GEOLOGIC MAP OF THE ROBINSON MTN. 1:100,000 QUADRANGLE, WASHINGTON

Compiled by

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GEOLOGIC MAP OF THE ROBINSON MTN. 1:100,000 QUADRANGLE, WASHINGTON

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INTRODUCTION

The Robinson Mtn. quadrangle is one of sixteen 1:100,000-scale quadrangles that cover the northeast quadrant of Washington State (Fig. 1). Geologic maps of these quadrangles have been compiled by the Washington Division of Geology and Earth Resources (DGER) geologists and will be the principal data sources for a new 1:250,000-scale geologic map of northeastern Washington. Fourteen of these quadrangle maps will be released as DGER open-file reports (listed below). The Chelan and Wenatchee quadrangle maps will not be open-filed because they have been published recently by the U.S. Geological Survey (Tabor and others, 1982, 1987).

Literature review and preliminary compilation of the Robinson Mtn. quadrangle geologic map began in 1985. During 1986 and 1987, reconnaissance and detailed geologic mapping was performed by DGER geologists in areas where previous geologic mapping was either inadequate or lacking. New geologic mapping was also acquired during that time through a DGER graduate student mapping program. Figure 2 is an index map showing sources of geologic map data used in the compilation of the Robinson Mtn. quadrangle map.

Age assignments of geologic units on the Robinson Mtn. 1:100,000-scale quadrangle were made following the flow chart in Figure 3. The geologic time scale devised for the "Correlation of Stratigraphic Units of North America (COSUNA)" project of the American Association of Petroleum Geologists (Salvador, 1985) was used, with slight modifications of the Eocene-Oligocene and Pliocene-Pleistocene boundaries (Armentrout and others, 1983; Prothero and Armentrout, 1985; Montanari and others, 1985; Aguirre and Pasini, 1985). All known radiometric ages from the Robinson Mtn. quadrangle are listed in Table 1.

Modal analyses and the International Union of Geological Sciences rock classification (Streckeisen, 1973) were used to assign plutonic rock names. Whole-rock geochemical data and the total alkali-silica (TAS) diagram (Zanettin, 1984) were the basis for assigning volcanic rock names. New whole-rock geochemical data from samples collected by DGER geologists are given in Tables 2 and 3.

<u>DGER Northeast Quadrant Open-File Reports</u>

Bunning, B. B., compiler, 1990, Geologic map of the east half of the Twisp 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-9, 52 p., 1 pl.

Gulick, C. W., compiler, 1990, Geologic map of the Moses Lake 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-1, 9 p., 1 pl.

Gulick, C. W., compiler, 1990, Geologic map of the Ritzville 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-2, 7 p., 1 pl.

Gulick, C. W.; Korosec, M. A., compilers, 1990, Geologic map of the Banks Lake 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-6, 20 p., 1 pl.

Gulick, C. W.; Korosec, M. A., compilers, 1990, Geologic map of the Omak 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-12, 52 p., 1 pl.

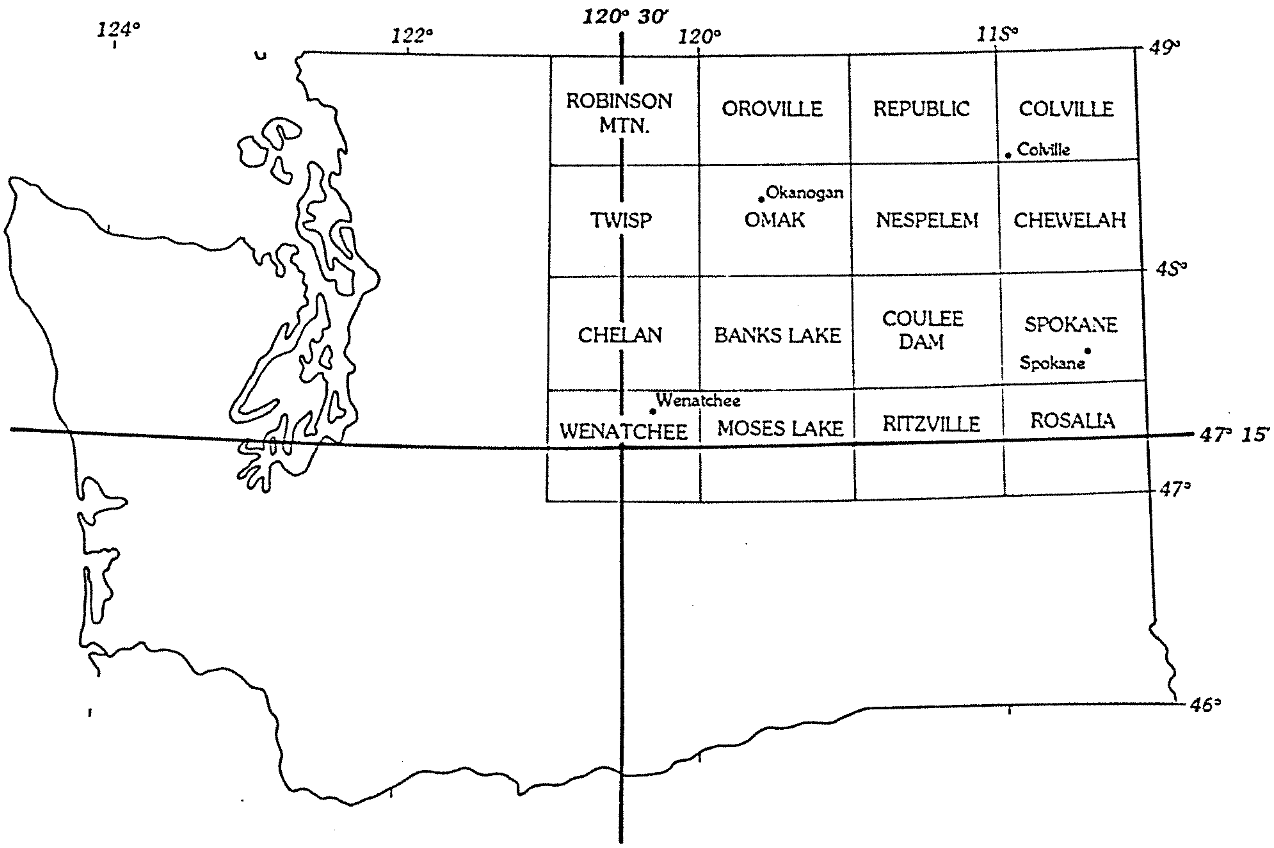

Figure 1. I:l00,000-scale quadrangles in the northeast quadrant of Washington.

EXPLANATION
(see Figure 2, facing page)

1. Barksdale, 1975, scale 1:125,000
2. Boggs, 1984, scale 1:36,200
3. Hawkins, 1963, scale 1:31,680
4. Hawkins, 1968, scale 1:63,360
5. Lawrence, 1967, scale 1:15,840
6. Lawrence, 1968, scale 1:100,000
7. McGroder, M. F.; Garver, J. I.; Mallory, V. S., University of Washington, written commun., 1989, scale 1:100,000
8. Riedell, 1979, scale 1:24,000
9. Staatz and others, 1971, scale 1:200,000
10. Tennyson, 1974, scale 1:48,000
11. Todd, V. R., U. S. Geological Survey, written commun., 1988, scale 1:62,500
12. Todd, V. R., U. S Geological Survey, written commun., 1989, scale 1:24,000
13. White, 1986, scale 1:24,000

Shaded area, DGER unpublished mapping

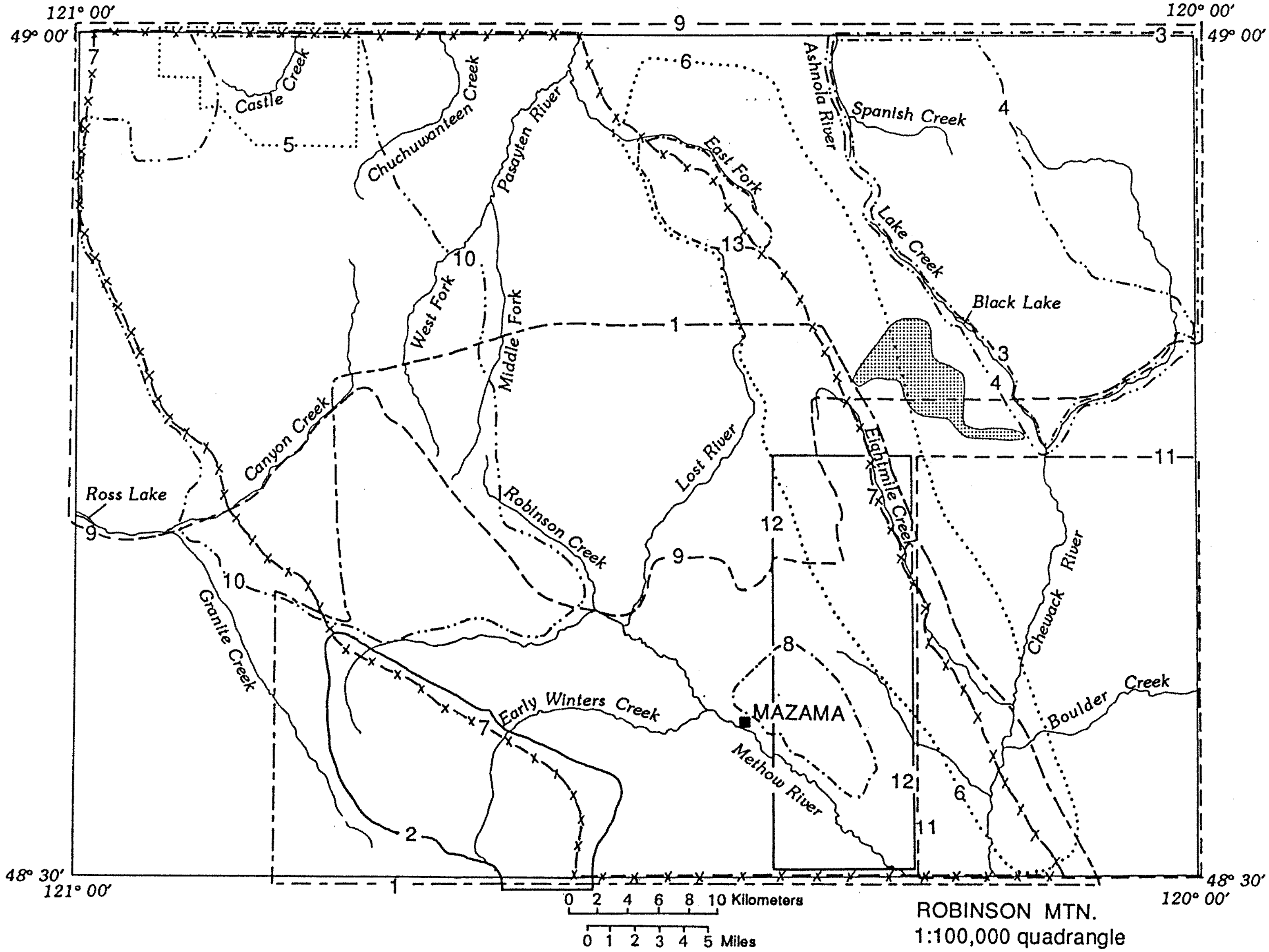

Figure 2. Sources of geologic map data, Robinson Mtn. 1:100,000-scale quadrangle

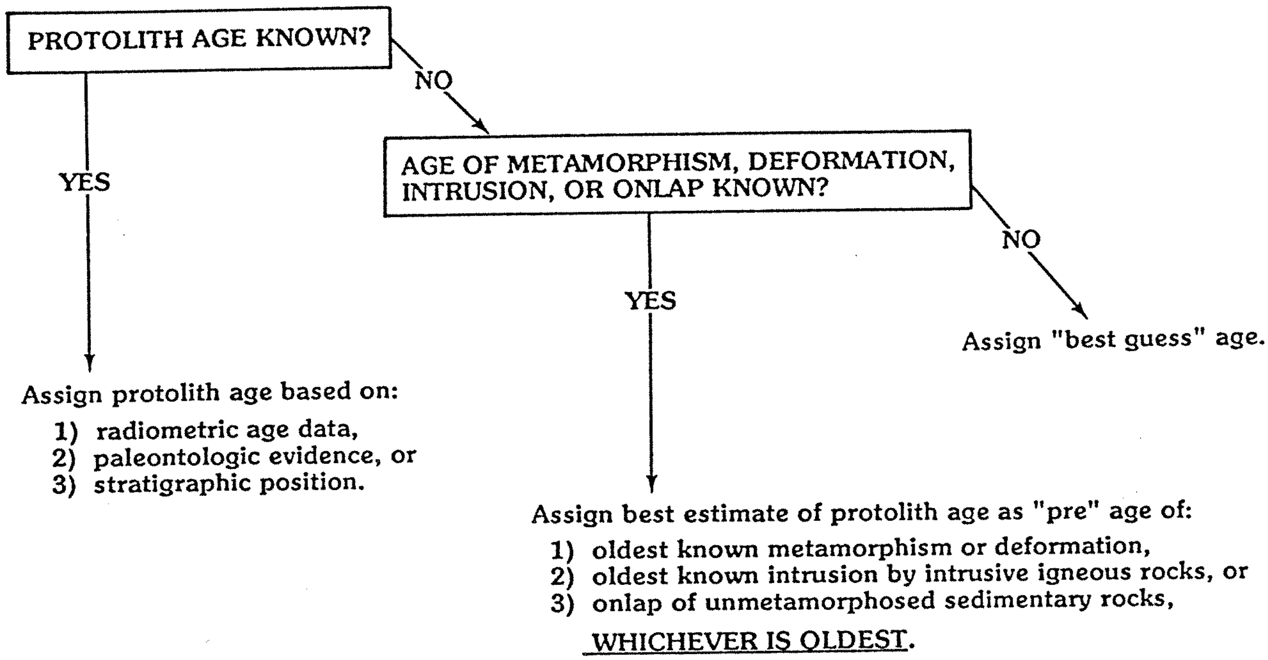

Figure 3. Flow chart for age assignment of geologic units. Protolith age or estimated protolith age may be assigned by correlation with other geologic units. The unit description includes information on how the age of the unit was determined.

Joseph, N. L., compiler, 1990, Geologic map of the Colville 1:100,000-scale quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-13, 78 p., 1 pl.

Joseph, N. L., compiler, 1990, Geologic map of the Nespelem 1:100,000-scale quadrangle Washington: Washington Division of Geology and Earth Resources Open File Report 90-16, 47 p., 1 pl.

Joseph, N. L., compiler, 1990, Geologic map of the Spokane 1:100,000-scale quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-17, 29 p., 1 pl.

Stoffel, K. L., compiler, 1990, Geologic map of the Oroville 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report.

Stoffel, K. L., compiler, 1990, Geologic map of the Republic 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-10, 62 p., 1 pl.

Stoffel, K. L.; McGroder, M. F., compilers, 1990, Geologic map of the Robinson Mtn. 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-5, 39 p., 1 pl.

