talus: one assayed 0.15 percent copper. Of more than 150 company surface samples, 25 assayed greater than 0.2 percent copper. Several shallow drill holes; the best averages 0.34 percent copper (87 ft).
				Unrecognized mining districts	
21	Cougar-Mountain Lion.	Disseminated---	Gold Copper Zinc	Pyritized rhyodacite plug at least 750 ft in diameter. Probably extends into wilderness, 1,000 ft to the west. Two adits 30 and 41 ft long.	Eight samples: four chip samples assayed from 0.01 to 0.03 oz gold per ton; (0.1 and 3.3 ft); one assayed 0.14 percent copper (3.3 ft); a select sample assayed 0.17 percent zinc.
92	Goff (area 06031A).	Unknown--------	Copper Silver Gold	Altered area of several square miles, containing small, localized, sulfide-bearing shear zones. Four adits: 105 ft, 80 ft, 10 ft, and 5 ft long; a 62-ft trench; at least four prospect pits.	Twenty-nine samples: four samples at the 5-ft adit assayed as much as 2.5 oz silver per ton, 0.01 oz gold per ton, and 0.05 percent copper in veinlets as much as 0.3 ft wide. Company reported 2 ft assaying 13.85 oz silver per ton, and 8.3 percent copper. Their location is vague.
2	Mount Buckindy.	Porphyry copper	Copper Molybdenum Silver byproduct	Remote, glacier-covered area. Company drilled five holes.	The best hole averaged 0.337 percent copper and 0.13 percent MoS_2 over 425 ft. Two intervals, 9 and 10 ft long, assayed more than 1 percent copper.

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[1] Numbers correspond to locations shown on accompanying map, MF-1652-A.

that of our colleagues. The following summary is based on the recognition of specific geologic, geochemical, geophysical, and mines and prospects criteria characteristic of a distinct deposit type (Erickson, 1982; Cox, 1983). In evaluating areas of mineral potential, we have developed recognition criteria as defined by a mineral-deposit model, formulated those criteria in definable terms, and summarized our observations for mineralized areas in the study area. This approach is model dependent; should new mineral deposit models become more appropriate based on future study, the Glacier Peak folio (MF-1652) should provide the basic observational data for new resource assessments.

The models for deposit types used in this evaluation are presented in tables 3-6 using the following general recognition criteria:

1. Regional geologic setting and structure.
2. Local geologic environment, including rock type, structural relationships, alteration, and observed mineralized rock.
3. Geochemistry of rocks, stream sediments, heavy-mineral concentrates panned from stream sediments, and mineralogy of the heavy-mineral concentrates.
4. Geophysical expressions indicated by the aeromagnetic and gravity surveys.
5. Evidence of mining activity, known deposits, and exploration and claim activity.

Detailed descriptions of the specific recognition criteria used for each model type are given below, along with specific references to geologic descriptions or summaries of features of that deposit type.

The principal types of mineral deposits that occur, or may be expected to occur, in the study area are (A) hot-springs deposits (Au and Ag); (B) base- and precious-metal hydrothermal-vein deposits and limestone-replacement deposits associated with igneous intrusive rocks (Au, Ag, Pb, Zn, Cu, and As); (C) disseminated porphyry deposits of both the copper-rich and molybdenum-rich type (Cu, Mo, W, and Au); (D) volcanogenic massive-sulfide deposits in the metamorphic Holden schist and gneiss belt (Cu, Zn, Au, and Ag); (E) gold-bearing quartz veins resulting from regional metamorphism; (F) zoned ultramafic rocks containing pod-shaped deposits of chromium and platinum-group metals, or ultramafic rocks containing magmatic concentrations of nickel, cobalt, chromium, and platinum-group metals; and (G) placer-gold deposits. Each of these deposit types is briefly discussed below, and the field observations, interpretation of the geologic setting, geochemistry, mineralogy, gravity, magnetics, and mining activity data leading to the resource assessment are summarized in the accompanying tables (3-6).

A. Hot-springs deposits

Hot-springs deposits, noted primarily for their large-volume, low-grade gold potential (Radtke and others, 1980; Silberman, 1982) occur in young, uneroded belts of volcanic rocks that are dominantly dacite and andesite, with lesser amounts of rhyodacite and rhyolite. Shallow felsic intrusions appear to provide the heat, and the vent areas are characterized by extensive hydrothermal alteration, particularly silicification, and brecciation. Deposits are generally associated with caldera margins, normal faulting, or complex volcanic centers characterized by presence of small intrusive plugs. Disseminated pyrite is common. Altered rocks and stream sediments have moderate to high levels of arsenic, antimony, mercury, gold, and silver. Barite is common in the heavy-mineral concentrates. The type area for these deposit is in the Great Basin. Similar deposits have recently been found in the Eocene Chumstick formation along the extension of the Entiat fault south of the study area, near Wenatchee, Wash.

Five areas (A-1 to A-5, fig. 3) may possibly have hot-springs-type deposits: Gamma Ridge-Gamma Hot Springs, Goff (06031A), the Round Lake volcanics area (06031G), Kennedy Hot Springs, and Sulphur Hot Springs. The data for each area are summarized in table 3. Four of the five areas considered do not sufficiently satisfy the deposit criteria to consider them as having a moderate potential for the occurrence of precious-metal resources. Although the Goff prospect (A-1) has anomalous concentrations of the precious metals, it lacks many of the essential features of the hot-springs-deposit model, including evidence of extensive silicification or the presence of a venting hydrothermal system. Likewise, the Round Lake volcanics area (A-2) lacks many essential features. Both areas are classified as having a low potential for the occurrence of precious-metal resources in this type of deposit. Two of the three active hot-springs areas, Kennedy (A-4) and Sulphur Hot Springs (A-5), also lack essential features of the model, primarily the close spatial association with contemporaneous volcanic-vent areas. These two areas also have a low potential for the occurrence of precious-metal resources in a hot-springs deposit. The Gamma Ridge-Gamma Hot Springs area (A-3) probably represents a hot-springs system related to recent volcanic activity at Glacier Peak that vented through the older volcanic rocks (Tabor and Crowder, 1969, p. 22-23). The presence of silicified rock, large altered areas, and favorable geochemical anomalies suggests that area A-3 has a moderate potential for the occurrence of precious-metal resources in a low-grade, disseminated hot-springs deposit.

B. Hydrothermal-vein and limestone-replacement deposits associated with igneous rocks

Base- and precious-metal hydrothermal veins are common peripheral features associated with porphyry-type deposits. They occur in thick volcanic piles of andesitic to rhyolitic composition associated with tensional or extensional regional tectonic stress patterns. They generally form within several thousand feet of the surface and are spatially associated with centers of volcanic activity. Geochemical anomalies commonly observed in stream sediments may include arsenic, antimony, silver, gold, tellurium, lead, zinc, and copper. Heavy-mineral concentrates may contain arsenopyrite, chalcopyrite, pyrite, galena, sphalerite, scheelite, cinnabar, native gold, and various sulfosalt minerals, such as tetrahedrite and tennantite. Widespread evidence of sericitic, kaolinitic, carbonatic, and propylitic alteration may be present. Thin envelopes of potassic alteration in wall rock may also occur along veins where chalcopyrite is