Waggoner, S. Z., compiler, 1990, Geologic map of the Chewelah 1:100,000-scale quadrangle, Washington-Idaho: Washington Division of Geology and Earth Resources Open File Report 90-14, 63 p., 1 pl.

Waggoner, S. Z., compiler, 1990, Geologic map of the Coulee Dam 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-15, 40 p., 1 pl.

Waggoner, S. Z., compiler, 1990, Geologic map of the Rosalia 1:100,000-scale quadrangle, Washington: Washington Division of Geology and Earth Resources Open File Report 90-7, 20 p., 1 pl.

Table 1. Radiometric age data, Robinson Mtn. 1:100,000 quadrangle

Map No.	Sample No.	Unit	Map Symbol	Location	Method	Material	Age (Ma)	Reference
1	M-85	Button Creek stock	Jit_b	SW/4 NW/4 sec. 13, T37N, R20E	K-Ar	hornblende biotite	153.2 ± 1.6 145.9 ± 1.0	Todd (1988)[9]
2	M-22	Button Creek stock	Jit_b	NE/4 NE/4 sec. 31, T37N, R21E	K-Ar	hornblende	150.2 ± 1.7	Todd (1988)[9]
3	HS0810864	Button Creek stock	Jit_b	SE/4 NW/4 sec. 13, T37N, R20E	K-Ar	biotite hornblende	150 ± 5 134 ± 7	This report, DGER data (1988)[1]
4	T-155	Trondhjemite of Doe Mountain	$KJit_d$	48°35.8'N, 120°4.5'W	K-Ar	biotite muscovite	108 ± 3 94.6 ± 2.8	Berry and others (1976)[2]
5	DM-1	Trondhjemite of Eightmile Creek	$KJog_e$	SE/4 NE/4 sec. 35, T36N, R21E	K-Ar	biotite hornblende	105.7 ± 0.8 104.7 ± 0.9	Todd (1988)[9]
6	DM-58	Amphibolite inclusion in trondhjemite of Eightmile Creek	----	NW/4 NW/4 sec. 20, T35N, R22E	K-Ar	hornblende biotite biotite	105.2 ± 1.3 100.9 ± 0.8 100.8 ± 0.9	Todd (1988)[9]
7	DM-85	Gneissic trondhjemite of Tiffany Mountain	$KJmi_t$	SE/4 NE/4 sec. 24, T36N, R22E	K-Ar	biotite biotite	104.5 ± 0.8 95.3 ± 0.7	Todd (1988)[9]
8	DM-9	Trondhjemite of Lamb Butte	$KJog_l$	NW/4 NW/4 sec. 25, T36N, R21E	K-Ar	biotite biotite	102.5 ± 0.7 99.8 ± 0.7	Todd (1988)[9]
9	901-g	Granodiorite gneiss complex of the Quartz Mountain area	$pJbg_q$	SW/4 sec. 17, T40N, R21E	K-Ar	amphibole	101.6 ±4.0	Hawkins (1968)[3]
10	DM-45	Mylonitic rocks along the Pasayten fault	$KJog_p$	NW/4 NW/4 sec. 2, T35N, R21E	K-Ar	biotite biotite	101.5 ± 0.7 101.3 ± 0.7	Todd (1988)[9]
11	H-1	Cathedral batholith, granodiorite	$Kigd_c$	48°52.3'N, 102°01.0'W	K-Ar	biotite	97.7 ± 2.9	Berry and others (1976)[2]
12	DM-48	Trondhjemite of Doe Mountain	$KJit_d$	SW/4SE/4 sec. 21, T36N, R22E	K-Ar	muscovite biotite	96.4 ± 0.7 96.3 ± 0.7	Todd(1988)[9]
13	DM-83	Trondhjemite of Doe Mountain (dike)	$KJit_d$	NE/4 SE/4 sec. 29, T37N, R22E	K-Ar	muscovite biotite	96.1 ± 0.7 95.7 ± 0.7	Todd (1988)[9]
14	DM-84	Gneissic trondhjemite of Tiffany Mountain	$KJmi_t$	SE/4 NE/4 sec. 24, T36N, R22E	K-Ar	biotite biotite	96.1 ± 0.7 94.1 ± 0.7	Todd (1988)[9]
15	Not given	Cathedral batholith, granodiorite	$Kigd_c$	SE/4 sec. 36, T39N, R22E	K-Ar	biotite	94.0 ± 2.8	Hawkins (1968)[3]
16	M-16	Cretaceous andesite and dacite plugs, sills, and dikes		NW/4 SW/4 sec. 9, T36N, R20E	K-Ar	hornblende	93.2 ± 4.9	Todd (1988)[9]

Table 1. Radiometric age data, Robinson Mtn. 1:100,000 quadrangle (continued)

Map No.	Sample No.	Unit	Map Symbol	Location	Method	Material	Age (Ma)	Reference
17	DM-25	Newby Group	$KJvs_n$	NE/4 NW/4 sec. 23, T35N, R21E	K-Ar	whole rock	90.4 ± 2.1	Todd (1988)[9]
18	18/650-685	Fawn Peak stock, diorite	Kii_f	not given; from drillhole	K-Ar	biotite (magmatic)	87.9 ± 3.5	Riedell (1979)[4]
19	PM-28A	Cretaceous andesite and dacite plugs, sills, and dikes		SE/4 NW/4 sec. 35, T37N, R20E	K-Ar	hornblende hornblende	87.8 ± 2.8 84.0 ± 2.7	Todd (1988)[9]
20	RWT 241-65	Pasayten stock	$Kigd_p$	SW/4 sec. 21, T38N, R18E	K-Ar	biotite hornblende biotite	87.7 ± 2.6 86.0 ± 2.6 85.3 ± 2.6	Tabor and others (1968)[5]
21	29/118-180	Fawn Peak stock, intrusion breccia	Kii_f	NW/4 sec. 20, T36N, R20E; from drillhole	K-Ar	biotite (magmatic)	87.6 ± 3.3	Riedell (1979)[4]
22	M-10	Fawn Peak stock	Kii_f	SW/4 NE/4 sec. 29, T36N, R20E	K-Ar	biotite	86.9 ± 0.7	Todd (1988)[9]
23	PM-17	Cretaceous andesite and dacite plugs, sills, and dikes	Kian	NE/4 SE/4 sec. 13, T35N, R20E	K-Ar	hornblende hornblende	86.9 ± 2.2 81.7 ± 1.8	Todd (1988)[9]
24	RWT 662-66	Rock Creek stock	$Kigd_r$	NE/4 sec. 4, T39N, R17E	K-Ar	hornblende	86.1 ± 2.6	Tabor and others (1968)[5]
25	DM-54	Cretaceous andesite and dacite plugs, sills, and dikes		SW/4 SW/4 sec. 20, T38N, R22E	K-Ar	hornblende	85.8 ± 2.2	Todd (1988)[9]
26	23/86-110	Fawn Peak stock, diorite	Kii_f	NW/4 sec. 20, T36N, R20E; from drillhole	K-Ar	biotite (secondary)	85.1 ± 3.5	Riedell (1979)[4]
27	23/510-560	Fawn Peak stock, quartz diorite	Kii_f	NW/4 sec. 20, T36N, R20E; from drillhole	K-Ar	biotite (secondary)	69.7 ± 2.9	Riedell (1979)[4]
28	JV-316	Lost Peak stock, granodiorite	$Eigd_l$	not given	K-Ar FT	biotite zircon	51.5 ± 1.0 47.9 ± 4.1	White (1986)[6]
29	6W73	Castle Peak stock, central phase	$Eigd_c$	NE/4 sec. 3, T40N, R16E	K-Ar	biotite hornblende	49.8 ± 1.5 49.5 ± 1.5	Tabor and others (1968)[5]
30	M-49A	Andesite(?) dike near Goat Wall		SW/4 NE/4 sec. 14, T36N, R19E	K-Ar	whole rock whole rock	49.2 ± 0.7 47.8 ± 0.6	Todd (1988)[9]
31	PM 15	Golden Horn batholith	Eig_g	48°35′N, 120°46′W	K-Ar	biotite	48 ± 2	Misch (1963, 1964)[7]

Table 1. Radiometric age data, Robinson Mtn. 1:100,000 quadrangle (continued)

Map No.	Sample No.	Unit	Map Symbol	Location	Method	Material	Age (Ma)	Reference
32	RWT 242-65	Monument Peak stock	Eig_m	NE/4 sec. 12, T38N, R18E	K-Ar	biotite	47.9 ± 1.4	Tabor and others (1968)[5]
33	JE-26-67	Golden Horn batholith	Eig_g	48°31.4'N, 120°38.4'W	K-Ar	arfvedsonite	47.8 ± 4.7	Engels and others (1976)[8]
34	PM-25B	Andesite(?) dike near Goat Wall		NW/4 NE/4 sec. 1, T36N, R19E	K-Ar	whole rock	47.3 ± 1.0	Todd (1988)[9]
35	PW84-MM75	Basalt of Middle Mountain	Eib_m	48°55'04"N, 120°28'27"W	K-Ar	whole rock	47.0 ± 0.6	White (1986)[6]
36	RM-84-K	Golden Horn batholith	Eig_g	NE/4 NW/4 sec. 5, T35N, R18E	K-Ar	biotite	46.9 ± 0.4	Todd (1988)[9]
37	JE-29A-67	Golden Horn batholith	Eig_g	48°34.3'N, 120°37.7'W	K-Ar FT	hornblende allanite	46.7 ± 1.9 42 ± 1.0	Engels and others (1976)[8] Naeser and others (1970)[10]
38	PM 36	Golden Horn batholith	Eig_g	48°32'N, 120°39'W	K-Ar	biotite	46.6 ± 1.4	Tabor and others (1968)[5]
39	JV 315	Volcanic rocks of Island Mountain	Ev_i	48°53'56"N, 120°28'26"W	FT	zircon	46.0 ± 4.1	White (1986)[6]
40	JV 209 R 209	Dacite plugs and dikes near Island Mountain	Eida	48°54'09"N, 120°25'28"W	FT K-Ar	zircon biotite	45.5 ± 3.9 44.4 ± 1.0	White (1986)[6]
41	PM 5	Golden Horn batholith	Eig_g	48°33'N, 120°43'W	K-Ar	biotite	38.8	Misch (1963, 1964)[7]
42	not given	Golden Horn batholith	Eig_g	not given	Rb/Sr isochron		38.8 ± 1.8	Davis and Stull (1984)

[1] DGER data (1988): $\lambda_\varepsilon + \lambda_\varepsilon' = 0.581 \times 10^{-10}$/yr; $\lambda_\beta = 4.962 \times 10^{-10}$/yr; $^{40}K/K$ total = 1.193×10^{-4} g/g
[2] Berry and others (1976): $\lambda_\varepsilon = 0.585 \times 10^{-10}$/yr; $\lambda_\beta = 4.72 \times 10^{-10}$/yr; $^{40}K/K$ total = 1.19×10^{-4} g/g
[3] Hawkins (1968): $\lambda_\varepsilon = 0.585 \times 10^{-10}$/yr; $\lambda_\beta = 4.72 \times 10^{-10}$/yr
[4] Riedell (1979): constants not reported
[5] Tabor and others (1968): constants not reported
[6] White (1986): constants not reported
[7] Misch (1963, 1964): constants not reported
[8] Engels and others (1976): constants not reported
[9] V. R. Todd (USGS, written commun., 1988): constants not reported
[10] Naeser and others (1970): constants not reported

Table 2. Major-element geochemistry data, Robinson Mtn. 1:100,000 quadrangle. Analyses by XRF, Department of Geology, Washington State University. Reported values are in weight percent, normalized to 100% on a volatile-free basis; FeO* is total iron expressed as FeO. *Sampled unit not shown on geologic map

Sample number	Map unit	Subsection	Sec	Twp	Rge	SiO_2	Al_2O_3	TiO_2	FeO*	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5
HS0810864	Jit_b	SE/4 NW/4	13	37	20E	63.08	16.95	0.61	6.00	0.13	6.74	2.44	0.78	3.07	0.09
BP0716871	$KJvs_n$	NW/4 NE/4	25	35	21E	68.24	15.94	0.71	4.15	0.11	1.62	1.02	1.04	6.96	0.20
BP0714874	Kvs_b	SE/4 NW/4	16	36	21E	51.29	18.53	0.80	9.98	0.14	10.15	6.57	0.13	2.33	0.08
BP0716872	$KJvs_n$	NW/4 SE/4	24	35	21E	56.00	17.82	1.01	9.24	0.15	5.16	2.76	0.25	7.44	0.17
BP0716873	Kian*	NE/4 NW/4	03	35	21E	55.01	19.80	0.86	7.78	0.13	7.16	4.93	0.26	3.86	0.21

Table 3. Trace-element geochemistry data, Robinson Mtn. 1:100,000-scale quadrangle. Analyses by XRF, Department of Geology, Washington State University. Values in ppm.

Sample	Ni	Cr	Sc	V	Ba	Rb	Sr	Zr	Y	Nb	Ga	Cu	Zn
HS0810864	16	17	25	166	350	17	446	97	24	4.0	17	49	50
BP0716871	3	0	15	62	547	16	717	101	24	2.4	10	45	88
BP0714874	23	78	38	297	111	2	404	45	15	1.9	17	107	91
BP0716872	4	10	28	255	199	5	319	57	23	2.2	15	142	79
BP0716873	28	21	23	219	263	2	1169	97	13	2.1	21	124	89

Acknowledgments

Special thanks to V. R. Todd for sharing her preliminary geologic maps of the Doe Mountain and Mazama 15-minute quadrangles, and to F. J. Menzer, Jr., M. A. Korosec, B. B. Bunning, C. W. Gulick, and A. M. Frey for many enlightening arguments about the geology of the Okanogan complex and the Methow basin. Thanks also to H. W. Schasse, V. R. Todd, H. A. Hurlow, J. W. Hawkins, Jr., and C. J. Greig for thorough reviews of an earlier draft of this report, and to J. E. Schuster, N. A. Eberle, H. W. Schasse, W. M. Phillips, B. A. Larson, and J. H. Leighton for invaluable assistance in preparation of the manuscript.

GEOLOGIC SETTING

The Robinson Mtn. 1:100,000-scale quadrangle contains three distinct geologic provinces, referred to herein as the Cascade complex, the Methow basin, and the Okanogan complex (Fig. 4). Two regional faults, the Hozameen and Pasayten faults, mark the boundaries between the geologic provinces.

The Cascade complex consists of a heterogeneous assemblage of greenstone, phyllite, schist, gneiss, and intrusive igneous rocks of several geologic ages. No attempt was made to compile the geology of the Cascade complex for this report.