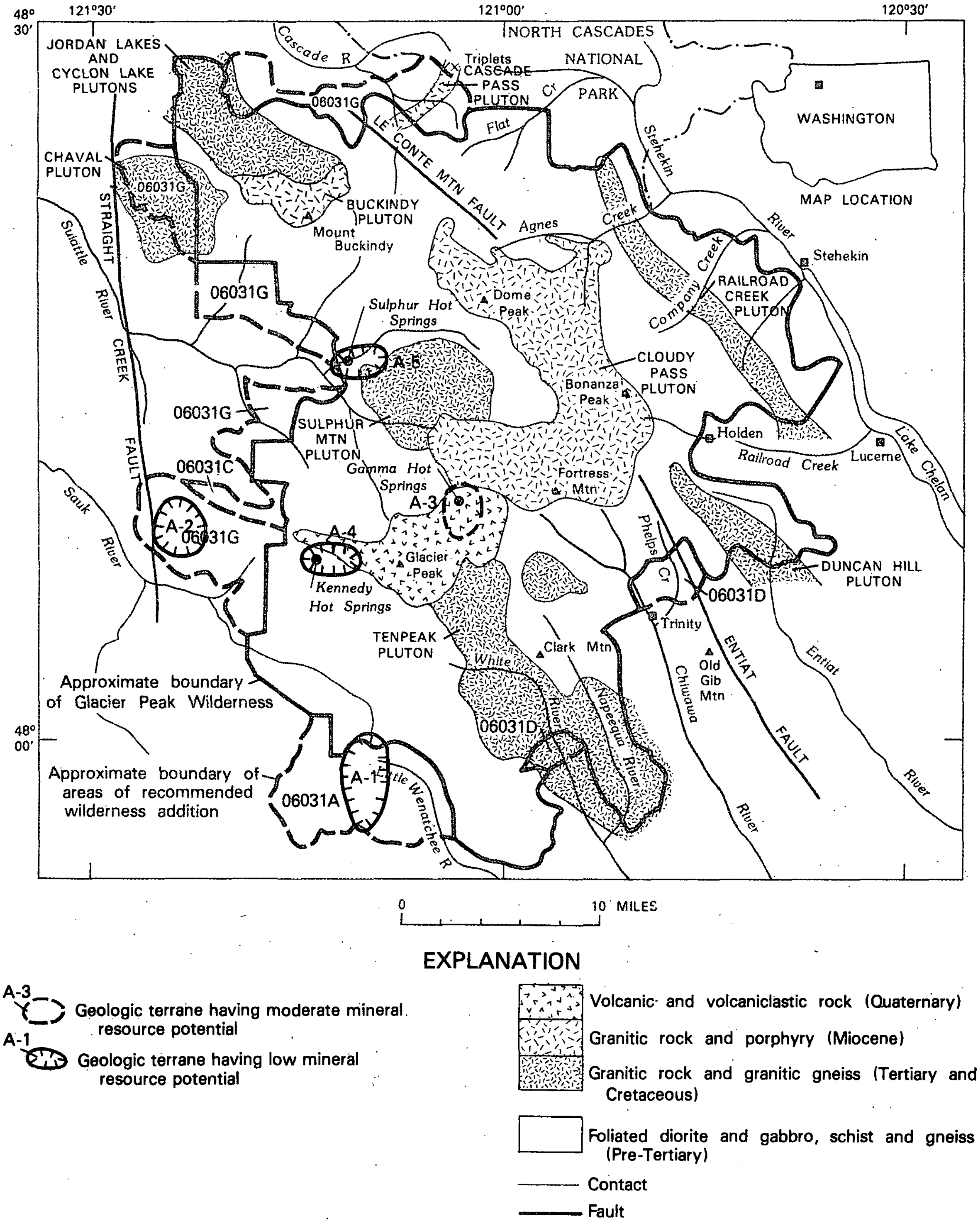

Figure 3.--Map showing locations and mineral resource assessment of areas discussed under the hot-springs model (see table 3).

Table 3.--Summary of data for the hot-springs-deposit model

[Field observations: +, feature observed; -, feature not present; ?, field observations not made or inconclusive. Geophysical anomalies: H, high; L, low; ?, no indication. Potential for occurrence of mineral resources: L, low; M, moderate. Minerals: Py, pyrite; Sch, scheelite; Ti-m, titanium minerals; Bar, barite. NA, not available]

Recognition *criteria*	Goff Prospect *(area A-1)*	Round Lake volcanics rocks *(area A-2)*	Gamma Ridge-Gamma Hot Springs *(area A-3)*	Kennedy Hot Springs *(area A-4)*	Sulphur Hot Springs *(area A-5)*
1. Regional geologic setting					
A. Intermediate to felsic volcanic rocks	+	+	+	+	-
B. Presence of caldera or volcanic center containing intrusive phases	+	+	+	?	-
C. Presence of high-angle normal faulting	?	?	?	?	?
2. Geologic environment					
A. Dacitic to rhyolitic volcanics and volcaniclastic rocks	+	+	+	-	-
B. Shallow level of erosion	+	+	+	-	-
C. Local structural fracturing	+	-	?	?	?
D. Primary porosity/permeability in rocks	+	+	+	-	-
E. Hydrothermal fracturing/brecciation	?	-	?	?	?
F. Alteration	Limonite	Limonite	Propylitic argillic	?	?
G. Silicification	-	-	+	-	-
H. Stockworks/veinlets	-	-	-	-	-
I. Presence of active hot springs	-	-	+	+	+
J. Presence of travertine	-	-	+	+	+
3. Geochemistry					
A. Anomalous anions or cations in hot-springs waters	NA[1]	NA[1]	NA[1]	[1]Cu, Zn, Mo	NA[1]
	NA[2]	NA[2]	[2]HCO_3^-, Cl^-	[2]Cl^-	[2]HCO_3^-, $SO_4^=$, Cl^-
	NA[3]	NA[3]	[3]H_2S, Cl^-	[3]HCO_3^-, Cl^-, Zn, Hg	[3]H_2S

B. Anomalous elements in stream sediments	Mo, Cu, Pb, Co, Mn, Zn, Ag, Au	Au, Pb	Au, Ag	None	Mo, Ni
C. Anomalous acid-soluble elements in stream sediments	As, Cu, Pb, Zn, Ag, P, Co, Ni, Mn, Ba	Cu, Co, Ni, Mn, Ba, W, Zn, As, Ti, Nb	Mo, Mn, Ni, Co, W, As, Sr, Ti, Nb	None	Cu, Zn, Co, Ni, Mn, Ba, Sr, Cr
D. Anomalous elements in panned concentrates	Mo, Cu, Pb, Hg, Ag, Co, W, Sn, Bi, Ba, B	Cu, Pb, Hg, Ag, As, Co, Ba, B, Bi, W	Cu, Pb, Hg, As, Ag, Co, Ba	Mn, Cu, Co	Mn, Co, Ba
E. Mineralogy of heavy-mineral concentrates	Py, Sch	Py, Ti-m	Py, Bar	NA	NA
F. Anomalous halo elements in rocks	Ba, Ni(?)	Ba	Mn, Ba	-	-
G. Anomalous commodity elements in rocks	Ag, Cu, Mo, Pb, Sn, Zn	Cu, Ag	Mo, Ag	-	-
4. Geophysics					
A. Magnetic indication	H	H	?	H	?
B. Gravity indication	?	?	L	?	?
5. Mining activity summary					
A. Known deposits	None	None	None	None	None
B. Mineral occurrences or zones containing possible undiscovered resources	Goff([4]#92, [5]G-33), Cu, Ag, Au	None	None	None	None
C. Number of prospects, workings, and the like (not including 5A)	9	0	0	0	0
6. Resource assessment	L	L	M	L	L

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[1] Data this study.

[2] Data from Tabor and Crowder (1969).

[3] Mariner and others (1982).

[4] Stotelmeyer and others (in press).

[5] Grant (1982).

abundant. Brecciation is a common feature. Ore minerals may be either disseminated or vein deposits in vugs, fractures, and open spaces (Barton, 1982; Berger, 1982; Berger and Eimon, 1983). The ores of the Monte Cristo district southwest of the study area are an excellent example of this type of hydrothermal vein deposit (Spurr, 1901; Church and others, 1983c).

High-grade, localized deposits may also result when hydrothermal solutions react with limestone or marble to form replacement deposits. Although no mappable limestone units (1:100,000 scale) are present in the study area, local geology also makes this type of deposit a feasible variant of the hydrothermal-vein deposit model; the Carmen property (table 2, no. 35) is a possible example of a hydrothermal limestone-replacement deposit. The data for areas having potential for base- and precious-metal vein deposits are summarized in table 4; areas are shown in figure 4 (areas B-1 to B-8).

Area B-1 has a high potential for the occurrence of precious-metal resources and contains three deposits having identified resources. The Deerfly prospect, a disseminated-silver deposit probably associated with the Glacier Peak hydrothermal system, has demonstrated resources of 174,000 tons containing 0.75 oz silver/ton, with some gold and copper. The deposit is in pervasively sheared granodiorite containing closely spaced quartz veins and showing sericitic alteration. Pyrite, arsenopyrite, chalcopyrite, pyrrhotite, and tourmaline are abundant; the rock also contains minor galena and sphalerite. The Crown Point mine has demonstrated resources of 1,300 tons containing 2.9 oz silver/ton, 2.6 percent copper, 0.39 percent lead, and 0.72 percent zinc. This deposit is in shears and small veins in a large quartz pod in weakly altered granodiorite of the Cloudy Pass pluton. The mine produced 10-12 tons of molybdenum ore (1901-02), and some museum specimens of molybdenite were removed, but the deposit is small. The Victor prospect, 1,800 ft north of the Crown Point mine, is probably part of the same hydrothermal system. Stringers of sulfides occur in altered granodiorite; galena, sphalerite, chalcopyrite, and bornite were identified, and ruby silver may be present. The Ideal prospect has demonstrated resources of 34,000 tons containing 1.42 oz silver/ton. It is on a quartz vein in orthogneiss cut by numerous lamprophyre dikes containing pyrite. Geologic inference suggests that the area of the Ideal prospect is underlain by the Cloudy Pass batholith.

Area B-2, which includes the Esmeralda and Peacock claims along Phelps Ridge, has a high potential for the occurrence of base- and precious-metal resources. The presence of scorodite (a hydrous iron arsenate) and abundant amorphous silica suggests shallow deposition of ore. Area B-2, Red Mountain, consists of extensively pyritized and altered gneiss overlying the Cloudy Pass pluton (Grant, 1982). It has a pronounced red color anomaly and widespread geochemical anomalies.

Area B-3, north of area B-1, in the Stehekin mining district, has a high potential for the occurrence of base- and precious-metal resources in hydrothermal veins and in limestone-replacement deposits in pre-Tertiary gneisses. Widespread geochemical anomalies reflect the distribution of sulfides along tensional shears in the roof rocks over the Cloudy Pass pluton or along nearby structural features. The Carmen deposit, which is either a tactite or limestone-replacement deposit, and the Copper King properties are along the same structure and have possible undiscovered base- and precious-metal resources. The Goericke property on Company Creek has possible undiscovered resources.

Area B-4 has a high potential for the occurrence of base- and precious-metal resources. A major sulfide vein at the Pioneer patented claims is in area 06031G. Demonstrated and inferred resources are 734,000 tons of silver-lead-zinc ore containing 6.46 oz silver/ton, 6.4 percent lead, 6.5 percent zinc, 0.52 percent copper, and 0.015 oz gold/ton. The deposit is adjacent to a large breccia pipe at the Triplets (Tabor, 1963). The Silver Queen prospect, just outside the boundary of the recommended wilderness addition, is a limestone-replacement deposit in Cascade River Schist of Misch (1966). It has an estimated 69 tons of mineralized rock in high-grade pods, containing 4.8 oz silver/ton, 5.0 percent lead, 2.0 percent zinc, and some copper, gold, and cadmium (see table 1). An adjacent area, B-5, has similar geochemical, geophysical, and geologic features (table 4) and has a moderate potential for the occurrence of base- and precious-metal resources in hydrothermal veins.