The Methow basin contains a thick sequence of Cretaceous and Jurassic sedimentary and volcanic rocks (Fig. 5), that is intruded by Late Cretaceous and Tertiary plutons (McGroder and Miller, 1989). A small pile of Tertiary volcanic and sedimentary rocks unconformably overlie the Cretaceous and Jurassic rocks along the eastern margin of the basin. The Okanogan complex is dominated by a huge, northwest-trending batholith of directionless leucocratic trondhjemite (KJi) that is flanked on the west by a narrow belt of gneissic leucocratic trondhjemite (KJog) and on the east by a belt of mixed metamorphic and igneous rocks (KJmi). Both the directionless and gneissic trondhjemite units are bounded on the north by a heterogeneous assemblage of banded gneiss (pJbg), amphibolite (pJam), and migmatite (KJmg). The banded gneiss and amphibolite are a regionally metamorphosed package of pre-Jurassic sedimentary and volcanic rocks. The migmatitic rocks and the mixed metamorphic and igneous rocks formed either by deep burial, ultra-metamorphism, and partial fusion (anatexis) of the sedimentary and volcanic rocks (Hawkins, 1963, 1968; Menzer, 1983), or by injection of magma into the sedimentary and volcanic rocks, producing migmatitic screens (V. R. Todd, USGS, written commun., 1988). Metamorphism and migmatization apparently occurred before intrusion of the directionless leucocratic trondhjemite, which was probably emplaced in the Late Jurassic or Early Cretaceous. The gneissic trondhjemite along the Pasayten fault apparently represents a group of igneous intrusions injected into an active ductile shear zone (an ancestral Pasayten fault?) during the Late Jurassic or Early Cretaceous.

DESCRIPTION OF MAP UNITS

Sedimentary and Volcanic Deposits and Rocks

Quaternary Sedimentary Deposits

Qs

Quaternary sediments, undivided (Holocene and Pleistocene)--Unconsolidated gravel, sand, silt, and clay of glacial, alluvial, and mass-wasting origins

Nonglacial Deposits

Qls

Mass-wasting deposits (Holocene)--Slopewash and talus deposits of unconsolidated silt, sand, and gravel; locally grades into glacial drift and alluvium

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Explanation for Figure 4 (facing page)

Contact	Anticline
Fault	Overturned anticline
Fault - ball on downthrown side	Syncline
Thrust fault	Overturned syncline
Strike - slip fault	

Q	Quaternary sediments
Tv	Tertiary volcanic and sedimentary rocks
KJsv	Cretaceous and Jurassic sedimentary and volcanic rocks
Ti	Tertiary intrusive rocks
TKi	Tertiary or Cretaceous intrusive igneous rocks
Ki	Cretaceous intrusive igneous rocks
KJi	Cretaceous or Jurassic intrusive igneous rocks
Ji	Jurassic intrusive igneous rocks
KJmi	Cretaceous or Jurassic mixed metamorphic and igneous rocks
KJmg	Cretaceous or Jurassic migmatite
KJog	Cretaceous or Jurassic orthogneiss
pJbg	Pre-Jurassic banded gneiss
pJam	Pre-Jurassic amphibolite

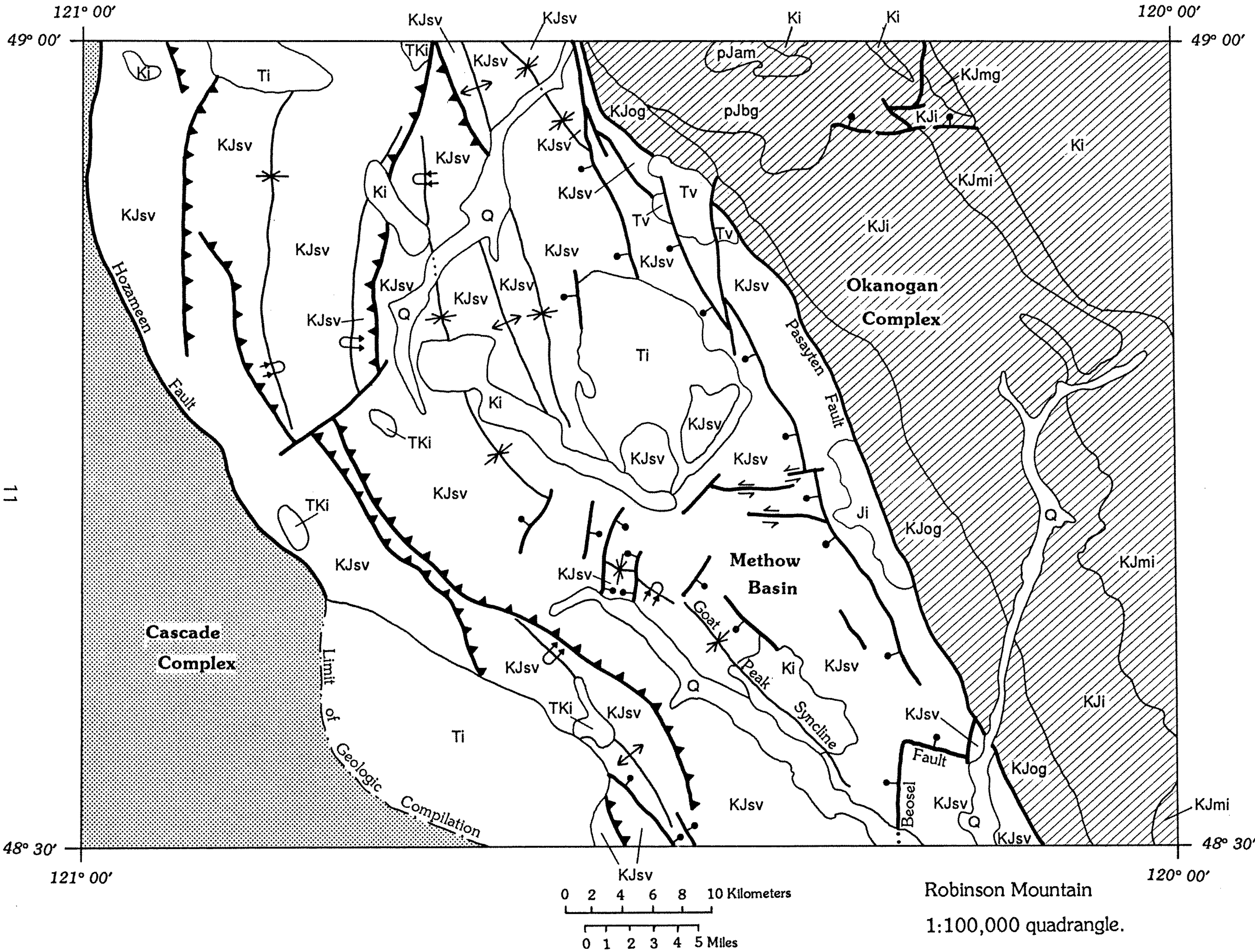

Figure 4. Generalized geologic map, Robinson Mtn. 1:100,000 quadrangle.

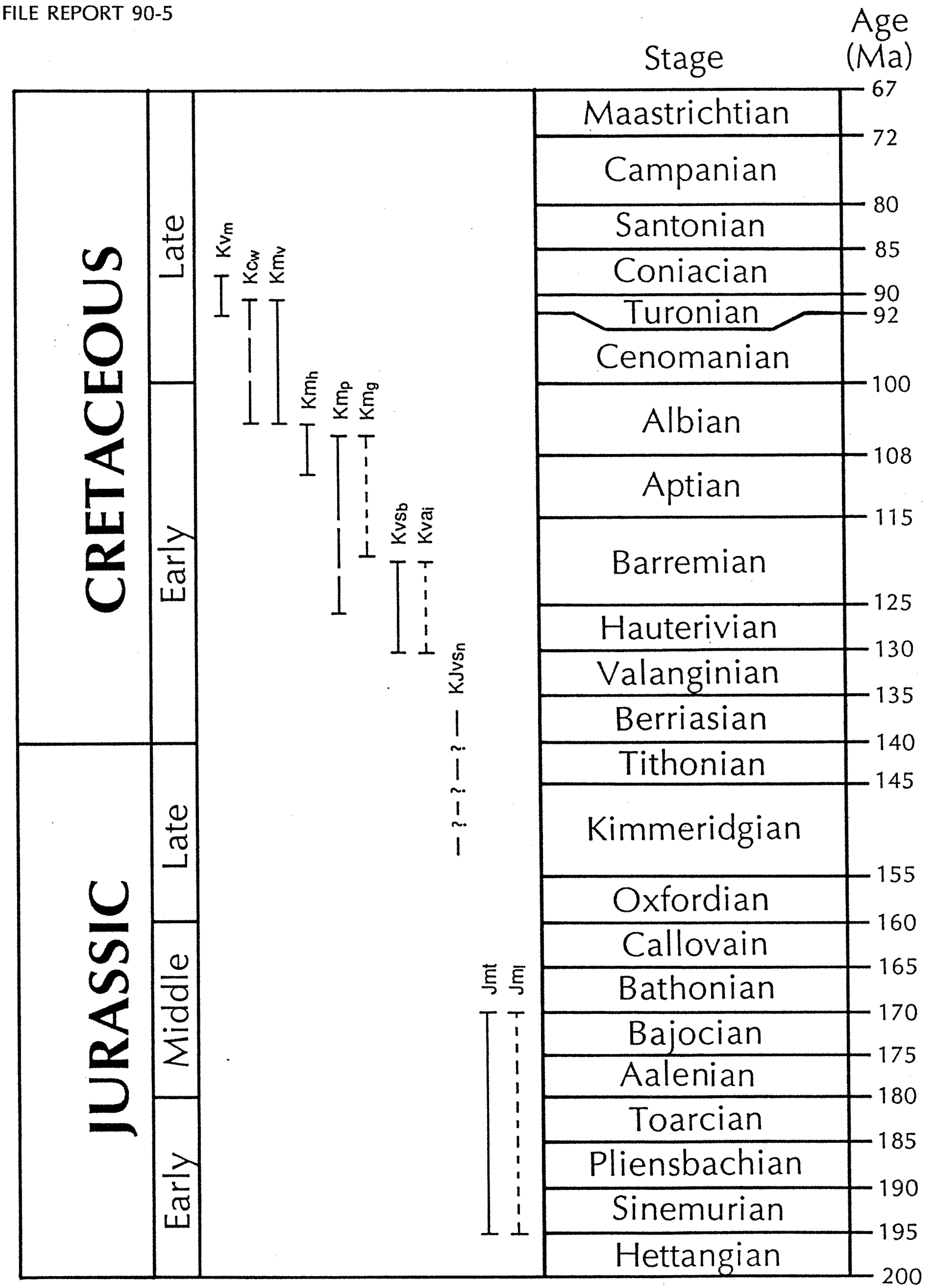

Figure 5. Duration diagram for Mesozoic sedimentary and volcanic rock units in the Methow basin

Qa

Alluvium (Holocene)--Stratified silt, sand, and gravel on modern alluvial plains and fans

Qoa

Older alluvium (Pleistocene)--Stratified silt, sand, and gravel in terraces above modern stream valleys

Glacial Deposits

Qgd

Glacial drift (Pleistocene)--Till and stratified drift that fills valleys and mantles uplands; locally includes colluvium

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Explanation for Figure 5 (facing page)

————	age known from reliable paleontologic or radiometric data
- — — —	age inferred from questionable paleontologic data or observed stratigraphic relationships
- - - - - - -	age inferred from correlation with other rock unit (s)
—?—?—	age essentially unknown

Kv_m	Midnight Peak Formation
Kc_w	Winthrop Sandstone
Km_v	Virginian Ridge Formation
Km_h	Harts Pass Formation
Km_p	Panther Creek Formation
Kw_g	Goat Creek Formation
Kvs_b	Buck Mountain Formation
Kva_i	andesite of Isabella Ridge
$KJvs_n$	Newby Group
Jm_t	Twisp Formation
Jm_l	Ladner Group

Tertiary Sedimentary and Volcanic Rocks

Eva_i, Ev_i, Ec_i

Volcanic rocks of Island Mountain (Eocene)--The volcanic rocks of Island Mountain are a heterogeneous assemblage of lava flows, tuff, volcanic breccia, and lithofeldspathic breccia and sandstone that cover approximately 15 km^2 at Island Mountain (T. 39 N., R. 19 E.) (Lawrence, 1968; Staatz and others, 1971; White, 1986). They are herein subdivided into three stratified rock units: Eva_i, andesite flows; Ev_i, volcanic rocks, undivided; and Ec_i, sedimentary rocks.

Eva_i

Andesite flows--Gray, aphyric to weakly porphyritic andesite flows and flow breccias that form the upper 200 m of the volcanic rocks of Island Mountain. The andesite is composed of less than 5 percent phenocrysts of plagioclase, hornblende, and clinopyroxene in an aphanitic groundmass. The rocks are commonly altered; secondary minerals include sericite, albite, calcite, magnetite, and chlorite. Thin crystal lithic tuff beds are locally intercalated with the flows and flow breccias.

Ev_i

Volcanic rocks, undivided--A heterogeneous unit of volcanic conglomerate and breccia, tuff, and minor lava flows that underlies the andesite flows at Island Mountain. The base of this 1,200-m-thick unit, well exposed on the south side of Island Mountain, is composed of porphyritic dacite boulder conglomerate with thin, discontinuous interbeds of water-laid sediments, tuff, and rhyodacite and dacite flows. On western Island Mountain, the basal conglomerate is unconformably overlain by massive, poorly sorted, dacite boulder conglomerate, which grades upward into dacite tuff breccia. On eastern Island Mountain, the basal conglomerate is overlain by a thick sequence of rhyolite breccia, lapilli tuff, tuff breccia, and rhyolite flows. The upper 300 m of this unit are composed of purple porphyritic dacite flows and minor gray, aphyric andesite flows.

Porphyritic dacite boulders in the conglomerate on western Island Mountain have yielded a fission-track zircon age of 46.0 ± 4.1 Ma (White, 1986). Because the conglomerate is intruded by the basalt of Middle Mountain, which has yielded a K-Ar whole rock age of 47 ± 0.6 Ma (White, 1986), the conglomerate is probably slightly older than 47 Ma.

Ec_i

Sedimentary rocks--Interbedded lithofeldspathic breccia and sandstone, crystal tuff, and rhyodacite and dacite flows or sills that form the basal unit of the volcanic rocks of Island Mountain (White, 1986); approximately 350 m thick. The breccia is massive, poorly consolidated, and crudely stratified in layers 1 to 10 m thick. It consists of subangular pebbles and cobbles in a poorly sorted matrix of sand and clay. Clasts are chiefly feldspathic sandstone, but argillite, dacite, and andesite clasts are also present. The crystal tuff and rhyodacite flows or sills that are interbedded with the breccia and sandstone are grayish white and porphyritic and contain small phenocrysts of quartz, feldspar, and biotite. The presence of both sedimentary and volcanic rock clasts in the breccia indicates that erosion and redeposition of Cretaceous sedimentary rocks accompanied Eocene volcanism near Island Mountain.