Area B-6 is on the Glacier Peak transverse shear belt of Grant (1969) near a granitic plug. This system has produced an intense red color anomaly, reflecting the surrounding pyritic shell, and is characterized by isolated geochemical anomalies and a favorable magnetic signature. No exploration work has been done in the area. On the basis of this study, area B-6 is assigned a low potential for the occurrence of base-metal resources in hydrothermal veins.

Area B-7, located mainly in area 06031A, south of the wilderness, is defined largely by geochemical anomalies associated with volcanic plugs. Company assay records from an adit in area B-7 indicate a silver vein having 13.85 oz silver/ton and 8.3 percent copper (Stotelmeyer and others, 1982), but there are no indications that this is anything other than a localized high-grade occurrence. Based on this study, area B-7 is also assigned a low potential for the occurrence of precious-metal resources.

The Cougar-Mountain Lion prospect (B-8), southeast of, but immediately adjacent to, the study area, is associated with a rhyodacite plug containing disseminated sulfides and is classified as having a low potential for the occurrence of base- and precious-metal resources in hydrothermal veins. Area B-8 extends into the wilderness.

C. Porphyry deposits

Porphyry deposits, that is, disseminated deposits formed by convecting hydrothermal systems in the rocks surrounding an intrusive, are generally classified according to the geologic conditions of emplacement. Both the volcanic- and plutonic-type porphyry deposits are common in the Canadian cordillera (Brown, ed., 1976). Hollister (1979) has briefly summarized the distribution of known porphyry-type deposits from the Canadian cordillera south into the Cascade Range of Washington and Oregon. Both copper- and molybdenum-rich systems occur in the study area.

Porphyry deposits are associated with calc-alkaline igneous intrusive belts that passively intrude regional zones of structural weakness caused

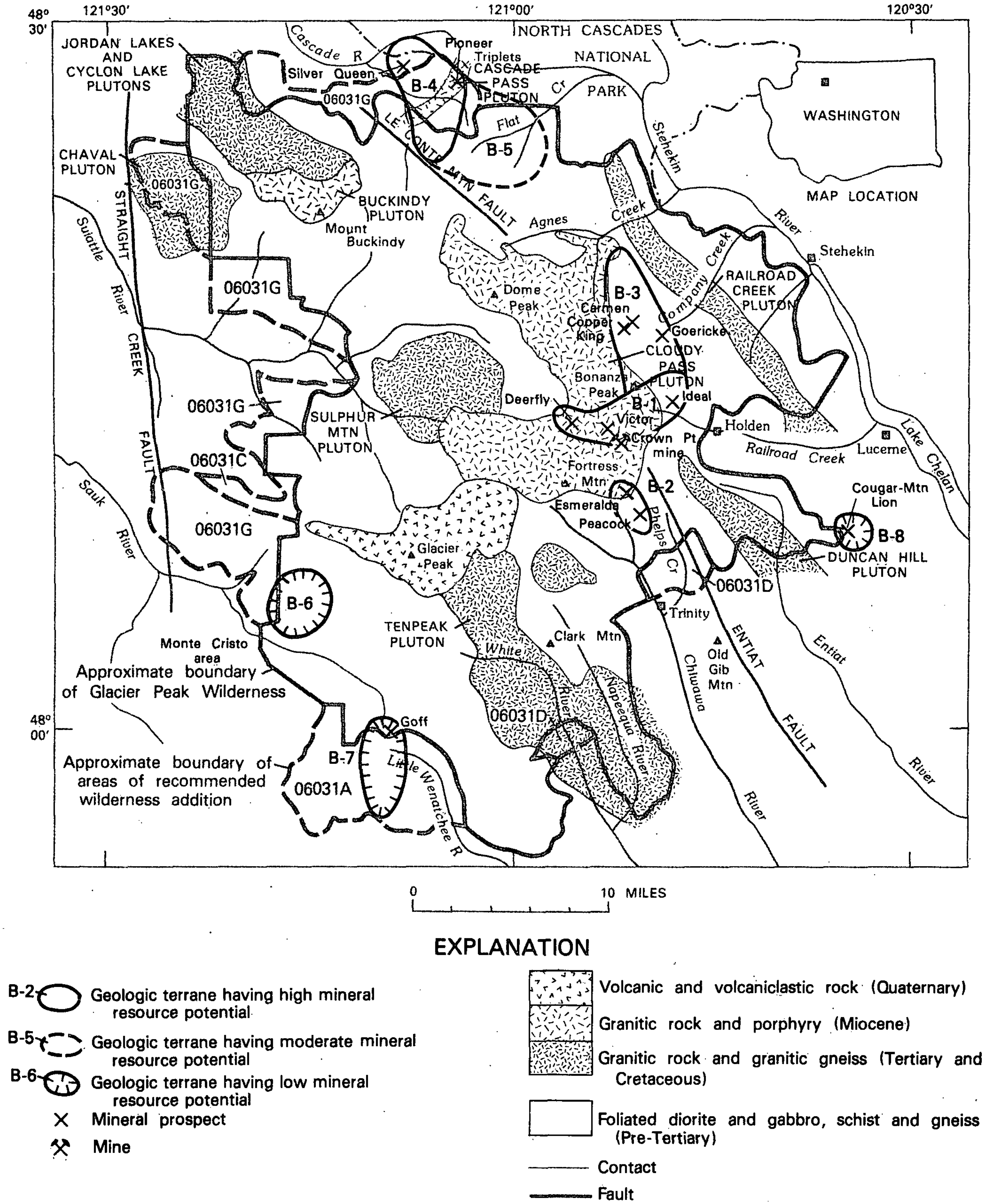

Figure 4.--Map showing locations and mineral resource assessment of areas discussed under the base- and precious-metal-vein model (see table 4).

Table 4.--Summary of data for base- and precious-metal hydrothermal-vein-deposit model

[Field observations: +, feature observed; -, feature not present; ?, field observations not made or inconclusive. Geophysical anomalies: H, high; L, low; RLG, regional linear gradient; ?, no indication. Potential for occurrence of mineral resources: L, low; M, moderate; H, high. Minerals: Sch, scheelite; Tour, tourmaline; Py, pyrite; Ti-m, titanium minerals; Cpy, chalcopyrite; Bar, barite; Gal, galena]

Recognition criteria	Area B-1	Area B-2	Area B-3	Area B-4	Area B-5	Area B-6	Area B-7	Area B-8
1. Regional geologic setting								
A. Calc-alkaline igneous belt	+	+	+	+	-	+	+	+
2. Geologic environment								
A. Dacitic/calc-alkaline volcanics	-	+	+	-	-	+	+	+
B. Associated with intrusive center	+	+	+	+	-	+	+	+
C. Presence of dike swarms	+	+	?	+	+	?	+	-
D. Shallow-level intrusion	+	+	+	+	?	+	+	+
E. Tensional fracturing	+	+	+	+	+	+	+	-
F. Primary porosity/permeability	-	-	-	-	-	-	+	-
G. Presence of intrusive breccia (breccia pipe or explosion breccia)	-	+	+	+	+	-	-	+
H. Alteration	Phyllic, sericitic	Phyllic, sericitic	Limonite	Quartz veining	Pyrite/ limonite	Propylitic	Limonite	Pyrite/ limonite
I. Disseminated pyrite	+	+	+	-	+	+	+	+
J. Vein filling	+	+	+	+	+	?	+	?
3. Geochemistry								
A. Anomalous elements in stream sediments	Mo, Pb, Zn, Ag, Au, Co, Mn, Ni	Mo, Cu, Pb, Ag, As, Co, Au, Sb	Mo, Zn, Au, Co	Mo, Cu, Pb, Zn, Ag, Au	Cu, Zn, Au, Ag, Co, Mn	Au, Cu, Pb, Mo	Mo, Cu, Pb, Co, Mn, Ag, Au, Zn	Pb, Zn, Ag, Au, Mn, Mo
B. Anomalous acid-soluble elements in stream sediments	Mo, Cu, Pb, Zn, Co, Mn, As, Ti	Mo, Cu, Pb, Zn, Co, Mn, As	Mo, Cu, Zn Co, Mn	Cr, Cu, Pb, Zn, Co, P, Sr, Ni, Mn, Ba	P, Mo, Cu, Zn, Co, Ba, Sr, Ni, Mn, Pb, As	Cu, Zn, Nb, Co, As, Ni, W, Ba, Mo, Mn	Cu, Pb, Zn, Ag, Co, Ni, Mn	Mo, Cu, Pb, Zn, Mn
C. Anomalous elements in panned concentrates	Mo, Cu, Pb, Ag, As, Co, Hg, W, Sn, Bi, B, Ba	Cu, Pb, Hg, Sn, Nb, Ba, B	Cu, Mo, Pb, Hg, Co, W, Bi, Ba, B	Cu, Pb, Hg, Ag, As, Co, W, Ba, B, Sn, Bi	Cu, Pb, Hg, Ag, As, Co, Ba, B, W, Sn	Cu, Pb, Hg, Ag, As, W, Nb, B	Mo, Cu, Pb, Hg, Ag, Co, W, Sn, Bi, Ba, B	Cu, Pb, Hg, Ag, Co, Mo, Bi, Sn
D. Mineralogy of heavy-mineral concentrates	Sch, Tour, Py, Ti-m	Sch, Py, Ti-m	Cpy, Py, Bar, Sch, Ti-m, Tour	Py, Gal, Sch, Ti-m	Py, Sch, Bar, Ti-m	Py, Ti-m	Py, Sch	Py, Ti-m
E. Anomalous halo elements in rocks	Mn, B, Ba, Bi, Cd, Zn, Sb	B, Mn, As, Sb, Bi, Ba	Mn, Sb	Ba, As, Sb, Mn, Cd	Mn, B, Ni, As, Sb	None	Ba, Ni(?)	None
F. Anomalous commodity elements in rocks	Ag, Pb, As, Mo	Ag, Au, Pb, Zn, Cu, Mo, W	As, Ag, Au, Cu, Pb, W, Zn	Pb, Zn, Ag, Cu, Mo	Ag, Pb, Cu, Mo, Zn	Ag, As	Ag, Cu, Mo, Pb, Sn, Zn	None