Mesozoic Sedimentary and Volcanic Rocks

Kv_m, Kc_m, Kvc_m

Midnight Peak Formation (Cretaceous)--A thick sequence of volcanic breccia, flows, volcaniclastic rocks, and nonmarine siltstone, sandstone, and conglomerate (Barksdale, 1948, 1975). In the eastern and central part of the Methow basin, the formation consists of a lower sedimentary unit, the Ventura Member, and an upper volcanic unit, the Volcanic Member (Barksdale, 1975). In the western part of the basin, the formation consists of unnamed volcaniclastic rocks (Tennyson, 1974; Tennyson and Cole, 1987). Since the relation between the volcaniclastic rocks and the Volcanic and Ventura Members is uncertain, the volcaniclastic rocks are herein assigned to the Midnight Peak Formation, undivided.

The Midnight Peak Formation is the youngest Mesozoic sedimentary unit in the Methow basin (Fig. 5). Although no fossils have been found in the unit, the age of the Midnight Peak Formation is reasonably well constrained by its stratigraphic relations with surrounding rock units. The Midnight Peak Formation unconformably overlies the middle Albian-Turonian(?) Winthrop Sandstone and Virginian Ridge Formation. On the east side of Goat Peak (sec. 7, T. 36 N., R. 20 E.), Midnight Peak Formation volcanic rocks grade into very fine grained igneous rocks of the Fawn Peak stock (88 Ma). The gradational nature of the contact and similar compositions of the volcanic and intrusive rocks suggest that the volcanic rocks are the extrusive equivalent of the stock. These relations suggest that the Midnight Peak Formation is Turonian or Coniacian in age.

Kv_m

Volcanic Member--Massive red, gray, and green volcanic rocks with thin interbeds of volcanic lithic conglomerate and sandstone and minor reddish-purple sandstone and shale (Barksdale, 1975). Maximum known thickness of the Volcanic Member is 3,170 m, measured near Canyon Creek (sec. 32, T. 34 N., R. 20 E.) on the adjacent Twisp 1:100,000-scale quadrangle (Barksdale, 1975). The Volcanic Member conformably overlies the Ventura Member in most places, but at Goat Wall (sec. 15, T. 36 N., R. 19 E.) the contact is unconformable.

Flows and tuff in the Volcanic Member are massive, homogeneous, and aphyric to slightly phyric. They are composed of sparse hornblende, pyroxene, and plagioclase phenocrysts in aphanitic groundmasses. Compositions range from basalt to andesite, with dacite and andesite most common. Most of the volcanic rocks are strongly altered.

The breccia and conglomerate intercalated with the volcanic rocks consist of subangular to subrounded rock fragments in fine-grained matrices of broken plagioclase crystals and crushed volcanic rock fragments. The clasts are chiefly hornblende-pyroxene-plagioclase porphyry, but diorite, volcanic sandstone, and recrystallized pumice occur locally.

Kc_m

Ventura Member--Red shale, siltstone, fine- to coarse-grained sandstone, conglomerate, and minor green to gray volcanic breccia. These lithologies are commonly interlayered in beds less than 1 m thick. The proportion of coarse-grained sandstone and conglomerate beds increases toward the top of the unit. Maximum thickness of the Ventura Member is approximately 620 m, measured near Midnight Mountain (sec. 23, T. 34 N., R. 19 E.) on the adjacent Twisp 1:100,000-scale quadrangle (Barksdale, 1975).

Siltstone and shale beds in the Ventura Member are generally dark red. Some of the shale contains oval or round masses of buff-colored fine-grained sandstone that may represent fossil burrows (V. R. Todd, USGS, written commun., 1989). Sandstone in the Ventura Member is very fine to coarse grained and poorly sorted. The angular to subangular grains are chiefly porphyritic volcanic rock fragments and broken crystals of feldspar (mostly plagioclase) and quartz. Minor chert and metamorphic rock fragments and epidote grains occur in some of the sandstone. The average sandstone composition is Q_{20}:F_{40}:L_{40} (Cole, 1973).

Crudely bedded, poorly sorted, and clast-supported pebble and cobble conglomerates form beds as much as 5 m thick in the Ventura Member. Pebbles are generally subangular to subrounded, and cobbles are chiefly subrounded to rounded. Clasts are dominantly chert and porphyritic volcanic rocks. Sandstone, siltstone, and argillite intraclasts, chert-pebble conglomerate, and volcanic breccia are subordinate. Limestone and granitoid clasts are rare. The composition of the sandy matrix of the conglomerate is similar to that of sandstone beds in the Ventura Member.

Sedimentary structures in the Ventura Member include horizontal laminations, ripple-drift laminations, cross-beds, channels, and crude bedding. Rip-up clasts commonly occur near the base of sandstone beds. The distribution of these sedimentary structures and the general upward-coarsening nature of the unit suggest that the Ventura Member sediments were derived from a western source and deposited on an alluvial plain prograding to the east (Mohrig and Bourgeois, 1986).

Kvc_m

Midnight Peak Formation, undivided--Well-bedded volcanic sandstone and siltstone, massive unsorted volcanic conglomerate, subordinate pyroxene-bearing volcanic flows or tuffs, and minor intercalated lenses of chert-pebble conglomerate and lithofeldspathic sandstone. The volcanic conglomerate and sandstone contain abundant subangular to subrounded lithic fragments of chert and microporphyritic hornblende-pyroxene-plagioclase volcanic rocks. The sandstone and siltstone contain euhedral to broken, subhedral crystals of augite, hornblende, and plagioclase in addition to the lithic fragments. The volcanic flows and tuffs are dark gray and sparsely phyric, with black euhedral pyroxene phenocrysts as much as 5 mm long. Rocks of the Midnight Peak Formation, undivided are restricted to the western part of the Methow basin, near Mount Ballard (sec. 20, T. 37 N., R. 17 E.) and Haystack Mountain (sec. 36, T. 38 N., R. 17 E.). The maximum measured thickness of the unit is approximately 900 m (Tennyson, 1974).

Kc_w

Winthrop Sandstone (Cretaceous)--Massive lithofeldspathic sandstone with thin siltstone and shale partings and sparse lenses of matrix-supported pebble conglomerate. Maximum thickness of the unit is approximately 4,120 m, measured along the east side of the Methow basin (Barksdale, 1975). It thins markedly to the west (Rau, 1987).

Sandstone beds in the Winthrop Sandstone are fine- to coarse-grained and are moderately well to poorly sorted. Grains are chiefly angular to subangular. Principal constituents include plagioclase, quartz, and biotite crystals and lithic clasts of porphyritic volcanic rocks, quartzite, lithofeldspathic sandstone (intraclasts), and minor chert. The average sandstone mode is Q_{32}:F_{48}:L_{20}. Coarse granular sandstones locally grade into thin (<1 m) interbeds of matrix-supported pebble conglomerate. Clasts in the conglomerate include chert, granitic and mafic plutonic rocks, porphyritic volcanic rocks, and shale (intraclasts). Dark gray shale and siltstone interbeds as much as 2 m thick are intercalated with the sandstone. Flame and load structures, convolute bedding, and cross-laminations are characteristic of these fine-grained rocks (V. R. Todd, USGS, written commun., 1989). Most of the Winthrop Sandstone is white to greenish gray, but red lithofeldspathic sandstone occurs at the top of the unit. The red sandstone was included in the overlying Midnight Peak Formation by previous workers, but is herein included in the Winthrop Sandstone because of its lithofeldspathic composition. In contrast, the red sandstone in the overlying Midnight Peak Formation is composed of porphyritic volcanic rock fragments and minor broken feldspar and quartz crystals.

Planar and trough cross-beds, scour-and-fill structures, shale rip-up clasts, ripples, ripple-drift laminations, horizontal laminations, and graded beds are all common in the Winthrop Sandstone. These sedimentary structures suggest that the unit was deposited in a fluvial-deltaic system along the margin of a marine basin (Tennyson and Cole, 1978; Trexler, 1984; Rau, 1987). Paleocurrent data and the westward decrease in average sandstone grain size and sandstone/shale ratios indicate east-to-west transport of the sediments (Cole, 1973; Rau, 1987). Modal compositions of the Winthrop Sandstone are similar to those of plutonic rocks in the Okanogan complex east of the Pasayten fault, suggesting that the plutonic rocks were the source of the Winthrop Sandstone (Cole, 1973; Rau, 1987).

The Winthrop Sandstone interfingers with and grades into the underlying Virginian Ridge Formation. Previous workers who included the red lithofeldspathic sandstone at the top of the Winthrop Sandstone in the Midnight Peak Formation thought that the contact between the two units is conformable. However, the contact between the volcaniclastic sediments of the Midnight Peak Formation and the lithofeldspathic sediments of the Winthrop Sandstone is everywhere unconformable. The Winthrop Sandstone is intruded by the Late Cretaceous (88 Ma) Fawn Peak stock.

Plant fossils are abundant in the Winthrop Sandstone. Leaves, twigs, and bark are concentrated in shale, siltstone, and fine-grained sandstone beds. Branches and tree trunks, as much as several meters long, occur in coarse-grained sandstone beds. The fossil flora from the Winthrop Sandstone has been assigned an Albian age (Barksdale, 1975; Rau, 1987), but Turonian marine fossils in the underlying Virginian Ridge Formation suggest that at least part of the Winthrop Sandstone may be younger (V. R. Todd, USGS, written commun., 1989). Age assignment of the formation (Fig. 5) should be considered tentative because it is "generally not possible to make age determinations to stage level in the Early and early Late Cretaceous of the Pacific Northwest region on the basis of leaf fossils" (J. A. Wolfe, USGS, written commun. to V. R. Todd).

Km_v, Kcg_v

Virginian Ridge Formation (Cretaceous)--Black mudstone, siltstone, and tabular beds of chert-grain sandstone and chert-pebble conglomerate. Minor lithofeldspathic sandstone occurs near the top of the unit. The Virginian Ridge Formation is herein subdivided into two informal map units, Km_v and Kcg_v. Both units are composed of mudstone, siltstone, sandstone, and chert-pebble conglomerate. Km_v contains less than 40 percent conglomerate; Kcg_v contains more than 40 percent conglomerate.

Black mudstone and siltstone are the dominant lithologies in the Virginian Ridge Formation. They commonly display graded beds, ripple-drift cross-laminations, and convolute bedding (V. R. Todd, USGS, written commun., 1989). Plant fragments are commonly concentrated along partings in the mudstone and siltstone. The fine-grained rocks are interbedded with, and commonly grade into, dark-gray, thin-bedded, fine- to medium-grained sandstone that is composed of subrounded to subangular grains of chert, plagioclase, quartz, and volcanic and sedimentary rocks. Chert-pebble conglomerate in the Virginian Ridge Formation forms lenticular beds as much as 6 m thick. The conglomerate is composed of subrounded to subangular pebbles and cobbles of gray to black chert and subordinate sedimentary and volcanic rocks in a sandy matrix of chert, quartzite, altered mafic volcanic rocks, feldspar, and quartz (Tennyson and Cole, 1987).

Near Little Cub Creek (sec. 6, T. 35 N., R. 21 E.), the basal part of the Virginian Ridge Formation consists of poorly sorted conglomerate, which is composed of well-rounded pebbles and cobbles of black argillite, andesitic breccia, lithic sandstone and minor chert in a sandy matrix of similar composition (Barksdale, 1975). This conglomerate may be correlative with the Patterson Lake conglomerate on the Twisp 1:100,000-scale quadrangle to the south (M. F. McGroder, J. I. Garver, and V. S. Mallory, University of Washington, written commun., 1989).

The Virginian Ridge Formation is more than 4,000 m thick near Cady Point (sec. 6, T. 37 N., R. 17 E.), but it thins markedly to the east (Barksdale, 1975). Eastward thinning and fining trends, sandstone/shale ratios, and paleocurrent data indicate that the chert-rich clastic rocks were derived from the west. Radiolarians from chert pebbles in the Virginian Ridge Formation have been tentatively identified as Triassic or Early Jurassic in age, suggesting that the Hozameen Group was the source (Trexler, 1984, 1985). Sedimentary structures such as ripple-drift cross-laminations, convolute laminations, graded beds, scour-and-fill structures, mudstone rip-up clasts, and rare cross-beds suggest that Virginian Ridge Formation sediments were deposited on a fan delta (Trexler, 1984, 1985).

The Virginian Ridge Formation and the Winthrop Sandstone interfinger and grade into each other in most places, but the contact between the two units is locally unconformable. Contacts between the Virginian Ridge Formation and the underlying Harts Pass, Panther Creek, and Goat Creek Formations and the Newby Group are typically unconformable.

The Virginian Ridge Formation contains abundant Albian to Cenomanian pelecypods and belemnites (Barksdale, 1975; Trexler, 1984). Turonian gastropods were recently recovered from the formation southeast of Slate Peak (sec. 1, T. 37 N., R. 17 E.) (V. R. Todd, USGS, written commun., 1989).

Ks_{wv}

Winthrop Sandstone/Virginian Ridge Formation, undivided (Cretaceous)--Interbedded black shale, siltstone, chert-grain sandstone, chert-pebble conglomerate, and feldspathic sandstone.

The Winthrop Sandstone/Virginian Ridge Formation, undivided unit in the central Pasayten Wilderness is chiefly thick-bedded, fine- to coarse-grained, lithofeldspathic sandstone and subordinate black shale, similar to rocks in the Winthrop Sandstone. Interbeds (to 1 m thick) of chert-pebble conglomerate, compositionally similar to rocks in the Virginian Ridge Formation, form up to 20 percent of the unit. Black shale, chert-grain sandstone, and chert-pebble conglomerate, very similar to rocks in the Virginian Ridge Formation, are the principal lithologies in the Winthrop Sandstone/Virginian Ridge Formation, undivided unit northeast of the Methow Valley, but interbeds of Winthrop Sandstone-like feldspathic sandstone are abundant and are locally dominant (V. R. Todd, USGS, written commun., 1989).

This unit occupies a large area between Slate Peak (sec. 1, T. 37 N., R. 17 E.) and Point Defiance (sec. 15, T. 39 N., R. 18 E.) in the central Pasayten Wilderness. Similar rocks also form a narrow northwest-trending belt between the Methow River valley (sec. 13, T. 35 N., R. 20 E.) and McLeod Mountain (sec. 18, T. 37 N., R. 20 E.) (V. R. Todd, USGS, written commun., 1989). These rocks are very similar to rocks in both the Winthrop Sandstone and Virginian Ridge Formation. They apparently represent an environment where the two formations were deposited simultaneously.

In the central Pasayten Wilderness, the Winthrop Sandstone/Virginian Ridge Formation, undivided unit grades laterally into both the Virginian Ridge Formation and the Winthrop Sandstone. The undivided unit also locally grades upward into the Winthrop Sandstone. The contact between the units is arbitrarily drawn, but generally coincides with the last occurrence of thick, laterally continuous, chert-pebble conglomerate beds (V. R. Todd, USGS, written commun., 1989).

No fossils have been found in the Winthrop Sandstone/Virginian Ridge Formation, undivided unit in the central Pasayten Wilderness, but a fossil leaf has been recovered from fine-grained, cherty sandstone in the unit northeast of the Methow Valley. The fossil is a "perfectly actinodromousdicotyledonous leaf, a type of foliar morphology unknown prior to the middle Albian" (J.

A. Wolfe, USGS, written commun. to V. R. Todd). Since the Winthrop Sandstone/Virginian Ridge Formation, undivided unit is correlative with the Winthrop Sandstone and Virginian Ridge Formation, a middle Albian to Turonian(?) age is suspected.

Km_h, Km_p, Km_g

Harts Pass group (Cretaceous)--Feldspathic sandstone, black shale, and conglomerate. The group, informally named by Tennyson (1974) and Tennyson and Cole (1987), includes the Harts Pass, Panther Creek, and Goat Creek Formations of Barksdale (1948, 1975). Distinctions between formations are made on the basis of the relative proportions of sandstone, shale, and conglomerate. The Harts Pass group is correlative with the Jackass Mountain Group in southern British Columbia (Coates, 1970; Jeletsky, 1972; McGroder and Miller, 1989; M. F. McGroder, J. I. Garver, and V. S. Mallory, University of Washington, written commun., 1989).

Sandstone in the Harts Pass group is generally light to dark gray, well sorted, and fine to coarse grained and has an average mode of Q_{35}:F_{55}:L_{10}. Plagioclase to K-feldspar ratios generally exceed 10:1 (Tennyson, 1974; Tennyson and Cole, 1987). Lithic grains include sedimentary, volcanic, plutonic, and metamorphic rock fragments. Sandstone grains are angular to subrounded. Shale in the Harts Pass group is black and fissile. It commonly contains silty laminae and carbonaceous partings. Plant fragments and impressions occur in the shale along the eastern margin of the Methow basin.

Conglomerate in the Harts Pass group forms beds from less than 1 m to tens of meters thick. Bedding is uncommon in the conglomerate. Where present, it is defined by discontinuous sandy lenses and aligned flat clasts (V. R. Todd, USGS, written commun., 1989). The conglomerate is composed of pebbles, cobbles, and boulders in a matrix of feldspathic sandstone. The boulders and cobbles are well rounded to subrounded; smaller clasts are subrounded to subangular. Clasts include a wide variety of rock types, including leucogranite, aplite, tonalite, diorite, gabbro, porphyritic andesite, quartzite, phyllite, amphibolite, sandstone, siltstone, shale, and minor vein quartz and chert.

Sandstone grain size and sandstone/shale ratios in the Harts Pass group increase toward the east. These observations, coupled with paleocurrent data that shows westward transport, indicate an eastern source for the Harts Pass group sediments. Modes suggest that the source terrain was composed of plutonic or metamorphic rocks of quartz dioritic to granodioritic composition (Tennyson, 1974). The sandstones are generally massive and commonly display parallel laminations, graded beds, cut-and-fill structures, groove marks, shale rip-up clasts, and rare cross-beds and flute casts. These sedimentary structures suggest deposition by turbidity currents on submarine fans in a westerly deepening marine basin (Tennyson and Cole, 1987).

Km_h

Harts Pass Formation--Light- to dark-gray, fine- to coarse-grained feldspathic sandstone, black shale, and minor pebble conglomerate. Barksdale (1975) described three units in the formation: (1) a basal, 975-m-thick interval of massive feldspathic sandstone with minor black shale partings; (2) a middle 760-m-thick sequence of feldspathic sandstone and black shale in roughly equal proportions; and (3) an upper 670-m-thick unit of thick-bedded feldspathic sandstone and subordinate black shale.

The Harts Pass Formation conformably overlies the Panther Creek Formation and is unconformably overlain by the Virginian Ridge Formation or the Winthrop Sandstone/Virginian Ridge Formation, undivided unit (Ks_{wv}). The Harts Pass Formation contains a diverse assemblage of marine fossils (pelecypods, ammonites, and gastropods) of late Aptian to middle Albian age (Barksdale, 1975; V. R. Todd, USGS, written commun., 1989).

Km_p

Panther Creek Formation--Chiefly black shale with lenticular beds of boulder conglomerate and minor layers of feldspathic sandstone. Black shale beds form nearly 90 percent of the formation in places. The maximum thickness of the Panther Creek Formation is 1,585 m (Barksdale, 1975).

The Panther Creek Formation conformably overlies the Goat Creek Formation and is conformably overlain by the Harts Pass Formation (Barksdale, 1975). At the type locality near Panther Creek (secs. 8 and 9, T. 37 N., R. 20 E.), the Panther Creek Formation contains several species of pelecypods that apparently range in age from late Hauterivian to early Albian (Barksdale, 1975). Aptian-Albian gastropods, pelecypods, and cephalopods have been recovered from the formation at three localities along Sweetgrass Ridge (sec. 12, T. 36 N., R. 20 E.) (V. R. Todd, USGS, written commun., 1989).

Km_g

Goat Creek Formation--Massive, well-sorted, light- to dark-gray, fine- to coarse-grained, feldspathic sandstone with minor interbeds of pebble conglomerate and black shale. The maximum thickness of the formation is 1,560 m (Barksdale, 1975). Compositions of the rocks in the Goat Creek Formation are very similar to those in the Harts Pass Formation.

The Goat Creek Formation is conformably overlain by the Panther Creek Formation. Contacts between the Goat Creek Formation and older rock units are marked by faults, so stratigraphic relations with the older rocks are unknown. No fossils have been found in the Goat Creek Formation in the United States, but Barremian to early Albian fossils have been recovered from the formation in British Columbia (Coates, 1974).

Kvs_b

Buck Mountain Formation (Cretaceous)--A heterogeneous unit of andesitic tuff, tuff breccia, lava flows, and volcanic lithic sandstone, siltstone, and shale. The unit forms a 3-km-wide, northwest-trending belt along the east side of the Methow basin between Button Creek (sec. 14, T. 37 N., R. 20 E.) and Cub Creek (sec. 10, T. 35 N., R. 21 E.). It consists of (1) a basal 1,525-m-thick unit of strongly altered andesitic breccia, subordinate massive andesitic flows, and minor interbedded volcanic sandstone and siltstone; (2) a middle 1,920-m-thick unit of volcanic lithic sandstone, siltstone, and black shale with lenticular conglomerate beds; and (3) an upper 975-m-thick unit of volcanic lithic sandstone, siltstone, and black shale without conglomerate (Barksdale, 1975).

Sandstone in the Buck Mountain Formation is well sorted and consists of subangular to subrounded fragments of andesite and broken crystals of plagioclase, hornblende, magnetite, and minor quartz. Conglomerate is composed of well-rounded pebbles and cobbles of andesite, chert, argillite, hypabyssal intrusive rocks, and sparse granitoid rocks and limestone set in a matrix of andesitic detritus.

Andesitic breccias in the Buck Mountain Formation are chiefly massive. They consist of subangular to subrounded to flattened clasts of porphyritic andesite in a matrix of euhedral plagioclase crystals. The volcanic rocks are typically fractured, silicified, and strongly altered. Chlorite, epidote, albite, and carbonate are common alteration products.

North of Cub Creek (sec. 32, T. 36 N., R. 21 E.), the Buck Mountain Formation is apparently unconformably overlain by the Harts Pass Formation. Elsewhere, contacts between the Buck Mountain Formation and other rock units are marked by faults.

Hauterivian to middle Barremian pelecypods, ammonites, and belemnites have been recovered from the Buck Mountain Formation at several localities (Barksdale, 1975; Maurer, 1958). Near Buck Mountain (sec. 21, T. 36 N., R. 21 E.), some of the beds that contain the Hauterivian-Barremian fossils also contain Berriasian-Barremian belemnites and Oxfordian-Valanginian(?) pelecypods (*Buchia*). The presence of fossils of two ages in a single stratigraphic horizon in the Buck Mountain Formation suggests that the older fossils were eroded from Late Jurassic and Early Cretaceous rocks and redeposited during the Hauterivian and Barremian (Fig. 5).

Kva_i

Andesite of Isabella Ridge (Cretaceous?)--Altered purple, green, and gray andesitic tuff and tuff breccia, with subordinate andesite and basalt flows and rhyolitic to dacitic tuff and breccia. Minor thin, lenticular beds of fine- to coarse-grained volcanic lithic sandstone, siltstone, mudstone, and andesitic pebble to boulder conglomerate are intercalated with the volcanic rocks in places. The unit was named by Dixon (1959) and forms a narrow, northwest-trending belt along the east side of the Methow basin between Button Creek (sec. 14, T. 37 N., R. 20 E.) and the Canadian border.

Tuff breccia in the andesite of Isabella Ridge is composed of angular to subrounded clasts of a wide variety of porphyritic volcanic rocks in a matrix composed of broken crystals of plagioclase, hornblende, pyroxene, and black opaque minerals. The flows and flow breccias are massive, fine-grained, porphyritic rocks composed of small phenocrysts of plagioclase and mafic minerals set in aphanitic groundmasses. The flows are chiefly andesite, but vary in composition from dacite to basalt (Staatz and others, 1971). Rhyolitic to dacitic tuff and breccia form lenticular layers up to 90 m thick. They consist of angular fragments of light yellowish-gray, quartz-bearing volcanic rock in a matrix of volcanic rock fragments, ash, and broken crystals of quartz, plagioclase, and hornblende.

Near Burgett Peak (sec. 11, T. 37 N., R. 20 E.), the andesite of Isabella Ridge overlies the Late Jurassic Button Creek stock along a relatively flat contact, but it is unclear whether the contact is a depositional contact or a low-angle fault (V. R. Todd, USGS, written commun., 1989). Contacts between the andesite of Isabella Ridge and all other rock units are marked by faults.

The andesite of Isabella Ridge is coeval with (or equivalent to) member A of the Pasayten Series (Daly, 1912), the volcanics of Billy Goat Mountain (Staatz and others, 1971), and the volcanic rocks of Isabella Ridge (V. R. Todd, USGS, written commun., 1989). Because the composition of the andesite of Isabella Ridge is similar to that of the volcanic rocks in the Buck Mountain Formation to the south, the two units may be time correlative, but represent different facies of a volcanic terrain. No fossils have been recovered from the andesite of Isabella Ridge to confirm this tentative correlation.

$KJvs_n$

Newby Group (Cretaceous or Jurassic?)--A thick sequence of andesitic breccia and flows, volcanic lithic sandstone, and black shale. The unit forms a narrow, northwest-trending belt along the west side of the Pasayten fault between Buck Lake (sec. 22, T. 36 N., R. 21 E.) and the southern border of the Robinson Mtn. 1:100,000-scale quadrangle. The Newby Group extends to the south onto the Twisp 1:100,000-scale quadrangle, where it covers many hundreds of square kilometers.

These rocks were previously assigned to the Buck Mountain Formation of the Newby Group by Barksdale (1975), but they are herein excluded from the Buck Mountain Formation because observed stratigraphic relations suggest they are significantly older than Hauterivian-Barremian. In the Robinson Mtn. quadrangle, the Newby Group is fault-bounded on all sides, so stratigraphic relations with other rock units are unclear. In the Twisp 1:100,000-scale quadrangle, the Newby Group is intruded by two igneous intrusions, the Fraser Creek complex and the Alder Creek stock, that have yielded K-Ar hornblende ages of approximately 139 Ma (V. R. Todd, USGS, written commun., 1988). These cross-cutting relations indicate that at least part of the Newby Group is Jurassic. Basaltic andesite in the Newby Group has yielded a K-Ar whole-rock age of 90.4 ± 2.1 Ma (V. R. Todd, USGS, written commun., 1988), but that age clearly does not represent the crystallization age of the volcanic rocks. Little else can be said about the age of the Newby Group because no fossils have been found in the unit.

Jm_t

Twisp Formation (Jurassic?)--Thin-bedded black shale, with interbeds of medium- to dark-gray, volcanic lithic sandstone and siltstone and poorly sorted pebble conglomerate. The sandstone and conglomerate are composed of euhedral plagioclase crystals and angular to subrounded clasts of fine-grained, porphyritic volcanic rocks, chert, and black slate (V. R. Todd, USGS, written commun., 1988).

Complex folding and faulting and the lack of stratigraphic marker beds prohibit measurement of the true thickness of the Twisp Formation. The thickest measured section is 1,220 m (Barksdale, 1975).

Horizontal laminations, ripple drift cross-laminations, graded beds, rip-up clasts, and flame structures are abundant in Twisp Formation. These sedimentary structures and paleocurrent data indicate that the sediments were derived from a volcanic terrain to the east, swept into a westerly deepening basin, and deposited by turbidity currents on submarine fans (Tennyson, 1974).

Contacts between the Twisp Formation and other rock units are typically marked by faults, so stratigraphic relations are uncertain. Age of the Twisp Formation is unknown because no age-diagnostic fossils have been found in the formation. Tennyson and Cole (1987) believe that the Twisp Formation is correlative with the Jurassic Ladner Group in southern British Columbia, which contains abundant Sinemurian to Bajocian marine fossils.

Jm_l

Ladner Group (Jurassic)--Interbedded volcanic lithic sandstone, pebble conglomerate, and black shale. The sandstone is dark gray-green, fine to medium grained, and poorly sorted. It consists chiefly of volcanic rock fragments and plagioclase crystals. Graded beds and cross-beds are common. The conglomerate consists of rounded clasts set in a dark gray-green sandy matrix. Clasts are chiefly volcanic rocks, but minor metamorphic rocks and rare granitoid rocks also occur (Tennyson, 1974). The Ladner Group crops out in two narrow belts near the Canadian border.

Tennyson (1974, p. 22) stated that this unit is "roughly equivalent to the volcanic-derived Ladner and Dewdney Creek Groups of Coates (1970, 1974) and Jeletsky (1972), or to the Newby Group of Barksdale (1948, 1960, 1974)." She assigned them to the Newby Group, but because they crop out along the Canadian border and are mappable extensions of the Ladner Group in southern British Columbia, they are herein re-assigned to the Ladner Group. No age-diagnostic fossils have been found in the Ladner Group on the Robinson Mtn. quadrangle, but in southern British Columbia the group contains numerous Sinemurian to Bajocian marine fossils (Coates, 1970, 1974).

Intrusive Igneous Rocks

Tertiary Intrusive Igneous Rocks

Tertiary Hypabyssal Intrusive Rocks

Eida,

Dacite plugs and dikes near Island Mountain (Eocene)--Plugs and dikes of gray and green porphyritic dacite. The dacite consists of as much as 30 percent phenocrysts of plagioclase, biotite, and quartz in a fine-grained groundmass of feldspar, quartz, and black opaque minerals (White, 1986). These north- to northwest-striking dacite plugs and dikes cut the Eocene volcanic rocks of Island Mountain and older volcanic, sedimentary, and metamorphic rocks near Island Mountain (T. 39 N., R. 19 E.). A K-Ar biotite age of 44.4 +/- 1.0 Ma and a fission-track biotite age of 45.5 +/- 3.9 Ma are reported from the plug along Deception Creek (White, 1986).