4. Geophysics								
A. Magnetic indication	L	?	RLG	H	H	L	H	H
B. Gravity indication	L	?	?	L	?	L	?	?
5. Mining activity								
A. Known deposits	Ideal ([1]#38), Ag Deerfly ([1]#46, [2]G-15), Ag Crown Pt. mine ([1]#43, [2]G-6), Au, Ag, Cu, Mo	None	None	Pioneer ([1]#7, [2]G-32), Pb, Ag, Zn, Cu, Au Silver Queen ([1]#5), Pb, Ag, Zn, Cu, Au, Cd	None	None	None	None
B. Mineral occurrences or zones with possible undiscovered resources	Victor ([1]#44, [2]G-29), Ag, Pb, Zn	Peacock ([1]#57), Au, Ag, Cu, As Esmeralda ([1]#56, [2]G-5), Au, Ag, Cu, As	Goericke ([1]#32, G-11), Cu, Ag Carmen ([1]#35), tactite-Cu, Pb, Zn, Ag Copper King ([1]#36), Cu, Co, Ag	Cascade ([2]G-30), Pb, Ag Epoch ([2]G-31), Pb, Ag	None	None	Goff ([1]#92, [2]G-33), Cu, Ag, Au	Cougar ([1]#21), Au, Zn, Cu
C. Number of prospects, workings, and the like (not including 5A)	8	20	7	4	0	0	9	6
6. Resource assessment	H	H	H	H	M	L	L	L

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[1] Stotelmeyer and others (in press).

[2] Grant (1982).

by crustal extension or strike-slip faulting. The igneous rocks of the volcanic-porphyry deposits have generally intruded slightly older volcanic rocks whereas the plutonic-porphyry deposits are found in complex batholithic terranes. Commonly, porphyry deposits are associated with breccia pipes and (or) dike swarms. Evidence of hydrothermal alteration is widespread. The porphyry deposits may be associated with a local gravity high.

The volcanic-porphyry deposit is generally characterized by argillic, phyllic, and propylitic alteration halos; the potassic alteration is rarely exposed. Alteration of mafic minerals to magnetite may produce a magnetic high associated with the deposit. Base- and precious-metal hydrothermal-vein deposits are common peripheral associations. Stockwork may have developed in the volcanic edifice or autobrecciation may indicate a shallow igneous cupola. Good circulation in permeable rocks is needed to form a deposit. Geochemical anomalies commonly observed in stream sediments may include manganese, copper, molybdenum, lead, zinc, silver, and gold. Heavy-mineral concentrates may contain tourmaline, gold, barite, molybdenite, galena, chalcopyrite, pyrite, bornite, scheelite, and sphalerite. Geochemical anomalies from this medium may contain barium, tin, tungsten, bismuth, and mercury, in addition to those elements anomalous in stream sediments. (See Grant, 1969; Lowell and Guilbert, 1970; Brown, ed., 1976; Pilcher and McDougall, 1976; Colley and Greenbaum, 1980; Beane and Titley, 1981; Titley and Beane, 1981; Chaffee, 1982a, b; Cox, 1982; Moss, 1982; Cox, 1983).

The plutonic-porphyry deposits are characterized by propylitic and phyllic alteration peripheral to a weakly developed potassic alteration zone surrounding the central, copper-rich ore zone. Veins of quartz, sericite, and pyrite form an intensely developed stockwork; deposits formed in rock fractured solely by regional tectonic stresses are generally low grade. Geochemical halos of base and precious metals are common, and evidence of a contact-hornfels zone may be difficult to distinguish in a complex batholithic intrusion. Geochemical anomalies found in stream sediments may include manganese, copper, molybdenum, cobalt, lead, zinc, silver, gold, and boron. Heavy-mineral concentrates commonly contain chalcopyrite, pyrite, tourmaline, galena, sphalerite, scheelite, and gold. Geochemical anomalies from concentrates may include tungsten, tin, arsenic, and barium in addition to those elements anomalous in the stream sediments. Hydrothermal alteration may cause replacement of magnetite by pyrite, resulting in the association of a magnetic low with the deposit (see Grant, 1969; Brown, 1976; Brown, ed., 1976; Pilcher and McDougall, 1976; Chaffee, 1982a, b; Cox, 1982; Moss, 1982).

One of the more important questions in evaluating the plutonic-porphyry deposits is the depth of erosion. Durning and Davis (1978) examined the geological and geochemical expressions of the exposed root zones of porphyry deposits and concluded that important characteristics of root zones are general absence of porphyritic texture in the intrusion, absence of breccia pipes, lack of closely spaced fractures, absence of vugs in veinlets, and sparsity of dikes. Chalcopyrite, pyrite, and molybdenite are present, but the chalcopyrite content decreases with depth. Secondary magnetite commonly replaces mafic minerals and sulfides. Poorly developed lead, zinc, silver, and gold geochemical halos are evident. There is extensive metasomatic alteration adjacent to veinlets, and pod-like, pegmatitic masses of quartz and potassium feldspar accompany magnetite and sulfides, analogous to the barren quartz core found in the Glacier Peak deposit (Grant, 1969). Zoning patterns of alteration are not well defined.

The principal mineral resources of the study area are in porphyry-type deposits. The resources and reserves defined by subsurface drilling at the Glacier Peak deposit (see tables 1 and 5; fig. 5, area C-1) constitute the most important known deposit. The area around the Glacier Peak prospect has 1.9 billion tons of demonstrated resources containing 0.334 percent copper and 0.02 percent molybdenum; tungsten, gold, and some silver are probable coproducts. The area contains 17 patented claims. The deposit is a late intrusive phase of the Cloudy Pass pluton that has disseminations and veinlets of sulfide minerals. Many of the features described by Grant (1969) as important elements in the plutonic-porphyry deposit were intersected by Bear Creek Mining Co. drilling at the site of the main ore body. The precious-metal deposit at the Deerfly prospect (B-1, fig.4) and the geochemical anomalies in area C-2 constitute the precious-metal halo surrounding this porphyry deposit. The potassic, sericitic, and chloritic (propylitic) zones, as mapped by Bear Creek Mining Co., close within the boundaries of area C-1. The axis of the deposit trends east-west and is marked by a linear magnetic low within the Cloudy Pass magnetic anomaly (Flanigan and others, 1983). The Fortress Mountain, Copper Point, and Esmeralda properties also have possible undiscovered resources (see table 2). Area C-1 (table 5) has a high potential for the occurrence of base-metal resources of copper, molybdenum, tungsten, and gold, and possible lead, zinc, and silver byproducts in porphyry deposits.

Area C-2, immediately west of C-1, has base- and precious-metal geochemical anomalies, but erosion has cut deeply into the interior of the Cloudy Pass pluton, and no indications of mineralization were observed in the rocks. This area is analogous to the barren metal halos surrounding the root zones of porphyries as discussed above (Durning and Davis, 1978, p. 88) and has a low potential for the occurrence of base- and precious-metal resources in porphyry deposits.

Area C-3 marks the axis of intrusion of the Cloudy Pass pluton along the Entiat fault. At the south end of area C-3, in area 06031D, the Royal Development mine, a breccia pipe, has inferred resources of 8.5 million tons containing 0.4 percent copper and 0.9 oz silver/ton. Similar breccia pipes are present at the north end of area C-3 at the Esmeralda and Peacock prospects (C-1). Area C-3 has a high potential for the occurrence of base-metal resources in breccia pipes or disseminated porphyry deposits.