Eib$_m$

Basalt of Middle Mountain (Eocene)--A small plug of dark gray to black, sparsely phyric basalt composed of less than 5 percent phenocrysts of plagioclase, orthopyroxene, clinopyroxene, hornblende, and olivine, and minor quartz xenocrysts in an aphanitic groundmass.

The basalt crops out on Middle Mountain (sec. 34, T. 40 N., R. 19 E.) and intrudes the Eocene volcanic rocks of Island Mountain. It has yielded a K-Ar whole-rock age of 47.0 +/- 0.6 Ma (White, 1986).

Andesite(?) dikes near Goat Wall (Eocene)--Numerous andesite(?) dikes cut the Midnight Peak Formation northeast of Goat Wall (T. 36 N., R. 19 E.). Because these rocks have not been studied in detail, their mineralogic and chemical composition is not well defined. K-Ar whole-rock ages of the andesite(?) range from 47 to 49 Ma (Table 1).

Rhyolite dikes near Diamond Creek (Eocene?)--Bright yellow, fine-grained rhyolite dikes with stretched miarolitic cavities. These dikes cut the andesite of Isabella Ridge near Diamond Creek (sec. 30, T. 39 N., R. 20 E.)(Lawrence, 1968). The dikes are probably correlative with rhyolite and rhyodacite dikes emanating from the border of the Monument Peak stock to the southwest and are therefore thought to be Eocene in age (Tabor and others, 1968).

Tertiary Plutonic Rocks

Eig$_g$

Golden Horn batholith (Eocene)--Directionless, pinkish-gray, fine- to coarse-grained, leucocratic granite with crystal-lined miarolitic cavities up to several meters in diameter. The granite in the southern half of the batholith is composed of more than 60 percent K-feldspar, approximately 30 percent quartz, less than 5 percent albite, and less than 5 percent arfvedsonite (sodic amphibole) and annite (iron-rich biotite). The K-feldspar-rich granite grades to the north into two varieties of K-feldspar-poor granite. One variety consists of equal amounts of perthitic orthoclase, plagioclase (oligoclase to albite), and quartz, and less than 5 percent biotite and hornblende. The other variety is composed of approximately 50 percent perthite, 35 percent quartz, albite (secondary), biotite, and amphibole.

The Golden Horn batholith is a large intrusion straddling Early Winters Creek in the southwestern part of the Robinson Mtn. 1:100,000-scale quadrangle (Stull, 1969; Barksdale, 1975; Boggs, 1984). The batholith was intruded into the Hozameen fault, the major fault bounding the southwestern side of the Methow basin. K-Ar hornblende ages of 47.8 ± 4.7 Ma and 46.7 ± 1.9 Ma, and K-Ar biotite ages of 48 ± 2 Ma, 46.9 ± 0.4 Ma, and 46.6 ± 1.4 Ma are reported from the batholith (Table 1). The ages suggest that magmatic crystallization occurred approximately 47 Ma. K-Ar biotite, fission-track allanite, and Rb-Sr isochron ages between 38 and 42 Ma (Table 1) probably represent post-crystallization hydrothermal alteration ages.

Eig_m

Monument Peak stock (Eocene)--Directionless, leucocratic biotite granite with an average composition of Q_{37}:A_{44}:P_{19}. It generally contains approximately 2 percent biotite and accessory apatite, zircon, sphene, and fluorite (Tabor and others, 1968). The Monument Peak granite stock, a 50-km² intrusion along the eastern side of the Methow basin, is dominantly fine grained and porphyritic, but medium-grained, equigranular rocks crop out in a small area near Monument Peak (sec. 18, T. 38 N., R. 19 E.). Porphyritic portions of the stock consist of 10 to 50 percent euhedral phenocrysts of K-feldspar, quartz, and plagioclase in a fine-grained groundmass of similar composition. The K-feldspar is commonly perthitic, and the plagioclase is chiefly oligoclase (An_{15-20}).

Miarolitic cavities are abundant in the Monument Peak stock. Vuggy quartz veins, locally fluorite-bearing, cut the granite along the margins of the intrusion (Staatz and others, 1971).

Yellowish-orange to pink quartz porphyry dikes that apparently emanate from the Monument Peak stock cut Cretaceous sedimentary rocks surrounding the intrusion (Tabor and others, 1968). These dikes are composed of euhedral to subhedral phenocrysts of quartz, K-feldspar, and plagioclase in aphanitic groundmasses. Most are probably rhyolitic or rhyodacitic in composition. The dikes generally strike northeast and dip steeply. They range from less than 1 m to more than 100 m wide, and are as much as 3 km long. Individual dikes are not shown on the geologic map (Plate 1).

The Monument Peak stock intrudes the Lost Peak stock and several Cretaceous sedimentary rock units. A single K-Ar biotite age of 47.9 ± 1.4 Ma is reported from the stock (Tabor and others, 1968).

$Eigd_c$, Eiq_c

Castle Peak stock (Eocene)--A central phase of directionless, coarse-grained granodiorite ($Eigd_c$) and a narrow border phase of directionless to weakly foliated, medium-grained quartz diorite (Eiq_c) (Lawrence, 1967). Dikes and small masses of aplite and pegmatite cut both phases.

The granodiorite is composed of approximately 50 percent plagioclase, 20 percent quartz, 15 percent orthoclase, and 15 percent mafic minerals. Biotite is generally more abundant than hornblende. The quartz diorite is composed of 60 percent plagioclase, 10 to 15 percent quartz, 0 to 5 percent orthoclase, and 15 to 30 percent mafic minerals, which include roughly equal proportions of hornblende and biotite. Average composition of the fine-grained aplite is Q_{22}:A_{33}:P_{45}. It contains as much as 10 percent biotite that is commonly altered to chlorite. Principal constituents of the pegmatite are quartz, orthoclase, and plagioclase. Tourmaline and beryl are common accessory minerals.

The Castle Peak stock is a 25-km² intrusion that straddles the Canadian border in the northwestern corner of the Robinson Mtn. 1:100,000-scale quadrangle. The stock was emplaced along the axial plane of a major syncline in broadly folded Cretaceous sedimentary rocks. Concordant K-Ar hornblende and biotite ages indicate that intrusion occurred at approximately 50 Ma (Table 1).

$Eigd_l$

Lost Peak stock (Eocene)--Directionless, light-gray to pinkish-gray, fine- to medium-grained, hornblende-biotite granodiorite and quartz monzonite (Tabor and others, 1968). The rocks are chiefly inequigranular, but are locally porphyritic. The average composition of the Lost Peak stock is Q_{28}:A_{23}:P_{49}. It contains approximately 10 percent mafic minerals. Biotite is generally more abundant than hornblende. Sphene, allanite, magnetite, ilmenite, and zircon are common accessory minerals.

The Lost Peak stock, a 35-km² intrusion along the eastern margin of the Methow basin, and dikes emanating from it intrude and locally metamorphose Cretaceous sedimentary rocks. The stock is intruded by the Monument Peak stock and associated quartz porphyry dikes. Near the contact with the Monument Peak stock, the Lost Peak stock is flooded with K-feldspar that has apparently metasomatically replaced plagioclase, quartz, and biotite (Tabor and others, 1968).

K-Ar biotite and fission-track zircon ages of 51.5 ± 1.0 Ma and 47.9 ± 4.1 Ma, respectively, are reported from the Lost Peak stock (White, 1986).

Tertiary or Cretaceous Intrusive Igneous Rocks

Tertiary or Cretaceous Hypabyssal Intrusive Rocks

Basalt dikes near Cathedral Creek (Tertiary or Cretaceous)--Black, aphanitic basalt dikes composed of plagioclase (average An_{50}), hornblende, and minor pyroxene.

The basalt dikes are abundant near Cathedral Creek (T. 40 N., R. 21 and 22 E.), in the northeastern corner of the quadrangle (Hawkins, 1963, 1968). They cut the gneissic trondhjemite of Tiffany Mountain, the trondhjemite of Doe Mountain, and the Cathedral batholith, so they must be Late Cretaceous or younger in age. They could be correlative with either the Late Cretaceous(?) Ashnola Gabbro or the Eocene basalt of Middle Mountain.

Dacite dikes near Remmel Lake (Tertiary or Cretaceous)--Porphyritic dacite dikes composed of plagioclase, hornblende, biotite, quartz, and minor K-feldspar phenocrysts in an aphanitic groundmass of similar composition. Many of the dikes are strongly altered. Chlorite, calcite, epidote, sericite, serpentine, and zeolites are common secondary minerals.

The dacite dikes near Remmel Lake (sec. 22, T. 40 N., R. 21 E.) cut migmatitic rocks and trondhjemite that are thought to be Late Jurassic or Cretaceous in age. The composition of the dikes is similar to that of both Eocene and Late Cretaceous plugs and dikes found elsewhere in the Robinson Mtn. 1:100,000-scale quadrangle (White, 1986; V. R. Todd, USGS, written commun., 1988).

Tertiary or Cretaceous Plutonic Rocks

TKi

Tertiary or Cretaceous intrusive igneous rocks, undivided--Small stocks of unknown age and composition crop out near Tamarack Peak (sec. 27, T. 38 N., R. 17 E.), on Majestic Mountain (sec. 24, T. 37 N., R. 16 E.), south of Early Winters Creek (sec. 36, T. 36 N., R. 18 E.), and near Osceola Peak (sec. 35, T. 39 N., R. 18 E.). These intrusions have been mapped only in a reconnaissance fashion (Tabor and others, 1968; Tennyson, 1974) and have not been described. Little is known about the age of these intrusions except that they all cut sedimentary rocks that are no older than the Harts Pass Formation. Therefore, they must be either Late Cretaceous or Tertiary in age.

TKi$_h$

Plagioclase porphyry stock near Heather Creek (Tertiary or Cretaceous)--Light-gray porphyritic rocks, composed of plagioclase, orthoclase, biotite, and hornblende phenocrysts in a microcrystalline groundmass of similar composition. Modal analysis of a single thin-section (Q_8:A_{22}:P_{70}) indicates a quartz monzodioritic composition (Staatz and others, 1971). Plagioclase and mafic minerals are commonly altered to calcite, chlorite, and iron oxides. This small stock, which straddles the Canadian border near Heather Creek, covers less than 2 km^2 on the Robinson Mtn. 1:100,000-scale quadrangle. Because it intrudes Early Cretaceous sedimentary rocks, this stock must be either Late Cretaceous or Tertiary in age.

Mesozoic Intrusive Igneous Rocks

Cretaceous Hypabyssal Intrusive Rocks

Kian,

Cretaceous andesite and dacite plugs, sills, and dikes--Gray porphyritic andesite and dacite plugs, sills, and dikes composed of abundant euhedral phenocrysts of white plagioclase and black hornblende, a few millimeters to 1 cm in length, in a microcrystalline to aphanitic groundmass of feldspar and quartz.

These plugs, sills, and dikes are widespread on the Robinson Mtn. 1:100,000-scale quadrangle. They cut Cretaceous and Jurassic sedimentary and volcanic rocks in the Methow basin and Mesozoic orthogneisses and plutonic rocks east of the Pasayten fault (V. R. Todd, USGS, written commun., 1988, 1989). The sills and dikes are typically concordant with bedding in the sedimentary rocks and with foliation in the orthogneisses.

These hypabyssal intrusions are compositionally similar to some of the Late Cretaceous stocks in the map area, and are probably their hypabyssal intrusive equivalents (V. R. Todd, USGS, written commun., 1988, 1989). K-Ar hornblende ages from the hypabyssal intrusions range from 82 to 93 Ma (Table 1).

Mesozoic Plutonic Rocks

$Kigd_r$

Rock Creek stock (Cretaceous)--Directionless, gray, medium-grained, equigranular, biotite-hornblende granodiorite and tonalite. The average composition is Q_{21}:A_{11}:P_{68}, with approximately 15 percent mafic minerals. Hornblende is generally more abundant than biotite (Tabor and others, 1968).

The Rock Creek stock is an elongate, 7-km-long, north-northwest-trending intrusion in the center of the Methow basin (T. 39 N., R. 17 E.). The stock intrudes several Cretaceous sedimentary rock units and has locally metamorphosed them to the hornblende-hornfels facies. The Rock Creek stock has yielded a K-Ar hornblende age of 86.1 ± 2.6 Ma (Tabor and others, 1968).

$Kigd_p$

Pasayten stock (Cretaceous)--Directionless, gray, medium-grained, equigranular, biotite-hornblende granodiorite and tonalite. The average composition is Q_{21}:A_9:P_{70}, with approximately 15 percent mafic minerals (Tabor and others, 1968). Hornblende is more abundant than biotite.

The Pasayten stock is a narrow, northwest-trending 20-km-long intrusion in the center of the Methow basin (T. 38 N., R. 18 E.). The stock intrudes the Winthrop Sandstone and the Winthrop Sandstone/Virginian Ridge Formation, undivided unit (Ks_{wv}), metamorphosing them to the hornblende-hornfels facies near the contacts. The country rocks are locally riddled with dikes emanating from the border of the stock. The southeast end of the Pasayten stock is intruded by the Eocene Monument Peak stock. The west end of the Pasayten stock is offset to the north, apparently along a concealed north-northeast-trending fault in the valley of the Middle Fork Pasayten River.

Replicate K-Ar biotite ages of 85.3 ± 2.6 Ma and 87.7 ± 2.6 Ma and a K-Ar hornblende age of 86.0 ± 2.6 Ma are reported from the Pasayten stock (Tabor and others, 1968).

Kii_f

Fawn Peak stock (Cretaceous)--Fine- to coarse-grained equigranular diorite, equigranular to porphyritic quartz diorite, plagioclase porphyry, and minor intrusion breccia (Reidell, 1979; V. R. Todd, USGS, written commun., 1989). Diorite and quartz diorite form the center of the stock. They grade outward into black, massive plagioclase porphyry, which forms a discontinuous border as much as 1 km wide on the north and south sides of the stock. Disseminated and veinlet-controlled porphyry copper-molybdenum mineralization occurs in the western part of the stock.

Principal constituents of the diorite and quartz diorite in the Fawn Peak stock are plagioclase, hornblende, pyroxene, and biotite. Quartz and K-feldspar are minor components. Black opaques, apatite, zircon, and sphene are common accessory minerals. Pyroxene is generally more abundant than hornblende in the quartz-free rocks; hornblende is more abundant that pyroxene in the quartz-bearing rocks.

The porphyritic rocks along the border of the stock are black and massive. They are composed of 1- to 2-mm-long euhedral plagioclase laths and stubby euhedral pyroxene phenocrysts set in a fine-grained groundmass of plagioclase, pyroxene, and black opaque minerals. The groundmass is altered to chlorite, sericite, and calcite in many places.

Breccia forms a pipelike-body on the northeast side of Flagg Mountain (sec. 20, T. 36 N., R. 20 E.). It consists of subrounded clasts, as much as 25 cm long, of diorite, quartz diorite, andesite, and andesite porphyry, in a matrix of plagioclase porphyry. The gray porphyry consists of 20 to 40 percent plagioclase (andesine), less than 10 percent quartz, and 5 to 10 percent hornblende and biotite in an aphanitic groundmass of similar composition. The breccia locally includes discontinuous pods and lenses of quartz, calcite, and metallic sulfide minerals.

The Fawn Peak stock intrudes the Winthrop Sandstone and the Midnight Peak Formation. The margins of the stock in many places contain 1- to 2-cm-long mafic inclusions, 2- to 15-cm-wide rounded epidotized fragments, and tabular inclusions of hornfelsed sandstone and siltstone up to 10 m long. Swarms of porphyritic sills and dikes emanating from the stock cut the country rocks as much as 1 km from the stock.

The Fawn Peak stock is an elongate, northwest-trending intrusion along the northeast side of the Methow River valley near Mazama (T. 36 N., R. 20 E.). The Fawn Peak stock is situated along the axis of the Goat Peak syncline and is spatially associated with outcrops of the Midnight Peak Formation, Volcanic Member (Kv_m). Massive, fine-grained igneous rocks of the Midnight Peak Formation grade into highly fractured, very fine grained igneous rocks of the Fawn Peak stock north of Goat Creek. The gradational nature of the contact and similar compositions of the volcanic and intrusive rocks suggest that the Fawn Peak stock is the intrusive equivalent of the Midnight Peak Formation, Volcanic Member (Barksdale, 1975; Reidell, 1979; V. R. Todd, USGS, written commun., 1989).

Three K-Ar magmatic biotite ages of approximately 88 Ma are reported from the Fawn Peak stock (Table 1). Altered rocks in the stock have yielded K-Ar biotite (secondary) ages of 85.1 ± 3.5 Ma and 69.7 ± 2.9 Ma.

$Kiqm_e$

Quartz monzonite near Ewart Creek (Cretaceous?)--Leucocratic quartz monzonite that consists of a central phase of directionless, grayish-white, medium-grained, porphyritic, leucocratic quartz monzonite that grades outward to a narrow border phase of fine- to medium-grained quartz monzonite (Hawkins, 1963; Staatz and others, 1971).

The porphyritic quartz monzonite consists of abundant 2-cm-long euhedral phenocrysts of perthitic microcline in a fine- to medium-grained groundmass of plagioclase, perthite, and quartz (Hawkins, 1963). Biotite generally forms less than 5 percent of the rocks. Muscovite, apatite, and magnetite are common accessory minerals.

The monzonite forms a narrow, northwest-trending, 3-km-long intrusion near Ewart Creek in the northeastern corner of the Robinson Mtn. 1:100,000-scale quadrangle. Abundant northeast- and northwest-trending pegmatite dikes radiate from the body.

The composition of the quartz monzonite near Ewart Creek is strikingly similar to that of the Cathedral batholith, which suggests that both were emplaced during the same intrusive event (Daly, 1912). However, the presence of the fine-grained border phase in the quartz monzonite near Ewart Creek and its sharp contact with the Cathedral batholith indicate that it was intruded after the batholith had solidified and cooled. These relations suggest that the age of the quartz monzonite near Ewart Creek is Late Cretaceous (Hawkins, 1963).

$Kigd_c$, $Kiqm_c$

Cathedral batholith (Cretaceous)--Directionless, buff to pinkish-tan, coarse-grained, leucocratic granodiorite and quartz monzonite that contain abundant K-feldspar megacrysts, large glomeroporphyritic quartz knots, and oval to disc-shaped mafic clots (Hawkins, 1963). Principal constituents are plagioclase (average An_{20}), perthitic K-feldspar, and quartz. The average composition is

Q_{34}:A_{25}:P_{41}. Biotite is ubiquitous, but rarely forms more than 5 percent of the rock. Sphene, zircon, apatite, magnetite, wolframite, pyrite, and rutile are common accessory minerals.

The Cathedral batholith covers approximately 200 km² in the northeastern corner of the Robinson Mtn. quadrangle and extends east onto the Oroville 1:100,000-scale quadrangle and north into Canada. The batholith intrudes the gneissic trondhjemite of Tiffany Mountain and the granodiorite gneiss complex of the Quartz Mountain area. It is cut by the quartz monzonite near Ewart Creek and by abundant pegmatite, aplite, and porphyritic dacite dikes (not shown on Plate 1). K-Ar biotite ages of 94.0 ± 2.8 Ma and 97.7 ± 2.9 Ma are reported from the batholith (Hawkins, 1968; Berry and others, 1976).

Kig_p

Park granite stock (Cretaceous?)--Directionless, coarse-grained, biotite granite. The Park granite stock is compositionally similar to the Cathedral batholith except that it contains slightly more K-feldspar than the batholith and the K-feldspar in the Park granite stock is not perthitic.

This small stock straddles the Canadian border near the Ashnola River (sec. 4, T. 40 N., R. 20 E.). and intrudes the granodiorite gneiss complex of the Quartz Mountain area. The age of the stock is unknown, but its compositional similarity to the Cathedral batholith led Daly (1912) to suggest that the two intrusions were comagmatic. A Cretaceous(?) age is tentatively assigned.

Kid_l

Lightning Creek stocks (Cretaceous?)--Light-gray, fine- to medium-grained, hornblende diorite with narrow (30-m-wide) borders of more mafic biotite-hornblende diorite (Daly, 1912; Staatz and others, 1971). Plagioclase and hornblende are the principal constituents. Biotite is present in the border phase but absent in the main phase. Quartz, K-feldspar, magnetite, ilmenite, apatite, and sphene are common accessory minerals. Alteration of hornblende to chlorite, calcite, and epidote, and plagioclase to sericite is common.

The two small Lightning Creek stocks in the northwestern corner of the Robinson Mtn. quadrangle near Lightning Creek (T. 40 N., R. 14 E.) are weakly foliated. Foliation generally strikes N40°W and dips steeply (Daly, 1912).

The age of the Lightning Creek stocks is uncertain, but because they intrude the Harts Pass Formation, they must be either Late Cretaceous or Tertiary. The weak foliation in the stocks suggest that they are older than the directionless Eocene intrusions in the region. A Late Cretaceous age is tentatively assigned.

Kid_m

Diorite near Middle Creek (Cretaceous?)--Distinctly layered hornblende diorite, with layers defined by variation in relative proportions of hornblende and plagioclase. Hornblende content varies from 20 to 70 percent (Staatz and others, 1971).

The age of this small intrusion on the ridge separating Middle and Grizzly Creeks (sec. 32, T. 39 N., R. 16 E.), along the western margin of the Methow basin is unknown. Staatz and others (1971) suggested that it is compositionally similar to, and probably correlative with, the Lightning Creek stocks. Therefore, a Late Cretaceous age is suspected.

Kigb$_a$

Ashnola Gabbro (Cretaceous?)--A heterogeneous layered body composed of dark-gray, medium- to coarse-grained, hornblende-pyroxene gabbro, olivine gabbro, norite, olivine norite, and minor intrusion breccia (Daly, 1912; Hawkins, 1963). Calcic plagioclase, hornblende, olivine, orthopyroxene, clinopyroxene, and opaque minerals are the principal constituents of the gabbro and norite. Rutile, sphene, apatite, zircon, magnetite, and quartz are common accessory minerals. The mafic rocks are locally strongly altered to serpentine, talc, chlorite, biotite, and sericite. The intrusion breccia is composed of large, angular to subrounded blocks of gabbro-norite in a matrix of pinkish-gray, medium- to coarse-grained leucocratic quartz diorite. Hawkins (1963) suggested that the leucocratic quartz diorite is a late differentiate of the gabbro-norite magma.

The Ashnola Gabbro is an elongate, northwest-trending 4-km-long intrusion that straddles the Canadian border near Beaver Creek (sec. 6, T. 40 N., R. 21 E.). The northwest trend of the Ashnola Gabbro is parallel to regional structural trends in the granodiorite gneiss complex of the Quartz Mountain area. Faint compositional layering in the gabbro strikes northeast, perpendicular to the foliation in the gneiss, and dips 45 to 70 degrees northwest (Hawkins, 1963).

Igneous microtextures, lack of metamorphism, and the presence of compositional layering perpendicular to the regional structural trend all indicate that the Ashnola Gabbro is a late- to post-metamorphic intrusion. Its age is probably Late Cretaceous (Hawkins, 1963).

KJit$_d$

Trondhjemite of Doe Mountain (Cretaceous or Jurassic?)--A very large homogeneous body of leucocratic (average color index = 5) biotite trondhjemite and granodiorite that grades from fine to medium grained along its western margin to medium to coarse grained on the north and east. Principal constituents are plagioclase (chiefly oligoclase), quartz, microcline, and biotite. Muscovite, pink garnet, apatite, zircon, hornblende, sphene, and opaques are common accessory minerals. Quartz occurs as equant to lenticular gray grains and granular aggregates as much as 3 cm long that locally impart a subporphyritic texture to the rocks. Microcline crystals are white or pink and range from 1 to 2.5 cm long. They increase in abundance from west to east. Sparse small (1 mm) recrystallized subhedral biotite grains and biotite aggregates are typical of the margins of the pluton, while larger (2 mm) grains and aggregates are more characteristic of the interior.

The trondhjemite of Doe Mountain is a northwest-trending batholith that stretches from Spanish Creek (T. 40 N., R. 20 and 21 E.) to the southern border of the Robinson Mtn. 1:100,000-scale quadrangle (Hawkins, 1963, 1968; V. R. Todd, USGS, written commun., 1988). It extends south onto the adjacent Twisp and Omak 1:100,000-scale quadrangles (J. R. Wilson, formerly USGS, written commun., 1986; A. M. Frey, University of Pittsburgh, written commun., 1988).

The interior and eastern margin of the trondhjemite of Doe Mountain is directionless to weakly foliated. Where foliation is measurable, it generally strikes north or northeast. Within 0.5 km of the contact with the trondhjemite of Lamb Butte along the western margin of the pluton, the trondhjemite of Doe Mountain is characterized by a moderate foliation, which strikes northwest. This foliation is defined by the alignment of platy biotite and lensoid quartz grains. V. R. Todd (USGS, written commun., 1988) believes that the northeast-striking foliation in the interior of the pluton is a primary flow foliation, while the northwest-striking foliation along the western margin of the pluton is a metamorphic foliation resulting from post-crystallization ductile deformation.

The contact of the trondhjemite of Doe Mountain with the trondhjemite of Lamb Butte to the west is gradational. Dikes and irregular bodies of leucocratic trondhjemite and pegmatite that resemble the trondhjemite of Doe Mountain cut the eastern margin of the trondhjemite of Lamb Butte, suggesting that the trondhjemite of Doe Mountain intrudes the trondhjemite of Lamb Butte. The trondhjemite of

Doe Mountain is locally fine to medium grained (chilled) at the contact with the trondhjemite of Lamb Butte.

The trondhjemite of Doe Mountain truncates layering in the gneissic trondhjemite of Tiffany Mountain to the east, suggesting that the trondhjemite of Doe Mountain intrudes the trondhjemite of Tiffany Mountain. Schlieren, spots, and irregular inclusions of heterogeneous gneissic rocks are abundant in the trondhjemite of Doe Mountain near the contact.

The nature of the contact between the trondhjemite of Doe Mountain and the granodiorite gneiss complex of the Quartz Mountain area to the north is unclear. Lawrence (1968) thought that the contact between the two units is an intrusive contact. Hawkins (1968) believed that the contact along Spanish Creek is marked by a high-angle normal fault.

Concordant K-Ar biotite and muscovite ages of 96.3 ± 0.7 Ma and 96.4 ± 0.7 Ma, respectively, and discordant K-Ar biotite and muscovite ages of 108 ± 3.0 Ma and 94.6 ± 2.8 Ma, respectively, are reported from the trondhjemite of Doe Mountain (Table 1). A fine-grained trondhjemite dike that cuts the trondhjemite of Doe Mountain, but is thought to be genetically related to it, yielded concordant K-Ar biotite and muscovite ages of 95.7 ± 0.7 Ma and 96.1 ± 0.7 Ma, respectively (Table 1). Thus, uplift and cooling of the trondhjemite of Doe Mountain through the K-Ar blocking temperatures occurred approximately 95 Ma. The crystallization age of the batholith is unknown, but Late Jurassic and Early Cretaceous U-Pb zircon ages have been reported from compositionally similar intrusions in the Eagle plutonic complex of southern British Columbia (Greig, 1988). Therefore, a Cretaceous or Jurassic(?) age is tentatively assigned.

$KJit_b$

Trondhjemite of Bald Mountain (Cretaceous or Jurassic?)--Directionless to weakly foliated, leucocratic trondhjemite and granodiorite that form two small intrusions near Bald Mountain (sec. 19, T. 40 N., R. 21 E.) (Hawkins, 1963, 1968). This trondhjemite is compositionally and texturally similar to the trondhjemite of Doe Mountain, but the two intrusions are apparently separated from each other by a high-angle normal fault (Hawkins, 1968).

The trondhjemite of Bald Mountain intrudes the granodiorite gneiss complex of the Quartz Mountain area and the migmatitic rocks near Spanish Creek. The age of the trondhjemite of Bald Mountain is unknown, but because it may be correlative with the trondhjemite of Doe Mountain, a Cretaceous or Jurassic(?) age is tentatively assigned.

Jit_b

Button Creek stock (Jurassic)--Directionless to strongly foliated, gray, medium-grained, biotite-hornblende tonalite. Principal constituents are plagioclase, quartz, hornblende, and biotite, with an average composition of Q_{33}:A_0:P_{67}. It generally contains 20 to 25 percent mafic minerals, with hornblende more abundant than biotite (Barksdale, 1975; Maurer, 1958). Alteration of plagioclase to sericite, and mafic minerals to chlorite is common.

The Button Creek stock is an elongate, 15-km^2 intrusion. Contacts between the Button Creek stock and the Buck Mountain Formation to the southwest are marked by faults. Near Burgett Peak (sec. 11, T. 37 N., R. 20 E.), the andesite of Isabella Ridge overlies the Button Creek stock along a relatively flat contact, but it is unclear whether the contact is a depositional contact or a low-angle fault (V. R. Todd, USGS, written commun., 1989).

K-Ar hornblende ages of 153.2 ± 1.6 Ma and 150.2 ± 1.7 Ma (V. R. Todd, USGS, written commun., 1988) and slightly discordant K-Ar hornblende and biotite ages of 134 ± 7 Ma and 150 ± 5 Ma, respectively (DGER data, this report), indicate that the stock is Late Jurassic in age.

Metamorphic Rocks

Orthogneisses

$KJog_l$

Trondhjemite of Lamb Butte (Cretaceous or Jurassic?)--Strongly foliated, medium-grained, leucocratic (average color index = 8) trondhjemite and granodiorite. The foliation is defined by 1- to 1.5-cm-long ribbon quartz grains, 1- to 3-mm-long recrystallized biotite aggregates, and 2.5- to 10-cm-long lens-shaped biotite clots. Biotitic inclusions and thin (1 - 3 cm) biotitic sheets are sparse in the trondhjemite of Lamb Butte; most are concentrated along the contact with the trondhjemite of Doe Mountain (V. R. Todd, USGS, written commun., 1988).