Area C-4 is largely unexplored, but contains three deposits discussed earlier as having possible undiscovered resources (see tables 2 and 5). Only the Goericke prospect has altered and mineralized rock typically associated with porphyry-copper deposits. Plugs and dikes of porphyritic quartz diorite and granodiorite intrude the schist and gneiss (Grant, 1982, p. 28). The regional linear gradient of the magnetic data suggests that the contact with the Cloudy Pass

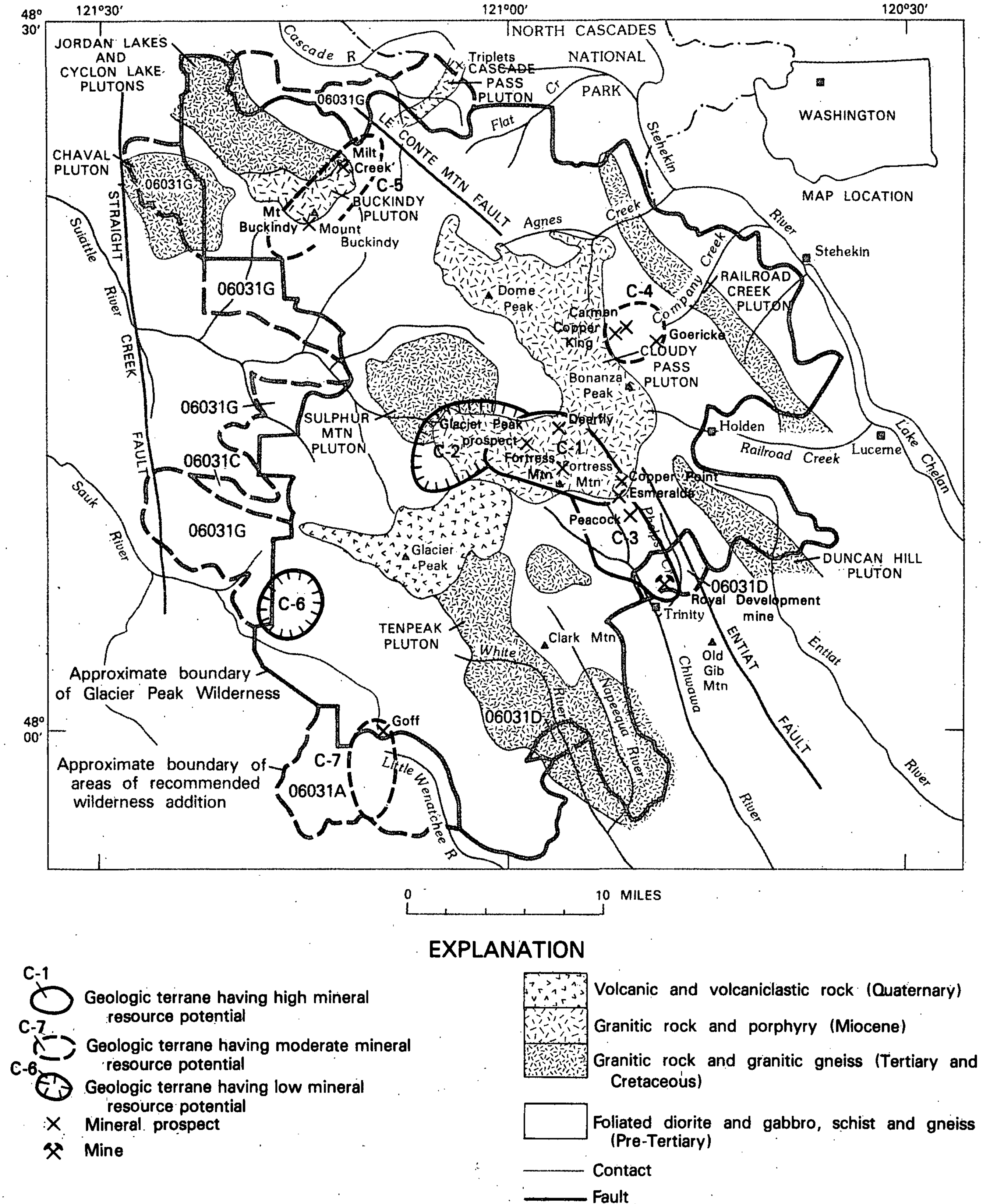

Figure 5.--Map showing locations and mineral resource assessment of areas discussed under the porphyry model (see table 5).

Table 5.--Summary of data for the porphyry copper-molybdenum-deposit model

[Field observations: +, feature observed; -, feature not present; ?, field observations not made or inconclusive. Geophysical anomalies: H, high; L, low; RLG, regional linear gradient; ?, no indication. Potential for occurrence of mineral resources: L, low; M, moderate; H, high. Minerals: Moly, molybdenum; Py, pyrite; Sch, scheelite; Bar, barite; Cpy, chalcopyrite; Ti-m, titanium minerals; Tour, tourmaline; Gal, galena. NA, not available]

	Plutonic porphyry type									Volcanic- porphyry type	
	Area C-1			Area C-2	Area C-3	Area C-4	Area C-5			Area C-6	Area C-7
Recognition criteria	Glacier Peak deposit	Fortress Mtn.	Esmeralda-Copper Pt.		Royal Development mine		Mount Buckindy	Milt Creek	Triplets	West Red Mtn.	Goff Prospect
1. Regional geologic setting											
A. Calc-alkaline igneous belt	+	+	+	+	+	+	+	+	+	+	+
B. Regional structural features	+	-	+	+	+	+	+	+	+	+	-
2. Geologic environment											
A. Quartz-diorite/granodiorite or intermediate volcanic rocks	+	+	+	+	+	+	+	+	+	+	+
B. Level of erosion	intermediate	intermediate	shallow	deep	shallow	shallow	intermediate	shallow	shallow	shallow	shallow
C. Age of igneous event	20 m.y.(?)	Miocene(?)	20 m.y.(?)	20 m.y.(?)	20 m.y.(?)	20 m.y.(?)	14 m.y.(?)	Miocene(?)	18 m.y.(?)	Miocene(?)	Miocene(?)
D. Porphyritic texture	+	-	+	?	+	+	+	+	+	-	-
E. Dike swarms	+	+	+	-	-	+	+	+	+	?	?
F. Igneous cupola	+	+	+	?	+	+	+	-	+	+	+
G. Tensional fracturing	+	+	+	-	+	+	-	+	+	+	+
H. Primary permeability/porosity	-	-	-	-	-	-	-	-	-	-	?
I. Presence of an intrusive breccia (breccia pipe or explosion breccia)	-	-	+	-	+	+	+	+	+	-	-
J. Presence of stockwork	+	+	+	-	-	?	+	-	?	?	?
K. Alteration	Propylitic/ sericitic/ potassic	Propylitic/ sericitic/ potassic	Phyllic/ sericitic	none observed	Propylitic/ phyllic	Chlorite/ sericite	Phyllic/ sericitic	Propylitic/ phyllic/ sericitic	Limonite	Propylitic	Limonite
L. Pyrite envelope	+	+	+	-	-	?	-	+	-	+	+
M. Barren quartz core	+	?	?	?	?	?	?	?	?	?	?
3. Geochemistry											
A. Anomalous metals in stream sediments	Mo, Cu, Pb, Ag, Zn, Au	None	Mo, Cu, Ag, Au	Pb, Zn, Ag, Au	Cu, Co, Ag	Mo, Zn, Co, Au	Mo, Cu, Pb, Ag, Au, Co	Mo, Cu, Zn, Pb, Ag, Au	Mo, Cu, Pb, Zn, Ag, Au	Au, Cu, Pb, Mo	Mo, Cu, Pb, Zn, Ag, Au, Co, Mn
B. Anomalous acid-soluble metals in stream sediments	As, Mo, Cu, Zn, Ti, Pb, Mn, Ba, Nb	Mo, Cu, As	Mo, Cu, Pb, Co, As, Nb, Ti	Mo, Cu, Pb, Zn, Ag, As, Sr, Ti	Cu, Zn, As, Ti, Sr	Mo, Cu, Zn, Co, Mn	Mo, Cu, Zn, Co, Pb, As, Ti, Nb	As, Mo, Cu, Pb, Zn, Ba, Co, Ni, Mn, Sr, Cr	P, Mo, Cu, Pb, Zn, As, Ba, Ni, Co, Mn, Sr	Nb, Cu, Zn, Co, Ni, W, Mo, Mn, As, Ba	Cu, Pb, Zn, Ag, Co, Ni, Mn
C. Anomalous metals in panned concentrates	Mo, Cu, Pb, Ag, As, Co, W, Sn, Bi, Hg, B, Ba	Cu, As, Co, Mn, W, Sn, Bi, Ba, B	Cu, Pb, Ag, As, Co, Mo, B, W	Mo, Cu, Pb, Hg, As, Ag, Co, W, Sn, B, Nb, Ba, Bi	Co, Mn, Cu, Pb, Ag, W, Bi	Cu, Co, Mn, B	Mo, Cu, Pb, Hg, As, Co, Ag, W, Sn, Bi, Nb	Mo, Cu, Pb, Ag, As, Co, W, Sn, Bi, Nb, Ba, B	Mo, Cu, Pb, Ag, As, Hg, Co, W, Sn, Bi, Ba	Cu, Pb, Hg, Ag, As, W, Nb, B	Mo, Cu, Pb, Hg, Ag, Co, W, Sn, Bi, Ba, B
D. Mineralogy of heavy-mineral concentrates	Moly, Py, Sch, Bar, Cpy, Ti-m, Tour	Sch, Tour, Ti-m	Sch, Py, Ti-m	Py, Ti-m	NA	Cpy, Py, Bar, Sch, Ti-m	Moly, Py, Sch, Ti-m, Tour	Py, Sch, Ti-m	Moly, Cpy, Gal, Py, Sch, Ti-m	Py, Ti-m	Py, Sch

E. Anomalous halo elements in rocks	As, Ag, B, Ba, Pb, Sb, Mn, Zn	As, Mn, Ag, B	B, Mn, As, Sb, Bi, Ba	None	As, Ba, Bi, Cd, Pb, Sb, Zn	As, B, Ba, Sb, Zn	B, Mn, As, Bi, Zn	Mn, As, Ba, Pb	Mn, As, B, Ba, Bi, Sb	Ag, As	Ba, Pb, Zn, Ag
F. Anomalous commodity elements in rocks	Cu, Co, Bi, Au, Ag, Mo, Sn, W, Pb	Cu, Mo, Pb	Cu, Mo, Pb, Ag, Au, Zn, W	None	Ag, Au, Cu, Mo, Sn, W	Au, Cu, Pb, Zn	Cu, Mo, Pb, Sn	Ag, Cu, Mo, Zn	Ag, Co, Cu, Mo, Pb, Zn	None	Cu, Mo, Sn
4. Geophysics											
A. Magnetic indication	local L on H	H	H	local L on H	?	RLG	H	H	H	L	H
B. Gravity indication	L	L	L	L	?	H	?	L	L	L	?
5. Mining activity summary											
A. Known deposits and commodities	Glacier Peak ([1]#48, [2]G-1), Cu, Mo, Ag, Au, W------- Deerfly ([1]#46, [2]G-15), Ag, Au, Cu------------------ Crown Pt. mine ([1]#43, [2]G-6), Au, Ag, Cu, Pb, Zn, Mo			None	Royal Development mine ([1]#64), Cu, Ag, W	None	Pioneer ([1]#7, [2]G-32), Pb, Ag, Zn, Cu, Au-- Silver Queen ([1]#5), Pb, Ag, Zn, Cu, Au, Co		None	None	None
B. Mineral occurrences or zones containing possible widespread resources	Fortress Mtn. ([1]#51, [2]G-3), Cu--------------------- Victor ([1]#44,[2]G-29), Ag, Pb, Zn-------------------- Copper Pt. ([1]#53,[2]G-24), Au, Ag, Cu, Pb, Zn-------- Esmeralda ([1]#56,[2]G-5), Cu, Au, Ag, As--------------			None	Peacock ([1]#57), Ag, Au, Cu, As	Goericke([1]#32, [2]G-11), Cu, Ag Carmen ([1]#35), Pb, Zn, Ag, Cu, Cd Copper King ([1]#36), Cu, Co, Ag	Mount Buckindy ([1]#2, [2]G-2), Cu, Mo, Ag----- Cascade ([2]G-30), Pb, Ag------------------ Epoch ([2]G-31), Pb, Ag--------------------		None	None	Goff ([1]#92, [2]G-33), Cu, Ag, Au
C. Number of prospects, workings, and the like (not including 5A)	25	25	25	0	6	6	5	5	5	0	9
D. Drilling activity	At least 75 drill holes with more than 50,000 ft of core (Grant, 1982)	Three drill holes, 263 ft of core (Grant, 1982)	None	None	Many drill holes, more than 10,000 ft of core	None	Five drill holes, 2,280 ft of core (Grant, 1982)	None	None	None	None
E. Resource assessment	H	H	H	L	H	M	M	M	M	L	M

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[1] Stotelmeyer and others (in press).
[2] Grant (1982).

pluton is nearby (Flanigan and others, 1983). This area has a moderate potential for the occurrence of base-metal resources in disseminated porphyry deposits.

Area C-5, in the vicinity of Mount Buckindy, has a moderate potential for the occurrence of copper and molybdenum resources in porphyry deposits. Widespread geochemical anomalies and locally altered rock are present; two breccia pipes are exposed on Mount Buckindy. The best intercepts from five drill holes in an area near the summit of Mount Buckindy averaged 0.34 percent copper and 0.13 percent molybdenum. Widespread geochemical anomalies along strike to the northeast in Milt Creek are described by Grant (1982, p. 24-25) as fracture-controlled mineralization. Propylitic alteration is widespread, numerous porphyritic dikes containing sulfides occur throughout the area outlined, as well as to the south of it, and vugs of quartz crystals occur in hydrothermal veins in the schist. This area has a moderate potential for the occurrence of base-metal resources in disseminated porphyry deposits. The Triplets, a large breccia pipe structure located along strike just northeast of the study area, may also contain resources of base metals in a deposit analogous to that found at the Royal Development mine (see area C-3, fig. 5).

Area C-6 contains a granitic plug that intruded gneiss. A pyritic halo weathers to form a pronounced red color anomaly. Geochemical anomalies surrounding the plug indicate possible base-metal mineralization (see discussion of area B-6). A weak propylitic-alteration halo is present. Little exploration work has been done. We have classified the area as one of low potential for the occurrence of base-metal resources in a porphyry deposit, although further work may prove that the area warrants a higher resource classification.

Area C-7, the Goff prospect, surrounds a Tertiary plug of dacitic rock having a strong gravity high. Geochemical anomalies are widespread, but they are particularily strong along an east-west fracture zone near the wilderness boundary. This area has a moderate potential for the occurrence of base-metal resources in a disseminated porphyry deposit.

Many less well defined geochemical anomalies of base metals occur throughout the study area, but existing data are not sufficient to warrant discussion of the mineral potential of these areas (see Church and others, 1982; Grant, 1982; Stotelmeyer and others, in press).

D. Volcanogenic massive-sulfide deposits

Volcanogenic massive sulfides, predominately pyrite or pyrrhotite deposits with associated chalcopyrite, sphalerite, and galena, form in belts of submarine volcanic rocks. Gold and silver are commonly substantial coproducts (Singer and others, 1982). Features of volcanogenic massive-sulfide deposits are described by Franklin and others (1981). In the geologic environment where island arcs occur along continental margins, basalt and lesser amounts of andesite and dacite are interbedded with clastic deposits, tuffs, ferruginous cherts, and carbonate sediments. The sulfide deposits are stratabound, and mineralogical banding results from primary deposition of sulfides on the sea floor. Hydrothermal alteration is largely confined to the small feeder zone, resembling a stockwork, below the deposit (see the description by Kinkel and others, 1956, of the stockwork exposed at the Mammoth mine in the West Shasta district of northern California). Chlorite and silica and sericitic alteration zones may surround massive-sulfide deposits, and then a larger, more easily detected, geochemical anomaly may result (Sangster, 1972; Doe, 1982). Geochemical anomalies, however, are generally subtle; zinc, barium, and either copper or silver may be found in the stream sediments. Heavy-mineral concentrates may contain barite, pyrite, pyrrhotite (found in the magnetic separate), and, rarely, chalcopyrite and sphalerite. Geochemical anomalies detected in heavy-mineral concentrates may include cobalt, mercury, and gold in addition to those elements anomalous in stream sediments. Generally, geophysical methods are useful in prospecting for massive-sulfide deposits because they are characterized by both a magnetic and a gravity contrast; electromagnetic methods have also been successful.

The pre-Tertiary metamorphic rocks in the east-central part of the study area are part of a belt of late Paleozoic oceanic sediments and island-arc volcanic rocks that are now preserved in thrust sheets north of the study area (Misch, 1966, pl. 1). This series of rocks was mapped by Cater and Crowder (1967) and Cater and Wright (1967) as the younger gneissic rocks of the Holden area. Detailed mapping (DuBois, 1954) of the area near the Holden mine, done in conjunction with company geologists, indicated abundant amphibolite and calc-silicate lenses. A brief summary of the geology of the Holden mine was presented by Youngberg and Wilson (1952). Amphibolites and metavolcanic rocks are more abundant in the geologic section near the Holden mine than to the north. Mattinson (1972, p. 3773) gave a late Paleozoic age of 265±15 m.y. for the metavolcanic rocks.

Ores of the Holden mine are stratabound and zoned; gold values parallel copper (chalcopyrite) content, and silver values peripheral to the chalcopyrite zones show a crude correlation with zones of iron-rich sphalerite and minor galena (Frank Ebbutt, unpub. data, 1938; Youngberg and Wilson, 1952). Magnetite is common; molybdenite and radioactive minerals are rare. DuBois (1954) described a conformable lens of anhydrite and numerous lime-silicate lenses that parallel the layering of the amphibolite in the Holden mine. We interpret these lenses as volcanic-exhalite layers intercalated with carbonate sediments deposited on the flanks of a submarine volcanic center. These characteristics (see table 6) suggest that the deposit at the Holden mine is a massive sulfide of late Paleozoic age that was subsequently metamorphosed to amphibolite grade (Nold, 1981). Sulfide stringers indicative of volcanogenic massive-sulfide deposits also occur to the north at the Mary Green deposit (see table 2), where workings expose a small pyrrhotite-rich zone. Grant (1982) states that these rocks can also be traced northwest into the Company Creek drainage basin (see the discussion of the Goericke prospect in the previous section). Studies of the Holden mine and tailings indicate resources in both (see table 1). Exploratory drilling during the late 1950's failed to prove additional ore reserves at depth. Recovery of precious metals and zinc from the mill tailings is not cost effective at this time.

The Holden belt (area D-1, fig. 6) is defined largely on the basis of geochemical anomalies and

Table 6.--Summary of data for the volcanogenic massive-sulfide-deposit model

[Field observations: +, feature observed; ?, field observations not made or inconclusive. Geophysical anomalies: H, high; ?, no indication. Potential for occurrence of mineral resources: M, moderate. Minerals: Py, pyrite; Sch, scheelite; Ti-m, titanium minerals; Tour, tourmaline]

Recognition criteria	Holden belt (area D-1)
1. Regional geologic setting	
A. Island-arc setting	+
2. Geologic environment	
A. Basalt>felsite	+
B. Calcarous sediments	+
C. Ultramafic associations	+
D. Exhalative layers	+
E. Iron-rich chert layers	?
F. Conformable, tabular sulfide strata	?
G. Gossans	+
H. Alteration	? (sericite schist)
3. Geochemistry	
A. Anomalous metals in stream sediments	Zn, Mo, Au, Ni
B. Anomalous acid-soluble metals in stream sediments	Nb, Mo, Cu, Zn, Co, Sr, Ni, Mn, Ti
C. Anomalous metals in panned concentrates	Cu, Mo, Mn, Ba, Sn, W, B
D. Mineralogy of heavy-mineral concentrates	Py, Sch, Ti-m, Tour
E. Anomalous halo elements in rocks	Ba, Zn, Co, Cu
F. Anomalous commodity elements in rocks	Ag, Au, Zn, Pb, Mo, Cu
4. Geophysics	
A. Magnetic indication	H
B. Gravity indication	?
5. Mining activity summary	
A. Known deposits	Holden mine ([1]#23, [2]G-Holden mine zone), Cu, Au, Ag, Zn
B. Mineral occurrences or zones containing possible undiscovered resources	Mary Green ([1]#29, [2]G-16), Cu, Ag
C. Number of prospects, workings, and the like (excluding 5A)	6
D. Resource assessment	M

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[1] Stotelmeyer and others (in press).