The trondhjemite of Lamb Butte is strongly hydrothermally altered in places, which has obliterated the otherwise ubiquitous foliation. Alteration is typically associated with brittle shear zones (1 cm to 100 m wide) and narrow slickensided surfaces that are thought to have formed during late movement along the Pasayten fault (V. R. Todd, USGS, written commun., 1988).

The trondhjemite of Lamb Butte forms a narrow, 1- to 4-km-wide, northwest-trending belt that stretches from the Canadian border to the southern border of the Robinson Mtn. 1:100,000-scale quadrangle (V. R. Todd, USGS, written commun., 1988; H. A. Hurlow, University of Washington, oral commun., 1989). It extends south onto the adjacent Twisp 1:100,000-scale quadrangle (A. M. Frey, University of Pittsburgh, written commun., 1988).

The trondhjemite of Lamb Butte grades into both the trondhjemite of Doe Mountain to the east and the trondhjemite of Eightmile Creek to the west (H. A. Hurlow, University of Washington, written commun., 1989). Near the contact with the trondhjemite of Doe Mountain, the trondhjemite of Lamb Butte is cut by abundant irregular layers of leucocratic trondhjemite that resemble the trondhjemite of Doe Mountain, and by numerous pegmatite, aplite, and fine- to medium-grained leucocratic granite dikes that may be late-stage differentiates of the trondhjemite of Doe Mountain. These relations suggest that the trondhjemite of Doe Mountain intrudes the trondhjemite of Lamb Butte (V. R. Todd, USGS, written commun., 1988). To the west, the trondhjemite of Lamb Butte is interlayered with the trondhjemite of Eightmile Creek, but the age relation between the two units is unclear.

Replicate K-Ar biotite ages of 102.5 ± 0.7 Ma and 99.8 ± 0.7 Ma are reported from the trondhjemite of Lamb Butte (V. R. Todd, USGS, written commun., 1988). These ages probably represent the age of latest ductile deformation of the intrusion, because thin-sections of the trondhjemite of Lamb Butte reveal igneous rock textures overprinted by high-temperature cataclastic and recrystallization fabrics. The crystallization age of the trondhjemite of Lamb Butte is unknown.

$KJog_e$

Trondhjemite of Eightmile Creek (Cretaceous or Jurassic?)--A medium- to coarse- grained, leucocratic (average color index = 10) trondhjemite composed of plagioclase (andesine), quartz, biotite, hornblende, and minor K-feldspar. Quartz occurs as lenticular gray grains. Plagioclase crystals are white, ovoid to prismatic, and as much as 2.5 cm long. Biotite occurs in aggregates. Hornblende grains range from 0.5 to 2.5 cm long and typically lie within foliation planes. As the eastern margin of the trondhjemite of Eightmile Creek is approached, large hornblende prisms display ragged, recrystallized borders replaced by biotite and gradually give way to small grains of relict hornblende and clots of hornblende and biotite oriented parallel to foliation planes.

Rare mafic inclusions, mafic and leucocratic schlieren, thin biotite sheets, and deformed and recrystallized gabbro are present in the trondhjemite of Eightmile Creek. Most are flattened parallel to the foliation in the trondhjemite. They probably represent remnants of wallrock engulfed by the trondhjemitic magma.

The trondhjemite of Eightmile Creek is a narrow, 1- to 2-km-wide, northwest-trending intrusion that parallels the Pasayten fault from the northern end of Eightmile Creek (sec. 7, T. 37 N., R. 21 E.) to the southern border of the Robinson Mtn. 1:100,000-scale quadrangle (V. R. Todd, USGS, written commun., 1988). It extends south onto the adjacent Twisp 1:100,000-scale quadrangle (A. M. Frey, University of Pittsburgh, written commun., 1988; H. A. Hurlow, University of Washington, oral commun., 1989).

Both the eastern and western borders of the trondhjemite of Eightmile Creek are zones of intense ductile shear. As the western margin is approached, the trondhjemite of Eightmile Creek becomes mylonitic and grades into mylonitic rocks along the Pasayten fault (unit $KJog_p$). Along its eastern margin, the trondhjemite of Eightmile Creek is strongly foliated and recrystallized. It is interlayered with the trondhjemite of Lamb Butte in a zone 100 to 400 m wide (V. R. Todd, USGS, written commun., 1988).

The trondhjemite of Eightmile Creek has yielded concordant K-Ar hornblende and biotite ages of 100.8 ± 0.9 Ma and 105.7 ± 0.8 Ma, respectively (V. R. Todd, USGS, written commun., 1988). However, since the trondhjemite of Eightmile Creek is characterized by a strong cataclastic fabric, the reported ages probably represent the age of latest ductile deformation of the intrusion and not the age of crystallization. Late Jurassic and Early Cretaceous U-Pb zircon ages are reported from compositionally and texturally similar rocks in the Eagle plutonic complex along the Pasayten fault in southern British Columbia (Greig, 1988). Therefore, a Cretaceous or Jurassic age is tentatively assigned.

$KJog_p$

Mylonitic rocks along the Pasayten fault (Cretaceous or Jurassic?)--Medium- to dark-gray, locally banded mylonitic orthogneiss, with layers from a few millimeters to 1 cm thick. The composition ranges from trondhjemite to granodiorite. Biotite is the chief mafic mineral. Textures are dominantly mylonitic, but relict igneous plagioclase and quartz grains are common. The mylonitic rocks along the Pasayten fault apparently represent a discrete pluton that was intruded along the Pasayten fault during regional ductile deformation (V. R. Todd, USGS, written commun., 1988).

These mylonitic rocks form a 1- to 2-km-wide belt along the east side of the Pasayten fault (Lawrence, 1968; Barksdale, 1975; Menzer, 1983; Hurlow, 1989; A. M. Frey, University of Pittsburgh, written commun., 1988; V. R. Todd, USGS, written commun., 1988). Mylonites, phyllonites, and pseudotachylites along the fault give way to strongly foliated mylonitic gneiss to the east, which in turn grades into moderately to weakly foliated orthogneiss further east.

Abundant thin leucocratic granite and pegmatite dikes and quartz veins cut the mylonitic gneisses. Most are oriented parallel to the foliation in the gneisses. Some of the dikes/veins are deformed and have been folded into concordance. Others are not deformed and were apparently injected concordant to layering.

A K-Ar biotite age of 101.4 ± 0.8 Ma is reported from the mylonitic rocks along the Pasayten fault (V. R. Todd, USGS, written commun., 1988). This age probably represents the age of the youngest ductile shearing along this part of the Pasayten fault, and is thus only a minimum age for crystallization of the pluton.

KJogm

Metagabbro near Ramsey Creek (Cretaceous or Jurassic?)--Heterogeneous metagabbro with textures ranging from fine grained and foliated to coarse grained and pegmatitic. Thin-sections reveal relict igneous textures overprinted by high-temperature strain and recrystallization (V. R. Todd, USGS, written commun., 1988). This fabric suggests that the metagabbro is a ductilely deformed intrusive body.

The metagabbro forms an elongate, 1-km-long, south-trending body near Ramsey Creek, 1 km east of the Pasayten fault (sec. 1, T. 35 N., R. 21 E.) (V. R. Todd, USGS, written commun., 1988). Age of crystallization of the metagabbro is unknown. A Cretaceous or Jurassic age is tentatively assigned.

Mixed Metamorphic and Igneous Rocks

$KJmi_t$

Gneissic trondhjemite of Tiffany Mountain (Cretaceous or Jurassic?)--A heterogeneous unit composed of leucocratic trondhjemitic and quartz dioritic gneiss interlayered with biotite-hornblende gneiss and schist, amphibolite, and calc-silicate rocks. The trondhjemitic gneiss is weakly to moderately foliated, medium to coarse grained, and leucocratic (average color index = 5). It contains sparse clots of recrystallized biotite and hornblende. The quartz dioritic gneiss is more strongly foliated and more mafic (color index = 20 to 25) than the trondhjemitic gneiss. Both exhibit igneous textures modified by strain and recrystallization. Schist, amphibolite, and calc-silicate rocks occur as inclusions, schlieren, and wisps within the trondhjemitic and quartz dioritic gneisses, forming discontinuous compositional layers ranging from less than 1 m to tens of meters thick. Isoclinal folds and complexly swirled foliations are common in dark, heterogeneous portions of the unit.

The gneissic trondhjemite of Tiffany Mountain forms a northwest-trending belt along the eastern border of the Robinson Mtn. quadrangle that extends east and south onto the adjacent Oroville and Twisp 1:100,000-scale quadrangles. On the Robinson Mtn. quadrangle, this unit includes the gneissic trondhjemite of Tiffany Mountain (V. R. Todd, USGS, written commun., 1988) and the "heterogeneous unit" of the Chewack River Gneiss complex (Hawkins, 1968). Correlative units on the adjacent 1:100,000-scale quadrangles include the gneissic trondhjemite of Tiffany Mountain (Rinehart, 1981), the Boulder Creek gneiss complex (Goldsmith, 1952), and a portion of the Summit-Frazer gneiss (A. M. Frey, University of Pittsburgh, written commun., 1988).

The trondhjemite of Doe Mountain apparently intrudes the gneissic trondhjemite of Tiffany Mountain because (1) layering in the gneissic trondhjemite of Tiffany Mountain is truncated at contacts with the trondhjemite of Doe Mountain; and (2) leucocratic dikes that resemble the trondhjemite of Doe Mountain locally cut the gneissic trondhjemite of Tiffany Mountain near the contacts between the two units.

K-Ar biotite ages reported from the gneissic trondhjemite of Tiffany Mountain range from 94.1 ± 0.7 to 104.5 ± 0.8 Ma (Table 1). The ages probably represent the age of uplift and cooling of the unit through the K-Ar blocking temperatures. The crystallization age of the igneous portions of the gneissic trondhjemite of Tiffany Mountain is uncertain, but is thought to be similar to the age of the trondhjemitic orthogneisses along the Pasayten fault, that is, Late Jurassic or Early Cretaceous.

KJmg$_s$

Migmatitic rocks near Spanish Creek (Cretaceous or Jurassic?)--Chaotic mixtures of banded biotite-hornblende schist and gneiss, amphibolite, and concordant to discordant layers, pods, and anastomosing dikes and swirls of directionless, leucocratic trondhjemite and granodiorite. The agmatitic rocks are breccias composed of angular to subangular blocks of strongly foliated mafic gneiss and schist enclosed in a matrix of directionless leucocratic trondhjemite and granodiorite. Several of these elongate, northwest-trending migmatite and agmatite bodies occur near Spanish Creek (T. 40 N., R. 21 E.) (Hawkins, 1963, 1968).

Layered Metamorphic Rocks

pJbg$_q$

Granodiorite gneiss complex of the Quartz Mountain area (pre-Jurassic?)--Chiefly banded rocks that consist of alternating layers of strongly foliated, biotite-hornblende quartz diorite gneiss, hornblende-biotite schist, calc-silicate gneiss and schist, amphibolite, and directionless to weakly foliated, leucocratic trondhjemite and granodiorite.

Compositional layers in the banded rocks range from thin streaks to zones more than 100 m thick. Hornblende-biotite schist layers contain 25 to 30 percent biotite, 15 to 20 percent hornblende, and the remainder plagioclase. They grade into schist and gneiss composed of as much as 45 percent amphibole (hornblende and actinolite) and various amounts of plagioclase, quartz, biotite, and pyroxene. Calc-silicate gneisses and schists contain 50 to 70 percent pyroxene (diopside), 15 to 25 percent garnet (grossularite-andradite), 5 to 20 percent plagioclase, 0 to 5 percent hornblende, and minor biotite, calcite, sphene, and quartz. Principal constituents of the directionless to weakly foliated, medium- to coarse-grained, leucocratic trondhjemite and granodiorite layers are plagioclase (chiefly oligoclase), quartz, microcline, and biotite.

This layered metamorphic complex straddles the Canadian border between the Pasayten River and Cathedral Lakes (T. 40 N., R. 19, 20, and 21 E.) (Hawkins, 1963, 1968; Staatz and others, 1971). West of the Ashnola River, the banded rocks are locally migmatized and contain irregularly shaped masses of directionless to weakly foliated, leucocratic trondhjemite and granodiorite that have not been mapped separately from the banded rocks (Staatz and others, 1971). East of the Ashnola River, the migmatitic rocks and the leucocratic trondhjemite and granodiorite have been mapped separately from the banded rocks. They are herein excluded from the granodiorite gneiss complex of the Quartz Mountain area and shown on the geologic map (Plate 1) as (1) migmatitic rocks near Spanish Creek; and (2) trondhjemite of Bald Mountain.

Most of the banded rocks of the granodiorite gneiss complex of the Quartz Mountain area are metamorphosed sedimentary and volcanic rocks, but the cross-cutting nature of some of the leucocratic trondhjemite and granodiorite layers suggests that they may be, at least in part, igneous intrusions (Hawkins, 1968; Staatz and others, 1971).

The granodiorite gneiss complex of the Quartz Mountain area grades into the hornblende gneisses of the Sheep Mountain area (Staatz and others, 1971). The complex is apparently in fault contact with the trondhjemite of Doe Mountain along the valley of Spanish Creek (Hawkins, 1968). It is intruded by the Ashnola Gabbro and the Cathedral batholith.

The granodiorite gneiss complex of the Quartz Mountain area has yielded a K-Ar hornblende age of 101.6 ± 4.0 Ma (Hawkins, 1968). This is almost certainly a metamorphic age. The protolith age is uncertain, but is thought to be pre-Jurassic.

pJam$_s$

Hornblende gneisses of the Sheep Mountain area (pre-Jurassic?)--Interlayered black, fine- to coarse-grained amphibolite and hornblende-biotite and hornblende-augite gneiss. Principal constituents of the rocks are hornblende, plagioclase, augite, and biotite. Quartz, magnetite, chlorite, epidote, and apatite are minor constituents. The amphibolite and gneiss are cut by numerous mafic dikes composed of olivine, plagioclase, pyroxene, and amphibole, and by abundant fine- to coarse-grained granodiorite dikes.

Foliation in the hornblende gneisses of the Sheep Mountain area generally strikes N65°W and dips steeply to the northeast, but local folding and swirling of the foliation is common (Staatz and others, 1971).

The hornblende gneisses of the Sheep Mountain area, originally named the Basic Complex by Daly (1912), cover approximately 12 km^2 along the Canadian border from Peeve Creek to the Ashnola River (T. 40 N., R. 20 E.) (Staatz and others, 1971).

The hornblende gneisses of the Sheep Mountain area apparently grade into the granodiorite gneiss complex of the Quartz Mountain area (Staatz and others, 1971). The age of the gneisses is uncertain, but is thought to be pre-Jurassic.

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