[2] Grant (1982).

geologic evidence. The outcrop pattern of the Holden schist and gneiss belt is roughly coincident with a regional zinc anomaly and sporadic gold, nickel, and molybdenum anomalies. However, these geochemical signatures may reflect, in part, Tertiary events along the Glacier Peak transverse structure of Grant (1969). Dikes of Tertiary(?) granodiorite porphyry occur in the Holden mine and on the ridge near the Mary Green prospect. A strong geochemical anomaly occurs immediately south of the Holden mine in the headwaters of the Entiat River (Church and others, 1983a, b) and is associated with Tertiary igneous activity. More detailed studies are needed to locate concealed deposits in the belt and to map the felsic and mafic volcanic units in the younger gneisses of the Holden belt. Area D-1 has a moderate potential for the occurrence of copper, zinc, gold, and silver resources in volcanogenic massive-sulfide deposits, on the basis of our current geologic data.

E. Gold-bearing quartz-vein deposits in metamorphic host rocks

Gold-bearing quartz veins are a common occurrence in greenstone belts of folded and metamorphosed continental margins such as the Abitibi belt of Canada (Boyle, 1979; Fryer and others, 1979) and the mother lode of the Sierra Nevada (Knopf, 1929). Quartz veins are associated with fractures or faults in the rocks. These deposits have anomalous gold, silver, arsenic, antimony, copper, and, locally, chromium signatures in stream sediments (Bohlke, 1982). Heavy-mineral concentrates may include gold, cinnabar, arsenopyrite, galena, sphalerite, stibnite, and sulfosalts. The chromium-rich micas occur in association with carbonates, commonly with dolomite, in this environment. Mercury, lead, zinc, and copper may occur as geochemical anomalies in the heavy-mineral concentrates as well as those elements anomalous in the stream sediments.

The general geologic indications for the presence of gold-bearing quartz veins have not been observed in the study area. However, area E-1 (see fig. 6), defined by the Chaval pluton in the northwestern part of the study area, contains the correct geochemical signature for this type of deposit. Alternatively, it also may be classified as a hydrothermal-vein deposit that should be considered under section B. The pluton is dioritic to tonalitic in composition (A. B. Ford, unpub. data, 1982; Ford and others, 1983) and has been metamorphosed. Gold anomalies occur in stream basins containing large quartz clasts, but the source veins were not found in outcrop. We have classified the outcrop area of the Chaval pluton as an area of low potential for the occurrence of gold resources in hydrothermal quartz veins.

Other areas of metamorphosed mafic volcanic rocks in the study area, namely the Holden area discussed in the previous section, are not probable areas where this model would be applicable because of the high metamorphic rank. Free gold, however, was separated from quartz-rich pods in the migmatitic Skagit Gneiss east of the Holden mine (see fig. 6), indicating that metamorphic concentration of gold may make this terrane a good source for gold in placer deposits.

F. Igneous cumulate deposits

Layered ultramafic complexes are sources of nickel, cobalt, chromium, and platinum-group metals. Nickel sulfides may be deposited near the base of layered mafic bodies (Foose, 1982). Stratiform chromite lenses also are common, for example, in the Stillwater Complex in Montana, where chromite pods occur in the lower third of layered igneous complexes (Jackson, 1968; Lipin and Page, 1982). Platinum-group metals may occur with chromite (McLaren and DeVilliers, 1982), or platinum-rich zones may also accumulate in the upper part of layered igneous complexes (Todd and others, 1982).

Two mafic igneous rock units occur in the study area. The Riddle Peaks pluton (F-1, fig. 6), north of Holden, is a hornblende gabbro. No ultramafic sequences are exposed. Reconnaissance geochemical studies of samples from this body (R. R. Carlson and E. F. Cooley, unpub. data, 1982) indicated no detectable platinum-group metals. Detailed mapping and geochemical studies necessary to delineate possible platinum-group metal deposits in the pluton are outside the scope of this study. The body is associated with a pronounced magnetic anomaly (Flanigan and others, 1983). Assessment of possible mineralized rock at depth by drilling was beyond the scope of this study. The area F-1 is assigned a low potential for the occurrence of nickel, cobalt, chromium, and platinum-group metal resources in magmatic segregations of mafic layered complexes.

Small bodies of ultramafic rocks are found in the central schist belt; geochemical studies indicate anomalous chromium, cobalt, and nickel in drainage basins confined either to the schist belt or in drainage basins along the Straight Creek fault west of the study area. Most of the ultramafic bodies are only tens to hundreds of feet long; the largest bodies of ultramafic rock found in the area are on Spire Point (Grant, 1966), north of Glacier Peak (F-2, fig. 6), and along the White River, south of the study area (Ford and others, in press). Because of the small size of the ultramafic bodies and their discontinuous nature, the area of the central schist belt has a low potential for the occurrence of nickel, cobalt, chromium, and platinum-group metal resources in pod-shaped deposits.

G. Placer deposits

Placer deposits are possible where gold, platinum, or heavy minerals such as garnet can be concentrated by hydraulic means in streams. No evidence for gold placers was found in the study area during either the geochemical reconnaissance or during specific studies for gold placers (Stotelmeyer and others, in press). The Railroad Creek drainage basin, below the Holden mine (see fig. 6), empties into Lake Chelan before any suitable change of stream gradient is encountered, and the area near the Glacier Peak deposit drains directly into the Suiattle River where a placer deposit would be difficult to find and work. Therefore, the study area has a low potential for the occurrence of placer-gold resources.

Potential for nonmetallic resources

Nonmetallic commodities examined during this study include pumice and cinder, marble, garnet, and,

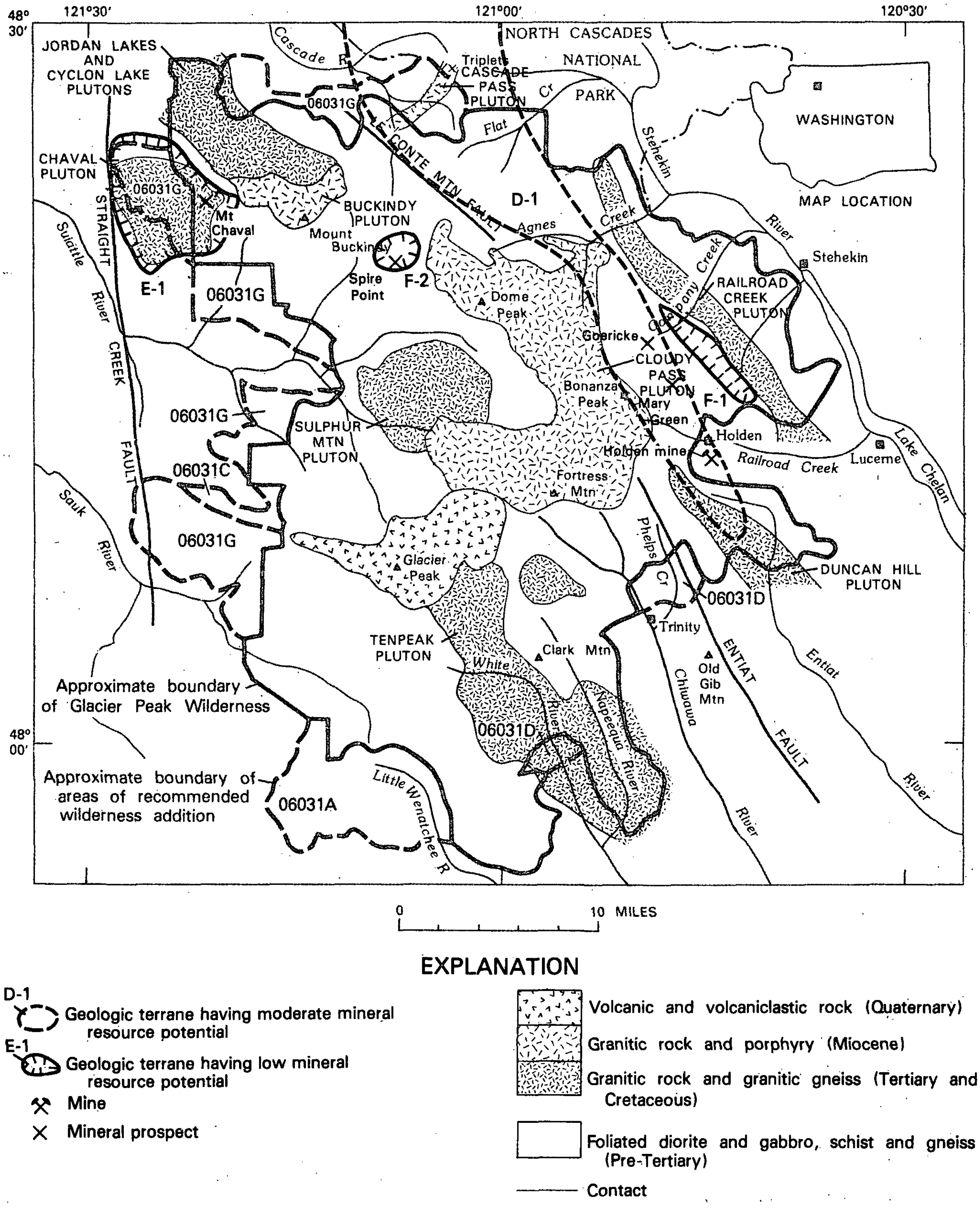

Figure 6.—Map showing locations and mineral resource assessment of areas discussed under the volcanogenic massive-sulfide model (D, see table 6), the metamorphic-hosted, gold-bearing quartz-vein model (E), the igneous-cumulate model (F), and the placer model (G).

Table 7.--Locations of nonmetallic resources in and near the Glacier Peak Wilderness and adjacent areas, Chelan, Skagit, and Snohomish Counties, Washington

[Leaders (--) indicate that deposit is too widespread to be shown on map by number]

No. on map[1]	Property	Type	Tonnage (except where noted)	Resource[2] classification	Commodity	Area
94	White Chuck cinder cone	Pyroclastic	24 million (cubic yards)	Indicated; subeconomic	Volcanic cinders	Wilderness
--	Pumice deposits	Pyroclastic accumulations	Not available	Numerous deposits, some of which have had production, in upper Chiwawa and Entiat River basins	Pumice	Wilderness
67	Chiwawa River pumice (study area only)	Pyroclastic	5.2 million (cu yd)	Inferred; marginal reserve	Pumice	06031D
99	Circle Peak - Meadow Mountain	Marbleized limestone	100 million	Inferred; subeconomic	Limestone	adjoins area 06031G
98	Lime Mountain	Marble	400 million	Inferred; subeconomic	Limestone	adjoins area 06031G
96	Garnet Creek - Ruby Creek (two adjacent deposits)	Garnet placer	2,000	Inferred; marginal reserve	Garnet	adjoins area 06031G

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[1] Numbers correspond to locations on accompanying map, MF-1652-A.
[2] U.S. Bureau of Mines and U.S. Geological Survey (1980).

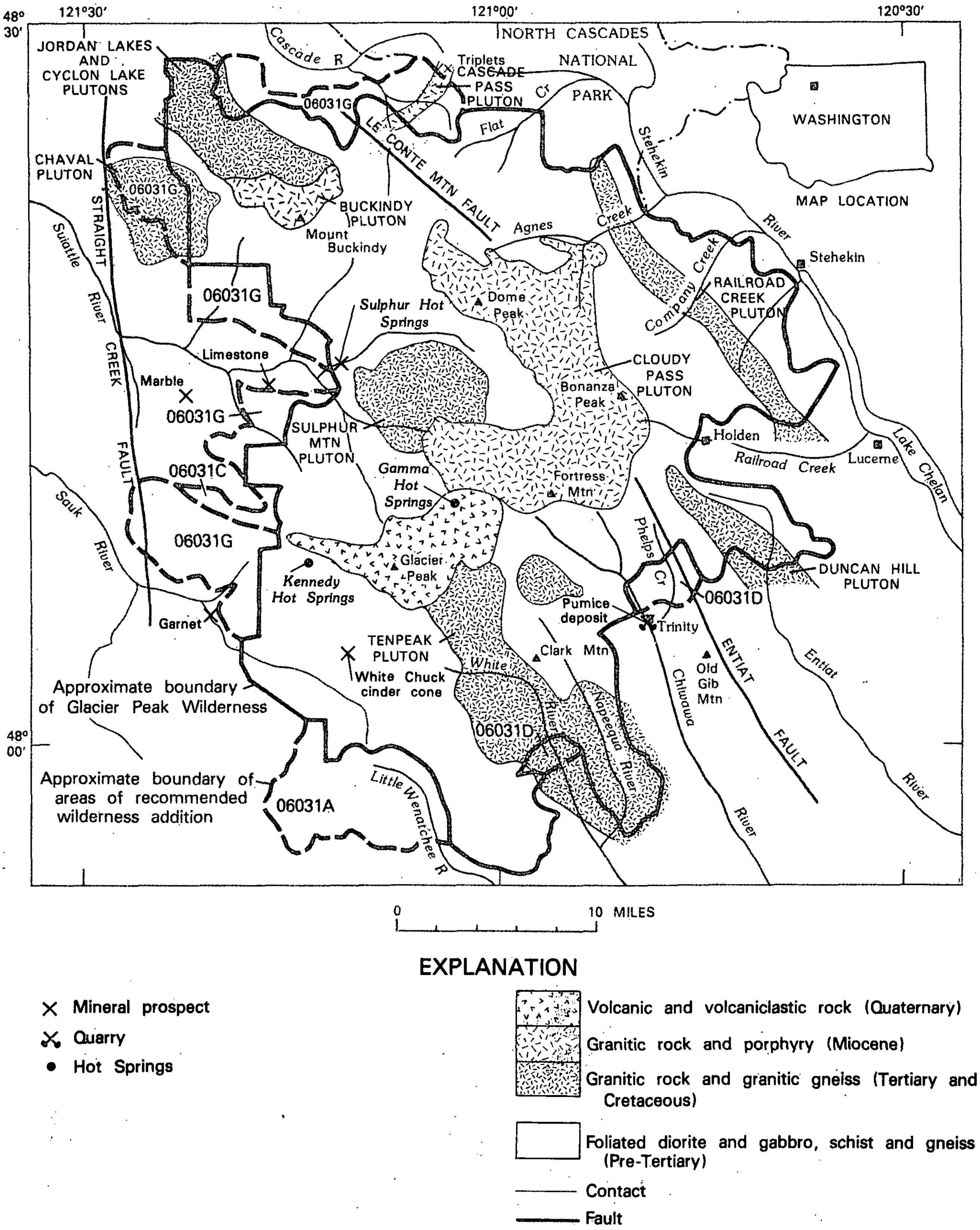

Figure 7.--Map showing locations of nonmetallic commodities (see table 7).

as possible byproducts of the mill tailings at the Holden mine, pyrite and silica. Other nonmetallic resources not examined might include sand and gravel, talc, soapstone, kyanite, and feldspar. Identified resources for several of these commodities are given in table 7. Nonmetallic resources in the study area include volcanic cinders at the White Chuck cinder cone and pumice from widespread deposits in the upper Chiwawa and Entiat River basins in the Glacier Peak Wilderness. A large pumice deposit also occurs just south of, but extends into, area 06031D; there has been minor production from this deposit (see fig. 7; table 7, no. 67). No production of pumice can be expected from other remote deposits within the study area. Nonmetallic commodities occurring adjacent to area 06031G consist of subeconomic deposits of marble and placer deposits of garnet.

Sand and gravel are abundant, but adequate resources exist outside the study area. Although some talc is produced just northwest of the study area, talc production from the small metaperidotite bodies in the central schist belt is not considered practical because of the sparse distribution and low grade of the occurrences. A feldspar deposit is under development near the southern border of the study area; an evaluation of feldspar potential was not made since no large pegmatitic bodies were found in the igneous or metamorphic terranes. A low potential for nonmetallic resources is indicated for the study area.

Potential for energy resources

The potential for the occurrence of geothermal resources must be considered in an area containing a dormant volcano such as Glacier Peak. Obvious indications of present and recent thermal activity in the wilderness are the three hot springs (fig. 7) and 17th- or 18th-century ash deposits from the Glacier Peak volcano (Beget, 1982). No fumarolic activity at Glacier Peak has been recorded since about 1900. Thermal-spring temperatures are: Kennedy Hot Springs, 35°C (95°F); Sulphur Hot Springs, 37°C (99°F); and Gamma Hot Springs, 65°C (149°F) (Mariner and others, 1982). Chemical geothermometers (Mariner and others, 1982) suggest the following aquifer temperatures: Sulphur, 110-117°C (230-243°F); Kennedy, 145-189°C (293-372°F); and Gamma, 178-216°C (352-421°F). Such temperatures, particularly that of Gamma Hot Springs, suggest a potential for the occurrence of a geothermal resource; however, these are indirect estimates, and none of the springs are associated with siliceous sinter, a general indicator of high subsurface temperature (Mariner and others, 1982). Gamma Hot Springs has been evaluated as a small hot-water convection system having reservoir temperatures greater than 150°C (302°F) (Brook and others, 1979, p. 56-57). Discharges from at least six small orifices in and near Gamma Creek, near a small but presently inactive travertine deposit, are in an extensive area of hydrothermally altered volcanic rock in which the alteration does not appear related to present hot-spring activity (T. E. C. Keith, written commun., 1982). The host rock is older than the lavas of the Glacier Peak volcano and may have erupted from the underlying tonalitic Cloudy Pass pluton in Miocene time (Tabor and Crowder, 1969). The size of the altered area suggests a relation either to the Cloudy Pass pluton or to more extensive, earlier hot-spring activity. A low potential for geothermal resources exists near the north and west sides of Glacier Peak in the Gamma Hot Springs area. Detailed hydrologic and heat-flow investigations and drilling would be required for a comprehensive evaluation of the geothermal potential. The rugged terrain, lack of roads, and remote location would hinder possible development of such resources.

No source beds for oil and gas occur within the study area, which is almost entirely underlain by igneous and metamorphic rocks and by volcaniclastic sediments (Ford and others, in press). Furthermore, no structural traps have been identified in rocks that have not been heated above the breakdown temperature of hydrocarbons. We consider the study area to have a low potential for the occurrence of oil and gas resources.

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